CHANGES IN BREEDING BIRD ABUNDANCE AND DIVERSITY ACROSS URBAN-RURAL GRADIENTS IN NORTHEASTERN GEORGIA, USA

by

MICHAEL CLAY PARRISH

(Under the Direction of Jeffrey A. Hepinstall-Cymerman)

ABSTRACT

Urbanization is rapidly changing the southeastern US landscape, particularly in Georgia, the fastest-growing Southeastern population center. Previous studies have suggested that avian communities and populations respond to landscape characteristics in scale-dependent ways. I conducted a 2-year (2007-2008) study of the response of breeding bird population abundance and community abundance, species richness, and relative diversity in young and mature residential developments to multiscale landscape characteristics at multiple scales across urban-rural development intensity gradients near Athens, Georgia. My data suggest that widely-available geospatial metrics of human disturbance, landscape composition and landscape configuration can be used to explain breeding bird abundance and diversity in residential developments (stepwise regressions: $0.33 < R^2_{adj} < 0.81$). This study sets the framework for a landscape-level understanding of the effects of housing developments on breeding birds in northeastern Georgia.

INDEX WORDS: Ornithology, Urban ecology, Urban-rural gradient, Urbanization, Multiscale landscape characteristics, Avian, Residential development, Landscape ecology

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DEDICATION

"It may be hard for an egg to turn into a bird; it would be a jolly sight harder for it to learn to fly while remaining an egg. We are like eggs at present. And you cannot go on indefinitely being just an ordinary, decent egg. We must be hatched or go bad."

- C. S. Lewis (b. 1898 – d. 1963)

This thesis is dedicated to my wonderful family, most especially my parents and brother, who have been a great source of support and encouragement throughout my life. I will always value the constant love, sound advice, moral support, and unwavering confidence in me that they have consistently offered. I'm more grateful than they know to have them in my life.

I also dedicate this thesis to my wonderful wife, Lindsay. Her patient love and confidence in me during the course of this endeavor were what sustained me through the series of excruciatingly early mornings in the field and frustratingly late hours in my office that resulted in this document you are now reading. Lindsay never once showed any doubt in my ability to do this, always boosted my confidence when I felt doubt of my own, made me laugh when I was frustrated, and was my comfort and support during this challenging experience. I couldn't have done it without you; I love you, Lindsay.

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TABLE OF CONTENTS

Page

CHAPTER

CHAPTER 1

CHANGES IN AVIAN ABUNDANCE AND DIVERSITY IN URBANIZING AREAS

URBANIZATION ON THE RISE

Worldwide, the percentage of people living in cities increased from 33% in 1960 to 47% in 1999; by 2030, it is expected that nearly 61% (5 billion) people will live in urban areas (Sadik 1999). Urbanization is “the process by which human settlement increases in: 1) population density and 2) intensity of land use in an area” (Marzluff 2001). In the southeastern United States, urbanization is rapidly changing the landscape. This is particularly evident in the state of Georgia, where the population increased by 26% to 8.2 million between 1990 and 2000 – the largest increase of any state in the southeastern U.S. over that period (Perry and Mackun 2001). A clear example of the impact of rapid population growth on natural and semi-natural habitats is found in Georgia’s capital city, Atlanta, where increases in high-density urban land use (89.4%) and low-density urban land use (119.2%; primarily residential) between 1973 and 1998 were paralleled by decreases in the region’s forest land (a 20.9% decline) and cropland/grassland (12.7% decline) during the same period (Yang and Lo 2002). The effects of urbanization on wildlife may be manifested for long periods of time – on the order of decades – after initial development takes place; these effects do not remain localized, but may alter ecological processes and biodiversity on adjacent and distant lands as well (Hansen, Knight et al. 2005).

RESPONSE OF AVIAN COMMUNITIES TO URBANIZATION

Bird communities can respond to urbanization in a number of ways, including: (a) changes in total abundance[1]; (b) changes in species richness or in the particular species which make up the assemblage; and (c) alterations of the community species evenness. Species making up communities may be subdivided into functional guilds according to commonalities between each species' behavioral traits (Bryce, Hughes et al. 2002). Many studies have documented changes in bird communities that are undesirable from a conservation standpoint.

Multiple studies have linked declines in avian species diversity with urbanization-linked reductions in native vegetation cover. Landscape fragmentation and development have been associated with declines in abundance and diversity of forest birds and increases in synanthropic species (species with strong commensal relationships to humans and/or human disturbances). Avian species richness typically increased with habitat reserve size; as urbanization of the surrounding landscape increased, however, the increase in species richness more likely resulted from the increased presence of synanthropic species (Donnelly and Marzluff 2004).

Increases in urbanization may lead to declines in bird communities stemming from disease. Housing density was a strong predictor of avian West Nile Virus (WNV) antibodies and urban/suburban land use was also consistently correlated with WNV antibody positive sites in a statewide WNV survey in Georgia from 2002-2004 (Gibbs, Wimberly et al. 2006).

Birds may respond to urbanization differently according to functional guilds, species groupings based on similarity of behavior, or other commonalities. For example avian guilds have been defined based on: (a) foraging characteristics (Bessinger and Osborne 1982); (b) native vs. exotic species status; (c) degree of territoriality; (d)

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[1] For definitions of important terms used in this thesis, see Appendix A.

synanthropic preference (Mills, Dunning et al. 1989); and (e) habitat preferences (Marzluff 2005). In Nebraska, along abandoned railroad rights-of-way, breeding season abundance, richness, and diversity was greater for neotropical migrants in more rural areas and greater for permanent residents in more urban areas; partial migrants had greater richness and diversity in rural transects, but their total abundance did not differ, suggesting changes in evenness between urban and rural areas (Poague, Johnson et al. 2000). In Arizona, housing density, percentage of paved area, vegetation metrics, and distance from washes have been correlated with variation in abundance, species richness, and evenness for three bird guilds (non-natives, natives, and native indicators) and was used to explain species richness responses to future development in the area (Germaine, Rosenstock et al. 1998). In Pennsylvania, landscape patch characteristics influenced species richness within functional (e.g., habitat preference, area sensitivity, migratory status, and nest placement) guilds (Bishop and Myers 2005).

Typically, in residential developments in northeast Georgia, builders begin development by clearing vegetation in 30-45 m wide strips for road construction and larger areas for water control structures. Lots for home construction are surveyed and cleared either all at once, in small groups (in phased developments), or individually as lots are purchased. Home construction takes place relatively continuously from site clearing until the final home is finished. Because only a relative handful of homes are under construction at any given time, construction disturbance may last for several years, shifting locations through the subdivision. After completion of construction in the development, the site shifts from the intensive disturbance regime of the clearing/construction phase into the relatively widespread, lower-intensity disturbance regime of a completed subdivision: lawn maintenance, frequent car and foot traffic, conversion of wild vegetation into lawns and non-native plantings, and application of pesticides and insecticides.

The age of residential developments also seems to play a role in bird community diversity (Donnelly and Marzluff 2006). Avian population density, species richness, and evenness of distribution declined with development age across three urban residential developments in Canada (Edgar and Kershaw 1994). In Canberra, Australia, bird species richness and density increased with age of suburbs (a proxy for vegetation regrowth); numbers of open forest, woodland, and grassland species decreased with distance to native vegetation remnant patches (Munyenyembe, Harris et al. 1989). In Seattle, Washington, synanthropic species increased in younger developments (Hepinstall, Marzluff et al. 2009).

RESPONSE OF AVIAN POPULATIONS TO URBANIZATION

Bird populations are often affected in different ways by urbanization, depending on the particular life history characteristics unique to a given species. For example, in Finnish towns, predation rates for ground nests were higher in towns than in adjacent forests and were higher in managed parks versus unmanaged ones; the location effects were attributed to increased predation by generalist avian nest predators and decreased amount of vegetation cover in more urbanized areas (Jokimaki and Huhta 2000). Changes in forest cover and configuration may affect different species with more or less severity, possibly due to differences in dispersal, susceptibility to predation and parasitism, and area requirements by individual species (Villard, Trzcinski et al. 1999).

As forests become fragmented by human alterations of the landscape, the amount of forest edge increases. One potential result of increased edge is an increased risk of nest predation, nest parasitism, and predation of adults. In Australia, reduced connectedness among habitat patches was linked to strong declines in population recruitment (Smith and Hellmann 2002). In Wisconsin, the harmful effects of proximity to forest edge on the nesting success of ground-nesting bird species extended at least 300 m into intact forest and may have limited nesting density at distances even farther from the edge (Flaspohler, Temple et al. 2001). Preliminary studies of the effect of noise pollution on bird song suggests that noisy urbanized habitats may limit breeding opportunities of birds, potentially reducing breeding opportunities and leading to declines in population abundance (Slabbekoorn and Peet 2003). Age of residential developments also appears to be associated with abundance of individual species. In Washington state, development age was positively correlated to species relative abundance of species in residential developments, possibly because of the impact of maturing landscaping vegetation (Donnelly and Marzluff 2006).

MULTISCALE LANDSCAPE PREDICTORS OF ABUNDANCE AND DIVERSITY

Bird communities and populations may vary in their response to landscape characteristics based on the spatial scale at which those characteristics are considered. In this thesis, I use the term ‘scale’ to refer to both ‘extent’ (size of the focal area under study), and ‘grain’ (the spatial resolution of a dataset) (Turner, Gardner et al. 2001). Some recent studies have begun to consider multiple scales when using landscape characteristics to explain avian abundance and diversity. As seen below, there is no standardization of spatial scales of importance in the field as yet; likely, spatial scale of importance varies with target organism and ecoregion.

Researchers in California have produced models explaining as much as 62% of avian species presence/absence using landscape characteristics (e.g., habitat patch size and proportion, distance to developed edge, and edge amount between developed and undeveloped land) within buffers of varying radius (i.e., 250, 500, 1000, 2000, and 3000 m from sample points); local habitat and physical conditions at sampling units were also incorporated into models (Bolger, Scott et al. 1997). Distribution and occurrence of riparian breeding birds in Idaho responded most strongly to vegetation metrics considered at larger scales (1 km^2) than at smaller scales (100 m^2 or 5 m^2) (Saab 1999). In Nebraska, avian habitat-use guild abundance and species richness responded differently to percent woody cover within various distances from survey transects (500 m, 1000 m, and 2000 m out from a transect); some individual bird species exhibited threshold values for percent woody cover, below which they did not occur (Perkins, Johnson et al. 2003). In South Australia, landscape variables at multiple spatial scales (radii of 2, 5, and 10 km) were successfully used to explain the distribution of woodland bird species; area was generally shown to be more important than landscape configuration and a plurality of species responded better to smaller-scale landscape variables, although many species had candidate models at the larger scales as well (Westphal, Field et al. 2003). In Oregon, native and non-native bird communities responded to landscape composition differentially, depending on the spatial scale at which landscape composition was measured (Hennings and Edge 2003).

PREVIOUS STUDIES IN THE ATHENS, GEORGIA AREA

Athens, Georgia has hosted many ornithological research studies for over a century, perhaps beginning with the egg collection efforts of Gilbert R. Rossignol in Clarke County around the beginning of the Twentieth century (Murphey 1945). Thomas D. Burleigh's (1938) research efforts in Athens from 1920 to 1935 (including almost daily records for the first decade) offer a valuable insight into the species assemblages and general patterns of occurrence of birds in Athens before urbanization had more thoroughly altered the landscape. In addition to his work in Clarke County as a whole, Burleigh (1927) published a subset of species records (1920 to 1927) based on observations made on the Georgia State College of Agriculture campus (now a part of the University of Georgia campus in Athens), including breeding records, extreme occurrence dates, and other notes. Burleigh (1958) was also the author of the first comprehensive treatment of Georgia's avifauna, Georgia Birds. A revised inventory of the birds of Athens was published 30 years after Burleigh's initial work was completed, listing species with their extreme dates of occurrence and rough estimates of their abundance (Tramer 1968).

Since Burleigh's work in the 1920s and 1930s, several species have apparently extended their breeding ranges into the Athens area. These range extensions may possibly be related in part due to alterations of the landscape due to processes of urbanization. This process was apparently in progress as early as the 1920s, when the American Robin[2] began to increase its numbers until becoming a fairly common summer breeder in the city (but not the neighboring countryside), whereas previously, the species was primarily a non-breeding migrant (Burleigh 1938). European Starlings were probably absent as breeders before around 1925 (Burleigh 1938) while they are now abundant. Before 1938, the House Wren was an irregular, scarce migrant (Burleigh 1938), but in 1950, it was first observed breeding in Athens (Odum and Johnston 1951) and the species is now a common breeder in the area. Recently, the Eurasian Collared Dove has expanded its range into Athens, with confirmed nesting reported at least as early as 1999 (Bell 1999); the species is now established in downtown Athens and was observed in the course of this study in less-developed neighboring counties. A number of other examples of possible breeding range expansions into northeastern Georgia over the last century have been noted (Odum and Burleigh 1946; Peake 1968; Hale, Jackson et al. 1978) with at least 23 species noted to have potentially expanded their breeding or wintering ranges into the Athens area between 1938 and 1976 (Allen 1979).

Although studies in the Southeast relating to the response of birds to urbanization are limited in number and scope, there have been several attempts to explore the effect of habitat characteristics on avian land usage patterns in the Athens

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[2] See Appendix E for scientific names of bird species mentioned in the text.

area. A small post-breeding season mist-netting study in 1977 compared relative density (net captures), species richness, and species evenness between an old-field/forest ecotone habitat and a subdivision in Athens. No significant differences were found between the two habitat types; however, community productivity was estimated to be 29% greater in the old field/forest ecotone (Meyers 1981). A study near Athens during the early 1990s compared wintering bird abundance and diversity along gas pipeline and power line rights-of-way to a series of landscape variables at multiple scales (ranging from the local patch scale out to 0.5 km from count-points). Birds were considered as entire site assemblages, by foraging guilds, and by individual populations of species. Landscape characteristics at small scales (within sampling plots) and larger scales (the matrix surrounding each plot, out to 500 m) explained large proportions (upwards of 70% for some models) of the variation in avian community and population abundance and diversity (Pearson 1993). Another study compared winter bird densities and habitat use patterns between urban and rural sites around Athens during the winters of 1989 and 1990; native woodland bird species were reported to use urban areas at higher densities and were generalist in their use of habitat within such areas (Yaukey 1996).

OBJECTIVES

The main objectives of this study were: (a) to explore the usefulness of the urban-rural gradient concept in identifying avian field sites in urbanized areas (chapter 2); (b) to explore how avian communities and populations respond to multi-scalar landscape patterns (chapter 3); and (c) to explore the use of multivariate and multiscale models of human disturbance, landscape composition, and landscape configuration to explain avian community and population patterns in residential developments in Athens, Georgia (chapter 4).

APPROACH

To achieve my objectives, I developed multiscale maps of the urban-rural gradient across the Athens, Georgia area. I used the gradient maps to locate a set of 36 sites (primarily residential developments) to serve as study sites. I generated a set of 15 multiscale landscape characteristics for each study site, representing aspects of the sites' landscape composition, landscape configuration, and human disturbance levels. During the avian breeding seasons of 2007 and 2008, I conducted a series of avian surveys to measure avian abundance and diversity on each of my study sites. I then used the 15 multiscale landscape characteristics to generate models explaining avian abundance and diversity on my study sites.

RATIONALE

The southeastern United States is characterized by its own unique pattern of land use. Most land in the region has been subject to human disturbance multiple times over the past 300 years. Since the arrival of European colonists, the southeastern landscape has been subject to ever-increasing alteration as human numbers have grown and required more resources to sustain them (Coleman, Bartley et al. 1977). Factors ranging from climate and extant biota to building regulations and modern patterns of urbanization combine to create a unique regional pattern of landscape use by both humans and animals. Urbanized environments represent unique settings, where basic ecological processes and patterns can be significantly altered by human activities (Shochat, Warren et al. 2006). Urban biodiversity is important to residents and urban green areas have intrinsic ecological value; however, in many areas there is a lack of basic urban ecological knowledge (Niemelä 1999). Birds are good ecological indicators and are easily surveyed (Clergeau, Mennechez et al. 2001); avian abundance and diversity data are frequently used to compare different cities and ecoregions

(Fernandez-Juricic and Jokimaki 2001). Despite unique patterns of historic land use and of present-day urbanization, studies of the response of the Southeastern avifauna to urbanization are limited in number and scope. Without a strong understanding of the response of birds to the Southeastern landscape, it is difficult to identify areas of current or future conservation concern or to predict the effects of ongoing landscape development on wildlife.

Georgia is the fastest-growing state in the Southeast (Perry and Mackun 2001) and is expected to gain an additional 1.4 million new residents between 2005 and 2025 (Campbell 1997). The rapid increase in population has resulted in a housing development boom. Urban land cover has increased from 300,000 ha in 1974 to over 1.3 million ha in 2005 (Kramer 2008). The landscape context (regional scale) and design and layout (landscape and local scale) of these new developments will determine their impact on the native avifauna. It is essential to understand how best to guide the development of the state if human interests are to be balanced with conservation needs. Decisions made during the planning and design of urban areas have a strong impact on the urbanized landscape, which, by extension, has a strong impact on biodiversity (Hostetler 1999). Understanding how changes in landscape composition affect individual species may be useful when those species have value as indicator species, enabling scientists to predict occurrence of multiple taxonomic groups (Fleishman, Thomson et al. 2005).

Urbanization will, no doubt, continue to increase in the future (Sadik 1999). It is essential to understand the effects of different urbanization patterns on bird communities and populations so that managers, planners, and policy makers may be scientifically informed in their decision-making processes (Marzluff 2001). This study begins to set the framework for understanding how landscape characteristics at multiple scales affect the abundance and diversity of breeding birds in residential developments in the

Piedmont region of Georgia. The data from this study may be combined with research on land use and land cover change to predict future trends for the avifauna in new and existing developments and to better understand how avian abundance and diversity vary with landscape patterns related to urbanization.

CHAPTER 2

SITE SELECTION AND CHARACTERIZATION

INTRODUCTION

Urbanization on the Rise

Human populations in cities worldwide are increasing rapidly; the United Nations Population Fund estimates that nearly 61% of the world population (5 billion people) will have migrated to urban areas by 2030 (Sadik 1999). As urban populations grow, the area of land impacted by human disturbance expands, the intensity of land use and population density increases; a process referred to as “urbanization” (Marzluff 2001). The effects of urbanization are evident in the southeastern United States, particularly in the rapidly-growing state of Georgia, where the population increased by 26% to 8.2 million between 1990 and 2000 (Perry and Mackun 2001). In Atlanta, Georgia, between 1973 and 1998, increases in high-density urban land use (89.4%) and low-density urban land use (119.2%; primarily residential) were paralleled by decreases in the region’s forest land (a 20.9% decline) and cropland/grassland (12.7% decline) during the same period (Yang and Lo 2002). These reductions in natural and semi-natural land cover are partly due to land conversion into residential developments. Associations between urbanization-related land changes and declines in bird populations have been clearly described in the literature (Chace and Walsh 2006), but investigations into the impact of urbanization on the birds of the Southeast, and Georgia in particular, are limited.

Avian Response to Urbanization

As a landscape undergoes urbanization, characteristics of the landscape are altered in several broad categories: (a) intensity and extent of human disturbance; (b) habitat composition; and (c) habitat configuration. In residential developments, initial disturbance includes site clearing, house construction, and introduction of horticultural plants. Continued human disturbance originates from sources such as: vehicle traffic, lawn maintenance, ambient noise, or presence of free-ranging pets. Housing density is a commonly used indicator of human development and disturbance levels (Theobald 2003). High levels of human-induced disturbance have been associated with changes in avian abundance and diversity which may be undesirable from a conservation standpoint (Bryce, Hughes et al. 2002; Lussier, Enser et al. 2006). Habitat composition is altered during urbanization, often with decreased natural land cover (e.g., forests) and increased human-altered land cover (e.g., impervious surfaces, agriculture, and horticulturally-maintained areas). Declines in natural cover have been associated with avian declines in multiple studies; for a review, see (Chace and Walsh 2006). Habitat configuration becomes more fragmented with greater urbanization. As fragmentation becomes greater, factors such as increased predation, increased parasitism, or increased human disturbance may lead to declines in bird populations (Robinson, Thompson et al. 1995; Mortberg 2001; Donnelly and Marzluff 2006). The importance of landscape patterns on species varies with spatial scale in many studies, with some spatial scales appearing to be more important to avian abundance and diversity than others (Bolger, Scott et al. 1997; Saab 1999; Perkins, Johnson et al. 2003; Westphal, Field et al. 2003). See chapter one for more on avian responses to urbanization.

Estimating Urbanization Intensity

Three commonly-used geospatial indicators used for estimating human disturbance and landscape change are: road density, housing density, and percentage of a landscape in developed land cover (Theobald 2003; Pidgeon, Radeloff et al. 2007). Roads alter the environment in multiple ways important to animals, including creation of movement corridors and barriers to movement, habitat fragmentation, disturbance from vehicles, chemical and physical changes to adjacent water bodies, and increased human access to habitat interiors; road density may represent an overall index of habitat suitability (Forman and Alexander 1998). Housing density is a useful indicator of human impact on land (e.g., alteration of native vegetation and introduction of exotic species) and represents a better indicator of human activity patterns than some other socioeconomic indicators such as population density (Theobald 2003). Another convenient estimator of human land use is the percentage of the landscape in developed land cover types (e.g., various urban use areas; park and recreation lands; transportation), which provide a basic reference to the degree of anthropogenic habitat alteration in an area (Pidgeon, Radeloff et al. 2007).

Location and Classification of Study Sites in Urbanized Areas

Through the use of GIS-based technologies, it is possible to quantify the degree of human alteration of landscapes for use in furthering an understanding of ecological interactions within those landscapes. Modern techniques and datasets make it possible to consider landscapes at scales much greater than were previously practicable. An important consideration when developing landscape metrics for use over large areas is that it should be easy to apply the metrics to large spatial extents (e.g., states or nations) and landscape metrics should be readily generated from existing, easily-accessible, digital sources (Theobald 2003). The selection of field study sites in urbanized environments presents a special challenge compared to those in more rural areas. Gradients of disturbance and landscape composition and configuration are not readily quantifiable based on commonly-available regional map layers, necessitating an approach to site selection that includes some degree of spatial data processing if sites are to be characterized accurately and expediently. Although up-to-date, fine-grained spatial data sources are becoming increasingly available, physical site visits remain a necessary step in site evaluation, particularly in urbanized locations where human impact on the landscape can be rapid and significant.

On occasion, very recent, unclassified spatial data become available to end-users, resulting in a choice of whether to use older classified data or to devote resources to classify the relevant portion of the newer data set. Using already-classified data saves time and resources, at the risk that the data are obsolete to some degree. Classification of more recent data can be time- and resource-intensive, but likely will provide additional accuracy to mapping efforts.

OBJECTIVES

In this chapter, I discuss how I characterized the landscape surrounding Athens, Georgia at multiple spatial scales. Specifically, my first objective was to locate a set of 36 study sites in residential developments in and near Athens, Georgia that represented points along urban-rural gradients of landscape- and regional-scale development intensity and development age (young versus mature); later, the study sites would be used for surveying avian assemblages (chapters 3 and 4). Using widely-available spatial datasets, I computed a set of variables that characterized the landscape at three spatial scales (0.01-0.02 km^2; 1 km^2; and 5 km^2). The spatial variables I calculated were used: (a) to support selection of avian survey sites; and (b) as explanatory variables of explain avian abundance and diversity (see chapters 3 and 4). My second objective was to compare two methods of quantifying landscape-scale (1 km^2) spatial patterns - screen-digitizing to classify forested land cover versus using previously-classified satellite land cover data.

METHODS

Study Area

My study area was located in the greater Athens, Georgia area (primarily in Clarke and Oconee Counties; to a lesser degree in Barrow, Jackson, Madison, and Oglethorpe Counties; Fig. 2.1) and covered approximately 1,130 km^2. Athens is located approximately 110 km northeast of Atlanta, Georgia. The study area was located within the middle piedmont physiographic region, along the midland slope (Burleigh 1958). The piedmont region is characterized by rolling hills and clay-containing soils. Before colonial settlement, the Piedmont was mostly covered with pine (*Pinus spp.*), hardwood, and mixed pine-hardwood forests; however, much of the land was cleared for agriculture by the 1900s (Coleman, Bartley et al. 1977). Today the landscape is a mixture of remnant and old-field succession forestland, production forestland, agriculture, and developed lands.

The population of Athens-Clarke County has grown rapidly over the past century. Around 1925, the population was approximately 20,000 (Burleigh 1925). By 1981, the population was around 50,000; since then, it has more than doubled to its present size of roughly 113,000 people and is currently growing at around 10% per year (Cooper 1981; Georgia Statistics System 2008a; Georgia Statistics System 2008b). Adjacent Oconee County was historically more rural, and in 2006 was home to approximately 31,000 people; however, since 2006, as Athens has grown, there has been a large migration to Oconee County and the population growth rate was 20% per year in 2008 (Georgia Statistics System 2008a; Georgia Statistics System 2008b).

Within the study area, single-family residential developments (neighborhoods) are typically constructed on land that was either a former agricultural field or one of the many large forest patches which are present throughout the landscape. These residential developments served as my avian study sites discussed in chapters 3 and 4. In my larger study, I was particularly interested in how breeding forest birds present during the breeding season responded to the conversion of forest land into residential developments. As such, I was primarily interested in residential developments that were built in formerly forested, upland areas, and I avoided neighborhoods built on land formerly cleared for agricultural use. I did not, however, distinguish between areas that were formerly natural forest versus mature plantation woodlands.

Characterization of Study Area Development Intensity

As part of my objective to locate avian study sites along an urban-rural gradient, I first had to characterize the level of development intensity within the study area landscape (1 km^2) and regional (5 km^2) spatial scales. I used three readily-available geospatial indicators representing human disturbance and landscape change to create a combined geospatial index of development intensity (Theobald 2001; Theobald 2003; Pidgeon, Radeloff et al. 2007): road density, housing density, and percent of the landscape in developed land cover. Road density (km/km^2) was calculated using the road type to weight a road's influence on the surrounding landscape. I used the national Wildlands-Urban Interface (WUI) database to derive housing density in 2000 (Hammer, Radeloff et al. 2007). The WUI housing density was derived from 2000 census block data (units or people / km^2). I derived the percentage of landscape in developed land cover using the 1998 Georgia GAP land cover map classes: 18 (Transportation); 22 (Low Intensity Urban); 24 (High Intensity Urban); 72 (Parks, Recreation); 73 (Golf Course); 201 (Forested Urban – Deciduous); 202 (Forested Urban – Evergreen); and

203 (Forested Urban – Mixed). See Table 2.1 for classes, scales, and sources of all geospatial data used in this study.

Using ArcMap software[3], I conducted a moving window analysis to create maps of development intensity gradients at landscape- (1 km^2) and regional-scale (5 km^2). In moving window analysis, a square or ‘window’ is centered over a location and parameter values of all pixels inside the window are used to calculate a metric which is then assigned to the central pixel in the window. The window is then moved one pixel and the procedure is repeated to assign a value to the new central pixel. This procedure is continued until all non-boundary pixels (i.e., pixels that have a window with all valid data values) are assigned the metric. I calculated the road density, housing density, and percent urban land cover at both scales for each point within the study area using moving windows of the appropriate size (33x33 30-m or 167x167 30-m pixels). I converted each gradient measure into an index by dividing the range of values into three classes corresponding to ‘low’, ‘medium’, and ‘high’ levels of each measure (Table 2.2)

Study Site Selection

To locate candidates for avian study sites, I compared the landscape- and regional-scale development intensity maps I generated to recent (2007) true color aerial photographs (Table 2.1). Using the aerial photos with the gradient maps, I identified locations of candidate landscapes (i.e., residential developments); for candidate landscapes, I determined their original land cover type (e.g., forested or old field) as well as the sites’ approximate location on gradients of regional-scale (Fig. 2.2) and landscape-scale development intensity (Fig. 2.3). I conducted physical site visits (by car

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[3] The maps and geospatial data analyses for this paper were generated using ArcMap software, version 9.03 of the ArcInfo System for Windows XP. Copyright 2006 ESRI Inc. ArcMap, ArcInfo and all other ESRI Inc. product or service names are registered trademarks or trademarks of ESRI Inc., Redlands, CA, USA.

and on foot as site access permitted) at potential study sites to visually assess landscape-scale development intensity and within-site matrix (forest vs. agriculture), to ascertain site suitability for future avian surveys, and to confirm site age.

Multiple factors were evaluated during ground visits to determine site suitability for future avian surveys. Surveyor safety was a chief requirement - the study site had to have a reasonably low probability of criminal activity and it needed to have sufficient vehicle pull-offs or low enough traffic volume that the surveyor would be safe from traffic. The amount of on-going disturbance had to be low enough for the surveyor to be able to hear bird songs from up to 100 m away. Also, sites had to be sufficiently accessible to the public; i.e., the surveyor would need to be able to find a sufficient number of positions that could be accessed without trespassing on private property.

While visiting potential sites, I classified the age of the residential developments as being either “young” or “mature” based on observations of any on-going human disturbances and/or construction. Young developments were sites in the construction phase between site clearing and completion of construction and were characterized by (a) recently-cleared areas; (b) on-going home and/or road construction; and (c) ongoing destructive alteration of vegetation (Fig. 2.4). Mature developments were sites in the post-construction phase and were characterized by (a) no recently-cleared lots; (b) no ongoing new home or road construction; and (c) ongoing alteration of vegetation that was limited to standard lawn maintenance practices (Fig. 2.5). When road density, housing density, and percentage of land in developed land cover at a site did not appear to be represented accurately (e.g., sites in early stages of development), I visually compared those sites to sites of known development intensity, and assigned development intensity levels to those sites.

I selected three replicates of each combination of landscape- and regional-scale development intensity and age class. I did not sample sites that had high regional-scale development intensity because few of these areas existed within my study area, and those that did were located in the urban core of Athens, and tended to be commercial or industrial areas, not single-family housing. I also indentified three sites within low landscape-scale development intensity zones that I considered to be of minimal landscape-scale development intensity to serve as reference sites; these sites were forested, upland parks and reserve areas subject to only minor human disturbance.

Avian Point-Count Sampling Points

The study sites I located using the approach outlined above were used later to sample avian communities. During each physical site visit, I located a series of sampling points (generally eight) where I conducted avian surveys during the breeding season. I attempted to fit eight points in each study site, with six points located within the neighborhood itself and two points located in larger patches of remnant forested fringe in or around the development. I allocated more effort to development than forest because previous studies have indicated that birds and vegetation vary more within development than in remnant forest patches (Donnelly and Marzluff 2004). Please see chapter three for an expanded description of how and where sampling points were located and how avian surveys were carried out. Avian sampling points were used as centers of interest for subsequent geospatial analyses as discussed below.

Characterization of Study Site Landscapes

My second objective was to develop a set of multiscale spatial measurements to characterize study landscapes that, based on previous studies, I hypothesized would be important in explaining abundance and diversity of birds on my sites (Tucker, Rushton et al. 1997; Saab 1999; Villard, Trzcinski et al. 1999; Lee, Fahrig et al. 2002; Theobald 2003; Green, Cornell et al. 2005; Hansen, Knight et al. 2005). I generated variables at three spatial scales: ‘local’ (0.01 to 0.02 km^2), ‘landscape’ (1 km^2), and ‘regional’ (5 km^2). The smallest scale represented an area approximately the size of a feeding territory for many of my targeted bird species (Schoener 1968). I chose 1 km^2 as the landscape scale of interest because it would easily encompass multiple feeding territories for a wide variety of small and medium landbirds. Currently, there is little consensus on the largest scale of importance for studies of this kind; previous, similar studies have used maximum scales of interest ranging from 0.5 km^2 to 10 km^2 (Pearson 1993; Bolger, Scott et al. 1997; Saab 1999; Perkins, Johnson et al. 2003; Westphal, Field et al. 2003). I chose a possibly conservative maximum scale of interest, 5 km^2. I developed variables from multiple data sources using several different methods to calculate metrics of interest (Table 2.1).

Window Analyses

I used moving window analyses in ArcMap to calculate, for each site at the landscape and regional scale, respectively: (a) mean percent area in developed land cover in 2005 (*Dev1km, Dev5km*); (b) mean percent area in agricultural land cover in 2005 (*Ag1km, Ag5km*); (c) mean percent area in forested land cover in 2005 (*For1km, For5km)*; (d) Road Density (km roads/ 1km^2; *RdDen1km, RdDen5km*); (e) housing density (houses per acre; *HDen1km, HDen5km*). I determined mean elevation (meters AMSL) at a landscape scale only (*Elev1km*). Metric means were the average value of the metric across all avian point-count locations on that given site. I also calculated housing density in a 150-m x 150-m local window (*HDen150m*) and number of houses within 150 m of a sample point (*Hnum150*m) for each site.

Screen-digitizing Aerial Photos

I used recent (2007), high resolution (1-m grain) aerial photographs (Table 2.1), to classify the landscape in a 100-m radius around each sampling location into five land cover classes. I centered a circular 5-m x 5-m vector fishnet over each sampling location. I classified each cell as: (a) tree canopy; (b) impervious surface (paved areas and roof surfaces; (c) lawn or horticulturally-maintained areas; (d) fields or pasture (abandoned or maintained); or (e) 'other' / 'unable to identify' (fig 2.6). I calculated the percentage of each land cover class within the circle (*For100m; Imp100m; Lawn100m; Field100m; or Other100m, respectively*). All screen-digitizing was completed at 1:1000 scale, allowing me to distinguish land cover categories easily. I calculated the mean of the above variables for all sampling locations on each site.

I had estimated (above) percentage of forested land cover at the landscape-scale using moving window analysis of satellite-based land cover classifications previously derived for another project (GLUT; Table 2.1). I was curious how similar those estimates would be compared to my visual interpretation of aerial photographs of my study area. To facilitate a comparison of the two methods, I screen-digitized forest cover percentage for each of my sites. I overlaid a second set of circular 10-m x 10-m fishnet grids ($1km^2$ area) over the geometric centroid of each site (calculated using all sampling locations on the site). I then classified the land cover in each circle as either 'forest canopy' or 'other' at 1:2000 scale using the same set of aerial photographs (Fig. 2.7) and calculated the percentage of each circle that was in forested land cover (*PctCan1km*). I compared the percent forest within 1 km of the site centroid and within 100 m of each sampling location derived from aerial photo interpretation and 2005 land cover (GLUT; Table 2.1).

Quantification of Landscape Pattern and Configuration

I used program FRAGSTATS (McGarigal, Cushman et al. 2002) and forest classes from the GLUT 2005 land cover data (Table 2.1) to calculate metrics[4] of landscape configuration and pattern. All metrics were calculated at the site-level (a 1-km^2 square centered on the centroid of each avian study site). I calculated the number of patches (*Pat1km*), patch density (*PDen1km*), amount of forest edge (*ForEdge1km*), largest patch index (*LPI1km*), mean Euclidian nearest-neighbor distance (*ENN1km*), contagion index (*Contagion1km*), and aggregation index (*AggIndex1km*) for each site. Pat1km is the number of forest patches on a site; PDen1km is the number of forest patches divided by site area. ForEdge1km is the amount of forest edge (m) on each site. LPI1km represents the percentage of the landscape made up by the largest forest patch. ENN1km is the mean distance (m) between neighboring forest patches. The contagion index ranges between 0, when forest patches are maximally disaggregated and interspersed, and 100, when forest patches are maximally aggregated into a single patch (i.e., it is an index of how “clumpy” the forest patches on a site are arranged); similarly, AggIndex1km ranges from 0, when patch types are maximally disaggregated, to 100, when the landscape consists of a single patch. See (McGarigal, Cushman et al. 2002) for more detailed discussion of how these landscape metrics are calculated by FRAGSTATS.

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[4] Landscape configuration metric definitions based on FRAGSTATS documentation: McGarigal, K., S. A. Cushman, et al. (2002). FRAGSTATS: Spatial pattern analysis program for categorical maps. Amherst, University of Massachusetts.

Screening Metrics for Extreme Correlation

I used SAS software[5] to determine which potential explanatory variables were correlated. I calculated Pearson correlation coefficients (SAS: PROC CORR) for all pair-wise combinations of the 26 landscape variables described above. I defined extreme correlations as having r-values more extreme than ± 0.70. Where r-values more extreme than ± 0.70 were detected, I screened out variables until no additional strong correlations were detected. I retained one variable from each strongly correlated pair, provided it was not also strongly correlated with another variable; retained variables were selected preferentially, so that the retained variable would be widely available and/or easily calculated for other regions. Ensuring that the final set of site characteristic variables were not excessively correlated was critical because the ultimate intended use for them was as explanatory variables in avian abundance and diversity models (chapter four).

RESULTS

Characterization of Study Area Development Intensity

Regional-scale development intensity levels were greatest within the urban core region of Athens and generally decreased with distance from the center of the city (Fig. 2.8). Development intensity zones (low, medium, and high) were relatively contiguous when considered at the regional scale and generally followed major transportation corridors. The medium development intensity zone was roughly concentric around the zone of high development intensity, though it exhibited a westward extension (along the transportation corridor to Atlanta, GA) and another extension to the northwest (which

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[5] The data analysis for this paper was generated using SAS/STAT software, Version 9.1 of the SAS System for Windows XP. Copyright 2002-2003 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA.

represents an industrial area near Athens). The surrounding area outside of the high and medium development intensity zones was classified as low development intensity and generally consisted of agricultural and rural residential land use.

Landscape-scale development intensity was also greatest within the urban core of Athens and generally decreased with distance from the center of the city (Fig. 2.9). At the finer-grained landscape scale, however, smaller areas of higher development intensity were revealed, most notably in two areas around Watkinsville, GA (in central Oconee county, south of Athens) and along the same transportation corridor and industrial area mentioned above. Areas of greater development intensity appeared more fragmented when considered at the landscape scale.

Study Site Selection

I located 33 residential developments and three forested reserves to serve as study sites (Fig. 2.10). Three residential sites each were located within the combinations of regional-scale development intensity (low or medium), landscape-scale development intensity (low, medium, or high), and site age (young or mature); see Appendix B for site illustrations. I was not able to locate any sites representing one triplet (high landscape-scale development intensity, low regional-scale development intensity, mature site age) because that combination of age and development intensity was not found within the study area. The three forest reserve sites represented areas of minimal landscape-scale development intensity; two sites were in local parks and one was in a university experimental forest (see Appendix B for site names and development intensity classes, and ages). Each of the 36 study sites were roughly square-shaped and 1 km^2 in area.

Potential study sites were first located using gradient maps and aerial photos and then evaluated using ground visits by car and on foot. Sites were eliminated from consideration most frequently due to problems gaining legal access to the properties.

Most potential study sites are under private ownership; because literally hundreds of property access agreements would have been necessary to legally cross private properties in the course of this study, sites with minimal public access (generally in the form of public roads) were not selected. Residential developments undergoing intensive, active construction and those near heavily-trafficked roads were eliminated due to high noise pollution. Several sites in areas of greater development intensity were judged to be too dangerous to the surveyor, either because too few safe pull-offs from the road were available, or because the areas appeared to be subject to relatively high crime rates.

Characterization of Study Site Landscapes

I calculated all pairwise Pearson correlations between the set of 26 site characteristic variables I initially developed and detected 17 extremely correlated relationships between variable pairs (Table 2.3); I preemptively removed *Field100m* from consideration before conducting Pearson correlations or screening exercises because my site selection protocol was purposefully biased away from sites with fields and/or pastures, and most sites did not possess that land cover type. Eleven of the 26 variables were responsible all of the 17 extreme correlations. For a complete correlation matrix, see Table 2.4.

Housing density and the number of houses within 150 m of a point-count centroid were 100% correlated. Percent of land cover types within 100 m of a point-count centroid were often strongly correlated. Land cover in lawn or garden was extremely, negatively correlated with forested land cover. Land cover under impervious surfaces was extremely correlated with lawn / garden land cover and was extremely negatively correlated with forested land cover.

Landscape-scale percent developed land cover was extremely correlated with landscape-scale percent forested land cover (negative correlation) and housing density (positive correlation). Regional-scale percent developed land cover had strong positive correlation with regional-scale road density and housing density and with landscape-scale housing density. Regional-scale housing density and regional-scale road density were very strongly correlated ($r = 0.90$).

Two variables (PCTCAN1km and FOR1km) both estimated landscape-scale percent forested land cover using two different methods (aerial photo interpretation versus classified satellite imagery); the two variables exhibited a strong positive correlation with one another (78.3%; Table 2.3). In general, percent forested land cover calculated using 2005 GLUT land cover data (mean: 47.4% forested) underestimated the amount of forest with respect to estimates made from aerial photo-interpretation (mean: 68.5% forested), averaging 21.1% lower. The local-scale measurements of percent forest within a 100-m radius around each count location were less correlated (58% correlated) with the aerial photo-interpreted measures of percent forested (mean: 45% forested) averaging 20.8% higher than that calculated using the 2005 GLUT land cover dataset (mean 65.8% forested). Several spatial pattern variables (largest patch size, aggregation index, and amount of forest edge) were strongly correlated with the contagion index. The number of patches and patch density were 100% correlated. The aggregation index was -99.2% correlated with the amount of forest edge.

Based on extreme Pearson correlations, I screened out 10 variables from my original set of 26: *HDen150m, Lawn100m, Imp100m, Dev1km, Dev5km, PctCan1km, HDen5km, Contagion1km, Pat1km,* and *AggIndex1km*. I also rejected *Other100m* because it was not a well-defined land cover type. During screening exercises, I classified one variable pair (*For1km* and *For5km; r* = 0.73) as not being extremely correlated because their *r*-value was only slightly above the elimination threshold.

After variable screening, I was left with a set of 15 variables that were not extremely correlated with one another: *HNum150m; For100m; Ag1km; For1km; RdDen1km; HDen1km; Elev1km; LPI1km; ENN1km; PDen1km; ForEdge1km; Ag5km; For5km; RdDen5km*; and *Age*. Appendix C (Table C.1) lists values for each retained variable by site. These variables describe aspects of human disturbance and landscape composition at the local, landscape, and regional scales, as well as of landscape configuration at the landscape- and regional-scales (Table 2.4).

DISCUSSION

Characterization of Study Area Development Intensity

My combined map of development intensity reveals that the landscape surrounding Athens, Georgia resembles a concentric zone pattern modified by transportation corridors, much as described by Hoyt (1939). At coarser spatial scales (regional-scale) the city is characterized by the classic “bull’s-eye” structure associated with urban sprawl: an urban core of high development intensity surrounded by roughly concentric rings of suburban and exurban land use patterns which only generally follow transportation routes. When areas of greater development intensity are considered at finer scales (landscape-scale), they appear more fragmented; this effect is due to the finer grain picking up on urbanization effects from small towns, large commercial areas, and relatively large residential areas which are masked by lower-development intensity surroundings when considered at larger spatial scales. At fine scales development clearly follows major transportation corridors (highways). In this regard, Athens is probably typical of many rapidly-growing medium-sized towns in the southeastern United States.

Study Site Selection

My method of selecting potential study sites using GIS-generated maps of landscape- and regional-development intensity followed up with ground visits proved to be an effective approach to the task. Because my map layers included up-to-date aerial photographs of the study area, I was able to rapidly locate residential developments which had very recently started the site clearing phase, long before the neighborhood's roads would have been included on county road maps; I was also spared the time and effort needed to visit multiple county planning offices to learn about the locations of current developments.

Combining housing density, road density, and percentage of landscape in developed land cover into a metric of development intensity greatly assisted me in the rapid and economical identification and classification of suitable study site neighborhoods. Although aerial photographic resolution was excellent and development intensity gradients were generally accurate, site visits were still necessary to confirm each location's suitability as an avian survey site (see chapter 3). For example, although photos suggested that particular developments were good site candidates, ground visits revealed too many problems (e.g., safety issues for observers or high noise/disturbance levels) for the sites to serve adequately as survey sites.

Characterization of Study Site Landscapes

My second objective was to develop a set of multiscale variables to explore how landscape composition and configuration explained variation in avian abundance and diversity. An additional requirement was that the types of datasets (e.g., maps of forest cover) used to generate these explanatory variables be widely and easily available to (or easily developed by) other researchers working on similar problems in other areas of the world (Theobald 2003). I also compared the benefit of hand-digitizing percent canopy cover vs. calculating it using automated procedures based on existing land use maps.

Eleven of my 26 initial variables were highly correlated (Table 2.3), with Pearson correlation coefficients more extreme than ± 70% (see Appendix C (Table C.2) for all correlations). In the instance of this study, these correlations were mainly due to two circumstances: (a) classification schemes utilizing a limited number of categories and (b) similarities between what variables are measuring. An example of the former is the local-scale land cover classification scheme, where relatively few classes (Forest; Lawn; Impervious Surface) dominated the landscape, and an increase in one necessarily resulted in a decrease in the others. Examples of the latter circumstance include the case of HDen150m and HNum150m, which essentially measure the same variable; or AggIndex1km and ForEdge1km which are both strongly related to the degree of fragmentation in a landscape. A high degree of correlation between landscape characteristics may actually represent an advantage in some situations, where easily-obtained variables may be substituted for less-available ones.

I reduced my initial set of 26 possibly useful explanatory variables down to 15 based on Pearson correlations (Table 2.4). I chose to include both For1km and For5km (percent of the landscape in forested land cover at the landscape and regional scales, respectively) despite a Pearson correlation coefficient between the pair of 0.73, because I believed that forest cover was an important component to landscape composition at both larger and more intermediate scales. The set of selected variables can be easily calculated from readily-available data sets or measured directly on the ground, which is important if they are to be applied to studies in other geographical areas (Theobald 2003). The types of variables I selected were consistent with measures representing human disturbance levels, landscape composition, and landscape configuration that were found in other studies to be important to bird community and population abundance and diversity (see next section).

Human Disturbance

I characterized human disturbance levels on study sites by measuring housing density, road density, and development age. Housing density and road density are commonly-used and easily-derived indicators of human land-use intensity (Theobald 2003). Residential development age has been cited as an important landscape characteristic to wildlife because as neighborhoods age, vegetation structure and composition change (Hansen, Knight et al. 2005).

Habitat Composition

Measuring land cover (i.e., habitat) composition is a basic way to consider whether habitat important to a species is present on a site. I characterized the percentage of remaining natural cover (in this study, natural land cover was forest, by design) and the percentage of agricultural cover. The percentage of forested land cover represents an important aspect of the amount of habitat available to avifauna where they may meet their life history requirements, such as foraging and nesting (Lee, Fahrig et al. 2002). Forested land cover was inversely correlated with landscape-scale developed land cover, and the local scale land cover types, ‘lawn’ and ‘impervious’, thereby representing not only the amount of beneficial habitat retained but the amount of altered habitat present. Conversion to agricultural land cover was the other main land alteration in vicinity of the study sites; because of the massive changes inherent to conversion to agriculture, it is postulated to be the greatest extinction threat to birds, globally (Green, Cornell et al. 2005).

Habitat Configuration

I considered habitat configuration only on the site-level (landscape-scale). At the local-scale, available landscape configuration data was too coarse-grained to accurately describe conditions. I did not consider configuration at the regional scale because my overarching purpose in evaluating configuration was to determine the relationship between habitat configuration and avian abundance and diversity; the home range scales of my target organisms were significantly smaller than 1 km^2 (Schoener 1968) (see chapter 3). Landscape pattern at the 1-km^2 scale is important to breeding birds (Saab 1999).

Independently of the amount of remaining forest habitat, fragmentation of habitat remnants by adjacent residential developments severely limits the ecological value of forests (Friesen, Eagles et al. 1995). Measures of fragmentation have been demonstrated to help explain variation in abundance of several forest-dwelling bird species (Lee, Fahrig et al. 2002). The set of fragmentation metrics I chose have been shown to predict the presence of many bird species irrespective of microhabitat features (Villard, Trzcinski et al. 1999); those metrics described a variety of characteristics of remaining forested habitat on my sites: its relative size (*LPI1km*), the distance between patches (*ENN1km*), number of patches present on a site (*PDen1km*), and amount of habitat edge (*ForEdge1km*). I also recorded average site elevation (*Elev1km*) because it has previously been of utility in modeling bird occurrence (Tucker, Rushton et al. 1997).

Screen-digitized Classification vs. Automated Classification

I explored the similarity between my measures *For1km* and *PctCan1km*. Both measured the same variable: the percentage of canopy cover in a 1 km^2 circular area centered on the site centroid. *PctCan1km* required significantly more effort to generate than For1km, because PctCan1km was created from screen-digitized aerial photographs which required several days of work to process. For1km was calculated from GLUT data (Table 2.1), which were already classified based on satellite image interpretation. Of the two measures, For1km underestimated forest cover relative to PctCan1km; however, the two measures were strongly correlated (78.3% correlated). Comparisons between the two methods when used to calculate local-scale percent forest showed much lower levels of correlation between the two methods (58% correlated) and a similar underclassification of forest cover by the satellite imagery-interpretation method relative to aerial photo-interpretation.

At coarser scales (landscape scale), this suggests that when satellite imagery-based classified land cover data are already available, they may be considered roughly equivalent to more expensive (in time or resources) aerial photo-interpretation classified land cover data. There may be a tendency to underestimate land cover types with the satellite imagery-based method, but the overall estimates are extremely correlated with the aerial photo interpretation method. At finer scales (local scale), it appears that while the underestimation of land cover types may persist, the close correlation between estimates made by the two methods becomes much weaker. In this situation, it may be cost-justified to invest in the labor-intensive process of aerial photo-interpretation because that process appears to result in land cover estimates which are more accurate on finer scales. When previously-classified satellite imagery is already available, and depending on the spatial scale involved, the cost savings of knowing when to invest in aerial photo classification and when not to may be substantial (potentially saving or costing weeks or months of labor-hours).

CONCLUSIONS AND RECOMMENDATIONS

Overall, my site selection methodology greatly simplified an otherwise expensive and time-consuming task and future researchers could benefit from a similar approach.

This study was intended to be an exploration of concept and feasibility for future, more intense research in this area; funding and resources were limited, which in turn limited my ability to sample across a wide range of points along the urban-rural gradients in the study area. My criteria for site selection were primarily based on proxies for landscape composition (i.e., amount of habitat) and I located 36 sites representing two points along a gradient of regional-scale development intensity, four points along a gradient of landscape-scale development intensity, and two points along a gradient of site age. I recommend that follow-up site selection efforts consider not only landscape composition, but also landscape pattern (e.g., metrics of fragmentation) in order to more effectively isolate explanations for avian abundance and diversity responses. I also recommend that sites representing finer intervals along the gradient of site age be located in order to better understand the effect of an aging site. Finally, the original land cover type for all of the study sites for the 2007-2008 field season was forested (either natural or secondary regrowth); I suggest that if resources allow, future survey efforts should be allocated to residential developments which are constructed in former agricultural lands.

In my case study of when it is cost-effective to invest in classifying land cover using aerial photo-interpretation (when satellite image-based land cover classification data are already easily available), I found that spatial scale appears to be an important criterion in making the decision to invest or not. At finer spatial scales, my results suggest that it may be worth the investment to produce more accurate, finer-grained land cover classification data; whereas at coarser scales, although satellite-based classifications may be somewhat less-accurate, they may be sufficiently correlated with aerial photo-interpreted classifications that the expenditure is not worthwhile. More research into this problem appears to be warranted.

Table 2.1: Data sources used to develop geospatial data layers.

Data Layer	Source	Classes (buffer distances used)	Scale / Resolution
2006, 2007 Digital Orthophotographs	National Agricultural Imagery Program	n/a	1 meter; true color
Housing Density	Wildlands-Urban Interface	Housing Density (units / km^2)	2000 block-scale housing density (units per km^2) converted to units per acre
Road Density	GA DOT General Highway Base Map, 1993	Interstate (500 m buffer) State Hwy (250 m buffer) State Route / County Road (100 m buffer) City Street / Public Road (75 m buffer) Private / Forest Service / Industry / DOT Proposed Road (25 m buffer)	Derived from 1:12,000 scale DOQQ
Developed Land Index	GAP 19 class land cover (1998) http://narsal.uga.edu/gap.html	Transportation (18); Utility ROW (20); Low Intensity Urban (22); High Intensity Urban (24); Parks, Recreation (72), Golf Course (73); Forested Urban - Deciduous (201); Forested Urban – Evergreen (202); Forested Urban – Mixed (203)	1 acre suggested MMU (30 m pixels)
Forest, Agriculture, Urban	2005 Georgia Land Use Trends (GLUT) land cover http://narsal.uga.edu/glut.html	Forest (Deciduous Forest [41], Evergreen Forest [42], Mixed Forest [43], Agriculture (Row Crop/Pasture [81]), Urban (Low Intensity Urban [21], High Intensity Urban [42])	1 acre suggested MMU (30 m pixels)
Site Age	Visual Assessment on Site	Young; Mature	n/a
Elevation	Georgia GIS Clearinghouse		1:24,000; 30 m pixels

Table 2.2: Cutoff values for variables used to calculate development intensity.

Intensity Index	% Road-influenced	Housing Density (# / acre)	% Developed Land Cover
Minimal	< 10	< 0.1	< 10
Low	10 – 25	0.1 – 0.5	10 – 25
Medium	25 – 50	0.5 – 1.0	25 – 50
High	> 50	> 1.0	> 50

Table 2.3: Extreme correlations between variables[1]. Correlations between all pair-wise combinations of 26 landscape metrics were determined using SAS software; variables exhibiting extreme (-0.70 < r > 0.70) Pearson correlation are summarized below.

Strongly-correlated Variable Pairings		Pearson Correlation Coefficient, *r*	Prob. > |*r*| under H_0: Rho=0
HDEN150m	HNum150m	1.0000	< 0.001
LAWN100m	FOR100m	-0.9172	< 0.001
IMP100m	FOR100m	-0.8541	< 0.001
IMP100m	LAWN100m	0.7238	< 0.001
DEV1km	FOR1km	-0.7505	< 0.001
DEV1km	HDEN1km	0.8149	< 0.001
DEV5km	RDDEN5km	0.8906	< 0.001
DEV5km	HDEN1km	0.7245	< 0.001
DEV5km	HDEN5km	0.8576	< 0.001
PCTCAN1km	FOR1km	0.7830	< 0.001
FOR1km	FOR5km	0.7314	< 0.001
HDEN5km	RDDEN5km	0.9024	< 0.001
PAT1km	PDEN1km	1.0000	< 0.001
CONTAGION1km	LPI1km	0.8685	< 0.001
CONTAGION1km	AGGINDEX1km	0.7117	< 0.001
CONTAGION1km	FOREDGE1km	-0.7200	< 0.001
AGGINDEX1km	FOREDGE1km	-0.9920	< 0.001

[1] *For a complete table of Pearson correlation coefficients between all variable combinations, see Appendix C (Table C.2).*

Table 2.4: Description of landscape metrics selected for site characterization. Metrics reflect aspects of human disturbance and landscape composition and configuration on study sites.

Variable	Description	Units	Scale [1]
Human Disturbance			
HNum150m	Number of Houses within 150 m of point-count location	Houses	Local
RdDen1km	Road density within 1x1 km square around site centroid	km roads / km^2	Landscape
RdDen5km	Road density within 5x5 km square around site centroid	km roads / km^2	Regional
HDen1km	Housing Density within 5x5 km square around site centroid	Houses / acre	Landscape
Age	Site age (young: ongoing construction; mature: post-construction)	n/a (binary)	Landscape
Landscape Composition			
For100m	% Forested land cover within 100x100 m square around site centroid	n/a (percentage)	Local
For1km	% Forested land cover within 1x1 km square around site centroid	n/a (percentage)	Landscape
For5km	% Forested land cover within 5x5 km square around site centroid	n/a (percentage)	Regional
Ag1km	% Agricultural land cover within 1x1 km square around site centroid	n/a (percentage)	Landscape
Ag5km	% Agricultural land cover within 5x5 km square around site centroid	n/a (percentage)	Regional
Landscape Configuration [2]			
Elev1km	Mean site elevation within 1x1 km square around site centroid	m (AMSL)	Landscape
LPI1km	Percentage of landscape made up of largest forest in 1x1 km square around site centroid	n/a (percentage)	Landscape
ENN1km	Mean distance between neighboring forest patches in 1x1 km square around site centroid	m	Landscape
PDen1km	Density of forest patches within 1x1 km square around site centroid	Patches / km^2	Landscape
ForEdge1km	Amount of forest/non-forest edge within 1x1 km square around site centroid	m	Landscape

[1] *Local scale = 0.01 – 0.02 km^2; landscape scale = 1 km^2; regional scale = 5 km^2.*

[2] *Metric definitions based on FRAGSTATS documentation: (McGarigal, Cushman et al. 2002).*

Figure 2.1: Map of study area (2007-2008).

Study area was located in the greater Athens, Georgia area (Clarke and Oconee and portions of Barrow, Jackson, Madison, and Oglethorpe Counties) and was approximately 1130 km^2. Athens is a rapidly-growing town of approximately 113,000 people, located in northeastern Georgia, USA, approximately 110 km northeast of the state capital, Atlanta. County boundaries and cities are shown overlaid on a 2007 true-color aerial photograph.

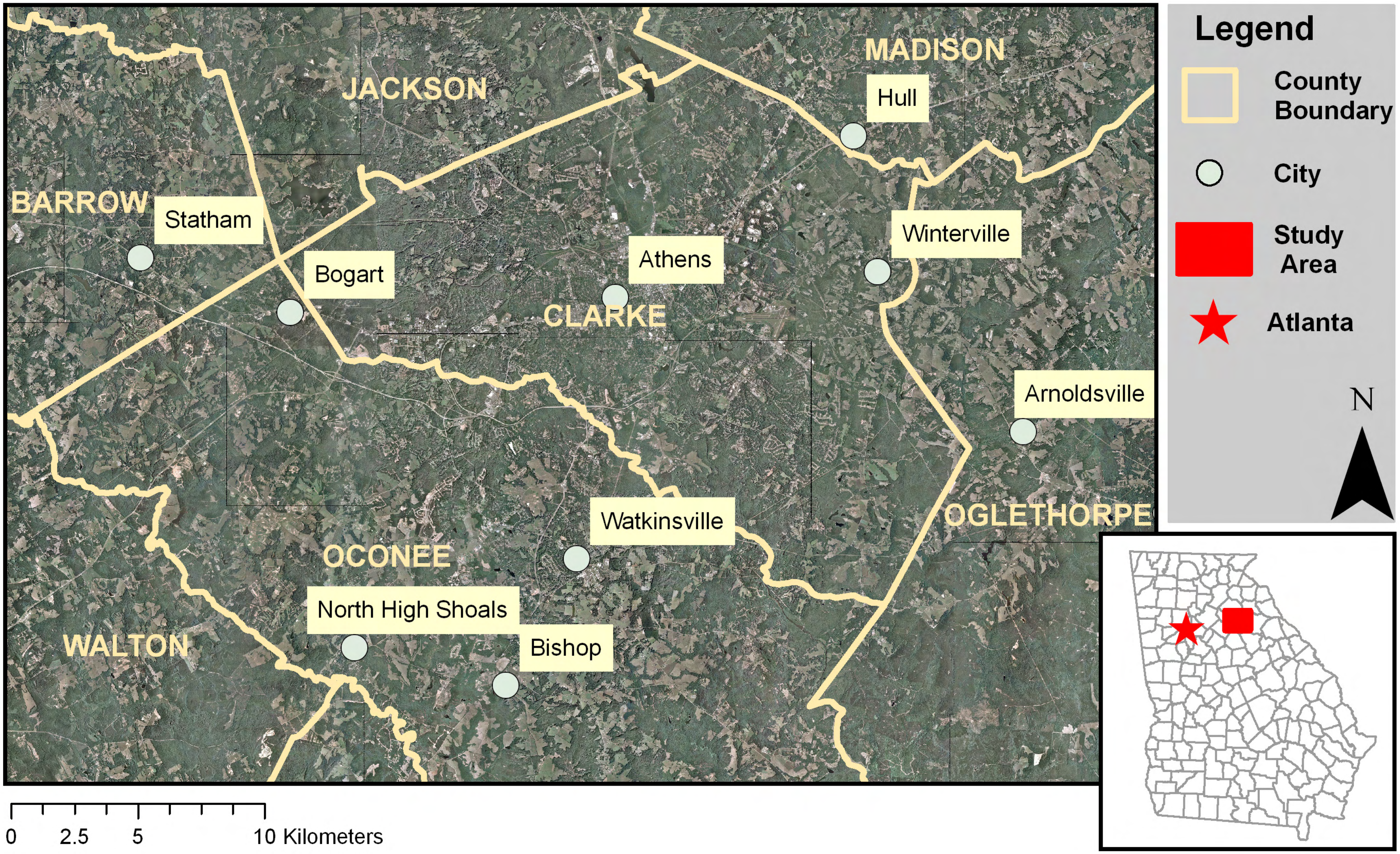

MADISON
JACKSON
BARROW
CLARKE
OCONEE
WALTON
OGLETHORPE
Hull
Winterville
Arnoldsville
Athens
Statham
Bogart
Watkinsville
North High Shoals
Bishop
Legend
County Boundary
City
Study Area
Atlanta
N
0
2.5
5
10 Kilometers

Figure 2.2: Regional-scale development intensity levels overlaid on study area aerial photo (detail).

Development intensity at the regional-scale (5 km^2) overlaid on aerial photographs of the study area was used with maps of development intensity at the local-scale (1 km^2) overlaid on site aerial photos (fig. 2.3) to assist selection of potential study sites (residential developments). Development intensity values were divided into equal thirds and classified as low, medium, or high.

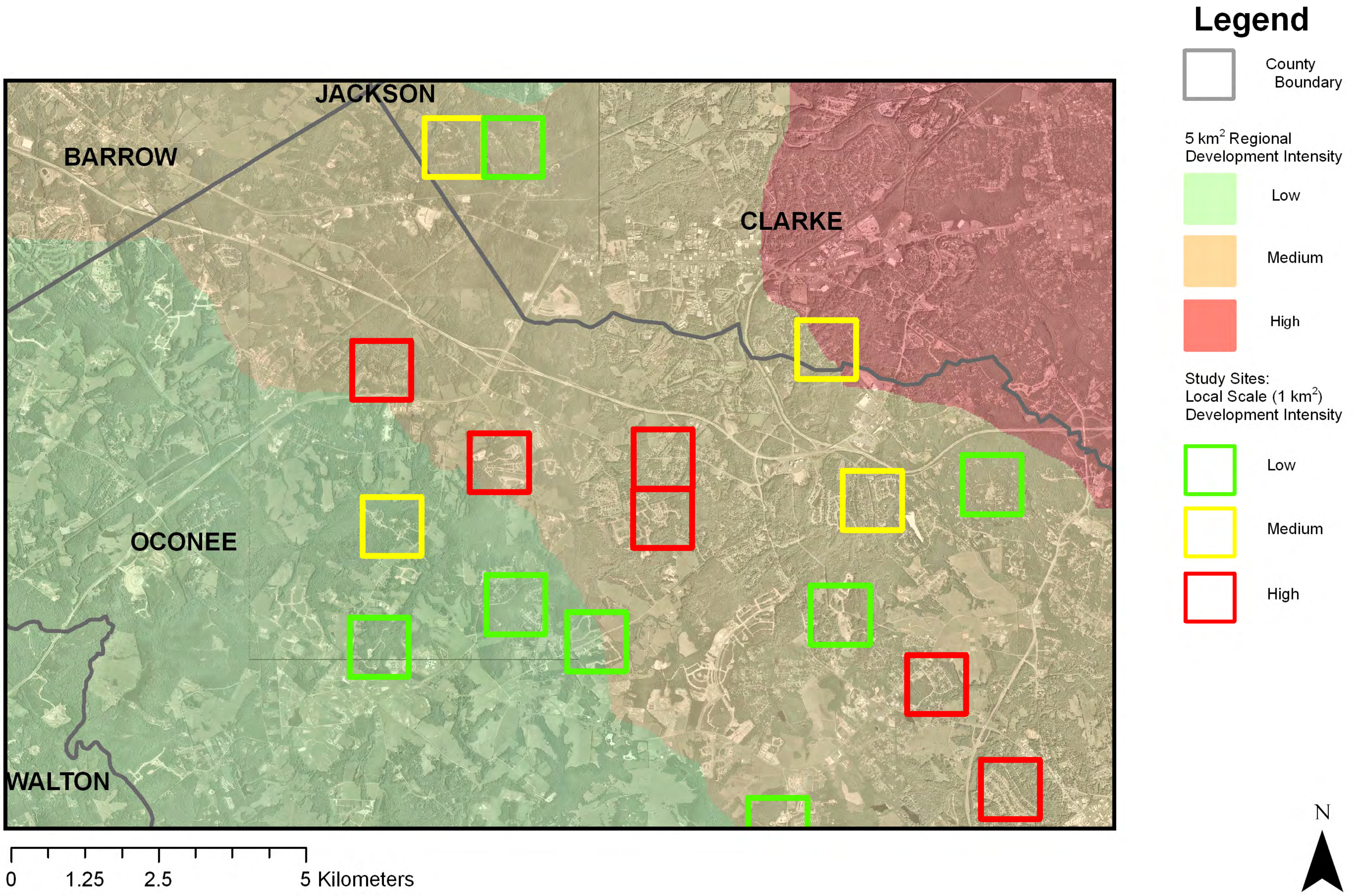

JACKSON
BARROW
CLARKE
OCONEE
WALTON
0
1.25
2.5
5 Kilometers
Legend
County Boundary
5 km^2 Regional Development Intensity
Low
Medium
High
Study Sites: Local Scale (1 km^2) Development Intensity
Low
Medium
High
N

Figure 2.3: Landscape-scale development intensity levels overlaid on study area aerial photo (detail).

Development intensity at the landscape-scale (1 km^2) overlaid on aerial photographs of the study area was used with maps of development intensity at the regional-scale (5 km^2) overlaid on aerial photos (fig. 2.2) to rapidly locate potential study sites (residential developments). Development intensity values were divided into thirds and classified as low, medium, or high; some areas could not be classified because appropriate data were not available.

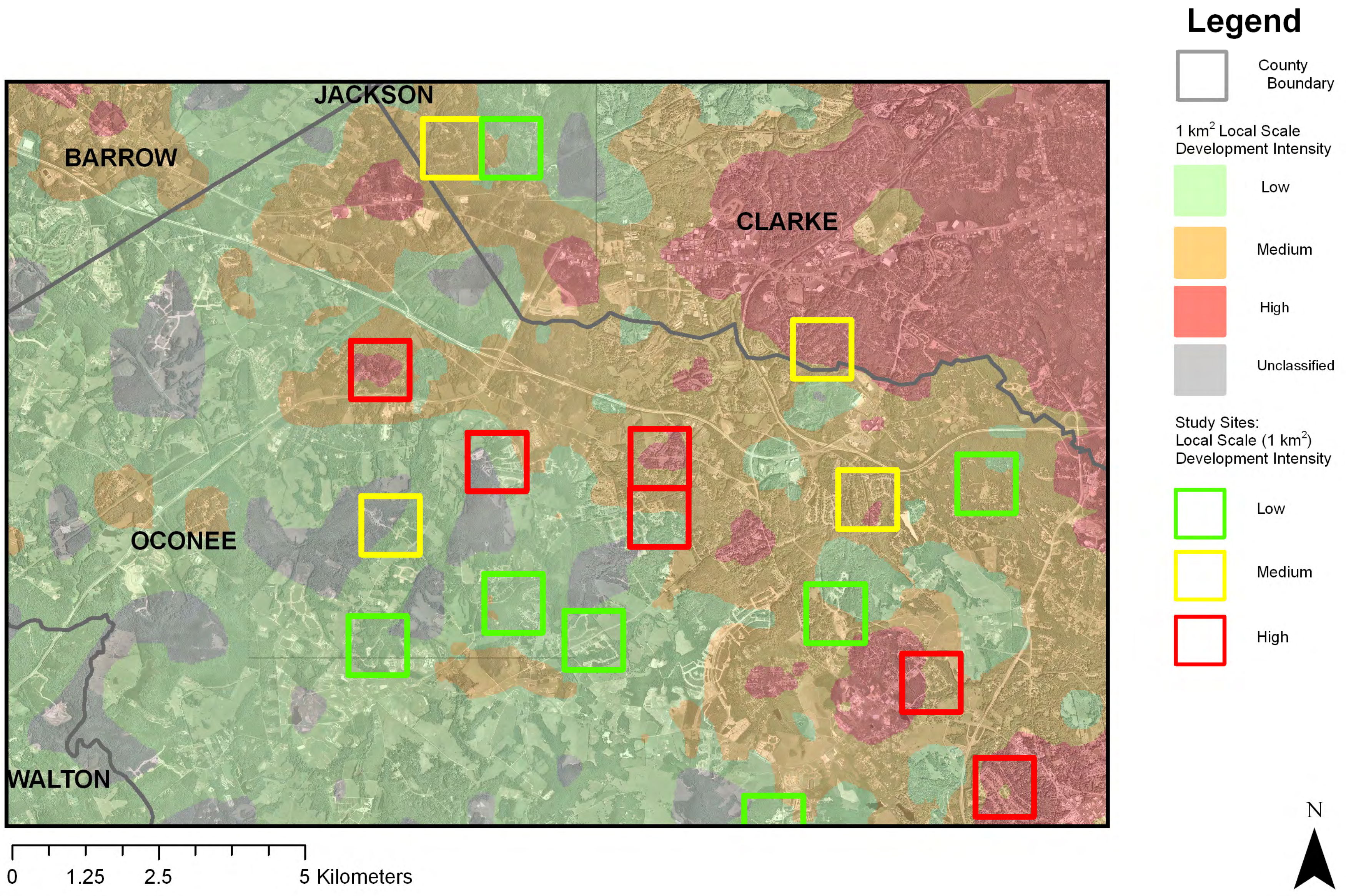

JACKSON
BARROW
CLARKE
OCONEE
WALTON
Legend
County Boundary
1 km^2 Local Scale Development Intensity
Low
Medium
High
Unclassified
Study Sites: Local Scale (1 km^2) Development Intensity
Low
Medium
High
N
0
1.25
2.5
5 Kilometers

Figure 2.4: Young study site undergoing active development (example).

Young developments were sites in the active construction phase between initiation of site clearing and completion of construction. These developments were characterized by: (a) site clearing, (b) ongoing home and/or road construction, and (c) ongoing aggressive vegetation alteration.


Legend
Study Sites:
Local Scale (1 km^2)
Development Intensity
🟩 Low
🟨 Medium
🟥 High
0
0.125
0.25
0.5 Kilometers
N

Figure 2.5: Mature study site in the post-development phase (example).

Mature developments were sites in the post-construction phase and were characterized by: (a) no major recently-cleared lots. (b) no ongoing new home or road construction. and (c) no ongoing alteration of vegetation beyond standard lawn maintenance practices.

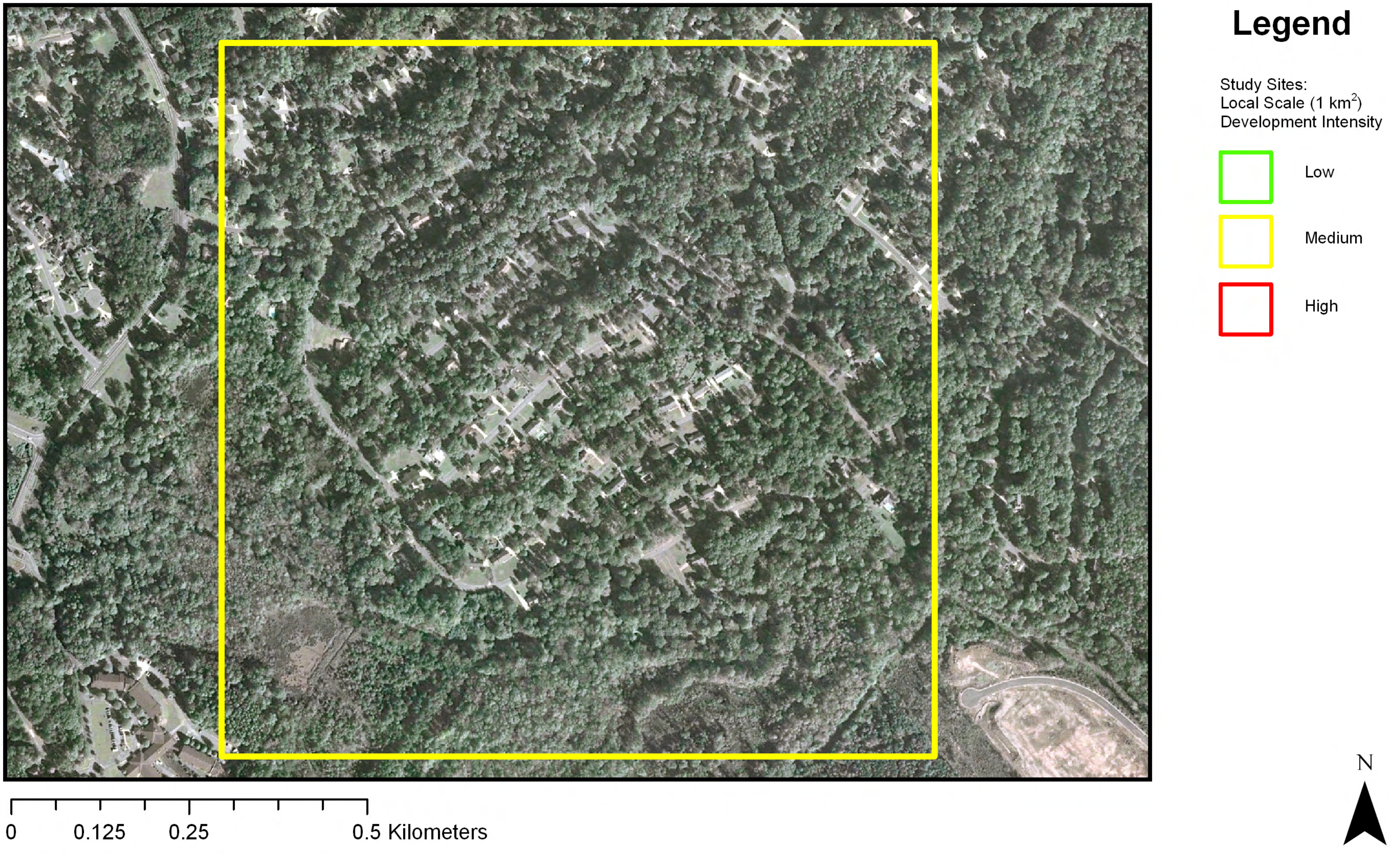

Legend
Study Sites:
Local Scale (1 km²)
Development Intensity
Low
Medium
High
N
0
0.125
0.25
0.5 Kilometers

Figure 2.6: Screen-digitized local-scale land cover (detail).

I used recent (2007), high resolution (1-m grain) aerial photographs to manually classify the landscape manually (5-m grain) in a 100-m radius around each point-count location into five land cover classes: (a) tree canopy; (b) impervious surface (paved areas and roof surfaces); (c) lawn or horticulturally-maintained areas; (d) fields or pasture (abandoned or maintained); or (e) ‘other’ or ‘unable to identify’. Hand-digitized land cover was used to generate data on land cover type percentages for use in explaining avian abundance and diversity.

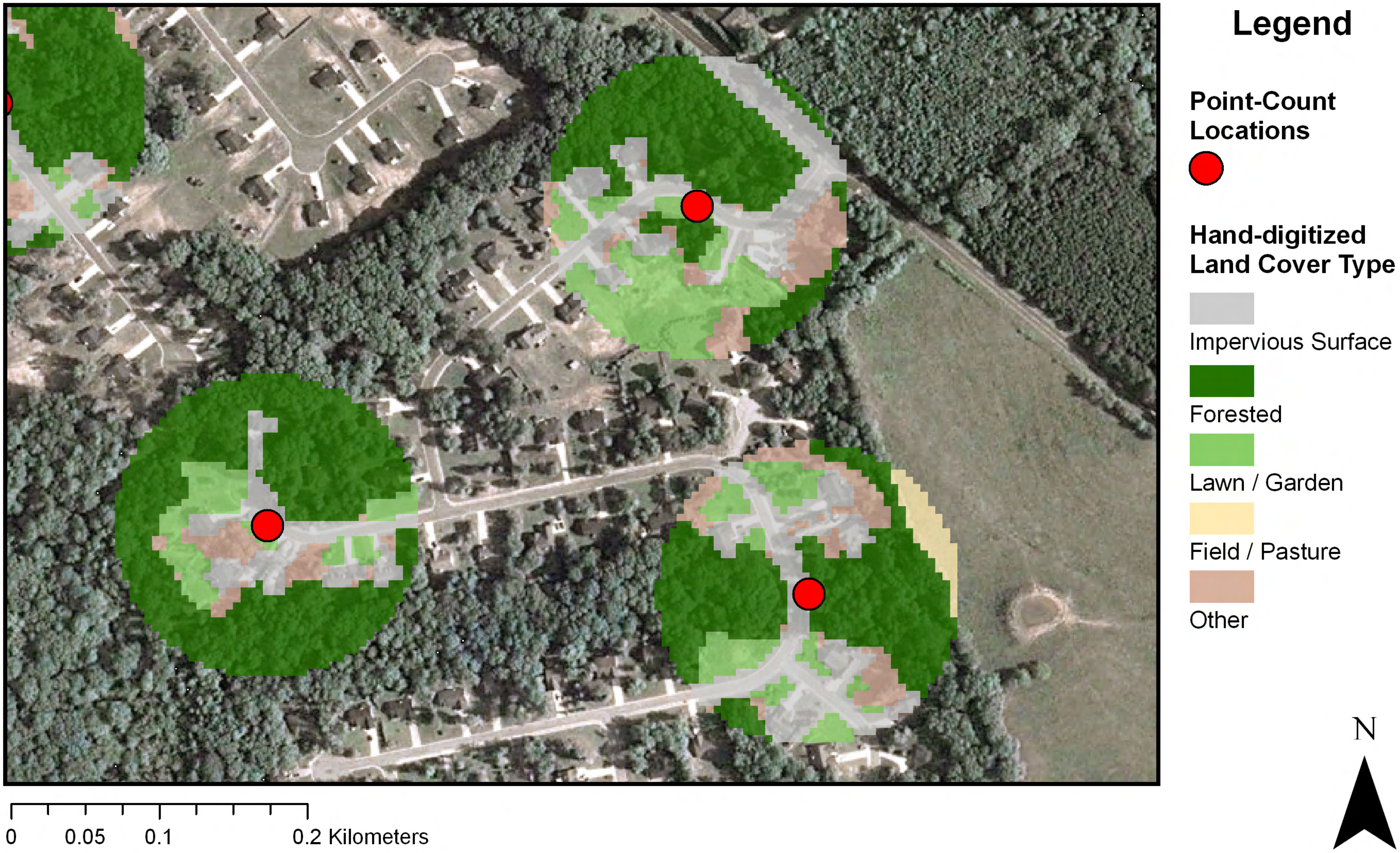

Legend
Point-Count Locations
Hand-digitized Land Cover Type
Impervious Surface
Forested
Lawn / Garden
Field / Pasture
Other
N
0
0.05
0.1
0.2 Kilometers

Figure 2.7: Screen-digitized landscape-scale land cover (detail).

I used recent (2007), high resolution (1-m grain) aerial photographs to manually classify the landscape (10-m grain) in a 1-km^2 circle centered on the site centroid at all study sites into either a forested or non-forested land cover class. Hand-digitized land cover was used to generate a site-level estimate of percentage of forested land cover for possible use in explaining avian abundance and diversity.


Legend
Site Centroid
Hand-digitized Land Cover Type
Non-Forested
Forested
N
0
0.125
0.25
0.5 Kilometers

Figure 2.8: Study Area Regional-scale ($5km^2$) Development Intensity

Regional-scale development intensity around Athens was greatest within the urban core and decreased with distance from the city, generally following major transportation corridors. The surrounding area in low development intensity primarily consisted of agricultural and rural residential land use.

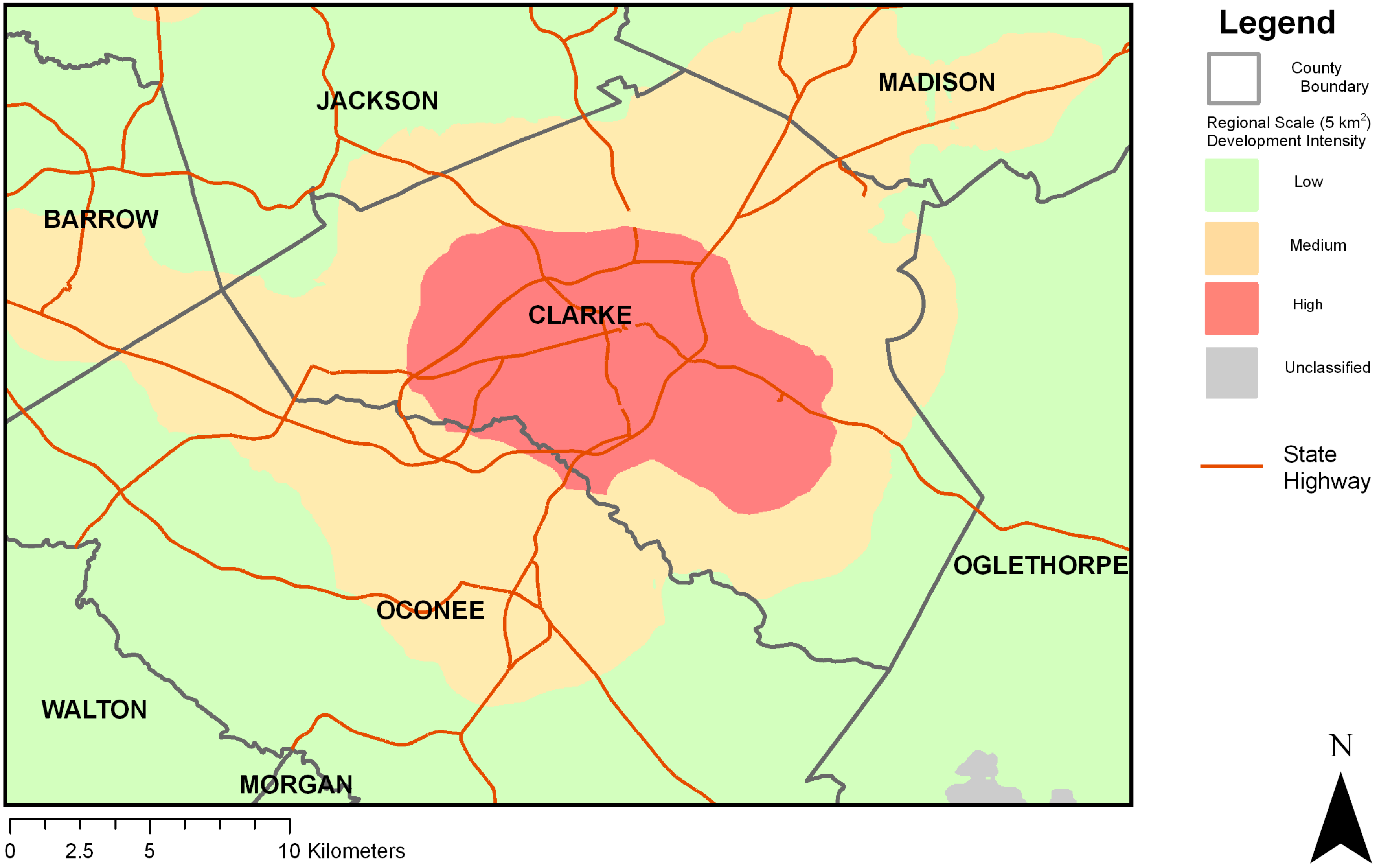

JACKSON
MADISON
BARROW
CLARKE
OCONEE
OGLETHORPE
WALTON
MORGAN
0
2.5
5
10 Kilometers
Legend
County Boundary
Regional Scale (5 km²) Development Intensity
Low
Medium
High
Unclassified
State Highway
N

Figure 2.9: Study Area Landscape-scale (1km^2) Development Intensity

Landscape-scale development intensity (DI), like regional-scale DI was greatest in the urban core region of Athens and generally decreased with distance from the core. Relative to the coarse-grained regional-scale DI map (Fig 2.8), the finer-grained landscape-scale DI map reveals greater variation in landscape DI; for example, areas of high DI such as the city of Watkinsville, GA (in central Oconee county) and along major transportation corridors become more apparent at finer resolution.

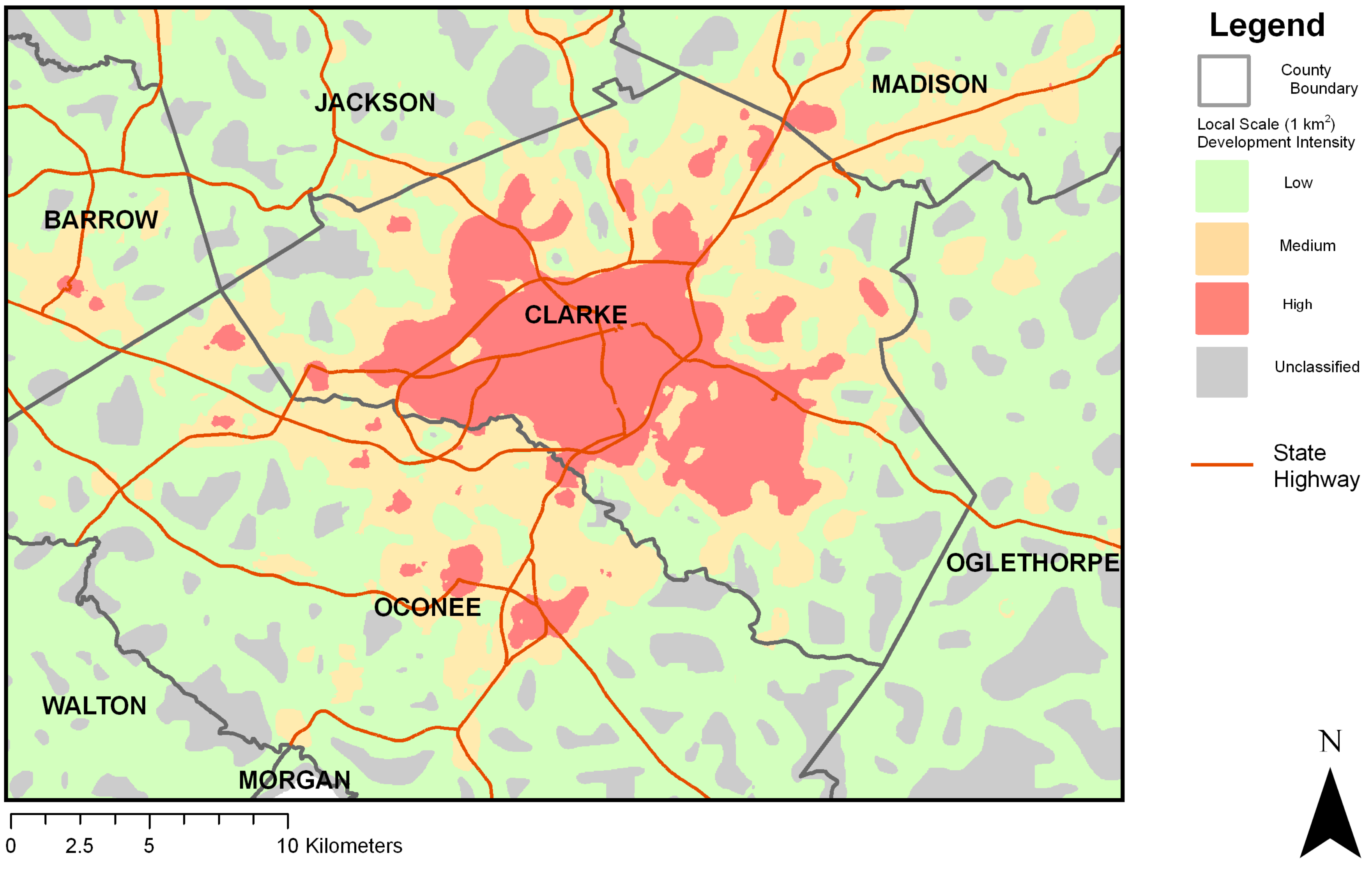
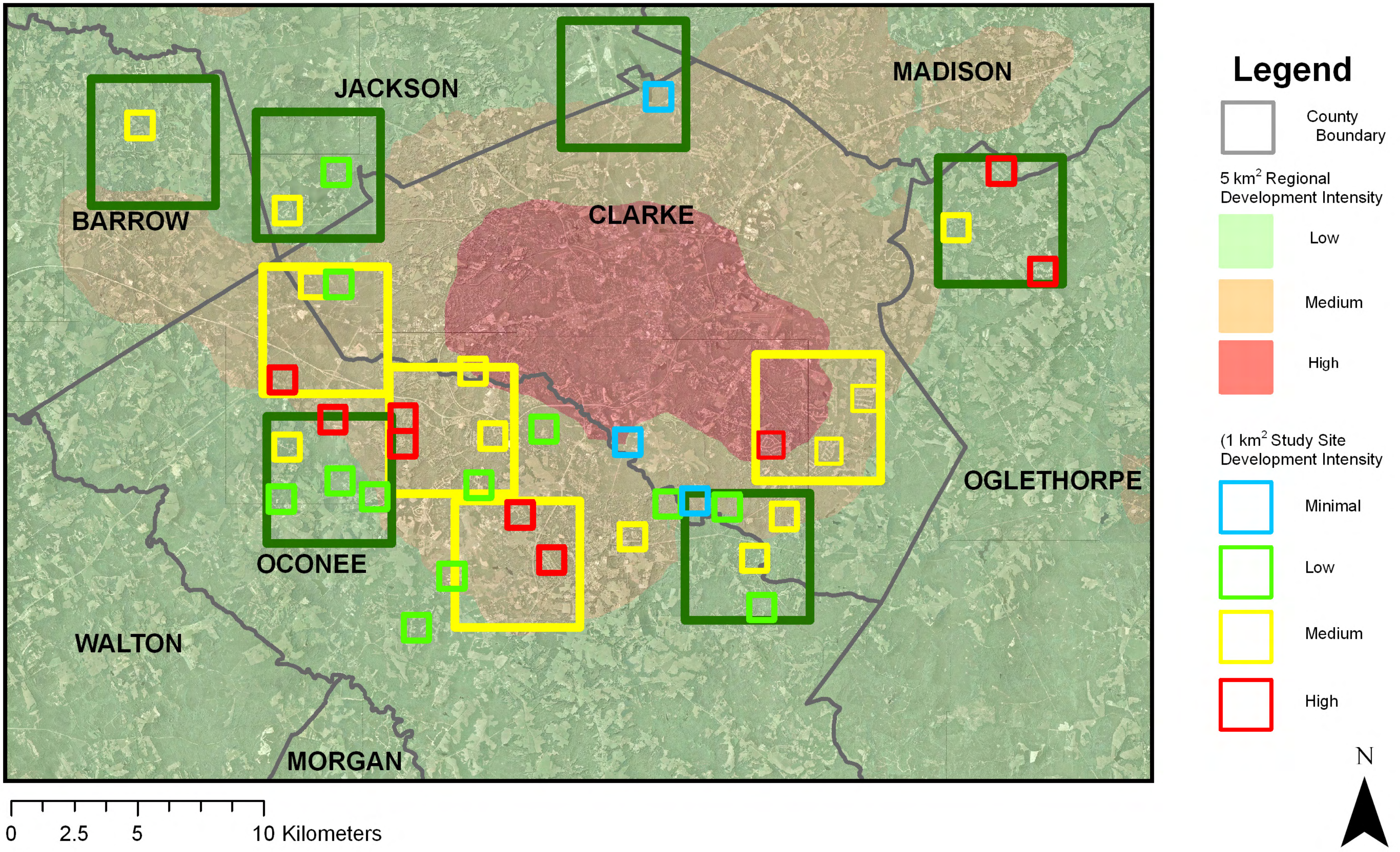

JACKSON
MADISON
BARROW
CLARKE
OCONEE
OGLETHORPE
WALTON
MORGAN
0
2.5
5
10 Kilometers
N
Legend
County Boundary
Local Scale (1 km²) Development Intensity
Low
Medium
High
Unclassified
State Highway

Figure 2.10: Avian survey site locations (2007-2008).

Sites were identified by using an urban-rural gradient approach combined with physical site visits. Here, study sites and regional-scale (5 km^2) development intensity are overlaid on 2007 true-color aerial photos of the study area. I located 36 1-km^2 study sites (small squares) representing four categories of local-scale (1 km^2) development intensity level (minimal, low, medium, and high) within two categories of regional-scale (5 km^2) development intensity (low and medium).


BARROW
JACKSON
CLARKE
MADISON
OGLETHORPE
OCONEE
WALTON
MORGAN
Legend
County Boundary
5 km^2 Regional Development Intensity
Low
Medium
High
(1 km^2 Study Site Development Intensity
Minimal
Low
Medium
High
N
0
2.5
5
10 Kilometers

CHAPTER 3

AVIAN SURVEYS IN RESIDENTIAL DEVELOPMENTS

INTRODUCTION

Avian Response to Urbanization

Around the world, human populations in urban areas are on the rise (Sadik 1999). Increases in human settlement and land use intensity are referred to as urbanization (Marzluff 2001). Urbanization is rapidly changing the landscape of the southeastern United States, particularly in the state of Georgia, the fastest-growing state in the Southeast between 1990 and 2000 (Perry and Mackun 2001). Despite the accepted knowledge of ongoing urbanization in Georgia (Kramer 2008), and well-documented associations between urbanization and loss of avian biodiversity (Chace and Walsh 2006), studies of the response of southeastern birds to urbanization-related landscape alteration are limited. Birds represent important indicators of urban ecosystem health and general biodiversity; a better understanding of avian-landscape relationships in urbanized settings may benefit land managers, urban planners, and policy makers (Marzluff 2001).

Bird communities respond to urbanization-related changes in their environment in many ways, including changes in abundance and diversity (species richness and evenness) (Marzluff 2001). Alterations in community-level abundance and diversity arise from changes in individual species abundance due to the particular ability of each species to adapt to the changes associated with urbanization. Many instances of alterations of avian abundance and diversity have been correlated with urbanization-attributed changes in the landscape (Chace and Walsh 2006). Commonly-cited urbanization-related mechanisms of population declines include: increases in disease prevalence, increases in predation and parasitism, increases in aggressive interloper species that drive out former resident species, declines in habitat quantity or quality leading to poor feeding opportunities, and increased disturbance levels disrupting breeding and maintenance of territory (see chapter one for a more complete discussion of this topic).

Bird species may respond to urbanization in similar ways according to functional guild affiliations. Functional guilds group animals based on commonalities in their behavior or use of habitat; where intra-guild species diversity is high, it can be inferred that the habitat is beneficial to all members of that guild (Bishop and Myers 2005). Some species, termed synanthropic (Johnston 2001) or human-commensal (Lenth, Knight et al. 2006), demonstrate greater tolerance to human disturbance and may adapt to human presence more easily than other species (see chapter one for examples of guild-level responses to urbanization).

Multiscale Landscape Predictors of Avian Abundance and Diversity

Many bird species apparently respond to landscape characteristics (e.g., patch size, amount of habitat edge) differently, depending on the spatial scale at which those characteristics are measured (Bolger, Scott et al. 1997). Both large and small scale resources are important in determining the distribution of birds in urban areas (Melles, Glenn et al. 2003). This scale-dependent aspect of the relationship of birds to their landscape is just beginning to be explored (for more examples, see chapter one).

Previous Studies in the Athens, Georgia Area

The avifauna of Athens, Georgia have been well-documented since the 1920s, when Thomas D. Burleigh (1938) began a 15-year research effort resulting in the first widely-published account of the area's birds, Birds of Athens, Clarke County, Georgia. There have been several attempts over the years to investigate effects of urbanization on birds in northeastern Georgia, but those studies were limited in scope and did not consider breeding birds (Meyers 1981) or occurred during the non-breeding season (Pearson 1993; Yaukey 1996). To date, there have been no multiscale studies of breeding bird abundance and diversity in residential developments in northeastern Georgia. As humans continue to alter the Southeastern landscape, a better understanding of avian-landscape relationships may help developers to mitigate damage to regional biodiversity and inform them of ways to enhance the ecological value of the altered landscape.

OBJECTIVES

The objective of this chapter was to determine how breeding bird communities and populations in residential developments varied across gradients of urbanization in Athens, Georgia. Specifically, I conducted avian surveys in 36 residential developments located at predetermined intensities of urban development measured at two scales (landscape, 1 km^2; and regional, 5 km^2) and age of development to measure community and population responses. I considered birds present in developments both as entire-site assemblages and by functional guilds.

METHODS

Study Area

My study area was located in the greater Athens, Georgia area (primarily in Clarke and Oconee Counties; to a lesser degree in Barrow, Jackson, Madison, and Oglethorpe Counties) and covered an area approximately 1,130 km^2 (fig. 2.1). Athens is located approximately 110 km northeast of Atlanta, Georgia. The area is experiencing rapid population growth, particularly in Athens-Clarke county and also in Oconee County (Georgia Statistics System 2008a; Georgia Statistics System 2008b). All study plots were located within the piedmont physiographic region of the state. The piedmont region is characterized by rolling hills and clay-containing soils. Prior to colonial settlement, the land was mostly covered with pine, hardwood, and mixed pine-hardwood forests; most of the land was cleared for agriculture during the 19th century and subsequently regrew during the 20th century (Cowell 1998). Today the landscape is a mixture of remnant and old-field succession forestland, production forestland, agriculture, and developed lands. For a more detailed description of the study area, refer to chapter two.

Within the study area, I located 36 1-km x 1-km study sites (33 in residential developments and 3 in primarily forested areas; fig. 2.10; Appendix B). I classified each site according to its position along urban-rural gradients of development intensity derived from two spatial scales: landscape-scale (1 km^2) development intensity (LDI; classes: minimal, low, medium, or high intensity) and regional-scale (5 km^2) development intensity (RDI; classes: low or medium intensity). Each site was also classified according to age class (young (clearing through construction phase), or mature (post-construction phase)). Every combination of LDI (except class 'minimal'), RDI, and age was represented by a triplet of sites, with the exception of one combination (RDI = low; LDI = high; Age = mature) which did not exist in the study area. The three primarily forested sites represented an additional triplet of sites; these sites consisted of parkland and forested reserves, were characterized by minimal-level LDI and mature age, but varied in their RDI (two were low RDI sites, and the third was medium RDI). See chapter two for site a discussion of classification methodology.

Avian Surveys

At each site, I located a series of sample points where I would conduct avian surveys. Sample points were generally located roadside, trailside, or within utility rights-of-way due to private-property access restrictions (for detailed descriptions of study sites, see Appendix B). Although surveys were conducted on the roadside, which would typically suggest the use of a high-visibility orange vest, I selected neutral-colored field clothing during surveys to avoid any potential chromotropic response (Gutzwiller 1993). Roadside points were located as close to remnant patches of forest as possible. Sample points should be spaced such that the detections at different points remain statistically independent (Reynolds, Scott et al. 1980). The limit of detectability of many small, non-singing land bird species is approximately 100 m (Hutto, Pletschet et al. 1986). To ensure sample independence, I positioned points such that they were generally >200 m apart and >150 m from landscape edges (where vegetation type changed) in upland areas away from water. I attempted to fit eight points in each study site, with six points located within the neighborhood itself and two points located in larger patches of remnant forested fringe in or around the development. If fringe areas were not accessible, I attempted to fit all eight points in the neighborhood. I allocated more effort to development than forest because previous studies have indicated that birds and vegetation vary more within development than in remnant forest patches (Donnelly and Marzluff 2004). The locations of all sample points were recorded using a GPS receiver.

I conducted two sets of 6-minute, modified variable-radius point-counts at each sample site in 2007 and again in 2008 (a total of 4 sets of counts per site). Long (> 10 min.) point-count durations lead to sampling error (Smith, Twedt et al. 1998); also, practice point-counts in residential developments suggested that few, if any, additional observations resulted from longer counting periods (pers. obs.). Counts were performed by a single observer (MP) between early May and 31 July (i.e., ‘the breeding season’).

Surveys were conducted between sunrise and 10:00 am on fog- and precipitation-free mornings when the wind was less than 16 kph. Survey days for each site were randomly scheduled to fall on weekdays. Two sites were surveyed per day. Adjacent sites were often surveyed on the same day to maximize efficiency; in those cases, the order in which sites were sampled was alternated from one sampling cycle to the next.

My survey approach combined the relative ease of data collection and analysis of the fixed-radius point-count technique (Hutto, Pletschet et al. 1986) while retaining some of the additional information obtainable from a more intensive variable-radius point-count (Reynolds, Scott et al. 1980). Ranking of species by abundance is possible using detection rates from fixed-radius point-counts only if the radius is short enough to ensure 100% detection (Hutto, Pletschet et al. 1986). Variable-radius point-counts measure detectability limits by determining the maximum distance at which a bird species can be observed (by measuring the distance to each bird observed). Understanding differences in detectability distances allows for comparisons between observations made in different habitats, in different years, or by different observers. Rather than estimate the distance to each bird observed as in a traditional variable-radius point-count, I assigned observed individual birds to concentric rings of range classes (0 to 10 m, 10 to 25 m, 25 to 50 m, 50 to 100 m) surrounding the observer. The use of range classes simplifies the task of estimating distance from the observer to birds, while still providing an understanding of detectability range by species.

Because point-counts were, for the most part, conducted road-side, disturbance from cars driving by may have influenced my results. Drive-bys were generally infrequent and brief; I did not interrupt counts when a car passed through the area, reasoning that birds utilizing roadside areas were likely acclimated to passing vehicle traffic and would therefore be fairly tolerant of brief noise from a passenger car driving past. I dealt with more intense disturbances (e.g., loud garbage trucks passing past my position or inquisitive residents stopping on foot or in a car to question what I was doing in the area) by pausing my count timer and waiting until the disturbance was over. I then waited one minute to allow bird activity to resume more normal levels before resuming my count for the remaining duration. Although it would be impossible in a residential development to totally eliminate disturbances by vehicles or suspicious/enthusiastic humans, I attempted to minimize any interruptions by prominently posting signs on my nearby vehicle indicating that a bird survey was underway and requesting that interested parties refrain from interrupting the surveyor. Loudly barking dogs in nearby yards were a particularly disruptive factor; in cases where a several-minute period of quiet waiting would not result in the dog becoming quieter, I was forced to leave the point without conducting a point-count and to return at a later time, if possible.

Upon arrival at a location of a point-count, I waited quietly for 1 minute to allow bird activity to resume more normal levels (Reynolds, Scott et al. 1980). All individual birds detected by sight or sound during a 6-minute period were recorded. At the conclusion of the count, I proceeded to the next point-count as rapidly as possible to minimize double counts.

Screening of Observations

My target set of species were forest-associated, breeding landbirds that fulfill most of their breeding season daily needs within an area smaller than a study site (1 km^2). Although all birds observed during point-counts were recorded, I later excluded certain observations from statistical analyses. Birds that were (a) water-associated species (e.g., waders, ducks, and shorebirds); (b) broadly-ranging species (e.g., swifts, swallows, raptors); (c) flyover birds not stopping within count circles; (d) upland game birds (except pigeons and doves); (e) primarily nocturnal or (f) relatively rare species observed at <10% of sites cumulatively for both years were excluded from analyses.

Species falling into groups a – d may have home ranges extending beyond the site scale sampled and therefore do not need to meet most or all their ecological requirements within the study site landscape (Schoener 1968; Chace and Walsh 2006). Primarily nocturnal species were systematically undercounted due to the survey design. Most species which fell into groups a – e also occurred in group f.

I also excluded from later analyses migrant birds occurring outside of their 'safe dates' as defined by the Georgia Breeding Bird Atlas Project (Georgia Department of Natural Resources 1996); safe dates for a given species are those dates within a defined period during which that species is assumed to be breeding, rather than migrating or wintering. Safe dates are only approximations of the breeding period; I interpreted the safe dates liberally, adding an additional 10 days to either side to increase my sampling duration each year.

Guild Assignments

Post-screening, species were classified into several functional guilds: (a) dominant breeding habitat; (b) migration strategy; and (c) synanthropic status. The dominant breeding habitat guild consisted of: early successional/field/grassland habitat breeders; upland/lowland forested habitat breeders; and urban breeders (Hamel 1992). Within the migration strategy guild, birds were classified as being either: neotropical migrants; partial migrants; or permanent residents (Askins, Lynch et al. 1990). Birds within the synanthropic status guild were designated as being either synanthropic or non-synanthropic (Johnston 2001). Every species received an assignment within each of the guilds (Appendix D).

Development of Avian Community and Population Metrics

I calculated landscape-scale (1 km^2) community metrics (mean total relative abundance per sample per site, MTRA; maximum species richness per site, S_{MAX}; relative diversity, J') and population metrics (mean species relative abundance per sample per site, MSRA) for all species occurring at each site. All community and population metrics were calculated using SAS software. I calculated community metrics for site assemblages of birds, as well as by guild subsets on each site. I also calculated community metrics by site and year to determine whether year-to-year variation in the distribution of observations was sufficiently small that I could pool data from 2007 and 2008. I used Minitab[6] to examine the relationship between community metrics from 2007 against 2008 and examined normal probability plots and plots of residuals vs. fits to determine if there was a year effect; finding no significant difference, I pooled data between years. Taken individually, the four metrics outlined above only describe a part of the community or population. Together, the metrics describe the total number of birds in each community and species (MTRA and MSRA, respectively), how many species are actually present (S_{MAX}) as well as how evenly distributed the individual birds are between those species compared to how evenly it is possible for them to be distributed (*J'*).

To calculate MTRA, I began by sorting all species observations by site number, guild assignment (if applicable), and observation cycle (i.e., which of the four site visits the datum came from). The total number of individuals observed was calculated for each grouping. Each sum was divided by the sampling effort (the number of point-counts performed per visit) for its observation cycle, yielding MTRA per sample per site for each of the four observation cycles. Finally, I averaged the four values to determine overall MTRA per sample per site for each site, thus accounting for differences in

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[6] The graphs for this paper and some statistical tests were generated using Minitab software, Version 15.1.1.0 of Minitab for Windows XP. Copyright 2007 Minitab Inc. Minitab is a registered trademark of Minitab Inc., State College, PA, USA

sampling effort. This final step was necessary because occasional problems occurred with site access (e.g., new construction beginning directly adjacent to an established point-count location) and because sampling effort varied between site visits.

I calculated site S_{MAX} by summing the total number of (screened) unique species observed on a site across all four visits. I also calculated S_{MAX} by guild groupings for each site. I chose to consider species richness in terms of the maximum species richness to gain the broadest understanding of which species were present at the sites across both years.

To calculate relative diversity for a given site, J’, I first calculated the Shannon evenness (H’; eq. 3.1). Next, I determined the theoretical maximum Shannon evenness for that site (H'_{max}; eq. 3.2). Site relative diversity, J’, is the ratio of H’ to H_{MAX} which I converted to a percentage when calculating J’ (Eq. 3.3) to facilitate comparisons.

Eq. 3.1

$$H' = -\sum_{i=1}^{s_{\max}} p_i \ln(p_i)$$

Here, S_{MAX} is the maximum species richness of a given site; p_i (the species relative abundance), is the ratio of n_i (species abundance of species i) to N (the site total abundance) (Zar 1999).

Eq. 3.2

$$H'_{\max} = \ln(s_{\max})$$

Here, S_{MAX} is the maximum species richness at a site (Zar 1999).

Eq. 3.3

$$J' = \frac{H'}{H'_{\max}} \bullet 100$$

…where *H’* and *H’max* are the site Shannon evenness and theoretical maximum Shannon evenness, respectively (Zar 1999).

Finally, I calculated MSRA, using essentially the same method as that I used to calculate MTRA, except calculated for each species by site and observation cycle. MSRA is species-specific, so I did not calculate MSRA for guild groupings. As with MTRA, I accounted for differences in sampling effort when calculating the metric.

Changes in Abundance and Diversity Across Urban-Rural Gradients

Analysis of variance (ANOVA) was used to examine the effects of RDI, LDI, and site age on community abundance and diversity measures (MTRA, S_{MAX}, and J' measures for entire-site bird assemblage and the 8 guild subgroups described above) and on population abundance (MSRA). All ANOVA tests were conducted using SAS software. A full fixed-effects factorial model with interactions was employed. For summary purposes, effects were considered significant if p-values were < 0.05. The method of least significant differences was used to examine pair-wise differences in factor levels (Steel and Torre 1960).

RESULTS

Avian Surveys

I performed modified variable-radius avian point-counts at 250 locations on 36 field sites during the breeding season (mid-May to 31 July) in both 2007 and 2008. I visited each site twice for a total of four visits per site and 144 total site visits. I conducted 490 point-counts during 2007 and 470 in 2008. Due to occasional difficulties with site access, 20 point-count locations (<5% of all point-count positions) were surveyed <4 times over the 2 years.

I observed 5,741 individual birds in 2007, representing 83 species; in 2008, I detected 5,627 birds from 82 species (see Appendix E for a list of species observed). In total, I observed 11,368 birds representing 89 species. After screening out records for non-target life history characteristics or relative scarcity, my dataset consisted of 9,188 individual observations from 50 species. The five most abundant species observed were (in descending order of abundance) Northern Cardinal, Blue Jay, Tufted Titmouse, Carolina Wren, and Red-bellied Woodpecker; the five least abundant species encountered were (in descending order of abundance) Song Sparrow, White-breasted

Nuthatch, Northern Flicker, Prairie Warbler, and Hooded Warbler. For an annotated list of incidental, notable observations made during avian surveys, see Appendix F.

Screening of Observations

I excluded 39 species from analyses based on the screening criteria outlined above (Appendix G). Of those 39 species, most (23) were excluded on the basis of non-target life history characteristics (e.g., wide-ranging species or waterbirds). Three species were non-breeding migrants represented by late-migrating individuals. A further 13 species would otherwise be considered target species, but were relatively scarce (occurring on <10% of sites across 2007-2008). See Appendix D for a list of species included in analyses and their guild assignments.

I plotted community metrics from 2007 against equivalent metrics from 2008 in Minitab and examined normal probability plots and plots of residuals vs. fits to see if there were major differences in the distributions or major outliers between the two years. I did not identify any major year-to-year differences in distribution or any major outliers for community metrics, so I pooled 2007 and 2008 observations during analyses. For a detailed treatment of that portion of the analysis, see Appendix H.

I estimated relative detectability between species by comparing the farthest range classes where I observed each species. Forty-nine of the 50 species that I included in analyses were detected in the farthest range class (50-100 m). The remaining species, Hairy Woodpecker, was only observed out as far as the 25-50 m range class.

Avian Abundance and Diversity Across Urban-Rural Gradients

I calculated avian community abundance and diversity metrics (MTRA, S_{MAX}, and J’) at each of my 36 study sites. I also calculated a measure of population abundance, MSRA, for 50 avian target species present on study sites. I determined mean values for each community metric (by entire site assemblages and guild subgroups; Tables 3.1, 3.2, 3.3, and 3.4) and population metric (by species; Table 3.5) according to where each site was positioned along gradients of RDI, LDI and site age.

The effects of RDI, LDI, and site age (AGE) on each of the community metrics (by entire site assemblages and guild subgroups) and the population metrics (by species) were examined using full fixed-effects factorial ANOVA. For the set of MTRA variables, LDI (n=3 models) and AGE (n=4) were most frequently identified as significant at the 0.05 level (Table 3.6). For urban breeders, partial migrants, and synanthropic species, LDI was significant. AGE was significant for early-successional breeders, forested habitat breeders, permanent residents, and synanthropic species.

For the set of S_{MAX} variables, the main effects, LDI (n=3) and AGE (n=1), and the interactions RDI*AGE (n=2) and RDI*LDI*AGE (n=1) were identified as significant (Table 3.7). LDI was significant for urban breeders, partial migrants, and synanthropes. AGE was significant for early-successional habitat breeders. The interaction RDI*AGE was significant for permanent residents and synanthropic species. The three-way interaction RDI*LDI*AGE was significant for synanthropic species.

For the set of J’ variables, only one main effect was significant at the 0.05 level. For non-synanthropic species J’, LDI was significant (Table 3.8). Overall, considering all 27 community variables, LDI was significant for the most models (n=7), followed by AGE (n=5). The interactions RDI*AGE and RDI*LDI*AGE were significant in fewer models (n=2 and n=1, respectively).

Variation in 17 of the 50 models of species MSRA variables were significantly explained by one or more of the three main effects and/or two-way interaction terms at the 0.05 level (Table 3.9). LDI was most frequently identified as being significant (included in n=10 models) followed by RDI*AGE (n=6), RDI (n=5), AGE (n=4), LDI*AGE (n=3), and RDI*LDI (n=2). The three-way interaction RDI*LDI*AGE was not significant for any MSRA measure. LDI was significant for Red-eyed Vireo, Carolina Chickadee, House Wren, American Robin, Northern Mockingbird, Brown Thrasher, Summer Tanager, Scarlet Tanager, Indigo Bunting, and Common Grackle; see Table 3.9 for a summary of all other significant relationships. Indigo Bunting MSRA was significantly explained by six effects: RDI, LDI, AGE, RDI*LDI, RDI*AGE, and LDI*AGE; whereas for other species, no more than two or three effects were significant.

DISCUSSION

Avian Surveys

Ensuring near-100% detectability within a particular distance from the observer allows for ranking of species by relative abundance (Hutto, Pletschet et al. 1986). When surveying birds in a residential development, detectability concerns offer a number of challenges, such as: (a) large obstacles (e.g., houses, fences, thick treelines) in the observer's survey field; (b) noise pollution (primarily from vehicles); and (c) ongoing disturbance (e.g., from nearby construction, vehicles, or inquisitive residents). I addressed the former challenge through careful point-count location selection and dealt with the latter challenges by adding flexibility to the count protocol as discussed in my methods. The habitats I sampled in were generally quite open, and I frequently had a line-of-sight to a large proportion of the count circles. All screened species (except Hairy Woodpecker) were detected regularly by sight and sound out to the outermost distance zone (50 – 100 m) suggesting that count-circles did not exceed detectability range. Hairy Woodpeckers were only observed out to the 25 to 50 m range class; they were a relatively rare species on my study sites and I believe random effects are likely responsible for this apparent detectability limit. The Downy Woodpecker, which is similar to the Hairy Woodpecker, but smaller and has with a quieter call (Jackson, Ouellet et al. 2002) was easily observable at the farthest detection zone and from personal observation, Hairy Woodpeckers are detectable to that distance as well. Detectability within the count circles did not appear to be strongly limiting and I observed most of the target species that I expected to detect on my study sites based on habitat, season, and species rarity (Burleigh 1938; Beaton, Sykes et al. 2003; Oconee Rivers Audubon Society 2003; Sibley 2003).

Avian Abundance and Diversity Across Urban-Rural Gradients

My objective in conducting avian point-count surveys was to determine patterns of avian abundance and diversity in young and mature residential developments across urban-rural gradients of landscape-scale and regional-scale development intensity (LDI and RDI, respectively). I considered the birds on my sites both as individual species as well as by their guild affiliations, an approach similar to that taken by Bishop and Myers (2005). I conducted analyses of variation to evaluate whether RDI, LDI, and site age significantly explained patterns among the sets of response variables.

My data indicate that landscape-scale development intensity is a predominant factor in explaining variation in the community abundance measures MTRA and S_{MAX} for several guild sub-groupings. Site age also appears to play a strong role in explaining variation in community abundance measures for many guild groups. These findings support the work of others who have discussed the importance of development intensity characteristics and site age to bird numbers (Munyenyembe, Harris et al. 1989; Edgar and Kershaw 1994; Germaine, Rosenstock et al. 1998; Melles, Glenn et al. 2003). As might be expected, interactions between age, RDI, and LDI also appear to be important to explaining variation in species richness.

Relative community diversity (J’) appears to respond to LDI, at least within some guild groups, but for most groups, J’ does not appear to be as well-explained by development intensity or age as MTRA or S_{MAX}. A previous study in Athens during the winter, non-breeding season, was more successful at modeling Shannon diversity variation using vegetation and landscape composition variables (Pearson 1993). This seeming contradiction may be explained by Tramer's (1969) hypothesis that diversity (determined by species richness and evenness) may be more influenced by changes in species richness during relatively benign conditions (i.e., spring/summer, when weather is not harsh and food is relatively plentiful) and be more influenced by evenness during harsher conditions (e.g., during colder months when food is less abundant); it has been suggested that, following Tramer's hypothesis, in the spring, community organization reflects resource-based interspecific competition while in the winter, birds are regulated by harsh climatological conditions (Rotenberry, Fitzner et al. 1979).

A wide range of individual bird species appear to vary in their abundance (MSRA) based on RDI, LDI, age, and their interactions; however, whereas the MSRA for some species appears to be well-explained by those factors (e.g., Indigo Bunting MSRA, for which RDI, LDI, age, and pairwise interactions of the three were significant), other species MSRA measures do not appear to be explained by those factors at all (e.g., Red-bellied Woodpecker). Previous research has also linked site age and development levels to population numbers (e.g., (Donnelly and Marzluff 2006)).

The three metrics used above to broadly describing the urban-rural gradient are useful for generally describing patterns of human land use and alteration, and do appear to explain some differences in avian abundance and diversity across the urban-rural gradient for some species and guild groupings of species; however, the RDI, LDI, and age do not, by themselves, include a very wide range of biologically meaningful characteristics (e.g., habitat configuration measures or amount of natural habitat remnants) which multiple studies have shown are important to birds (for multiple examples of important landscape characteristics, see chapter 1). The three urbanization-related metrics used in this chapter are sufficient for gaining a broad understanding of the variation in avian abundance and diversity over the urban-rural gradient, but to better understand how birds responding to a human-altered landscape, it is necessary to consider landscape characteristics in greater detail.

Table 3.1: Community abundance measures for entire site assemblages varied with study site location: regional-scale development intensity (RDI), landscape-scale development intensity (LDI), and site age (AGE). Each combination of RDI, LDI, and AGE was represented by three study sites.

			Entire Site Assemblage		
			MTRA [1]	**S_{MAX}** [2]	**J’** [3]
RDI	**LDI**	**AGE**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
LOW	**LOW**	**YOUNG**	2.262 (0.104)	30.333 (2.082)	89.804 (1.606)
		MATURE	2.496 (0.078)	35.000 (3.606)	88.105 (0.566)
	MEDIUM	**YOUNG**	2.310 (0.071)	35.333 (3.055)	89.328 (2.457)
		MATURE	2.374 (0.104)	33.667 (3.215)	89.144 (1.772)
	HIGH	**YOUNG**	2.262 (0.203)	32.000 (2.646)	87.428 (1.861)
MEDIUM	**LOW**	**YOUNG**	2.263 (0.158)	32.333 (4.509)	87.534 (3.684)
		MATURE	2.391 (0.09)	29.333 (2.082)	88.213 (4.102)
	MEDIUM	**YOUNG**	2.412 (0.148)	33.000 (4.359)	87.825 (1.309)
		MATURE	2.355 (0.062)	30.667 (1.155)	86.427 (1.627)
	HIGH	**YOUNG**	2.397 (0.123)	35.333 (2.517)	86.636 (2.45)
		MATURE	2.437 (0.069)	32.667 (4.041)	87.181 (0.143)
N/A	**MINIMAL**	**MATURE**	2.199 (0.156)	32.667 (5.508)	88.431 (0.966)

[1] *MTRA: mean total relative abundance per sample per site* [2] S_{MAX}*: maximum species richness (2007-2008)* [3] *J’: relative diversity*

Table 3.2: Community abundance measures for dominant breeding habitat guild subgroups varied with study site location: regional-scale development intensity (RDI), landscape-scale development intensity (LDI), and site age (AGE). Each combination of RDI, LDI, and AGE was represented by three study sites.

			Dominant Breeding Habitat								
			Early Successional			Forested			Urban		
			MTRA [1]	S_{MAX} [2]	J' [3]	MTRA [1]	S_{MAX} [2]	J' [3]	MTRA [1]	S_{MAX} [2]	J' [3]
RDI	LDI	AGE	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
LOW	LOW	YOUNG	1.094 (0.068)	6.667 (1.155)	85.950 (3.484)	1.951 (0.198)	21.000 (2.646)	88.081 (1.488)	0.412 (0.114)	2.667 (2.082)	64.660 (5.296)
		MATURE	0.801 (0.153)	6.000 (2.646)	89.283 (2.533)	2.234 (0.169)	25.000 (2.646)	86.466 (1.251)	0.738 (0.702)	4.000 (3)	77.243 (8.432)
	MEDIUM	YOUNG	0.982 (0.173)	7.333 (0.577)	90.393 (4.701)	2.000 (0.117)	23.333 (2.517)	86.270 (4.058)	0.668 (0.197)	4.667 (0.577)	87.003 (3.728)
		MATURE	0.610 (0.025)	4.667 (0.577)	89.952 (9.133)	2.144 (0.116)	24.667 (3.215)	87.183 (1.012)	0.835 (0.278)	4.333 (0.577)	88.787 (7.035)
	HIGH	YOUNG	1.122 (0.275)	8.000 (1)	88.691 (3.644)	1.896 (0.23)	19.000 (3.606)	83.397 (3.533)	0.588 (0.067)	5.000 (1)	80.457 (6.273)
MEDIUM	LOW	YOUNG	0.902 (0.149)	6.667 (0.577)	83.365 (4.126)	1.963 (0.12)	21.667 (4.041)	85.421 (4.859)	0.701 (0.238)	4.000 (1)	68.610 (10.588)
		MATURE	0.685 (0.239)	5.000 (0)	89.064 (2.795)	2.194 (0.131)	21.000 (1.732)	87.442 (2.834)	0.619 (0.309)	3.333 (0.577)	78.319 (21.552)
	MEDIUM	YOUNG	0.933 (0.016)	6.667 (0.577)	90.890 (4.482)	2.013 (0.306)	21.000 (5)	85.521 (2.674)	1.055 (0.332)	5.333 (1.528)	79.743 (5.376)
		MATURE	0.717 (0.172)	5.667 (0.577)	88.939 (2.167)	2.066 (0.099)	20.667 (1.528)	84.187 (4.826)	0.924 (0.241)	4.333 (0.577)	75.872 (16.941)
	HIGH	YOUNG	0.727 (0.092)	5.667 (0.577)	86.529 (3.188)	1.987 (0.145)	23.333 (3.512)	83.792 (1.819)	1.250 (0.334)	6.333 (0.577)	81.894 (2.79)
		MATURE	0.915 (0.082)	6.667 (1.155)	81.550 (4.792)	1.961 (0.051)	19.667 (5.508)	85.537 (3.36)	1.330 (0.228)	6.333 (1.155)	78.897 (6.773)
N/A	MINIMAL	MATURE	0.571 (0.217)	6.000 (1.732)	90.876 (1.279)	2.076 (0.144)	25.000 (3.606)	87.969 (1.497)	0.228 (0.107)	1.667 (0.577)	72.193 (0)

[1] *MTRA: mean total relative abundance per sample per site* [2] S_{MAX}*: maximum species richness (2007-2008)* [3] *J': relative diversity*

Table 3.3: Community abundance measures for migratory strategy guild subgroups varied with study site location: regional-scale development intensity (RDI), landscape-scale development intensity (LDI), and site age (AGE). Each combination of RDI, LDI, and AGE was represented by three study sites.

			Migratory Strategy								
			Neotropical Migrant			**Permanent Resident**			**Partial Migrant**		
			MTRA [1]	**S_{MAX}** [2]	**J'** [3]	**MTRA** [1]	**S_{MAX}** [2]	**J'** [3]	**MTRA** [1]	**S_{MAX}** [2]	**J'** [3]
RDI	**LDI**	**AGE**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
LOW	**LOW**	**YOUNG**	1.285 (0.362)	12.333 (3.215)	84.932 (1.616)	1.427 (0.221)	7.667 (0.577)	86.575 (2.24)	1.276 (0.183)	10.333 (3.215)	90.185 (4.812)
		MATURE	1.244 (0.318)	13.000 (1)	87.358 (9.207)	1.748 (0.145)	9.667 (1.155)	84.425 (6.001)	1.478 (0.513)	12.333 (4.163)	88.437 (2.517)
	MEDIUM	**YOUNG**	1.113 (0.162)	14.000 (1.732)	90.312 (2.389)	1.547 (0.171)	8.667 (1.155)	88.218 (5.077)	1.452 (0.081)	12.667 (0.577)	87.328 (5.95)
		MATURE	1.048 (0.043)	12.333 (2.082)	91.814 (4.5)	1.658 (0.186)	9.000 (1)	86.714 (1.413)	1.522 (0.139)	12.333 (1.528)	88.404 (7.823)
	HIGH	**YOUNG**	1.092 (0.364)	11.333 (3.512)	84.072 (8.554)	1.455 (0.158)	7.667 (1.155)	81.973 (6.433)	1.428 (0.294)	13.000 (1)	86.328 (2.836)
MEDIUM	**LOW**	**YOUNG**	0.878 (0.207)	10.000 (2.646)	86.334 (3.885)	1.588 (0.133)	9.000 (1)	90.876 (0.304)	1.461 (0.123)	13.333 (1.528)	80.837 (10.371)
		MATURE	1.005 (0.263)	10.667 (2.082)	86.853 (6.414)	1.776 (0.056)	7.333 (1.155)	91.622 (3.353)	1.446 (0.051)	11.333 (1.528)	87.165 (5.896)
	MEDIUM	**YOUNG**	0.903 (0.286)	10.667 (5.508)	87.097 (6.106)	1.696 (0.168)	8.667 (1.155)	82.565 (4.798)	1.641 (0.138)	13.667 (1.155)	89.878 (3.764)
		MATURE	0.900 (0.193)	9.667 (2.517)	84.007 (9.078)	1.643 (0.062)	8.000 (1)	81.137 (7.738)	1.585 (0.075)	13.000 (1)	87.181 (5.44)
	HIGH	**YOUNG**	0.845 (0.24)	10.667 (2.517)	85.141 (0.754)	1.616 (0.092)	10.000 (1)	83.370 (6.904)	1.710 (0.23)	14.667 (1.528)	86.004 (5.63)
		MATURE	0.648 (0.13)	9.000 (3.606)	89.466 (0.887)	1.589 (0.093)	9.000 (1)	86.242 (1.459)	1.880 (0.184)	14.667 (1.155)	86.219 (2.687)
N/A	**MINIMAL**	**MATURE**	1.346 (0.37)	14.000 (4)	85.622 (1.341)	1.473 (0.019)	8.667 (0.577)	83.419 (5.194)	0.992 (0.128)	10.000 (2)	89.231 (2.841)

[1] *MTRA: mean total relative abundance per sample per site* [2] S_{MAX}: *maximum species richness (2007-2008)* [3] *J': relative diversity*

Table 3.4: Community abundance measures for synanthropic status guild subgroups varied with study site location: regional-scale development intensity (RDI), landscape-scale development intensity (LDI), and site age (AGE). Each combination of RDI, LDI, and AGE was represented by three study sites.

			Synanthropic Status					
			Non-Synanthropic			Synanthropic		
			MTRA[1]	S_{MAX}[2]	J'[3]	MTRA[1]	S_{MAX}[2]	J'[3]
RDI	**LDI**	**AGE**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
LOW	**LOW**	**YOUNG**	1.455 (0.113)	14.333 (2.517)	87.827 (1.952)	1.839 (0.13)	16.000 (2)	88.079 (2.784)
		MATURE	1.385 (0.097)	14.667 (2.082)	88.556 (2.153)	2.210 (0.109)	20.333 (3.215)	86.703 (0.927)
	MEDIUM	**YOUNG**	1.337 (0.075)	15.667 (1.528)	87.710 (3.854)	1.979 (0.127)	19.667 (1.528)	88.473 (1.259)
		MATURE	1.259 (0.184)	14.333 (2.887)	90.728 (4.191)	2.104 (0.072)	19.333 (0.577)	88.116 (1.405)
	HIGH	**YOUNG**	1.372 (0.215)	14.000 (3.606)	85.436 (2.341)	1.898 (0.165)	18.000 (1.732)	85.157 (1.998)
MEDIUM	**LOW**	**YOUNG**	1.327 (0.175)	14.000 (2.646)	86.367 (2.345)	1.921 (0.164)	18.333 (2.082)	85.557 (4.583)
		MATURE	1.320 (0.112)	13.333 (1.155)	88.664 (2.735)	2.101 (0.094)	16.000 (1)	87.702 (5.039)
	MEDIUM	**YOUNG**	1.259 (0.15)	13.667 (3.786)	88.860 (4.655)	2.153 (0.167)	19.333 (0.577)	86.591 (0.942)
		MATURE	1.271 (0.045)	11.333 (1.528)	88.734 (2.21)	2.077 (0.064)	19.333 (0.577)	83.003 (2.367)
	HIGH	**YOUNG**	1.222 (0.245)	13.667 (1.528)	85.561 (1.584)	2.141 (0.161)	21.667 (1.155)	85.669 (2.712)
		MATURE	1.211 (0.087)	12.000 (2.646)	83.886 (3.003)	2.205 (0.091)	20.667 (2.309)	86.819 (0.528)
N/A	**MINIMAL**	**MATURE**	1.453 (0.17)	17.667 (4.041)	85.407 (2.158)	1.748 (0.128)	15.000 (1.732)	87.562 (2.878)

[1] *MTRA: mean total relative abundance per sample per site* [2] S_{MAX}*: maximum species richness (2007-2008)* [3] *J': relative diversity*

Table 3.5: Population abundance measures (mean species relative abundance) for 50 bird species observed on study sites varied with study site location: regional-scale development intensity (RDI), landscape-scale development intensity (LDI), and site age (AGE). Each combination of RDI, LDI, and AGE was represented by three study sites.

			MSRA [1] by Bird Species [2]								
			MODO	YBCU	RTHU	RHWO	RBWO	DOWO	HAWO	NOFL	PIWO
RDI	**LDI**	**AGE**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
LOW	**LOW**	**YOUNG**	0.460 (0.047)	0.316 (0.083)	0.096 (0.167)	0.000 (0)	0.579 (0.057)	0.623 (0.101)	0.136 (0.236)	0.118 (0.204)	0.068 (0.118)
		MATURE	0.711 (0.223)	0.431 (0.17)	0.381 (0.178)	0.000 (0)	0.664 (0.176)	0.615 (0.076)	0.210 (0.037)	0.059 (0.102)	0.155 (0.146)
	MEDIUM	**YOUNG**	0.751 (0.181)	0.356 (0.152)	0.240 (0.109)	0.000 (0)	0.720 (0.151)	0.526 (0.024)	0.083 (0.144)	0.000 (0)	0.059 (0.102)
		MATURE	0.783 (0.041)	0.385 (0.146)	0.337 (0.029)	0.059 (0.102)	0.681 (0.186)	0.638 (0.1)	0.101 (0.175)	0.000 (0)	0.250 (0.25)
	HIGH	**YOUNG**	0.671 (0.359)	0.295 (0.368)	0.251 (0.234)	0.000 (0)	0.550 (0.136)	0.499 (0.068)	0.000 (0)	0.000 (0)	0.068 (0.118)
MEDIUM	**LOW**	**YOUNG**	0.590 (0.097)	0.385 (0.231)	0.220 (0.192)	0.331 (0.182)	0.722 (0.142)	0.662 (0.066)	0.127 (0.111)	0.059 (0.102)	0.155 (0.146)
		MATURE	0.627 (0.204)	0.383 (0.371)	0.075 (0.129)	0.000 (0)	0.878 (0.177)	0.522 (0.102)	0.000 (0)	0.000 (0)	0.118 (0.204)
	MEDIUM	**YOUNG**	0.662 (0.171)	0.295 (0.14)	0.152 (0.264)	0.279 (0.31)	0.747 (0.291)	0.554 (0.299)	0.075 (0.129)	0.075 (0.129)	0.096 (0.167)
		MATURE	0.482 (0.159)	0.210 (0.037)	0.249 (0.091)	0.000 (0)	0.499 (0.132)	0.562 (0.031)	0.000 (0)	0.083 (0.144)	0.063 (0.109)
	HIGH	**YOUNG**	0.535 (0.312)	0.059 (0.102)	0.183 (0.186)	0.059 (0.102)	0.623 (0.05)	0.637 (0.098)	0.118 (0.102)	0.118 (0.102)	0.142 (0.129)
		MATURE	0.724 (0.072)	0.059 (0.102)	0.177 (0.177)	0.000 (0)	0.551 (0.057)	0.695 (0.105)	0.063 (0.109)	0.109 (0.189)	0.126 (0.109)
N/A	**MINIMAL**	**MATURE**	0.295 (0.27)	0.561 (0.181)	0.152 (0.264)	0.000 (0)	0.699 (0.076)	0.514 (0.14)	0.186 (0.177)	0.068 (0.118)	0.276 (0.022)

[1] *MSRA = Mean species relative abundance per sample per site.* [2] *Banding codes based on USGS Bird Banding Laboratory's North American Bird Banding Manual (Gustafson, Hildenbrand et al. 1997). See Appendix E for common names.*

			MSRA [1] by Bird Species [2]								
			EWPE	**ACFL**	**EAPH**	**GCFL**	**WEVI**	**YTVI**	**REVI**	**BLJA**	**AMCR**
RDI	**LDI**	**AGE**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
LOW	**LOW**	**YOUNG**	0.136 (0.118)	0.167 (0.289)	0.368 (0.172)	0.442 (0.148)	0.272 (0.241)	0.000 (0)	0.641 (0.319)	0.758 (0.098)	0.646 (0.058)
		MATURE	0.083 (0.144)	0.384 (0.335)	0.559 (0.071)	0.601 (0.02)	0.118 (0.102)	0.219 (0.206)	0.515 (0.327)	0.716 (0.356)	0.557 (0.089)
	MEDIUM	**YOUNG**	0.287 (0.251)	0.177 (0.177)	0.447 (0.089)	0.382 (0.228)	0.167 (0.144)	0.000 (0)	0.413 (0.093)	0.708 (0.309)	0.548 (0.044)
		MATURE	0.305 (0.306)	0.322 (0.103)	0.394 (0.07)	0.449 (0.198)	0.125 (0.217)	0.059 (0.102)	0.391 (0.04)	0.819 (0.177)	0.501 (0.098)
	HIGH	**YOUNG**	0.195 (0.205)	0.089 (0.154)	0.386 (0.051)	0.448 (0.035)	0.377 (0.356)	0.126 (0.218)	0.285 (0.257)	0.769 (0.079)	0.303 (0.264)
MEDIUM	**LOW**	**YOUNG**	0.083 (0.144)	0.000 (0)	0.379 (0.089)	0.300 (0.01)	0.059 (0.102)	0.000 (0)	0.000 (0)	0.882 (0.306)	0.413 (0.278)
		MATURE	0.000 (0)	0.231 (0.262)	0.293 (0.267)	0.364 (0.052)	0.000 (0)	0.068 (0.118)	0.623 (0.053)	0.819 (0.175)	0.711 (0.271)
	MEDIUM	**YOUNG**	0.279 (0.113)	0.068 (0.118)	0.281 (0.246)	0.469 (0.053)	0.096 (0.167)	0.143 (0.124)	0.068 (0.118)	0.892 (0.187)	0.574 (0.252)
		MATURE	0.000 (0)	0.229 (0.199)	0.393 (0.147)	0.368 (0.069)	0.166 (0.288)	0.138 (0.12)	0.298 (0.258)	0.817 (0.049)	0.411 (0.201)
	HIGH	**YOUNG**	0.262 (0.148)	0.134 (0.231)	0.388 (0.157)	0.366 (0.064)	0.161 (0.154)	0.118 (0.102)	0.373 (0.238)	0.811 (0.204)	0.613 (0.248)
		MATURE	0.122 (0.211)	0.000 (0)	0.442 (0.079)	0.437 (0.052)	0.059 (0.102)	0.000 (0)	0.104 (0.181)	0.953 (0.076)	0.591 (0.202)
N/A	**MINIMAL**	**MATURE**	0.238 (0.212)	0.554 (0.093)	0.248 (0.042)	0.360 (0.138)	0.132 (0.228)	0.151 (0.133)	0.776 (0.095)	0.478 (0.13)	0.469 (0.155)

[1] MSRA = Mean species relative abundance per sample per site. [2] Banding codes based on USGS Bird Banding Laboratory's North American Bird Banding Manual (Gustafson, Hildenbrand et al. 1997). See Appendix E for common names.

			MSRA [1] by Bird Species [2]								
			CACH	TUTI	WBNU	BHNU	CARW	HOWR	BGGN	EABL	WOTH
RDI	LDI	AGE	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
LOW	LOW	YOUNG	0.462 (0.069)	0.779 (0.161)	0.000 (0)	0.089 (0.154)	0.654 (0.119)	0.000 (0)	0.571 (0.169)	0.059 (0.102)	0.474 (0.13)
		MATURE	0.740 (0.182)	0.988 (0.268)	0.241 (0.22)	0.263 (0.251)	0.700 (0.174)	0.059 (0.102)	0.401 (0.352)	0.185 (0.163)	0.356 (0.087)
	MEDIUM	YOUNG	0.594 (0.084)	0.688 (0.235)	0.059 (0.102)	0.235 (0.229)	0.714 (0.133)	0.059 (0.102)	0.245 (0.268)	0.427 (0.135)	0.416 (0.075)
		MATURE	0.677 (0.118)	0.826 (0.269)	0.000 (0)	0.338 (0.127)	0.540 (0.092)	0.252 (0.236)	0.299 (0.259)	0.245 (0.268)	0.516 (0.14)
	HIGH	YOUNG	0.461 (0.173)	0.569 (0.319)	0.000 (0)	0.068 (0.118)	0.697 (0.046)	0.126 (0.109)	0.468 (0.289)	0.443 (0.179)	0.063 (0.109)
MEDIUM	LOW	YOUNG	0.602 (0.116)	0.689 (0.181)	0.000 (0)	0.352 (0.309)	0.726 (0.017)	0.059 (0.102)	0.083 (0.144)	0.260 (0.089)	0.201 (0.182)
		MATURE	0.649 (0.082)	0.996 (0.126)	0.000 (0)	0.402 (0.364)	0.788 (0.079)	0.000 (0)	0.396 (0.094)	0.195 (0.205)	0.430 (0.23)
	MEDIUM	YOUNG	0.565 (0.132)	0.640 (0.179)	0.075 (0.129)	0.173 (0.16)	0.570 (0.027)	0.068 (0.118)	0.296 (0.262)	0.320 (0.336)	0.223 (0.194)
		MATURE	0.596 (0.209)	0.771 (0.215)	0.000 (0)	0.361 (0.041)	0.704 (0.033)	0.292 (0.263)	0.225 (0.201)	0.462 (0.096)	0.411 (0.369)
	HIGH	YOUNG	0.406 (0.134)	0.783 (0.107)	0.142 (0.129)	0.357 (0.109)	0.717 (0.123)	0.335 (0.138)	0.281 (0.245)	0.353 (0.178)	0.361 (0.109)
		MATURE	0.491 (0.045)	0.794 (0.065)	0.086 (0.149)	0.192 (0.171)	0.628 (0.031)	0.299 (0.259)	0.248 (0.059)	0.325 (0.13)	0.389 (0.184)
N/A	MINIMAL	MATURE	0.419 (0.114)	0.862 (0.16)	0.000 (0)	0.263 (0.126)	0.690 (0.203)	0.000 (0)	0.687 (0.289)	0.144 (0.25)	0.186 (0.177)

[1] MSRA = Mean species relative abundance per sample per site. [2] Banding codes based on USGS Bird Banding Laboratory's North American Bird Banding Manual (Gustafson, Hildenbrand et al. 1997). See Appendix E for common names.

			MSRA [1] by Bird Species [2]								
			AMRO	GRCA	NOMO	BRTH	EUST	NOPA	PIWA	PRAW	BAWW
RDI	LDI	AGE	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
LOW	LOW	YOUNG	0.086 (0.149)	0.068 (0.118)	0.155 (0.146)	0.198 (0.172)	0.000 (0)	0.226 (0.254)	0.363 (0.161)	0.000 (0)	0.000 (0)
		MATURE	0.492 (0.618)	0.102 (0.177)	0.373 (0.421)	0.373 (0.339)	0.167 (0.289)	0.333 (0.323)	0.372 (0.075)	0.059 (0.102)	0.298 (0.264)
	MEDIUM	YOUNG	0.428 (0.207)	0.102 (0.177)	0.555 (0.134)	0.383 (0.267)	0.059 (0.102)	0.059 (0.102)	0.422 (0.154)	0.059 (0.102)	0.180 (0.157)
		MATURE	0.688 (0.285)	0.273 (0.044)	0.538 (0.216)	0.472 (0.166)	0.000 (0)	0.138 (0.12)	0.464 (0.217)	0.000 (0)	0.258 (0.234)
	HIGH	YOUNG	0.402 (0.242)	0.000 (0)	0.461 (0.243)	0.068 (0.118)	0.000 (0)	0.063 (0.109)	0.305 (0.188)	0.068 (0.118)	0.244 (0.212)
MEDIUM	LOW	YOUNG	0.335 (0.437)	0.210 (0.037)	0.572 (0.122)	0.235 (0.026)	0.118 (0.204)	0.059 (0.102)	0.443 (0.182)	0.000 (0)	0.235 (0.026)
		MATURE	0.407 (0.108)	0.059 (0.102)	0.215 (0.373)	0.421 (0.074)	0.000 (0)	0.251 (0.065)	0.497 (0.142)	0.000 (0)	0.202 (0.215)
	MEDIUM	YOUNG	0.443 (0.207)	0.204 (0.204)	0.925 (0.282)	0.523 (0.104)	0.068 (0.118)	0.000 (0)	0.068 (0.118)	0.000 (0)	0.096 (0.167)
		MATURE	0.897 (0.392)	0.326 (0.303)	0.352 (0.331)	0.569 (0.096)	0.000 (0)	0.063 (0.109)	0.284 (0.246)	0.063 (0.109)	0.000 (0)
	HIGH	YOUNG	0.927 (0.337)	0.350 (0.153)	0.652 (0.225)	0.495 (0.174)	0.059 (0.102)	0.000 (0)	0.348 (0.156)	0.059 (0.102)	0.000 (0)
		MATURE	1.008 (0.532)	0.310 (0.097)	0.700 (0.156)	0.558 (0.07)	0.233 (0.218)	0.063 (0.109)	0.392 (0.187)	0.063 (0.109)	0.059 (0.102)
N/A	MINIMAL	MATURE	0.127 (0.111)	0.059 (0.102)	0.000 (0)	0.245 (0.095)	0.000 (0)	0.102 (0.177)	0.586 (0.166)	0.170 (0.156)	0.212 (0.217)

[1] *MSRA = Mean species relative abundance per sample per site.* [2] *Banding codes based on USGS Bird Banding Laboratory's North American Bird Banding Manual (Gustafson, Hildenbrand et al. 1997). See Appendix E for common names.*

			MSRA [1] by Bird Species [2]								
			HOWA	SUTA	SCTA	EATO	CHSP	FISP	SOSP	NOCA	BLGR
RDI	LDI	AGE	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
LOW	LOW	YOUNG	0.068 (0.118)	0.295 (0.11)	0.235 (0.251)	0.561 (0.145)	0.068 (0.118)	0.218 (0.378)	0.000 (0)	1.041 (0.121)	0.358 (0.048)
		MATURE	0.068 (0.118)	0.354 (0.177)	0.083 (0.144)	0.245 (0.268)	0.304 (0.364)	0.118 (0.204)	0.059 (0.102)	1.136 (0.079)	0.000 (0)
	MEDIUM	YOUNG	0.059 (0.102)	0.394 (0.203)	0.083 (0.144)	0.368 (0.143)	0.356 (0.087)	0.000 (0)	0.000 (0)	1.039 (0.132)	0.366 (0.067)
		MATURE	0.000 (0)	0.383 (0.075)	0.068 (0.118)	0.432 (0.086)	0.217 (0.24)	0.000 (0)	0.000 (0)	1.154 (0.058)	0.000 (0)
	HIGH	YOUNG	0.000 (0)	0.308 (0.111)	0.000 (0)	0.682 (0.16)	0.263 (0.251)	0.301 (0.325)	0.000 (0)	1.161 (0.137)	0.253 (0.109)
MEDIUM	LOW	YOUNG	0.000 (0)	0.349 (0.098)	0.000 (0)	0.707 (0.007)	0.487 (0.116)	0.059 (0.102)	0.000 (0)	0.980 (0.04)	0.118 (0.204)
		MATURE	0.000 (0)	0.254 (0.222)	0.177 (0.177)	0.493 (0.174)	0.260 (0.293)	0.000 (0)	0.000 (0)	1.163 (0.078)	0.000 (0)
	MEDIUM	YOUNG	0.068 (0.118)	0.152 (0.264)	0.000 (0)	0.636 (0.098)	0.595 (0.105)	0.068 (0.118)	0.167 (0.289)	1.174 (0.248)	0.186 (0.177)
		MATURE	0.000 (0)	0.083 (0.144)	0.063 (0.109)	0.625 (0.106)	0.582 (0.161)	0.000 (0)	0.098 (0.169)	1.309 (0.246)	0.000 (0)
	HIGH	YOUNG	0.059 (0.102)	0.059 (0.102)	0.000 (0)	0.599 (0.138)	0.568 (0.216)	0.000 (0)	0.000 (0)	1.098 (0.251)	0.059 (0.102)
		MATURE	0.000 (0)	0.102 (0.177)	0.000 (0)	0.817 (0.095)	0.253 (0.25)	0.000 (0)	0.155 (0.269)	1.107 (0.01)	0.000 (0)
N/A	MINIMAL	MATURE	0.127 (0.111)	0.554 (0.173)	0.282 (0.075)	0.463 (0.151)	0.127 (0.111)	0.059 (0.102)	0.000 (0)	0.961 (0.126)	0.000 (0)

[1] *MSRA = Mean species relative abundance per sample per site.* [2] *Banding codes based on USGS Bird Banding Laboratory's North American Bird Banding Manual (Gustafson, Hildenbrand et al. 1997). See Appendix E for common names.*

			MSRA [1] by Bird Species [2]				
			INBU	COGR	BHCO	HOFI	AMGO
RDI	LDI	AGE	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
LOW	LOW	YOUNG	0.086 (0.149)	0.068 (0.118)	0.155 (0.146)	0.198 (0.172)	0.000 (0)
		MATURE	0.492 (0.618)	0.102 (0.177)	0.373 (0.421)	0.373 (0.339)	0.167 (0.289)
	MEDIUM	YOUNG	0.428 (0.207)	0.102 (0.177)	0.555 (0.134)	0.383 (0.267)	0.059 (0.102)
		MATURE	0.688 (0.285)	0.273 (0.044)	0.538 (0.216)	0.472 (0.166)	0.000 (0)
	HIGH	YOUNG	0.402 (0.242)	0.000 (0)	0.461 (0.243)	0.068 (0.118)	0.000 (0)
MEDIUM	LOW	YOUNG	0.335 (0.437)	0.210 (0.037)	0.572 (0.122)	0.235 (0.026)	0.118 (0.204)
		MATURE	0.407 (0.108)	0.059 (0.102)	0.215 (0.373)	0.421 (0.074)	0.000 (0)
	MEDIUM	YOUNG	0.443 (0.207)	0.204 (0.204)	0.925 (0.282)	0.523 (0.104)	0.068 (0.118)
		MATURE	0.897 (0.392)	0.326 (0.303)	0.352 (0.331)	0.569 (0.096)	0.000 (0)
	HIGH	YOUNG	0.927 (0.337)	0.350 (0.153)	0.652 (0.225)	0.495 (0.174)	0.059 (0.102)
		MATURE	1.008 (0.532)	0.310 (0.097)	0.700 (0.156)	0.558 (0.07)	0.233 (0.218)
N/A	MINIMAL	MATURE	0.127 (0.111)	0.059 (0.102)	0.000 (0)	0.245 (0.095)	0.000 (0)

[1] *MSRA = Mean species relative abundance per sample per site.* [2] *Banding codes based on USGS Bird Banding Laboratory's North American Bird Banding Manual (Gustafson, Hildenbrand et al. 1997). See Appendix E for common names.*

Table 3.6: Summary of ANOVA test to examine effects of regional-scale (5 km^2) development intensity (RDI), landscape-scale (1 km^2) development intensity (LDI), and site age (AGE) on avian community abundance (MTRA) for entire site bird assemblages and avian functional guilds: (a) dominant breeding habitat (early-successional; forested; urban); (b) migratory strategy (neotropical migration; permanent residence; partial migration); and (c) synanthropic status (synanthropic; non-synanthropic).

	Significance Levels [1]							
	Main Effects			Interactions				
Species Grouping	**RDI**	**LDI**	**AGE**	**RDI*LDI**	**RDI*AGE**	**LDI*AGE**	**RDI*LDI*AGE**	**Model R^2**
Site Assemblage		*	*					0.420
Early-successional Habitat	*		**			*		0.639
Forested Habitat			**					0.357
Urban Habitat	*	**						0.606
Neotropical Migrant		*						0.453
Permanent Resident			**					0.475
Partial Migrant		**						0.603
Synanthropic		**	**		*	*		0.664
Non-synanthropic								0.291

[1] (blank) = non-significant at level 0.10; * = significant at level 0.10; ** = significant at level 0.05

Table 3.7: Summary of ANOVA test to examine effects of regional-scale (5 km^2) development intensity (RDI), landscape-scale (1 km^2) development intensity (LDI), and site age (AGE) on avian community species abundance (S_{MAX}) for entire site bird assemblages and avian functional guilds: (a) dominant breeding habitat (early-successional; forested; urban); (b) migratory strategy (neotropical migration; permanent residence; partial migration); and (c) synanthropic status (synanthropic; non-synanthropic).

	Significance Levels [1]							
	Main Effects			**Interactions**				
Species Grouping	**RDI**	**LDI**	**AGE**	**RDI*LDI**	**RDI*AGE**	**LDI*AGE**	**RDI*LDI*AGE**	**Model R^2**
Site Assemblage								0.307
Early-successional Habitat	*		**					0.509
Forested Habitat								0.333
Urban Habitat		**						0.598
Neotropical Migrant								0.283
Permanent Resident					**			0.474
Partial Migrant		**						0.441
Synanthropic		**			**		**	0.668
Non-synanthropic								0.338

[1] (blank) = non-significant at level 0.10; * = significant at level 0.10; ** = significant at level 0.05

Table 3.8: Summary of ANOVA test to examine effects of regional-scale (5 km^2) development intensity (RDI), landscape-scale (1 km^2) development intensity (LDI), and site age (AGE) on avian community diversity (J') for entire site bird assemblages and avian functional guilds: (a) dominant breeding habitat (early-successional; forested; urban); (b) migratory strategy (neotropical migration; permanent residence; partial migration); and (c) synanthropic status (synanthropic; non-synanthropic).

	Significance Levels[1]							
	Main Effects			Interactions				
Species Grouping	**RDI**	**LDI**	**AGE**	**RDI*LDI**	**RDI*AGE**	**LDI*AGE**	**RDI*LDI*AGE**	**Model R^2**
Site Assemblage								0.243
Early-successional Habitat								0.407
Forested Habitat								0.269
Urban Habitat								0.383
Neotropical Migrant								0.221
Permanent Resident				*				0.405
Partial Migrant								0.223
Synanthropic								0.324
Non-synanthropic		**						0.386

[1] (blank) = non-significant at level 0.10; * = significant at level 0.10; ** = significant at level 0.05

Table 3.9: Summary of ANOVA test to examine effects of regional-scale (5 km^2) development intensity (RDI), landscape-scale (1 km^2) development intensity (LDI), and site age (AGE) on avian mean species relative abundance (MSRA).

Species	Significance Levels[1]							Model R^2
	Main Effects			Interactions				
	RDI	LDI	AGE	RDI*LDI	RDI*AGE	LDI*AGE	RDI*LDI*AGE	
Mourning Dove		*						0.407
Yellow-billed Cuckoo								0.430
Ruby-throated Hummingbird				*				0.386
Red-headed Woodpecker	*		**		**			0.600
Red-bellied Woodpecker								0.413
Downy Woodpecker								0.315
Hairy Woodpecker				*				0.373
Northern Flicker								0.203
Pileated Woodpecker								0.248
Eastern Wood-Pewee								0.384
Acadian Flycatcher								0.497
Eastern Phoebe							*	0.322
Great Crested Flycatcher								0.400
White-eyed Vireo	*							0.281
Yellow-throated Vireo								0.355
Red-eyed Vireo	*	**		*	**	**		0.674
Blue Jay		*						0.341
American Crow								0.317
Carolina Chickadee		**	**					0.514
Tufted Titmouse			*					0.361
White-breasted Nuthatch						*		0.457
Brown-headed Nuthatch								0.297
Carolina Wren					*			0.371
House Wren		**						0.504

Species	Significance Levels[1]							Model R^2
	Main Effects			Interactions				
	RDI	LDI	AGE	RDI*LDI	RDI*AGE	LDI*AGE	RDI*LDI*AGE	
Blue-gray Gnatcatcher		*						0.421
Eastern Bluebird		*						0.395
Wood Thrush			*					0.435
American Robin		**	*					0.518
Gray Catbird								0.483
Northern Mockingbird		**			**	*		0.594
Brown Thrasher	*	**	*					0.564
European Starling								0.325
Northern Parula		*						0.412
Pine Warbler				**				0.475
Prairie Warbler	**							0.468
Black-and-white Warbler				*	*			0.385
Hooded Warbler								0.403
Summer Tanager		**						0.542
Scarlet Tanager		**			*			0.488
Eastern Towhee	**	*				**		0.635
Chipping Sparrow	**							0.503
Field Sparrow	*							0.337
Song Sparrow								0.261
Northern Cardinal		*						0.376
Blue Grosbeak	**		**		**			0.770
Indigo Bunting	**	**	**	**	**	**		0.891
Common Grackle		**						0.525
Brown-headed Cowbird								0.415
House Finch		*			**			0.550
American Goldfinch								0.361

[1] (blank) = non-significant at level 0.10; * = significant at level 0.10; ** = significant at level 0.05

CHAPTER 4

MODELING AVIAN RESPONSES TO MULTISCALE LANDSCAPE CHARACTERISTICS

INTRODUCTION

Avian Response to Urbanization

Human population growth has substantially altered and continues to alter landscapes on a global scale (Alig, Kline et al. 2004). Urbanization in the southeastern United States, especially the state of Georgia, has been rapid in the past 20 years and with urbanization has come extensive restructuring of the natural landscape (Perry and Mackun 2001; Yang and Lo 2002). Birds respond to urbanization-related landscape changes in a variety of ways, including via: (a) changes in community total abundance; (b) changes in species richness and species evenness (collectively, species diversity); and (c) changes in population abundance (Marzluff 2001).

Despite the accepted knowledge of ongoing urbanization in Georgia (Kramer 2008), and well-documented associations between urbanization and loss of avian biodiversity (Chace and Walsh 2006), few studies have attempted to explain patterns of avian communities using multiscale models. Birds are known to vary in their response to landscape composition depending on the spatial scale at which it is considered (Hennings and Edge 2003). Saab (1999) demonstrated the importance considering habitat at a variety of scales, particularly that of the habitat matrix surrounding research areas of interest. Villard and others (1999) found that both the composition and configuration of landscapes were important in predicting presence/absence of bird species. The effects of human disturbance on birds are poorly understood, but they appear to vary by species and spatial scale of the disturbance, with changes in disturbance levels accompanied by shifts in species assemblages and numbers on sites (Lussier, Enser et al. 2006). See chapter one for more details.

Multiscale Landscape Predictors of Avian Abundance and Diversity

Resources at both large and small scales are important in predicting the distribution of birds in an urbanized environment (Melles, Glenn et al. 2003). Human disturbance levels, habitat composition, and habitat configuration directly impact both what resources are present on a site and how available those resources are to birds. Understanding how birds respond to characteristics of their landscapes at multiple spatial scales is therefore an important component in solving the problem of explaining variation in avian abundance and diversity in urbanized areas.

OBJECTIVES

In this chapter, I explore the utility of using multiscale measures of habitat composition and configuration to explain patterns of avian abundance and diversity in residential developments in northeastern Georgia (reported on in chapter three). I used stepwise regressions to generate explanatory models of avian mean total relative abundance, maximum species richness, relative diversity, and mean species relative abundance using a set of 15 variables that represent aspects of human disturbance, landscape composition, and landscape configuration. I then evaluate those models to determine which landscape characteristics may be of utility in explaining avian abundance and diversity.

METHODS

Study Area

My study area was located in the greater Athens, Georgia area (primarily in Clarke and Oconee Counties; to a lesser degree in Barrow, Jackson, Madison, and Oglethorpe Counties; Fig. 2.1) and covered an area approximately 1,130 km^2. Athens is located approximately 110 km northeast of Atlanta, Georgia in the Piedmont physiographic region of the state. This area is experiencing rapid human population growth, particularly in Clarke County (where Athens is located) and in Oconee County (Georgia Statistics System 2008a; Georgia Statistics System 2008b).

Site Selection and Landscape Classification

I limited the scope of my study area to residential-style developments constructed in formerly-forested, upland areas and avoided neighborhoods built on former fields or pasture land. I did not distinguish between areas which were formerly natural forest versus mature plantation woodlands. Using maps depicting relative development intensity at landscape and regional scales (1 km^2 and 5 km^2, respectively) and recent (2007) aerial photography, supplemented by physical site visits, I located thirty-six 1x1 km study sites (33 in residential developments and 3 in primarily forested areas; Fig. 2.10) which were targeted for avian point-count sampling.

For each site, I developed a set of multiscale landscape variables characterizing aspects of human disturbance, landscape composition, and landscape configuration that I hypothesized would be important in explaining the abundance and diversity of birds breeding at each site. Landscapes variables were classified according to scale as: local-scale (0.01 to 0.02 km^2); landscape-scale (1 km^2); or regional-scale (5 km^2). I used 15 variables that depict various attributes of landscape composition and configuration. These variables were chosen from an initial, larger set of 26 variables which were screened to remove variables exhibiting extreme levels of correlation (Pearson correlation coefficients greater than ± 0.70; Table 2.3 and Appendix C). For a more detailed explanation of how these landscape characteristic metrics were calculated, see chapter two.

Avian Surveys and Development of Community and Population Metrics

During the avian breeding seasons (early May to 31 July) of 2007 and 2008, I conducted modified variable-radius point-counts on each of the study sites described above. I carried out a total of four sets of counts, generally at around 8 locations per site, for a total of 960 point-counts at 250 locations across both years. Overall, I observed 11,368 birds from 89 species.

The target set of species was breeding landbirds that use forested land cover and fulfill most of their daily needs within an area approximately the size of a study site (1 km^2). I excluded migrant birds, scarcely-distributed species, and species with life history characteristics not fitting those outlined above, reducing my dataset to 9,188 birds representing 50 species. I classified each of the 50 species according to functional guilds of: (a) dominant breeding habitat (forested, early successional/field, or urban); (b) migratory strategy (neotropical migrants, permanent residents, and partial migrants); and (c) synanthropic status (synanthropic or nonsynanthropic).

For each site, I calculated avian community metrics (mean total relative abundance per sample per site, *MTRA*; maximum avian species richness per site, S_{MAX}; and relative avian diversity, *J'*) as well as population metrics (mean species relative abundance per sample per site, *MSRA*). Community metrics were calculated both for the entire-site assemblage and by guild groups; population metrics were calculated for each species occurring on each site. Refer to chapter three for a more detailed explanation of avian survey methodology and survey results.

Stepwise Regressions

I used SAS software to perform 77 forward-and-backward stepwise regression procedures ($\alpha_{enter} = 0.15$; $\alpha_{retain} = 0.15$) to explore how communities, populations, and guilds responded to landscape characteristic variables (Hocking 1976; SAS Institute Inc. 2008). I modeled community responses (*MTRA;* S_{MAX}*; J'*) for each of 8 species subsets within guilds (dominant breeding habitat; migratory strategy; synanthropic status) and for entire-site assemblages (a total of 27 regressions); I also modeled population responses (*MSRA*) for the 50 species described above. Using Minitab software, I examined all variables for non-normal distributions or a curvilinear responses to predictors and transformed them where necessary to achieve a reasonable approximation of normality before including them in models; I used square-root (Ag1km, Ag5km, For1km, For5km, RdDen1km, RdDen5km, HDen1km, Hnum150m, and all MSRA measures) and natural log (ENN1km and all MTRA measures) transformations.

RESULTS

Stepwise Regressions

I conducted a total of 77 stepwise regressions to generate models explaining avian community abundance and diversity and avian population abundance metrics using multiscale landscape-derived explanatory variables. I considered variables in stepwise regression models with an $R^2_{ADJ} < 0.33$ to have weak explanatory value and drew limited conclusions from those models; this cutoff level is more conservative than in a similar previous study (Donnelly and Marzluff 2006). I considered variables in models with $0.33 \leq R^2_{ADJ} < 0.50$ to have moderate explanatory value and models with $R^2_{ADJ} \geq 0.50$ to have strong explanatory value. All explanatory variables retained by the models were significant at the $\alpha = 0.15$ level.

Community Models

I modeled community responses (*MTRA,* S_{MAX}*, and J'*; tables 4.1, 4.2, and 4.3, respectively) for each of 8 species subsets within guilds (dominant breeding habitat; migratory strategy; synanthropic status) and for entire-site assemblages (a total of 27 regressions). Of the 27 potential community models, 3 models had no significant relationships between my predictors and the response variables; 13 models exhibited only weak explanatory value ($0.06 < R^2_{ADJ} < 0.33$); 4 models had moderate explanatory value ($0.37 < R^2_{ADJ} < 0.47$); and 7 models exhibited strong explanatory value ($0.55 < R^2_{ADJ} < 0.81$). I focus the remainder of this section on the 11 community models that explained > 33% of the variation in their response.

Of the best 11 models of community metrics, most were *MTRA* models (n=7), compared with S_{MAX} (n=4) or *J'* (n=0). The most frequently selected explanatory variable was the local-scale metric For100m (selected in 7 models). The most frequently occurring landscape scale explanatory variable was HDen1km (selected in 4 models), while the most frequently selected regional-scale variable was Ag1km (selected in 4 models). All explanatory variables except HNum150m and RdDen1km occurred in at least one community model where $R^2_{ADJ} > 0.33$; however, PDen1km was only included in one model.

Mean Total Relative Abundance per sample per site

As mentioned above, my models explained *MTRA* better than S_{MAX} or *J'*. Four MTRA models predicted > 50% of the variation in their response and three others predicted between 37% and 47% of the variation in their response (Table 4.1). Age was included as an explanatory variable in three MTRA models; in every case where it was included, greater MTRA was associated with older sites. No MTRA models selected HNum150m or RdDen1km for inclusion in the model.

Entire Site Assemblage MTRA

My model explained 54.4% of the variation in total site MTRA. Site MTRA responded to six landscape metrics at three spatial scales as well as to site age. At the local spatial scale, total site MTRA was lower at sites with a greater percentage of forested land cover. At the landscape scale, site assemblage MTRA was negatively associated with percent agriculture and ENN; MTRA was positively associated with LPI. Entire site assemblage MTRA was negatively associated with increased agricultural and forest land cover at the regional scale. MTRA was higher at mature sites than at young sites.

Dominant Breeding Habitat Guild

My guild models for MTRA by dominant breeding habitat had high explanatory value for urban-breeding (R^2_{ADJ} = 0.80) and early successional/old field-breeding (R^2_{ADJ} = 0.47) guild subgroups, and explained slightly less of the variation of the forest-breeding guild (R^2_{ADJ} = 0.37). At the local scale, urban and early successional breeder MTRA responded negatively to %For100m. At the landscape scale, urban breeder MTRA was positively associated with housing density, elevation, and amount of forest edge. Early-successional breeder MTRA was negatively associated population density. Forest habitat breeder MTRA was negatively associated with percent of landscape in agricultural land cover and with elevation. Forest breeder MTRA was positively associated with amount of forested land cover at the regional scale. Urban breeder MTRA was greater at more mature sites.

Migratory Strategy Guilds

My models for MTRA by migratory guild were successful at explaining MTRA for partial migrants ($R^2_{ADJ} = 0.81$) and neotropical migrants ($R^2_{ADJ} = 0.55$), but only weakly explained permanent resident MTRA ($R^2_{ADJ} = 0.29$). At the local scale, short distance migrant MTRA showed a negative response to increased percent canopy cover. At the landscape scale, partial migrant MTRA was negatively associated with higher amount of forested landscape and positively associated with amount of forest edge. Neotropical migrant MTRA was positively associated with amount of forested landscape and with increased forest patch size. At the regional scale, partial migrant MTRA was positively associated with landscape percentage in agricultural land cover, while neotropical migrants were negatively associated with road density. Partial migrant MTRA was greater at mature sites.

Synanthropic Status Guilds

The model of synanthropic species MTRA had moderate explanatory value ($R^2_{ADJ} = 0.41$), but non-synanthropic species MTRA was only weakly explained by its model ($R^2_{ADJ} = 0.20$). Synanthropic species MTRA not significantly associated with any local-scale landscape metrics. It was positively associated with increased landscape-scale housing density and negatively associated with landscape-scale distance between forest patches. Synanthropic species MTRA was negatively associated with regional-scale road density and did not respond in a significant way to site age.

Maximum Species Richness per site

I generated nine S_{MAX} models (table 4.2), four of which explained > 33% of the variation in the dependent variable. Of those four models, two explained S_{MAX} for subgroups of the dominant breeding habitat guild (urban breeders and early-successional breeders); one explained S_{MAX} for a subgroup of the migratory strategy guild (partial migrants); and one explained S_{MAX} for a subgroup of the synanthropic status guild (synanthropes). R^2_{ADJ} for the four models ranged between 0.41 and 0.71. All other guild subgrouping S_{MAX} measures and site assemblage S_{MAX} resulted in models with weak explanatory value ($0.00 < R^2_{ADJ} < 0.33$). Several landscape characteristics at a variety of spatial scales were frequently included in S_{MAX} models, and included: (a) amount of forest at the local scale (3 models); (b) housing density at the landscape scale (2 models); amount of agricultural land cover at the regional scale (2 models); and site age (2 models).

Dominant Breeding Habitat Guild

Of the S_{MAX} models, the model of urban habitat breeder S_{MAX} had the greatest explanatory value ($R^2_{ADJ} = 0.71$). The model of early-successional habitat breeder S_{MAX} also had strong explanatory value ($R^2_{ADJ} = 0.55$). Urban habitat breeders were negatively associated with the amount of forest on the local scale. They were positively associated with housing density at the landscape scale and with amount of agricultural land cover at the regional scale. Urban breeder S_{MAX} was greater at mature sites. Early-successional habitat breeder S_{MAX} was not associated with any of the local-scale habitat characteristics. It was negatively associated with amount of forested land cover and positively associated with increased distance between forest patches, both at the landscape scale. It was also positively associated with amount of agricultural land cover at the regional scale. Early-successional habitat breeder S_{MAX} was not significantly associated with a particular site age class.

Migratory Strategy Guilds

The model of partial migrant S_{MAX} was the only model from the migratory strategy guild with strong explanatory value ($R^2_{ADJ} = 0.59$). Partial migrant S_{MAX} was negatively associated with amount of forest at the local scale. It was not significantly associated with any landscape-scale habitat characteristic variables, but showed a negative association with regional-scale amount of forested area. Partial migrant S_{MAX} was greater at more mature sites.

Synanthropic Status Guilds

Synanthropic species S_{MAX} was the only model from the synanthropic status guild with moderate explanatory value ($R^2_{ADJ} = 0.41$). Maximum species richness of synanthropes was negatively associated with amount of forest at the local scale and positively associated with landscape-scale housing density. There was no apparent significant association between synanthrope S_{MAX} and site age.

Relative Diversity

None of the nine relative diversity models (Table 4.3) had more than a weak explanatory value ($0.00 < R^2_{ADJ} < 0.30$). The relative diversity models with the greatest explanatory value were for synanthropic species ($R^2_{ADJ} = 0.30$), entire site assemblage ($R^2_{ADJ} = 0.30$), and forest habitat breeder ($R^2_{ADJ} = 0.29$).

Population Models

I generated linear models of MSRA for 50 species at the site level (Table 4.4). Fourteen models explained greater than half of the variation in the MSRA for individual bird species (House Finch, Black-and-white Warbler, American Robin, Northern Mockingbird, Brown Thrasher, Blue Grosbeak, Acadian Flycatcher, Yellow-billed

Cuckoo, Indigo Bunting, Red-eyed Vireo, Common Grackle, Field Sparrow, House Wren, and Summer Tanager; $0.51 < R^2_{ADJ} < 0.74$). Eight more models had moderate explanatory value ($0.34 < R^2_{ADJ} < 0.49$) for variation in MSRA (Scarlet Tanager, Northern Flicker, Gray Catbird, Mourning Dove, Chipping Sparrow, Tufted Titmouse, Eastern Towhee, and Great Crested Flycatcher). I focus the on the 22 models with $R^2_{ADJ} > 0.33$.

All explanatory variables occurred in at least one MSRA model. The most frequently selected explanatory variable was local-scale amount of forested habitat (For100m; 10 models). The most frequently-selected landscape-scale variables were amount of forested landscape (For1km; 7 models) and housing density (HDen1km; 7 models). Amount of agricultural land cover was the most frequently-selected regional-scale variable (Ag5km; 6 models). Site age (Age) was included in 7 models. Ten models (American Robin, Red-eyed Vireo, Common Grackle, Field Sparrow, House Wren, Summer Tanager, Scarlet Tanager, Gray Catbird, Mourning Dove, and Great Crested Flycatcher) had negative intercept estimates.

DISCUSSION

General findings

My results support the findings of other studies that suggest measures of landscape composition, pattern, human alteration, and age (as a proxy for disturbance level) can be used successfully (i.e., explaining >33% of observed variation) to explain variation in breeding bird community abundance and diversity and population abundance (for examples, see chapter 1). My data suggest the set of landscape metrics I considered vary in their relative importance based on the spatial scale at which are considered. For example, percent forested land cover was more frequently selected as an important variable at smaller spatial scales. This is consistent with previous studies that have demonstrated the importance of spatial scale when considering relationships between the landscape and bird numbers (Saab 1999; Hostetler 2001; Hennings and Edge 2003). Using forward-and-backward stepwise linear regression, I successfully generated explanatory models of for avian community responses (mean total relative abundance, maximum species richness, and relative diversity for each site), and population responses (mean species relative abundance per site) based on 14 landscape metrics.

Choice of Significance Level in Stepwise Regressions

I considered these analyses exploratory because I was uncertain about the relative strength of community and population responses to my multiscale predictors. As an exploratory analysis, a model averaging approach was inappropriate (Burnham and Anderson 2002). While I recognize that my choice of the significance levels at which variables enter and are retained by models ($\alpha_{enter} = 0.15$; $\alpha_{retain} = 0.15$) may elevate the type 1 error rate when multiple models are fitted, I consider this to be appropriate given that the objective of my exploratory analysis was primarily to identify possible models to describe avian-landscape relationships. The outcome of such an approach should be that there is a lowered risk of missing potentially significant relationships, while some of the identified models may prove to be less plausible as more data are examined in future studies.

Community Models

Responsiveness of Community Metrics to Landscape Characteristics

Community response models were generally most effective at explaining large proportions of the variation in MTRA for most guild groupings; for 7 of 9 MTRA models, $0.37 \leq R^2_{ADJ} \leq 0.81$. This is consistent with previous studies, many of which have shown strong associations between group total abundance and landscape metrics (Bessinger and Osborne 1982; Mills, Dunning et al. 1989; Marzluff 2005). MTRA modeling efforts were more successful than efforts to model S_{MAX} or J'; efforts to model S_{MAX} yielded several models with moderate or strong explanatory value, but no models with $R^2_{ADJ} > 0.33$ resulted for the J' groups.

The overall weaker response of S_{MAX} may be related to the way in which community-level changes in a landscape occur: in some circumstances, landscape-level habitat changes may alter the species makeup of an area without changing its overall species richness (Parody, Cuthbert et al. 2001), which may partly explain why only four of the S_{MAX} models had strong or moderate explanatory value. An alternate explanation for the weak response of S_{MAX} to landscape characteristics is related to limitations in my site selection process. High species evenness is associated with both moderately low biomass and moderately low richness (Weiher and Keddy 1999). My sites represented a fairly even range of species richness values and I was not able to control for total biomass when selecting sites; either of those factors may partly explain the poor relationship between J' and landscape characteristics on my study sites. Future investigators should consider using site biomass as a selection criteria when locating future study sites to determine if controlling for biomass may elucidate any potential relationships between species evenness and landscape characteristics. Choosing sites along a wider section of the urban-rural gradient, particularly in much more urbanized areas may also benefit efforts to model evenness.

Seasonality may be responsible for the poor explanatory value of my set of J' models. Tramer (1969) hypothesized that diversity (determined by species richness, S, and evenness, from which J' is derived) may be more influenced by variation in species richness during relatively benign conditions (i.e., during the spring breeding season, when the climate is gentle and food is available) and be more influenced by evenness during harsher conditions (e.g., during colder months when food is scarce); this is fitting with my observation in chapter 3, that J’ did not appear to vary much in response to the urban-rural gradient. A comparative study of birds numbers on my study sites in the winter months would address the possibility of a stronger relationship during winter between site J’ and the landscape composition and configuration.

Use of Functional Guilds to Identify Community-level Responses to the Landscape

The explanatory power of my community metric models was variable. The responses of some groups within guilds were better explained than others. My models were better at explaining MTRA for birds based on their dominant breeding habitat or migratory strategy than for synanthropic status or for entire sites. It may be that within larger groups, contrary responses by individual species mask the responses of other species.

Groupings of birds which are more generalist in their behavior or habitat requirements (e.g., permanent residents) appear to be less sensitive to landscape characteristics than more specialist groupings, consistent with predictions based on previous modeling efforts by Hepinstall and others (2008). Care must be taken when lumping birds by guild to ensure intra-guild similarity in life history attributes and use of habitat; if individual species within a guild have strong – but differing - responses to a variable, they may mask the importance of that variable for the overall group. For example, my MTRA and S_{MAX} models for the permanent residence subgroup of the migratory strategy guild had lower R^2_{ADJ} than either of the migratory groups within the same guild, suggesting that MTRA and S_{MAX} of permanent residents varied less with the landscape than was the case with migrants; this may be explained by the greater tendency towards short-term ‘specialist’ exploitation of habitats by migratory species relative to permanent residents, which tend towards more generalist responses to their habitat (Gill 1994). Recent work by Devictor and others (2008) suggests that specialist species are more impacted (negatively) by landscape degradation than generalist species. Subdividing observations into smaller, more homogeneous species groupings – and hence, into more specialist groupings - seemed to improve the explanatory value of my models (e.g., urban habitat breeding birds). Exploring alternate grouping categories may increase future success in explaining community-level responses to landscape changes.

Population Models

Responsiveness of Population Abundance to Landscape Characteristics

My results suggest that landscape metrics measured at multiple spatial scales are also suitable for explaining variation in MSRA explanatory variables for select species. Species with specialist tendencies in their life histories (e.g., in breeding habitat preference) are likely to show strong correlation between MSRA and landscape characteristics in models; species with more generalist tendencies may be poor candidates for such a modeling approach. Previous research efforts have produced robust models of species richness for multiple taxonomic groups (e.g., birds and butterflies) as a function of indicator species occurrence (Fleishman, Mac Nally et al. 2001); my results suggest that a complimentary approach to the prediction of abundance and diversity of species, using easily-derived landscape characteristics directly as explanatory variables rather than surveying for the presence of indicator species, may have similar applications.

Mean Species Relative Abundance (MSRA)

Some species are more generalist in their habitat needs than others and these species will usually exhibit a weaker response to landscape alteration than specialist species (Hepinstall, Krohn et al. 2002; Hepinstall, Alberti et al. 2008). Using landscape characteristic variables, I was able to produce robust models explaining 34% - 50% of the variation in MSRA for 8 species and 50% - 74% of the variation in 14 more. In accordance with the predictions of Hepinstall and others (2008) and Devictor and others (2008), the species models best able to explain MSRA were for birds that tend to be more specific in their habitat needs. For example, Acadian Flycatchers (model R^2_{ADJ} = 0.63) require relatively undisturbed mature forests and are thought to be area-dependent (Whitehead and Taylor 2002); Black-and-white Warblers (model R^2_{ADJ} = 0.70) show strong preferences for forest type, canopy closure, and vegetation characteristics (Kricher 1995); and House Finches (model R^2_{ADJ} = 0.74) breed almost exclusively in settled areas in the eastern US (Hill 1993). Other species, which are typically more generalist in their use of the landscape, were much less responsive to the set of explanatory variables: for example, Downy Woodpeckers (model R^2_{ADJ} = 0.13) are very flexible in their dominant habitat, even venturing away from woodlands to feed in open areas, nesting in fence posts (Jackson and Ouellet 2002); and Northern Cardinals (model R^2_{ADJ} = 0.21) use a variety of habitat types, including “areas with shrubs and/or small trees, including forest edges and interior, shrubby areas in logged and second-growth forests, marsh edges, grasslands with shrubs, successional fields, hedgerows in agricultural fields, and plantings around buildings” (Halkin and Linville 1999).

Using Multiscale Landscape Characteristics to Explain Avian Abundance and Diversity

Importance of Considering the Landscape at Multiple Scales

Both community and population metrics (MTRA, S_{MAX}, and MSRA) responded strongly to landscape explanatory variables at each of the three scales I considered in my site characterization. The most frequently-selected explanatory variable for each metric was local-scale percent forested land cover, suggesting that during the breeding season, smaller spatial scales may be of particularly high importance; however, many explanatory variables were included at the landscape and regional scale as well, indicating that total relative abundance and species richness are also responding to the landscape at much larger scales than merely the local scale. This makes logical sense; factors at larger spatial scales are often important constraints on factors at smaller scales (Hostetler 2001). The literature reflects uncertainty regarding the relative importance of spatial scale to birds (Saab 1999; Westphal, Field et al. 2003; Donnelly and Marzluff 2004), but there is a general agreement – which my results support - that considering the composition and pattern of the landscape at a variety of scales is important to better understand patterns of avian abundance and diversity (Hostetler 2001; Hennings and Edge 2003). I limited the maximum extent of my analyses to the 5 km^2 scale, but studies in other areas have suggested that landscape pattern and composition may impact bird communities at larger scales, ranging from 10 km^2 (Westphal, Field et al. 2003) to 36 km^2 (Bohning-Gaese 1997).

Importance of Landscape Characteristics to Birds

All of the 15 landscape variables I selected to describe my sites were incorporated into one or more community or population metric models where $R^2_{ADJ} > 0.33$. Metrics of landscape composition and of landscape configuration were both important explanatory variables in my models of abundance and diversity across the urban-rural gradient. Many of these variables represent multiple aspects of human influences on sites. For example, landscape-scale housing density (the most frequently-selected landscape-scale variable in models) correlates with human disturbance levels (e.g., noise, traffic, and vegetation alteration), patterns of landscape configuration (i.e., fragmentation), and the resulting composition of the landscape (i.e., amount of retained habitat) (Theobald 2001). Site age was another frequently-selected variable that represented a complex array of human influence on sites and was of great utility in explaining patterns of abundance and diversity.

Table 4.1: Mean total relative abundance per sample per site (MTRA) models. MTRA was modeled using forward-and-backward stepwise regression for entire site assemblages and for functional guilds: dominant breeding habitat (forested, early-successional, urban); migratory strategy (neotropical migration, permanent residence, partial migration); and synanthropic status (synanthropic vs. non-synanthropic). If an explanatory variable entered the model and was retained ($\alpha_{enter} = 0.15$; $\alpha_{retain} = 0.15$), the sign of the variable coefficient is given. Models are ranked by descending model R^2_{ADJ}.

Subset of Responses Used in Model	Explanatory Variables[1]																Model R^2_{ADJ}
	Intercept	Hnum150m	For100m	Ag1km	For1km	RdDen1km	HDen1km	Elev1km	LPI1km	ENN1km	PDen1km	ForEdge1km	Ag5km	For5km	RdDen5km	Age	
Partial Migrant	+		-		-							+	+			-	**0.814**
Urban Habitat	+		-				+	+				+				-	**0.801**
Neotropical Migrant	+				+				+						-		**0.553**
Site Assemblage	+		-	-					+	-			+	+		-	**0.544**
Early-successional Habitat	+		-								-						**0.465**
Synanthropic	+						+			-					-		**0.411**
Forest Habitat	+			-				-						+			**0.372**
Permanent Resident	+			-						-							**0.293**
Non-synanthropic	+						-										**0.204**

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[1] *See Table 2.4 for variable descriptions.*

Table 4.2: Maximum species richness per site (S_{MAX}) models. S_{MAX} was modeled using forward-and-backward stepwise regression for entire site assemblages and for functional guilds: dominant breeding habitat (forested, early-successional, urban); migratory strategy (neotropical migration, permanent residence, partial migration); and synanthropic status (synanthropic vs. non-synanthropic). If an explanatory variable entered the model and was retained ($\alpha_{enter} = 0.15$; $\alpha_{retain} = 0.15$), the sign of the variable coefficient is given. Models are ranked by descending model R^2_{ADJ}.

Subset of Responses Used in Model	Explanatory Variables [1]															Model R^2_{ADJ}
	Intercept	Hnum150m	For100m	Ag1km	For1km	RdDen1km	HDen1km	Elev1km	LPI1km	ENN1km	PDen1km	ForEdge1km	Ag5km	For5km	RdDen5km	Age	
Urban Habitat	+		-				+						+			-	**0.707**
Partial Migrant	+		-											-		-	**0.594**
Early-successional Habitat	-				-					+			+				**0.550**
Synanthropic	+		-				+										**0.414**
Forest Habitat	+			-				-									**0.325**
Neotropical Migrant	+				+												**0.241**
Non-Synanthropic	+				+												**0.116**
Site Assemblage	+																**NS**
Permanent Resident	+																**NS**

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[1] *See Table 2.4 for variable descriptions.*

Table 4.3: Relative diversity per site (*J'*) models. Relative diversity was modeled using forward-and-backward stepwise regression for entire site assemblages and for functional guilds: dominant breeding habitat (forested, early-successional, urban); migratory strategy (neotropical migration, permanent residence, partial migration); and synanthropic status (synanthropic vs. non-synanthropic). If an explanatory variable entered the model and was retained ($\alpha_{enter} = 0.15$; $\alpha_{retain} = 0.15$), the sign of the variable coefficient is given. Models are ranked by descending model R^2_{ADJ}.

	Explanatory Variables[1]																
Subset of Responses Used in Model	**Intercept**	**Hnum150m**	**For100m**	**Ag1km**	**For1km**	**RdDen1km**	**HDen1km**	**Elev1km**	**LPI1km**	**ENN1km**	**PDen1km**	**ForEdge1km**	**Ag5km**	**For5km**	**RdDen5km**	**Age**	**Model R^2_{ADJ}**
Synanthropic	**+**								**-**					**+**			**0.300**
Site Assemblage	**+**						**-**							**+**			**0.299**
Forest Habitat	**+**				**+**												**0.286**
Permanent Resident	**+**				**+**				**-**								**0.267**
Non-synanthropic	**+**			**-**										**+**			**0.190**
Early-successional Habitat	**+**													**+**			**0.141**
Neotropical Migrant	**+**			**-**													**0.129**
Partial Migrant	**+**												**-**				**0.056**
Urban Habitat	**+**																**NS**

[1] *See Table 2.4 for variable descriptions.*

Table 4.4: Mean species relative abundance per sample per site (MSRA) models. MSRA was modeled using forward-and-backward stepwise regression for each of 50 species. If an explanatory variable entered the model and was retained ($\alpha_{enter} = 0.15$; $\alpha_{retain} = 0.15$), the sign of the variable coefficient is given. Models are ranked by descending model R^2_{ADJ}.

	Explanatory Variables[1]																
Species	**Intercept**	**Hnum150m**	**For100m**	**Ag1km**	**For1km**	**RdDen1km**	**HDen1km**	**Elev1km**	**LPI1km**	**ENN1km**	**PDen1km**	**ForEdge1km**	**Ag5km**	**For5km**	**RdDen5km**	**Age**	**Model R^2_{ADJ}**
House Finch	+		-					-									0.738
Black-and-white Warbler	+				+	-		-	+				+				0.704
American Robin	-		-				+	+				+				-	0.671
Northern Mockingbird	+		-								+						0.662
Brown Thrasher	+	-			-					-	+						0.645
Blue Grosbeak	+	-														+	0.631
Acadian Flycatcher	+		+					-							-		0.630
Yellow-billed Cuckoo	+				+					-		-					0.624
Indigo Bunting	+						-				-					+	0.615
Red-eyed Vireo	-		+		+												0.570
Common Grackle	-						+						+			-	0.545
Field Sparrow	-			+			-				+	-					0.530

	Explanatory Variables [1]															
Species	Intercept	Hnum150m	For100m	Ag1km	For1km	RdDen1km	HDen1km	Elev1km	LPI1km	ENN1km	PDen1km	ForEdge1km	Ag5km	For5km	RdDen5km	Age	Model R^2_{ADJ}
House Wren	-	-				+	+										0.529
Summer Tanager	-				+							-					0.505
Scarlet Tanager	-		+										+				0.491
Northern Flicker	+												-	-	-	+	0.487
Gray Catbird	-						+	+					+	+		-	0.470
Mourning Dove	-		-	-			+						+	+		-	0.466
Chipping Sparrow	+		-	-							+						0.431
Tufted Titmouse	+		+									+					0.422
Eastern Towhee	+				-												0.366
Great Crested Flycatcher	-		-		+				+								0.335
European Starling	+		-										+			-	0.314
Carolina Chickadee	-											+		+			0.306
Pileated Woodpecker	+							-	-								0.302
Pine Warbler	+						-	+								-	0.293
Red-bellied Woodpecker	+				+	-			+	-							0.288

	Explanatory Variables [1]																
Species	**Intercept**	**Hnum150m**	**For100m**	**Ag1km**	**For1km**	**RdDen1km**	**HDen1km**	**Elev1km**	**LPI1km**	**ENN1km**	**PDen1km**	**ForEdge1km**	**Ag5km**	**For5km**	**RdDen5km**	**Age**	**Model R^2_{ADJ}**
Brown-headed Cowbird	+		-		+												**0.286**
Northern Parula	-		+											+			**0.278**
Song Sparrow	+				-				+								**0.264**
Wood Thrush	-											+					**0.253**
Eastern Bluebird	+		-	-		+											**0.252**
Yellow-throated Vireo	+			-				-									**0.239**
White-breasted Nuthatch	-	+															**0.229**
American Goldfinch	+							-			-						**0.216**
Northern Cardinal	+								+								**0.211**
Blue-gray Gnatcatcher	-				+												**0.210**
Blue Jay	+				-												**0.181**
Brown-headed Nuthatch	-										+						**0.173**
Ruby-throated Hummingbird	+			-													**0.169**
Carolina Wren	+										-	+					**0.158**
Downy Woodpecker	+									-	-						**0.125**

	Explanatory Variables[1]																
Species	**Intercept**	**Hnum150m**	**For100m**	**Ag1km**	**For1km**	**RdDen1km**	**HDen1km**	**Elev1km**	**LPI1km**	**ENN1km**	**PDen1km**	**ForEdge1km**	**Ag5km**	**For5km**	**RdDen5km**	**Age**	**Model R^2_{ADJ}**
Prairie Warbler	-									+							**0.120**
Red-headed Woodpecker	+															+	**0.098**
American Crow	+	+															**0.064**
Hooded Warbler	+						-										**0.063**
Eastern Wood-Pewee	+		-														**0.054**
Hairy Woodpecker	+																**NS**
Eastern Phoebe	+																**NS**
White-eyed Vireo	+																**NS**

[1] *See Table 2.4 for variable descriptions.*

CHAPTER 5

RESEARCH SUMMARY

RESEARCH SUMMARY

Site Selection and Characterization (Chapter 2)

I located thirty-six 1 km^2 study landscapes in single-family residential developments in the Athens, Georgia area using a combination of GIS-derived development intensity metrics and aerial photographs, supplemented with physical site visits. Sites were classified according to development intensity at two spatial scales (landscape-scale, 1 km^2; regional-scale, 5 km^2) and site age. Each study site landscape was characterized by fifteen metrics describing aspects of landscape composition, landscape configuration, and human disturbance at a variety of scales (local-scale, 0.01 km^2; landscape-scale; and regional-scale). See Table 2.4 for descriptions of each landscape characteristic variable. In addition to characterizing the landscape, I also compared two methods of estimating land cover amount (satellite imagery-based classification vs. aerial photo interpretation). I found that for my study area, it appeared that although the average satellite-based land cover classifications underestimated forest cover, they were nevertheless highly-correlated with the results of the more resource-intensive aerial photo-interpretation method at coarse (but not fine) spatial scales; I therefore suggested that aerial photo-interpretation was more justified when finer scale accuracy was desired, but that the additional expenditure for aerial photo-interpretation was probably not warranted for many coarser scale research needs.

Avian Surveys in Residential Developments (Chapter 3)

During the spring-summer avian breeding seasons of 2007 and 2008, I conducted modified variable-radius point-counts to survey avian abundance and diversity on each of my field sites. I measured avian community metrics (mean total relative abundance, MTRA; maximum species richness across both years, S_{MAX}; relative diversity, J') and population metrics for 50 species (mean species relative abundance, MSRA). Community metrics were calculated for the entire site assemblage and by avian functional guilds (dominant breeding habitat; migratory strategy; synanthropic status). I determined that abundance and diversity of some species and guild groups varied with the landscape- and regional-scale development intensity and site age metrics previously measured for each site.

Modeling Avian Response to Multiscale Landscape Characteristics (Chapter 4)

I conducted a series of linear regressions to model avian community and population response to the 15 urbanization-related multiscale landscape characteristics measured for each study site. The resulting 77 models varied in the strength of response: 4 community and 8 population models had moderate explanatory value (defined as $0.33 \leq R^2_{ADJ} < 0.50$) and 7 community and 14 population models had strong explanatory value (defined as $R^2_{ADJ} \geq 0.50$); all explanatory variables retained by the models were significant at the $\alpha = 0.15$ level. Efforts to model MTRA were more successful than those to model S_{MAX} or J'; while population models appeared to be better at explaining MSRA for species with specialist life history habits compared to generalist species. Only models where $R^2_{ADJ} > 0.33$ are considered for the remainder of this section.

Within community metric models, the most frequently included characteristics were (at each scale): percentage of forested land cover (local scale); housing density (landscape-scale); and amount of agricultural land cover (regional-scale). Age was included in 5 of 13 community metric models where $R^2_{ADJ} > 0.33$. For population metric models, the most frequently included variables were (at each scale): percentage of forested land cover (local scale); percentage of forested land cover and housing density (landscape-scale variables); and percentage of agricultural land cover (regional-scale) 7 of 22 population metric models where $R^2_{ADJ} > 0.33$ included site age.

RESEARCH IMPACT

This study builds the existing literature on the use of multiscale landscape characteristics to explain variation in avian communities and populations and supports the findings of other studies that suggest these bird-landscape relationships may be of significant use in conservation endeavors. To date, studies of the effects of urbanization-related landscape alteration on birds had not yet been performed in the unique landscapes of the southeastern US in any systematic way. This pilot study demonstrates the viability of using easily-obtained landscape variables to explain avian abundance and diversity in the southeastern US. My modeling efforts show that variation in avian communities and populations can be successfully explained through the use of easily measured landscape characteristics using widely-available software tools and easy-to-conduct field survey techniques. It is hoped that the results of this study will help convince other researchers in the region that landscape-based models of species and guild abundance and diversity represent an under-exploited management tool which may provide conservation-minded stake-holders with more options to preserve desired species and habitats.

As the landscapes of Georgia and the Southeast continue to be developed, urban planners will bear an increasing popular mandate to direct development in such a way as to support the retention of as much native biodiversity as possible while balancing conservation needs with the needs of developers. A better understanding of how human disturbance and landscape composition and configuration impact wildlife can help developers pursue increasingly popular “green” building initiatives. Although this study focused on understanding how human disturbance and landscape composition and configuration impact birds in forested landscapes, many of the overarching themes of this study could easily be adapted to the study of other taxa in other habitats. For example, similar work has been carried out in Nevada with both birds and butterflies (Fleishman, Mac Nally et al. 2001; Fleishman, Thomson et al. 2005).

Conservation efforts in more pristine locales may also benefit from a similar approach. The ability to accurately model species occurrence using relatively easy, inexpensive, widely-available geospatial data could improve efforts to protect endangered species by helping managers to identify problem areas and high quality habitat, and generate “what-if?” scenarios to predict the effects of future urban growth on populations and communities before that growth has a chance to impact those areas.

The results of this pilot study indicate that there is merit in further developing a landscape-based approach to avian conservation in the Southeast. With the current, rapid state of urban and exurban development in the region, it is important to pursue an understanding of the effects of development on wildlife as quickly as possible; large amounts of habitat are being altered each year with no true understanding of the impact that such development will have on natural resources for decades to come. A larger-scale exploration of the concepts outlined in this study is warranted and should be supported by research institutions in the region.

FUTURE RESEARCH

Because of the small-scale, exploratory nature of this study, the size of my study area was limited to the region around Athens, Georgia. Athens represents a medium-sized, rapidly growing city, similar in many ways to a number of other cities around the Southeast; but there are also many other types of urban centers in the Southeast, ranging from small towns to sprawling metropolises like Atlanta, Georgia, each representing unique combinations of urban growth, land use, and development plans. To gain a better understanding of the relationships explored in this study, it will be necessary to methodically survey within the range of development styles present across Georgia and the Southeast. Although development of subdivisions represents one threat to avian habitat, farming may well represent the greatest extinction threat to birds in the world (Green, Cornell et al. 2005). An understanding of the effects of landscape on avian communities and populations would not be complete without work being done in agricultural settings.

The set of landscape predictors I used in this study were geared towards predicting abundance and diversity of breeding, upland forest birds. Landscape metrics important to species which are not predominantly forest-dwelling species (e.g., Eastern Meadowlark) are poorly represented in my set of explanatory variables. Future research goals should include developing a better understanding of avian occurrence patterns in the diverse range of other habitats of the Southeast. Also, avian usage of urban and rural habitats changes seasonally (Yaukey 1996), and future research must investigate how the landscape impacts avian communities and populations during the rest of each year.

The scope of this study was limited to the identification of patterns in avian occurrence in residential development landscapes during the spring/summer breeding season. The results of this investigation therefore suggest that a measurable relationship exists between birds and their landscape’s pattern of disturbance, composition, and configuration; however, the functional nature of that relationship remains to be explored. Now that some patterns are beginning to emerge, it will be important to begin to delve into the relationships between those patterns and the biological functions they influence (e.g., predation, communication, and breeding attempts).

One area of agroecology that has recently been gathering attention is the question of whether it is better to proceed with wildlife-friendly or land-sparing farming methods, where wildlife-friendly methods represent a lower intensity, higher-footprint production approach and land-sparing methods utilize a higher-intensity, smaller-footprint production (with total production being the same between the two) – the question: which method results in greater biodiversity? (Green, Cornell et al. 2005; Fischer, Brosi et al. 2008). A similar conundrum exists in the housing industry (or rather, “should” exist): is it more ecologically-sound to construct high-density style residential developments surrounded by greater amounts of (presumably) minimally-disturbed habitat (i.e., a land-sparing approach to producing the ‘crop’ of homes to sell) or is it better to develop larger areas of land at a lower level of habitat disturbance (i.e., a wildlife-friendly approach)? In some parts of Georgia, so-called “green” subdivisions are currently en vogue, with small “conservation plots” being set aside by developers and touted as being beneficial to wildlife – but are such subdivisions actually succeeding in providing useful wildlife habitat? Would it be better to simply create high-density developments with small footprints on the landscape? I suspect that future research into this question would likely provide some very thought-provoking results.

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APPENDIX A

DEFINITIONS OF TERMS

In the ecological literature, some frequently-used terms (e.g., “diversity”) are sometimes used by different authors to represent different concepts (Spellerberg and Fedor 2003). To avoid confusion, I will begin by defining several terms as they are used throughout this work.

Abundance

A generic term referring to numbers of individuals without specifying the groupings of those individuals.

Diversity

A generic term referring to both species richness and relative diversity.

Guild

(see Response Guild)

Landscape

“An area that is spatially heterogeneous in at least one factor of interest” (Turner, Gardner et al. 2001).

Relative diversity, J'

Relative diversity is the ratio of the measured Shannon evenness of a site, H', to the theoretical maximal Shannon evenness of the site, H'_{max} (Zar 1999).

Response Guild

Response guilds are “groups of species that require similar habitat, food, or other elements for survival” (O'Connell, Jackson et al. 1998).

Shannon Index, H’ (also, Shannon evenness)

A diversity index used to represent the biodiversity of an area. The Shannon index is maximized with greater species richness and greater species evenness (Zar 1999).

Spatial Scale

'Scale' is characterized by both 'extent' ("size of the study area or the duration of time under consideration"), and 'grain' ("finest level of spatial resolution possible within a given data set") to describe areas of interest (Turner, Gardner et al. 2001). Here, I use scale in the sense of spatial scale, where smaller scale represents finer resolution (detail) and generally smaller spatial extents, and larger scale represents coarser resolution and generally larger spatial extents.

Species abundance

A count of the total number of individuals of a species present in a defined geographical area.

Species evenness

A measure of the evenness of distribution of individuals between species present in a defined geographical area. Maximum evenness is achieved when there are an equal number of individuals representing each species in an area.

Species richness

A count of the number of unique species present in a defined geographical area.

Synanthropic species

A species which easily adapts to the presence of humans and/or cohabits with them, often seeking out and utilizing resources which humans make available, and exhibiting increased fitness as a result. Synanthropy is a "human-mediated symbiosis, usually of mutualism or commensalism…[representing] a wide degree of relationship to humans, ranging from obligate commensalism …to species only very marginally commensal." (Johnston 2001).

Total abundance

A count of the total number of individuals from all species present in a defined geographical area.

(Sadik 1999)

Urbanization

“The process by which human settlement increases in: 1) population density and 2) intensity of land use in an area” (Marzluff 2001).

APPENDIX B

EXPANDED DESCRIPTION OF STUDY SITES

STUDY AREA

My study area was located in the greater Athens, Georgia area (primarily in Clarke and Oconee Counties; to a lesser degree in Barrow, Jackson, Madison, and Oglethorpe Counties; Fig. B.1) and covered an area approximately 1,130 km^2. Athens is located approximately 110 km northeast of Atlanta, Georgia. The study area was located within the middle piedmont physiographic region of the state, along the midland slope (Burleigh 1958). The Piedmont region is characterized by rolling hills and clay-containing soils. Prior to colonial settlement, the Piedmont was mostly covered with pine, hardwood, and mixed pine-hardwood forests; however, much of the land had been cleared for agriculture by the 1900s (Coleman, Bartley, et al. 1977). Today the landscape is a mixture of remnant and old-field succession forestland, production forestland, agriculture, and developed lands.

Within the study area, single-family residential developments (neighborhoods) are typically constructed on land that was either a former field or one of the many large forest patches which are present throughout the landscape. These residential developments served as study sites. When selecting study sites, I limited the scope of my study area to developments which were built in formerly forested, upland areas and avoided neighborhoods built on former fields or pasture land. I did not distinguish between areas which were formerly natural forests versus mature plantation woodlands.

STUDY SITE SELECTION

I classified each study site with regard to its local-scale (1 km^2) and regional-scale (5 km^2) development intensity level using derived maps of development intensity gradients and aerial photographs of the study area. Local-scale development intensity levels were subdivided into the classes: minimal; low; medium; and high. Regional-scale development intensity levels were subdivided into: low; medium; and high. I also classified sites according to the age of the residential developments. I conducted physical site visits at potential study sites to confirm actual levels of local- and regional-scale development intensity, to ascertain site suitability for future avian surveys, and to determine site age. See chapter 2 for more information on how study sites were classified by development intensity level and site age.

Once three suitable sites were identified for a given combination of local- and regional-scale development intensity and age, I stopped looking for additional sites within that combination (table B.1). I did not sample inside of the relatively small, highly-disturbed zone of high regional-scale development intensity represented by the urban core of Athens, because of difficulty locating single-family, neighborhood-style developments within that area. I was not able to locate any sites for the combination, low regional-scale development intensity, high local-scale development intensity, mature age. For the local-scale development intensity class ‘minimal’, I selected three sites; these sites were forested, upland parks and reserve areas subject to only minor human disturbance.

Table B.1: All potential combinations of regional-scale development intensity (columns), local-scale development intensity (rows), and site age (sub-cells) for study sites. The combination RDI = Low; LDI = High; Age = Mature did not exist in the study area.

		Regional Development Intensity (RDI)	
		Low	**Medium**
Local Development Intensity (LDI)	**Minimal**	Mature	
	Low	Young	Young
		Mature	Mature
	Medium	Young	Young
		Mature	Mature
	High	Young	Young
		Mature	Mature

Avian Point-Count Sampling Points

I located a set of thirty-six study sites and classified them according to their local- and regional-scale development intensity and site age (Table B.2). At each site, I located a series of sampling points (generally eight) where I would conduct avian surveys later in the year (Fig. B.2). I attempted to fit eight points in each study site, with six points located within the neighborhood itself and two points located in larger patches of remnant forested fringe in or around the development. See chapter three for an expanded description of how sampling points were located and how avian surveys were carried out.

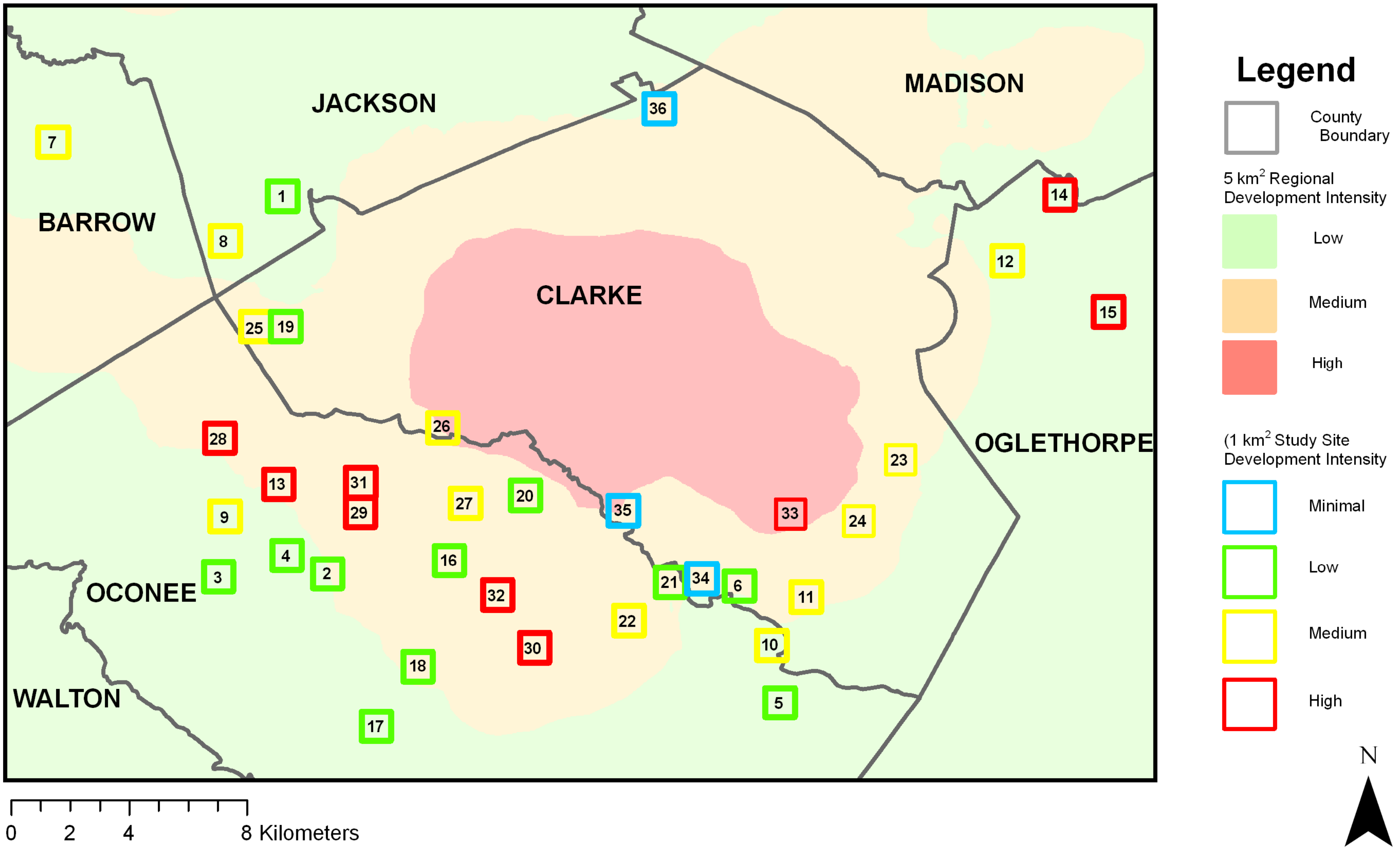
Table B.2: Site names for all study sites selected for use in study. Most sites were of type ‘residential development (RD), but several were either parkland or research forest. Regional and local development intensity were assigned to each site based on a geospatial index and site age was assigned based on field visits.

			Development Intensity		
Site Number	**Site Name**	**Land Use**	**Regional Scale**	**Local Scale**	**Site Age**
1	Riverbend	Residential	Low	Low	Young
2	Brookhaven / Morningside	Residential	Low	Low	Young
3	Piedmont Glen	Residential	Low	Low	Young
4	Mallard Lakes / Rocky Branch Farms	Residential	Low	Low	Mature
5	Old Mill Chase	Residential	Low	Low	Mature
6	Red Fox Run	Residential	Low	Low	Mature
7	Seven Oaks / Emerald Pointe	Residential	Low	Med	Young
8	Bear Creek Estates	Residential	Low	Med	Young
9	Somerset	Residential	Low	Med	Young
10	Skipstone	Residential	Low	Med	Mature
11	Idylwood	Residential	Low	Med	Mature
12	Beaverdam Creek	Residential	Low	Med	Mature
13	Triple Creek	Residential	Low	High	Young
14	Pine Ridge	Residential	Low	High	Young
15	Pinewood Hills	Residential	Low	High	Young
16	Meadow Springs	Residential	Med	Low	Young
17	Boulder Springs	Residential	Med	Low	Young
18	Coldwater Creek	Residential	Med	Low	Young
19	Huff Lake	Residential	Med	Low	Mature
20	Crystal Hills	Residential	Med	Low	Mature
21	Broadlands	Residential	Med	Low	Mature

Site Number	Site Name	Land Use	Development Intensity Regional Scale	 Local Scale	Site Age
22	Victoria Station	Residential	Med	Med	Young
23	Saint Charles / Oak Park	Residential	Med	Med	Young
24	Old Lexington Trace	Residential	Med	Med	Young
25	Pheasant Run / Pleasant Pines	Residential	Med	Med	Mature
26	Kingswood	Residential	Med	Med	Mature
27	Birchmore Hills	Residential	Med	Med	Mature
28	Trotters Walk	Residential	Med	High	Young
29	Rowan Oak / Laurel Shoals	Residential	Med	High	Young
30	Christian Lake	Residential	Med	High	Young
31	Fieldstone / Canyon Creek	Residential	Med	High	Mature
32	Stonebridge / Daniell Plantation	Residential	Med	High	Mature
33	East Creek Bend	Residential	Med	High	Mature
34	Whitehall Forest	Forested Reserve	Low	Minimal	Mature
35	Botanical Gardens	Forested Reserve	Med	Minimal	Mature
36	Sandy Creek Park	Forested Reserve	Low	Minimal	Mature

Figure B.1: Approximate Locations of Study Sites (overview).

Study site local-scale (1 km^2) development intensity was classified as either ‘minimal’, ‘low’, ‘medium’, or ‘high’. Study site approximate locations are overlaid on a regional-scale (5 km^2) development intensity gradient divided into three classes: ‘low’, ‘medium’, or ‘high’. See chapter 2 for more information on how study sites were located and the landscape was classified.


JACKSON
MADISON
BARROW
CLARKE
OGLETHORPE
OCONEE
WALTON
1
2
3
4
5
6
7
8
9
10
11
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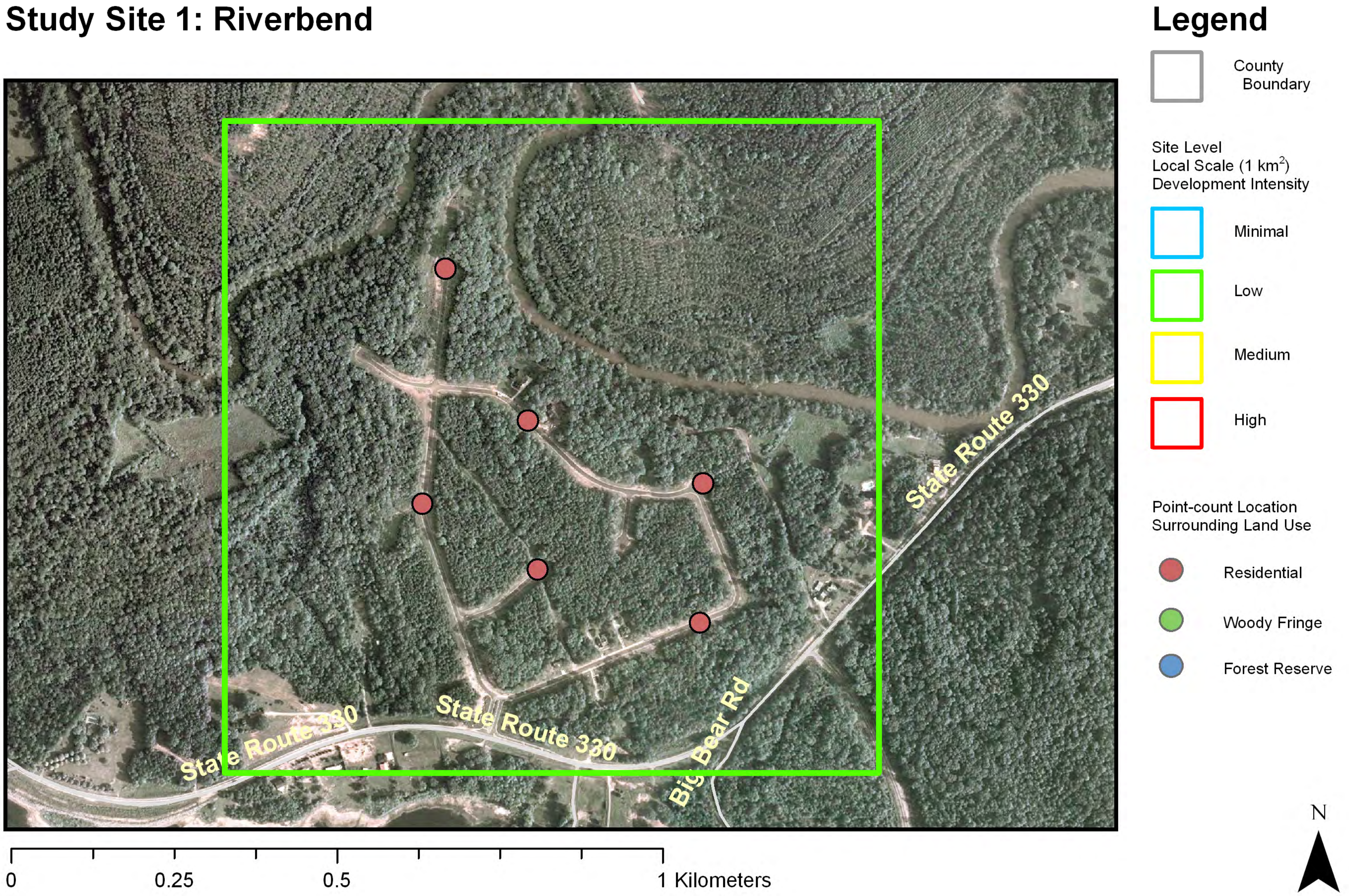
30
31
32
33
34
35
36
0
2
4
8 Kilometers
Legend
County Boundary
5 km^2 Regional Development Intensity
Low
Medium
High
(1 km^2 Study Site Development Intensity
Minimal
Low
Medium
High
N

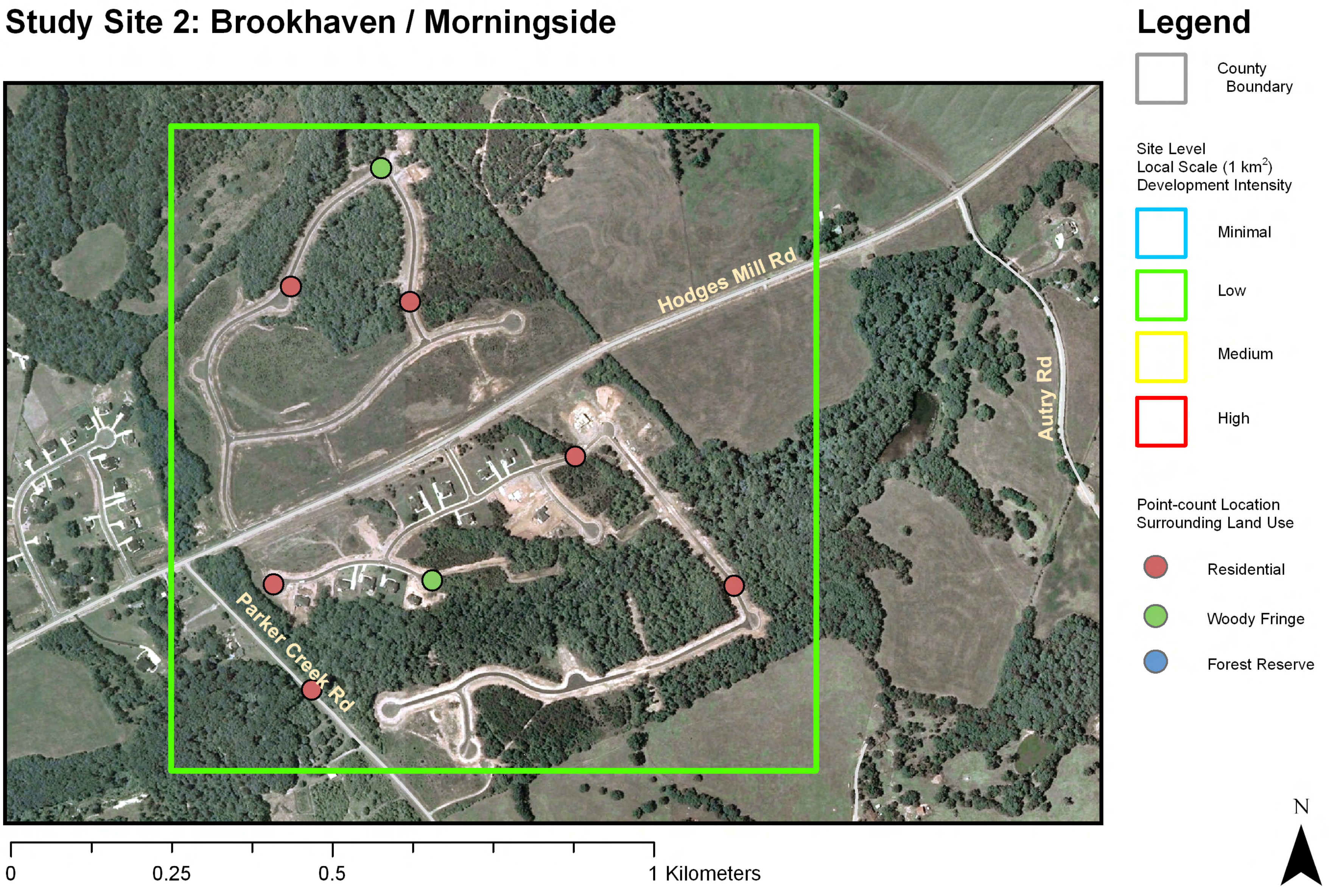
Figure B.2: Study Site Maps.

Study sites were located in residential developments and forested reserves. Each site, for the most part, was located within a 1 km^2 square. Local-scale (1 km^2) development intensity within the study site is indicated by the color of the bounding square. The locations of avian point-count surveys (count stations) are indicated by colored circles; color indicates land use surrounding a point: residential development; woody fringe adjacent to a development; or forested reserve. Study site number is indicated on each map.

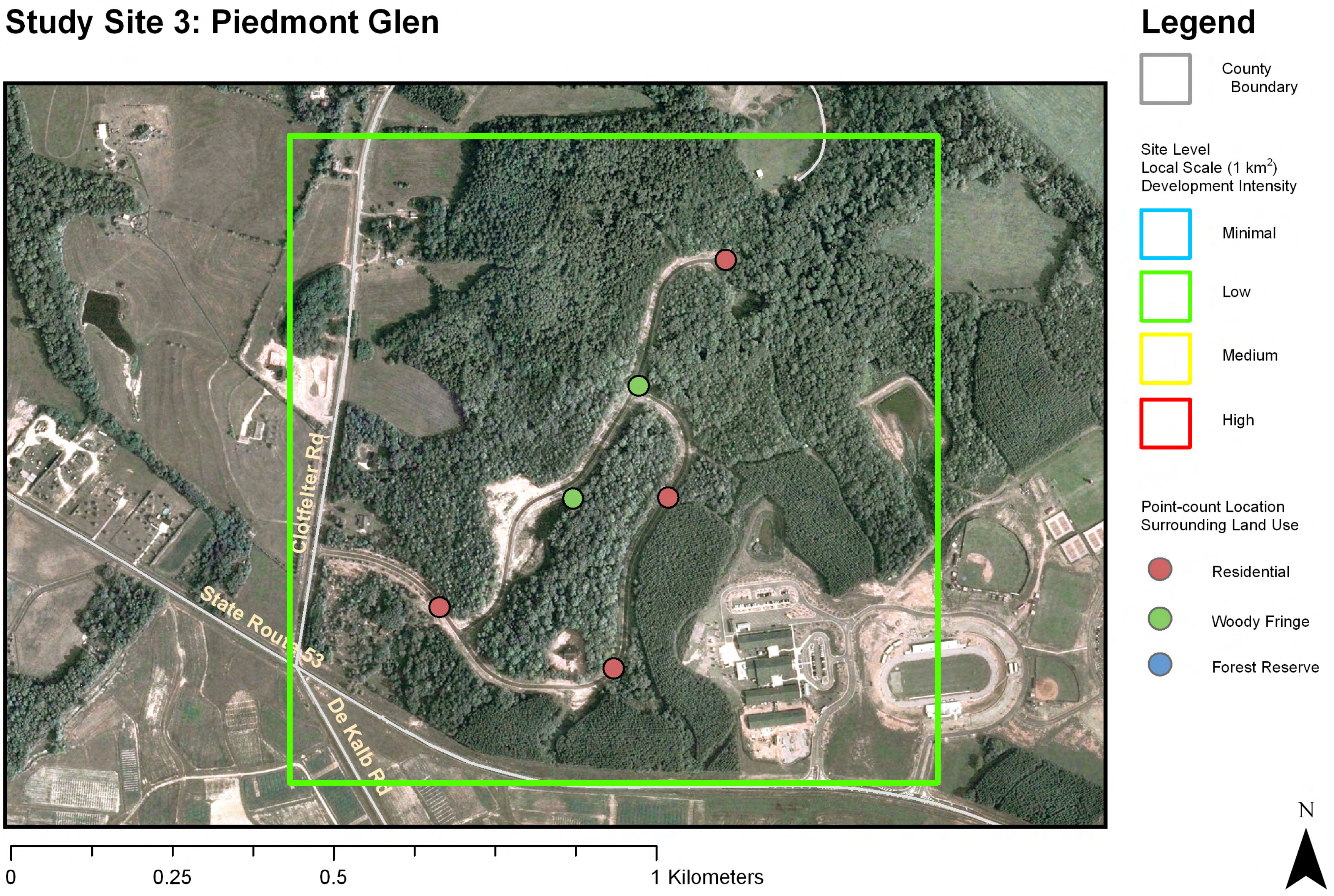
Study Site 1: Riverbend



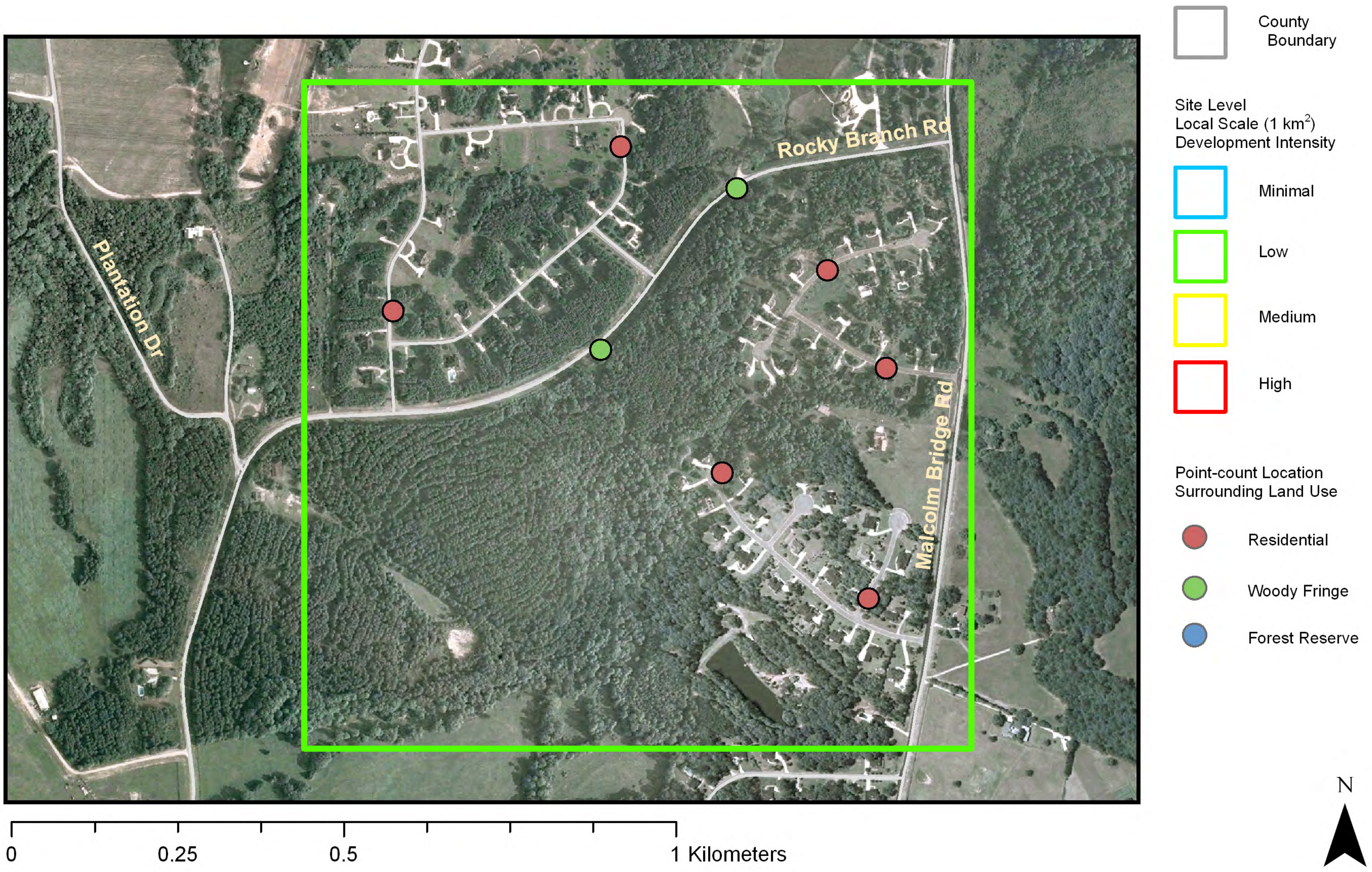
Study Site 2: Brookhaven / Morningside



Study Site 3: Piedmont Glen

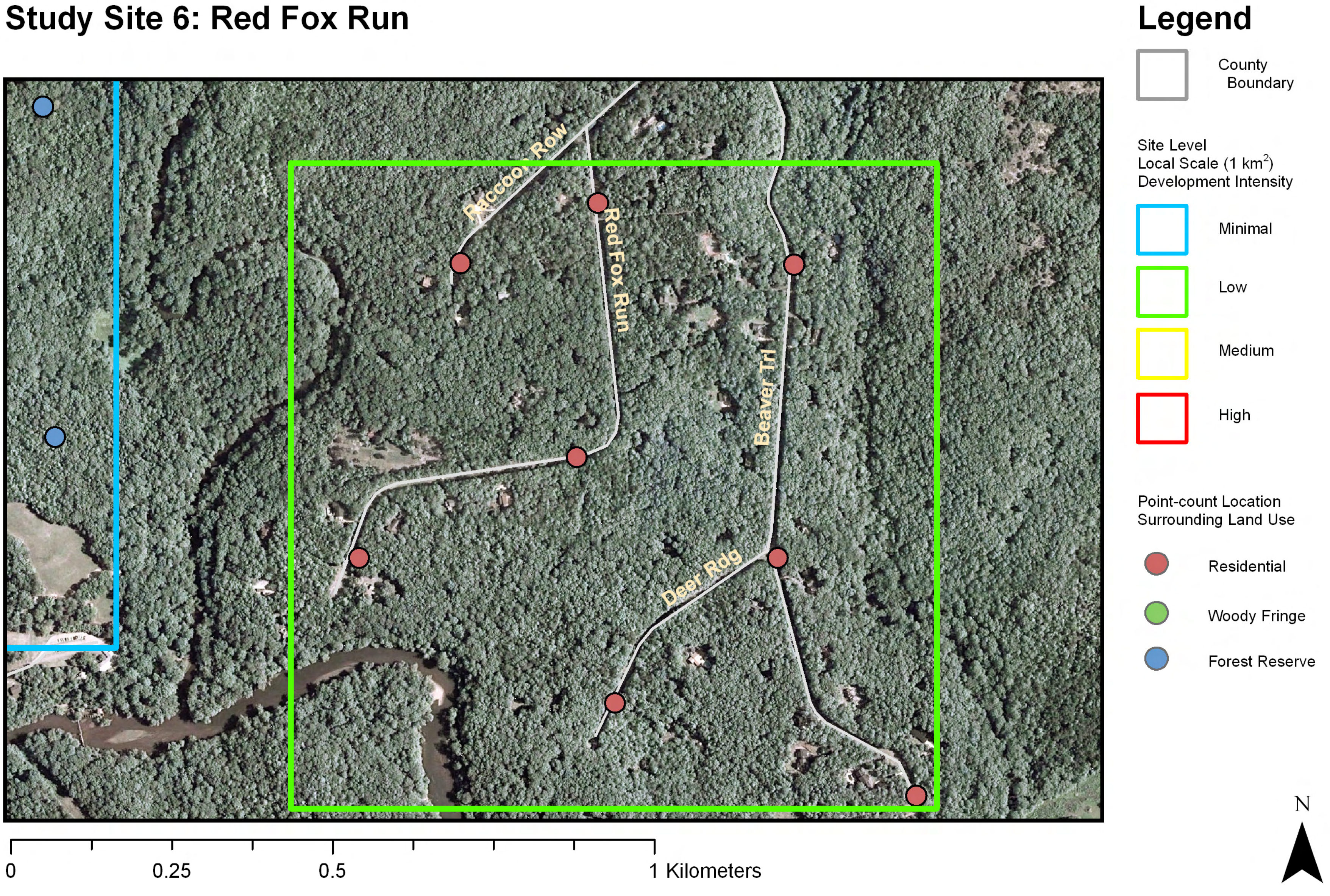


Study Site 4: Mallard Lakes / Rocky Branch Farms

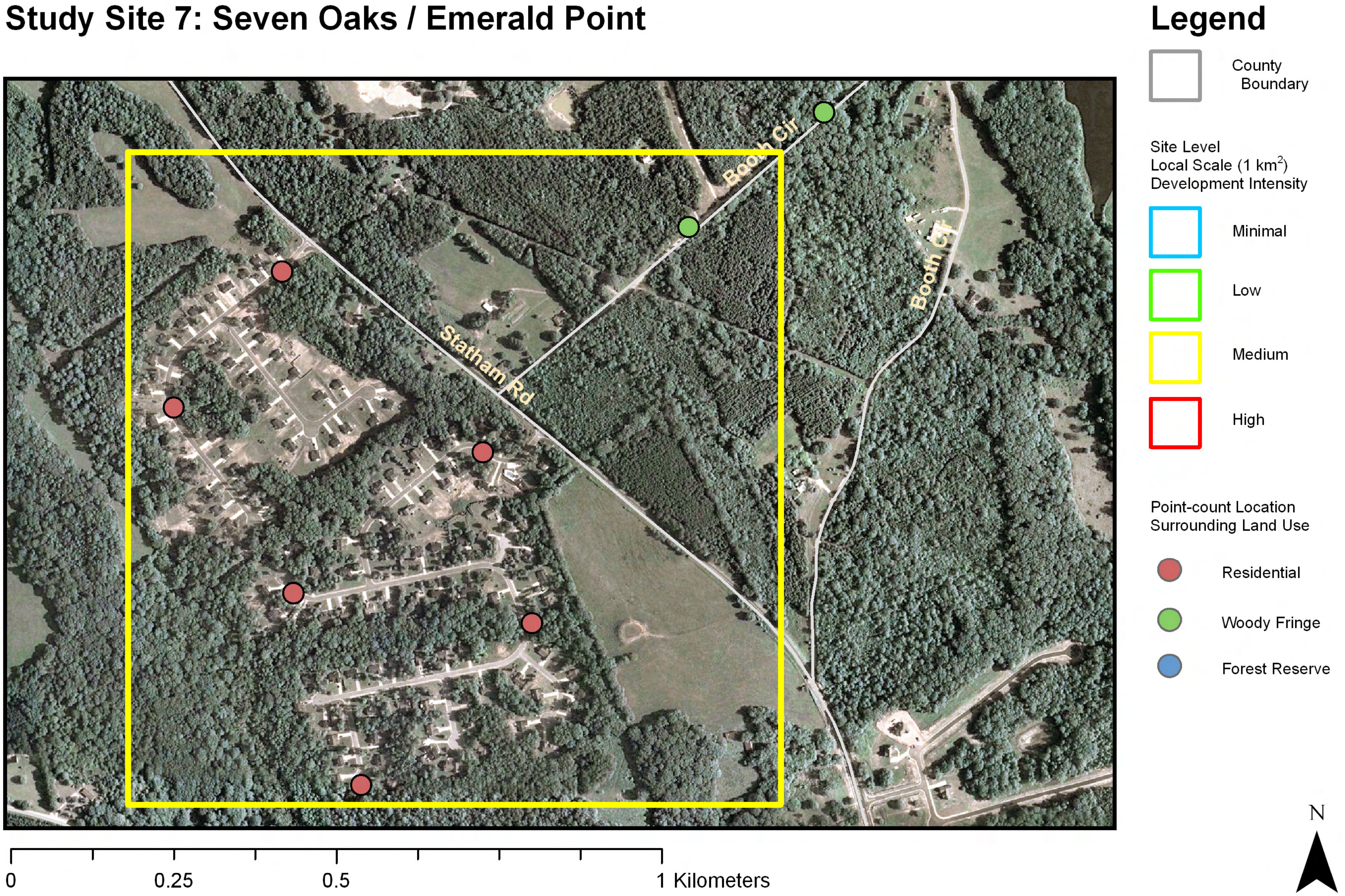


Study Site 5: Old Mill Chase

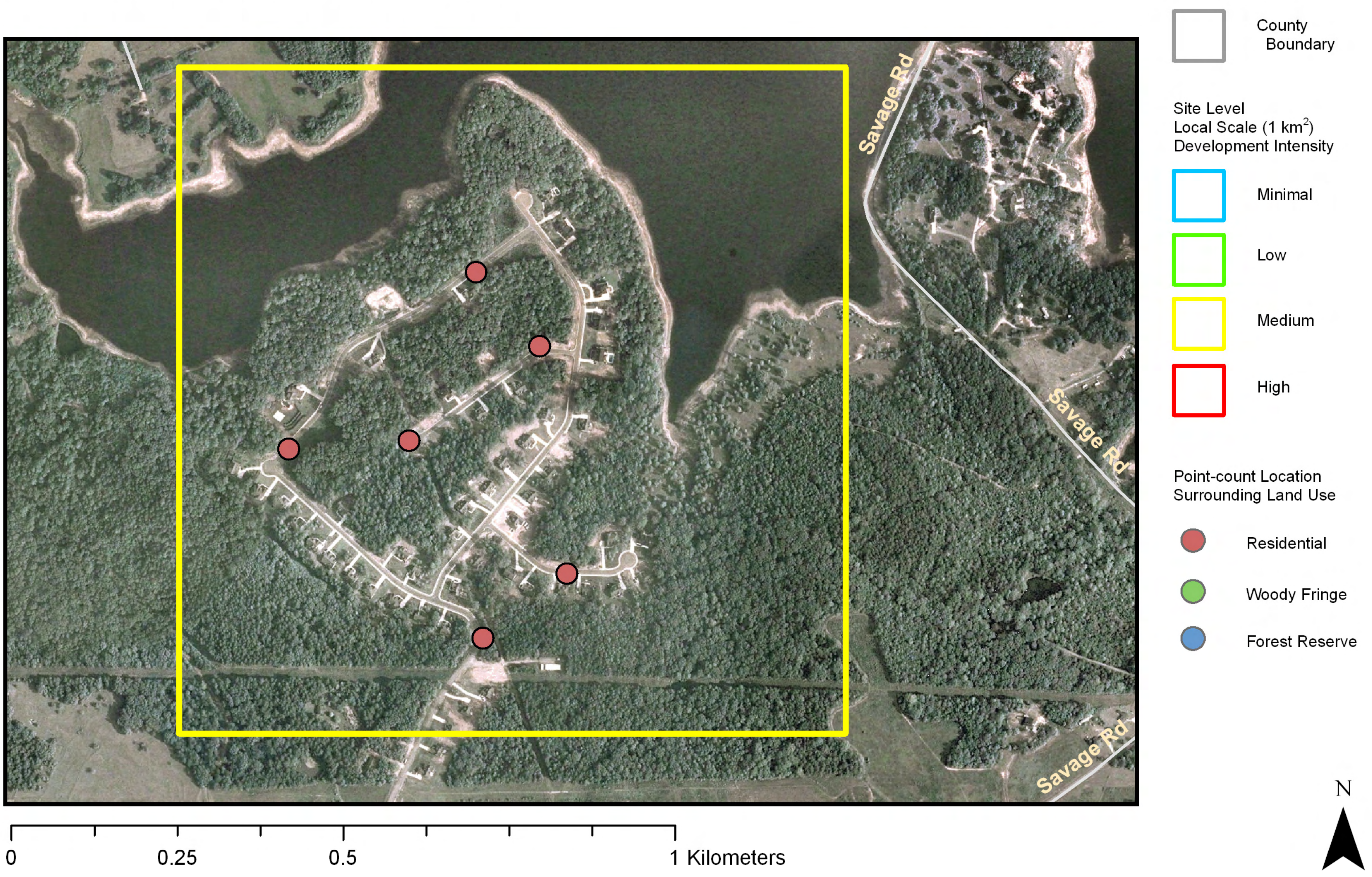
Study Site 6: Red Fox Run



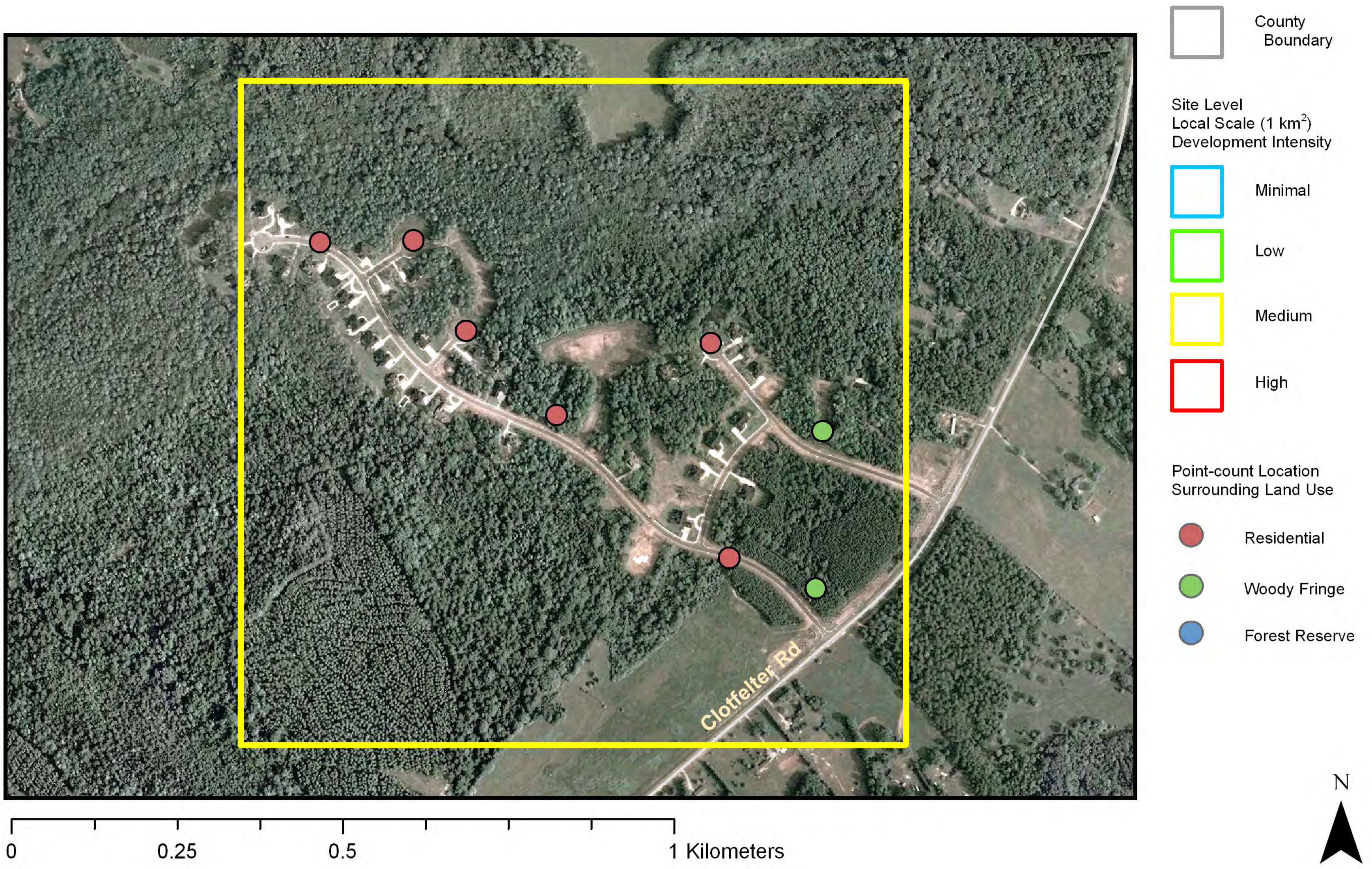
Study Site 7: Seven Oaks / Emerald Point



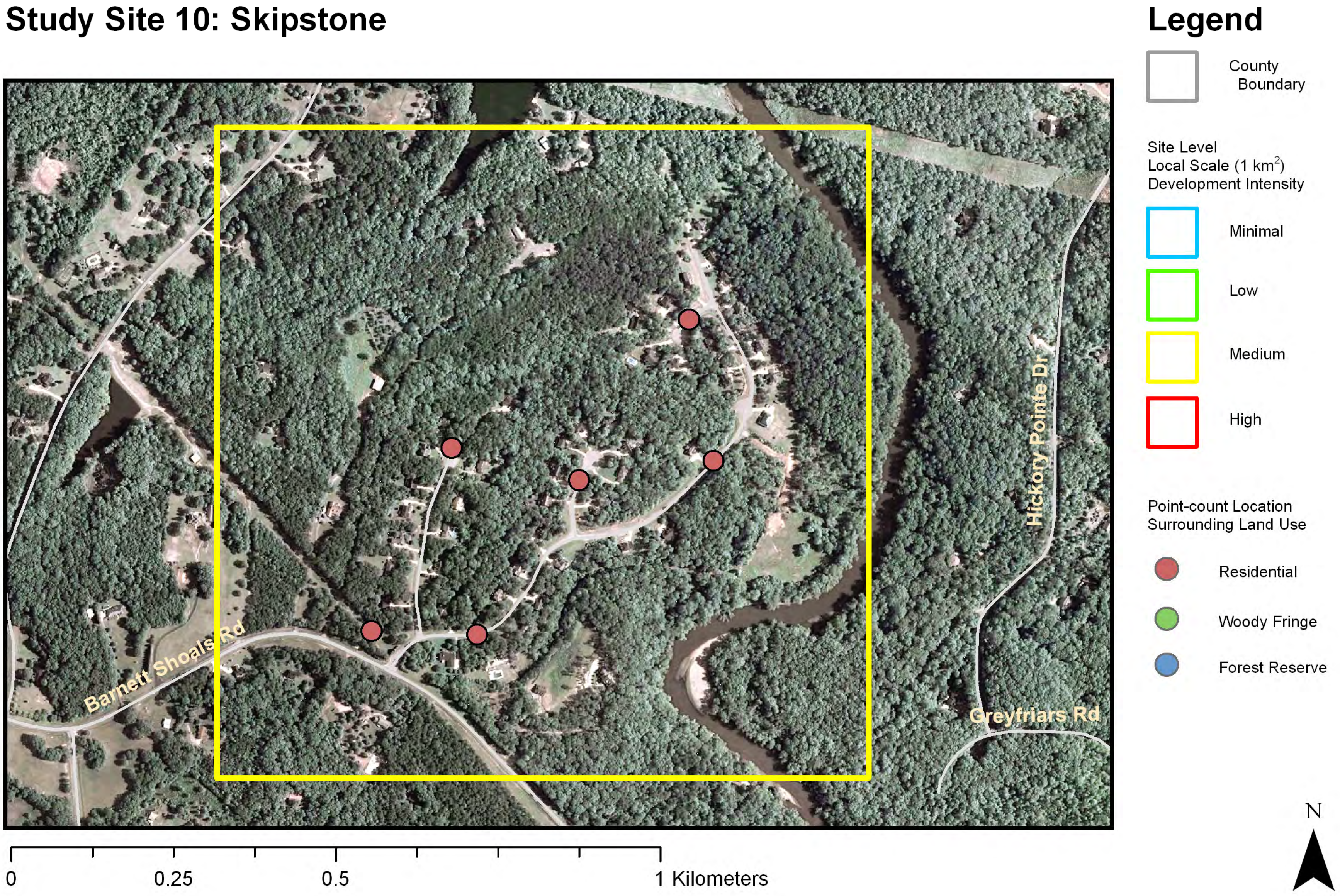
Study Site 8: Bear Creek Estates



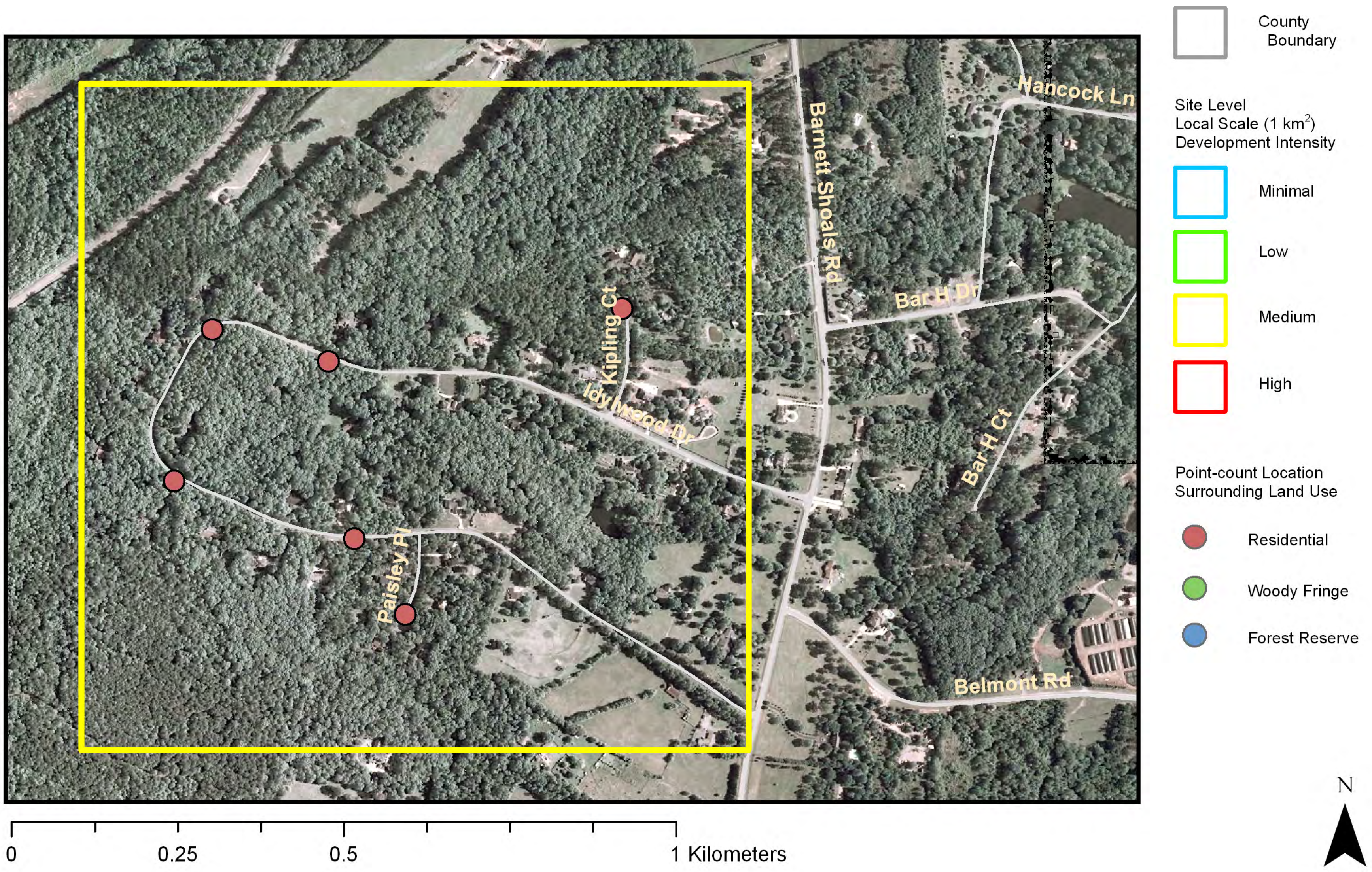
Study Site 9: Somerset



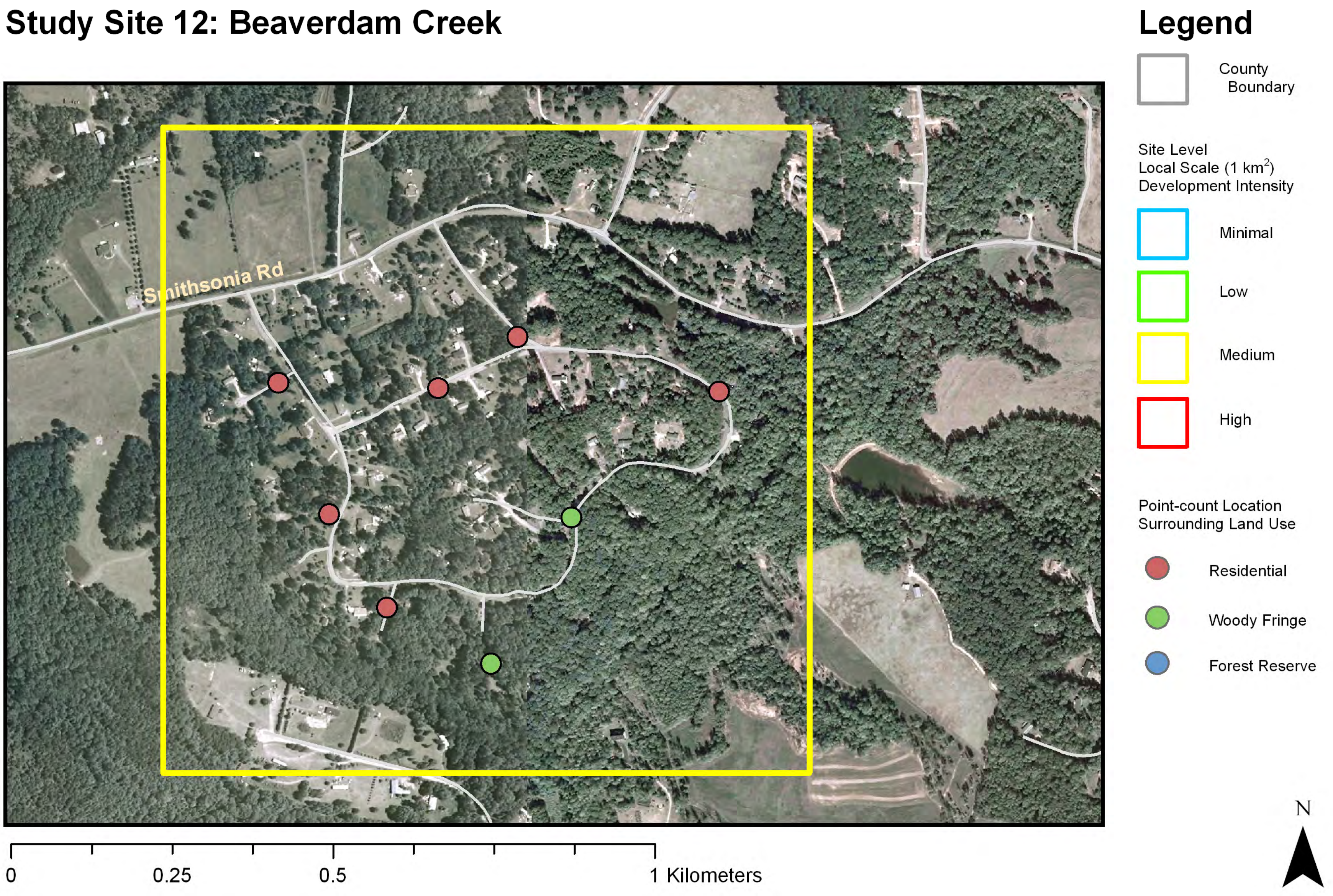
Study Site 10: Skipstone



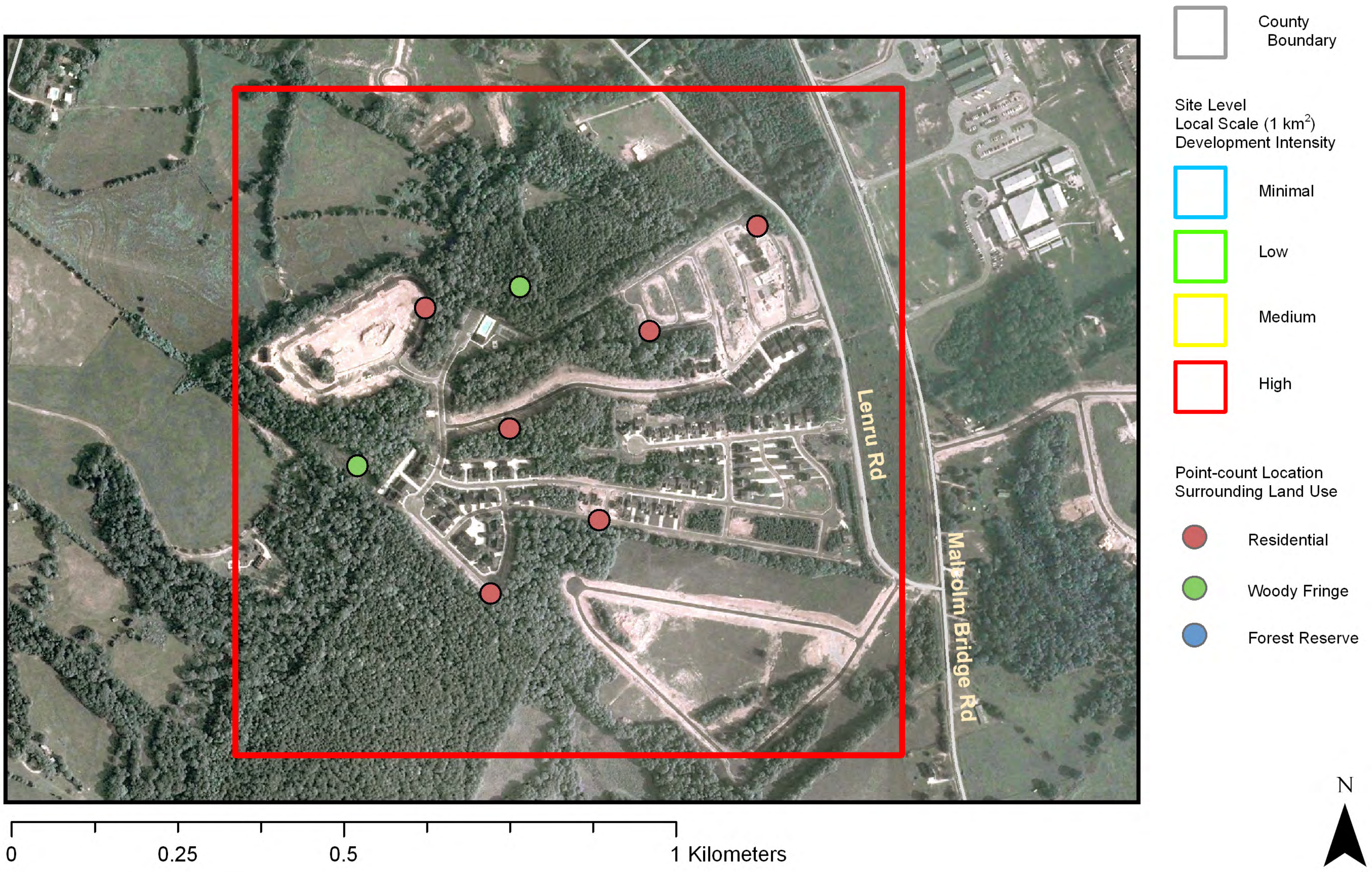
Study Site 11: Idylwood



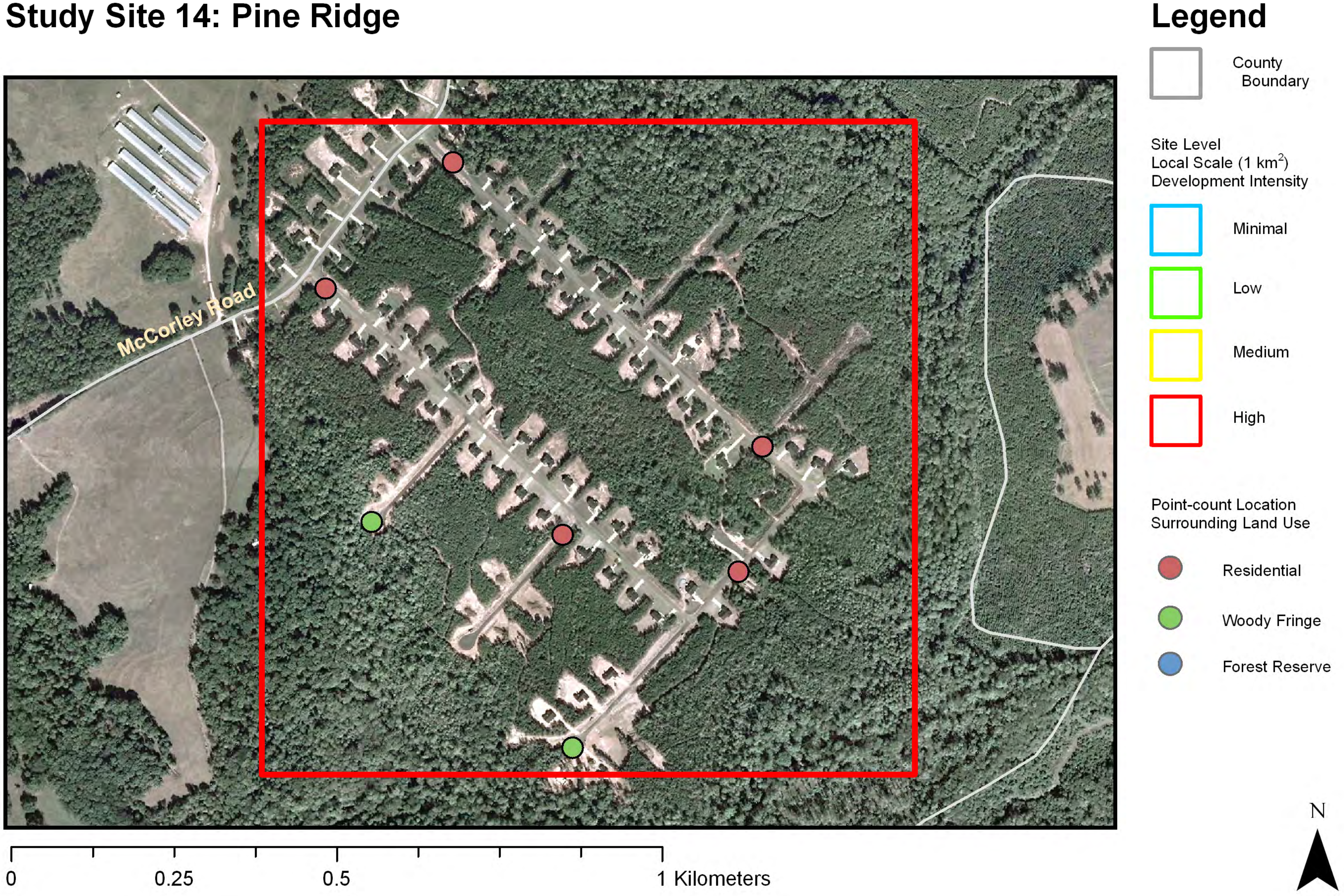
Study Site 12: Beaverdam Creek



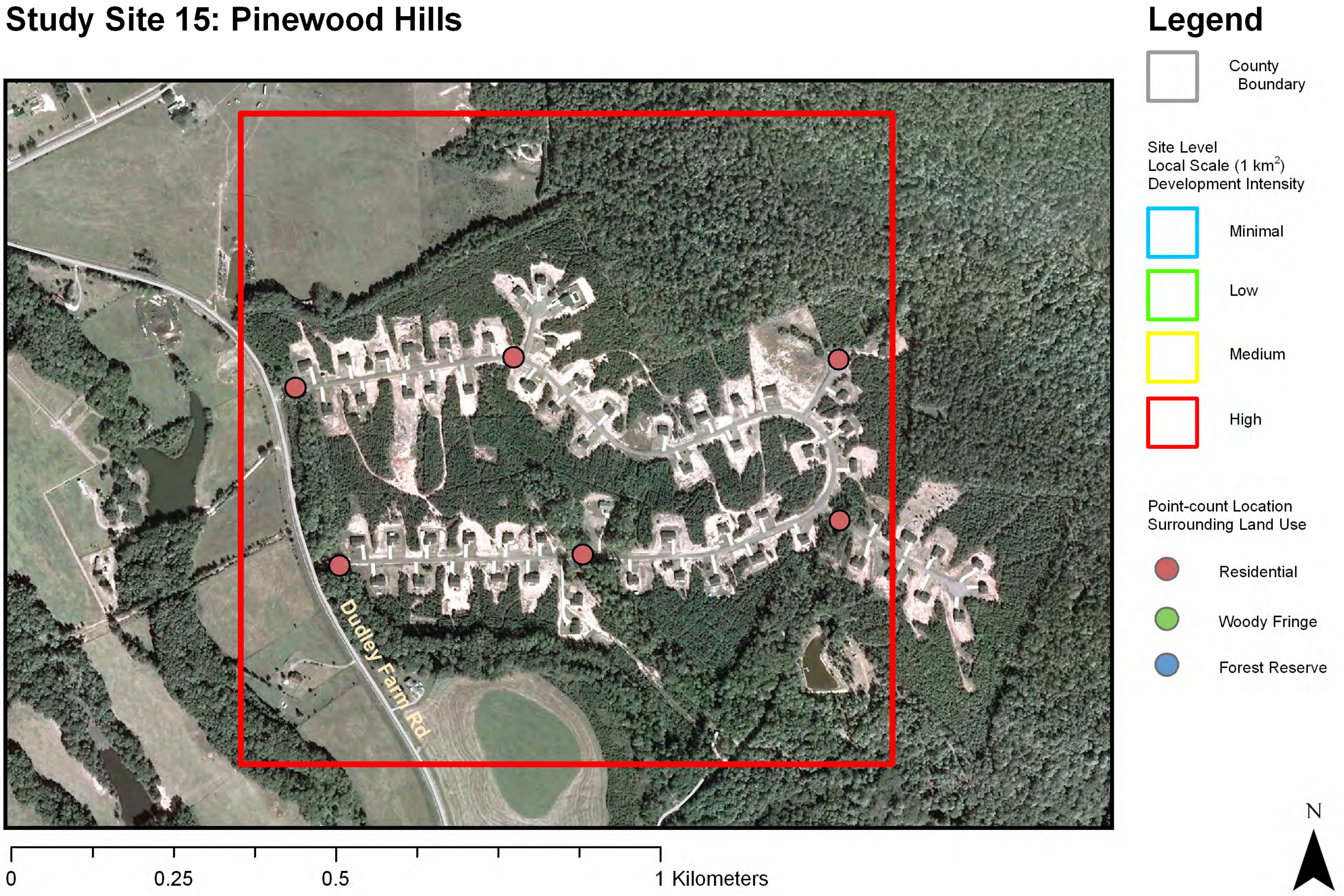
Study Site 13: Triple Creek



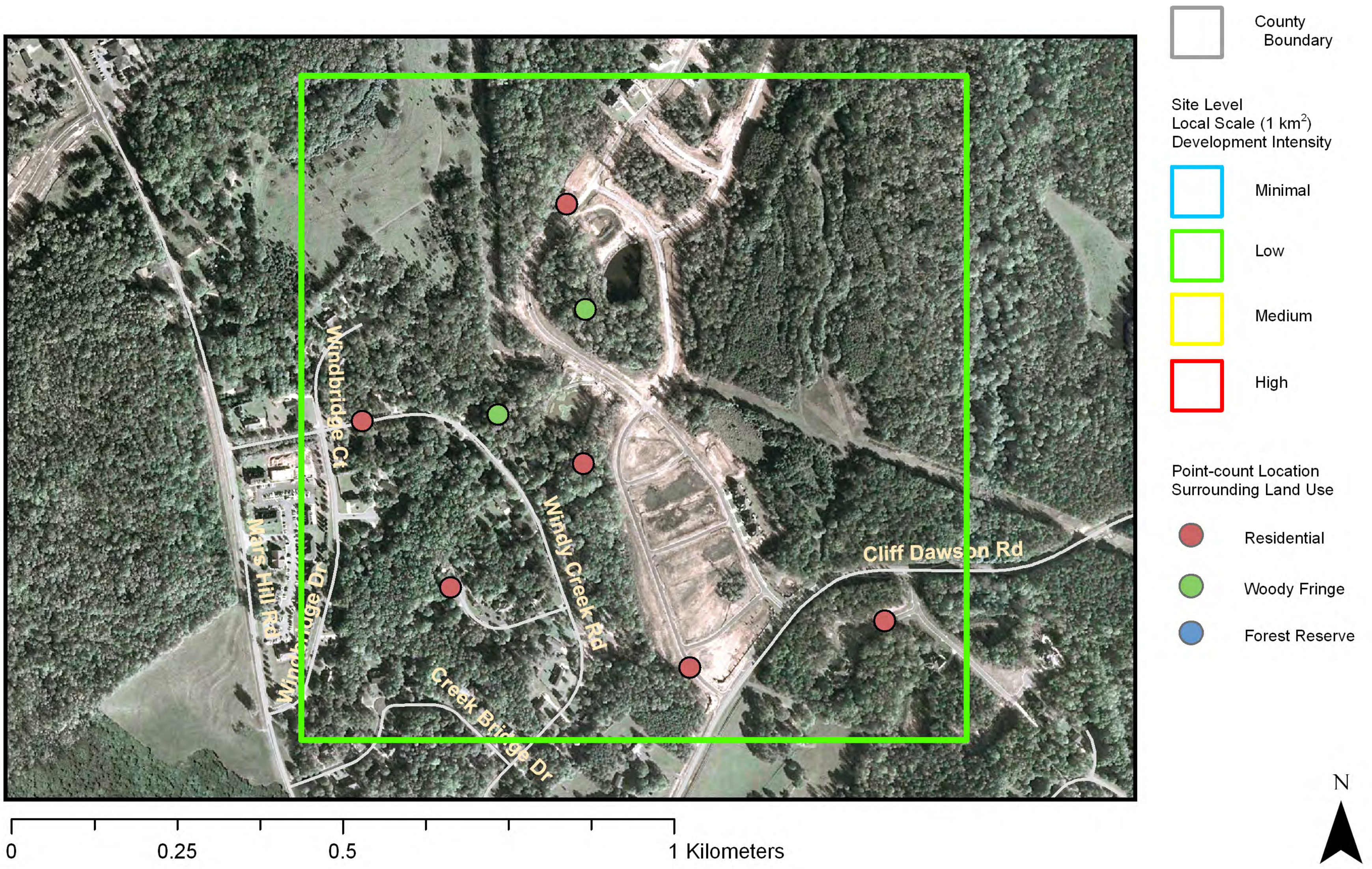
Study Site 14: Pine Ridge



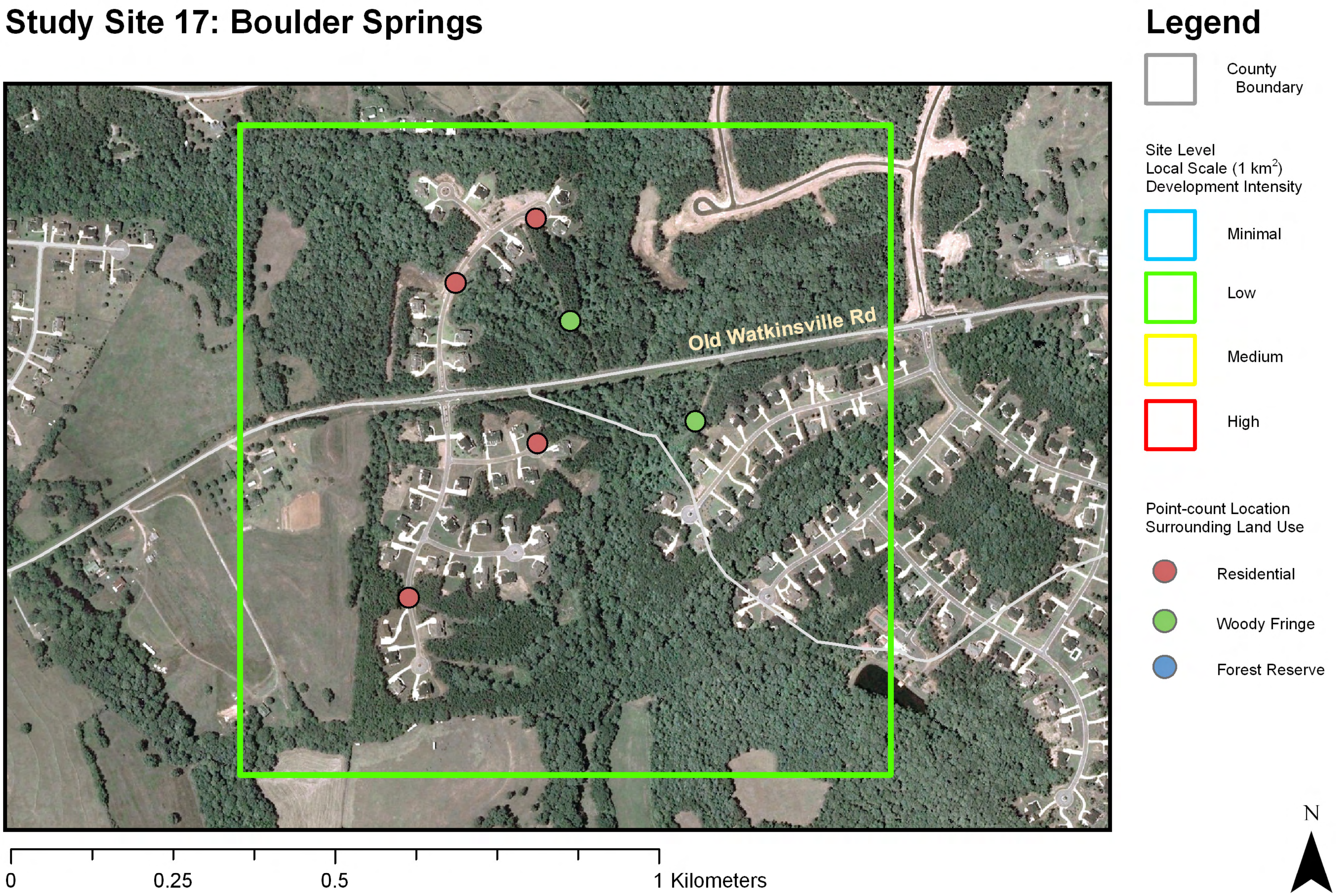
Study Site 15: Pinewood Hills



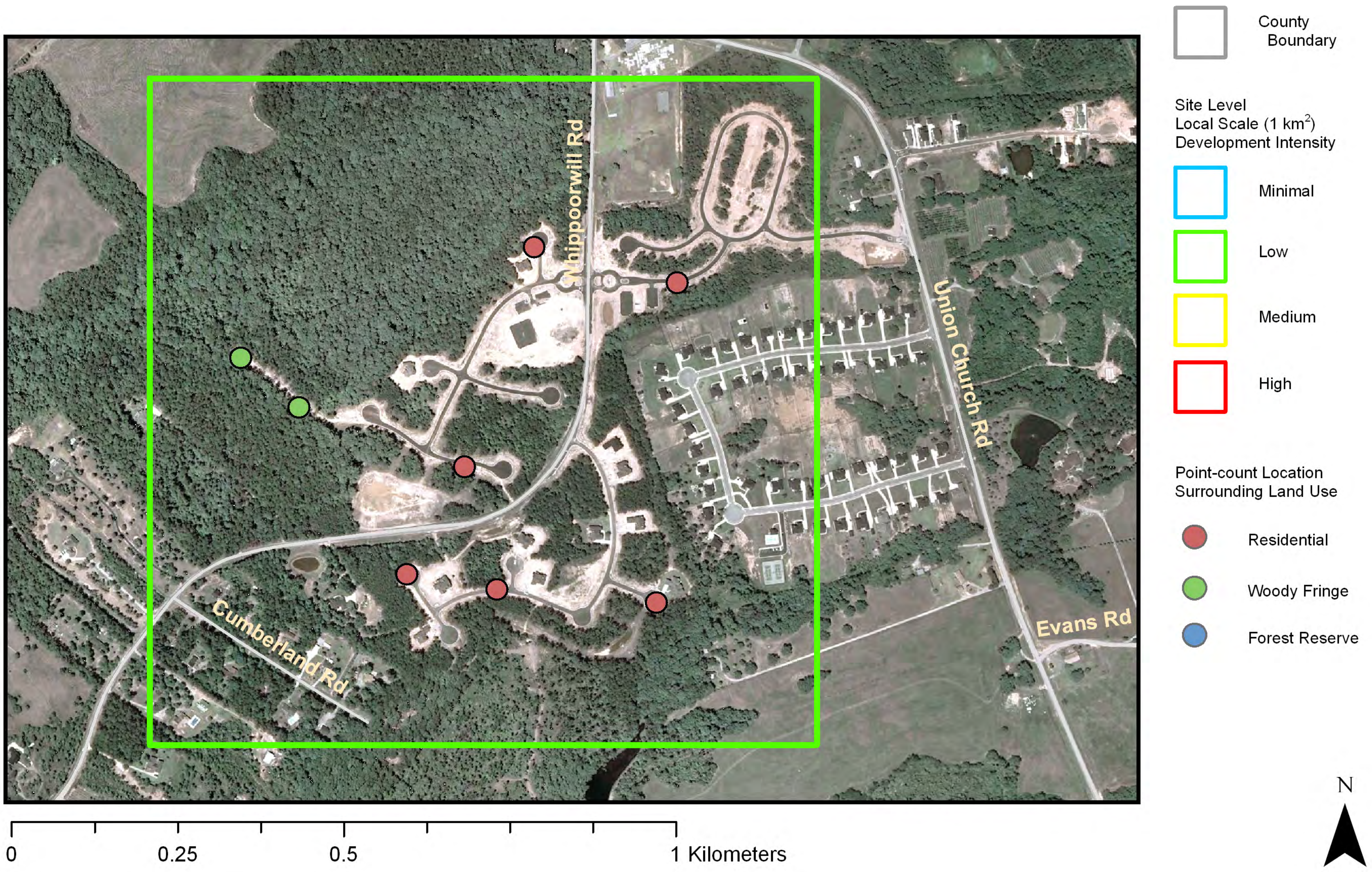
Study Site 16: Meadow Springs



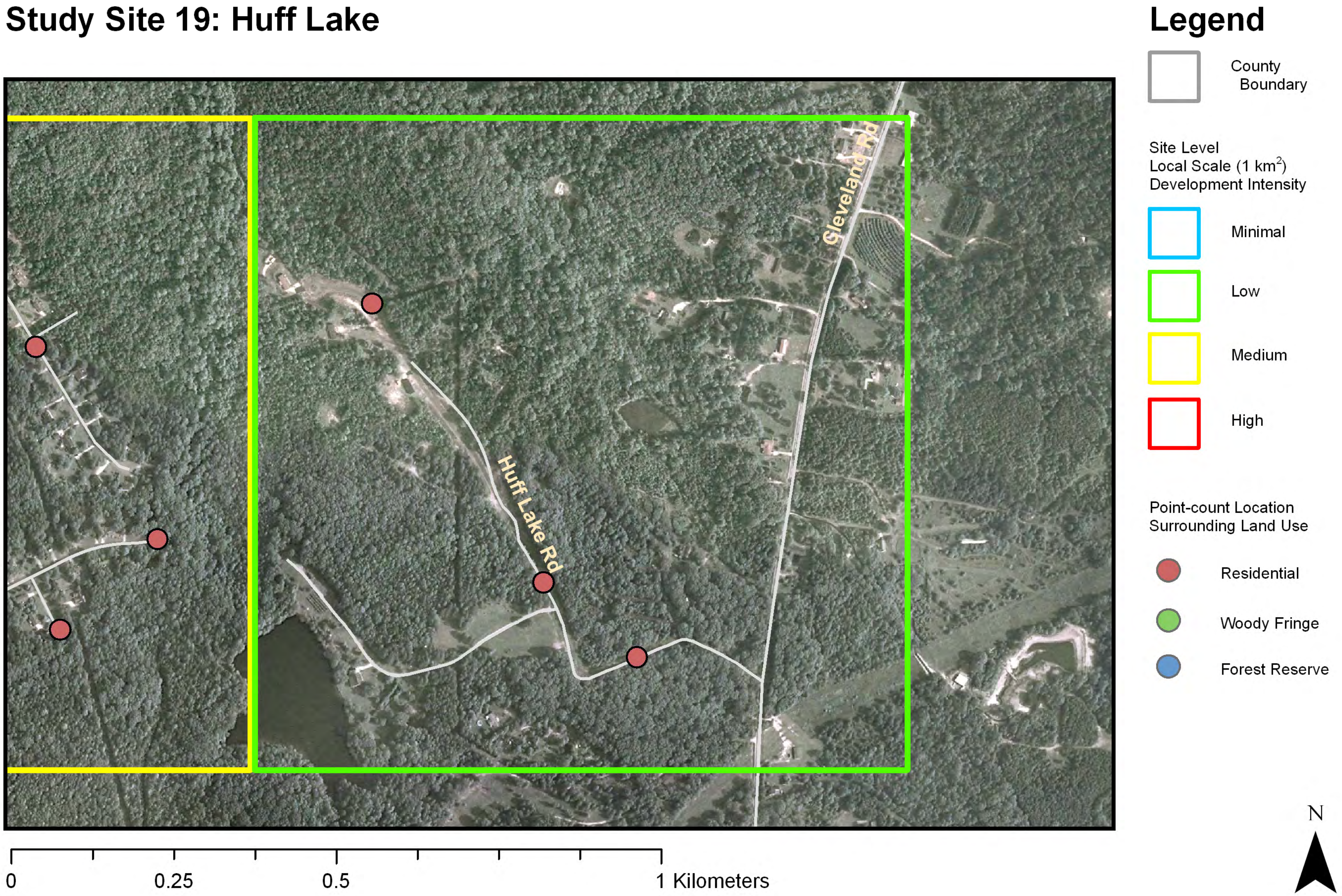
Study Site 17: Boulder Springs



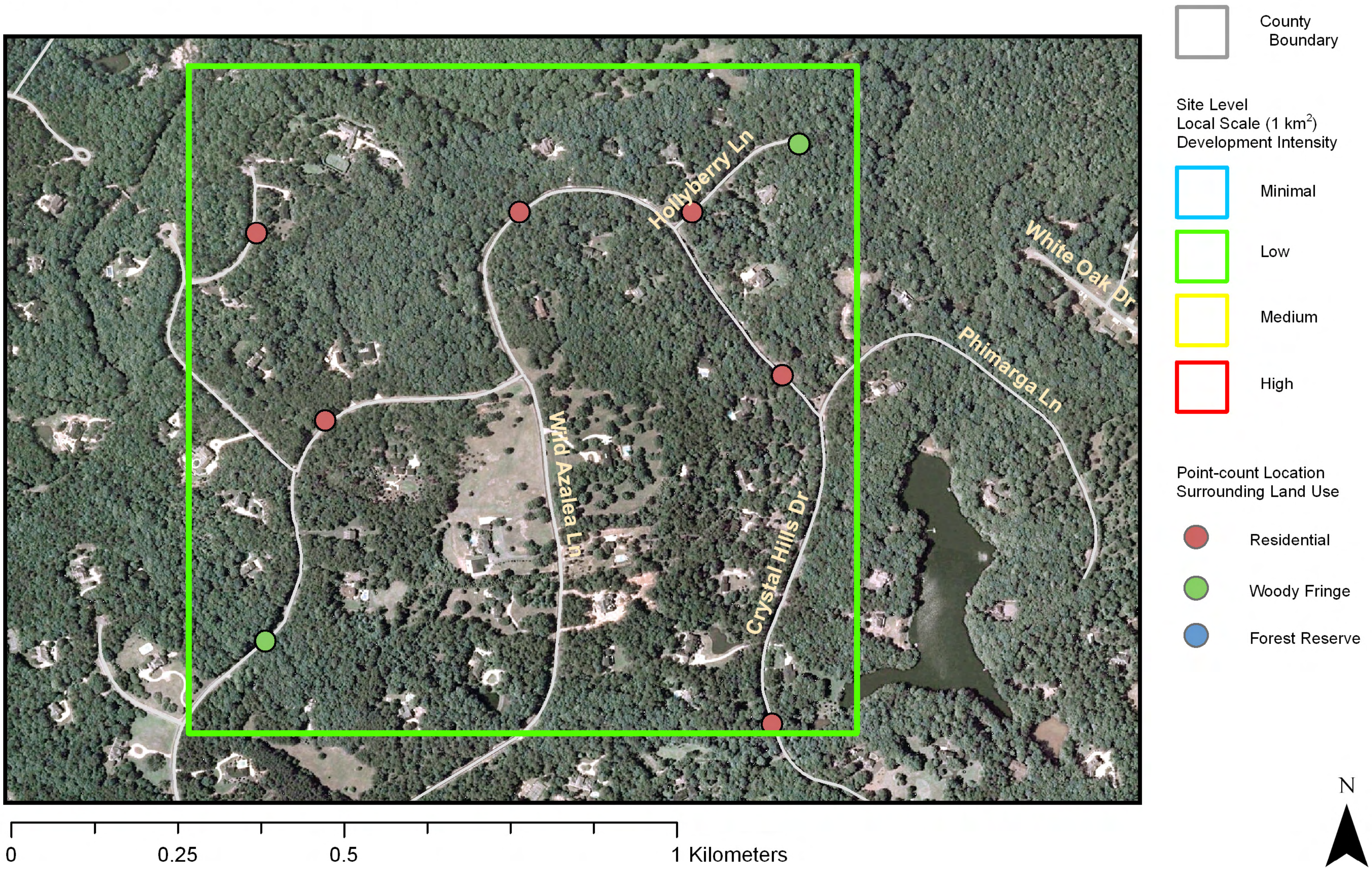
Study Site 18: Coldwater Creek



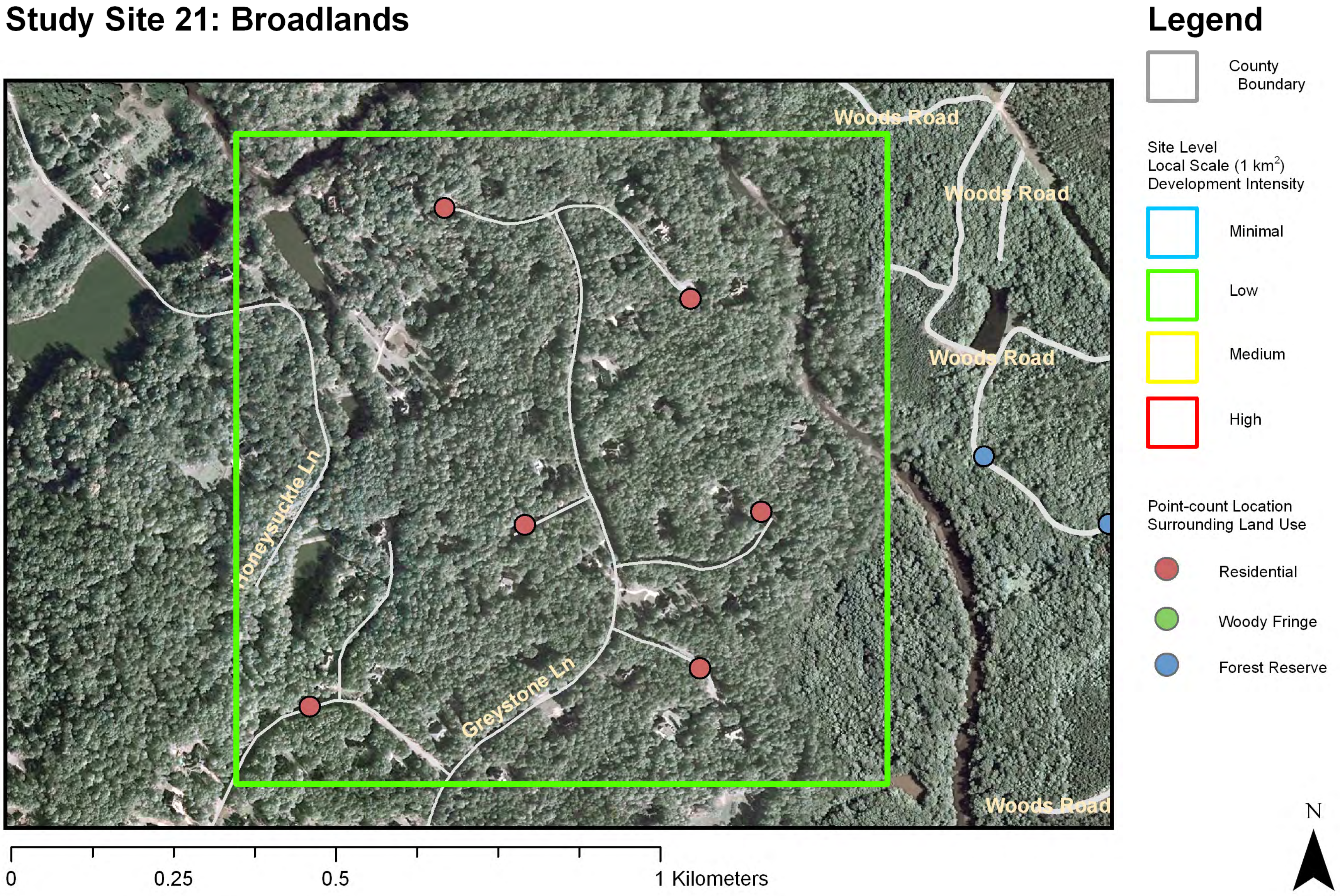
Study Site 19: Huff Lake



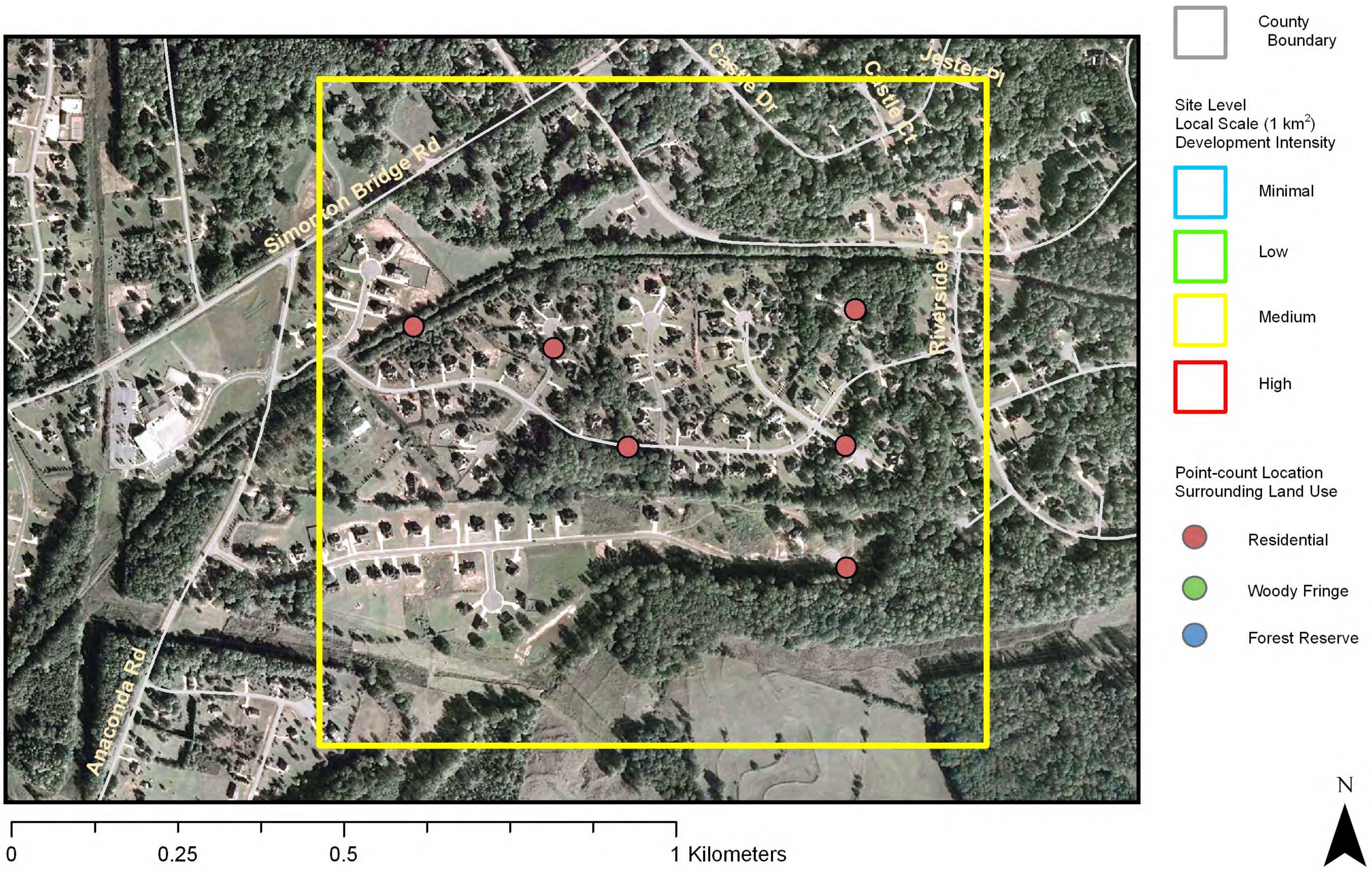
Study Site 20: Crystal Hills



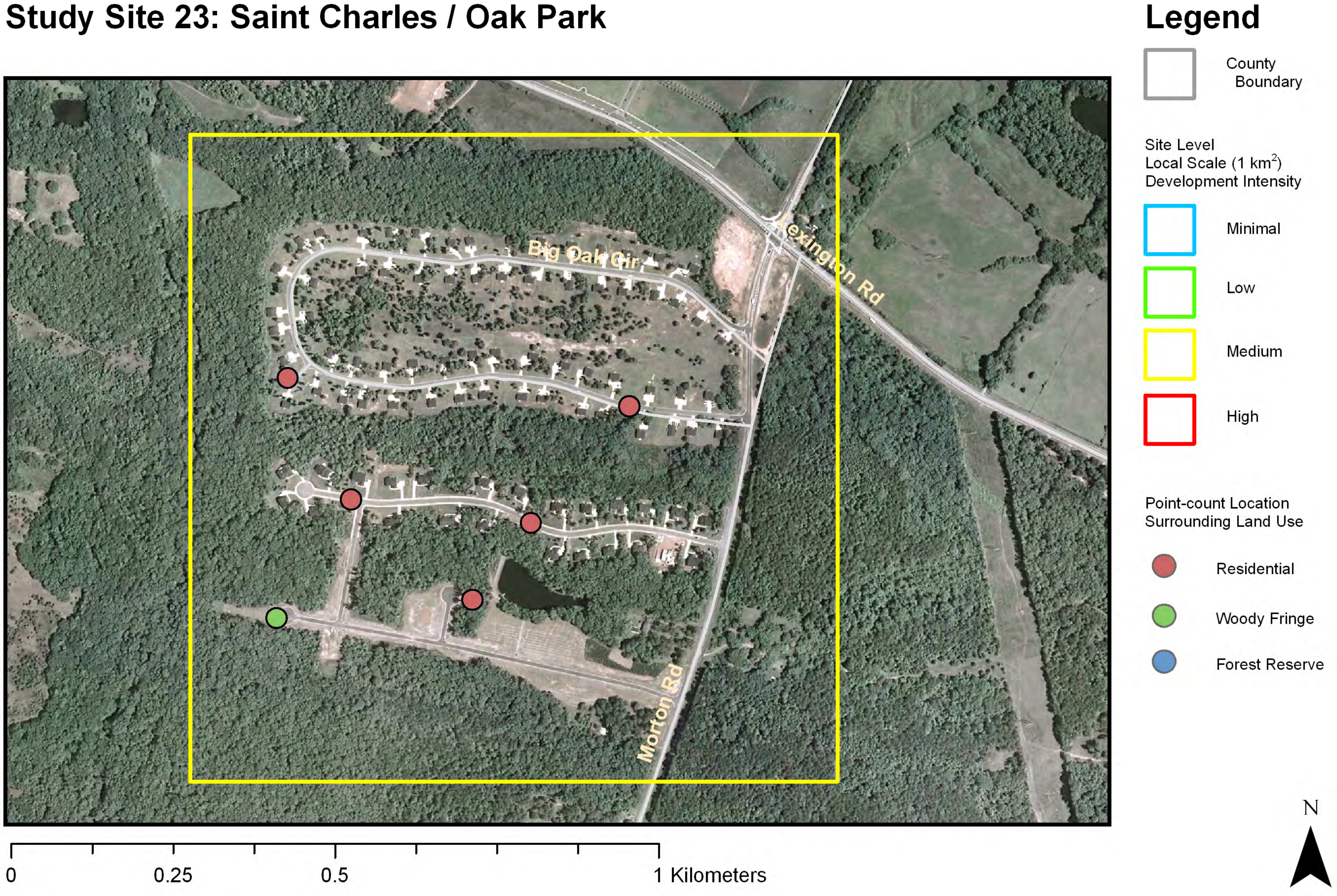
Study Site 21: Broadlands



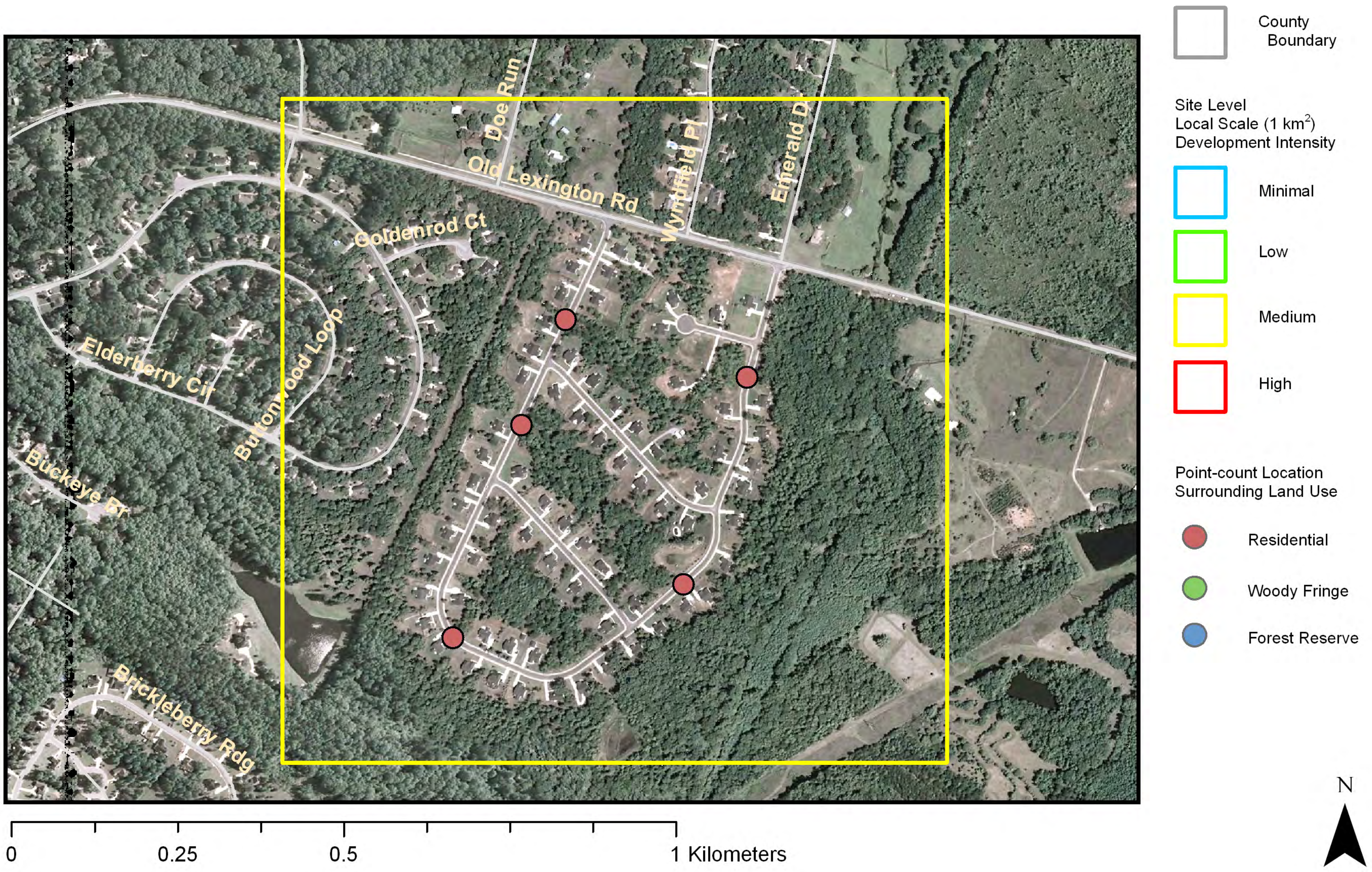
Study Site 22: Victoria Station



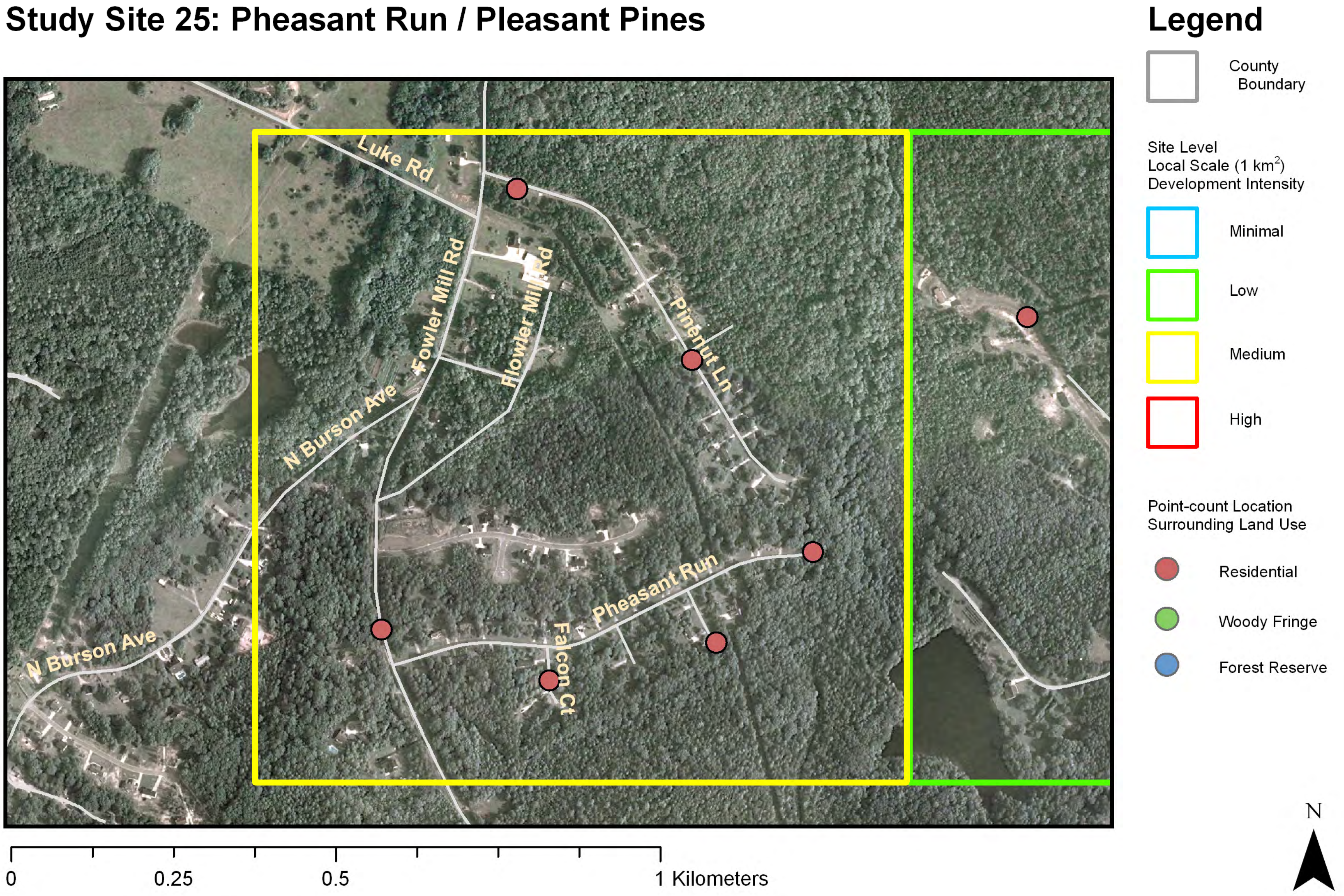
Study Site 23: Saint Charles / Oak Park



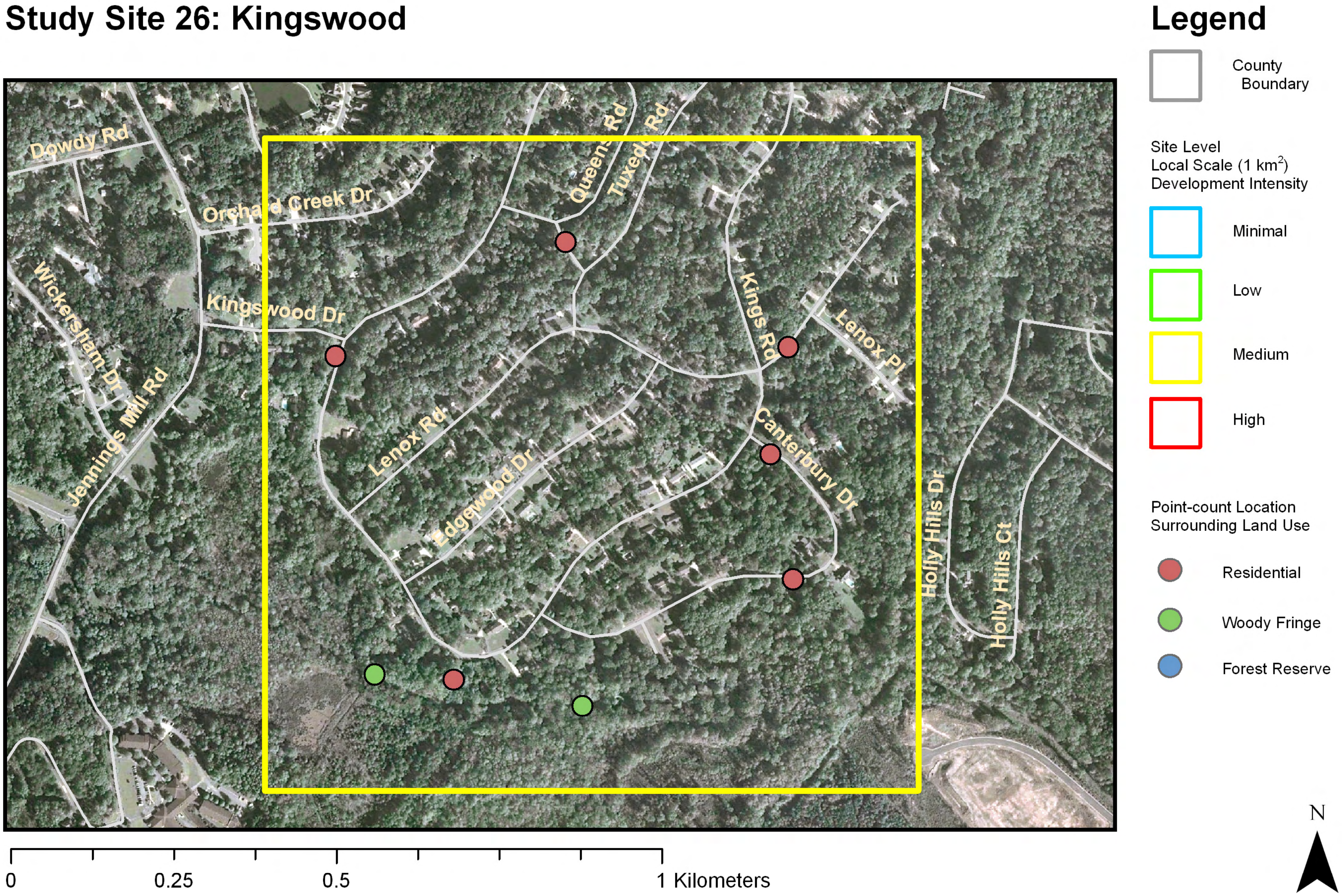
Study Site 24: Old Lexington Trace



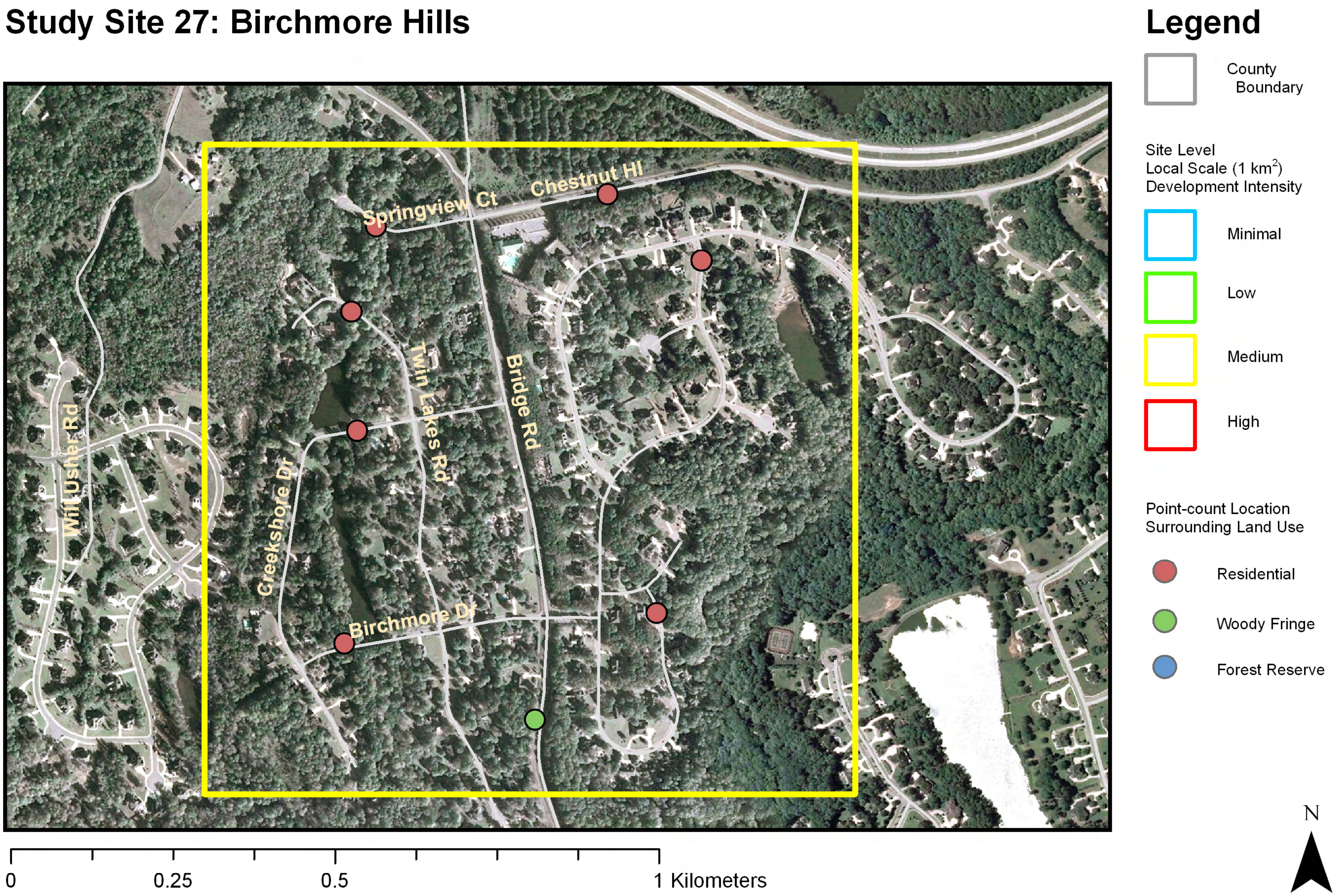
Study Site 25: Pheasant Run / Pleasant Pines



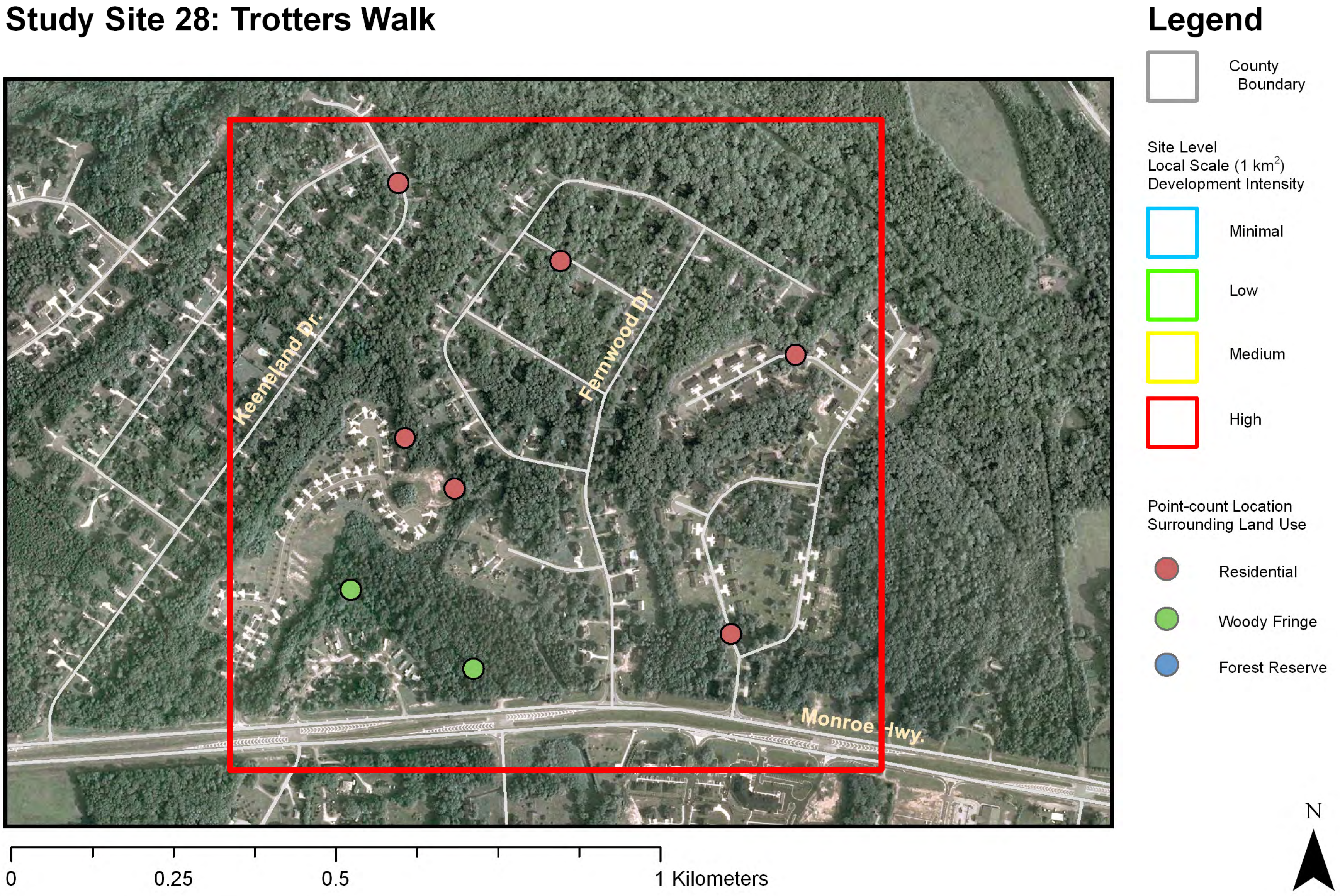
Study Site 26: Kingswood



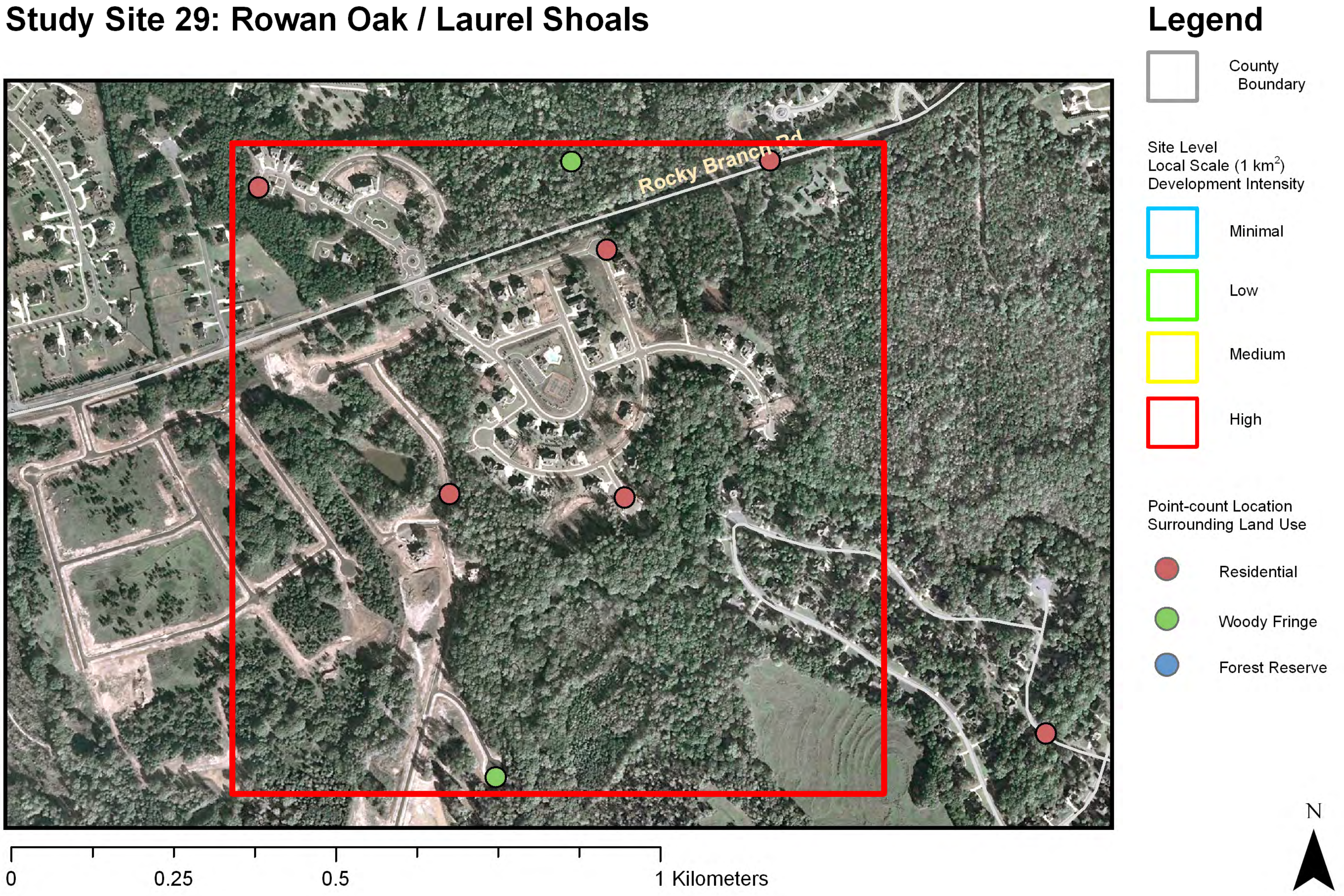
Study Site 27: Birchmore Hills



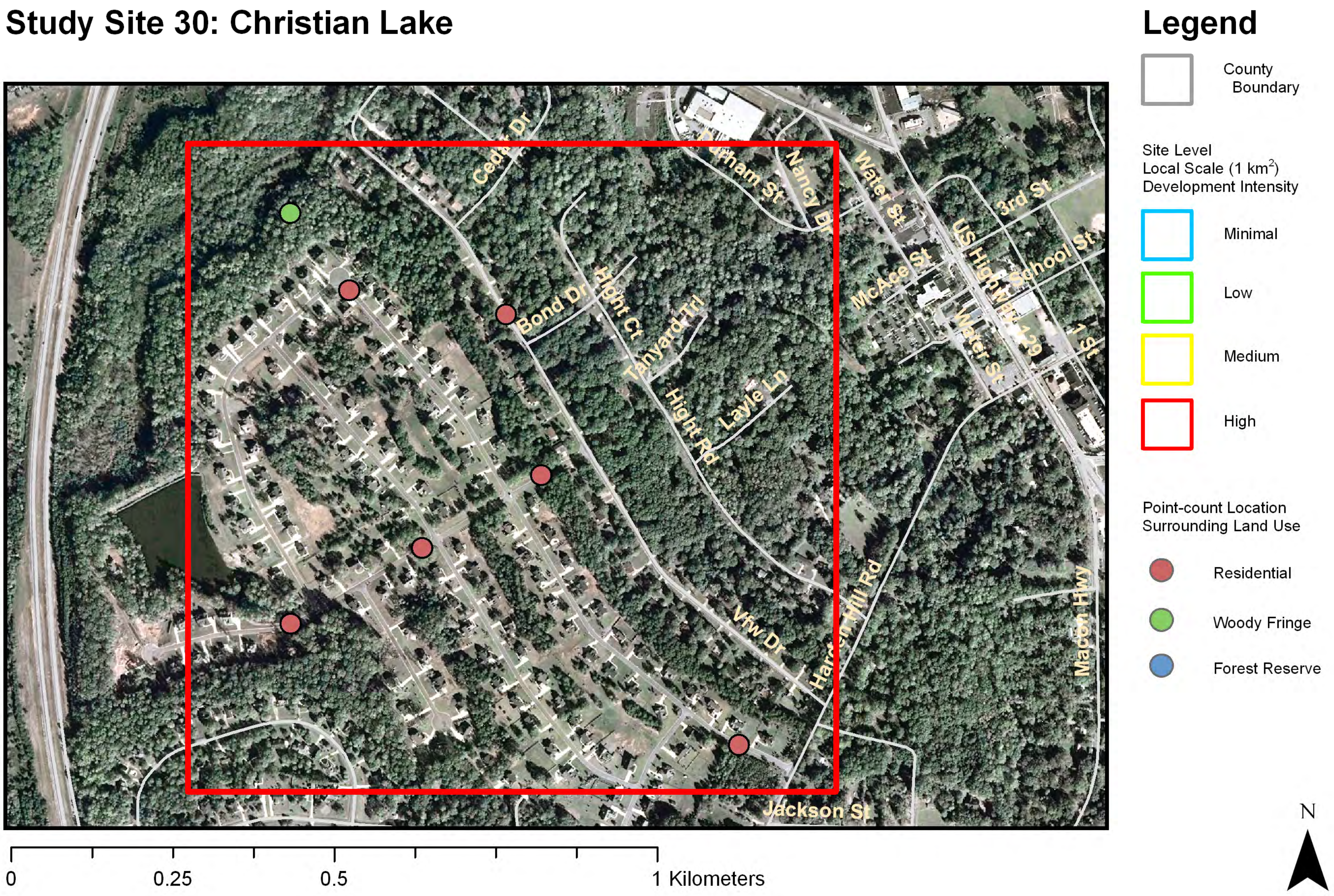
Study Site 28: Trotters Walk



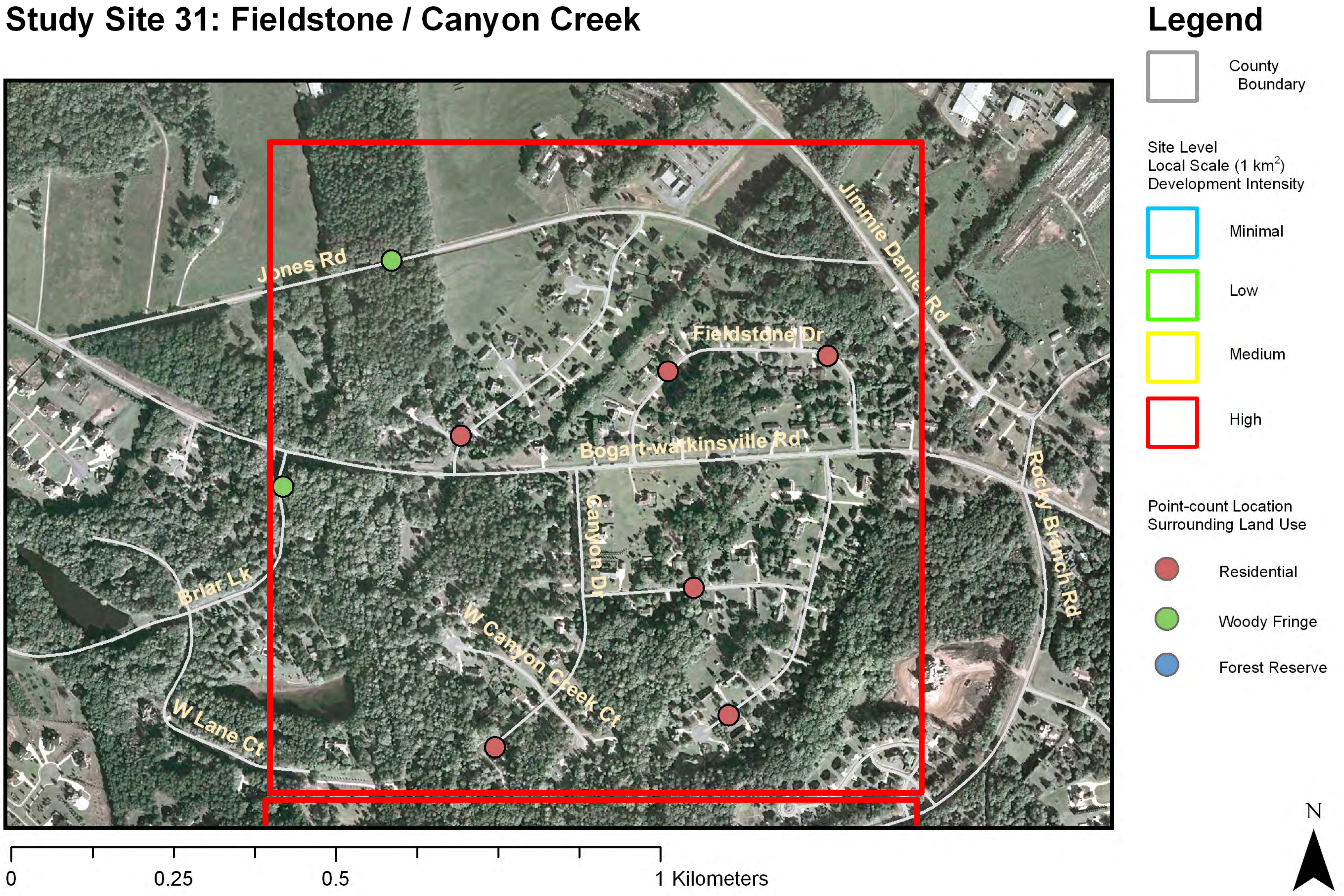
Study Site 29: Rowan Oak / Laurel Shoals



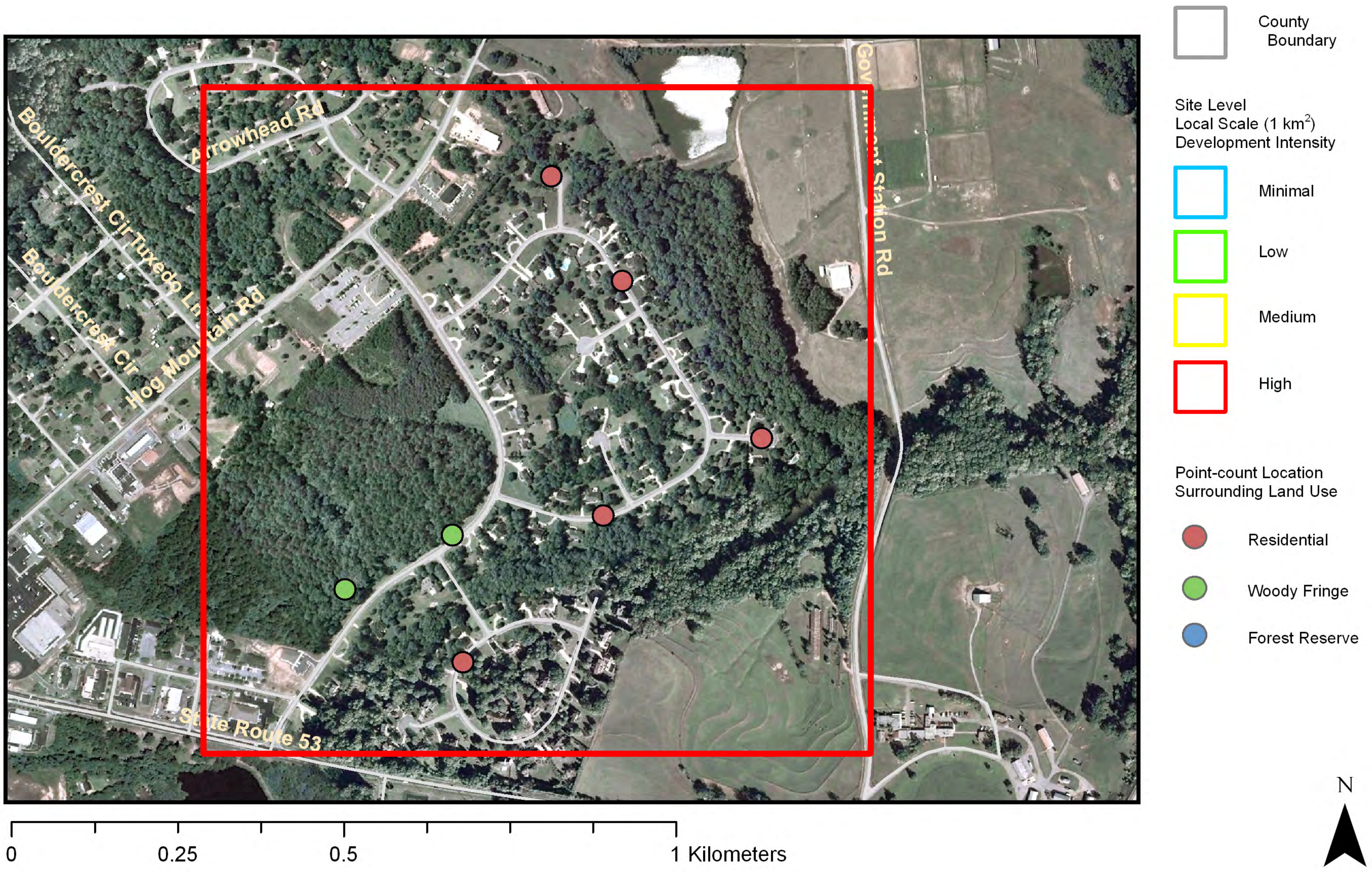
Study Site 30: Christian Lake



Study Site 31: Fieldstone / Canyon Creek

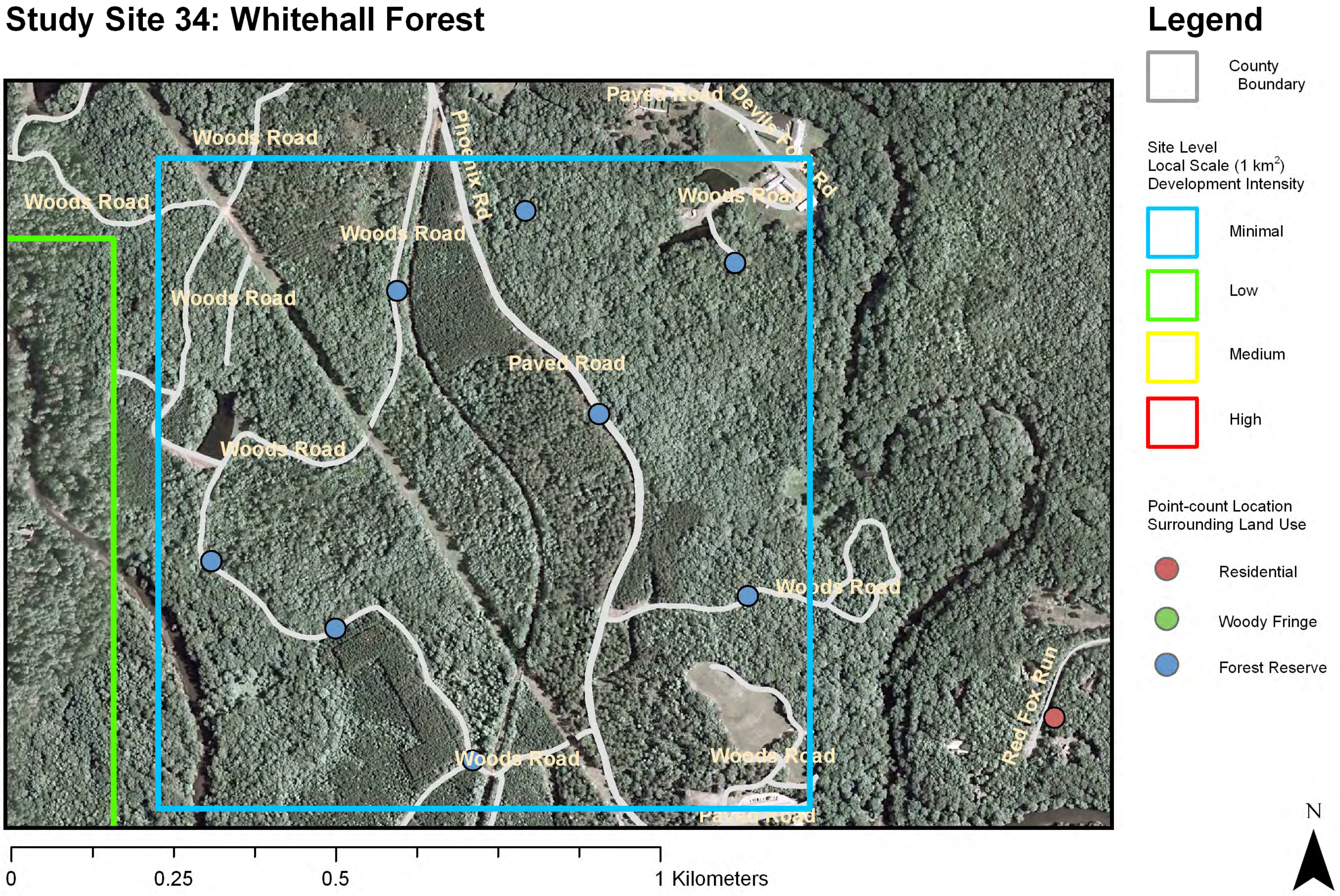


Study Site 32: Daniell Plantation

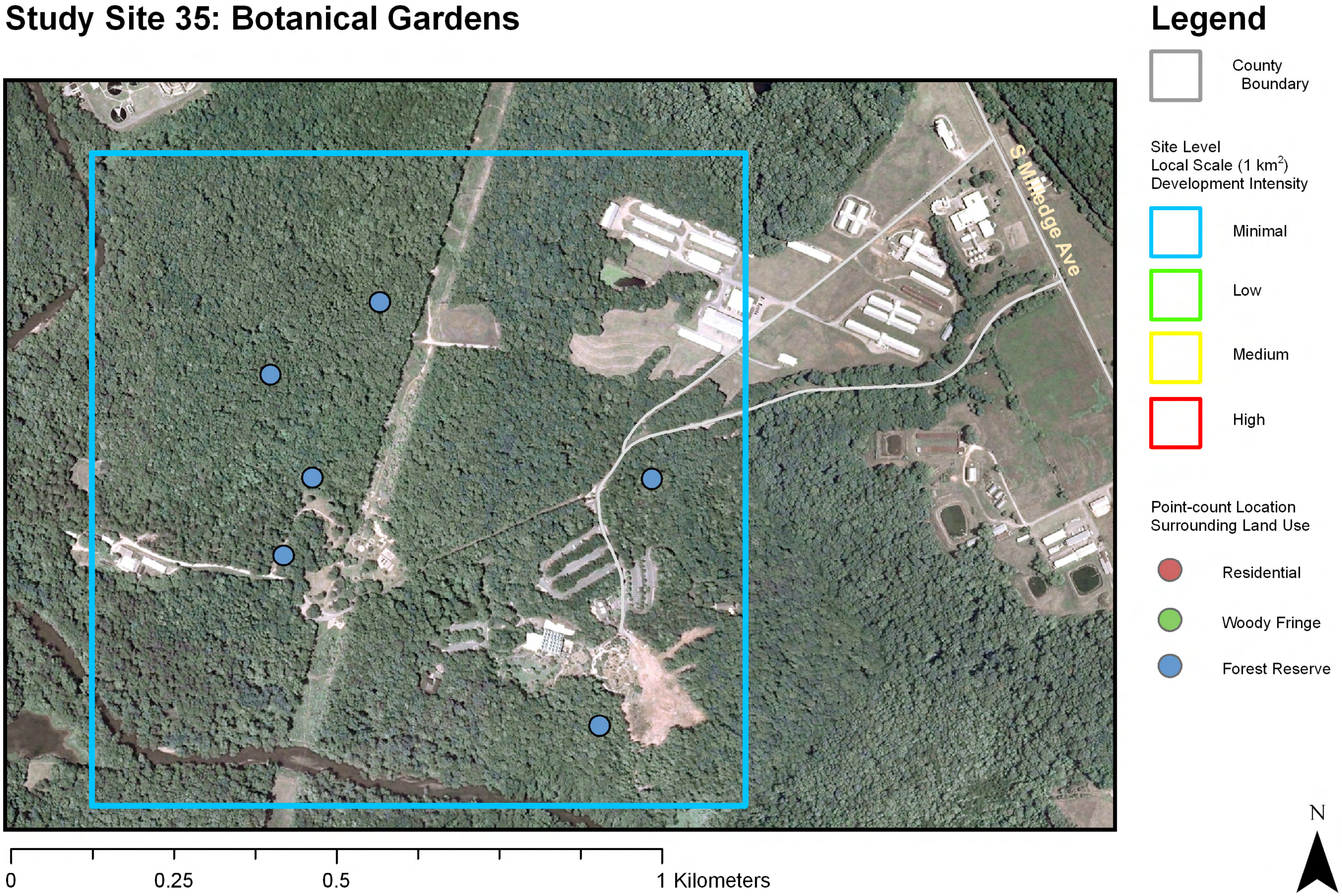


Study Site 33: East Creek Bend

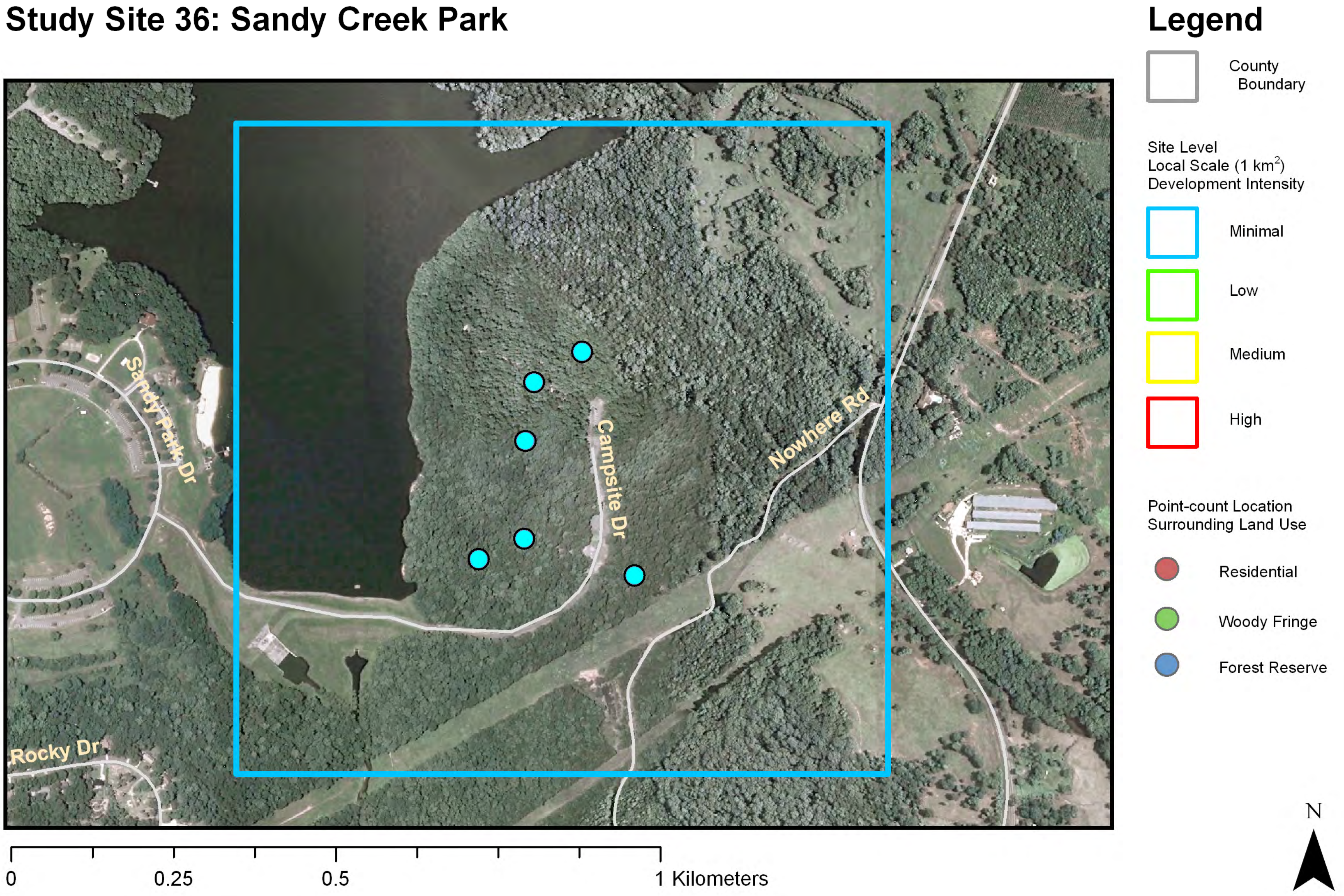
Study Site 34: Whitehall Forest



Study Site 35: Botanical Gardens



Study Site 36: Sandy Creek Park



APPENDIX C

LANDSCAPE CHARACTERISTIC VARIABLE VALUES AND CORRELATIONS

In chapter two, I generated a set of fifteen landscape characteristic variables reflecting aspects of human disturbance, landscape composition, and landscape configuration which may be expected to change with urbanization. Summary statistics for measurements of those 15 variables on study sites are available in chapter two; Table C.1 depicts the values taken on by those variables on each of the thirty-six study sites in this study. Table C.2 is a matrix of all pairwise Pearson correlations between the 15 landscape characteristic variables. See chapter two for more information.

Table C.1: Site-level values for each of the fifteen landscape characteristics measuring levels of human disturbance, landscape composition, and landscape configuration on thirty-six study sites in and around Athens, GA. Variable descriptions and units may be found in chapter two.

Site Number [1]	HNum150m	For100m	Ag1km	For1km	RdDen1km
1	45.000	75.393	6.795	63.453	0.967
2	23.632	56.956	50.413	26.630	1.718
3	16.942	71.199	14.968	45.363	1.486
4	37.082	46.395	21.212	34.986	1.776
5	79.293	79.902	7.714	66.208	1.339
6	121.320	89.861	0.735	81.543	1.961
7	43.811	66.261	8.724	48.944	1.484
8	15.000	55.323	2.479	61.341	0.436
9	4.836	55.206	8.724	51.240	0.556
10	77.740	64.777	4.132	60.147	1.643
11	48.467	86.875	8.632	74.931	0.972
12	20.155	68.731	16.253	38.568	2.997
13	35.700	57.710	34.894	47.107	1.232
14	0.000	50.873	2.571	69.146	0.949
15	25.122	44.417	23.049	33.425	0.857
16	77.376	64.869	10.744	37.006	1.960
17	26.047	55.707	17.355	53.168	1.455
18	57.125	64.627	13.131	55.280	1.342
19	52.000	73.855	6.887	60.882	2.142
20	121.720	87.643	4.683	57.576	1.392
21	112.000	91.398	2.204	71.350	1.097
22	41.240	44.172	51.883	17.998	1.623
23	41.333	47.566	8.356	43.526	1.084
24	165.000	39.608	7.530	35.354	1.827
25	40.247	70.591	2.663	56.566	1.644
26	68.690	87.124	1.102	24.518	3.822
27	36.905	68.377	9.183	16.804	2.718
28	72.140	51.975	10.744	18.366	0.804
29	70.500	62.096	8.999	45.546	1.564
30	44.240	52.335	8.540	25.161	1.957
31	70.165	59.165	16.253	24.610	2.790
32	20.372	53.445	25.069	26.446	2.915
33	78.265	58.270	6.336	26.814	1.049
34	33.535	97.354	10.652	82.645	2.455
35	41.000	86.531	9.275	71.166	2.252
36	1.000	97.239	12.948	53.352	0.430

Site Number [1]	Elev1km	LPI1km	ENN1km	PatchDen1km	ForEdge1km
1	215.127	57.484	88.987	9.183	10680
2	238.455	72.911	91.623	10.203	8130
3	249.280	52.433	80.975	4.081	9630
4	233.967	64.279	120.112	14.284	7740
5	178.422	63.912	75.575	15.305	13230
6	180.444	80.349	91.077	10.203	9900
7	232.940	49.311	73.547	13.264	11820
8	225.834	59.321	134.205	13.264	9570
9	231.531	50.138	145.680	6.122	9960
10	175.719	55.372	93.023	13.264	11310
11	197.656	75.298	107.023	10.203	10170
12	214.684	52.433	75.665	15.305	11490
13	239.841	43.710	128.124	7.142	8250
14	215.113	68.779	148.767	7.142	8250
15	220.470	64.647	102.028	12.244	8010
16	217.280	61.800	77.668	9.183	12630
17	202.985	50.781	95.550	8.162	8760
18	236.510	53.995	125.989	9.183	8910
19	232.193	56.198	80.257	17.345	13170
20	199.646	49.954	73.288	20.406	16170
21	179.820	70.891	63.634	18.366	14490
22	202.369	79.798	97.198	13.264	7530
23	206.723	56.198	77.379	9.183	9540
24	195.049	61.157	78.381	18.366	10890
25	231.403	43.710	72.280	17.345	15450
26	200.166	74.380	106.730	19.386	10020
27	212.685	82.645	97.572	11.223	6780
28	239.603	80.808	93.186	18.366	10290
29	218.066	39.027	87.153	12.244	10740
30	216.390	70.064	75.940	17.345	10260
31	231.709	75.390	81.722	14.284	9870
32	220.463	73.095	77.160	12.244	8460
33	202.383	72.911	103.475	15.305	7500
34	184.243	82.645	145.940	10.203	6390
35	187.339	71.258	122.944	10.203	8730
36	213.980	51.332	95.390	10.203	8190

Site Number [1]	HDen1km	Ag5km	For5km	RdDen5km	Age
1	0.143	11.449	64.072	1.223	1
2	0.236	40.590	36.774	1.730	1
3	0.223	44.430	35.835	1.467	1
4	0.354	43.820	33.666	1.628	0
5	0.264	23.131	61.576	1.165	0
6	0.452	13.389	64.233	1.721	0
7	0.318	41.314	41.916	1.433	1
8	0.179	26.842	50.056	1.350	1
9	0.209	38.284	36.061	1.444	1
10	0.229	16.759	64.502	1.303	0
11	0.321	16.731	60.361	1.642	0
12	0.534	31.460	48.976	1.590	0
13	0.246	30.478	37.893	1.612	1
14	0.086	33.978	46.258	1.437	1
15	0.165	36.161	47.926	1.044	1
16	0.539	21.503	36.459	2.330	1
17	0.294	29.772	50.834	1.382	1
18	0.299	33.669	40.080	1.598	1
19	0.337	9.757	59.669	1.924	0
20	0.353	13.984	37.750	2.937	0
21	0.372	19.000	60.296	1.819	0
22	0.648	26.810	48.786	1.774	1
23	0.413	28.484	41.938	2.087	1
24	0.522	18.911	44.645	2.046	1
25	0.489	13.629	58.288	1.879	0
26	0.832	8.462	24.637	2.952	0
27	0.534	16.960	35.896	2.574	0
28	0.682	32.493	36.452	1.764	1
29	0.417	26.182	34.727	1.970	1
30	0.770	31.805	29.919	2.199	1
31	0.571	21.801	32.317	2.070	0
32	0.596	29.331	30.840	2.421	0
33	0.702	9.316	42.217	2.656	0
34	0.292	15.644	61.809	1.806	0
35	0.333	12.084	45.613	3.193	0
36	0.106	14.827	54.946	1.161	0

[1] *See Appendix B to cross-reference site numbers with site names and locations.*

Table C.2: Matrix of Pearson correlation coefficients for all pairwise combinations of landscape characteristic variables. Definitions of variables may be found in chapter 2

	HDen150m	**HNum150m**	**Other100m**	**For100m**	**Lawn100m**	**Imp100m**	**Dev1km**
HDen150m	1.000	1.000	-0.119	0.144	-0.125	0.033	0.266
HNum150m	1.000	1.000	-0.119	0.144	-0.125	0.033	0.266
Other100m	-0.119	-0.119	1.000	-0.177	-0.075	0.003	-0.028
For100m	0.144	0.144	-0.177	1.000	-0.917	-0.854	-0.241
Lawn100m	-0.125	-0.125	-0.075	-0.917	1.000	0.724	0.237
Imp100m	0.033	0.033	0.003	-0.854	0.724	1.000	0.338
Dev1km	0.266	0.266	-0.028	-0.241	0.237	0.338	1.000
Dev5km	0.309	0.309	-0.057	0.052	-0.049	0.029	0.682
Ag1km	-0.322	-0.322	0.074	-0.402	0.434	0.067	-0.047
Ag5km	-0.443	-0.443	0.277	-0.585	0.526	0.374	-0.071
PctCan1km	0.313	0.313	-0.168	0.688	-0.649	-0.502	-0.376
For1km	0.061	0.061	-0.081	0.605	-0.573	-0.491	-0.750
For5km	0.111	0.111	-0.176	0.440	-0.412	-0.333	-0.588
RdDen1km	0.136	0.136	-0.062	0.157	-0.098	-0.157	0.473
RdDen5km	0.340	0.340	-0.063	0.156	-0.131	-0.093	0.560
HDen1km	0.280	0.280	-0.108	-0.155	0.175	0.253	0.815
HDen5km	0.377	0.377	-0.140	0.149	-0.112	-0.055	0.497
Elev1km	-0.481	-0.481	0.328	-0.440	0.383	0.233	0.207
LPI1km	0.130	0.130	-0.282	0.079	0.031	-0.067	0.292
Pat1km	0.561	0.561	-0.381	0.062	0.017	0.140	0.525
ENN1km	-0.439	-0.439	0.062	-0.059	0.079	-0.033	-0.421
Contagion1km	-0.089	-0.089	-0.149	-0.020	0.119	-0.035	0.236
AggIndex1km	-0.459	-0.459	0.072	-0.302	0.349	0.134	-0.048
PatDen1km	0.561	0.561	-0.381	0.062	0.017	0.140	0.525
ForEdge1km	0.480	0.480	-0.069	0.287	-0.342	-0.103	0.061
Age	-0.198	-0.198	0.476	-0.614	0.512	0.354	-0.149

	Dev5km	Ag1km	Ag5km	PctCan1km	For1km	For5km	RdDen1km
HDen150m	0.309	-0.322	-0.443	0.313	0.061	0.111	0.136
HNum150m	0.309	-0.322	-0.443	0.313	0.061	0.111	0.136
Other100m	-0.057	0.074	0.277	-0.168	-0.081	-0.176	-0.062
For100m	0.052	-0.402	-0.585	0.688	0.605	0.440	0.157
Lawn100m	-0.049	0.434	0.526	-0.649	-0.573	-0.412	-0.098
Imp100m	0.029	0.067	0.374	-0.502	-0.491	-0.333	-0.157
Dev1km	0.682	-0.047	-0.071	-0.376	-0.750	-0.588	0.473
Dev5km	1.000	-0.140	-0.431	-0.096	-0.481	-0.611	0.556
Ag1km	-0.140	1.000	0.456	-0.676	-0.463	-0.247	0.047
Ag5km	-0.431	0.456	1.000	-0.553	-0.296	-0.432	-0.233
PctCan1km	-0.096	-0.676	-0.553	1.000	0.783	0.586	-0.028
For1km	-0.481	-0.463	-0.296	0.783	1.000	0.731	-0.295
For5km	-0.611	-0.247	-0.432	0.586	0.731	1.000	-0.304
RdDen1km	0.556	0.047	-0.233	-0.028	-0.295	-0.304	1.000
RdDen5km	0.891	-0.141	-0.445	0.074	-0.278	-0.471	0.559
HDen1km	0.725	-0.015	-0.223	-0.223	-0.645	-0.480	0.537
HDen5km	0.858	-0.179	-0.549	0.112	-0.255	-0.350	0.408
Elev1km	-0.033	0.334	0.599	-0.603	-0.431	-0.525	-0.134
LPI1km	0.217	0.114	-0.201	-0.001	-0.187	-0.015	0.325
Pat1km	0.412	-0.241	-0.370	0.090	-0.239	-0.029	0.276
ENN1km	-0.141	0.046	0.138	0.108	0.248	-0.034	-0.206
Contagion1km	0.182	0.289	-0.091	-0.155	-0.270	-0.107	0.287
AggIndex1km	-0.010	0.423	0.242	-0.388	-0.284	-0.252	0.019
PatDen1km	0.412	-0.241	-0.370	0.090	-0.239	-0.029	0.276
ForEdge1km	0.045	-0.440	-0.259	0.386	0.271	0.231	-0.039
Age	-0.261	0.293	0.595	-0.410	-0.226	-0.288	-0.444

	RdDen5km	HDen1km	HDen5km	Elev1km	LPI1km	Pat1km	ENN1km
HDen150m	0.340	0.280	0.377	-0.481	0.130	0.561	-0.439
HNum150m	0.340	0.280	0.377	-0.481	0.130	0.561	-0.439
Other100m	-0.063	-0.108	-0.140	0.328	-0.282	-0.381	0.062
For100m	0.156	-0.155	0.149	-0.440	0.079	0.062	-0.059
Lawn100m	-0.131	0.175	-0.112	0.383	0.031	0.017	0.079
Imp100m	-0.093	0.253	-0.055	0.233	-0.067	0.140	-0.033
Dev1km	0.560	0.815	0.497	0.207	0.292	0.525	-0.421
Dev5km	0.891	0.725	0.858	-0.033	0.217	0.412	-0.141
Ag1km	-0.141	-0.015	-0.179	0.334	0.114	-0.241	0.046
Ag5km	-0.445	-0.223	-0.549	0.599	-0.201	-0.370	0.138
PctCan1km	0.074	-0.223	0.112	-0.603	-0.001	0.090	0.108
For1km	-0.278	-0.645	-0.255	-0.431	-0.187	-0.239	0.248
For5km	-0.471	-0.480	-0.350	-0.525	-0.015	-0.029	-0.034
RdDen1km	0.559	0.537	0.408	-0.134	0.325	0.276	-0.206
RdDen5km	1.000	0.596	0.902	-0.191	0.304	0.367	-0.133
HDen1km	0.596	1.000	0.621	-0.054	0.436	0.544	-0.281
HDen5km	0.902	0.621	1.000	-0.323	0.323	0.367	-0.055
Elev1km	-0.191	-0.054	-0.323	1.000	-0.328	-0.227	0.082
LPI1km	0.304	0.436	0.323	-0.328	1.000	0.150	0.132
Pat1km	0.367	0.544	0.367	-0.227	0.150	1.000	-0.467
ENN1km	-0.133	-0.281	-0.055	0.082	0.132	-0.467	1.000
Contagion1km	0.221	0.382	0.257	-0.187	0.869	-0.084	0.346
AggIndex1km	-0.052	0.030	0.074	0.103	0.398	-0.485	0.615
PatDen1km	0.367	0.544	0.367	-0.227	0.150	1.000	-0.467
ForEdge1km	0.076	-0.019	-0.043	-0.122	-0.413	0.522	-0.603
Age	-0.346	-0.139	-0.350	0.460	-0.284	-0.395	0.145

	Contagion1km	AggIndex1km	PatDen1km	ForEdge1km	Age
HDen150m	-0.089	-0.459	0.561	0.480	-0.198
HNum150m	-0.089	-0.459	0.561	0.480	-0.198
Other100m	-0.149	0.072	-0.381	-0.069	0.476
For100m	-0.020	-0.302	0.062	0.287	-0.614
Lawn100m	0.119	0.349	0.017	-0.342	0.512
Imp100m	-0.035	0.134	0.140	-0.103	0.354
Dev1km	0.236	-0.048	0.525	0.061	-0.149
Dev5km	0.182	-0.010	0.412	0.045	-0.261
Ag1km	0.289	0.423	-0.241	-0.440	0.293
Ag5km	-0.091	0.242	-0.370	-0.259	0.595
PctCan1km	-0.155	-0.388	0.090	0.386	-0.410
For1km	-0.270	-0.284	-0.239	0.271	-0.226
For5km	-0.107	-0.252	-0.029	0.231	-0.288
RdDen1km	0.287	0.019	0.276	-0.039	-0.444
RdDen5km	0.221	-0.052	0.367	0.076	-0.346
HDen1km	0.382	0.030	0.544	-0.019	-0.139
HDen5km	0.257	0.074	0.367	-0.043	-0.350
Elev1km	-0.187	0.103	-0.227	-0.122	0.460
LPI1km	0.869	0.398	0.150	-0.413	-0.284
Pat1km	-0.084	-0.485	1.000	0.522	-0.395
ENN1km	0.346	0.615	-0.467	-0.603	0.145
Contagion1km	1.000	0.712	-0.084	-0.720	-0.142
AggIndex1km	0.712	1.000	-0.485	-0.992	0.185
PatDen1km	-0.084	-0.485	1.000	0.522	-0.395
ForEdge1km	-0.720	-0.992	0.522	1.000	-0.184
Age	-0.142	0.185	-0.395	-0.184	1.000

APPENDIX D

AVIAN FUNCTIONAL GUILD ASSIGNMENTS FOR SPECIES USED IN ANALYSES

Table D.1: Bird species detected during point-counts were separated into subsets based on functional guilds of (a) dominant breeding strategy, (b) migration strategy, and (c) synanthropic status. Functional guild groupings were used as a way to group species by commonalities in their response to landscape composition and configuration.

	Functional Guild		
Common Name	**Dominant Breeding Habitat [1]**	**Migration Strategy [2]**	**Synanthropic Status [3]**
Mourning Dove	F	P	S
Yellow-billed Cuckoo	F	N	S
Ruby-throated Hummingbird	F	N	S
Red-headed Woodpecker	F	P	N
Red-bellied Woodpecker	F	R	S
Downy Woodpecker	F	R	S
Hairy Woodpecker	F	R	S
Northern Flicker	F	P	S
Pileated Woodpecker	F	R	N
Eastern Wood-Pewee	F	N	N
Acadian Flycatcher	F	N	N
Eastern Phoebe	E	P	S
Great Crested Flycatcher	E	N	N
White-eyed Vireo	F	N	N
Yellow-throated Vireo	F	N	N
Red-eyed Vireo	F	N	S
Blue Jay	F	P	S
American Crow	U	P	S
Carolina Chickadee	F	R	S
Tufted Titmouse	F	R	S
White-breasted Nuthatch	F	R	S
Brown-headed Nuthatch	F	R	N
Carolina Wren	F	R	N
House Wren	U	P	S
Blue-gray Gnatcatcher	F	N	N
Eastern Bluebird	E	P	S
Wood Thrush	F	N	N
American Robin	U	P	S
Gray Catbird	F	N	S
Northern Mockingbird	U	R	S
Brown Thrasher	F	P	N
European Starling	U	P	S

	Functional Guild		
Common Name	Dominant Breeding Habitat [1]	Migration Strategy [2]	Synanthropic Status [3]
Northern Parula	F	N	N
Pine Warbler	F	P	N
Prairie Warbler	E	N	N
Black-and-white Warbler	F	N	N
Hooded Warbler	F	N	N
Summer Tanager	F	N	N
Scarlet Tanager	F	N	N
Eastern Towhee	E	P	N
Chipping Sparrow	F	N	N
Field Sparrow	E	P	N
Song Sparrow	E	P	S
Northern Cardinal	F	R	S
Blue Grosbeak	E	N	N
Indigo Bunting	E	N	N
Common Grackle	U	P	S
Brown-headed Cowbird	E	P	S
House Finch	U	P	S
American Goldfinch	F	P	S

[1] *Dominant Breeding Habitat Guild Categories:*
F*: forested habitat* ***E****: early successional / field habitat* ***U****: urban habitat*

[2] *Migratory Strategy Guild Categories:*
N*: neotropical migration* ***R****: permanent residence* ***P:*** *partial migration*

[3] *Synanthropic Status Categories:*
N*: non-synanthropic species* ***S****: synanthropic species*

APPENDIX E

BIRD SPECIES OBSERVED DURING STUDY

Table E.1: The following bird species were observed during point-count surveys in residential developments in the greater-Athens, Georgia, USA area during the 2007 and 2008 breeding season (mid-May through July 31).

Common Name [1]	**Scientific Name** [1]	**Banding Code** [2]
Canada Goose	*Branta canadensis*	CAGO
Wood Duck	*Aix sponsa*	WODU
Mallard	*Anas platyrhynchos*	MALL
Wild Turkey	*Meleagris gallopavo*	WITU
Great Blue Heron	*Ardea herodias*	GBHE
Green Heron	*Butorides virescens*	GRHE
Black Vulture	*Coragyps atratus*	BLVU
Turkey Vulture	*Cathartes aura*	TUVU
Mississippi Kite	*Ictinia mississippiensis*	MIKI
Cooper's Hawk	*Accipiter cooperii*	COHA
Red-shouldered Hawk	*Buteo lineatus*	RSHA
Broad-winged Hawk	*Buteo platypterus*	BWHA
Red-tailed Hawk	*Buteo jamaicensis*	RTHA
Killdeer	*Charadrius vociferus*	KILL
American Woodcock	*Scolopax minor*	AMWO
Rock Pigeon	*Columba livia*	ROPI
Eurasian Collared-Dove	*Streptopelia decaocto*	EUCD
Mourning Dove [3]	*Zenaida macroura*	MODO
Yellow-billed Cuckoo [3]	*Coccyzus americanus*	YBCU
Chuck-will's-widow	*Caprimulgus carolinensis*	CWWI
Chimney Swift	*Chaetura pelagica*	CHSW
Ruby-throated Hummingbird [3]	*Archilochus colubris*	RTHU
Belted Kingfisher	*Megaceryle alcyon*	BEKI
Red-headed Woodpecker [3]	*Melanerpes erythrocephalus*	RHWO
Red-bellied Woodpecker [3]	*Melanerpes carolinus*	RBWO
Yellow-bellied Sapsucker	*Sphyrapicus varius*	YBSS
Downy Woodpecker [3]	*Picoides pubescens*	DOWO
Hairy Woodpecker [3]	*Picoides villosus*	HAWO
Northern Flicker [3]	*Colaptes auratus*	NOFL
Pileated Woodpecker [3]	*Dryocopus pileatus*	PIWO
Eastern Wood-Pewee [3]	*Contopus virens*	EWPE
Acadian Flycatcher [3]	*Empidonax virescens*	ACFL
Eastern Phoebe [3]	*Sayornis phoebe*	EAPH
Great Crested Flycatcher [3]	*Myiarchus crinitus*	GCFL

Common Name [1]	Scientific Name [1]	Banding Code [2]
Eastern Kingbird	*Tyrannus tyrannus*	EAKI
White-eyed Vireo [3]	*Vireo griseus*	WEVI
Yellow-throated Vireo [3]	*Vireo flavifrons*	YTVI
Red-eyed Vireo [3]	*Vireo olivaceus*	REVI
Blue Jay [3]	*Cyanocitta cristata*	BLJA
American Crow [3]	*Corvus brachyrhynchos*	AMCR
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	NRWS
Cliff Swallow	*Petrochelidon pyrrhonota*	CLSW
Barn Swallow	*Hirundo rustica*	BARS
Carolina Chickadee [3]	*Poecile carolinensis*	CACH
Tufted Titmouse [3]	*Baeolophus bicolor*	TUTI
White-breasted Nuthatch [3]	*Sitta carolinensis*	WBNU
Brown-headed Nuthatch [3]	*Sitta pusilla*	BHNU
Carolina Wren [3]	*Thryothorus ludovicianus*	CARW
House Wren [3]	*Troglodytes aedon*	HOWR
Blue-gray Gnatcatcher [3]	*Polioptila caerulea*	BGGN
Eastern Bluebird [3]	*Sialia sialis*	EABL
Swainson's Thrush	*Catharus ustulatus*	SWTH
Wood Thrush [3]	*Hylocichla mustelina*	WOTH
American Robin [3]	*Turdus migratorius*	AMRO
Gray Catbird [3]	*Dumetella carolinensis*	GRCA
Northern Mockingbird [3]	*Mimus polyglottos*	NOMO
Brown Thrasher [3]	*Toxostoma rufum*	BRTH
European Starling [3]	*Sturnus vulgaris*	EUST
Cedar Waxwing	*Bombycilla cedrorum*	CEDW
Northern Parula [3]	*Parula americana*	NOPA
Yellow-rumped Warbler	*Dendroica coronata*	YRWA
Pine Warbler [3]	*Dendroica pinus*	PIWA
Prairie Warbler [3]	*Dendroica discolor*	PRAW
Black-and-white Warbler[3]	*Mniotilta varia*	BAWW
Worm-eating Warbler	*Helmitheros vermivorum*	WEWA
Ovenbird	*Seiurus aurocapilla*	OVEN
Louisiana Waterthrush	*Seiurus motacilla*	LOWA
Kentucky Warbler	*Oporornis formosus*	KEWA
Common Yellowthroat	*Geothlypis trichas*	COYE
Hooded Warbler [3]	*Wilsonia citrina*	HOWA
Yellow-breasted Chat	*Icteria virens*	YBCH
Summer Tanager [3]	*Piranga rubra*	SUTA
Scarlet Tanager [3]	*Piranga olivacea*	SCTA
Eastern Towhee [3]	*Pipilo erythrophthalmus*	EATO
Chipping Sparrow [3]	*Spizella passerina*	CHSP
Field Sparrow [3]	*Spizella pusilla*	FISP
Song Sparrow [3]	*Melospiza melodia*	SOSP
Northern Cardinal [3]	*Cardinalis cardinalis*	NOCA
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	RBGR
Blue Grosbeak [3]	*Passerina caerulea*	BLGR
Indigo Bunting [3]	*Passerina cyanea*	INBU
Red-winged Blackbird	*Agelaius phoeniceus*	RWBL

Common Name [1]	**Scientific Name** [1]	**Banding Code** [2]
Eastern Meadowlark	*Sturnella magna*	EAME
Common Grackle [3]	*Quiscalus quiscula*	COGR
Brown-headed Cowbird [3]	*Molothrus ater*	BHCO
Orchard Oriole	*Icterus spurius*	OROR
House Finch [3]	*Carpodacus mexicanus*	HOFI
American Goldfinch [3]	*Carduelis tristis*	AMGO
House Sparrow	*Passer domesticus*	HOSP

[1] *Common and scientific names follow the A.O.U. Check-list of North American Birds, Seventh Edition, 49th Supplement (American Ornithologists' Union 1983).*

[2] *Banding codes follow USGS Bird Banding Laboratory's North American Bird Banding Manual (Gustafson, Hildenbrand et al. 1997).*

[3] *Species was included in analyses after screening out observations of (a) water-associated species; (b) raptors; (c) broadly-ranging species; (d) flyover birds not stopping within count circles; (e) upland game birds (except doves); (f) nocturnal species; (g) species observed at <10% of sites over both years; and (h) migrating birds.*

APPENDIX F

INCIDENTAL AVIAN OBSERVATIONS

A number of previous studies have documented range expansions of multiple bird species into northeastern Georgia; as the greater Athens, Georgia area has benefitted from long-term ornithological studies, many of those expansions have been noted there (Burleigh 1938; Odum and Burleigh 1946; Odum and Johnston 1951; Peake 1968; Hale, Jackson et al. 1978; Allen 1979; Bell 1999). Although this research project was not specifically geared towards the detection of range expansions, during the course of the study, several incidental observations were made of birds which may be of interest to future researchers. Those observations are outlined below.

Mississippi Kite (MIKI)

A single bird flew over the Old Mill Chase subdivision in Oconee county on July 6, 2007. Another MIKI was observed there on July 30, 2008. MIKI are uncommon as non-breeding birds in the Piedmont (Beaton, Sykes et al. 2003)

Broad-winged Hawk (BWHA)

A single BWHA was observed June 25, 2007 while surveying in the nature walk area of the Rowan Oak subdivision in Oconee county. A single male was clearly heard vocalizing on several occasions while apparently circling above the canopy, out of view. BWHA are uncommon to common breeders in the Piedmont (Beaton, Sykes et al. 2003).

Eurasian Collared-dove (EUCD)

On May 14, 2008, a male EUCD was heard calling in the Trotters Walk subdivision in Oconee county. A pair of EUCD was observed in proximity to each other on June 6, 2008 in the Coldwater Creek subdivision (under construction) in Oconee county, with at least one bird calling regularly; another bird was observed on electrical wires near the adjacent Oconee County high School off of Hwy-53. On July 9, 2008, a male EUCD was heard calling in the Rocky Branch Farms subdivision in Oconee county. These records may indicate that the species is expanding into Oconee county area from the Athens area, where EUCD has been recorded since 1999 (Bell 1999).

Yellow-bellied Sapsucker (YBSS)

A single YBSS was clearly seen in Whitehall Forest in Clarke county, on May 14, 2008. This was a very late record for the species in this area. The extreme spring date for this species in the Piedmont is May 15 (Beaton, Sykes et al. 2003)

Scarlet Tanager (SCTA)

I recorded 27 SCTA across both years of this study. Birds were observed well-into the breeding season, with one pair (a male and a female) noted in proximity as late as July 3, 2007. Birds were located as late as July 17. This supports reports that SCTA is a local breeder in the lower Piedmont (Beaton, Sykes et al. 2003), and suggests that SCTA may have expanded its range since a 1979 study, when only five males were observed in the Athens area, with none remaining past mid-May (Allen 1979).

APPENDIX G

BIRD SPECIES EXCLUDED FROM ANALYSES

In this study, I targeted species that were forest-associated, breeding landbirds that fulfill the majority of their daily needs with an area the size of my study sites (1 km^2). I excluded certain observations from later analyses. I excluded 39 species because of (a) undesired aspects of life history (water-associated species (e.g., waders, ducks, and shorebirds); broadly-ranging species (e.g., swifts, swallows, raptors, game birds other than those in *Columbidae*); nocturnal species); (b) status as a migrant (i.e., non-breeding, late-departing individuals); and (c) relative scarcity (species observed at <10% of sites over both years). The latter group generally represented birds which treat the upland, forested (or formerly so) habitat at count points as marginal habitat and rarely use it. Reasons for excluding species are outlined in Table C.1.

Table G.1: List of bird species excluded from analyses and reason for exclusion.

Common Name [1]	Reason for Exclusion
Canada Goose	Life history
Wood Duck	Life history
Mallard	Life history
Wild Turkey	Life history
Great Blue Heron	Life history
Green Heron	Life history
Black Vulture	Life history
Turkey Vulture	Life history
Mississippi Kite	Life history
Cooper's Hawk	Life history
Red-shouldered Hawk	Life history
Broad-winged Hawk	Life history
Red-tailed Hawk	Life history
Killdeer	Life history
American Woodcock	Life history
Rock Pigeon	Relative scarcity
Eurasian Collared-Dove	Relative scarcity
Chuck-will's-widow	Life history
Chimney Swift	Life history
Belted Kingfisher	Life history
Yellow-bellied Sapsucker	Migrant
Eastern Kingbird	Relative scarcity
Northern Rough-winged Swallow	Life history
Cliff Swallow	Life history
Barn Swallow	Life history
Swainson's Thrush	Life history
Cedar Waxwing	Life history
Yellow-rumped Warbler	Migrant
Worm-eating Warbler	Relative scarcity
Ovenbird	Relative scarcity
Louisiana Waterthrush	Relative scarcity
Kentucky Warbler	Relative scarcity
Common Yellowthroat	Relative scarcity
Yellow-breasted Chat	Relative scarcity
Rose-breasted Grosbeak	Migrant
Red-winged Blackbird	Relative scarcity
Eastern Meadowlark	Life History
Orchard Oriole	Relative scarcity
House Sparrow	Relative scarcity

[1] *Common and scientific names follow the A.O.U. Check-list of North American Birds, Seventh Edition, 49th Supplement (American Ornithologists' Union 1983).*

APPENDIX H

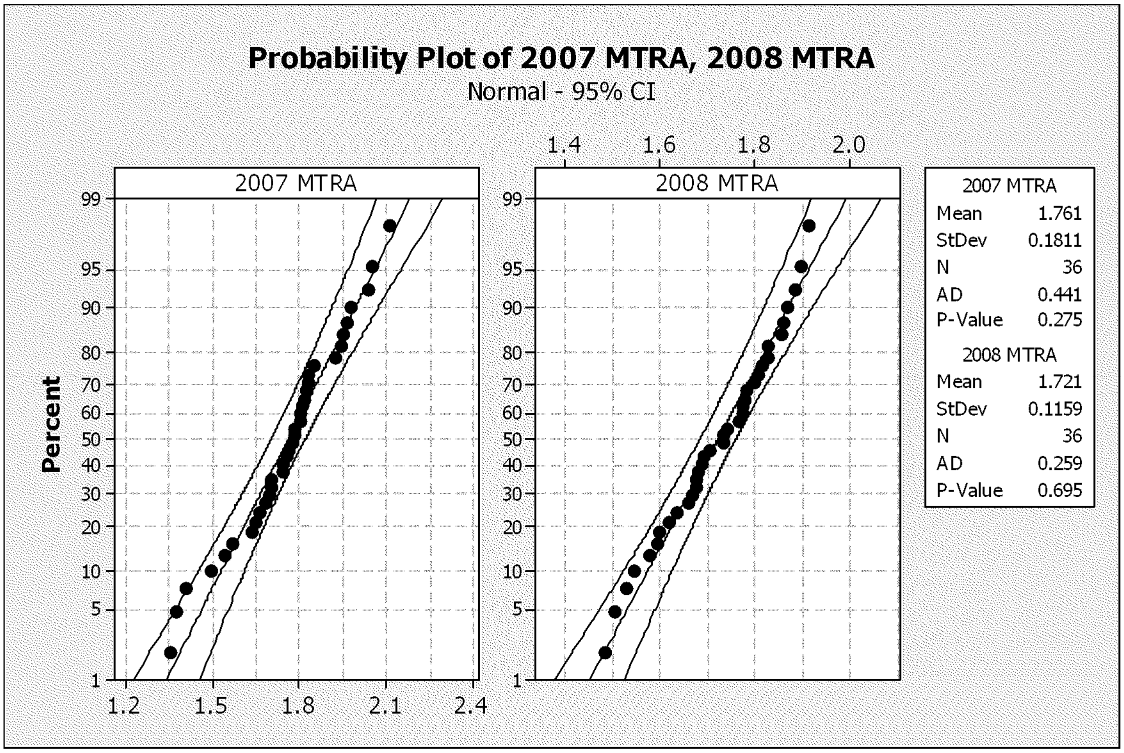
TESTS FOR A YEAR-EFFECT IN AVIAN COMMUNITY METRICS (2007-2008)

To determine whether I could compare data between years (i.e., was there a year effect?), I compared plots of 2007 community metrics vs. 2008 metrics. All graphs were generated using Minitab software. I created paired normal probability plots of 2007 and 2008 *MTRA*, S_{MAX}, and *J'*. Using the normal probability plots I was able to compare sample distributions from year to year. If the metrics from both sets of samples appeared to be from the same (i.e., normal) distribution, then I interpreted it as evidence that there was not a year effect. If the normal distribution fit my data, the plotted points should fit a roughly straight line and fall close to the fitted distribution line, and the Anderson-Darling (AD) statistic should be small and its associated p-value should be greater than my chosen α significance level. For the AD tests, I chose a significance level of $\alpha = 0.05$.

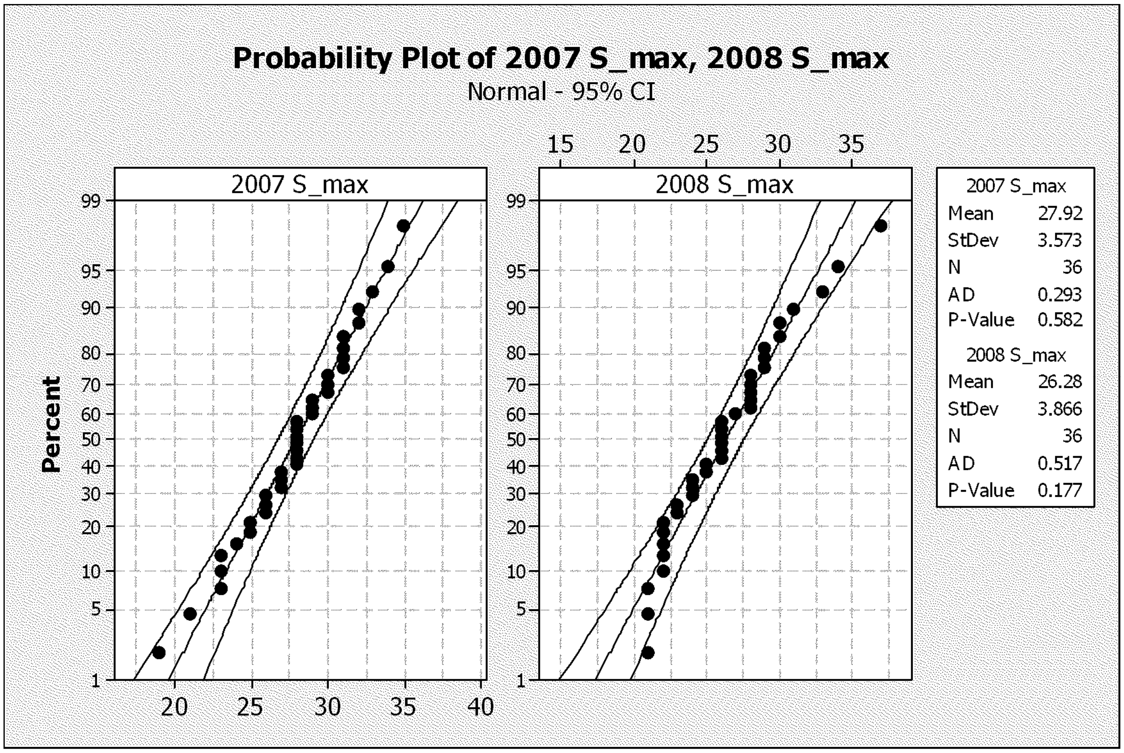
Plots H.1, H.2, and H.3 show paired plots of 2007 and 2008 *MTRA*, S_{MAX}, and *J'*, respectively. In each plot, although there is some minor variation in the sampled metrics, the plotted points are reasonably straight and close to the fitted distribution line. Also, all plots have a small AD statistic value ($0.259 < AD < 0.517$) and associated p-values for each statistic are all > 0.10. I interpret this as evidence that 2007 and 2008 data came from the same, normal distribution and are thus comparable across years.

Plots H.4, H.5, and H.6 are plots of residuals vs. fits for paired community metric data from 2007 and 2008 (using the same three metrics in the same order). In these plots, residuals should be randomly distributed around zero, with no recognizable patterns to the distribution. Plot H.4, *MTRA*, appears to be randomly distributed around zero with no recognizable patterns in the data. Plot H.5, S_{MAX}, shows a fairly random distribution around zero, but does exhibit a spike between fitted values of 26 and 27. The spike may indicate the presence of outliers, but I believe that it reflects a situation where landscape-level habitat changes may alter the species makeup of an area without changing its overall species richness (Parody, Cuthbert et al. 2001). Plot H.6, *J'*, has a random distribution around 0, with a slightly lower density of points at lower fitted values, possibly indicating some minor outliers again. Overall, the plots of residuals vs. fits do not appear to show any strong year effects or major outliers other than what I described above.

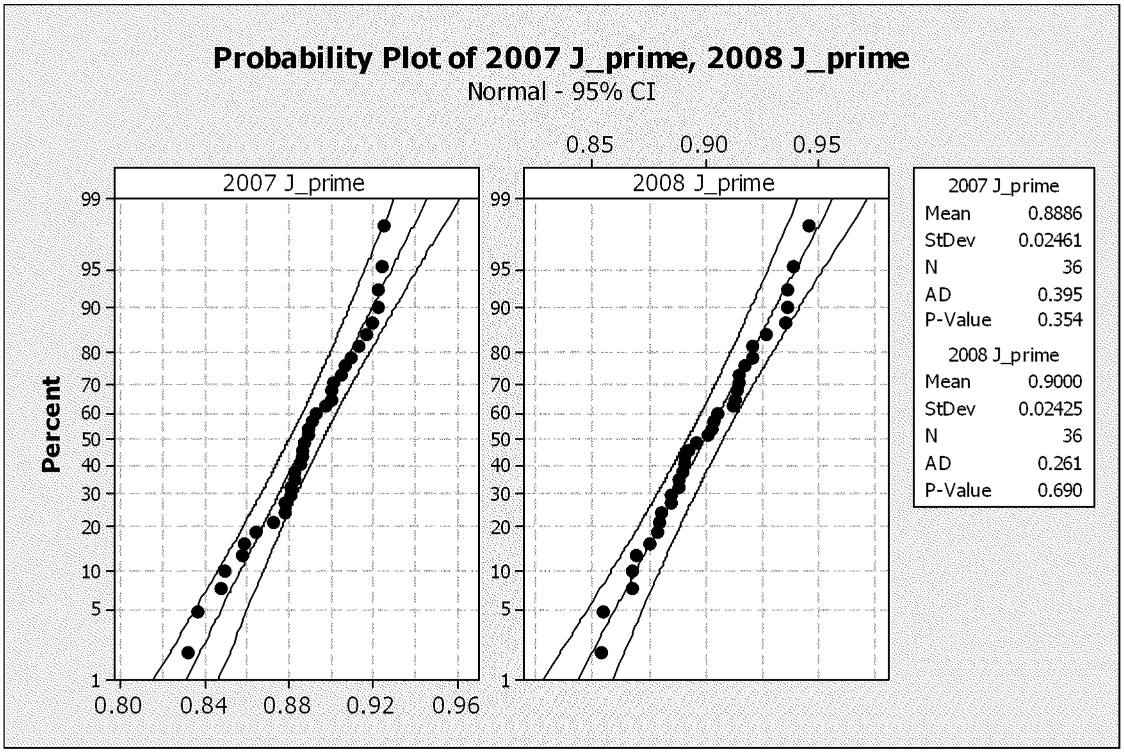
Plot H.1:



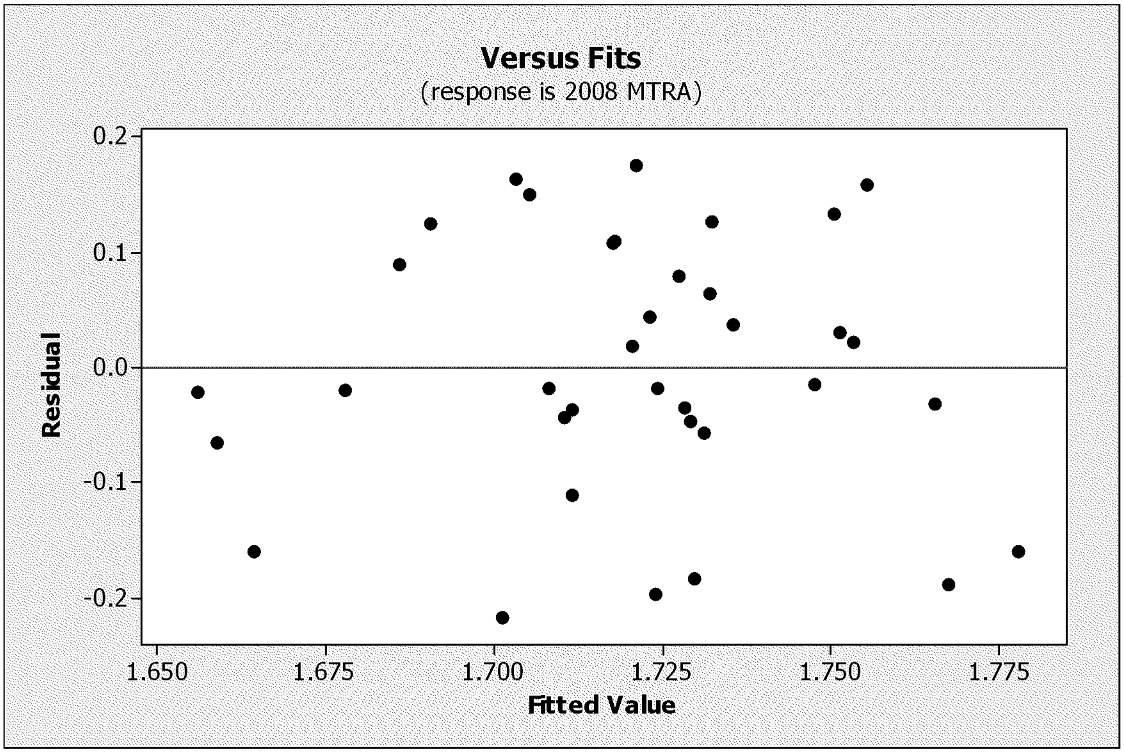
Plot H.2



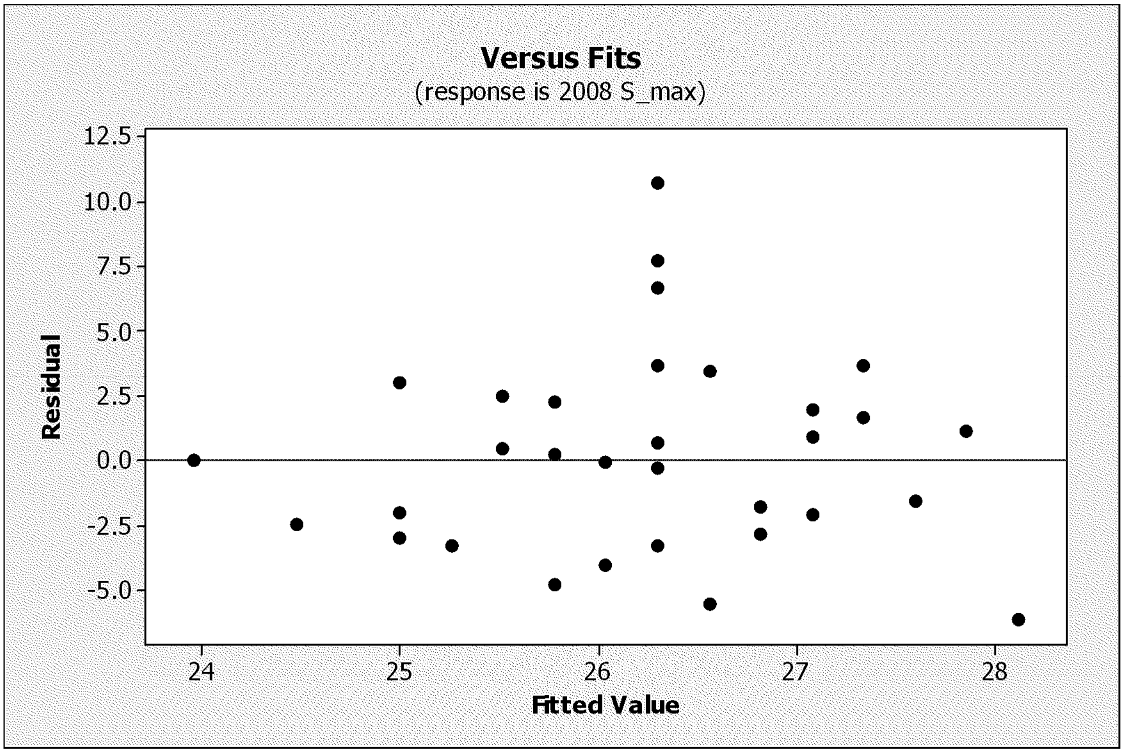
Plot H.3



Plot H.4



Plot H.5



Plot H.6