MANAGING FOR WILDLIFE HABITAT AND CONNECTIVITY IN THE DUKE FOREST: CASE STUDIES OF BOBCATS AND THREE SALAMANDER SPECIES

by

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EXECUTIVE SUMMARY

Overview. Landcover within the Piedmont ecoregion of North Carolina has been greatly impacted by urbanization. Duke Forest is one of the largest remaining forest habitat patches within this mostly urban landscape matrix. This project assisted Duke Forest with its comprehensive wildlife management plan through the synthesis and analysis of past work and provided future recommendations. Specifically, this project combined a previous regional wildlife connectivity report, a salamander distribution report, and a new examination of mammal occurrences using species distribution modeling to promote wildlife monitoring and management of potential wildlife corridors within the Duke Forest. Research questions included:

- Where should wildlife management be prioritized in the Duke Forest to maximize overlap between Duke Forest land, regional connectivity plans, and the distributions of priority species?
- What are some best practices for how to manage priority hotspots identified in the Duke Forest for each species?

Answering these two questions allows this project to be useful for Duke Forest, but also useful on a larger scale for applying regional connectivity plans on the ground with a single landowner. In particular, combining connectivity models and species distribution models to predict important habitat for fauna is a valuable tool to better assess where animals may be on the ground or where they have the possibility to be, if managed correctly.

Methods. The first step was to determine how to crosswalk a regional wildlife habitat connectivity analysis with available species distribution models (*e.g.,* Tuttle et al. 2019 and Geschke 2019). To begin, I evaluated the habitats and representative species modeled in the connectivity plan. The connectivity plan used a habitat guild approach in which a suite of indicator species (*i.e*. a guild) corresponded with a particular habitat type, and a single focal species from each guild was selected to further refine the model. Focal species included the bobcat (representing the sparsely settled mixed habitat guild), eastern box turtle (representing the dry-wet hardwood and mixed forests habitat guild), and four-toed salamander (representing the general wet-mesic hardwood forest habitat guild). I then looked for corresponding Maxent-based species distribution models from Geschke (2019). A four-toed salamander model was available, but there was not one for the bobcat or the box turtle. However, the box turtle represents an animal habitat guild that includes marbled and spotted salamanders; species distribution models for these species were available from Geschke. Since a Maxent bobcat model was not available, I created one by researching habitat variables and collecting bobcat occurrence points from a variety of sources.

Amphibians are of particular concern since their prevalence is declining worldwide, and Duke Forest is currently employing citizen science to help monitor their populations. Bobcats are of salience since there have been 2 sightings within the forest recently, but otherwise the species is secretive and presumed to be rare.

The species distribution model results for each indicator species were overlaid with the connectivity priority areas determined by the regional wildlife connectivity plan to generate maps of “hotspots.” These hotspot locations could then be used by Duke Forest to prioritize and focus habitat management activities specific to the habitat types and animals that use them. In addition, a final overlay map showing the salamander hotspots for all salamander species was created because these animals are

most sensitive to changes created by forest management. To provide recommendations for Duke Forest, literature was consulted, and Duke Forest's future management areas were considered.

Results & Conclusions. This project resulted in maps of predicted habitat for the bobcat, for both Duke Forest and for Durham, Orange, and Chatham counties. Other results included connectivity and species overlay maps for the three guilds and a combined salamander hotspot overlay. This last salamander hotspot overlay showed where Duke Forest needs to prioritize its sensitivity for management. There were 2 main areas of conservation in Duke Forest in the Blackwood and Durham divisions. Pine harvests are planned adjacent to both hotspots, which is where the management recommendations would be best utilized.

Recommendations included management pertaining to timber harvest, prescribed fire, streamside management zones, and vernal pools/constructed wetlands. These recommendations are mainly providing more specifics for Duke Forest in regard to their current management practices such as timing and associated effects that may not have been considered. With these recommendations, Duke Forest may be able to develop management protocols that protect land within its forest that will ensure wildlife movement within the Triangle region.

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INTRODUCTION

Wildlife conservation in increasingly fragmented urbanized areas is becoming a necessary consideration today. Due to rising human population and the resulting development, contiguous wildlife habitat has become divided or "fragmented" into smaller patches on the landscape (Hilty et al. 2019). The isolation of these patches makes it difficult for animals to move among them for food, water, and reproduction (Cosgrove et al. 2018); furthermore, looming climate change exacerbates isolation effects since smaller areas are less resilient to ecological disturbances and threats (Ament et al. 2014).

However, linking these isolated patches with wildlife corridors allows for movement of animals daily within their home range, for migration, and for future necessary movement due to climate change or natural disasters (Ament et al. 2014). Besides being necessary for wildlife, conserving habitat within human landscapes can also provide ecosystem services and financial gain for companies. For example, conversion of medians and roadsides from grass to wildflowers will save transportation departments money, reduce their carbon emissions from maintenance, and help support pollinator populations (Conniff 2018). Natural habitats may provide an ecosystem service like clean water, and it is cheaper to buy this land and protect it than have to treat the water after it is polluted from human land usage (Conniff 2018).

An ideal study area for wildlife conservation within an urban-forest matrix is Duke Forest in Durham, NC. This master's project delves into wildlife connectivity on the Duke Forest and beyond. Protecting habitat corridors for movement through its land will enable Duke Forest to prioritize wildlife connectivity and management. Duke Forest is suspected to be a hotspot of regional connectivity because it has several large patches of natural and managed habitat totaling just over 7,000 acres (Office of the Duke Forest 2020). Connection among Duke Forest patches and other patches is vital to ensure wildlife proliferation. In addition, Duke Forest has over 1,200 acres over 12 sites that are included in the North Carolina Registry of Natural Heritage Areas, maintained by the NC Natural Heritage Program (NCNHP). The agreement between the registry and Duke states that the Forest should "maintain these areas for the perpetuation of natural processes, natural communities, and rare species populations" (Office of the Duke Forest 2020). Timber harvesting is not permitted in these sites unless harvesting is shown to have great benefit to the ecological community, and the NCNHP is consulted.

Moreover, Duke Forest has prioritized wildlife management within its overall management plan, with the goal of providing habitat for as diverse an amount of native Piedmont species as is possible (Office of

the Duke Forest 2020). However, this goal is situated within Duke Forest's teaching and research missions and must be compatible with silvicultural prescriptions promoting these missions (Office of the Duke Forest 2020). Management on the Duke Forest is certified to Forest Stewardship Council (FSC) guidelines which consider environmental, social, and economic standards (Office of the Duke Forest 2021).

Duke Forest's current wildlife management plan is targeted at landscape and stand levels because species lists and population estimates are not available for the forest overall (Office of the Duke Forest 2020). Work is currently under development to incorporate the results of a 2017 Master's Project evaluating alternative management approaches for Duke Forest (Office of the Duke Forest 2020). Prime tenets include doing no harm or minimizing negative impacts to wildlife from timber harvest and recreation use. The forest uses work from citizen science, master's projects, and class projects to better understand wildlife diversity and movement and establish baseline wildlife information. Inherent to this project is the Forest's desire to use management interventions to promote particular species, taxa, or guilds of importance.

Timber management may have great implications on wildlife habitat or connectivity, and specific guidelines pertaining to harvesting include harvesting irregularly shaped areas, leaving oak mast species, retaining snags for cavity nesters, and retaining coarse woody debris such as slash piles as cover. Half of the regeneration on the forest stems from clearcutting and then planting, which is needed for research and teaching. However, clear cut areas are limited to 40 acres unless necessary for research. Prescribed fire is implemented on a 3-4 year interval as a silvicultural research and teaching tool. Duke Forest buffers ephemeral streams by 50 feet as a riparian management zone (RMZ) while for perennial and intermittent streams and surrounding wetlands, 100 feet (50 feet wider than the BMP streamside management zone) is employed. Harvesting may still occur within these zones, but the Forest is sure to closely examine management within these areas (Office of the Duke Forest 2020).

Past Master's Projects have worked on directing the course of wildlife management within the Duke Forest. A 2017 Master's Project helped focus wildlife management efforts onto citizen science herpetofauna efforts due to the limited staff and funding of Duke Forest and high prioritization of these species (Kramer et al. 2017). In this way, wildlife monitoring can involve the research and teaching goals of the Duke Forest while establishing baseline data to determine how management affects species and to show trends in species populations over time.

This project will build upon Kramer et al.'s (2017) wildlife management approach objective of using research outputs to focus management efforts to promote a particular species, taxa, or guild (Office of the Duke Forest 2020). Other past Master's Projects including those of Geschke (2019), have provided useful habitat distribution information, which is incorporated into the current project. In this, I identify areas to manage based on the species and the value of their habitat connectivity to regional landscapes beyond the Duke Forest.

Duke Forest is located within the larger subset of the Eno River and New Hope Creek-Jordan Lake watersheds, where there are over 65 Natural Heritage Natural Areas (Tuttle et al. 2019). A recent regional wildlife connectivity plan, *A Landscape Plan for Wildlife Habitat Connectivity in the Eno River and New Hope Creek Watersheds, North Carolina*, used habitat guilds to map habitat connectivity within these watersheds to determine habitat-corridor networks that have high connectivity value and should be conserved (Tuttle et al. 2019).

Choosing focal or indicator species to monitor habitat is often done in connectivity work (Hilty et al. 2019). Focal species are those that warrant special protection. These may consist of ecological indicators (species that share habitat requirements), keystone species (species which have a disproportionate impact on the landscape), umbrella species (species that require large areas), flagship species (species that are popular or will retain public interest), and vulnerable species (threatened or rare species) (Noss 1990). Indicator species for the regional wildlife connectivity plan had similar habitat and movement needs and responded similarly to landscape fragmentation; to select these indicator species, habitat and movement characteristics, barriers to movement, sensitivity to development and fragmentation, and primary stressors were all incorporated (Tuttle et al. 2019). In addition, in the regional analysis, focal species were selected for further model refinement from each of the three main guilds.

This project incorporated four species from all three habitat guilds, with two of those species being focal species. I used modeled species habitats of three salamander species and one mammal species and overlaid these with the connectivity priorities from the Eno-New Hope Plan to provide Duke Forest areas to monitor and manage that will be beneficial to creating corridors for wildlife to move or migrate. While there are many ways to model species distributions, I used maximum entropy models using the program Maxent to model bobcat, *Lynx rufus*, species distributions.

The Maxent statistical modelling program requires presence-only species occurrence points as well as environmental layers to determine the difference between habitat and non-habitat. While Maxent has been promoted as a "presence only" model, it actually fits the difference between the species distribution (presences) and a large random sample of "background" points (pseudo-absences). Maxent is easy to use and is particularly useful, when compared to other modeling strategies, if there is a small amount of occurrence data (Elith et al., 2006). Bobcats are useful to examine here, particularly when considering fire and timber harvest effects at a larger scale since bobcats are one of the top predators in the region; indicators by bobcats may show responses at multiple trophic levels (McNitt et al. 2020). The bobcat overlay in addition will be useful for Duke Forest to prioritize where to focus its camera trap deployment to verify mammal presence and the potential for management effort.

The other three species distributions came from Julia Geschke's 2019 master's project, *Modeling Salamander Habitat and Connectivity in Durham and Orange Counties, North Carolina*. I used the species distributions from three species mapped in this project: marbled salamanders (*Ambystoma opacum*), spotted salamanders (*Ambystoma maculatum*), and four-toed salamanders (*Hemidactylium scutatum*). Amphibians, in general, are useful for examination because they have a variety of life cycles, limited dispersal capability, and specific habitat requirements: thus, they are good bioindicators (Semlitsch et al. 2009). Four-toed salamanders are a species of special concern in North Carolina, and Duke Forest might consider adding small impoundments or transplanting individuals to new sites so the species can proliferate (Office of the Duke Forest 2020).

This project will help inform and support both the Duke Forest wildlife management plan and connectivity plan through the synthesis and analysis of past work, integration of original work, and suggestions of recommendations for the future. Considering overlay between these four species distributions and the connectivity project, I will be able to propose recommendations for areas for Duke Forest to manage to achieve connectivity and wildlife goals.

Objective

With this project, I aim to determine where wildlife management should be prioritized on the Duke Forest to maximize overlap between Duke Forest land, regional connectivity plans, and the distributions of priority species. Within this overall framework, I address the question of where wildlife management should be prioritized in the Duke Forest to maximize overlap between Duke Forest land, regional connectivity plans, and four species: bobcats, four-toed salamanders, spotted salamanders, and marbled

salamanders. To accomplish this, I create a bobcat distribution model for Durham, Orange and Chatham counties at large. I then overlay this and three other salamander distribution models onto the regional connectivity data to determine hotspots or priority management areas.

A secondary aim of this project is to conduct a literature review to determine best practices for how to manage priority areas identified in the Duke Forest for each species. By fulfilling these objectives, I can provide the Duke Forest with the tools it needs for species-specific wildlife management in the context of regional habitat connectivity planning.

MATERIALS & METHODS

Overview

For this project, I first had to determine how to crosswalk the regional connectivity analysis with available species distribution models. I used species from a previous salamander distribution report to represent two out of the three habitat guilds, and then I created a bobcat model for the third habitat guild. I used Maxent to create a bobcat distribution model for Duke Forest from a larger model of Chatham, Durham, and Orange counties. I then layered this and three other salamander distribution models onto regional connectivity data to determine hotspots or priority management areas for Duke Forest for each habitat guild. Finally, I researched what management practices will be best for Duke Forest in these hotspots to prioritize both habitat within the forest and the ability of species to connect to other habitats outside forest boundaries.

1. Study Areas

There were two nested study areas for this project (Figure 1). Both were located within the Piedmont ecoregion of North Carolina within the United States. The Piedmont is a transitional zone between the Appalachian Mountains to the northwest and the flat coastal plain to the southeast, and it extends from northern Virginia down through Alabama (US EPA 2013). Land cover changes in the Piedmont have been profound within the last 200 years, shifting from dominant forest to farmland to forest and spreading urbanization today (Griffith et al. 2002).

Within the Piedmont, the first study area was all Duke Forest divisions within Durham, Orange, and Chatham counties (all divisions except the Dailey division). Duke Forest is a teaching and research forest primarily, but it also focuses on multiple-use forest management and wildlife management within these contexts. Moreover, Duke Forest is committed to utilizing the research generated from students and professional scientists to shape its management plans (Office of the Duke Forest 2020). Twelve hundred acres at 12 sites of Duke Forest are recognized as part of the North Carolina Registry of Natural Heritage Areas, which affirms Duke Forest's commitment to positive land stewardship (Office of the Duke Forest 2020).

The Duke Forest is nested within the second study area, all of Durham, Orange, and Chatham counties, since greater habitat acreage is needed for a robust connectivity analysis and for considering land conservation in general. In creating the bobcat Maxent model, I used this second larger study area since there were few bobcat occurrences within the Duke Forest divisions. Past connectivity modeling within the area has focused first on Duke Forest to provide recommendations for habitat management and further research and then within the larger county context to be useful for other projects.

Study Areas

3-Counties

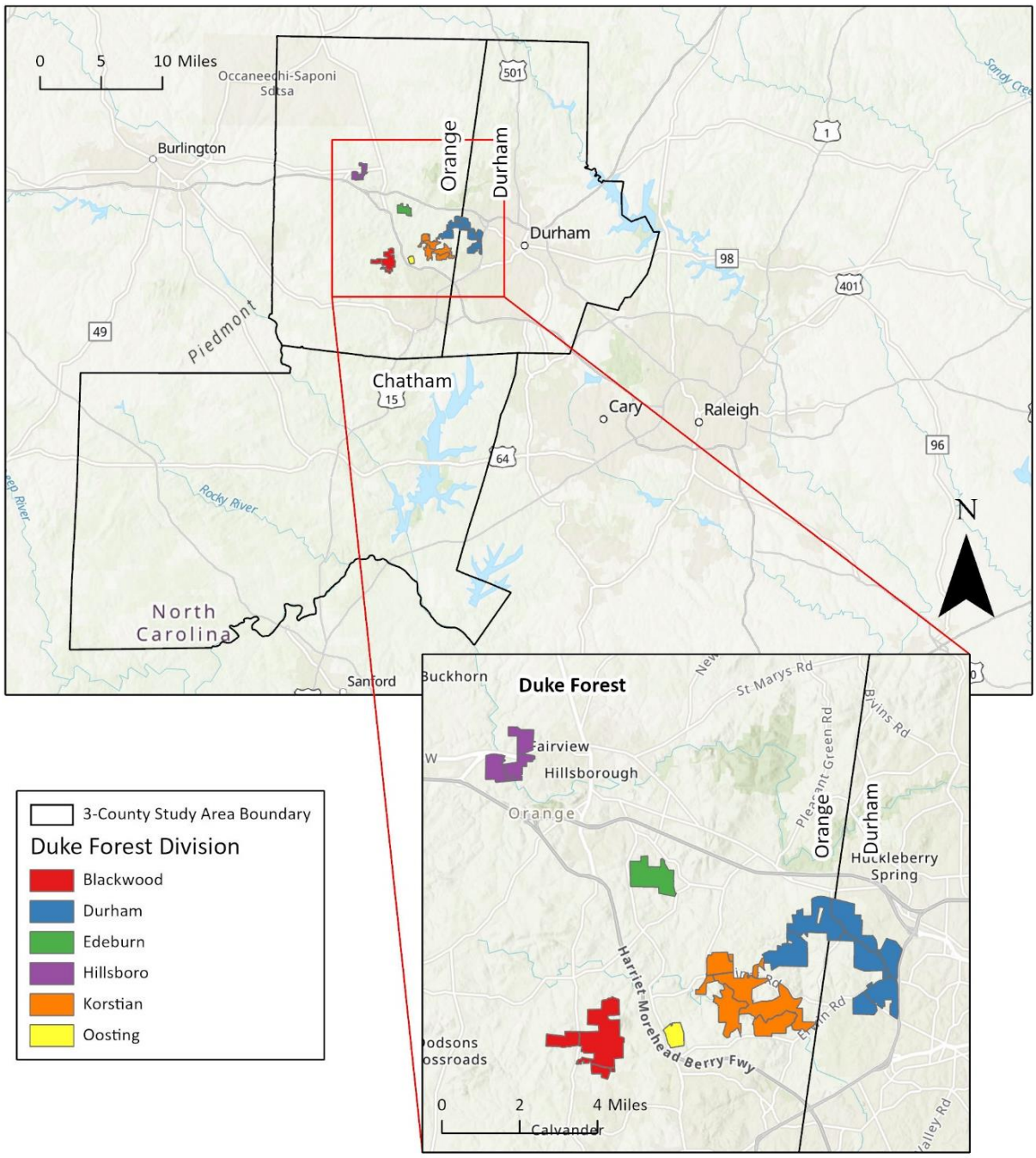


Figure 1. Map of 3-counties study area (top) and Duke Forest study area (bottom).

1.1. Study Organisms

To select study organisms for this project, I considered the habitats and representative species modeled in the regional wildlife habitat connectivity plan and then compared these to available data. Three main habitat guilds were examined in the plan, where guilds consisted of a collection of indicator species with similar movement and habitat needs (Tuttle et al. 2019). Within each of the guilds, specific indicator species were selected as focal species for further refinement of the modeling. Focal species included the bobcat (representing the sparsely settled mixed habitat guild), eastern box turtle (representing the dry-wet hardwood and mixed forests habitat guild), and four-toed salamander (representing the general wet-mesic hardwood forest habitat guild).

I was able to locate a Maxent four-toed salamander model from a previous salamander distribution report (Geschke 2019). There was not a species distribution model for a bobcat or eastern box turtle. However, Geschke (2019) also generated Maxent-based spotted and marbled salamander species distributions, which were two other indicator species within the same guild as the box turtle. Since there was not a Maxent-based bobcat species distribution model, I created one for this study. Thus, study organisms included in this project included bobcats (*Lynx rufus*), four-toed salamanders (*Hemidactylium scutatum*), marbled salamanders (*Ambystoma opacum*), and spotted salamanders (*Ambystoma maculatum*). With these three salamander and bobcat distributions, I had species from each of the three guilds distinguished in the recent regional wildlife connectivity analysis, two of which are focal species (bobcats and four-toed salamanders). Amphibians are of special importance to the Duke Forest since expert data has alerted the Forest as to their significance (Office of the Duke Forest 2020) and there has been a recent bobcat sighting in the Duke Forest Blackwood Division, so this is of particular salience to the Forest office.

2. Bobcat Modeling

2.1. Literature Review

To obtain information about bobcat habitat and determine important variables for the Maxent model, I conducted a literature review utilizing Duke University Library Portal, Web of Science, and Google Scholar. Peer-reviewed journal articles were searched for using terms such as “bobcat distribution modeling”, “bobcat habitat modeling”, “bobcat habitat”, “bobcat connectivity”, and “bobcat least cost

path." Data from the literature was compiled into a table including source and habitat criteria (Appendix 1, Table 1.1). To be included, the article had to have studied bobcats and have occurred in the southeastern region of the country, defined as Virginia, Tennessee, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, and Arkansas. Based on the literature review, I compiled a list of relevant habitat variables to be used in the modeling and then compared this list to available geospatial data to determine how I would represent important habitat considerations in the Maxent model.

2.2. Geospatial Data Collection

After the literature review was completed, I represented as many variables as possible with geospatial data. Geospatial data was compiled from Duke Forest staff and Google searches. Final datasets used for analysis are listed below, along with their source:

- Duke Forest Boundaries, Roads and Trails: Duke Forest
- County Boundaries: North Carolina Department of Transportation (NCDOT)
- Roads: NCDOT
- Land Cover: Southeast Gap Analysis Project (SEGAP)
- Elevation: 1/3 arc-second DEM, US Geological Survey (USGS)
- Streams: National Hydrography Dataset (NHD), USGS

Data projection used was the NAD 1983 State Plane North Carolina FIPS 3200 Feet (Lambert Conformal Conic) with linear units in US Survey Feet. This is Duke Forest's chosen projection and common in North Carolina. All layers were re-sampled to a common 10m resolution based on the 1/3 arc second USGS DEM.

2.3. Bobcat Occurrence Data

Bobcat occurrence data was compiled from a few sources. There were 29 data points used in building the model for the 3-county study area (with only 2 points falling within Duke Forest) (Appendix 2, Table 2.1). I considered only using bobcat observations since 2000 to account for land change usage, but I decided against it due to the small sample size and large bobcat range.

I obtained 14 occurrence points from the Eno-New Hope Landscape Conservation Group. This group compiled bobcat occurrences for their regional landscape modeling and, as such, this data comes from a variety of sources. These include observations from the Piedmont Wildlife Center, NC State Parks

Natural Resources Inventory Database (NRID), Eno-New Hope Landscape Conservation Group members, North Carolina Natural Heritage Program natural area inventories, iNaturalist data, and additional fieldwork. Dates of observations range from 1988- 2019.

Two bobcat occurrence points were obtained from Triangle Land Conservancy (TLC). Both occurrences were in one of TLC's publicly accessible preserves, Brumley Forest, in Durham in 2010 and 2018. Although the GPS locations were estimates, I am confident in the accuracy of the information within a bobcat's range.

Eleven of the occurrence points were obtained from eMammal. eMammal is a website that stores and manages camera trap research projects. I found camera trap projects within the 3-county study area and identified which camera traps had isolated bobcat pictures. Camera traps capturing pictures of bobcats came from several projects run by the North Carolina Museum of Natural Sciences and the North Carolina Wildlife Resources Commission, and dates of camera capture spanned from 2014-2018.

Two last occurrence points were obtained from Sara DiBacco Childs, Director of Duke Forest. These were recent camera trap pictures from 2019 that had not been uploaded to eMammal yet. They were part of the Mast and Mammals project occurring within Duke Forest. These were the only 2 occurrence points within Duke Forest.

2.4. Maxent Habitat Modeling

2.4.1 Geospatial Data Preparation

With so few sample points in the Duke Forest, the study area for the bobcat Maxent modelling was the Durham, Orange, and Chatham county area. I projected all the geospatial data into the NAD 1983 State Plane North Carolina FIPS 3200 feet. I then resampled all the rasters to a 10-meter resolution to match the USGS DEM. Lastly, I clipped the variables to the three-county region to show accurate comparisons.

I created DEM derivatives with the 1/3 arc second (~10m DEM) which included aspect and slope.

For a distance to roads variable, I used the NCDOT roads layer for the 3-county study area and merged NCDOT and Duke Forest roads and trails to create a distance to roads variable for the study area.

To create a distance to streams variable, I kept intermittent and perennial streams and removed connectors, canals/ditches, and artificial paths from the National Hydrography Dataset. Intermittent

and perennial streams were considered the most relevant to represent surface waters. These streams were used to create the distance to stream layer for the 3-county study area.

Since bobcats have a large home range, I decided to create focal layers to represent average landcover types within the average bobcat home range. To create the focal layers, I used the average bobcat range in the southeast from a variety of papers, summarized in Cochrane et al. 2006. This was 17.25 km^2, and I used a circle around the bobcat occurrence point to estimate the home range size where the radius was 2.34 km. I created focal forest, focal scrub/shrub, focal agriculture, and focal developed area layers from the landcover (SEGAP) layer. The exact SEGAP values used to create each focal layer can be found in Appendix 3, Table 3.1.

Lastly, the literature review showed that bobcats may be influenced by their proximity to the edge of forests, their primary habitat. I therefore included both edge density and distance to edge as variables in the Maxent model.

2.4.2. Data

Data included in the Maxent model:

- Elevation
- Slope
- Aspect
- Distance to Roads
- Distance to Streams
- Focal Forest
- Focal Shrub/Scrub
- Focal Agriculture
- Focal Developed
- Forest Edge Density
- Distance to Forest Edge

I used the DEM as a mask to set all rasters to the same cell size and extent. Rasters were then transformed into ASCII format for input into Maxent. I checked for correlation of environmental variables using ENMTools and avoided any variables that were >= 0.70 correlated (Appendix 4, Table 4.1). None of the variables were correlated to that extent, so they were all included in the model.

Variables close to this threshold were focal agriculture and DEM (0.6328) and focal forest and focal development (-0.6924).

2.4.3. Maxent Settings

I chose to run Maxent at the default beta regularization coefficient of 1. This default value has been tuned according to a variety of taxonomic groups (Phillips and Dudik 2008). I used cross-validation to ensure that a variety of models were run and compared to each other. This strategy of utilizing k-fold cross validation (in this instance, k = 10) is advantageous for assessing uncertainty in predictions (Merow et al 2013). 10 models were run with a few points withheld from each for model fitting, and then these 10 models were averaged to examine the differences in confidence intervals.

These were the settings for the final Maxent run:

- β value = 1
- 10 replicates as cross validation
- Nothing in "random test percentage"
- Write background predictions: checked
- Create response curves: checked
- Make pictures of predictions: checked
- Do jackknife to measure variable importance: checked
- Output format: logistic

The final Maxent model was then brought back into GIS and transformed from ASCII to raster format. This raster format was that of a logistic continuous probability which I then found a threshold to yield a discrete classification. To choose a threshold for "habitat" from the Maxent model, I used R v. 3.6 (R Core Team 2019) and contributed package ROCR (Sing et al. 2005). Receiver operating characteristics (ROC) were examined, which are a proven method of optimizing classification models (Vayssieres et al. 2000). ROC curves compare model sensitivity (how well the model predicts "true" cases or the true positive rate, TPR) and specificity (how well the model predicts "false" cases or the true negative rate, TNR) (Pearce and Ferrier 2000). Since this model was created with only presences, I wanted to try to maximize TPR without categorizing the entire study area as bobcat habitat. I compared pseudoabsences (generated by Maxent) with presences. I varied the true positive rate and examined the defined habitat data: I eventually decided on using a true positive rate of 95% to differentiate between habitat and non-habitat. The threshold value was then 0.1418674. To be considered bobcat habitat, a pixel had to have

this logistic probability of habitat or larger. The logistic regression was then collapsed into a binary classification of habitat or non-habitat. Frequency distributions of probabilities predicted by the model and the confusion matrix used to determine the threshold can be found in Appendix 5.

3. Connectivity Overlay

3.1 Species and Regional Connectivity Overlay

To find overlap between individual species and habitat types, I used the regional connectivity data from the Eno-New Hope Landscape Conservation Group (Tuttle et al. 2019). I obtained the geospatial layers from Julia Tuttle, the project ecologist and coordinator. I used ArcGIS Pro to create maps portraying the overlap between indicator species distributions and the areas important for regional connectivity within the Eno-New Hope watershed. I did not include areas of "unranked" connectivity value in generating the priority areas, since these were habitat patches or corridors that were not connected to the main corridor network. The three salamander habitat distributions were obtained from Julia Geschke's 2019 Master's Project. I used her Maxent-produced habitat distributions since I was taking a conservative approach to locate areas where the species might be.

First, I created maps for each habitat guild of importance, so I overlapped four-toed salamanders with the general wet-mesic hardwood forest layer, spotted or marbled salamanders with the dry-wet hardwood and mixed forest layer, and bobcats with the sparsely settled mixed habitat layer. To eliminate small habitat patches and aim for areas that would be the best for salamanders and bobcats to occupy, I used thresholds of 1,000 m^2 and 250,000 m^2 respectively to determine priority areas for the taxon. I then combined all salamander hotspot overlap areas into a priority map for use if Duke Forest would like to maximize its conservation value with a few main areas and focus on salamanders since these animals are most sensitive to management actions. I characterized these areas to help determine which management strategies might be most effective for Duke Forest.

3.2 Literature Review on Management Action Effects by Representative Species

To provide Duke Forest with recommendations for wildlife management based on connectivity, I conducted a literature review. The goal was to determine which interventions managers can take to promote habitat on the ground. I used Duke University Library Portal, Web of Science, and Google Scholar. Peer-reviewed journal articles were searched for using terms such as "wildlife management,"

"timber harvest", "clearcut," "buffer", and the individual species names. Data from the literature was compiled into a table (Appendix 6, Table 6.1).

3.3 Management Recommendations

From the literature review and consultation with Duke Forest GIS layers, I compiled a list of management recommendations that Duke Forest may use to promote habitat for the salamander species. If recommendations are used within the overlap areas, Duke Forest will provide habitat not just within Duke Forest, but on a broader landscape connectivity level.

RESULTS

1. Bobcat Modeling

1.1. Literature Review

The full table of information collected in the literature review can be found in Appendix 1 (Table 1.1).

Bobcat (*Lynx rufus*)

Migration: No details found in the literature.

Road Density/Distance to Roads: Roads may serve as travel corridors or provide edge habitats, those being positively correlated with bobcat sighting (Lovallo and Anderson 1996 as cited by Little et al. 2018; Frey and Conover 2006; Barding and Nelson 2008 as cited by Little et al. 2018), but bobcats also avoid roads due to unsuitable habitat or movement inhibition (Kelly and Hollub 2008; Hess et al. 2006; Hess and King 2002). Overall, distance to roads may not influence bobcat occupancy strongly (Erb et al. 2012).

Elevation: Elevation may influence bobcats in the southeast. One study found that the probability of bobcat use increased as elevation increased, though not to a significant amount (Conner and Leopold 1998).

Aspect: No details found in the literature.

Slope: Steepness influenced bobcats in one study where the authors asserted that “bobcats preferred steeper slopes because of the relative seclusion offered by such areas (Zezulak and Schwab 1979; Hamilton 1982)" (Conner and Leopold 1998).

Temperature: No details found in the literature.

Precipitation: No details found in the literature.

Land Cover: Bobcats have been shown to use a multitude of habitats (Lancia et al. 1982; Diefenbach et al. 2013), some of which may be influenced by the land cover type their prey is utilizing (Cochrane et al. 2006; Zwank et al. 1985 as cited in Godbois et al. 2003). In general, bobcats are associated with local forest cover (Erb et al. 2012; Parsons et al. 2019), but many enjoy a diversity of vegetation within a forested landscape (Little et al. 2018) due to the need for different habitats for traveling, bedding and denning, and finding shelter from extreme temperatures (Jorge et al. 2020).

Canopy Cover: No details found in the literature.

Patch Size/Complexity: Bobcats may prefer edges because of prey resources such as rodent species and white-tailed deer (Chamberlain and Leopold 1999 as cited in Constible et al. 2006). Dense vegetation may provide concealment while stalking (Lariviere and Walton 1997 as cited in Constible et al. 2006). Bobcats have been shown to avoid forest interior, but they are also associated with large core forests (McNitt et al. 2020; Kays et al. 2017).

Stream Density/Distance to Water: Streams may function as travel corridors for bobcats (Rolley 1983; Shiflet 1984 as cited in Conner and Leopold 1998), or bobcats may prefer creeks due to the drift piles harboring prey (Maser and Trappe 1984 as cited in Conner and Leopold 1998). However, these wet areas may be considered lower in habitat quality by bobcats (Hess et al. 2006).

Management/Disturbance Tolerance: Bobcats have been shown to reduce or alter their behavior presumably to avoid human interaction and to avoid anthropogenic land covers (Roberts et al. 2010; Cove et al. 2019; George and Crooks 2006 and Taylor and Knight 2001 as cited in Erb et al. 2012). The US Geological Survey categorizes the human impact disturbance level of bobcats as medium (USGS 2017).

1.2. Maxent Habitat Modeling

The Maxent model revealed that focal agriculture (39%), distance to roads (23.3%), and distance to streams (11.2%) were the most informative variables in determining bobcat habitat. The probability of bobcat habitat increased as agricultural land increased to about 5%, after which bobcat habitat had an inverse relationship with agricultural land. Bobcat habitat had a positive relationship with distance to roads. This is easily visible in the Duke Forest predicted habitat map in the evident lack of habitat surrounding roads (Figure 5). The relationship with streams was a bit more complicated, with bobcat habitat occurring right next to streams or much further away. The higher probability next to streams is visible in the predicted bobcat habitat likelihood map, with high probabilities of habitat located close to Jordan Lake in the eastern section of Chatham county (Figure 2).

I set Maxent to do jack-knifing, which helps show the explanatory power provided by variables individually. The amount of agricultural land within the home range had the most explanatory power by itself, and the variable that had the most information not present in other variables was distance to roads (when omitted, the gain of the model was decreased the most). With the stated threshold, the model had an accuracy of 66.78% with the TPR of 96.55% and TNR of 66.69%.

There was a much larger percentage of Duke Forest designated as bobcat habitat when compared to the 3-county study area (Table 1). Within the 3-county area, as compared to Duke Forest, there is more development and urbanization (Figure 4). Over 50% of each division was predicted to be habitat while a large amount of the habitat predicted was in Durham, Korstian, or Blackwood divisions (Table 2).

Table 1. Maxent predicted habitat area (in acres) for both study areas.

	Acres Within 3-County Study Area	**Acres Within Duke Forest**
	304,435.05	4,380.44
Percentage of Area	33.80%	65.91%

Table 2. Maxent predicted habitat area divided by division in Duke Forest.

Duke Forest Division	**Acres**	**Percentage of Duke Forest Habitat**	**Percentage of Division**
Blackwood	768.64	17.55%	67.11%
Durham	1760.84	40.20%	72.22%
Edeburn	277.55	6.34%	57.03%
Hillsboro	302.75	6.91%	51.90%
Korstian	1114.61	25.45%	60.96%
Oosting	156.05	3.56%	95.27%

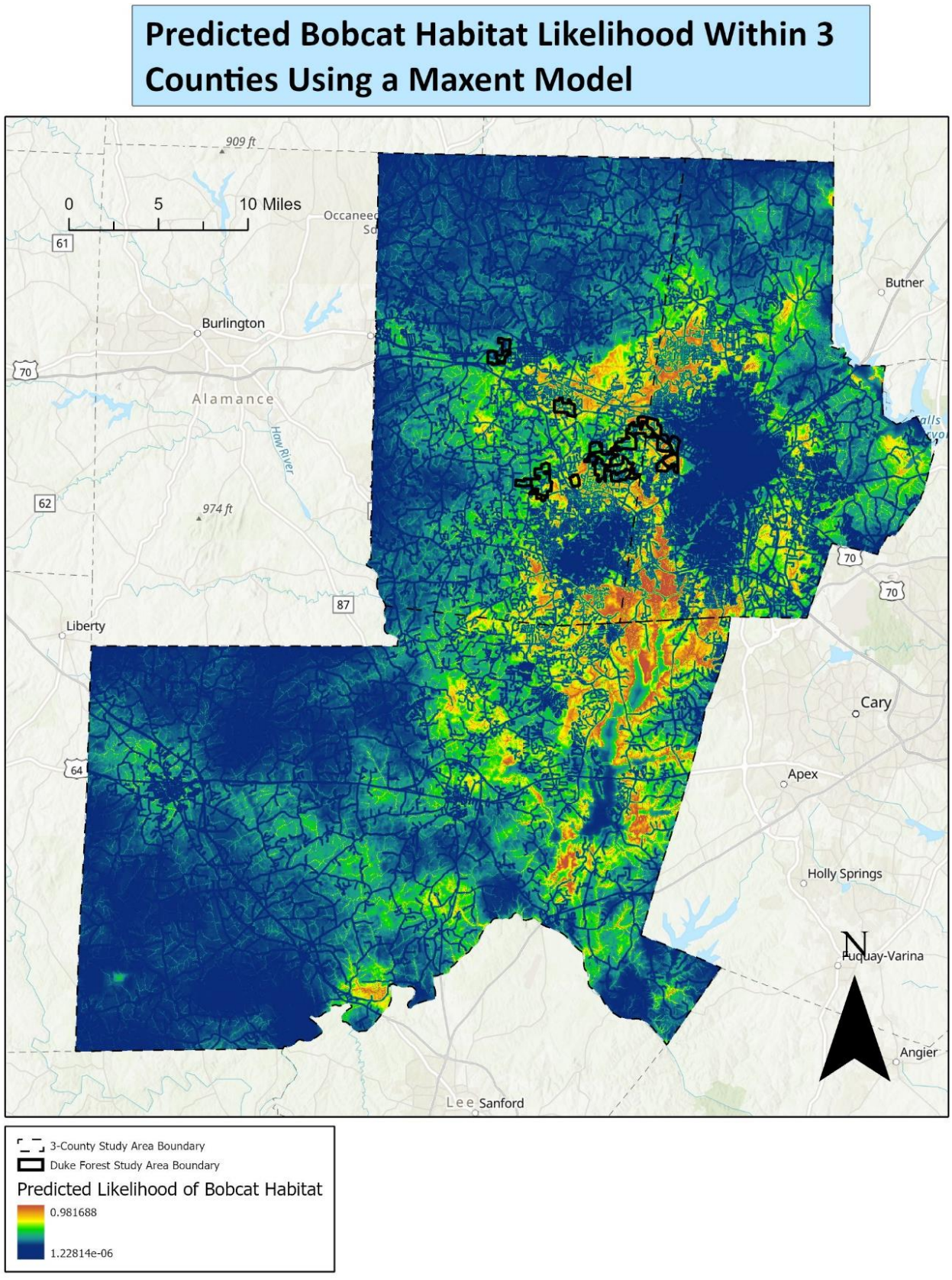


Figure 2. Predicted likelihood of bobcat habitat within 3 counties from a Maxent model.

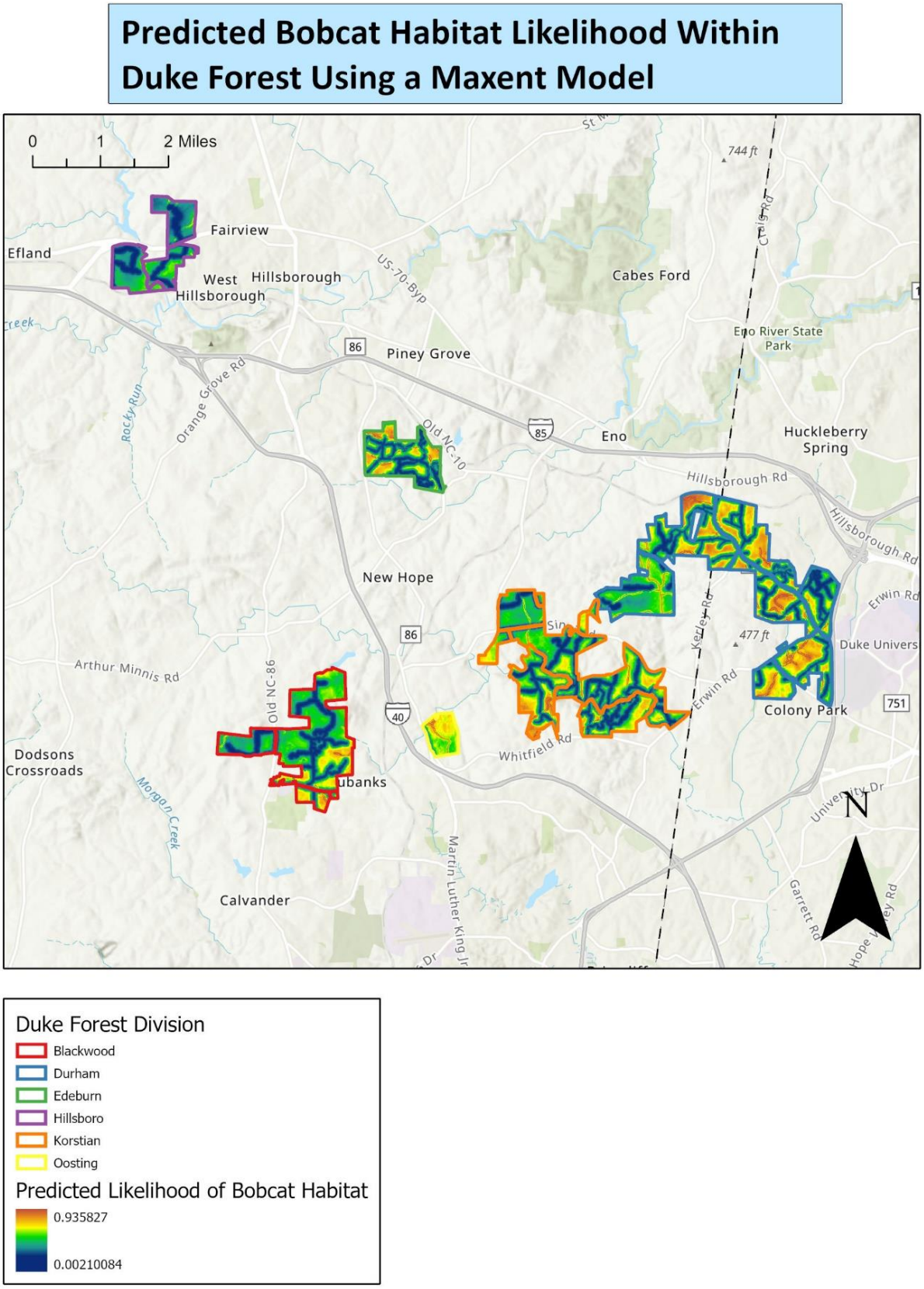


Figure 3. Predicted likelihood of bobcat habitat within Duke Forest from a Maxent model.

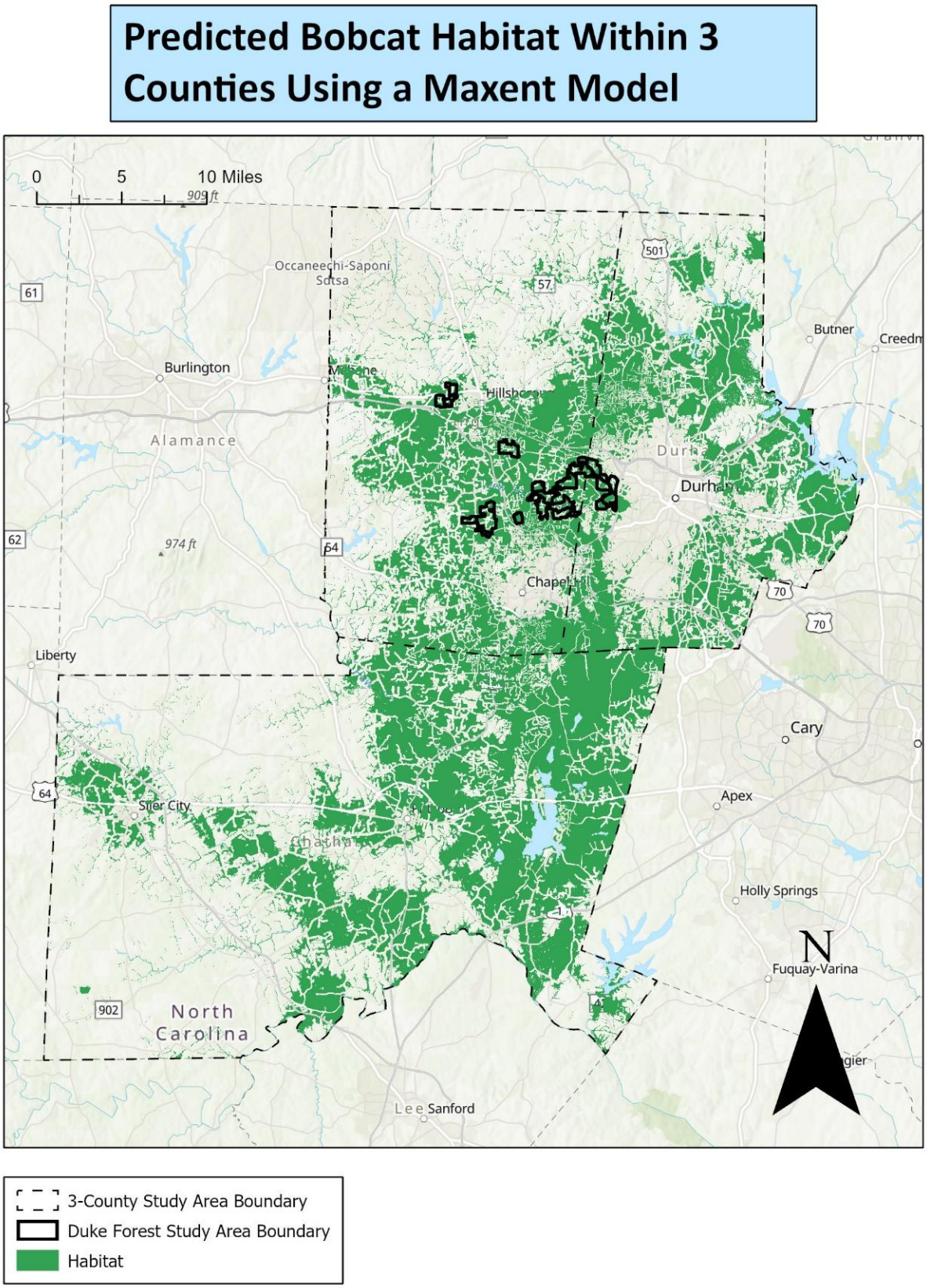


Figure 4. Predicted bobcat habitat within 3 counties form a Maxent model.

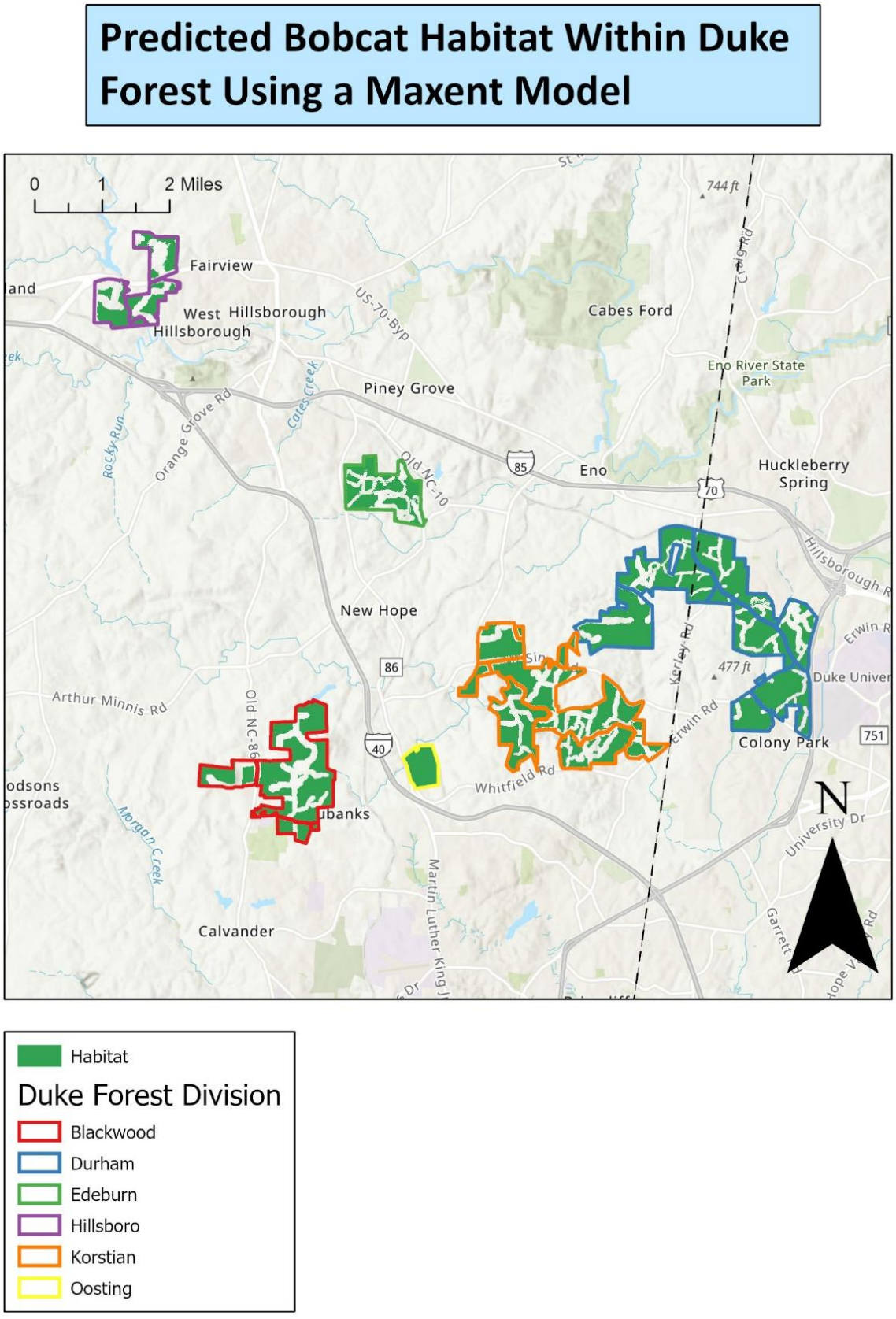


Figure 5. Predicted bobcat habitat within Duke Forest from a Maxent model.

2. Connectivity Overlay

2.1. Species and Regional Connectivity Overlay

2.1.1. General Wet-Mesic Hardwood Forest Guild

The four-toed salamander hotspots within Duke Forest totaled 170.70 acres, which was 13.50% of the connectivity priority area within Duke Forest and only 2.57% of Duke Forest land. There are few large hotspots (Figure 6), and two that are most distinctive are located in the middle of the Blackwood division and in the southwest portion of the Durham division. Blackwood contains the largest amount of hotspot area, followed by the Korstian and Durham divisions (Table 4).

When considering four-toed salamander habitat, I examined the overlap between the Maxent-predicted four-toed salamander habitat (Geschke 2019) and the connectivity areas. There was a larger proportion of predicted habitat outside of the connectivity areas than within the connectivity areas by a measure of about 3:2 (Table 3).

Table 3. Maxent predicted four-toed salamander habitat overlap with connectivity areas.

	Habitat Within Connectivity Area	**Habitat Outside of Connectivity Area**
Acres	191.85	272.83
Percentage of Habitat	41.29%	58.71%

Table 4. Four-toed salamander hotspots divided by Duke Forest division

Duke Forest Division	**Acres**	**Percentage of Hotspots**	**Percentage of Division**
Blackwood	116.81	68.50%	10.20%
Durham	24.09	14.13%	0.99%
Edeburn	2.74	1.61%	0.56%
Hillsboro	0.62	0.36%	0.11%
Korstian	24.14	14.16%	1.32%
Oosting	2.13	1.25%	1.30%

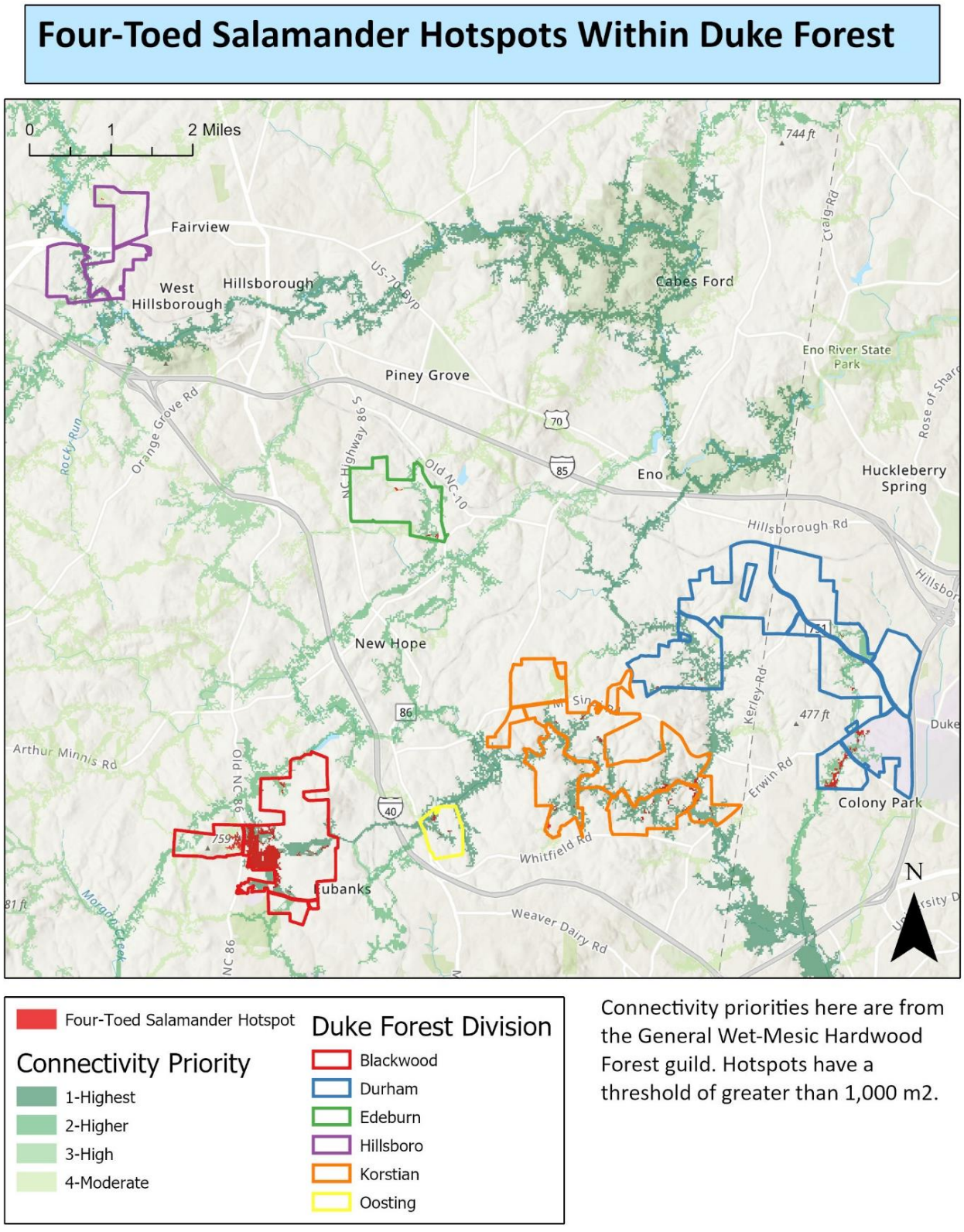


Figure 6. Four-toed salamander hotspots within Duke Forest determined from Maxent model and regional connectivity analysis.

Examining the characterizations of the hotpot area for this guild will help with management strategy analysis. Using the Southeastern Gap Analysis Project habitat types, a majority of the hotspots (about 65%) were located in Southern Piedmont small floodplain and riparian forest with the next largest percentage (about 19%) located in southern Piedmont dry oak-pine forest hardwood modifier (Table 5).

Table 5. Amount of four-toed salamander hotspot acreage within different SEGAP habitat types.

SEGAP Habitat Description	Acres	Percentage
Southern Piedmont Small Floodplain and Riparian Forest	110.55	64.77%
Southern Piedmont Dry Oak-(Pine) Forest - Hardwood Modifier	32.62	19.11%
Evergreen Plantations or Managed Pine (can include dense successional regrowth)	7.29	4.27%
Southern Piedmont Mesic Forest	6.40	3.75%
Southern Piedmont Dry Oak-(Pine) Forest - Mixed Modifier	5.63	3.30%
Southern Piedmont/Ridge and Valley Upland Depression Swamp	2.57	1.51%
Successional Shrub/Scrub (Other)	1.66	0.97%
Southern Piedmont Dry Oak-(Pine) Forest - Loblolly Pine Modifier	1.33	0.78%
Pasture/Hay	0.91	0.54%
Other - Herbaceous	0.89	0.52%
Developed Open Space	0.82	0.48%
Open Water (Fresh)	0.02	0.01%

More specifically, within the cover types designated by Duke Forest (by tree species and age), the hotspots occurred most frequently in the Yellow Poplar-Sweetgum; White, Black, Red Oak Hardwood Mix; Uneven-aged cover type, which made up about 63% of the hotspot cover types. The cover type with the next highest hotspot acreage composed about 6% of hotspots (Table 6).

Table 6. Amount of four-toed salamander hotspot acreage within 10 highest Duke Forest (DF) cover types.

DF Code	Cover Type Description	Acres	Percentage
AC-U	Yellow Poplar-Sweetgum; White, Black, Red Oak Hardwood Mix; Uneven-aged	107.66	63.30%
LA-U	Loblolly Pine; Yellow Poplar-Sweetgum Conifer-Hardwood Type; Uneven-aged	9.79	5.75%
A-U	Yellow Poplar-Sweetgum Type; Uneven-aged	9.56	5.62%
C-U	White, Black, Red Oak Type; Uneven-aged	9.56	5.58%
E-U	Mixed Hardwood Species Type; Uneven-aged	8.15	4.79%
LE-U	Loblolly Pine; Mixed Hardwood Species Conifer-Hardwood Type; Uneven-aged	5.21	3.07%
L-2	Loblolly Pine Type; 21-30 years old	2.74	1.61%
M-8	Miscellaneous Pine Species Type; 81-90 years old	2.27	1.34%
L-3	Loblolly Pine Type; 31-40 years old	1.58	0.93%
L-1	Loblolly Pine Type; 11-20 years old	1.33	0.78%

2.1.2. Dry-Wet Hardwood and Mixed Forest Guild

The marbled or spotted salamander hotspots within Duke Forest totaled 1548.28 acres, which was 48.11% of the connectivity priority area within Duke Forest and about 23.3% of Duke Forest land. The hotspots for this guild are most concentrated and larger than for the four-toed salamander hotspots (Figure 7). There is also dispersion of the hotspots for this guild across each division (Table 8).

When considering marbled and spotted salamander habitat, I examined the overlap between the Maxent-predicted marbled and spotted salamander habitat (Geschke 2019) and the connectivity areas. For these salamanders, there was a more even amount of predicted habitat within and outside of the connectivity areas, with the habitat outside of the connectivity area being slightly larger (Table 7).

Table 7. Maxent predicted marbled or spotted salamander habitat overlap with connectivity areas.

	Habitat Within Connectivity Area	Habitat Outside of Connectivity Area
Acres	1588.81	1898.97
Percentage of Habitat	45.55%	54.45%

Table 8. Marbled or spotted salamander hotspots divided by Duke Forest division.

Duke Forest Division	Acres	Percentage of Hotspots	Percentage of Division
Blackwood	385.43	24.96%	33.65%
Durham	341.72	22.13%	14.01%
Edeburn	174.26	11.28%	35.81%
Hillsboro	92.99	6.02%	15.94%
Korstian	459.74	29.77%	25.15%
Oosting	90.29	5.85%	55.13%

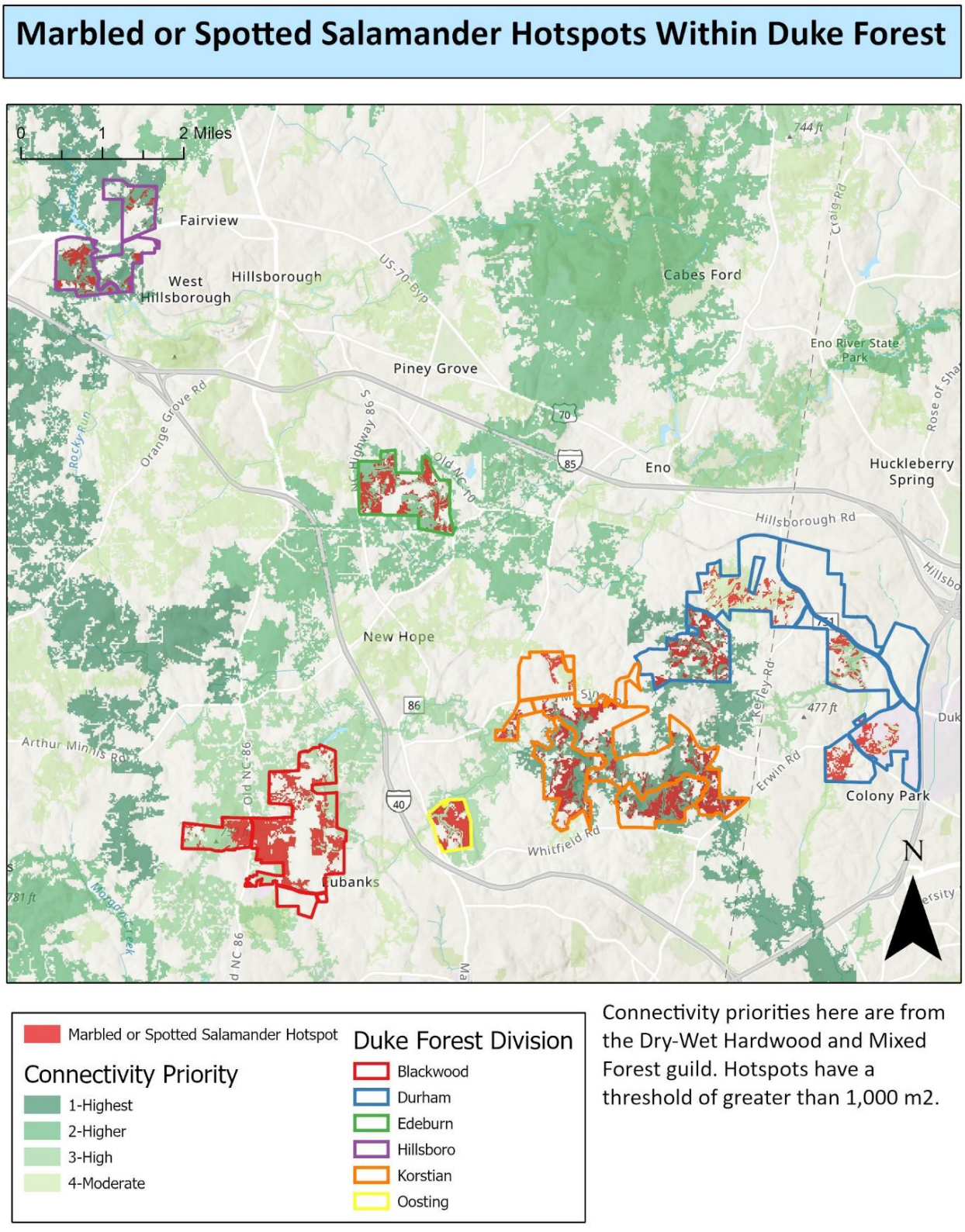


Figure 7. Marbled or spotted salamander hotspots within Duke Forest determined from Maxent model and regional connectivity analysis.

Using the Southeastern Gap Analysis Project habitat types, a majority of the hotspots (about 66%) were located in Southern Piedmont dry oak-pine forest hardwood modifier with the next largest percentage (about 12%) located in the Southern Piedmont small floodplain and riparian forest habitat (Table 9). This was the opposite of the four-toed salamander guild.

Table 9. Amount of marbled or spotted salamander hotspot acreage within different SEGAP habitat types.

SEGAP Habitat Description	Acres	Percentage
Southern Piedmont Dry Oak-(Pine) Forest - Hardwood Modifier	1017.87	65.74%
Southern Piedmont Small Floodplain and Riparian Forest	187.11	12.08%
Southern Piedmont Dry Oak-(Pine) Forest - Mixed Modifier	106.25	6.86%
Evergreen Plantations or Managed Pine (can include dense successional regrowth)	75.54	4.88%
Southern Piedmont Mesic Forest	72.90	4.71%
Successional Shrub/Scrub (Other)	28.81	1.86%
Southern Piedmont Dry Oak-(Pine) Forest - Loblolly Pine Modifier	22.76	1.47%
Developed Open Space	17.74	1.15%
Other - Herbaceous	8.95	0.58%
Pasture/Hay	5.46	0.35%
Southern Piedmont/Ridge and Valley Upland Depression Swamp	3.34	0.22%
Open Water (Fresh)	0.79	0.05%
Utility Swath - Herbaceous	0.35	0.02%
Low Intensity Developed	0.15	0.01%
Bare Soil	0.15	0.01%
Row Crop	0.12	0.01%

More specifically, within the cover types designated by Duke Forest (by tree species and age), the hotspots occurred most frequently in the White, Black, Red Oak; Uneven-aged class which made up about 28% of the cover types. The cover type with the next highest hotspot acreage was the yellow poplar-sweetgum; white, black, red oak hardwood mix; uneven-aged at about 24% of hotspots (Table 10).

Table 10. Amount of marbled or spotted salamander hotspot acreage within 10 highest Duke Forest (DF) cover types.

DF Code	Cover Type Description	Acres	Percentage
C-U	White, Black, Red Oak; Uneven-aged	430.48	28.09%
AC-U	Yellow Poplar-Sweetgum; White, Black, Red Oak Hardwood Mix; Uneven-aged	366.55	23.92%
A-U	Yellow Poplar-Sweetgum; Uneven-aged	88.17	5.75%
LE-U	Loblolly Pine; Mixed Hardwood Species Conifer-Hardwood Type; Uneven-aged	80.65	5.26%
E-U	Mixed Hardwood Species; Uneven-aged	55.75	3.64%
LA-U	Loblolly Pine; Yellow Poplar-Sweetgum Conifer-Hardwood Type; Uneven-aged	44.97	2.93%
L-2	Loblolly Pine; 21-30 years old	39.61	2.58%
NF	Non-forested	34.08	2.22%
LC-U	Loblolly Pine; White, Black, Red Oak Conifer-Hardwood Type; Uneven-aged	31.63	2.06%
AE-U	Yellow Poplar-Sweetgum; Mixed Hardwood Species Hardwood Mix; Uneven-aged	27.58	1.80%

2.1.3. Sparsely Settled Mixed Habitat Guild

The bobcat hotspots within Duke Forest totaled 2278.45 acres, which was 43.33% of the connectivity priority area within Duke Forest and about 34.28% of Duke Forest land. The hotspots for this guild are concentrated and large (Figure 8). The hotspots in each division make up at least 15% of the land within each division (Table 12).

When considering bobcat habitat, I examined the overlap between the Maxent-predicted bobcat habitat and the connectivity areas. For bobcats, the habitat within the connectivity area was much higher than the habitat outside of the connectivity areas (Table 11).

Table 11. Maxent predicted bobcat habitat overlap with connectivity areas.

	Habitat Within Connectivity Area	Habitat Outside of Connectivity Area
Acres	3510.12	870.33
Percentage of Habitat	80.13%	19.87%

Table 12. Bobcat hotspots by Duke Forest division.

Duke Forest Division	Acres	Percentage of Hotspots	Percentage of Division
Blackwood	539.60	23.68%	47.11%
Durham	756.24	33.19%	31.01%
Edeburn	73.02	3.20%	15.00%
Hillsboro	128.22	5.63%	21.98%
Korstian	628.81	27.60%	34.39%
Oosting	152.56	6.70%	93.14%

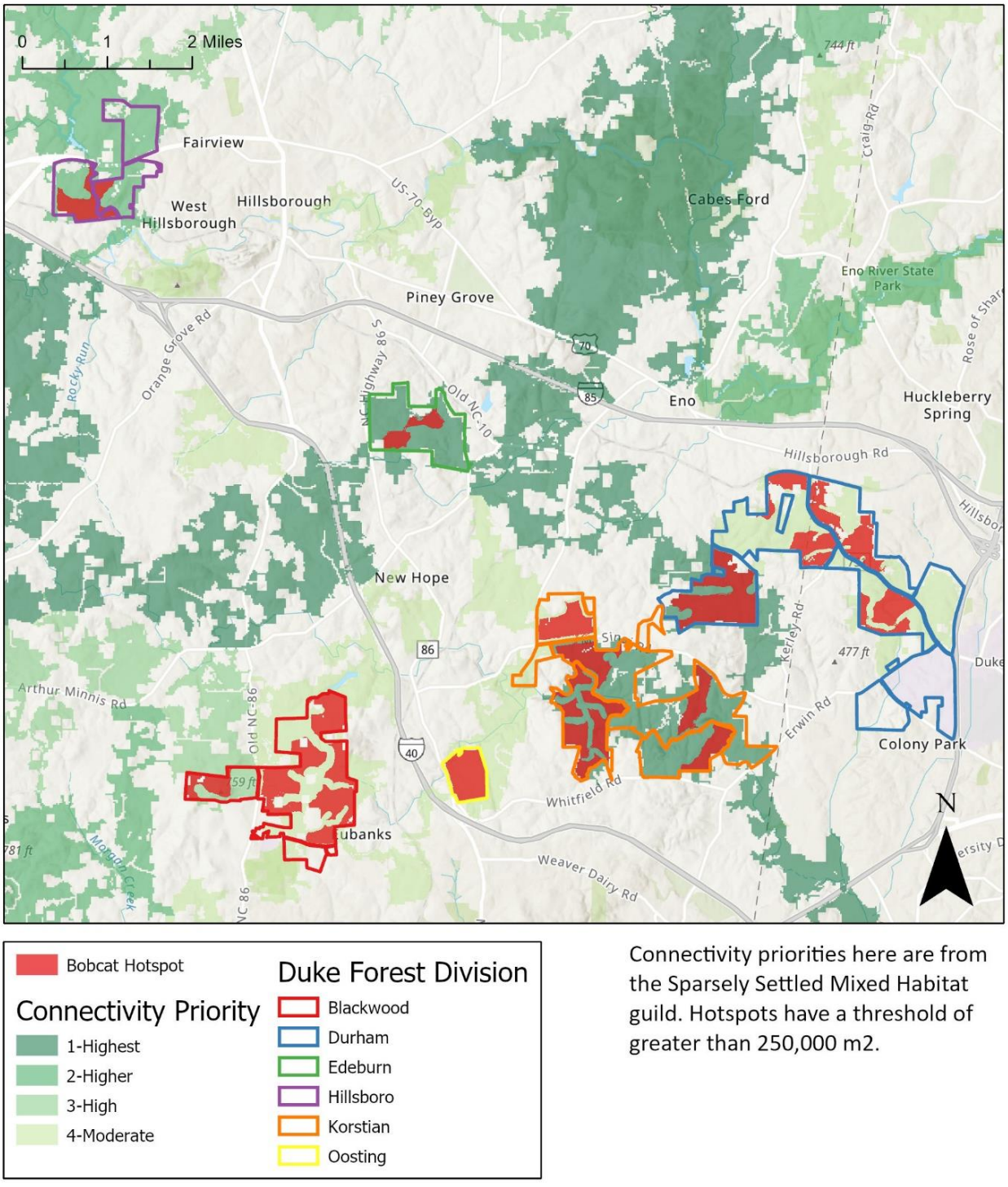


Figure 8. Bobcat hotspots within Duke Forest determined from Maxent model and regional connectivity analysis.

Using the Southeastern Gap Analysis Project habitat types, about half (48.77%) of the hotspots were located in Southern Piedmont dry oak-pine forest hardwood modifier with the next largest percentage (about 27%) located in the Evergreen plantations or managed pine (including dense successional regrowth) (Table 13).

Table 13. Amount of bobcat hotspot acreage within different SEGAP habitat types.

SEGAP Habitat Description	Acres	Percentage
Southern Piedmont Dry Oak-(Pine) Forest - Hardwood Modifier	1111.30	48.77%
Evergreen Plantations or Managed Pine (can include dense successional regrowth)	610.77	26.81%
Southern Piedmont Dry Oak-(Pine) Forest - Mixed Modifier	201.44	8.84%
Southern Piedmont Mesic Forest	131.58	5.78%
Southern Piedmont Small Floodplain and Riparian Forest	113.42	4.98%
Southern Piedmont Dry Oak-(Pine) Forest - Loblolly Pine Modifier	41.41	1.82%
Successional Shrub/Scrub (Other)	39.59	1.74%
Other - Herbaceous	17.59	0.77%
Pasture/Hay	5.71	0.25%
Developed Open Space	4.69	0.21%
Bare Soil	0.37	0.02%
Southern Piedmont/Ridge and Valley Upland Depression Swamp	0.52	0.02%
Open Water (Fresh)	0.02	0.00%
Low Intensity Developed	0.02	0.00%

More specifically, within the cover types designated by Duke Forest (by tree species and age), the hotspots occurred most frequently in the White, Black, Red Oak; Uneven-aged class which made up about 19% of the hotspot cover types. The cover type with the next highest hotspot acreage was the yellow poplar-sweetgum; white, black, red oak hardwood mix; uneven-aged at about 11% of hotspots (Table 14). Thus, the bobcat hotspots were fairly distributed among a variety of Duke Forest cover types.

Table 14. Amount of bobcat hotspot acreage within 10 highest Duke Forest (DF) cover types.

DF Code	Cover Type Description	Acres	Percentage
C-U	White, Black, Red Oak; Uneven-aged	422.52	18.55%
AC-U	Yellow Poplar-Sweetgum; White, Black, Red Oak Hardwood Mix; Uneven-aged	249.13	10.94%
L-3	Loblolly Pine Type; 31-40 years old	163.76	7.19%
L-0	Loblolly Pine Type; 1-10 years old	158.49	6.96%
LE-U	Loblolly Pine; Mixed Hardwood Species Conifer-Hardwood Type; Uneven-aged	111.44	4.89%
L-2	Loblolly Pine Type; 21-30 years old	108.21	4.75%
A-U	Yellow Poplar-Sweetgum; Uneven-aged	100.82	4.43%
L-1	Loblolly Pine Type; 11-20 years old	96.37	4.23%
E-U	Mixed Hardwood Species; Uneven-aged	82.68	3.63%
LA-U	Loblolly Pine; Yellow Poplar-Sweetgum Conifer-Hardwood Type; Uneven-aged	63.41	2.78%

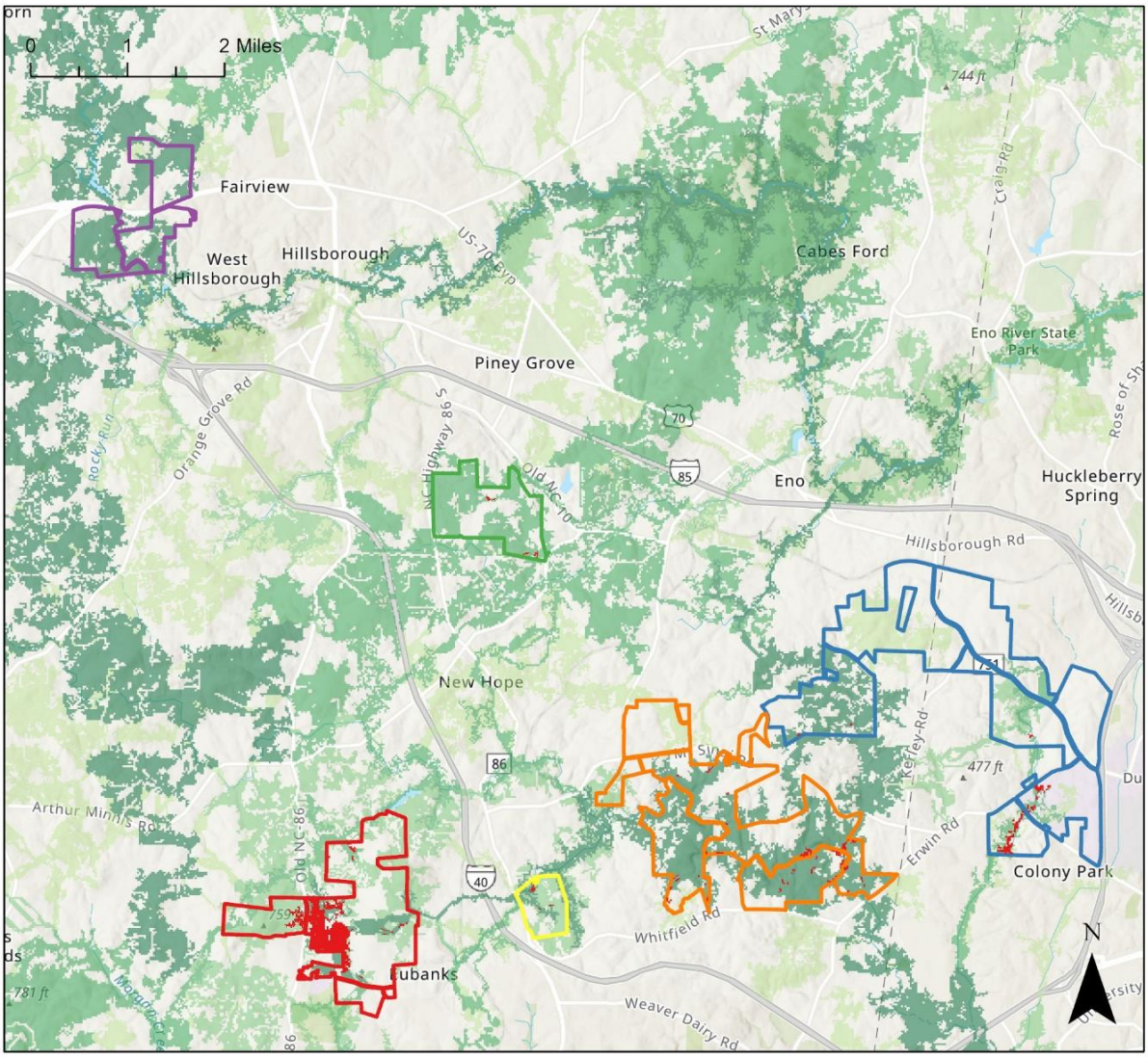
2.1.4. Combination Salamander Hotspots

The overlap of the marbled or spotted salamanders and the four-toed salamanders totaled 163.68 acres, which was 4.93% of the connectivity priority area within Duke Forest and 2.46% of Duke Forest land. This represents area very important to species of these two guilds and important to connectivity with areas off Duke Forest property. Most of these hotspots are in the Blackwood division, but there are smaller quantities in the Durham and Korstian division too (Table 15).

Table 15. Salamander hotspots by Duke Forest Division.

Duke Forest Division	Acres	Percentage of Hotspots	Percentage of Division
Blackwood	115.45	70.61%	10.08%
Durham	22.19	13.57%	0.91%
Edeburn	2.74	1.68%	0.56%
Hillsboro	0.32	0.20%	0.06%
Korstian	20.71	12.66%	1.13%
Oosting	2.10	1.28%	1.28%

Salamander Hotspots Overlay within Duke Forest



Salamander Hotspot Overlay

Connectivity Priority
- 1-Highest
- 2-Higher
- 3-High
- 4-Moderate

Duke Forest Division
- Blackwood
- Durham
- Edeburn
- Hillsboro
- Korstian
- Oosting

Connectivity priorities here are from both the Dry-Wet Hardwood and Mixed Forest guild and the General Wet-Mesic Hardwood Forest guild, with the higher priority values displayed on top. Hotspots are from the marbled or spotted salamander hotspots overlaid with the four-toed salamander hotspots.

Figure 9. Salamander hotspot overlay within Duke Forest determined from Maxent model and regional connectivity analysis.

Using the Southeastern Gap Analysis Project habitat types, about two-thirds of the hotspots were located in Southern Piedmont small floodplain and riparian forest (66.85%) with the next largest percentage (about 19%) located in the Southern Piedmont dry oak-pine forest-hardwood modifier (Table 16).

Table 16. Amount of salamander hotspot acreage within different SEGAP habitat types.

SEGAP Habitat Description	Acres	Percentage
Southern Piedmont Small Floodplain and Riparian Forest	109.42	66.85%
Southern Piedmont Dry Oak-(Pine) Forest - Hardwood Modifier	31.70	19.37%
Southern Piedmont Mesic Forest	6.13	3.74%
Evergreen Plantations or Managed Pine (can include dense successional regrowth)	5.09	3.11%
Southern Piedmont Dry Oak-(Pine) Forest - Mixed Modifier	4.84	2.96%
Southern Piedmont/Ridge and Valley Upland Depression Swamp	2.57	1.57%
Successional Shrub/Scrub (Other)	1.56	0.95%
Southern Piedmont Dry Oak-(Pine) Forest - Loblolly Pine Modifier	1.33	0.82%
Other - Herbaceous	0.54	0.33%
Developed Open Space	0.25	0.15%
Pasture/Hay	0.22	0.14%
Open Water (Fresh)	0.02	0.02%

More specifically, within the cover types designated by Duke Forest (by tree species and age), the hotspots occurred most frequently in the Yellow poplar-sweetgum; white, black, red oak hardwood mixed; uneven-aged class which made up about 66% of the hotspot cover types. The cover type with the next highest hotspot acreage was the yellow poplar-sweetgum; uneven-aged at about 6% of hotspots (Table 17).

Table 17. Amount of salamander hotspot acreage within 10 highest Duke Forest (DF) cover types.

DF Code	Cover Type Description	Acres	Percentage
AC-U	Yellow Poplar-Sweetgum; White, Black, Red Oak Hardwood Mix; Uneven-aged	107.29	65.80%
A-U	Yellow Poplar-Sweetgum; Uneven-aged	9.54	5.85%
LA-U	Loblolly Pine; Yellow Poplar-Sweetgum Conifer-Hardwood Type; Uneven-aged	9.22	5.65%
C-U	White, Black, Red Oak; Uneven-aged	9.02	5.53%
E-U	Mixed Hardwood Species; Uneven-aged	8.01	4.91%
LE-U	Loblolly Pine; Mixed Hardwood Species Conifer-Hardwood Type; Uneven-aged	5.21	3.20%
M-8	Miscellaneous Pine Species Type; 81-90 years old	2.27	1.39%
AE-U	Yellow Poplar-Sweetgum; Mixed Hardwood Species Hardwood Mix; Uneven-aged	1.26	0.77%
L-0	Loblolly Pine Type; 1-10 years old	1.19	0.73%
ME-2	Miscellaneous Pine Species; Mixed Hardwood Conifer-Hardwood Type; 21-40 years old	1.14	0.70%

2.2. Literature Review on Management Action Effects by Representative Species

The full table of information collected in the literature review can be found in Appendix 6 (Table 6.1). Please note that research on general amphibians or salamanders was done to supplement the other salamander research and is not all inclusive.

Effects of Management Actions on Bobcats: Timber harvest may be beneficial to bobcat due to an increase in debris and subsequent denning and resting sites (Boyle and Fendley 1987), concealment cover, or prey (McNitt et al. 2020). Prescribed burning may be beneficial for bobcats by drawing prey to the area due to an increase in dense herbaceous cover (Cochrane et al. 2006, Jorge et al. 2020, Little et al. 2018) or by creating edge habitat (McNitt et al. 2020). However, increasing pyrodiversity may

decrease bobcat populations (Jorge et al. 2020), or small-scale fires may not have a large influence on bobcat habitat selection (Little et al. 2018). There was little data found in the literature for effects of streamside management zones (SMZs) or constructed wetlands on bobcats. Lastly, planted food plots may support bobcat prey population but may serve to concentrate bobcats in a smaller area (Cochrane et al. 2006).

Effects of Management Actions on Salamanders or Amphibians in General: Timber harvest may cause a variety of microclimate changes including changes in air and soil temperature, wind speed, light intensity, and relative humidity (McLeod and Gates 1998). Removal of portions of the canopy may minimize negative effects on amphibian populations compared to clearcutting (Semlitsch et al. 2009) but may still decrease salamander abundance (Tilghman et al. 2012). Low-intensity prescribed fire may not have much of an impact on coarse woody debris as high intensity fires (and thus lower impact on salamanders) (Moseley et al. 2003), but salamanders have been shown to avoid burned areas in the short-term (Schurbon and Fauth 2003). Ruts and ditches created by firebreaks may act as population sinks (Pilliod et al. 2003). Wider SMZs than is currently the standard may help protect against edge effects from harvest areas (Guzy et al. 2019). No details were found in the literature for constructed wetland effect or food plot effects.

Effects of Management Actions on Four-Toed Salamanders: There was little found in the literature about timber harvest effects. In one study, four-toed salamander adults were more prevalent in unburned pine areas than pine areas probably due to the reduced density and basal area of standing trees, canopy closure, and litter depth (McLeod and Gates 1998). When considering SMZs, in on study the mean probability of occupancy for four-toed salamanders didn't increase to 50% until a 50m SMZ width was enforced (Guzy et al. 2019). Constructed wetlands would benefit four-toed salamanders if they had more canopy cover, moss, steep pond edges, and faced north (King 2012, Wahl III et al. 2008, Chalmers and Loftin 2006). No details were found in the literature about how food plots affected four-toed salamanders.

Effects of Management Actions on Marbled or Spotted Salamanders: Marbled and spotted salamanders favor forests more than cut-over forests (McLeod and Gates 1998). This is due to a variety of negative impacts of harvesting, including changes in canopy cover, leaf litter depth, presence of refuges, soil conditions, edge effects, and road construction. Location of the timber harvest relative to the wetland (Homan et al. 2014) and the amount of harvesting may also affect marbled and spotted salamanders. However, many of these studies have been short-term, and more work is needed to

determine how long these effects last. In a few studies, marbled or spotted salamanders preferred unburned forests over burned forests (Means and Campbell 1981 as cited in Russell et al. 1999, Klaus and Noss 2016). A few studies have shown that SMZs would benefit marbled or spotted salamanders if they were at least greater than 30m (Guzy et al. 2019, Gamble et al. 2006, Perkins and Hunter, Jr. 2006). Constructed wetlands could be beneficial to these salamanders if they are large and deep (Petranka et al. 2003); however, one study found that marbled salamanders were only found in natural ephemeral wetlands in one study (Denton and Richter 2013). No details were found in the literature about how food plots affected marbled or spotted salamanders.

DISCUSSION

1. Bobcat Modeling

1.1. Literature Review

Results from the literature review resulted in a low amount of literature confined to the southeast as opposed to the northeast or Midwest. However, with the literature I was able to consult, I felt that I obtained a reasonable idea of habitat variables important to bobcats. If there was conflicting literature, I decided to include the habitat variable anyway to be conservative and see what effects the model produced.

1.2. Maxent Habitat Modeling

While Maxent has been employed for species distribution modeling for many years, there are many variables that can be adjusted within its settings. For this project, the main method of manipulation within the Maxent "black box" was cross-validations. With the Maxent model, I focused on tuning to fit a certain number of true positives, meaning occurrence points that the model correctly predicted as habitat. It's difficult to justify that a Maxent model is "true" because species have been shown to use habitat that's not always of high quality or have been shown not to inhabit areas where there's "perfect" habitat. While aiming to gain a true positive rate without categorizing the entire study area as bobcat habitat, I feel that I did an adequate job. I would have liked to have had more data points to better inform the Maxent model, but a challenge of bobcats is their shyness and large home ranges.

2. Connectivity Overlay

2.1 Species and Regional Connectivity Overlay

2.1.1. Combination Salamander Hotspots

Prioritization for Duke Forest within these combination of salamander hotspots represents areas that need to be considered for both the marbled or spotted salamanders and four-toed salamanders. Thus, this shows the areas that are important as habitat and connectivity to species within the Dry-Wet Hardwood and Mixed Forest Guild and the General Wet-Mesic Hardwood Forest Guild. I've noted two main priority areas where the hotspots are concentrated (Figure 10). Within these areas, the largest chunk of salamander hotspot overlay was in the middle of the Blackwood division. Most of this hotspot is in the Meadow Flats registered natural heritage area where timber harvest is restricted (Figure 11). However, there are future pine harvests planned adjacent to this area to the east (Figure 12). Those harvest areas are planned from fiscal year 2029/2030 to 2038/2039, and care should be taken in these locations.

The other reasonably connected hotspot chunk is in the southern Durham division (Figure 10). This area is not within a Natural Heritage Area, and pine harvests are planned adjacent to this section in the between the fiscal year 2019/2020 and 2038/2039 and then again between the fiscal year 2049/2050 and 2058/2059 (Figure 12).

There are very few of the overlay salamander hotspots that are directly within planned pine harvests. These two large hotspot chunks are within the best management areas for a multitude of salamander species and within major pond corridors, as ascertained by Geschke 2019, Figure 29. This effort validated that these areas should indeed be priority management for connectivity between wetlands and for connectivity outside of Duke Forest.

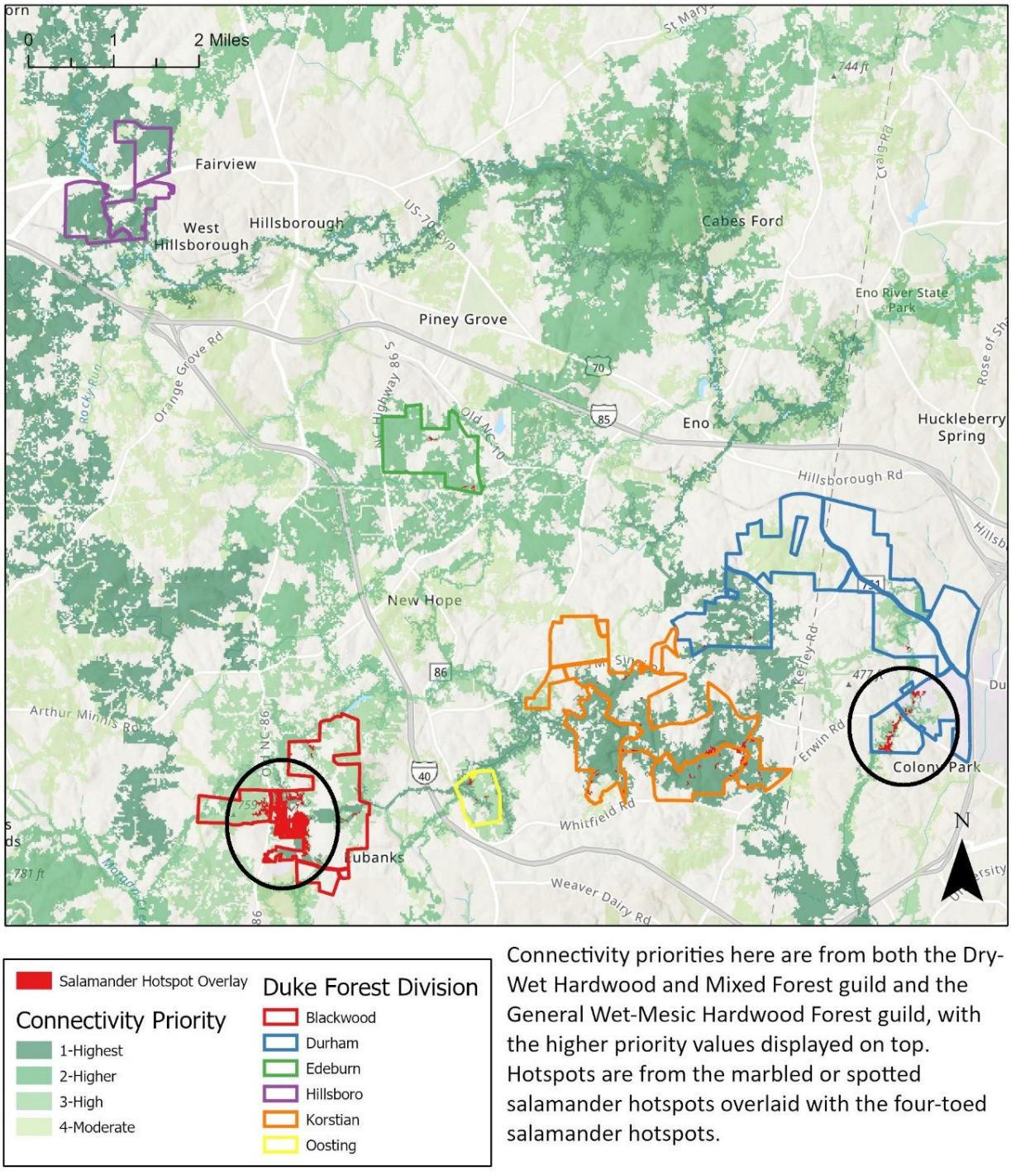


Figure 10. Priority areas for Duke Forest management consideration for habitat and connectivity.

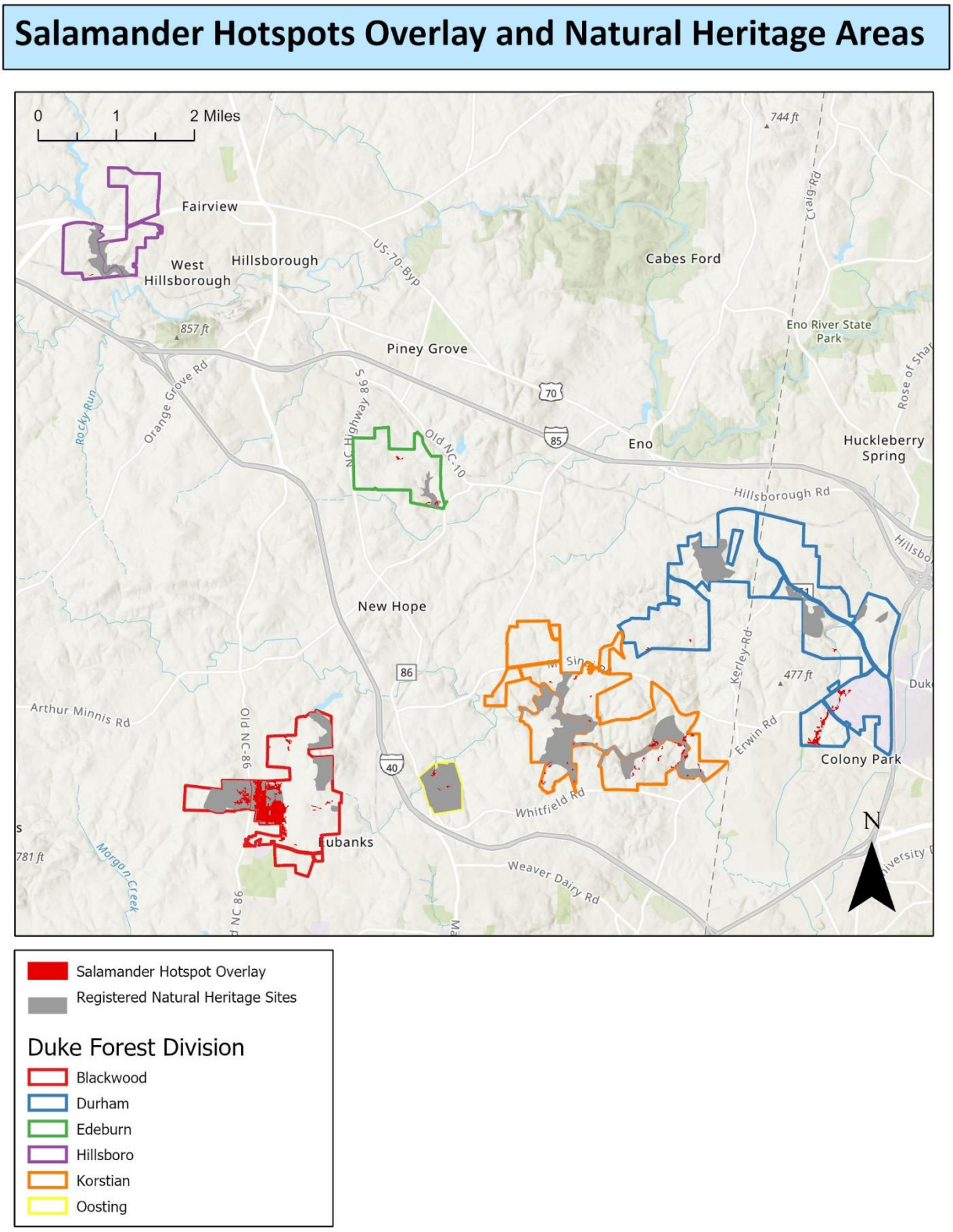


Figure 11. Salamander hotspot overlay with Registered Natural Heritage Areas.

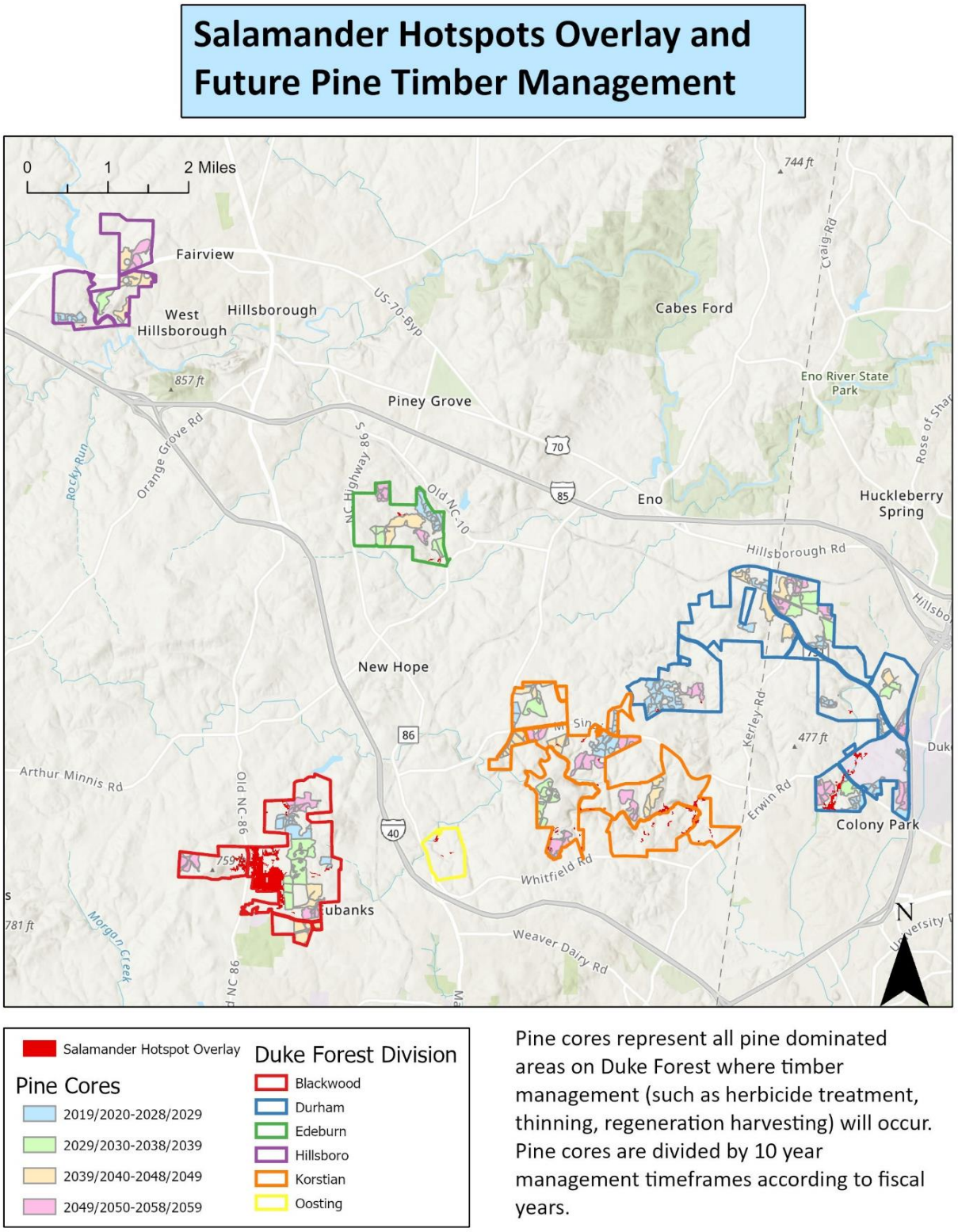


Figure 12. Salamander hotspots overlay with pine core areas representing future pine timber harvest (colored by 10-year segments).

2.1.2. Sparsely Settled Mixed Habitat Guild

First, one way to validate bobcat connectivity hotspots, and what I would urge Duke Forest to do would be to engage in bobcat population monitoring. One non-invasive way to do this would be deploying camera traps at the hotspots identified. Even though the bobcat hotspot is predicted habitat overlaid with connectivity, the bobcats may not actually be using these connectivity corridors or Duke Forest in general for habitat. The bobcat hotspots overlap some with the Natural Heritage Areas, but there are also many hotspots outside of these protected areas (Figure 13). Since the bobcat hotspots are much larger than the salamander hotspots, there was greater overlap between the bobcat hotspots and potential timber harvest areas (Figure 14). Timber harvest is not as much of a detriment to bobcats, however, since they have larger ranges and can avoid direct impacts.

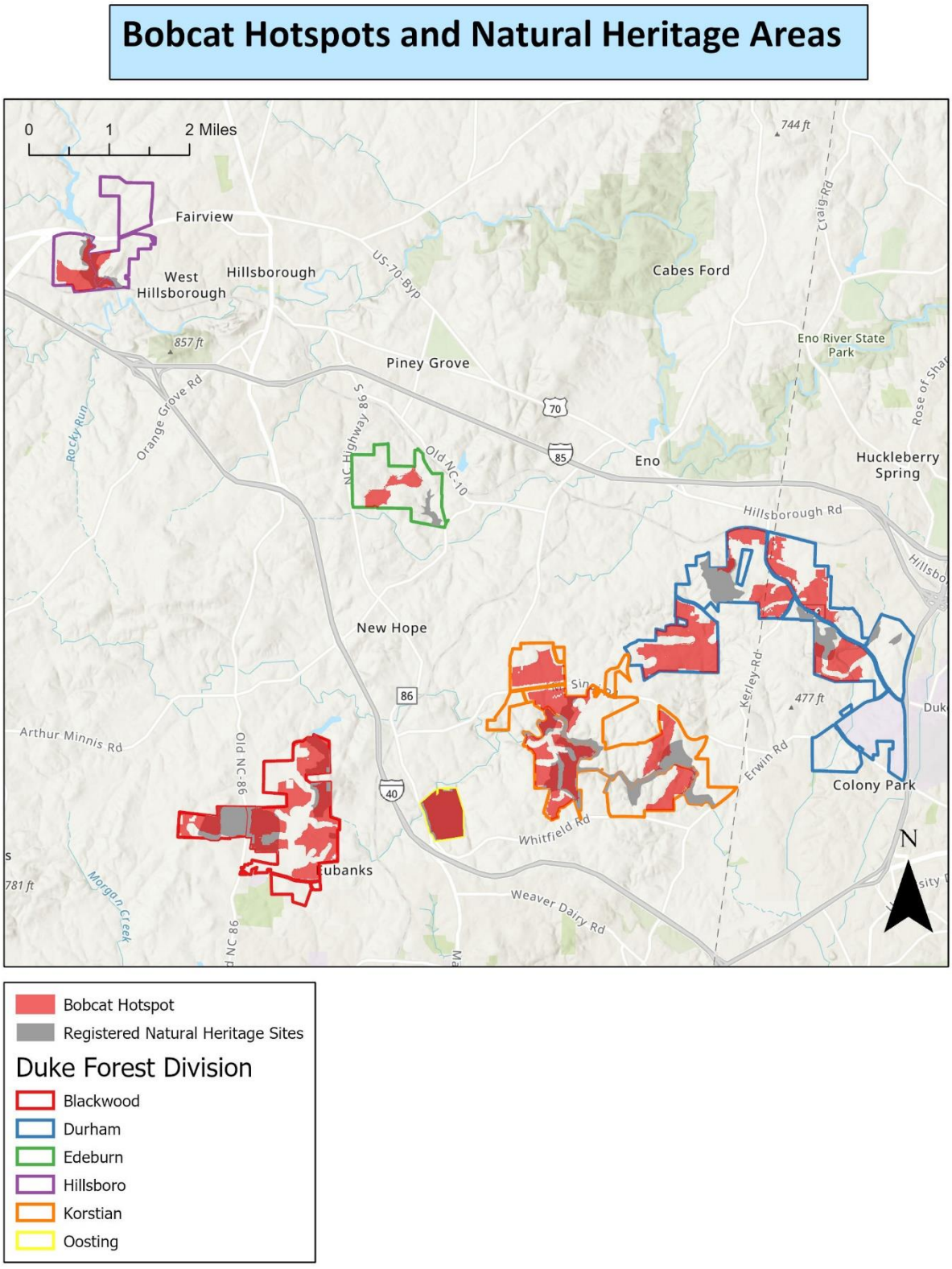


Figure 13. Bobcat hotspots with Registered Natural Heritage Areas.

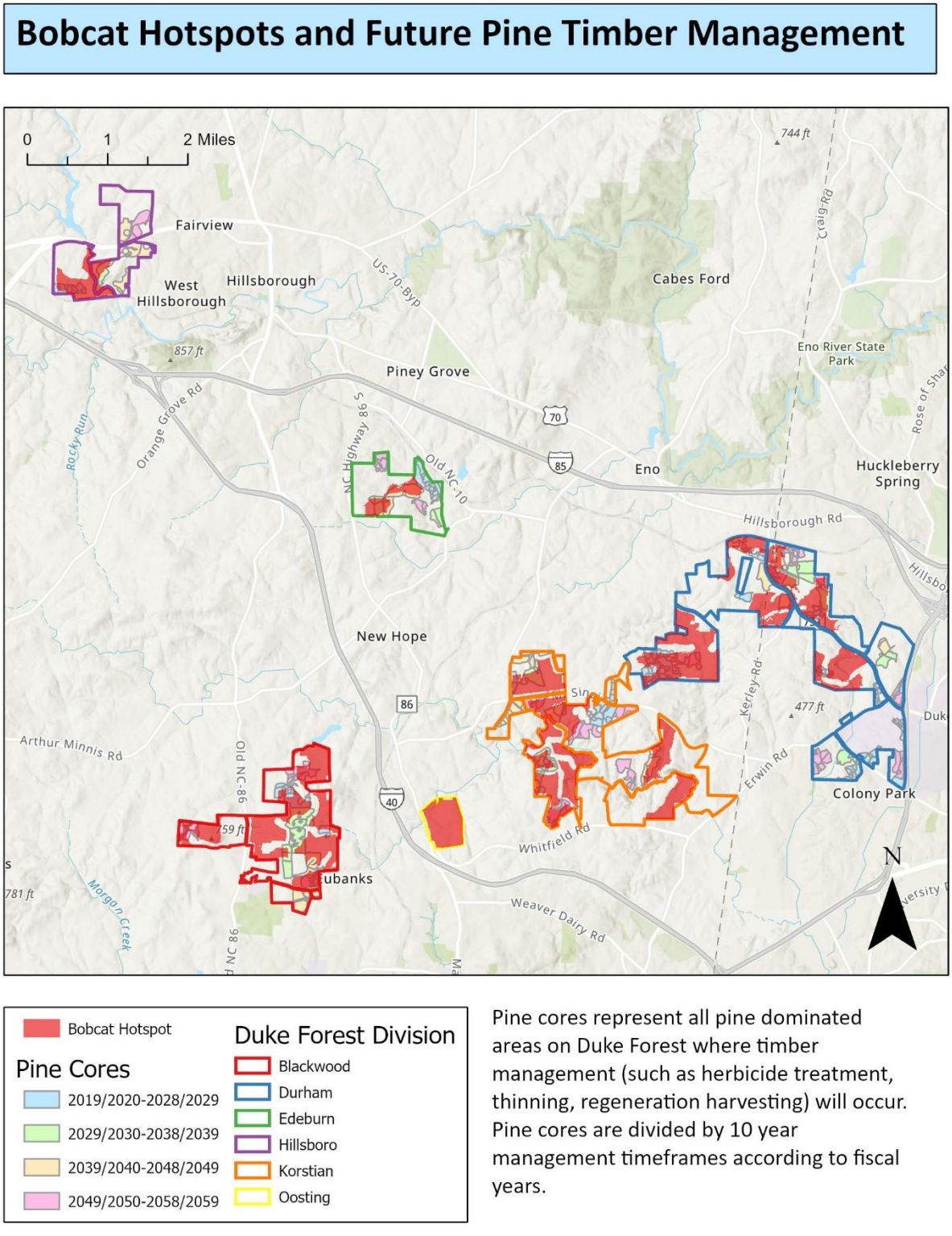


Figure 14. Bobcat hotspot with pine core areas representing future pine timber harvest (colored by 10-year segments).

2.2. Literature Review on Management Action Effects by Representative Species

The literature review of management implications for the bobcat, four-toed salamander, and marbled or spotted salamanders revealed some gaps in literature. It was difficult to find literature pertaining to influence of prescribed fire on bobcats, presumably due to the wide-ranging characteristics of the animal. In addition, more work could be done examining the specific influence of timber harvest on bobcat habitat usage, including studying a wide range of harvest prescriptions and stand ages (McNitt et al. 2020). There were not a multitude of studies involving four-toed salamanders individually, probably due to their secretive and seasonal behavior (Guzy et al. 2019). For salamander research in general, more work needs to be conducted that focuses on salamander reactions in the long-term, not just 1-2 years post-management action. Specifically, longer-term studies of movement behavior are needed and might help determine the maximum size for clearcuts nearby salamander habitat (Graeter et al 2008). Further research would include studying impacts of forest harvesting on a variety of salamander age classes, how species respond to different sizes of coarse woody debris, and amphibian response in burned vs. unburned riparian zones (Felix et al. 2010, Semlitsch et al. 2009, Pilliod et al. 2003).

2.3. Management Recommendations for Duke Forest

2.3.1. Species Biology Background

Prioritization for Duke Forest should focus on the salamanders mentioned in this report. The four-toed salamander, marbled salamander, and spotted salamander may all be affected by timber harvest, prescribed fire, and the size of streamside management zones due to their biology and natural history traits. Ambystomid salamanders spend most of their life underground but emerge aboveground to breed in aquatic habitats (Morris and Maret 2007). Hardwood stands tend to contain more amphibians than pine stands since hardwood leaves have a higher pH than coniferous needles (Schurbon and Fauth 2003). Spotted and marbled salamanders generally lay eggs in ephemeral pools since there are fewer predators than permanent pools (Petranka 1998 as cited in Chambers 2008). Spotted salamanders tend to deposit their eggs on underwater vegetation while marbled salamanders tend to deposit their eggs under leaf litter and woody debris (Cromer et al. 2002). Four-toed salamanders, on the other hand, lack lungs and, as such, need moist habitat to respire through their skin (Petranka et al. 1993 as cited in Morris and Maret 2007). They live and lay eggs aboveground in terrestrial habitat or on moss in vernal pools; four-toed salamanders are thus sensitive to management practices altering leaf litter, temperature, and forest floor moisture (Petranka et al. 1993 as cited in Morris and Maret 2007). While

bobcats may have other suitable habitat within mobility distance, salamanders have poor dispersal and changes in their habitat will be detrimental. With this in mind, I've presented some recommendations for Duke Forest to improve their practices in these prioritization areas.

2.3.2. Timber Harvest Recommendations

Much of the recommendations within the timber harvest section build and provide more specifics for techniques that Duke Forest already uses. One of the main priorities for Duke Forest should be avoiding clearcuts or timber harvesting that segment salamander populations, leading to reproductive isolation (Todd et al. 2009). Thus, clearcuts should be avoided if possible within the connectivity priority areas identified by Geschke 2019 and within the connectivity priority areas identified here. Vernal pools in Duke Forest should be treated as a single management unit (3+ pools within ¼ mile of each other), and zones should be extended around the cluster rather than the individual pools (deMaynadier and Houlahan 2008). Since clearcuts can have detrimental effects on salamanders, harvest should aim to retain at least 75% of the forest canopy if they are nearby connectivity areas (Felix et al. 2010).

Timing of harvesting activities should be considered: harvesting activities should be restricted to the wintertime when the ground is frozen, and there is a smaller chance of direct mortality of salamanders and other herpetofauna (deMaynadier and Houlahan 2008). Along this line, it is best to conduct harvesting in dry seasons to reduce rutting and soil compaction associated with severe hydrological disturbances (Cromer et al. 2002).

Soil compaction should be minimized to the extent possible during logging to reduce detriment to burrows for salamanders (Osbourn et al. 2014). Logging roads should not be constructed within a reasonable distance of existing vernal pools (Chambers 2008), and less invasive methods such as track or wide tire vehicles should be used (Cromer et al. 2002). Skidder trails should run parallel to slopes if possible to follow natural contours and minimize soil erosion (Bailey et al. 2006). In general, effects beyond just the designated harvest area must be considered to minimize the effect of management on canopy and litter (deMaynadier and Hunter, Jr. 1998

2.3.3. Prescribed Fire Recommendations

Recommendations for how to conduct prescribed fire to reduce impacts on amphibians include defining more specifics as to when the burn should be conducted, as well as reducing incidental effects from burning. To reduce impact on coarse woody debris, leaf litter, and bare ground creation, fires should be

burned at a low intensity (Moseley et al. 2003). Burning should be avoided in May, June, and July since woodland salamanders are most active aboveground then (Harper et al. 2016). If burning near a wetland and there are other wetlands nearby, leave one of the other nearby wetlands unburned so re-colonization of the burned area is possible (Schurbon and Fauth 2003). Avoid constructing road breaks and fire breaks near wetlands due to their potential as population sinks if they fill with water and amphibians attempt to breed in them (Pilliod et al. 2003). Minimize sedimentation loss (Pilliod et al. 2003). When water levels are naturally low, prescribed fires may burn into wetlands since historically wetlands burned, and burns can help control succession (Bailey et al. 2006).

2.3.4. Streamside Management Zone Recommendations

Management related to streamside management zone should expand upon Duke Forest's current buffer to consider more of the terrestrial habitat. Hydroperiods should be considered with buffering: if amphibian conservation is a major priority in an area and hydroperiod is short (<4 months), buffers wider than 100m may be useful. If amphibians are only one of a suite of wildlife one is managing for, only pools with hydroperiods longer than four months may be necessary for investment return (Veysey Powell and Babbitt 2015). Buffers should include both a vernal pool protection zone of 31m or 100ft and then a vernal pool life zone of 31m-122m/100-400 feet (deMaynadier and Houlahan 2008). Within the vernal pool protection zone, limited harvests may be conducted while retaining >75% canopy cover, operating on frozen or dry soil, avoiding the use of heavy machinery, and retaining abundant coarse woody debris (CWD) (deMaynadier and Houlahan 2008). The vernal pool life zone should exist for migration, dispersal, connectivity, and nonbreeding habitat for adults, and only partial harvests should occur here with while still retaining >50% canopy cover, operating on frozen or dry soil, abundant CWD, and harvest openings <0.3 ha (3/4 acre) (deMaynadier and Houlahan 2008).

2.3.5. Vernal Pool/Constructed Wetland Recommendations

Constructing vernal pools for the proliferation of species like the four-toed salamander should be a last resort. Natural wetlands are better for the species. However, if constructing becomes important to the forest, natural vegetation must be supported, compaction around the pool should be avoided as much as possible, the vernal pool should aim to emulate slopes of natural ponds, and the pond should be buffered at least 30-300m to provide for connectivity (Calhoun et al. 2014). Ideally, pool vegetation should be monitored for at least 5 years after creation (Calhoun et al. 2014). If specifically creating pools for four-toed salamanders, wetlands should contain many trees, downed woody debris, moss, and

upturned soil clumps with steep pond edges facing north (King 2012, Wahl III et al. 2008, Chalmers & Loftin 2006). These elements will provide the wetland with ideal microhabitats for nesting.

CONCLUSION

With the expansion of urbanization, wildlife connectivity is becoming more important in addition to only wildlife habitat protection. Animals must be able to move between habitat patches, and Duke Forest, located in an urban area, is a prime spot for employing connectivity protection between habitat within its forest and the surrounding habitats.

This project first created a Maxent model to predict habitats for bobcats located in Durham, Orange, and Chatham counties. This predicted habitat map may be used to highlight areas for bobcat conservation. This project also considered indicator species from the regional connectivity plan and developed recommendations for forest management related to these species to maximize connectivity in the future (Table 18). While bobcats were not found to be affected greatly by management, more damage can be done to salamanders.

I hope this work will help to highlight how regional connectivity can be applied at more of a local level. Thus, these recommendations for Duke Forest will aid in their management plans for the future and heighten awareness for wildlife connectivity.

Table 18. Recommendations for Duke Forest to provide for wildlife connectivity within their management types

Management Type	Recommendations

Timber Harvest	• Location and Amount of Cutting
	  ○ Avoid clearcuts within connectivity priority areas (identified by Geschke 2019 and here) and treat nearby vernal pools as one management unit
	  ○ If close to connectivity area, retain at least 75% of canopy with timber harvest
	• Timing
	  ○ Restrict harvesting in winter and conduct in dry seasons
	• Associated Effects
	  ○ Do not construct logging roads nearby vernal pools, and use track or wide tire vehicles if possible
	  ○ Run skidder trails parallel to slopes
	  ○ Consider effects beyond just designated harvest area

Prescribed Fire	• General Burning Practices
	  ○ Burn at low intensity
	  ○ Allow burns to creep into wetlands but if burning around wetland group, leave one of wetlands unburned
	• Timing
	  ○ Avoid burning in May, June, and July
	• Associated Effects
	  ○ Avoid constructing fire lines near wetlands and minimize sedimentation loss

Streamside Management Zones	• Consider buffers > 100m if focusing solely on amphibian conservation in an area
	• Redefining buffers
	  ○ Vernal pool protection zone (31m/100ft): limited harvests while retaining >75% canopy cover and retaining CWD
	  ○ Vernal pool life zone (31m-122m/100-400ft): partial harvests with >50% canopy cover, abundant CWD, harvest openings <0.3 ha (0.75 acres)

Vernal Pool/Constructed Wetlands	• Constructing wetlands should be a last resort!
	• BMPs if constructing:
	  ○ Support natural vegetation, avoid compaction around pool, emulate natural slopes, buffer pool by 30-300m
	  ○ Monitor pool vegetation for 5+ years after creation
	  ○ 4-toed salamander specific pools: contain many trees, downed woody debris, moss, upturned soil clumps, steep pond edges facing north

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APPENDIX

1. Bobcat Habitat Literature Review Table
2. Bobcat Occurrence Points
3. Focal Habitat Layers
4. Correlation Score of Variables
5. Bobcat Maxent Thresholding
6. Management Action Effects Literature Review Table

1. Bobcat Habitat Literature Review Table

Table 1.1. Literature review of relevant habitat variables for the bobcat

Habitat Variable	
Migration	No details found in the literature.
Road Density/Distance to Roads	Roads may serve as travel corridors (Lovallo and Anderson 1996 as cited by Little et al. 2018) and provide edge habitats (Frey and Conover 2006; Barding and Nelson 2008 as cited by Little et al. 2018). But bobcats have avoided main roads (Kelly and Holub 2008), movement may be threatened by roads (Hess and King 2002), and within 100m of a road may be considered low quality habitat (Hess et al. 2006). In at least one study, distance to roads did not influence bobcat occupancy strongly (Erb et al. 2012).
Elevation	Elevation may influence bobcats in the southeast. One study found that the probability of bobcat use increased as elevation increased, though not to a significant amount (Conner and Leopold 1998).
Aspect	No details found in the literature.
Slope	One study found that as the slope of the area increased, the probability of bobcat use increased (Conner and Leopold 1998). They believed that "bobcats preferred steeper slopes because of the relative seclusion offered by such areas (Zezulak and Schwab 1979; Hamilton 1982)" (Conner and Leopold 1998).
Temperature	No details found in the literature.
Precipitation	No details found in the literature.
Land Cover	Bobcats "use a variety of habitats to meet daily, seasonal, and yearly needs" (Lancia et al. 1982), "adapt readily to a variety of habitats and ecological conditions" (Diefenbach et al. 2013), and may be influenced by presence of prey in certain areas (Cochrane et al. 2006; Zwank et al. 1985 as cited in Godbois et al. 2003): "bobcats in southern environs may be able to successfully exploit preferred prey items throughout each season by simply altering habitat selection patterns rather than shifting prey selection" (Chamberlain et al. 2003). However, another study has shown that the density of bobcats had more of an effect on habitat than prey (Benson et al. 2006). In general, bobcats are associated with local forest cover (Erb et al. 2012; Parsons et al. 2019). Bobcats preferred recent clear cuts and hardwood stands over pine dominated stands in one study (Rucker et al. 1989) and another's "findings demonstrate the importance of vegetation diversity (e.g., mature pine, mixed pine/hardwoods, hardwoods, agriculture/food plots, shrub-scrub) for bobcats in a forested landscape" (Little et al. 2018). Bobcats used agriculture, shrub/scrub, hardwood and wetland cover types (Kirby et al. 2010), and "hardwood stands...are frequently used by bobcats for den sites, thermal refugia, and travel corridors (Conner et al. 1992)" (Jorge et al. 2020).
Canopy Cover	No details found in the literature.

Patch Size/Complexity	Bobcats may prefer edges for prey resources. Bobcats have been shown to avoid the forest interior (McNitt et al. 2020) and "space requirements of bobcats appeared to decrease as habitat patches over the entire landscape became more complex in shape" (Constible et al. 2006). "Generalist rodent species and white-tailed deer, which are important food resources for bobcats (Chamberlain and Leopold 1999)..are expected to increase near edges (Williamson and Hirth 1985; Manson et al. 1999; Bowers and Dooley 1999; Nupp and Swihart 2000) and dense vegetation may provide stalking cover for bobcats (Lariviere and Walton 1997)" (Constible et al. 2006). However, another study found that "bobcats were the most specialized wilderness species in our study, with a positive association with large core forests" (Kays et al. 2017).
Stream Density/Distance to Water	One study defines low quality habitat as riverine/estuarine herbaceous and water (Hess et al. 2006); however, in another study, the "probability of bobcat use increased as distance to…creeks decreased" (Conner and Leopold 1998) perhaps due to prey concentrating in drift piles along creeks (Maser and Trappe 1984 as cited in Conner and Leopold 1998). Bobcats may also use creeks to move between other habitats (Rolley 1983; Shiflet 1984 as cited by Conner and Leopold 1998). When compared to coyotes, bobcats used greater amounts of wetter habitat like cutthroat seepage slopes, marshes, and swamps (Thornton et al. 2004). However, when comparing water availability to other parts of the country, "water is not likely to be a critical factor to bobcats in the East, because in this region there are probably few areas that do not offer adequate free water" (Boyle and Fendley 1987).
Management/Disturbance Tolerance	Bobcats have been shown to "reduce their activity and selected cover during diurnal periods, presumably to avoid interactions with humans" (Roberts et al. 2010), and they "were positively associated with increasing distances from anthropogenic land covers of development, roads, and crops" (Cove et al. 2019). Bobcats have "repeatedly shown avoidance and flight behavior within short distances of heavily used trails (George and Crooks 2006; Taylor and Knight 2001)" (Erb et al. 2012). The USGS categorizes the human impact disturbance level of bobcats as medium, meaning that "only portions of the landscape identified as being highly or moderately influenced by human disturbance are eliminated from the predicted distribution" (US Geological Survey 2017).

2. Bobcat Occurrence Points

Table 2.1. Bobcat occurrence points used in analysis

Latitude	Longitude	Date	County	Source
35.82183432	-78.97257749	1992	Chatham	ENH Landscape Conservation Group
35.85898219	-79.00765805	1992	Chatham	ENH Landscape Conservation Group
35.829324	-79.057544	2005	Chatham	ENH Landscape Conservation Group
35.7312202	-79.01002687	2006	Chatham	ENH Landscape Conservation Group
35.74993662	-79.12565452	2008	Chatham	ENH Landscape Conservation Group
35.71606	-79.53984	2015	Chatham	eMammal
35.66901	-79.12014	2016	Chatham	eMammal
35.65212	-79.06391	2017	Chatham	eMammal
35.65844	-79.06601	2017	Chatham	eMammal
35.70897	-79.20045	2017	Chatham	eMammal
35.815	-78.9359	2018	Chatham	eMammal
35.832613	-78.99598	2019	Chatham	ENH Landscape Conservation Group
35.88366675	-79.00680955	1988	Durham	ENH Landscape Conservation Group
36.06705115	-78.95736884	2006	Durham	ENH Landscape Conservation Group
35.923912	-78.982954	2012	Durham	ENH Landscape Conservation Group
35.87808	-78.95025	2014	Durham	eMammal
35.917599	-78.972104	2015	Durham	ENH Landscape Conservation Group
36.06883	-78.92357	2016	Durham	eMammal
35.88532582	-79.01471016	1988	Orange	ENH Landscape Conservation Group
35.88631688	-79.02134494	1988	Orange	ENH Landscape Conservation Group
36.01404538	-79.11549536	1988	Orange	ENH Landscape Conservation Group
36.07537406	-79.02846318	2004	Orange	ENH Landscape Conservation Group
36.03702	-79.047723	2010	Orange	TLC
35.98813	-79.12578	2014	Orange	eMammal
36.05878	-79.18003	2014	Orange	eMammal
35.88605	-79.01522	2017	Orange	eMammal
36.036135	-79.044964	2018	Orange	TLC
35.96848	-79.09823	2019	Orange	Duke Forest
35.97126	-79.0916	2019	Orange	Duke Forest

3. Focal Habitat Layers

Table 3.1. Development of focal habitat layers from the SEGAP land cover layer.

SEGAP Value	SEGAP Count	SEGAP Habitat Description	Focal Layer
66	1250905	Southern Piedmont Dry Oak-(Pine) Forest - Hardwood Modifier	Forest
68	122634	Southern Piedmont Mesic Forest	Forest
71	538649	Evergreen Plantations or Managed Pine (can include dense successional regrowth)	Forest
86	119291	Southern Piedmont Dry Oak-(Pine) Forest - Loblolly Pine Modifier	Forest
100	63	Southeastern Interior Longleaf Pine Woodland	Forest
108	256498	Southern Piedmont Dry Oak-(Pine) Forest - Mixed Modifier	Forest
4	339955	Developed Open Space	Developed
5	116880	Low Intensity Developed	Developed
6	42377	Medium Intensity Developed	Developed
7	12789	High Intensity Developed	Developed
127	151178	Successional Shrub/Scrub (Other)	Shrub/Scrub
146	170849	Other – Herbaceous	Shrub/Scrub
147	5654	Utility Swath – Herbaceous	Shrub/Scrub
148	639010	Pasture/Hay	Agriculture
149	60056	Row Crop	Agriculture

4. Correlation Scores of Variables

Table 4.1. Correlation scores between variables for bobcat habitat model

	Slope	Aspect	Distance to Edge	Distance to Roads	Distance to Streams	Edge Density	DEM	Focal Agriculture	Focal Development	Focal Forest	Focal Shrub
Slope	1.0000	-0.0041	-0.0536	-0.0138	-0.0985	0.0342	-0.0222	-0.1401	0.0218	0.1613	-0.0465
Aspect	1.0000	1.0000	-0.0094	-0.0153	-0.0099	-0.0004	0.0213	0.0118	0.0003	0.0064	0.0046
Distance to Edge	1.0000	1.0000	1.0000	0.1334	0.2514	-0.3606	-0.1118	-0.1745	0.2393	-0.1936	-0.2003
Distance to Roads	1.0000	1.0000	1.0000	1.0000	0.1099	-0.0904	-0.1454	0.0270	-0.3034	0.1504	0.2500
Distance to Streams	1.0000	1.0000	1.0000	1.0000	1.0000	-0.1741	-0.0826	-0.1360	-0.0047	-0.0481	-0.0670
Edge Density	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.2899	0.2101	-0.4020	0.4046	0.3249
DEM	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.6328	-0.1953	0.0338	-0.0612
Focal Agriculture	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	-0.3921	-0.2014	0.1837
Focal Development	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	-0.6924	-0.5314
Focal Forest	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.3100
Focal Shrub	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

5. Bobcat Maxent Thresholding

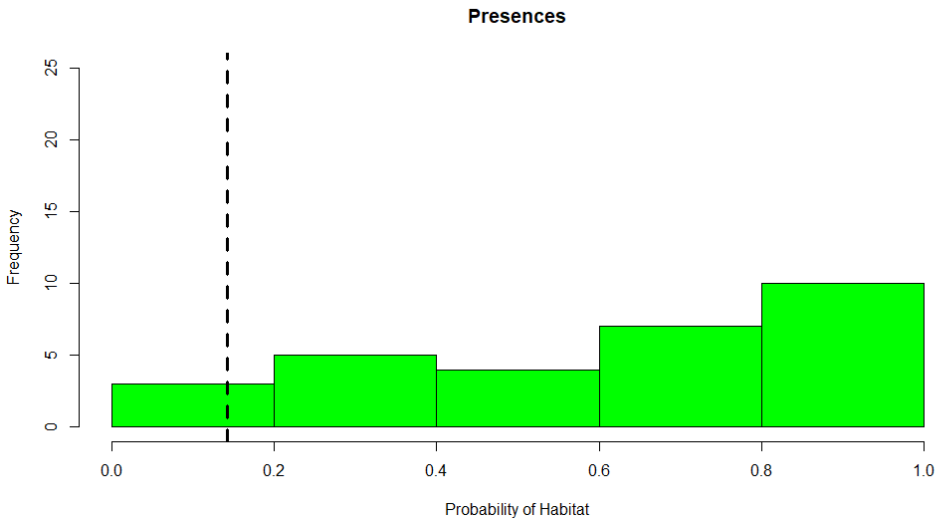

Figure 5.1. Frequency distribution of habitat probabilities predicted by bobcat Maxent model. The threshold is indicated on the histogram: the probability above this threshold indicates habitat.

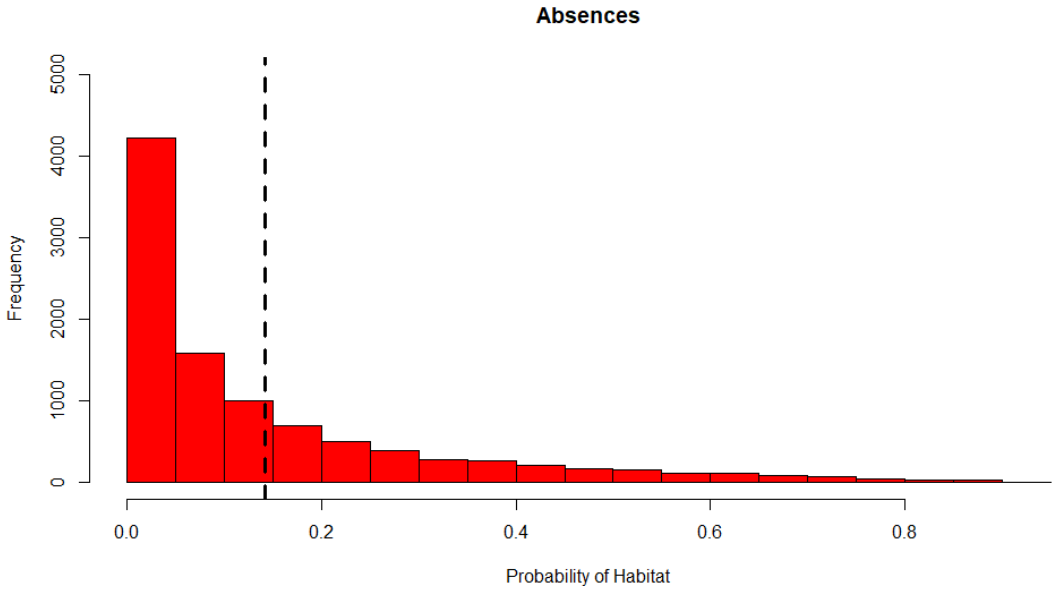

Figure 5.2. Frequency distribution of nonhabitat probabilities predicted by bobcat Maxent model. The threshold is indicated on the histogram: the probability above this threshold indicates habitat.

Table 5.1. Confusion matrix used to determine the bobcat Maxent model threshold

		Observed Habitat (Data)	
Predicted Habitat (Model)		**Habitat**	**Not Habitat**
	Habitat	28 (96.55%)	3331 (33.31%)
	Not Habitat	1 (3.45%)	6669 (66.69%)

6. Management Action Effects Literature Review Table

Table 6.1. Effects of management actions (timber harvest, prescribed burning, streamside management zones (SMZs), constructed wetlands, and food plots) on bobcats, four-toed salamanders, marbled, or spotted salamanders.

	Timber Harvest
Bobcat (Sparse Settled Mixed Habitats)	Timber harvest may be beneficial to bobcat due to the increase in debris and subsequent denning and resting sites (Boyle and Fendley 1987), concealment cover, or prey (McNitt et al. 2020). Bobcat prey such as cotton rats and cottontail have been shown to prefer cleacuts and young (<5 yrs.) pine plantations (Boyle and Fendley 1987).
General Amphibian/Salamanders	Logging has a variety of microclimate effects including change in air and soil temperature, wind speed, light intensity, and relative humidity, and it reduces microhabitat produced by leaf litter and CWD (McLeod and Gates 1998). One study showed that a lower number of amphibians after a clearcut might have been due to local hotspots becoming more concentrated in the SMZ of the clearcut treatment (Goldstein et al. 2005). Negative impact on amphibian populations can be avoided by removing only a section of the canopy (50% or less) (Semlitsch et al. 2009). However, one study showed that "with partial [timber] removal, short-term reductions in salamander abundance of approximately 50% can be expected" and "with clearcutting, a moderately larger short-term reduction should be anticipated" but that populations typically increased as forests regenerated (Tilghman et al. 2012).
Four-Toed Salamander (General Wet Mesic-Hardwood Forests)	No details found in the literature.

Marbled or Spotted Salamanders (Dry-Wet Hardwood and Mixed Forests)	Marbled salamanders have been shown to be very forest-dependent (Todd et al. 2009), and spotted salamanders have been highlighted as one species very sensitive to management, especially up to a conservative 25-35m of silvicultural edges (Demaynadier and Hunter, Jr. 1998). Thus, spotted and marbled salamanders have been shown to favor forests more than cut-over forests (McLeod and Gates 1998) and clear-cutting in particular has been shown to reduce survival in juvenile and adult ambystomatid salamanders (Todd et al. 2014). Timber harvest can have a variety of specific implications on these species. Timber harvest affects canopy cover, leaf litter depth, presence of refuges, soil conditions, edge effects, and road construction, which can all in turn affect marbled and spotted salamanders. Canopy removal affects microhabitat conditions such as pH, dissolved oxygen, and water temperature, so in one study, spotted salamanders did not lay eggs in clear-cut or cuts only retaining 25-50% of trees (Felix et al. 2010). The addition of refuges such as burrows and coarse woody debris may compensate or add to the probability of salamanders settling in cleacuts that they would not normally due to canopy removal (Osbourn et al. 2014). However, another study showed that there were fewer salamanders in clear-cut forest models where CWD was present rather than not present (Harper et al. 2015). Size of clearcuts (those larger than 4 ha) may limit species mobility (Graeter et al. 2008). However, another study showed that in all clear-cut scenarios, size of harvested patches did not influence population size; the populations of marbled and spotted declined by about 50% (Harper et al. 2015). Other microclimate effects such as soil moisture will affect whether marbled salamanders will enter a clearcut area (Graeter et al. 2008). Degree of edge contrast influences placement of salamanders: sharper edges have more of an effect (Demaynadier and Hunter, Jr. 1998). Another important consideration from timber harvesting is effects on soil compaction: one study showed that timber harvest caused a reduction by 52.4% of natural burrows for spotted and marbled salamanders to use (Osbourn et al. 2014), and bare soil has a negative effect on spotted salamander location in another study (Demaynadier and Hunter, Jr. 1998). The creation of roads for timber harvesting may cause habitat reduction which may make it difficult for salamanders to seek out new habitat because of their lack of dispersal capability (Chambers 2008), and spotted and marbled salamanders may choose not to breed in pools close by logging roads (Chambers 2008). Another study showed that marbled salamanders avoided wetlands created by gap or skid trails while spotted salamanders did not (Cromer et al. 2002). Spotted salamanders may be able to combat some of this habitat loss by moving toward higher-quality habitats like forests over fields or clearcuts (Pittman and Semlitsch 2013). In addition, many of these studies have been short-term; one study measuring salamander abundance after 5 years of thinning in a limited area showed that spotted and marbled salamanders showed no difference between cut and control ponds and attributed this to their canopy-tolerance characteristic (Skelly et al. 2014). Another study showed over 11-12 years, spotted and marbled salamanders are not found more often in intact forests than clearcut areas (Morris and Maret 2007). Effects may also have to do with the degree of harvesting; only juveniles were negatively affected by partial harvesting in one study (Todd et al. 2014). Harvesting and its distance to ponds is one last consideration: a study found that spotted salamanders showed "thresholds in occupancy when forest cover was considered within 100m and 300m from the edge of the breeding pond, but no at smaller (30m) or greater (500m, 100m) spatial scales" (Homan et al. 2014).

	Prescribed Burning
Bobcat (Sparse Settled Mixed Habitats)	Dense herbaceous cover resulting from consistent prescribed burning provides for prey support (Cochrane et al. 2006, Jorge et al. 2020, Little et al. 2018). However, increasing pyrodiveristy (a mosaic of post-fire conditions) may decrease bobcat population (Jorge et al. 2020). However, bobcats also prefer rarely burned hardwood forests (Godbois et al. 2003). Bobcats may be attracted to recently burned areas initially, but small-scale fires (<40 ha) may not have large influence on bobcat habitat selection (Little et al. 2018). Irregular shape and clumping of large burned areas, however, may provide suitability for bobcats along edges to disturbed areas (McNitt et al. 2020).
General Amphibian/Salamanders	Low intensity fires probably will not have an impact on coarse woody debris, reducing leaf litter, and increase of bare ground and thus have a lower impact on herpetofauna than high intensity fires (Moseley et al. 2003). However, one study found that salamanders were rarely located at sites recently burned but that salamander richness then increased over time (Schurbon and Fauth 2003). Fire may be useful for preventing succession around wetlands (Russell et al. 1999). Woodland salamanders are most active aboveground in May, June, and July, so it would be best to avoid burning then (Harper et al. 2016; Pilliod et al. 2003). Amphibians have been shown to be negatively affected by fire, herbicide, and both fire and herbicide (Greene et al. 2016). Ruts and ditches created from road breaks and fire breaks "may act as population sinks if amphibians attempt to breed in these ephemeral wetlands that are subject to rapid drying, high reproductive failure, and increased road mortality" (Pilliod et al. 2003).
Four-Toed Salamander (General Wet Mesic-Hardwood Forests)	Four-toed salamander adults were more prevalent in pine areas than burned pine areas probably due to reduced density and basal area of standing trees, canopy closure, and litter depth (McLeod and Gates 1998).
Marbled or Spotted Salamanders (Dry-Wet Hardwood and Mixed Forests)	Marbled salamanders preferred hardwood forests over burned pine areas in Florida, perhaps due to a lack of adaptation of species to fire (Means and Campbell 1981 as cited in Russell et al. 1999). In one study, spotted salamanders only occurred in wetlands that hadn't been burned in 8 years that weren't mulched (Klaus and Noss 2016).

	Streamside Management Zones (SMZs)
Bobcat (Sparse Settled Mixed Habitats)	No details found in the literature.
General Amphibian/Salamanders	Wider SMZs may help protect against edge effects from harvest areas: maximum amphibians species richness was not reached in one study until a 55m SMZ (Guzy et al. 2019). One review outlined SMZ guidelines to protect the terrestrial and aquatic habitat of salamanders (Semlitsch and Bodie 2003; for more information, see discussion).
Four-Toed Salamander (General Wet Mesic-Hardwood Forests)	In one study, the mean probability of occupancy does not increase to 50% until a 50m SMZ width was enforced, probably due to specific habitat requirements (Guzy et al. 2019).
Marbled or Spotted Salamanders (Dry-Wet Hardwood and Mixed Forests)	Wide SMZs are needed for marbled and spotted salamanders: one study showed that the mean occupancy probability did not increase to 50% until about 50m SMZ width for marbled salamanders and 45m for spotted salamanders (Guzy et al. 2019). Another study showed that most adult and juvenile marbled salamanders were in forests beyond 30m from pond edges (Gamble et al. 2006), and spotted salamanders in a different study were captured at a much lower rate in buffer treatments than in partial harvest treatment and controls, indicating that a buffer of 23-35m may not be adequate to compare to unharvested areas (Perkins and Hunter, Jr. 2006). Hydroperiods must also be considered: a shorter hydroperiod tends to show less biomass in a 100m buffer than a reference (Veysey Powell and Babbitt 2015).

	Constructed Wetlands
Bobcat (Sparse Settled Mixed Habitats)	No details found in the literature.
General Amphibian/Salamanders	No details found in the literature.
Four-Toed Salamander (General Wet Mesic-Hardwood Forests)	In one study focusing on natural and constructed wetlands, many four-toed salamander eggs were found mostly in natural wetlands with moss and a large amount of canopy cover (King 2012). Other studies showed that ponds with steep pond edges, facing north, and containing moss will create best microhabitats for four-toed salamanders (Wahl III et al. 2008, Chalmers and Loftin 2006).
Marbled or Spotted Salamanders (Dry-Wet Hardwood and Mixed Forests)	The species richness and number of egg masses of spotted salamanders are positively correlated with pond size, depth, and hydroperiod (Petranka et al. 2003; Denton and Richter 2013), and spotted salamanders have been shown to favor large and deep ponds when compared to smaller breeding sites (Petranka et al. 2003 as cited in Petranka et al. 2003), perhaps due the reduced level of predators in constructed ponds. Mole salamanders had an inverse relationship with the amount of aquatic vegetation, and marbled salamanders were almost always found in natural ephemeral pools in one study, perhaps due to the fluctuating water levels in the constructed wetland (Denton and Richter 2013).

	Food Plots
Bobcat (Sparse Settled Mixed Habitats)	Bobcat prey population in one study was supported by agriculture crops and quail food plots; a negative implication of this is that bobcat are concentrated in a smaller area (Cochrane et al. 2006).
General Amphibian/Salamanders	No details found in the literature.
Four-Toed Salamander (General Wet Mesic-Hardwood Forests)	No details found in the literature.
Marbled or Spotted Salamanders (Dry-Wet Hardwood and Mixed Forests)	No details found in the literature.