GRAY FOX AND RED FOX DISTRIBUTIONS OF DURHAM AND ORANGE COUNTIES, NORTH CAROLINA

by

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EXECUTIVE SUMMARY

North Carolina's research triangle has undergone and continues to undergo rapid development and urban expansion. As the human population expands, habitat fragmentation and human activity intensification will affect wildlife. Many species will be affected directly as humans continue to develop natural ecosystems. As such, Duke Forest has recently decided to implement a new management plan to incorporate biodiversity and species conservation. Specifically, Duke Forest has requested further research on mammal diversity to understand where mammal habitat is most likely to occur. For this project, two species have been selected. The species of interest are the native gray fox and introduced red fox.

This project analyzes predicted gray fox and red fox distributions across Durham County and Orange County, North Carolina with a specific focus on Duke Forest. Two modeling methods have been conducted to predict gray fox and red fox habitat. The first method is a rules-based modeling approach, while the second is a Maximum Entropy (Maxent) modeling approach. The resulting predicted habitat distributions will help to inform Duke Forest's management team of conservation priorities. These priorities include land conservation and on-the-ground management strategies.

Fox occurrence data were gathered from several sources. GIS data were collected from state resources and Duke Forest. The rules-based models did not require occurrence data, so they were constructed using GIS environmental habitat layers. The Maxent models were constructed using GIS habitat and the occurrence data.

As a result, this project developed a series of maps that display predicted gray fox and red fox habitat distributions throughout the two-county and Duke Forest study areas. Gray foxes did not occur in the predicted “best” habitats as often as red foxes did according to the models. This could reflect sampling bias or the result of urbanization. Gray foxes showed a preference for intact ecosystems, but there were occurrences throughout urbanized areas. Land use change could greatly shift the species distributions at the local scale.

The North Carolina Piedmont hosts a high diversity of species. However, land use change will continue to fragment and disturb natural habitat. Making management and conservation decisions now is critical to ensure biodiversity conservation for the future.
This report recommends the following next steps to implement Duke Forest's biodiversity management goals:

- Develop a future project to incorporate coyote habitat models and eastern cottontail rabbit habitat models. These models can be used to further refine the red fox and gray fox models, since these models lack predator/prey relationships, which is a key limitation.

- As model occurrence data comes available with time, it should be included in these models to fine-tune and update model outputs and accuracy.

- According to the model outputs, Duke Forest managers should consider mesic forest stands and grasslands as priority areas. Particularly, gray foxes seem to prefer oak and pine stands along forest edge near grasslands.

- In priority areas, focus on improving the microhabitat to encourage mammal use and establishment. Experts suggest avoiding any harmful practices such as chemical and pesticide use and large clear cuts. Managers may implement practices for promoting mammal diversity, such as controlled understory burns.

- Survey priority areas year-round to determine if habitats are used all year or seasonally. Fox activity may shift as breeding activity and denning activity change throughout the year. Thus, understanding where habitat is year-round might offer insight for managers.

- Potentially implementing a citizen science survey or camera trapping project based on the hotspot map to determine mammal presence/activity in these areas.

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# Table of Contents

**Introduction** ........................................................................................................... 1

**Background** .................................................................................................................. 2

**Objective** ........................................................................................................................ 3

**Materials & Methods** .................................................................................................. 4

- Literature Review ........................................................................................................ 4
- Expert Survey ................................................................................................................ 4
- Geospatial Data Collection .......................................................................................... 5
- Study Areas .................................................................................................................... 6
- Fox Occurrence Data .................................................................................................. 7
- Habitat Modeling .......................................................................................................... 9

**Results** .......................................................................................................................... 14

- Literature Review ........................................................................................................ 14
- Expert Survey ................................................................................................................ 16
- Rules-based Models ...................................................................................................... 18
- Maxent Models ............................................................................................................. 19
- Model Comparison ....................................................................................................... 21

**Discussion** ..................................................................................................................... 22

- Literature Review ........................................................................................................ 22
- Expert Survey ................................................................................................................ 22
- Rules-based Models ...................................................................................................... 23
- Maxent Models ............................................................................................................. 24
- Model Comparison ....................................................................................................... 26
- Recommendations for Duke Forest ............................................................................... 27

**Conclusion** .................................................................................................................... 28

**References** .................................................................................................................... 29

**GIS Sources** .................................................................................................................. 35
LIST OF TABLES

Table 1: Breakdown of Occurrences by Species and Data Source........................................8
Table 2: Rules-based Model Accuracy .................................................................................. 19
Table 3: Maxent Model Accuracy ........................................................................................ 20
Table 4a: Maxent Predicted Habitat Areas ........................................................................... 21
Table 4b: Rules-based Predicted Habitat Areas ................................................................... 21
Appendix 1, Table 5: Literature Review Results .................................................................. 58
Appendix 3, Table 6a: Fox Occurrences by Data Source ....................................................... 65
Appendix 3, Table 6b: Fox Occurrences by County ............................................................... 65
Appendix 4, Table 7: SEGAP Reclassification Breakdown .................................................... 66
Appendix 5, Table 8a: Gray Fox Variable Averages and Response Counts .......................... 68
Appendix 5, Table 8b: Gray Fox Variable Rankings of Importance ....................................... 69
Appendix 5, Table 9a: Red Fox Variable Averages and Response Counts ............................ 70
Appendix 5, Table 9b: Red Fox Variable Rankings of Importance ......................................... 71
Appendix 6, Table 10a: County Maxent β Value and AUC Scores ....................................... 72
Appendix 6, Table 10b: Duke Forest Maxent β Value and AUC Scores ............................... 72
Appendix 7, Table 11: Maxent logistic thresholds ................................................................. 73
LIST OF FIGURES

Figure 1: Study Areas .................................................................................................................. 7
Figure 2: Maxent Regularization Multiplier (β) Values .............................................................. 13
Figure 3: Counties Gray Fox Rules-based Model Habitat Distribution Map .............................. 37
Figure 4: Duke Forest Gray Fox Rules-based Model Habitat Distribution Map ......................... 38
Figure 5: Counties Red Fox Rules-based Model Habitat Distribution Map ............................... 39
Figure 6: Duke Forest Red Fox Rules-based Model Habitat Distribution Map ......................... 40
Figure 7: Counties Gray Fox Maxent Model Habitat Distribution Map ...................................... 41
Figure 8: Counties Gray Fox Maxent Model Habitat Patches Distribution Map ......................... 42
Figure 9: Duke Forest Gray Fox Maxent Model Habitat Distribution Map ............................... 43
Figure 10: Duke Forest Gray Fox Maxent Model Habitat Patch Distribution Map ..................... 44
Figure 11: Gray Fox Maxent Model Habitat Duke Forest Interp. Distribution Map .................... 45
Figure 12: Counties Red Fox Maxent Model Habitat Distribution Map ...................................... 46
Figure 13: Counties Red Fox Maxent Model Habitat Patches Distribution Map ......................... 47
Figure 14: Red Fox Maxent Model Habitat Duke Forest Interp. Distribution Map ..................... 48
Figure 15: Duke Forest Red Fox Maxent Model Habitat Patch Distribution Map ...................... 49
Figure 16: Top Fox Diversity Areas throughout Durham and Orange Counties ......................... 50
Figure 17: Gray Fox Diversity Hotspots throughout Durham and Orange Counties .................... 51
Figure 18: Red Fox Diversity Hotspots throughout Durham and Orange Counties .................... 52
Figure 19: Top Fox Diversity Hotspots throughout Duke Forest .............................................. 53
Figure 20: Gray Fox Diversity Hotspots throughout Duke Forest ............................................ 54
Figure 21: Gray Fox Diversity Hotspots Interpolated throughout Duke Forest ........................... 55
Figure 22: Red Fox Diversity Hotspots throughout Duke Forest ............................................. 56
Appendix 2, Figure 23: Expert survey questionnaire .................................................................. 59
Appendix 8, Figure 24: Recommended Sites .............................................................................. 74
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INTRODUCTION

Currently, Duke Forest is a modern working forest used for recreation, commercial logging, and research. Duke Forest strives to focus on sustainable harvesting and management. Duke Forest follows three guidelines for its management: practical and economic techniques for managing timber, developing an experimental forest for research in the sciences associated with growing timber, and providing an outdoor laboratory for students of forestry (Duke Forest, 2018). These pillars remain in place today. However, urban development and infrastructure led to fragmentation throughout Duke Forest. In turn, fragmentation leads to many implications for biodiversity, going as far as endangering species (Joppa, N. L. et al., 2008).

Sara Childs, the Director of the Duke Forest, has expressed an interest in maintaining the biodiversity of Duke Forest as a diverse ecosystem. In particular, she is interested in addressing the following questions to help expand Duke Forest’s management practices:

- What is the current species richness of mammal species throughout Duke Forest?
- Which habitats and sections of Duke Forest are most critical in maintaining Duke Forest’s integrity as an ecosystem?

Currently, Duke Forest is working towards implementing a new management plan that foregrounds biodiversity. The management plan’s goal is to “promote a diverse population of animals native to the Piedmont of North Carolina.” To approach these goals, the Duke Forest team intends to implement management for “a diversity of habitats at the landscape and stand levels.” Duke Forest managers have defined three objectives to reach these management goals: 1) Do No Harm, 2) Wildlife Monitoring and Baseline Information Establishment, and 3) Using Management Interventions to Promote Wildlife.

Duke Forest houses a diverse array of habitats and species. At present, Duke Forest implements a variety of management techniques to promote a healthy ecosystem. These management practices include timber management, prescribed fire, mowing, and natural canopy openings. Some sections of Duke Forest are designated as Wildlife Management Zones. However, Duke Forest managers would like a better understanding of the wildlife using these zones at present.
This study aims to work towards the Duke Forest's key questions and management goals by focusing on two mammal species: the gray fox and red fox. This study increases understanding of the spatial distributions between gray foxes and red foxes throughout North Carolina's Triangle area and Duke Forest. I hypothesize that red foxes and gray foxes will share similar habitat, since both species are considered generalists. This may have implications for management as these species are suspected to compete for suitable habitat and resources. The second component of the project will be to determine potential fox habitat hotspots for future Duke Forest wildlife surveys. This study will provide baseline data for Duke Forest to use in future mammal management and planning.

**Background**

Little is known about the diversity of mammals throughout the Duke Forest. No studies or surveys have been conducted to document evidence for fox species. As such, this project seeks to determine which species occupy Duke Forest regularly and use its resources. Duke Forest holds an active interest in maintaining forest integrity and biodiversity to ensure a sustainable and healthy ecosystem. In turn, it is imperative to understand the resources that mammals are using to help plan and prioritize conservation strategies and future logging activity.

Since Duke Forest is situated in an urbanized and urbanizing region, there are many points of fragmentation. Forest fragmentation may influence mammal species distributions and abundance patterns. Research has found that habitat adjacent to roads and habitat off the right-of-way of roads have a significantly different influence on mammal distributions (Lowell *et al.*, 1983). Another factor is fragmentation's impact on species composition and structure of vegetation, since many mammals rely on these resources for food and shelter to persist throughout an ecosystem (Yahner, 1986a). Prey and food abundance have been found to have a significant effect on mammals, and food availability fluctuates heavily with the weather and seasonal availability (Yahner, 1992).

Ultimately, it is important to understand how urbanization and urbanizing areas affect mammal diversity and species richness. As the Research Triangle and Duke Forest face increasing urbanization, pressure on species will continue. This project compares the introduced red fox's habitat distribution to the native gray fox's habitat distribution. Understanding these distributions will offer insight for the most suitable habitat for foxes of management interest. The comparison between
distributions will be used to determine areas of conservation and management priority for Duke Forest managers.

**Objective**

This project sought to understand aspects of species diversity of foxes throughout Duke Forest, Durham County, NC and Orange County, NC. Probable fox habitat for two species of foxes were identified using two different modelling techniques.

These modeling techniques compared fox habitat distributions between rules-based modeling approaches and Maxent modeling approaches. The rules-based models were derived from a literature review and expert opinions, while the Maxent model was created using public access sources. Fox presences were collected from iNaturalist, GBIF, and eMammal. These comparisons were used to identify potential biodiversity hotspots throughout Orange County, North Carolina, Durham County, North Carolina, and Duke Forest. The model comparison highlighted where expected fox habitat was likely. The comparison examined both rules-based and Maxent models to see if they highlighted the same habitat areas. As such, this helped us determine if the simpler rules-based model could accurately determine habitat with few occurrence points. I used the models and their resulting species habitat maps to locate areas of high biodiversity throughout the study areas. These biodiversity hotspots were recommended as high priority fox habitat for Duke Forest’s management team.

The mammal biodiversity hotspots (referred to as hotspots) provided guidance for where foxes were most likely to occur and helped inform how those areas should be managed. Areas that were described as habitat without fox occurrence observations were recommended as areas for future study and monitoring to determine if foxes were present. In turn, these findings helped provide Duke Forest with baseline fox data for future management decisions.
MATERIALS & METHODS

I. Literature Review

The project began with a literature review that examined the current expected distributions and natural histories of mammals throughout North Carolina, specific factors that may influence small mammal habitat selection, and any small mammal data already recorded for the Duke Forest and Durham region. This informed later selection of critical variables for fox habitat modeling.

Duke University Library's online portal and Google Scholar were used to access peer-reviewed journal articles. The following search terms were used to filter through literature: “mammal distribution modeling,” “mammal habitat modeling,” “mammal habitat”, as well as “[species name] habitat” for every species featured in this analysis. To be included, the articles needed to involve the mammal species in question. Articles written about mammals in the same genus were also collected and used if very little species-specific data was found. A table was created to list the source, species, and habitat criteria collected from the literature (Appendix Section 1, Table 5). The literature review was used to create a list of important habitat criteria for the mammal species in question. Then, these critical habitat variables were compared to available geospatial data. The best available geospatial data layers were selected to create rules-based and Maxent habitat probability models.

II. Expert Survey

To understand variable importance, I conducted an expert survey. The survey was created with Qualtrics software for distribution to gray and red fox experts. Experts were asked to determine and rank potential habitat variables and forest management strategies. The survey was used to determine relative importance for each variable that would account for habitat and those variables subcategories (i.e. land cover’s importance and the classes within land cover such as agriculture compared to high density development). Experts’ opinion results helped inform variable reclassification and the importance of Duke Forest management practices.

The survey was sent to 20 identified experts on November 18, 2019 and an additional 3 experts on December 19, 2019. The survey closed March 1, 2020. Experts are defined as academics who are publishing or have published research
on mammals or wildlife managers who manage the selected species. Experts were asked to fill out the survey for the species they felt confident in understanding. Survey questions are listed in Appendix Section 2, Figure 23.

The following four experts submitted responses to the survey on gray foxes:

- Michael Chamberlain, Professor at the University of Georgia
- Bruce Leopold, Sharp Distinguished Professor at Mississippi State University
- Mike Conner, Assistant Professor & Scientist at the University of Georgia
- Morgan Morales, PhD candidate at the University of Wisconsin – Madison

The following seven experts submitted responses to the survey on red foxes:

- Timothy R. Van Deelen, Professor at the University of Wisconsin - Madison
- Todd E. Gosselink, Iowa Department of Natural Resources Wildlife Management Staff
- John A. Bissonette, Wildland Resources Professor Emeritus at Utah State University
- Daniel J. Harrison, Professor of Wildlife Ecology at University of Maine
- Maximilian L. Allen, Assistant Wildlife Ecology Faculty at Illinois Natural History Survey
- David Drake, Professor and Extension Wildlife Specialist at the University of Wisconsin - Madison
- Morgan Morales, PhD candidate at the University of Wisconsin – Madison

Experts’ responses were scored and assigned values as qualitative categories (0-100 scale). This scheme was used for the rules-based models as guidelines for reclassification. Scoring guidelines are as follows:

- 0 = Absolute non-habitat
- 30 = Occasional use
- 70 = Consistent use
- 100 = Best habitat, highest survival
- Don't know/unsure – these choices were not included in the averages.

III. Geospatial data collection

Once the literature review was finished to determine species-habitat relationships, geospatial data was collected to account for a variety of habitats. I collected the
data from Duke Forest staff, ArcGIS portals and online databases, and Google searches. The following geospatial data have been used in this analysis:

- Duke Forest boundaries: Duke Forest
- Duke Forest operations: Duke Forest
- Duke Forest vegetation cover/stand age: Duke Forest
- Duke Forest roads and trails: Duke Forest
- Roads: Integrated Statewide Road Network (ISRN) Version 2, NCDOT
- County boundary: NCDOT
- Land cover: Southeast Gap Analysis Project and National Land Cover Database 2016
- Elevation: 1/3 arc second DEM, USGS National Map Viewer
- Streams: NHD Flowline, USGS

All geospatial data were projected or reprojected to NAD 1983 State Plane North Carolina FIPS 3200 Feet (Lambert Conformal Conic) with linear units in US Survey Feet. I chose this projection because it is Duke Forest’s chosen projection. Then, all layers were re-sampled to a common 20 m x 20 m resolution based on the 1/3 arc second USGS DEM.

IV. Study Areas

Two study areas have been selected for this analysis. The first study area included Duke Forest’s Durham, Korstian, and Blackwood Divisions. The second was the larger Durham and Orange Counties area. The larger-scale study was selected because it would provide potential habitat connectivity for land conservation in the Triangle region.
Figure 1: This is the map of the study area and focus area. The two-county area is the larger study area, and Duke Forest is the focus area highlight in red and showcased in the bottom map.

V. Fox Occurrence Data

Mammal occurrence points from 2000 to 2019 were collected from a variety of data sources, including eMammal, Global Biodiversity Information Facility, and iNaturalist. A total of 339 species occurrence points was used for these models, and the species were represented relatively evenly (Table 1). Species occurrence data was last collected on August 30, 2019.

The presence points recording methods are unclear, so collection may include some uncertainty. Species presence samples may include some sampling bias, given the nature of the data source. The data used in this study constitutes presence-only data, and there are no absence points to compare.
I obtained 21 research-grade occurrence points from iNaturalist.org. iNaturalist is an open-access platform for anyone to upload observations of flora or fauna publicly. Most uploads are submitted with a picture along with geographic location. The submitter has the option to self-identify the species or wait for opinions from other users. These identifications are subject to expert review to determine legitimacy. I downloaded all records of the selected mammal species within the Durham-Orange counties study area. Usable data was defined as the following:

- From the year 2000 or later
- “Positional accuracy” (coordinate precision) was <=100 m
- Geographic coordinates were not obscured
- The observation was “Research Grade” – species ID confirmed by at least 2 additional users and identified to the species level

**GBIF**

I obtained 5 occurrence points from The Global Biodiversity Information Facility. The Global Biodiversity Information Facility (GBIF) is an international network that offers an open source to biodiversity data collections across the world. Data submitted to GBIF is filtered through set data standards including the Darwin Core standards. From the data collections, I selected the North Carolina Museum of Natural Sciences collection. However, I only used occurrences that had geographic information.

**eMammal**

I obtained 305 occurrence points from the eMammal database. eMammal is an international data management system for camera trap research projects. All data are reviewed and archived at the Smithsonian. To select the data, I chose to Browse Data and drew a polygon around the Triangle area. Then, I selected all projects, subprojects, and all species. In total, this should have all the camera trap presence
points throughout the duration of the projects. This way, I would have all the occurrences and could parse out data as needed.

VI. Habitat Modeling

a. Geospatial Data Preparation

I conducted all analyses using ESRI's ArcPro GIS Version 2.4.3 (ESRI, 2011) and Python Version 3.6.2 (Van Rossum, G., & Drake Jr, F. L., 1995).

To begin the analysis, I created the two study areas 1) Durham and Orange Counties, NC and 2) Duke Forest boundaries (for the Korstian, Durham, and Blackwood divisions). Then, I projected all the geospatial data to the NAD 1983 StatePlane North Carolina FIPS 3200 Feet. Once projected properly, I resampled all the rasters to a 20-meter resolution to match the DEM. Finally, I clipped the variables to both study regions to ensure the models would cover comparable areas.

To create a distance from streams layer, I selected perennial and intermittent streams. These streams were selected since they were deemed the most relevant for surface waters. These surface waters were used to create the distance to streams layers for the counties study area. For the Duke Forest study area, these streams and the Duke Forest streams layers were combined to create a distance to streams layer for the Duke Forest study area.

I used the North Carolina Department of Transportation (NCDOT) and combined it with Duke Forest's roads layers. The combined layer was used to create a distance to roads raster for the counties study area and Duke Forest study area.

All variables were checked for correlation using R version 3.6.1 before including them in the models (R Core Team, 2018). For this analysis, correlation was defined as $r >= 0.7$. Only two sets of variables correlated with one another. The National Land Cover 2016 (NLCD 2016) dataset correlated ($r = 0.802$) with the SEGap layer, so I removed the NLCD 2016 layer from the analysis. The focal forest layers derived from the above datasets correlated with one another (0.706), so I chose to remove the focal forest layer derived from the NLCD 2016 layer.

b. Rules-based Modeling
Rules-based modeling approaches are tools to predict habitat through assigning variables a rank of importance or a “rule.” I chose a rules-based approach to develop a “habitat suitability index” (Pearce et al., 2002). In turn, this model expressed where likely habitat occurs based on environmental factors. This modeling scheme uses habitat features to predict likely habitat for a species based on the species’ habitat preferences and requirements. I have surveyed experts for their input to determine which variables are the most important predictors in determining likely red fox habitat and likely gray fox habitat.

**Data**

I selected the following datasets because they could be assigned habitat scores values in accordance with the expert surveys and literature review. Some variables have not been assigned habitat values (i.e. slope), because of an information gap in the current science.

I also created a focal forest layer based on land cover. This layer is designed to serve as a proxy for edge. It accounts for radii within 150 meters.

The following data have been included in the rules-based models:

- Elevation
- Aspect
- Distance to Water
- Distance to Roads
- SEGAP land cover (these categories were reclassified to make fewer categories)
- Duke Forest veg cover *Duke Forest only
  - For the rule-based model, this dataset was utilized to provide stand age and land cover
- Focal forest analysis layer (150m) for the SEGAP

**Scoring**

Each of the habitat variables was broken into categories for the rules-based models. Every category received a score between 0-100 based on the scheme from Majka et al. (2007) with some minor adjustments.
• 0 = absolute non-habitat
• 30 = lowest value associated with occasional use
• 50 = lowest score associated with consistent use
• 70 = lowest score associated with highest survival
• 100 = best habitat, highest survival

I translated the results from the expert surveys into the scores above and took the average for these scores. I assigned a weight to each variable based on how important each was relative to the other variables. The weights determined how important the variables were in the final models. I created models in ArcGIS modelbuilder for each species for each study area. Then, I reclassified each environmental variable for each species using the methods stated above. Finally, I combined the reclassified data layers and assigned them weights as described above.

As a result, I created a binary “habitat” and “non-habitat” map output. The models can theoretically range between 0 (non-habitat) and 100 (best habitat). I define “habitat” as pixels with a value greater than or equal to 60. I also added each of the original maps together to create a “mammal hotspot” map for both study areas.

**Model Accuracy**

I used the occurrence of true positives and false negatives to determine model accuracy. Species presence points (occurrences) were overlaid on the predicted habitat. True positives are defined as occurrence points that fall within predicted habitat. False negatives are defined as occurrences points that fell outside the predicted habitat.

**Maxent Modeling**

For this analysis, I used Maxent Version 3.4.1. Maxent, or “Maximum Entropy,” is a statistical-based modeling approach that uses presence datasets to determine probable habitat within a fixed geographic region. Maxent examines a collection of environmental variables and assigns their pixel values to presence-only data. These values are used to predict likely habitat for the specified geographic area (Phillips et al., 2005). Maxent trains the model using the different training samples within the dataset, which are occurrence points not withheld from the model. I selected 15%
of the occurrences for random testing, which means these occurrences were withheld from the model. I chose 15% since the dataset is relatively small, but the AUC value for 15% was greater than the AUC value for 10%. No samples were held for the Duke Forest site, since this site only had 3 occurrences.

I did not condense or edit the variables into categories as I did with the rules-based models. However, categorical data was specified as such in the Maxent software.

The following data are included in Maxent models:

- Elevation
- Distance water
- Distance to roads
- Slope
- Aspect
- Focal forest analysis layer (150m) for the SEGAP
- SEGAP land cover (county study area only)
- Duke Forest vegetation cover (Duke Forest study area only)

I used the DEM to mask each of the rasters and set their cell size, and the study areas (both counties and Duke Forest) were selected as the extents.

**Maxent Settings**

I chose to run Maxent with a β value of 0.5 for all study sites and species. The β value is a regularization coefficient used to fit the models. In turn, the β value identifies the Area Under the Curve. This means, the model correctly assigns a presence-based pixel value over a random pixel value (Radosavljevic and Anderson 2014). The β value can influence how well the model fits, and adjusting this parameter may provide a better result with less complexity within the model (Warren and Seifert 2011 and Radosavljevic and Anderson 2014). As such, I tested five different AUC values for each study site and species. These AUC values included 0.5, 1, 1.5, 2, and 2.5. The highest AUC values indicate better fit for the Maxent model. AUC values were highest at 0.5 for each study site for each species, so these model parameters were selected. Variables were imported and run based on their data nature (i.e. categorical variables such as land cover were run as categorical data).
Final Maxent runs were defined as follows:

- Assigned $\beta$ value (0.5 for all study areas and species)
- 15% in random test percentage
- Nothing in the “Bias layer”
- Output format: logistic
- Create Response Curves: checked
- Make pictures of predictions: checked
- Do jackknife to measure variable performance: checked

When finalized, I brought the Maxent results into ArcGIS Pro version 2.4.3 and transformed them to raster format. I set the cut-off threshold for habitat as the “logistic threshold – balance training omission, predicted area and threshold value” which is the typical value selected for this purpose (Appendix Sections 5 and 6, Tables 10a-11). This was done for both study areas.
RESULTS

I. Literature Review

All data from my literature review can be found in Appendix Section 1, Table 1.

Gray Fox (Urocyon cinereoargenteus)

Designation: Game Species, common throughout state (NCWRC)

Migration/Dispersal: Gray foxes tended to remain within their home range and did not disperse or migrate far (Riley, 2006).

Effect of roads: Gray foxes have been recorded to use roads (Deuel et al., 2017).

Elevation: None.

Aspect: None.

Slope: None.

Patch Size/Complexity: Researchers found a negative relationship between (urban) edge habitat and core habitat. Gray foxes prefer nearer patches and larger patch size (Crooks, 2002). Gray foxes showed a preference for core areas in some studies (Deuel et al., 2017 and Crooks, 2002). However, other studies show gray foxes prefer edge (Rountree III, 2004, Deuel et al., 2017 and Joly and Myers, 2000). It remains unclear if there is some factor that determines when edge is preferred to core or vice versa. Cooper et al. found that gray foxes prefer less complexity in patch size and distance between patches. Gray foxes prefer greater variability in patch size and proximity (Cooper et al., 2012).

Vegetation/land cover: Gray foxes are found in urban habitats and have higher densities in smaller fragments (Crooks, 2002). Gray foxes were found closer to hardwood stands, roads, agricultural lands, human dwellings, pastures/food plots, shrublands, and scrublands than expected. Gray foxes selected habitats including hardwood, human use, and roads (Deuel et al., 2017). Gray foxes prefer higher percentages of woodland areas (Harrison, 1993). Gray foxes have been found to be most abundant in forests interspersed with farms (Carey, 1982). Gray foxes prefer mature pine and mixed stands, but hardwood stands are important (Chamberlain, 2000 and Farias et al., 2012). However, gray foxes have been noted to avoid development (Farias et al., 2012).
Management/Disturbance tolerance: Gray foxes avoid clearings, which implies logging activities may affect their selected habitat (Harrison, 1993).

Distance to water: None.

Red Fox (Vulpes vulpes)

Designation: Game Species, common throughout state (NCWRC)

Migration/Dispersal: According to Trewhella et al., an increase in red fox home-range size and a decrease in population density correlate with a greater mean and maximum dispersal distance (1988).

Effect of roads: None.

Elevation: Red foxes prefer elevations below 200 meters (Walton et al., 2017).

Aspect: Red foxes prefer dens with southern exposure (Goldyn et al., 2003).

Slope: None.

Patch Size/Complexity: Red foxes prefer core habitats (Rountree III, 2004). Edge habitats are not significant for red foxes (Theberge and Wedeles, 1989). Patch size may influence red fox habitat selection (Mueller et al., 2018). However, a recent study finds that red foxes prefer fragmented areas with greater portions of edge (Hradsky et al., 2017).

Vegetation/land cover: Red foxes inhabit deciduous and coniferous forests, marshes, shrub savannahs, reclaimed surface mines, farmland interspersed with woodland, and intensively farmed land. Red foxes seem to prefer diversity-rolling farmland with sparsely wooded areas, marshes, and streams (Adkins and Stott, 1998, Carey, 1982, Harris, 1977, Goldyn et al., 2003, and Walton et al., 2017). Theberge and Wedeles found that red foxes prefer brushy habitats (1989). Red foxes tended toward pine forests and away from human infrastructure (Rountree III, 2004). According to research, red foxes selected cropland and sought open fields and were found to be more inclined toward human development and roads (Halpin and Bisonette, 1987 and Gosselink et al., 2003). Rural foxes avoided cover-rich areas (Gosselink et al., 2003). Gosselink et al. also found that red foxes opted for abandoned farmsteads and avoided woodlands (2003). However, some studies
found red foxes prefer urban open spaces (Mueller et al., 2018). Other studies find that red foxes tended to stay away from urban areas (Goldyn et al., 2003).

**Management/Disturbance tolerance:** Red foxes preferred open fields, which may be an important piece for management strategies (Rountree III, 2004).

**Distance to water:** Distance to water may influence red fox habitat selection (Harrison et al., 1989). Adkins and Stott suggest red foxes may prefer areas closer to water (1998).

II. **Expert Survey**

A summary of all expert survey responses can be found in the appendix (Appendix Section 5, Tables 8a-9b).

**Gray Fox (Urocyon cinereoargenteus)**

**Distance to water:** Gray foxes appear to prefer moderate distances from water.

**Patch Size/Complexity:** Larger patches of any complexity were preferred.

**Aspect:** There was no preference among aspect.

**Land Cover:** Mesic forest and dry oak forest were considered the best habitat. However, successional scrub/shrub/herbaceous was also rated highly. Developed open space/low intensity developed areas and dry pine forest were considered as acceptable habitat as well.

**Distance to roads:** There was no definitive relationship between gray foxes and roads.

**Forest Age:** Gray foxes appear to prefer older forests.

**Forest Management:** Tree harvest is expected to have a negative impact on gray foxes. Herbicide/Chemical application is expected to have a negative to moderate impact on gray foxes. However, controlled understory burns are expected to promote gray fox habitat.

**Variable importance:** Land cover, patch complexity, area of forest, patch size, and area of edge are the most important habitat predictors for gray foxes.
Comments:
“I suggest coyotes have the strongest effect on gray fox habitat selection in SE US.” (expert survey results, January 23, 2020).

Red Fox (*Vulpes vulpes*)

**Distance to water:** Closer bodies of water seem to be more likely red fox habitat.

**Patch Size/Complexity:** Small complex patches scored higher than large and/or simple patches. Red foxes prefer greater edge areas.

**Aspect:** South/West facing aspects scored higher as red fox habitat than north/east facing aspects.

**Land Cover:** Developed open space/low intensity developed scored the highest among land cover variables. Successional scrub/shrub/herbaceous, agriculture (pasture/hay/row crop), and open fields all scored relatively highly as habitat. However, bare soil scored lowest, suggesting it is unsuitable habitat.

**Distance to roads:** There does not appear to be a strong relationship between red fox habitat and roads.

**Forest Age:** Red foxes do not prefer older forests.

**Forest Management:** Herbicide/chemical application and pine plantation (no heavy equipment, planting by hand, holes dug 8-9 inches into soil) appear to have negative effects on red fox habitat. Controlled understory burn and no operations/disturbance appear to have a positive effect on red fox habitat. Tree Harvest (includes seed tree, shelterwood, selective cut, thinning, etc. with heavy equipment on the ground) does not show any conclusive relationship with red fox habitat.

**Variable importance:** Land cover was identified as the most important variable. Area of edge and patch complexity were the second and third most important variables respectively.

Comments:
“Distribution of red foxes is likely heavily influenced by coyotes.” (expert survey results, November 18, 2019).
“Foxes tend to be generalists.” (expert survey results, November 13, 2019).

“Tough to answer these questions. Red Foxes are such generalists from using urban areas to intensively cropped areas. Disturbance can be good at some level for red foxes if it helps promote prey species like rabbits associated with early successional habitat. Hopefully, this helps.” (expert survey results, November 13, 2019).

III. Rules-based Models

For the gray foxes at the counties-scale, the largest and most continuous patch segments were identified between Hillsboro and Durham. These large patches included Eno River State Park and Duke Forest along with neighboring undeveloped areas. Non-habitat included most of the urbanized areas, but there were some large “habitat” patches located along the edge of urbanized areas. This pattern held true in the Duke Forest study area as well.

For the red foxes at the counties-scale, there were far fewer “habitat” patches. Most of the “habitat” was identified within or near developed areas and roads. This pattern held true in the Duke Forest study area as well.

I overlaid each species’ presence points on the habitat (score >=60) to determine model accuracy. Points that fell within predicted habitat (true positive) or fell outside of predicted habitat (false negative) were identified. A true positive is an occurrence point that falls within a predicted habitat pixel. This means, the species has been ground-truthed to use habitat where habitat is predicted. A false negative is an occurrence point that falls within a predicted “unsuitable” habitat pixel. This means, the species has been ground-truthed as using areas where habitat is predicted to be “unsuitable” or not ideal.

A high model accuracy expresses that occurrences are consistently falling on pixels the model identifies as “habitat.” Thus, the model’s “habitat” is predicting where foxes have been recorded. A low model accuracy indicates the foxes have not been recorded where the model identifies “habitat.”
The rules-based models were not trained using presence points, so it is expected the occurrence data do not align with the models entirely. This would explain the lower accuracy within the rules-based models.

The model accuracy is based on the assigned “habitat” threshold. The assigned >= 60 cut-off value for “habitat” also includes more marginal habitat in the models. A cutoff of >= 80 would include only the best habitat and limit the scope for potential management at the risk of producing more false negatives. A cut off value of >= 50 would include less suitable habitats. In turn, my results indicate foxes are using less suitable habitats compared to what the expert survey and literature suggest. The low accuracy indicates that identified “habitat” does not necessarily reflect how foxes use habitat on the ground based on the occurrence data. The model accuracy may indicate missing parameters that would influence fox habitat suitability, or the habitat threshold is too high. An acceptable model accuracy would be above 50% and preferably above 70%, because this is the percentage by which occurrences fall within predicted habitat. The model accuracy describes the model’s fit, and this low fit indicates less than half of the gray fox occurrences were recorded in “suitable” habitat. The rules-based model for the gray foxes was a much poorer fit than the rules-based model for the red foxes. However, neither model showed a substantial and conclusive accuracy.

IV. Maxent Models

There were no red fox presences recorded within Duke Forest, so Maxent models could not be created for red foxes within the Duke Forest study area. However, the red fox Maxent model created for the county region was used to interpolate for the Duke Forest study area.

At the county-level study area, land cover (63.1%), forest area (14.8%), and elevation (13.1%) were the most informative variables for the model. Land cover showed the
The strongest relationship in determining gray fox habitat. At the county level, gray foxes were associated positively with Developed Open Space, Southern Piedmont Mesic Forest, Successional Shrub/Scrub, Successional Grassland/Herbaceous, and Pasture/Hay. The Maxent county-level reports show a negative relationship between gray foxes and Open water, High Intensity Developed, and Bare Soil. As elevation increased, gray fox habitat probability decreased. Percentage forest cover had a positive effect on gray fox habitat probability. However, 60% forest cover had the highest effect on gray fox habitat at the county scale. This could indicate gray foxes prefer more open forested areas. Elevations over 200 meters fell below 70% logistic output, and the fall dramatized with higher values.

Meanwhile, land cover (67.7%) and elevation (13.2%) were the most informative variables for the red foxes at the county level according to the Maxent model. Land cover was the most important variable for identifying red fox habitat. Red foxes within the county study area showed strong relationships with Developed Open Space, High Intensity Developed, Southern Piedmont Dry Oak-(Pine) Forest, and Southern Piedmont Small Floodplain and Riparian Forest. However, High Intensity Development had a negative effect on red foxes within the county study area. Elevation had a dramatic effect on red foxes within the county study area. Elevations at 133 meters had a 0.53 logistic output as habitat, but elevations over 150 meters dropped to 0.35 logistic output and continued to fall. This expresses how fox habitat likelihood fell with increasing elevation.

I overlaid each species’ presence points on the predicted habitat from Maxent (score >=50) to determine model accuracy. Points that fell within predicted habitat (true positive) or fell outside of predicted habitat (false negative) were identified.

The Maxent models were tested using 15% of the presence points, so it is expected the occurrence data will align with the Maxent models more accurately than the rules-based models. The cutoff thresholds for habitat were based on the logistic thresholds for each species and study area.

<table>
<thead>
<tr>
<th>Maxent Accuracy (2-Counties Study Area)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Species</strong></td>
</tr>
<tr>
<td><strong>U. cinereoargenteus</strong></td>
</tr>
<tr>
<td><strong>V. vulpes</strong></td>
</tr>
<tr>
<td><strong>Average:</strong></td>
</tr>
</tbody>
</table>

*Table 3: Percentage of occurrences that fell within Maxent model predicted habitat.*
V. Model Comparison

The rules-based models predicted more “habitat” than the Maxent models in almost every case (Table 4a and Table 4b). An important note is the difference in how the models are created. The rules-based models are built based on the selected “habitat” criteria while the Maxent models are created based on presence data. Thus, the models are not necessarily directly comparable.

<table>
<thead>
<tr>
<th></th>
<th>Species</th>
<th>Acres Within 2-County Study Area</th>
<th>Acres Within Duke Forest</th>
<th>Percentage of Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U. cinereoargenteus</td>
<td>33768</td>
<td>190</td>
<td>3.53%</td>
</tr>
<tr>
<td></td>
<td>V. vulpes</td>
<td>30423</td>
<td>177</td>
<td>3.29%</td>
</tr>
<tr>
<td></td>
<td>U. cinereoargenteus</td>
<td>N/A</td>
<td>893</td>
<td>16.59%</td>
</tr>
</tbody>
</table>

Table 4a: Area (in acres) of predicted Maxent habitat for both study areas.

<table>
<thead>
<tr>
<th></th>
<th>Species</th>
<th>Acres Within 2-County Study Area</th>
<th>Acres Within Duke Forest</th>
<th>Percentage of Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U. cinereoargenteus</td>
<td>101437</td>
<td>1342</td>
<td>24.91%</td>
</tr>
<tr>
<td></td>
<td>V. vulpes</td>
<td>54710</td>
<td>220</td>
<td>4.08%</td>
</tr>
</tbody>
</table>

Table 4b: Area (in acres) of predicted rules-based habitat for both study areas.

The gray fox models show a very different distribution to one another. Based on the county-level Maxent models, gray foxes were shown to prefer less developed spaces and more natural and agricultural ecosystems. The expert survey and rules-based models express that gray foxes prefer more intact ecosystems. This might explain why the model accuracy for the rules-based model is drastically lower (10.65%) than the Maxent models (99.41%).

Comparatively, the red fox Maxent models highlight a similar “habitat” distribution to the rules-based models. The red fox Maxent model's accuracy was 98.24%, while the red fox rules-based model was 17.65%. However, the Maxent models did not highlight roads in the same way the rules-based models did. The rules-based model highlighted roads more definitively. The Maxent models include less areas of development than the rules-based models did, which would explain why there was more “habitat” according to the rules-based model. As such, the “habitat” threshold for the Maxent model might have led to stricter distribution patterns than the rules-based models.
The >= 60 cut-off value for “habitat” also includes more marginal habitat in the rules-based models. A cutoff of >= 80 would include only the best habitat and limit the scope for potential management at the risk of producing more false negatives. In turn, my rules-based models are more liberal than they could have been with a higher habitat cut-off value. Given that the rules-based models identified more “habitat,” the habitat criteria might be a bit broader than what foxes exemplify.

**DISCUSSION**

I. Literature Review

Comparatively, both red and gray foxes have been studied a relatively even amount. However, I found a large geographic discrepancy between the species. Gray foxes have been studied more commonly in the southeastern United States. Red foxes have been introduced to several countries across the world, and they have been studied in the context of invasions and changing ecologies. Thus, it is hard to determine the habitat requirements and preferences for the North Carolina piedmont, given the locality of this paper's study areas. Therefore, I chose to supplement the literature review with an expert survey.

II. Expert Survey

Generally, the expert responses fell in line with the literature review results. Both experts and literature indicated that gray and red foxes are habitat generalists. Both species are willing to explore and use more marginal habitat. The Maxent models suggest gray foxes prefer forested and grassland habitats, while red foxes prefer more urbanized habitats. However, the occurrences suggest neither fox uses these habitats exclusively. Thus, it is difficult to parse where foxes are most likely to occur. Habitat modeling is a crude measure to identify areas of conservation concern. Another keynote is that these models do not incorporate ecological relationships.

Some experts suggested a relationship between fox species and coyotes, but I have opted to leave ecological modeling outside the scope of this paper at present. Ecological relationships should be modeled in the future. Specifically, predator and prey relationships should be modeled or incorporated as a variable within the models to help inform the models created here. I strongly advise this for future
studies on fox species throughout Duke Forest and Durham and Orange counties, since this is a key limitation to this study.

The goal of this paper is to offer a baseline of potential fox habitat for Duke Forest. The results from the models provide guidance for identifying priority study areas and priority management areas. These priority areas can be ground-truthed and surveyed throughout the future to determine active habitat use and microhabitat features. Future microhabitat features should be incorporated into the models to further their accuracy and better identify probable fox habitat.

III. Rules-based Models

The rules-based models predicted more habitat than the Maxent models. This may be, in part, because the rules-based models did not include scores for slope and aspect because experts did not have definitive opinions on these variables. Thus, they have not been included in the rules-based models. Alternatively, the land cover reclassifications may have been too broad. The Maxent model maintained all land cover classes, but the reclassification system combined some classes together for scoring purposes. Future models may want to consider using a broader classification scheme. Another consideration to keep in mind is these rules and scores have been assigned based on the general southeastern United States. Only experts who studied foxes within the southeastern United States have been surveyed, but fox behavior and preferences may be different at the local scale. Foxes have a very wide range, and these scores may not apply fully in North Carolina’s piedmont.

The rules-based models are more theoretical based on expected habitat variables, so it is expected that the occurrence data do not “fit” the rules-based models as well as they do the Maxent models. Therefore, more habitat may have been predicted because the rules-based models were not structured based on the narrower range of the occurrence locations.

Based on the rules-based models, both gray foxes and red foxes appear to be using “suitable” habitat. However, this may not be the most ideal habitat based on the current $\geq 60$ threshold. As such, increasing the threshold to a more “ideal” habitat threshold is expected to change the portion of presences that fall within the predicted habitat. It is important to remember the occurrence data may be biased based on their sampling schemes. Many of these samples contain convenience bias,
since these samples are most likely recorded in areas easily accessed by observers. There is no way to guarantee species’ absence from a given location either, so it is possible the species are using all highlighted habitat and have not yet been observed in these locations. As stated before, the rules-based models do not rely on the occurrence data to generate predicted habitat.

According to the rules-based models, forested areas surrounding the more urbanized Durham area are most suited for gray foxes while red foxes seemed to prefer the direct urban areas. However, the rules-based models had low percentages of model accuracy. At the county-scale, the gray fox rules-based model was 10.65% accurate, while the red fox was 17.65% accurate. The average rules-based model accuracy was 33.33%. The model accuracy indicates how often occurrences fell within a designated “suitable habitat.” The gray fox accuracy was expected, but the red fox accuracy was surprisingly high. Research using similar modeling methods have found that these accuracies are not unusual. Compared to Geschke’s model accuracy average (20%), these are a bit low (2019). Despite the rules-based model accuracy, rules-based models may indicate where habitat is “most suitable” and should still be used as indices for fox habitat. Occurrence data may be biased based on observers’ convenience, which would affect the model accuracy. Observations may be biased towards “less suitable” habitat, so expert opinion may be more reliable in determining conservation priorities. Future studies should survey “suitable habitat” areas to determine fox presence.

IV. Maxent Models

Maxent has become the standard among ecologists when modeling predictive habitat. However, questions still arise when determining the “best practices” for Maxent. Within the software, there are various settings that may be adjusted and will change the model’s results. This paper looked at one example of this. Changing the regularization parameter (\( \beta \)) will cause over-fitting or under-fitting of the model. Thus, I have attempted to adjust \( \beta \) and select the “best” model fit based on maximizing the AUC.

For the red fox, Maxent highlighted low density development areas and less forested areas. Maxent predicted very little red fox habitat throughout Duke Forest. The only highlighted areas were along the roads, which indicated Maxent was selecting less developed areas and developed open space. However, they showed a
preference for dry pine forest as well. This would suggest red foxes are using roads and edge areas more frequently than dense forest. This would explain the lack of occurrence data for red foxes throughout Duke Forest; there was little suitable habitat for red foxes.

Meanwhile, the Maxent models highlighted grasslands and forested areas for the gray fox habitat. Some low-density urban development was included, but it was not as prevalent as it was with the red foxes. This suggests gray foxes may use more urbanized habitats but prefer more intact landscapes. Most of the identified gray fox habitat falls within the Korstian and Durham divisions. Specifically, pine and oak stands show a higher suitability for gray fox habitat. Grasslands and scrublands also show a positive relationship with gray fox habitat, so these patches should be of conservation priority.

The Maxent models had high rates of “true positives,” which suggest the models “fit” the data well. Maxent habitat probability models are based on the occurrence points used to create the models. In turn, the data’s quality will determine the model’s quality. As stated before, some of the occurrence data may be biased. This would affect the Maxent modeling results, assuming some of the data express convenience sampling. We can see gray foxes and red foxes prefer roads, but this may be a result of convenience sampling within the occurrence data. Alternatively, this could reflect foxes’ responses to urbanization. As human development continues, gray and red foxes are increasingly entering human dwellings.

The Maxent county-level models had very high rates of accuracy, which was expected because they were trained using the occurrence data. High model accuracy is common within Maxent models for this reason. The gray fox and red fox Maxent model accuracies were all nearly 100%. This is typical of Maxent models since the occurrences train the data to assign the pixel values. Geschke’s Maxent models had an average of 99% accuracy. However, Maxent models are only as informative as the data that have trained them. If there is bias within the observations’ sampling schemes, then that will create bias within the Maxent models. The occurrence data used to create these Maxent models had relatively few points. Should more occurrence data come available, these data should be included in these models to help fine-tune them. Future studies should compare sampling schemes and compare Maxent models to understand how sampling may affect Maxent distribution results.
V. Model Comparison

No model is entirely accurate. The rules-based models and Maxent models each have strengths and faults. I recommend wildlife managers use a rules-based modeling approach when a species has few presence points, a species’ habitat requirements are well documented in literature, and/or when a manager may contact species experts about regional habitat requirements. However, Maxent has been shown to perform well with small sample sizes. I recommend using a Maxent modeling approach, when there are > 10 presence points based on literature recommendations (Hernandez et al., 2008, Kumar and Stohlgren, 2009, and Thorn et al., 2009). Ideally, these presence points would be unbiased in their sampling scheme since Maxent outputs are derived from the input data. When possible, using both approaches to compare both sets of model outputs is the ideal option. With both sets of outputs, managers could compare to see where the models agree and disagree when identifying habitat. Where both models agree and identify probable habitat, managers can prioritize those areas with the greatest certainty that ideal habitat is present.

A point to note is that there are no guarantees gray and red foxes are occupying the entire region of suitable habitat. There may be areas where foxes have been extirpated or the ecosystem cannot sustain them. For example, prey and predator densities may drive fox distributions and have not been included in these distributions. As such, gray and/or red foxes may occupy marginal or unsuitable habitats and would not be accounted for.

The rules-based models predicted a greater amount of habitat compared to the Maxent models. I expect this is because the expert suggestions stated gray foxes and red foxes are generalist species. Thus, the experts were possibly more general in deciding which variables should be considered as habitat. Still, the rules-based models and Maxent models shared a fair amount of overlap.

It is important to note, all the steps to develop these models have been influenced by my choices, such as choosing the settings for the Maxent models. These choices have influenced the models' results. I have not compared the Maxent model results under different settings at this time, and I would recommend doing so for future studies. However, I do not expect a great difference in the results.

I would recommend placing priority on areas where the models agree on habitat. These patches and segments are likely to be habitat on the ground and will likely
have fox activity. These areas may be improved further if managers opt to promote fox microhabitat features. Controlled understory burns are expected to also improve habitat.

VI. Recommendations for Duke Forest

I recommend the following next steps to implement Duke Forest’s biodiversity management goals:

- Develop a future project to incorporate coyote habitat models and eastern cottontail rabbit habitat models. These models can be used to further refine the red fox and gray fox models, since these models lack predator/prey relationships, which is a key limitation.
- As model occurrence data comes available with time, it should be included in these models to fine-tune model outputs and accuracy.
- According to the model outputs, Duke Forest managers should consider mesic forest stands and grasslands as priority areas. Particularly, gray foxes seem to prefer oak and pine stands along forest edge near grasslands.
- In priority areas, focus on improving the microhabitat to encourage mammal use and establishment. Experts suggest avoiding any harmful practices such as chemical and pesticide use and large clear cuts. Managers may implement practices for promoting mammal diversity, such as controlled understory burns.
- Survey priority areas year-round to determine if habitats are used all year or seasonally. Fox activity may shift as breeding activity and denning activity change throughout the year. Thus, understanding where habitat is year-round might offer insight for managers.
- Potentially implementing a citizen science survey or camera trapping project based on the hotspot map to determine mammal presence/activity in these areas.

CONCLUSION

Overall, fox species throughout the North Carolina Piedmont ecoregion are understudied. The Durham Triangle area is rapidly urbanizing and expanding, which will lead to more direct confrontation between human development and mesopredators such as foxes.
This paper focuses on comparing two methods of modeling species habitat distributions. These methods include a rules-based modeling approach and a Maxent modeling approach. Both approaches have been conducted throughout Durham and Orange counties. Both modeling methods have strengths and drawbacks, and they did not fully agree on habitat consistently. However, when occurrence/presence data is lacking, a rules-based theoretical model is the preferable approach. When species occurrence/presence data is available and unbiased, a Maxent model approach is preferable. The best option considers both modeling approaches and compares to see where habitat is identified and overlaps for foxes. The overlap will indicate the “best” potential suitable habitat for the species of interest.

These model outputs should be used to help managers determine conservation priority areas and where to prioritize management practices and on-the-ground surveys. These highlighted habitat areas should serve as a guide for management practices. Chemical application and large clear cuts should be avoided in these areas for gray fox ecosystem health. Controlled understory burns may be implemented to encourage gray fox habitat. As urbanization continues to increase and quicken, it is critical to conserve the “best” habitat available at present.

The Triangle portion of the North Carolina Piedmont is one of the most urbanized parts of the state. Still, it is home to a diverse array of species. These species include both the gray fox and red fox. Urbanization and development will continue, so it is important to identify and prioritize conservation concerns now. I hope this analysis offers insight for future conservation goals and achievements.
REFERENCES


GIS Sources


GBIF.org (5th August 2019) GBIF Occurrence Download
https://urldefense.proofpoint.com/v2/url?u=https3A__doi.org_10.15468_dl.osge8y&d=DwICAU&c=imBPVzF250nBGMvOCsiEgHoG1i6YHLROsJ_gZ4adc&r=ICHFCVo0bfOLR5GWnIQVcE1Mmp69iavTrN_tkYTheQ&m=IE2e5Kch2Ql7bGC2-boeYzav3NRY9IcHYyyX2hLkMIY&s=M7CtjxVIQfGQzdXDnLHhHEB4Nniayhjctype=Ry2iIx4fBA&e=


Office of the Duke Forest (boundaries, vegetation cover, streams, rivers, roads, and trails)


FIGURES

I. Rules-based Results

Gray Fox County Rules-based Habitat Distributions

Legend
- Counties
- Gray Fox Occurrences

Gray Fox Habitat
Value
- 0
- 1

Orange County is on the left. Durham County is on the right.

Madison Cole
4/17/2020
See Geospatial Data Collection for Data sources
AD 1983 State Plane North Carolina FIPS 3200 Feet
Lambert Conformal Conic

Figure 3: Counties Gray Fox Rules-based Model Habitat Distribution Map.
Figure 4: Duke Forest Gray Fox Rules-based Model Habitat Distribution Map.
Figure 5: Counties Red Fox Rules-based Model Habitat Distribution Map.
Figure 6: Duke Forest Red Fox Rules-based Model Habitat Distribution Map.

Legend

- Duke Forest
- Red Fox Habitat DF

Value
- 0
- 1

*There are no presence points for red foxes within the Duke Forest study area.*
II. Maxent Models

Gray Fox County Maxent Habitat Distributions

Figure 7: Counties Gray Fox Maxent Model Habitat Distribution Map.
Figure 8: Counties Gray Fox Maxent Model Habitat Patches Distribution Map.
Figure 9: Duke Forest Gray Fox Maxent Model Habitat Distribution Map. This model uses Duke Forest's land cover layers to determine gray fox habitat.
Figure 10: Duke Forest Gray Fox Maxent Model Habitat Patch Distribution Map. This model uses Duke Forest's land cover layers to determine gray fox habitat.
Figure 11: Gray Fox Maxent Model Habitat Duke Forest Interpolation Distribution Map. This model uses SEGAP’s land cover layers to determine gray fox habitat.
Figure 12: Counties Red Fox Maxent Model Habitat Distribution Map.
Figure 13: Counties Red Fox Maxent Model Habitat Patches Distribution Map.

Legend
Red Fox Predicted Habitat
Value
Maxent Habitat
Counties

Orange County is on the left. Durham County is on the right.

Madison Cole
4/17/2020
See Geospatial Data Collection for Data sources
AD 1983 State Plane North Carolina FIPS 3200 Feet
Lambert Conformal Conic

Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other contributors.
Figure 14: Red Fox Maxent Model Habitat Duke Forest Interpolation Distribution Map. This model uses SEGAP's land cover layers to determine red fox habitat.
**Figure 15**: Duke Forest Red Fox Maxent Model Habitat Patch Distribution Map. This model uses SEGAP’s land cover layers to determine red fox habitat.
III. Habitat Hot Spot Maps

Fox Diversity County Hotspot Habitat Distributions

Legend
- Counties
- County Hotspots
  Value
  - High Diversity
  - Low Diversity

Orange County is on the left. Durham County is on the right.

Madison Cole
4/17/2020
See Geospatial Data
Collection for Data sources
AD 1983 State Plane North
Carolina FIPS 3200 Feet
Lambert Conformal Conic

Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org and other contributors, Esri, Garmin, GEBCO, NOAA, National Geographic, and other contributors

Figure 16: Top Fox Diversity Areas throughout Durham and Orange Counties.
Figure 17: Gray Fox Diversity Hotspots throughout Durham and Orange Counties.
Figure 18: Red Fox Diversity Hotspots throughout Durham and Orange Counties.
Top Fox Diversity Duke Forest Habitat Distributions

Figure 19: Top Fox Diversity Hotspots throughout Duke Forest.
Figure 20: Gray Fox Diversity Hotspots throughout Duke Forest.
Figure 21: Gray Fox Diversity Hotspots Interpolated throughout Duke Forest.
Red Fox Diversity Duke Forest Hotspot Distributions

Figure 22: Red Fox Diversity Hotspots throughout Duke Forest.
APPENDIX

I. Literature Review Table
II. Expert Survey Questions
III. Fox Occurrence Data
IV. SEGAP Condensing Breakdown
V. Expert Survey Summary & Rules-Based Scoring
VI. Maxent β Value and AUC Scores
VII. Maxent Logistic Thresholds
VIII. Recommended Points for Duke Forest Mammal Surveys
## I. Literature Review Table

<table>
<thead>
<tr>
<th>Species</th>
<th>Designation</th>
<th>Critical Habitat Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray Fox (Urocyon cinereoargenteus)</td>
<td>Game Species, common throughout state (NCWRC)</td>
<td>Gray foxes tended to remain within their home range and did not disperse or migrate far (Hiley, 2006). Gray foxes have been recorded to use roads (Deuel et al., 2017). Researchers found a negative relationship between (urban) edge habitat and core habitat. Gray foxes prefer nearer patches and larger patch size (Crooks, 2002). Gray foxes showed a preference for core areas in some studies (Deuel et al., 2017 and Crooks, 2002). However, other studies show gray foxes prefer edge (Rountree III, 2004, Deuel et al., 2017 and Joly and Myers, 2000). It remains unclear if there is some factor that determines when edge is preferred to core or vice versa. Cooper et al. found that gray foxes prefer less complexity in patch size and distance between patches. Gray foxes prefer greater variability in patch size and proximity (Cooper et al., 2012). Gray foxes are found in urban habitats and have higher densities in smaller fragments (Crooks, 2002). Gray foxes were found closer to hardwood stands, roads, agricultural lands, human dwellings, pastures/food plots, shrublands, and scrublands than expected. Gray foxes selected habitats including hardwood, human use, and roads (Deuel et al., 2017). Gray foxes prefer higher percentages of woodland areas (Harrison, 1993). Gray foxes have been found to be most abundant in forests interspersed with farms (Carey, 1982). Gray foxes prefer mature pine and mixed stands, but hardwood stands are important (Chamberlain, 2000 and Farias et al., 2012).</td>
</tr>
<tr>
<td>Red Fox (Vulpes vulpes)</td>
<td>Game Species, common throughout state (NCWRC)</td>
<td>According to Trewhella et al., an increase in red fox home-range size and a decrease in population density correlate with a greater mean and maximum dispersal distance (1988). Red foxes prefer elevations below 200 meters (Walton et al., 2017). Red foxes prefer dens with southern exposure (Goldyn et al., 2003). Red foxes prefer core habitats (Rountree III, 2004). Edge habitats are not significant for red foxes (Theberge and Wedeles, 1989). Patch size may influence red fox habitat selection (Mueller et al., 2018). However, a recent study finds that red foxes prefer fragmented areas with greater portions of edge (Hradsky et al., 2017). Red foxes inhabit deciduous and coniferous forests, marshes, shrub savannahs, reclaimed surface mines, farmland interspersed with woodland, and intensively farmed land. Red foxes tend to prefer diversity-rolling farmland with sparsely wooded areas, marshes, and streams (Adkins and Stott, 1998, Carey, 1982, Harris, 1977, Goldyn et al., 2003, and Walton et al., 2017). Theberge and Wedeles found that red foxes prefer brushy habitats (1989). Red foxes tended toward pine forests and away from human infrastructure (Rountree III, 2004). According to research, red foxes selected cropland and sought open fields and were found to be more inclined toward human development and roads (Halpin and Bisonette, 1987 and Gosselink et al., 2003). Rural foxes avoided cover-rich areas (Gosselink et al., 2003). Gosselink et al. also found that red foxes opted for abandoned farmsteads and avoided woodlands (2003). However, some studies found red foxes prefer urban open spaces (Mueller et al., 2018). Other studies find that red foxes tended to stay away from urban areas (Goldyn et al., 2003). Red foxes preferred open fields, which may be an important piece for management strategies (Rountree III, 2004). Distance to water may influence red fox habitat selection (Harrison et al., 1989). Adkins and Stott suggest red foxes may prefer areas closer to water (1998).</td>
</tr>
</tbody>
</table>

**Table 5: Literature review results by species.**
II. Expert Survey Questions

Name (optional):

Preferred e-mail address (optional):

**Gray fox (Urocyon cinereoargenteus)**

**NOTE:** A second survey was created for the red fox (*Vulpes vulpes*).

Please answer the following questions to the best of your own expert knowledge for this species. If you don't know or are unsure, select the Don't Know/Unsure answer.

**Figure 23:** Expert survey questionnaire.

<table>
<thead>
<tr>
<th>Distance to water:</th>
<th>Absolute non-habitat</th>
<th>Occasional use</th>
<th>Consistent use</th>
<th>Best habitat, highest survival</th>
<th>Don't Know/Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50 meters</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>50-400 meters</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>&gt; 400 meters</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Patch size/complexity:</th>
<th>Absolute non-habitat</th>
<th>Occasional use</th>
<th>Consistent use</th>
<th>Best habitat, highest survival</th>
<th>Don't Know/Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small patches &lt; 50 hectares</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Large patches &gt; 50 hectares</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Complex patches</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Simple patches</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>
### Aspect:

<table>
<thead>
<tr>
<th></th>
<th>Absolute non-habitat</th>
<th>Occasional use</th>
<th>Consistent use</th>
<th>Best habitat, highest survival</th>
<th>Don't Know/Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>North/East</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South/West</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Land cover:

<table>
<thead>
<tr>
<th>Land cover</th>
<th>Absolute non-habitat</th>
<th>Occasional use</th>
<th>Consistent use</th>
<th>Best habitat, highest survival</th>
<th>Don't Know/Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developed open space/Low intensity developed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium/High intensity developed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bare Soil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesic Forest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry Oak Forest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry Pine Forest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evergreen Plantations of Managed Pine (can include dense successional regrowth)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Successional Scrub/Shrub/Herbaceous</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agriculture (pasture/hay/row crop)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open Fields</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Habitat farther from roads is better for this species:

- Strongly agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Strongly disagree
- Don't Know/Unsure
Does this species prefer old forests?

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Maybe</td>
<td></td>
</tr>
<tr>
<td>Don't Know/Unsure</td>
<td></td>
</tr>
</tbody>
</table>

Does this species prefer greater edge areas?

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Maybe</td>
<td></td>
</tr>
<tr>
<td>Don't Know/Unsure</td>
<td></td>
</tr>
</tbody>
</table>
Please rank the following forest operations based on their impact on the species:

<table>
<thead>
<tr>
<th></th>
<th>Strong negative impact</th>
<th>Weak negative impact</th>
<th>No impact</th>
<th>Weak positive impact</th>
<th>Strong positive impact</th>
<th>Don't Know/Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree Harvest (includes seed tree,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>shelterwood, selective cut, thinning,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>etc. with heavy equipment on the</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ground)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herbicide/Chemical application</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pine plantation (no heavy equipment,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>planting by hand, holes dug 8-9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>inches into soil)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Controlled understory burn</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No operations/disturbance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Finally, drag and drop the variables to rank their importance in determining quality habitat/presence of this species. (1 = most important, 10 = least important)

- Distance to water
- Patch complexity
- Patch size
- Area of forest
- Area of edge
- Distance to roads
- Aspect
- Land cover
- Forest age
- Forest operations

Any comments?

Would you or any of your contacts be willing to take this survey for gray foxes (Urocyon cinereoargenteus) or a similar survey for any of the following species:

- Red fox (Vulpes vulpes)
- Eastern cottontail (Sylvilagus floridanus)
- Southern short-tailed shrew (Blarina carolinensis)
- American beaver (Castor canadensis)

If so, who?
III. Fox Occurrence Data

<table>
<thead>
<tr>
<th></th>
<th>eMammal</th>
<th>iNat Durham</th>
<th>iNat Orange</th>
<th>GBIF</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey Fox</td>
<td>149</td>
<td>14</td>
<td>2</td>
<td>4</td>
<td>169</td>
</tr>
<tr>
<td>Red Fox</td>
<td>157</td>
<td>7</td>
<td>5</td>
<td>1</td>
<td>170</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>306</td>
<td>21</td>
<td>7</td>
<td>5</td>
<td><strong>339</strong></td>
</tr>
</tbody>
</table>

**Table 6a:** Fox occurrences by data source.

<table>
<thead>
<tr>
<th></th>
<th>Durham</th>
<th>Orange</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey Fox</td>
<td>114</td>
<td>55</td>
<td>169</td>
</tr>
<tr>
<td>Red Fox</td>
<td>93</td>
<td>77</td>
<td>170</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>207</td>
<td>132</td>
<td><strong>339</strong></td>
</tr>
</tbody>
</table>

**Table 6b:** Fox occurrences by county.
Table 7: This is how I chose to group and reclassify the land cover types.
V. Expert Survey Summary & Rules-Based Scoring

Tables 8a-9b. The tables below show the scoring system for both fox species’ rules-based models. Tables 8a and 8b are specific to the grey foxes, while tables 9a and 9b are specific to the red foxes.
**Table 8a: Grey fox variable averages and response counts.**

<table>
<thead>
<tr>
<th>Distance to water:</th>
<th>Absolute non-habitat</th>
<th>Occasional use</th>
<th>Consistent use</th>
<th>Best habitat, highest survival</th>
<th>Don’t Know/Unsure</th>
<th>Average Score:</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50 meters</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>50-400 meters</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td></td>
<td></td>
<td>67.5</td>
</tr>
<tr>
<td>&gt; 400 meters</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td>57.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Patch size/complexity:</th>
<th>Absolute non-habitat</th>
<th>Occasional use</th>
<th>Consistent use</th>
<th>Best habitat, highest survival</th>
<th>Don’t Know/Unsure</th>
<th>Average Score:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small patches &lt; 50 hectares</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td>57.5</td>
</tr>
<tr>
<td>Large patches &gt; 50 hectares</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td>57.5</td>
</tr>
<tr>
<td>Complex patches</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>67.5</td>
</tr>
<tr>
<td>Simple patches</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aspect:</th>
<th>Absolute non-habitat</th>
<th>Occasional use</th>
<th>Consistent use</th>
<th>Best habitat, highest survival</th>
<th>Don’t Know/Unsure</th>
<th>Average Score:</th>
</tr>
</thead>
<tbody>
<tr>
<td>North/East</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>South/West</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>70</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Land cover:</th>
<th>Absolute non-habitat</th>
<th>Occasional use</th>
<th>Consistent use</th>
<th>Best habitat, highest survival</th>
<th>Don’t Know/Unsure</th>
<th>Average Score:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developed open space/Low intensity developed</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>57.5</td>
</tr>
<tr>
<td>Medium/High intensity developed</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>Bare Soil</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>57.5</td>
</tr>
<tr>
<td>Mesic Forest</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td>67.5</td>
</tr>
<tr>
<td>Dry Oak Forest</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td>67.5</td>
</tr>
<tr>
<td>Dry Pine Forest</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>57.5</td>
</tr>
<tr>
<td>Evergreen Plantations of Managed Pine (can include dense successional regrowth)</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td>57.5</td>
</tr>
<tr>
<td>Successional Scrub/Shrub/Herbaceous</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>60</td>
</tr>
<tr>
<td>Agriculture (pasture/hay/row crop)</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>40</td>
</tr>
<tr>
<td>Open Fields</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Habitat farther from roads is better for this species:</th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
<th>Don’t Know/Unsure</th>
<th>Average Score:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>56.25</td>
</tr>
</tbody>
</table>

**Does this species prefer old forests?**

- Yes: 2
- No: 1
- Maybe: 1
- Don’t Know/Unsure: 1

**Does this species prefer greater edge areas?**

- Yes: 3
- No: 1
- Maybe: 1
- Don’t Know/Unsure: 1

**Please rank the following forest operations based on their impact on the species:**

<table>
<thead>
<tr>
<th>Operation</th>
<th>Strong negative impact</th>
<th>Weak negative impact</th>
<th>No impact</th>
<th>Weak positive impact</th>
<th>Strong positive impact</th>
<th>Don’t Know/Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree Harvest (includes seed tree, shelterwood, selective cut, thinning, etc. with heavy equipment on the ground)</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>Herbicide/Chemical application</td>
<td>2</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td>37.5</td>
</tr>
<tr>
<td>Pine plantation (no heavy equipment, planting by hand, holes dug 8-9 inches into soil)</td>
<td>2</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>56.25</td>
</tr>
<tr>
<td>Controlled understory burn</td>
<td></td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td>87.5</td>
</tr>
<tr>
<td>No operations/disturbance</td>
<td>1</td>
<td></td>
<td></td>
<td>2</td>
<td>1</td>
<td>50</td>
</tr>
</tbody>
</table>
Table 8b: Grey fox variable rankings of importance.

<table>
<thead>
<tr>
<th>Variables in Order</th>
<th>Average Rank</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area of Edge</td>
<td>5.33</td>
<td>3</td>
</tr>
<tr>
<td>Patch Size</td>
<td>5.33</td>
<td>3</td>
</tr>
<tr>
<td>Patch Complexity</td>
<td>5.00</td>
<td>2</td>
</tr>
<tr>
<td>Land Cover</td>
<td>4.00</td>
<td>1</td>
</tr>
<tr>
<td>Area of Forest</td>
<td>5.33</td>
<td>3</td>
</tr>
<tr>
<td>Aspect</td>
<td>13.00</td>
<td>8</td>
</tr>
<tr>
<td>Distance to Water</td>
<td>6.67</td>
<td>4</td>
</tr>
<tr>
<td>Distance to Roads</td>
<td>9.00</td>
<td>6</td>
</tr>
<tr>
<td>Forest Age</td>
<td>8.00</td>
<td>5</td>
</tr>
<tr>
<td>Forest operations</td>
<td>10.00</td>
<td>7</td>
</tr>
</tbody>
</table>
Table 9a: Red fox variable averages and response counts.

<table>
<thead>
<tr>
<th>Distance to water:</th>
<th>Absolute non-habitat</th>
<th>Occasional use</th>
<th>Consistent use</th>
<th>Best habitat, highest survival</th>
<th>Don't Know/Unsure</th>
<th>Average Score:</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50 meters</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td></td>
<td></td>
<td>54.0</td>
</tr>
<tr>
<td>50-400 meters</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
<td>63.3</td>
</tr>
<tr>
<td>&gt; 400 meters</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td>50.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Patch size/complexity:</th>
<th>Absolute non-habitat</th>
<th>Occasional use</th>
<th>Consistent use</th>
<th>Best habitat, highest survival</th>
<th>Don't Know/Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small patches &lt; 50 hectares</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large patches &gt; 50 hectares</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complex patches</td>
<td>2</td>
<td>6</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simple patches</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aspect:</th>
<th>Absolute non-habitat</th>
<th>Occasional use</th>
<th>Consistent use</th>
<th>Best habitat, highest survival</th>
<th>Don't Know/Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>North/East</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>South/West</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Land cover:</th>
<th>Absolute non-habitat</th>
<th>Occasional use</th>
<th>Consistent use</th>
<th>Best habitat, highest survival</th>
<th>Don't Know/Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developed open space/Low intensity developed</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium/High intensity developed</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bare Soil</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesic Forest</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry Oak Forest</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry Pine Forest</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evergreen Plantations of Managed Pine (can include dense successional regrowth)</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td></td>
<td>36.7</td>
</tr>
<tr>
<td>Successional Scrub/Shrub/Herbaceous</td>
<td>2</td>
<td>5</td>
<td></td>
<td></td>
<td>58.6</td>
</tr>
<tr>
<td>Agriculture (pasture/hay/row crop)</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td></td>
<td>57.1</td>
</tr>
<tr>
<td>Open Fields</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Habitat farther from roads is better for this species:</th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
<th>Don't Know/Unsure</th>
<th>Average Score:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly agree</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>50.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Does this species prefer older forests?</th>
<th>Yes</th>
<th>No</th>
<th>Maybe</th>
<th>Don't Know/Unsure</th>
<th>Average Score:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td></td>
<td>7.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Does this species prefer greater edge areas?</th>
<th>Yes</th>
<th>No</th>
<th>Maybe</th>
<th>Don't Know/Unsure</th>
<th>Average Score:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td></td>
<td>92.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Please rank the following forest operations based on their impact on the species:</th>
<th>Strong negative impact</th>
<th>Weak negative impact</th>
<th>No impact</th>
<th>Weak positive impact</th>
<th>Strong positive impact</th>
<th>Don't Know/Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree Harvest (includes seed tree, shelterwood, selective cut, thinning, etc. with heavy equipment on the ground)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>50.0</td>
</tr>
<tr>
<td>Herbicide/Chemical application</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td></td>
<td>10.0</td>
</tr>
<tr>
<td>Pine plantation (no heavy equipment, planting by hand, holes dug 8-9 inches into soil)</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
<td>40.0</td>
</tr>
<tr>
<td>Controlled understory burn</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td>75.0</td>
</tr>
<tr>
<td>No operations/disturbance</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td></td>
<td>75.0</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Variables in Order</th>
<th>1</th>
<th>6</th>
<th>1</th>
<th>3</th>
<th>-</th>
<th>2</th>
<th>5</th>
<th>Average Rank: 3.0</th>
<th>Rank: 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area of Edge</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td>3</td>
<td>-</td>
<td>2</td>
<td>5</td>
<td>3.0</td>
<td>2</td>
</tr>
<tr>
<td>Patch Size</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>8</td>
<td>-</td>
<td>4</td>
<td>2</td>
<td>3.5</td>
<td>3</td>
</tr>
<tr>
<td>Patch Complexity</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>-</td>
<td>3</td>
<td>3</td>
<td>3.5</td>
<td>3</td>
</tr>
<tr>
<td>Land Cover</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>4</td>
<td>2.2</td>
<td>1</td>
</tr>
<tr>
<td>Area of Forest</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>-</td>
<td>6</td>
<td>6</td>
<td>5.8</td>
<td>5</td>
</tr>
<tr>
<td>Aspect</td>
<td>6</td>
<td>10</td>
<td>8</td>
<td>10</td>
<td>-</td>
<td>10</td>
<td>10</td>
<td>9.0</td>
<td>9</td>
</tr>
<tr>
<td>Distance to Water</td>
<td>7</td>
<td>3</td>
<td>5</td>
<td>9</td>
<td>-</td>
<td>5</td>
<td>1</td>
<td>5.0</td>
<td>4</td>
</tr>
<tr>
<td>Distance to Roads</td>
<td>8</td>
<td>7</td>
<td>7</td>
<td>5</td>
<td>-</td>
<td>7</td>
<td>8</td>
<td>7.0</td>
<td>6</td>
</tr>
<tr>
<td>Forest Age</td>
<td>9</td>
<td>8</td>
<td>9</td>
<td>2</td>
<td>-</td>
<td>9</td>
<td>9</td>
<td>7.7</td>
<td>7</td>
</tr>
<tr>
<td>Forest operations</td>
<td>10</td>
<td>9</td>
<td>10</td>
<td>6</td>
<td>-</td>
<td>8</td>
<td>7</td>
<td>8.3</td>
<td>8</td>
</tr>
</tbody>
</table>

**Table 9b**: Red fox variable rankings of importance.
VI. Maxent β Value and AUC Scores

<table>
<thead>
<tr>
<th>County</th>
<th>β values</th>
<th>0.5</th>
<th>1.0</th>
<th>1.5</th>
<th>2.0</th>
<th>2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># Observations</td>
<td>AUC</td>
<td>AUC</td>
<td>AUC</td>
<td>AUC</td>
<td>AUC</td>
</tr>
<tr>
<td>Gray</td>
<td>169</td>
<td>0.829</td>
<td>0.815</td>
<td>0.803</td>
<td>0.791</td>
<td>0.785</td>
</tr>
<tr>
<td>Red</td>
<td>170</td>
<td>0.852</td>
<td>0.827</td>
<td>0.813</td>
<td>0.805</td>
<td>0.798</td>
</tr>
</tbody>
</table>

Table 10a: The resulting AUC score for the two-county area for each Maxent β-value. The highest scores are highlighted in yellow, as these were the β-values chosen because they fit the models best.

<table>
<thead>
<tr>
<th>DF</th>
<th>β values</th>
<th>0.5</th>
<th>1.0</th>
<th>1.5</th>
<th>2.0</th>
<th>2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># Obs</td>
<td>AUC</td>
<td>AUC</td>
<td>AUC</td>
<td>AUC</td>
<td>AUC</td>
</tr>
<tr>
<td>Gray</td>
<td>3</td>
<td>0.996</td>
<td>0.994</td>
<td>0.994</td>
<td>0.757</td>
<td>0.757</td>
</tr>
<tr>
<td>Red</td>
<td>0</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 10b: The resulting AUC score for the Duke Forest area of interest for each Maxent β-value. The highest score is highlighted in yellow, as this was the β-values chosen because it fit the model best. The red fox model does not have a score, because there are no occurrence data.
VII. Maxent logistic thresholds

<table>
<thead>
<tr>
<th>Species</th>
<th>B</th>
<th>County</th>
<th>DF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray</td>
<td>0.5</td>
<td>0.033</td>
<td>0.026</td>
</tr>
<tr>
<td>Red</td>
<td>0.5</td>
<td>0.011</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 11: These are the logistic threshold values that determined habitat "cut-offs" for the Maxent models. DF stands for Duke Forest, B is the Maxent β-value, county refers to the two-county study area.
VIII. Recommended Points for Duke Forest Mammal Surveys

Figure 24: These are the sites I recommend to Duke Forest for future Mammal Surveys to determine fox presence.