A Comprehensive Assessment of Red Wolf Reintroduction Sites

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Cover photo: Madeleine McMillan

Executive Summary[1]

The red wolf (*Canis rufus*) is the world's rarest wild canid, with fewer than 60 wolves living in the wild, and likely even fewer than 40. After being declared extinct in the wild in 1980, the wolf was reintroduced to Alligator River National Wildlife Refuge in North Carolina in 1987 and successfully established itself, with the small initial population growing to 150 within two decades. Recent increases in mortality have reduced the wolf's numbers to their current low levels, and the Fish and Wildlife Service now faces the difficult decision of where else to reintroduce the red wolf within its historic range.

This Masters Project is an attempt to analyze the current landscape of the Southeast from both an ecological and sociological perspective to determine the best possible places for red wolves to successfully establish a new population. I first conducted a literature review to identify key variables that affect the suitability of an area and found five such factors: available habitat, available prey, concentrations of livestock, recreational hunters, and the age of local residents. The reintroduction effort has to begin on federally owned and protected land, and so I next set out to select a suite of potential sites for the reintroduction to take place, establishing a list of 21 such locations.

The relationship between all of the variables I considered is complex, so to properly weight them against each other I surveyed 14 experts in red wolf biology and management. I received responses from 10 of the experts and used this information to construct models in ArcGIS to determine the overall suitability of a site. After assembling a Weighted Sum model based on available data and calculating descriptive statistics, the sites all received a suitability score. The highest-scoring sites were Croatan National Forest in North Carolina and Okefenokee National Wildlife Refuge in Georgia. Fish and Wildlife should focus future reintroduction efforts on these locations, which strike the best available balance between suitable ecology and low chances of human-wolf conflict.

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[1] For more information, contact the author at sfoneal14@gmail.com.

Introduction

I. The Issue

The world's most endangered wild canid species lives only a three-hour drive from Duke University in the coastal wetlands of North Carolina. The red wolf (*Canis rufus*) once covered a geographic range that encompassed much of the land east of the Mississippi River[2], but today is limited to only a series of National Wildlife Refuges on the Albemarle Peninsula of North Carolina. As a recovery criterion of the US Fish and Wildlife Service's Red Wolf Species Survival Plan (SSP), the Fish and Wildlife Service ("USFWS" or "the Service") aimed to reintroduce the wolves and establish wild populations in three locations within the historic range of the red wolf.[3] Recent research has focused mostly on the status and habits of the wolves living in their limited current range, but managers will need to consider a broader range of issues if they hope to see future reintroductions succeed elsewhere.

This Masters Project aims to lay out a set of suggestions for where red wolves could be reintroduced successfully. I sought to understand what drives the success or failure of such a project, both ecologically and socially, in order to take a comprehensive look at the benefits or drawbacks of all possible sites. The literature on red wolves has not sufficiently dealt with this question, and to avoid a failed reintroduction that could cripple the entire program it is worthwhile to fully address the site selection process before moving any animals back into the wild in a new location.

II. History and Controversy

North Carolina is home to a diverse array of wildlife living in habitats ranging from the coastal plains to the piedmont and the mountains. The red wolf was among the many species driven to the brink of extinction by habitat loss and hunting during the widespread development of the United States, and in 1980 the species was declared extinct in the wild.[4] The last remaining wild individuals were captured from swampy forests along the Louisiana-Texas border between 1973-1980, and those that were

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[2] Ronald M. Nowak, "The Original Status of Wolves in Eastern North America," *Southeastern Naturalist* 1, no. 2 (June 1, 2002): 95–130, https://doi.org/10.1656/1528-7092(2002)001[0095:TOSOWI]2.0.CO;2.; U.S. Fish and Wildlife Service, "Endangered Red Wolves," October 1997, https://digitalmedia.fws.gov/cdm/singleitem/collection/document/id/1940/rec/1. ; International Wolf Center, "North Carolina." http://www.wolf.org/wow/united-states/north-carolina/.
[3] U. S. Fish and Wildlife Service, "Red Wolf Recovery/Species Survival Plan" (U.S. Fish and Wildlife Service, Southeast Region, 1989).
[4] *Id* at Executive Summary.

determined to be pure examples of the red wolf phenotype were captured and moved into captivity to initiate captive breeding programs.[5]

This breeding program began at Point Defiance Zoo in Tacoma, Washington and grew rapidly, starting with a small population of 15 breeding individuals. Following American Zoological Society (AZA) approval of the Species Survival Plan in 1984, it gradually expanded to more facilities and became one of the most successful captive breeding programs in the country.[6]

The reintroduction effort took the next step in September of 1987 when four pairs of adult red wolves were released into Alligator River National Wildlife Refuge (NWR) in northeastern North Carolina as a non-essential experimental population.[7] These wolves on the Albemarle Peninsula were able to successfully establish themselves and founded a truly wild population that grew to number approximately 151 individuals by 2005.[8] They have expanded their range into neighboring Pocosin Lakes National Wildlife Refuge as well, along with other parcels of federal land and private property.

A second reintroduction took place in Great Smoky Mountains National Park, where a family of red wolves was released into the wild in 1991.[9] This project lasted less than a decade however and was terminated in 1998 after wolves dispersed widely outside of the Park and experienced high mortality. Most remaining wolves were recaptured, and scientists posited that the project likely failed due to a lack of food and a preference for the less mountainous habitat outside the Park.[10] This left the wolf population centered around Alligator River NWR as the only successful reintroduction site, and this remains the case to this day despite the Red Wolf Recovery Plan's goal of establishing three sites.

The recovery effort has been hampered by political and scientific controversy in recent years. This turmoil and the management decisions it has spurred have led to a severe rise in mortality of wolves and a subsequent decline in their population in the wild, dropping to approximately 45-60 wolves by 2016, when the USFWS last updated their mortality numbers.[11] These numbers likely overestimate the

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[5] *Id* at 12.
[6] *Id* at 12.
[7] *Id* at 17.
[8] Joseph W. Hinton et al., "Survival and Population Size Estimates of the Red Wolf," *The Journal of Wildlife Management* 81, no. 3 (March 28, 2017): 417–28, https://doi.org/10.1002/jwmg.21206.
[9] U.S. Fish and Wildlife Service, "Notice of Termination of the Red Wolf Reintroduction Project in the Great Smoky Mountains National Park," *Federal Register* 63, no. 195 (October 8, 1998): 54151. https://www.fws.gov/redwolf/Reviewdocuments/1998_FR(63)54151-54153.pdf
[10] *Id*.
[11] U.S. Fish and Wildlife Service, "Table 1. Causes of Mortality in Wild Red Wolves." (June 13, 2016). https://www.fws.gov/redwolf/Images/Mortalitytable.pdf; Hinton et al., "Survival and Population Size Estimates of the Red Wolf."

number of wolves currently remaining in the wild, as in the spring of 2017 only 29 individuals were known by the USFWS to have functioning radio collars.[12]

One of the reasons for the controversy surrounding the program is the current debate over the genetic status of the red wolf as a true species.[13] This report will not attempt to address these issues as they are outside the purview of selecting a new reintroduction site, but it would be remiss to not acknowledge these concerns. The questions of genetic purity and what makes a "true" red wolf have been enough to hamper the management of the species and create a modest amount of public opposition to the continued protection of the red wolf in recent years.

An example of the impact of this pressure is the decision by the USFWS to suspend its Adaptive Management Plan in 2015, which had been designed "to study, monitor and adaptively manage hybridization with coyotes, which was identified as the existential threat to the red wolf at the time the plan was developed."[14] This decision was followed up by the issuance of several "take" permits, allowing the killing of red wolves by private landowners, as well as the removal of wolves from private land by the Service.[15]

Even more recently, in September of 2016 the USFWS announced significant changes to the Red Wolf Recovery Plan.[16] The most relevant components of this new strategy were 1) to remove many of the wild red wolves from their current habitat and place them back in captivity indefinitely in order to bolster the captive breeding stock, and 2) to identify other potential project areas where they might establish new "Non-essential Experimental Populations," as described in the Endangered Species Act (ESA).[17] The Service does not intend to completely eliminate the current "non-essential experimental" wild population,

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[12] Ron Sutherland, "By Night, Hunters Would Blast Red Wolves into Extinction," *The News & Observer*, March 4, 2017, sec. Op-Ed, http://www.newsobserver.com/opinion/op-ed/article136432798.html.

[13] Selection of relevant papers: Bridgett M. von Holdt et al., "Whole-Genome Sequence Analysis Shows That Two Endemic Species of North American Wolf Are Admixtures of the Coyote and Gray Wolf," *Science Advances* 2, no. 7 (July 1, 2016): e1501714, https://doi.org/10.1126/sciadv.1501714; Bridgett M. von Holdt et al., "Admixture Mapping Identifies Introgressed Genomic Regions in North American Canids," *Molecular Ecology* 25, no. 11 (May 12, 2016): 2443–53, https://doi.org/10.1111/mec.13667; Linda Y. Rutledge et al., "Conservation Genomics in Perspective: A Holistic Approach to Understanding Canis Evolution in North America," *Biological Conservation* 155 (October 1, 2012): 186–92, https://doi.org/10.1016/j.biocon.2012.05.017; Justin H. Bohling and Lisette P. Waits, "Factors Influencing Red Wolf–coyote Hybridization in Eastern North Carolina, USA," *Biological Conservation* 184 (April 1, 2015): 108–16, https://doi.org/10.1016/j.biocon.2015.01.013.

[14] U.S. Fish and Wildlife Service, "Red Wolf Adaptive Management Plan, FY13-FY15," February 2013.; Group Solutions, Inc., "Red Wolf Recovery Team Final Recommendations," September 6, 2016.

[15] Heidi Ridgley, "The Long and Winding Road," *Defenders Magazine*, January 26, 2017, https://defenders.org/magazine/winter-2017/long-and-winding-road.

[16] Cynthia K. Dohner to Regional Director, Southeast Region, "Recommended Decisions in Response to Red Wolf Recovery Program Evaluation," September 12, 2016.; U. S. Fish and Wildlife Service, "Science Leads Fish and Wildlife Service to Significant Changes for Red Wolf Recovery," Press Release, September 12, 2016, https://www.fws.gov/news/ShowNews.cfm?ref=science-leads-fish-and-wildlife-service-to-significant-changes-for-red-&_ID=35794.

[17] *Id.*

but will restrict their protected territory solely to Alligator River NWR, removing them from private lands and attempting to keep them solely within Dare County.[18] This decision has been challenged in court by a number of conservation organizations who believe restricting the territory of the wolves so dramatically will lead to increased mortality and doom them in the wild, [19] and has also been called into question by the scientists whose Population Viability Analysis the Service relied upon when making their decision to declare the captive population to be at-risk.[20]

The original deadline for the Service to announce their final determination on this matter, along with the new potential locations to establish a wild population, was October of 2017. Despite issuing an Advanced Notice of Proposed Rulemaking in May of 2017,[21] the Service has not published a final report or decision on the matter at this time and declares on the website of the Southeast Regional Office that the "Service must first secure the captive population before establishing any new populations in the wild."[22]

III. Importance of Wolves: Why Reintroductions Matter

The idea of reintroducing wolves and other apex predators to environments where they formerly roamed is not just a flight of fancy by wildlife-loving biologists, or part of an effort by government agencies to increase their control over lands. After centuries of persecution and removal, the loss of wolves is reflected clearly in ecosystems throughout their historic range. Species such as coyote that formerly were confined to the West of the United States have moved into the East in several waves, filling in the niche formerly occupied by wolves and mixing with many other canid species they encounter.[23] This expansion of geographic range and ecological function is known as "mesopredator release," and can have far-ranging effects.[24] The populations of other species such as white-tailed deer

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[18] *Id.*

[19] Ridgley, "The Long and Winding Road."

[20] Lisa Faust et al. to Cynthia K. Dohner, "PVA Team Response to USFWS," October 11, 2016.

[21] U.S. Fish and Wildlife Service, Advance notice of proposed rulemaking; notice of intent to prepare a National Environmental Policy Act document, "Endangered and Threatened Wildlife and Plants; Nonessential Experimental Population of Red Wolves (Canis rufus) in North Carolina," *Federal Register* 82, no. 98 (May 23, 2017): 23518. https://www.gpo.gov/fdsys/pkg/FR-2017-05-23/pdf/2017-10551.pdf

[22] U.S. Fish and Wildlife Service, "Red Wolf Recovery Program Review," Southeast Region of the U.S. Fish and Wildlife Service, November 28, 2017, https://www.fws.gov/southeast/faq/red-wolf-recovery-program-review/.

[23] Elizabeth Heppenheimer et al., "Demographic History Influences Spatial Patterns of Genetic Diversity in Recently Expanded Coyote (Canis Latrans) Populations," *Heredity* 120, no. 3 (March 2018): 183–95, https://doi.org/10.1038/s41437-017-0014-5; IUCN, "Canis Latrans: Gese, E.M., Bekoff, M., Andelt,W., Carbyn, L. & Knowlton, F.: The IUCN Red List of Threatened Species 2008: E.T3745A10056342" (International Union for Conservation of Nature, June 30, 2008), https://doi.org/10.2305/IUCN.UK.2008.RLTS.T3745A10056342.en.

[24] William J. Ripple et al., "Widespread Mesopredator Effects after Wolf Extirpation," *Biological Conservation* 160 (April 1, 2013): 70–79, https://doi.org/10.1016/j.biocon.2012.12.033.

have also exploded without the pressure of predation from wolves in the East, resulting in increases in car accidents with deer and associated costs for humans.

The reintroduction of wolves into an area can help reverse some of these trends and can have remarkable restorative effects on entire ecosystems. This has been demonstrated by the success of the reintroduction of wolves to the Greater Yellowstone Ecosystem. Since wolves were brought back over two decades ago, elk numbers have declined, various types of vegetation have greatly increased in size and distribution due to decreased browsing pressure, songbirds have returned to former territories, and beavers have increased in both number and activity, changing the hydrological profile of certain areas.[25]

These effects are dramatic, and have demonstrated the impact that restoring large, high-trophic-level predators such as wolves to an ecosystem can have for native flora and fauna. Restoring the red wolf to a wider range of territories could have a similar impact on its historic range, possibly alleviating some of the changes brought on by wide-scale development and land change in the Eastern United States.

IV. Goals of the Study

This study is therefore aimed to provide useful information for the Service to consider when making their future selection for a recovery site, and can be used by my client, Wildlands Network, to advocate for adherence to the Recovery Plan in accordance with the best available science. Previous efforts to identify suitable sites for reintroduction have focused primarily on ecological characteristics, and the most comprehensive previous effort in the public literature was conducted in the year 2000 focusing on general geographic areas rather than particular parcels of government-owned land.[26] This study aimed to consider both ecological and social factors that can affect the success of a reintroduced population, as the human element can override even the best of biological fits. I also started with an open-ended search for specific sites, including both state and federal lands to allow for the consideration of locations where the government would have legal authority to introduce species.

While the genetics and politics of red wolves may both be highly controversial, the species remains listed as Endangered under the Endangered Species Act[27] and deserves the full protection of the

[25] Robert L. Beschta and William J. Ripple, "Riparian Vegetation Recovery in Yellowstone: The First Two Decades after Wolf Reintroduction," *Biological Conservation* 198 (June 1, 2016): 93–103, https://doi.org/10.1016/j.biocon.2016.03.031; Robert L. Beschta and William J. Ripple, "Large Predators and Trophic Cascades in Terrestrial Ecosystems of the Western United States," *Biological Conservation* 142, no. 11 (November 1, 2009): 2401–14, https://doi.org/10.1016/j.biocon.2009.06.015.

[26] Frank T. van Manen, Barron A. Crawford, and Joseph D. Clark, "Predicting Red Wolf Release Success in the Southeastern United States," *The Journal of Wildlife Management* 64, no. 4 (2000): 895–902, https://doi.org/10.2307/3803197.

[27] U.S. Fish and Wildlife Service, "Species Profile for Red Wolf (Canis Rufus)," ECOS: Environmental Conservation Online System, accessed April 8, 2018, https://ecos.fws.gov/ecp0/profile/speciesProfile?spcode=A00F.

law. This study provides a useful method to evaluate locations as potential sites for reintroduction and gives Wildlands Network and the Service data that they can use to make choices in the very near future about where to continue the wild population of red wolves.

Methods

I. Identifying the Issue

Due to prior work with red wolves based on other projects and work at a summer internship, I had already collected and read a great deal of literature on red wolves. I decided to continue working with the species in a new and potentially useful capacity. After deciding in July of 2017 to analyze potential reintroduction sites, I began this new independent project in earnest.

I approached Wildlands Network and Dr. Ron Sutherland with my idea for the Masters Project, as I had worked with him previously on my prior red wolf project. They were interested in supporting and guiding my work, because according to Dr. Sutherland "Wildlands Network is very interested in promoting the recovery of red wolves across the former range of the species, and is interested in using the best available data for identifying the most logical places to start new recovery programs." He said that they are "excited to look at the data and inform advocacy and scientific efforts to steer the course of Fish and Wildlife Service and encourage them to start new programs."

II. Methods Overview

The first step in predicting which sites are the most suitable for red wolf reintroduction was to identify the factors that predict their success or failure. This was achieved through a literature review and produced a list of five key variables, both social and ecological, that influence the likelihood of a successful reintroduction. I then identified the sites that I would analyze for suitability and surveyed a group of experts to determine the relative importance of each variable. Using this information, I produced data layers in ArcGIS and calculated a weighted sum, producing suitability scores for each potential site. Finally, I calculated additional statistics to examine the similarity of various sites and identify how each variable contributed to the overall scores.

III. Literature Review for Variable Identification

The first step was to conduct a thorough literature review on red wolf biology and on the social factors that can affect individual attitudes and feelings towards wolves. This was conducted using the Duke University Library Summon search engine, as well as specific databases such as Web of Science. I also was provided with a database of relevant articles by Dr. Sutherland, along with a similar cache of documents provided by my summer employer, the Center for Biological Diversity.

The number of studies on red wolves is relatively limited, and this is made more difficult by the fact that there has not been a substantial wild population since the early 20th Century, which was never fully studied. All studies conducted in the wild in the last 30-40 years have looked at very limited and artificially selected settings, mainly in their current range in eastern North Carolina. This may not present true representations of the wolves' preferences and habits, as it is unknown how they behaved in a truly natural state before their elimination by humans. Similarly, given their limited geographic range, the amount of studies done on social attitudes towards red wolves is fairly limited. Therefore, I used a number of studies that dealt with social surveys related to grey wolves, as the subtle distinctions between the two species are probably not widely known or understood by the general public.

A number of trends and themes emerged during the search, and these formed the basis for my variables moving forward. The key ecological factors that determined the success of red wolves appeared to be the type of suitable habitat available[28] and the amount of prey available.[29] The sociological factors that appeared to be the most consistent in shaping views towards wolves were the age of an individual,[30] their ownership of livestock,[31] and their pursuit of recreational hunting.[32] I also identified several sources

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[28] Joseph W. Hinton and Michael J. Chamberlain, "Space and Habitat Use by a Red Wolf Pack and Their Pups During Pup-Rearing," *The Journal of Wildlife Management* 74, no. 1 (December 13, 2010): 55–58, https://doi.org/10.2193/2008-583; Justin A. Dellinger et al., "Habitat Selection of a Large Carnivore, the Red Wolf, in a Human-Altered Landscape," *Biological Conservation* 157 (January 1, 2013): 324–30, https://doi.org/10.1016/j.biocon.2012.09.004; Joseph W. Hinton et al., "Space Use and Habitat Selection by Resident and Transient Red Wolves (Canis Rufus)," *PLOS ONE* 11, no. 12 (December 21, 2016): e0167603, https://doi.org/10.1371/journal.pone.0167603; Joseph W. Hinton, "RED WOLF (CANIS RUFUS) AND COYOTE (CANIS LATRANS) ECOLOGY AND INTERACTIONS IN NORTHEASTERN NORTH CAROLINA" (University of Georgia, 2014).

[29] Justin A. Dellinger et al., "Food Habits of Red Wolves during Pup-Rearing Season," *Southeastern Naturalist* 10, no. 4 (December 1, 2011): 731–40, https://doi.org/10.1656/058.010.0412; Michael K. Phillips, V. Gary Henry, and Brian T. Kelly, "Restoration of the Red Wolf," *USDA National Wildlife Research Center - Staff Publications*, January 1, 2003, 272–88.

[30] Christopher K. Williams, Göran Ericsson, and Thomas A. Heberlein, "A Quantitative Summary of Attitudes toward Wolves and Their Reintroduction (1972-2000)," *Wildlife Society Bulletin (1973-2006)* 30, no. 2 (2002): 575–84; Alistair Bath, "The Public and Wolf Reintroduction in Yellowstone National Park," *Society & Natural Resources* 2, no. 1 (January 1, 1989): 297–306, https://doi.org/10.1080/08941928909380693; Tulchin Research, "Polling Finds North Carolina Voters Strongly Back Red Wolf Recovery," August 17, 2016, https://defenders.org/publications/Defenders-of-Wildlife-Red-Wolf-Public-Memo.pdf.

[31] Meredith S. Berry, Norma P. Nickerson, and Elizabeth Covelli Metcalf, "Using Spatial, Economic, and Ecological Opinion Data to Inform Gray Wolf Conservation," *Wildlife Society Bulletin* 40, no. 3 (September 21, 2016): 554–63, https://doi.org/10.1002/wsb.687; Jennifer Pate et al., "Coloradans' Attitudes toward Reintroducing the Gray Wolf into Colorado," *Wildlife Society Bulletin (1973-2006)* 24, no. 3 (1996): 421–28; Williams, Ericsson, and Heberlein, "A Quantitative Summary of Attitudes toward Wolves and Their Reintroduction (1972-2000)"; Bath, "The Public and Wolf Reintroduction in Yellowstone National Park."

[32] Berry, Nickerson, and Metcalf, "Using Spatial, Economic, and Ecological Opinion Data to Inform Gray Wolf Conservation"; Pate et al., "Coloradans' Attitudes toward Reintroducing the Gray Wolf into Colorado."

that delineated the historic range of red wolves before their widespread removal from the environment, which will be explored in more depth in the next section.[33]

IV. Selecting Sites

With these potential variables in mind, I began moving my work into ArcGIS and downloading data to form the backbone of my analysis. This included state boundaries from The National Map program at the U.S. Geological Survey (USGS).[34] Using the historic ranges provided in the literature, which are in general agreement, I drew a line representing the boundary of my study area that extended from Eastern Texas across Oklahoma and Missouri, then northeast to Pennsylvania and New Jersey (Figure 1). I also drew a second line to complete the circle and create a polygon that I could use to clip the extent of other data files so they only covered the historic range.

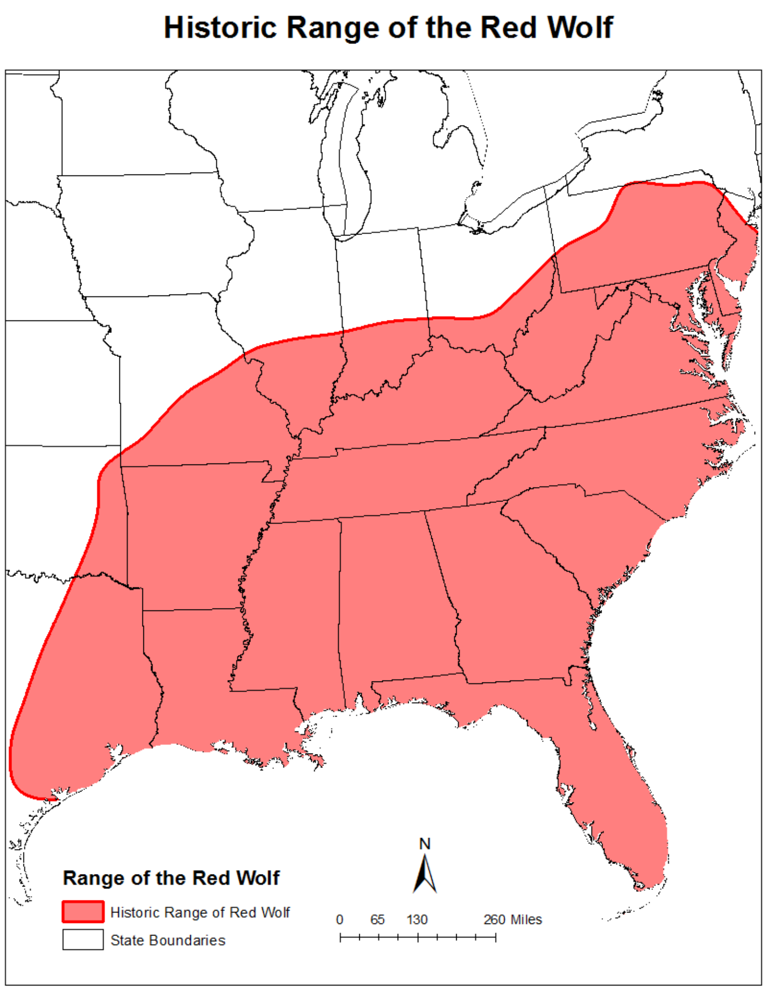

Figure 1. This area was used to represent the historic range of the red wolf across the Eastern United States before their extirpation by humans. The western boundary was drawn based on the average extent from numerous historical sources.

[33] Nowak, "The Original Status of Wolves in Eastern North America"; U.S. Fish and Wildlife Service, "Endangered Red Wolves."; International Wolf Center, "North Carolina."
[34] U.S. Geological Survey, The National Map. July 2017. Small-Scale Data Download. https://nationalmap.gov/small_scale/atlasftp.html

To identify which sites should be the focus of my analysis, I had to determine a set of parameters by which to evaluate sites. I initially decided that the sites must be located within the historic range of the wolves and have some level of protected status at either the state or federal level. This is necessary because in order for the federal government to implement their Species Survival Plan and introduce the wolves, they must have the authority to introduce animals onto the piece of land in question. This would be too difficult to manage if attempting to balance a number of private land owners, and so the core introduction areas must be protected and managed by a governmental authority. Beyond that, I determined that a site must be at least as large as Alligator River National Wildlife Refuge, or 152,000 acres in size.[35] As the wolves have already run into opposition from abutting land owners in their current location, it would seem prudent to ensure that any future sites have at least as much available, contiguous land for them to utilize.

The largest available database of public and protected lands is the Protected Areas Database of the United States (PAD-US), which is maintained by the National Gap Analysis Project (GAP) within USGS.[36] I downloaded data for four different regions, the Midwest, Northeast, Southeast, and Southcentral, then combined them all into a single Shapefile and clipped it to only keep the sites that were within the historic range polygon. From there, I selected only the protected sites that met the minimum size requirement of 152,000 acres. This reduced the data from thousands of potential choices to fewer than 100.

I then proceeded to remove sites that were owned by the Department of Defense and Department of Energy, because although these are well-protected they are also often enclosed and would severely limit the ability of wolves to disperse naturally. The remaining sites included several in southern Florida that were primarily marine and/or coastal protected areas, and so I removed those as well (e.g., Everglades National Park and Biscayne National Park). I also removed Great Smoky Mountains National Park, due to the prior failed reintroduction effort in that Park.

Finally, areas that either overlapped entirely or shared significant amounts of border were merged together into a single file. These include two parcels of Ouachita National Forest divided only by the Arkansas-Oklahoma border, Tate's Hell State Forest and Apalachicola National Forest in Florida, and Nantahala National Forest and Chatahoochee-Oconee National Forest across the North Carolina-Georgia state line. This left me with a set of 21 protected areas to serve as core sites for potential reintroductions (Figure 2, Table 1).

[35] U.S. Fish and Wildlife Service, "Alligator River National Wildlife Refuge," n.d., https://www.fws.gov/southeast/pdf/fact-sheet/alligator-river-national-wildlife-refuge.pdf.

[36] U.S. Geological Survey, Gap Analysis Program (GAP). May 2016. Protected Areas Database of the United States (PAD-US), version 1.4 Combined Feature Class. https://gapanalysis.usgs.gov/padus/data/download/.

I also created shapefiles for Alligator River and Pocosin Lakes National Wildlife Refuges, the federal protected areas that form the core of the current Red Wolf Recovery Area, and joined them together to form one site for the "current" range. I conducted all of the analyses on these sites as well in order to compare the potential sites to the suitability of their present range.

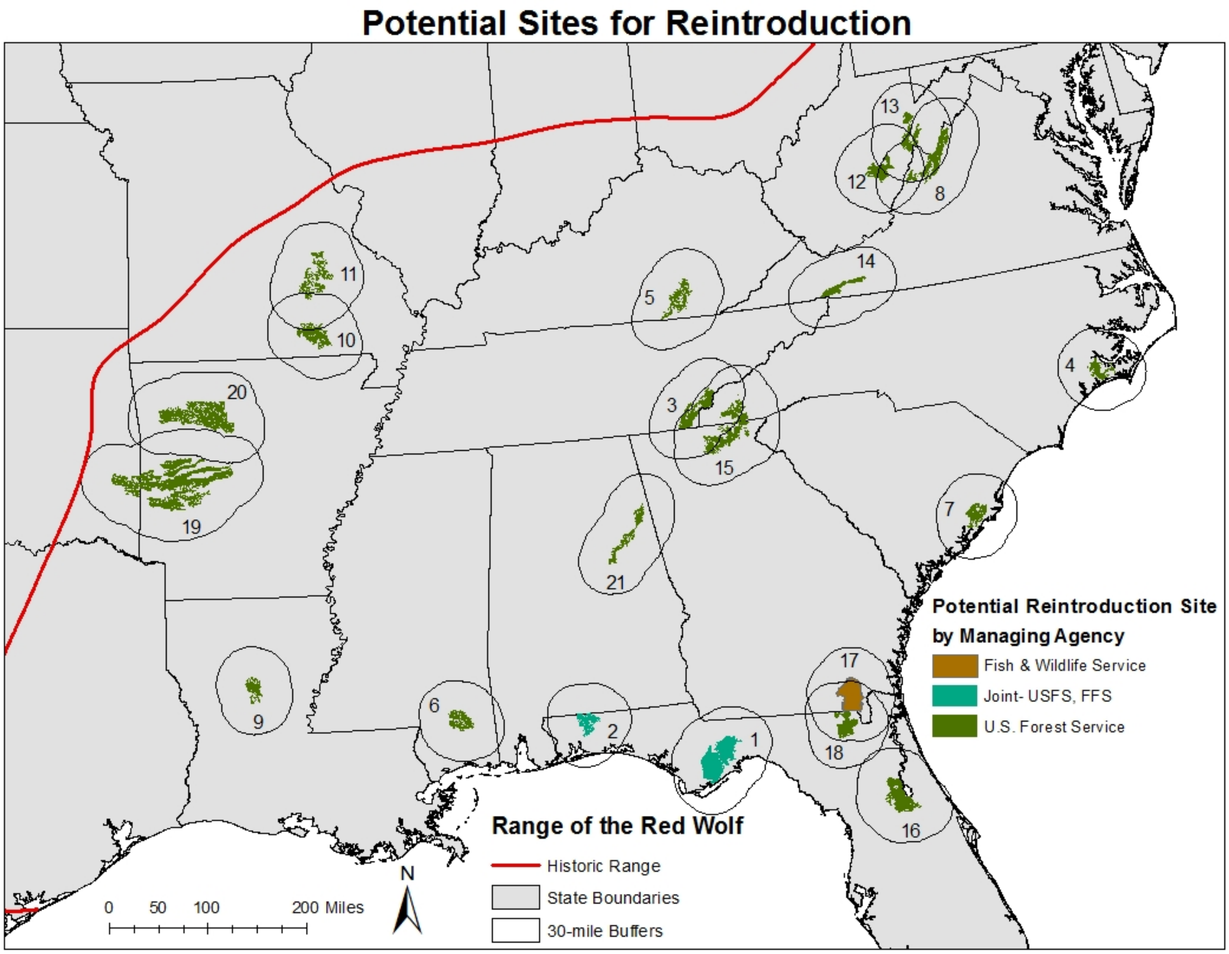

Figure 2. The final set of 21 possible sites for the reintroduction of red wolves within their historic range. All sites are classified by their managing agency, 18 of which are managed exclusively by the U.S. Forest Service with one owned by U.S. Fish and Wildlife Service and two jointly managed by Florida Forest Service and other agencies. Names for each site are provided in Table 1.

Table 1. Key to the potential reintroduction sites as labeled in Figure 2. When not provided in the PADI-GAP dataset, names were obtained from the U.S. Forest Service website.[37]

Number	Site
1	Apalachicola National Forest (FL)/Tate's Hell State Forest (FL)
2	Blackwater River State Forest (FL)
3	Cherokee National Forest (TN)
4	Croatan National Forest (NC)
5	Daniel Boone National Forest (KY)
6	De Soto National Forest (MS)
7	Francis Marion and Sumter National Forests (SC)
8	George Washington and Jefferson National Forest (VA)
9	Kisatchie National Forest (LA)
10	Mark Twain National Forest (1) (MO)
11	Mark Twain National Forest (2) (MO)
12	Monongahela National Forest (1) (WV)
13	Monongahela National Forest (2) (WV)
14	Mount Rogers National Recreation Area (VA)
15	Nantahala National Forest /Chatahoochee-Oconee National Forest (NC/GA)
16	Ocala National Forest (FL)
17	Okefenokee National Wildlife Refuge (GA)
18	Osceola National Forest (FL)
19	Ouachita National Forest (AR/OK)
20	Ozark-St. Francis National Forest (AR)
21	Talladega National Forest (AL)

V. Locating Data

The wide geographic range across which sites were located, encompassing states from Oklahoma to Florida to West Virginia, made finding data at the appropriate scale and of acceptable quality a challenge. Based on the literature review, the five variables that I considered were: Age of local residents, the amount of livestock owned by people in the area, the amount of hunting that takes place around the site, the amount of prey available for red wolves to consume, and the type of land cover and habitat available to them.

Determining the age of residents around a site was relatively straightforward, as the United States Census Bureau puts out their data in easily accessible formats. Their TIGER products (Topologically Integrated Geographic Encoding and Referencing) are available in formats that are easily integrated into ArcGIS, and I was able to download shapefiles that included the median age of residents on a county-by

[37] U.S.D.A. Forest Service, "FSTopo Map Products," FS Geodata Clearinghouse, accessed April 12, 2018, https://data.fs.usda.gov/geodata/rastergateway/states-regions/states.php.

county basis for the entire study area. These were available as "TIGER/Line with Selected Demographic and Economic Data" from the Census Bureau website, and I used the data from the 2010 Census.[38]

When considering the availability of prey, the issue for the study became availability of data. Species such as rabbits, nutria and raccoons can be a large component of a red wolf's diet,[39] but there is very limited data available about their relative ranges and local concentrations. Deer are also a frequent source of food for red wolves[40] and due to the presence of range-wide data for white-tailed deer I chose to use them as the proxy for food availability.

A team at the University of Minnesota's Forest Ecosystem Health Lab and the U.S. Department of Agriculture, Forest Service-Northern Research Station digitized a dataset of white-tailed deer density estimates for the Eastern United States in 2016.[41] The data used in their digital product came from a 2009 report by the Quality Deer Management Association (QDMA), and was compiled with information supplied to them from 2001-2005 by state wildlife agencies.[42] In conversation with Dr. Sutherland, we agreed that this represented the best and most recent estimate of deer densities over such a wide range. The data were downloaded from the University of Minnesota's website and clipped to only cover the study area.

Data on livestock abundance was obtained from the Food and Agriculture Organization of the United Nations. Their Agriculture and Consumer Protection Department has produced data on the spatial distribution of many forms of agricultural activity, including a project known as "Gridded Livestock of the World," which estimates global distribution of a variety of livestock animals.[43] I downloaded their global dataset for cattle, which was updated in 2014 for higher resolution and accuracy than their 2007 version.[44]

The choice to use cattle as representative of livestock conflict was based on a number of factors. First, there is a long history of cattle ranchers being opposed to wolves and favoring their hunting and

[38] United States Census Bureau, TIGER Products. 2010. TIGER/Line with Selected Demographic and Economic Data, 2010 Census, Counties. https://www.census.gov/geo/maps-data/data/tiger-data.html
[39] Glynn A. Riley and Roy T. McBride, "A Survey of the Red Wolf (Canis Rufus)" (U.S. Department of the Interior, Fish and Wildlife Services, 1972), http://hdl.handle.net/2027/mdp.39015077581356.
[40] Phillips, Henry, and Kelly, "Restoration of the Red Wolf"; Dellinger et al., "Food Habits of Red Wolves during Pup-Rearing Season."
[41] Brian F. Walters, Christopher W. Woodall, and Matthew B. Russell, "White-Tailed Deer Density Estimates across the Eastern United States, 2008," March 13, 2016, http://dx.doi.org/10.13020/D6G014.
[42] Kip Adams, Joe Hamilton, and Matt Ross, "QDMA's Whitetail Report" (Quality Deer Management Association, 2009).
[43] Food and Agriculture Organization of the United Nations, Agriculture and Consumer Protection Department. 2007. "Gridded Livestock of the World." http://www.fao.org/ag/againfo/resources/en/glw/home.html
[44] Timothy P. Robinson et al., "Mapping the Global Distribution of Livestock," *PLOS ONE* 9, no. 5 (May 29, 2014): e96084, https://doi.org/10.1371/journal.pone.0096084.

persecution.[45] Further, considering the specific circumstances of the Eastern United States, there is a pervasive low level of sheep and goat abundance, making the data so sparse as to be uninformative. The practices of keeping hogs and chickens in this part of the world typically involve keeping the animals indoors in dense, largely self-contained enclosures, reducing the likelihood of potential conflict with predators. After making this decision and acquiring the FAO data, I clipped the Raster files to just cover the extent of the study area.

The data to evaluate land cover and habitat type came from the National Land Cover Database (NLCD) from 2011.[46] This is developed by the Multi-Resolution Land Characteristics Consortium from Landsat imagery and is available freely online in Raster format. I clipped this data to the extent of the wolves' historic range as well.

The final variable to consider was hunting, which does not have a single national database to draw from. Instead, I decided to use harvest of white-tailed deer as a proxy for the intensity of hunting at the county level. Every state has an agency that regulates hunting, sets the opening and closing dates for each season, and issues permits to hunt various species based on their management strategy. These agencies also put out annual reports that include the statistics on hunting for the previous year, including total harvest and typically a breakdown by county.

I acquired the best available data for each state in the range of the red wolf that had a potential reintroduction site within it and joined that data as tables to shapefiles of all the counties in the respective state. Many of the states had data online in highly inaccessible formats, and so I created a series of scripts in the Python coding language to scrape the data either from websites or PDFs, when the data came in that format. A sample of these scripts and a table of sources for the hunting data is available in the Appendix (Figure 6 & Table 6).

Data was available on a county-by-county basis for every state in question except for Mississippi and Louisiana. I contacted the Louisiana Department of Wildlife and Fisheries and the Mississippi Department of Fish and Game to inquire about what data they may have available at the county level, and I was told that Mississippi does not have a harvest reporting system at the county level.[47] Louisiana did have such data available and provided it to me via email.[48]

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[45] Berry, Nickerson, and Metcalf, "Using Spatial, Economic, and Ecological Opinion Data to Inform Gray Wolf Conservation"; Pate et al., "Coloradans' Attitudes toward Reintroducing the Gray Wolf into Colorado"; Williams, Ericsson, and Heberlein, "A Quantitative Summary of Attitudes toward Wolves and Their Reintroduction (1972-2000)."

[46] Homer, C.G., et al., "Completion of the 2011 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information." 2015. *Photogrammetric Engineering and Remote Sensing* 81, no. 5, p. 345-354.

[47] R. Hamrick, MS DWFP, personal communication. January 11, 2018.

[48] J. Bordelon, LA DFW, personal communication. January 11, 2018.

To account for the lack of county-level data in Mississippi, I used the total estimated harvest from their statewide phone survey of hunters and averaged that across all counties in the state. Additionally, several states only have "reported harvest" numbers available, which they emphasized were different from the actual harvest data. For example, in Alabama it is estimated that only 35% of deer harvest is reported.[49] Georgia's county-by-county data[50] only totaled about 58% of their estimated total harvest for the state[51], and in Louisiana they estimate that only about 50% of deer killed are reported to the agency.[52] Based on these statistics, I adjusted all counties in each of those states by their state's respective proportion in order to bring the total level of harvest closer to reality.

VI. Surveying Experts

One of the most difficult parts of designing a model that accounts for multiple variables is deciding how to weight them. For this project, I turned to the experts to help make the decision for me. I developed a list of 14 experts on the topic of red wolf biology, based on their published research, involvement with the red wolf recovery team, or work in the field with the experimental population in North Carolina. The experts were promised anonymity for their participation in the survey, and so I cannot include a list of their names in this report.

I created the survey using software available to Duke students through Qualtrics, and a copy of this survey may be found in the Appendix (Figure 7). The questions asked the experts to assign weights from 0-100 for all five of the variables described above, assessing each independently. The experts were also asked to estimate how far away from the core protected areas these variables should be evaluated (choosing from a multiple-choice list). This second question aimed to set zones of a certain distance around the sites, within which I could evaluate the variables. Dr. Sutherland provided edits before the survey was distributed. Additionally, Dr. Cagle and I conferred with the Duke Internal Review Board (IRB) and were told the survey did not meet the baseline for human subject research and so was exempt from IRB approval.

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[49] The Associated Press, "More than 82,000 Deer Killed in Alabama during 2016-17 Hunting Season," AL.com, March 8, 2017, https://www.al.com/news/birmingham/index.ssf/2017/03/more_than_82000_deer_killed_in.html.
[50] Georgia Department of Natural Resources, "Georgia Hunter Resources (WRD Harvest Data)," 2018, https://gamecheckresults.gooutdoorsgeorgia.com/DeerByCounty.aspx.
[51] Georgia Wildlife, "2016-17 Georgia Deer Harvest Summary," 2017, http://georgiawildlife.com/sites/default/files/wrd/pdf/harvest-summaries/deer/16-17_Deer_Harvest_Summary.pdf.
[52] J. Bordelon, LA DFW, personal communication. February 12, 2018.

VII. Assembling the Final Model

With all of the data collected and the weights elicited from the experts, I put everything together in a series of ArcGIS models and scored each potential site. This first involved putting all data layers into the same Datum (WGS84) and Projection (Albers Equal Area). Then, for each variable I reclassified the previous values into scores that represent their suitability for the red wolves. These tables are available in the Appendix (Tables 7-11). These scores were based off of the literature for the land cover variable, as a number of studies have looked at the preferred habitat of red wolves (in this case, grasslands and longleaf pine savannahs with a tolerance for hardwood forests and wetlands).[53] For the other variables, it was simply assumed that the response was along a roughly linear gradient from negative to positive.

Once all variables had been reclassified onto a scale of 1-10, with 10 being the best or most suitable conditions, I converted the data in polygon format to Raster format with 30-meter cell size. After conferring with John Fay about the differences between a Weighted Sum and Weighted Overlay tool in ArcGIS, I decided to proceed with the Weighted Sum tool, which provides a more granular look at the results and does not re-scale things to a predetermined range. In order to run this tool, I had to input all five variable Raster files with their reclassified values and their assigned weights (Table 2).

Once this tool had run, the result was a Raster image with the suitability score calculated for every pixel in the historic range (Figure 3). To evaluate the suitability of each individual site, I drew buffer zones of 30 miles around each of the proposed locations (Figure 3) and calculated the Zonal Statistics for each of these zones. However, due to a quirk of ArcGIS, this method could not handle the areas where zones overlapped and produced only partial scores for some sites. To correct this, I consulted with John Fay and created a looping iterator tool in ArcGIS that would select each site individually, draw a buffer around that particular site and calculate the statistics for it without the interference of nearby sites (Appendix Figure 8). This produced accurate mean values for each 30-mile buffer around (and including) the protected core sites.

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[53] Hinton et al., "Space Use and Habitat Selection by Resident and Transient Red Wolves (Canis Rufus)"; Hinton and Chamberlain, "Space and Habitat Use by a Red Wolf Pack and Their Pups During Pup-Rearing"; Dellinger et al., "Habitat Selection of a Large Carnivore, the Red Wolf, in a Human-Altered Landscape."

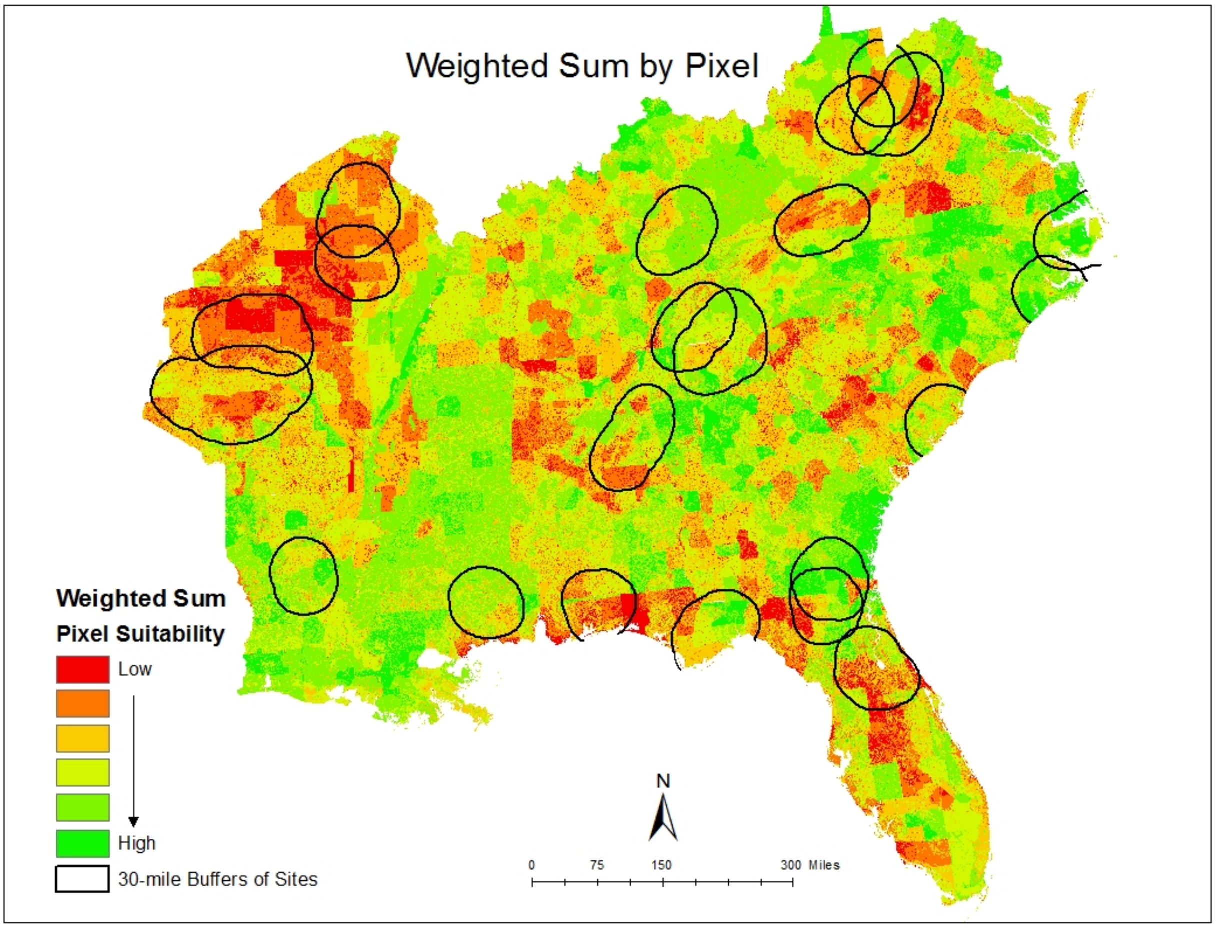

Figure 3. After weighting and reclassifying each variable, this represents a "suitability surface" for red wolves. The areas with the highest weighted sum values are represented in green, and the lowest are in red. The scores were calculated for each 30 meter-by-30 meter pixel that was covered by all five variables, and statistics were calculated on this surface within each 30-mile buffer zone.

VIII. Statistical Analysis

I repeated this looping tool for all five variables individually to get scores for each variable for each zone. The goal of this was to see which variable has the biggest impact on each location. In order to properly measure the value of the land cover dataset, I had to use a "Mask" based on the Deer raster so that it would not count open ocean as potential habitat for the coastal sites in the dataset. As the dataset with the smallest extent, the Deer image set the boundaries for what went into the final equation, and so using it as a Mask ensures that these results match the inputs that would have gone into the Weighted Sum, where only pixels with values for all five images were included.

After calculating scores for all five variables in all 22 zones (the 21 new sites plus the current range), I compiled them into a table and imported them into the R software package. I then calculated a Euclidian Distance matrix, comparing all 22 sites against each other across all five variables, thereby producing a 22x22 matrix containing measures of ecological "distance" between each site based on the mean values of each contributing variable. The distance measurements are akin to measuring the dissimilarity between sites, with those pairs that have higher values being the most dissimilar.

Results

I. Survey Statistics

Response to the survey was excellent, as I received a much higher rate of completion than anticipated. After distributing the survey in early December 2017, and sending a reminder in early January 2018, I recorded complete responses from 10 out of 14 experts for a response rate of 71.4%. Many researchers also had constructive feedback on the project and offered to serve as resources.

The responses to the survey provided weights for the variables, which are provided in Table 2. Responses were highly varied, but I chose to use mean value for the weights in the final overlay. Additionally, experts chose a distance around each site within which I should analyze the key variables. Based on the responses (Table 3), the mean distance to consider outside the core area was 29 miles, and the median was 30 miles, so I chose to use 30 miles as my zone to analyze around the protected areas.

Table 2. Weights to the variables from expert survey.

Variable	Mean Weight	Median Weight	Range	Std. Deviation
Age of residents	44.8	50.5	2 – 90	30.39
Presence of Cattle (livestock ownership)	39.4	45	1 – 80	23.93
Amount of Deer for prey	67.6	75	5 – 100	28.7
Type of Habitat/Land Cover	62	64	40 – 81	13.36
Amount of Hunting	78.9	71.5	50 - 100	18.26

Table 3. Expert survey results for how far away from core site to analyze. (* = One respondent selected 5 miles on the survey but emailed me afterwards to state that he misunderstood the question and wished to change his response to 40 miles.)

Distance from Core Site to Analyze	Number of Responses
1 mile	0
5 miles	0*
10 miles	1
20 miles	4
40 miles	5*

II. Ranking Sites

The weighted sum was calculated for each 30-meter by 30-meter pixel in the study area, based on the weight-adjusted values of all five variables. This produced the equation in Figure 4, used by the Weighted Sum tool to assign a score to every pixel that the five Raster images had in common:

Pixel Score = 0.789*(Hunting reclassification) + 0.676(Deer reclassification) + 0.62*(Land Cover reclassification) + 0.448*(Age reclassification) + 0.394*(Cattle reclassification)

Figure 4. Equation used to assign suitability scores to each pixel within the historic range of the red wolf.

The 30-mile buffer zones that were used to define each site's relevant surroundings were analyzed using the Zonal Statistics tool, producing a mean weighted sum value for the entire area around each site. These mean weighted sums are reported in Table 4 and sorted from the most to least suitable sites, based on my analysis. The sites were also grouped into tiers based on these results, with sites being considered roughly equivalent within tiers. These are displayed visually in Figure 5 and were created by appending the mean weighted sums to their respective sites in ArcMap and then classifying them into 5 classes based on Arc's Natural Breaks/Jenks classification method.

Table 4. Mean suitability scores from the Weighted Sum tool for each potential reintroduction area. (Abbreviations: NF = National Forest, FWS = U.S. Fish & Wildlife Service, USFS = U.S. Forest Service, FFS = Florida Forest Service.)

Site Name	**Agency**	**State(s)**	**Weighted Sum Mean Score**	**Tier**
Okefenokee National Wildlife Refuge	FWS	GA	2015	1
Croatan National Forest	USFS	NC	2009	1
Alligator River & Pocosin Lakes National Wildlife Refuges (*current range*)	FWS	NC	1994	-
Kisatchie National Forest	USFS	LA	1876	2
Osceola National Forest	USFS	FL	1874	2
Daniel Boone National Forest	USFS	KY	1855	2
De Soto National Forest	USFS	MS	1846	2
Nantahala National Forest/Chattahoochee-Oconee National Forest	USFS	NC/GA	1807	2
Cherokee National Forest	USFS	TN	1793	2
Apalachicola National Forest/Tate's Hell State Forest	USFS/FFS	FL	1789	2
Francis Marion and Sumter National Forests	USFS	SC	1787	2
Talladega National Forest	USFS	AL	1697	3
Monongahela National Forest (Unit 2)	USFS	WV	1678	3
George Washington and Jefferson National Forest	USFS	VA	1659	3
Mount Rogers National Recreation Area	USFS	VA	1657	3
Monongahela National Forest (Unit 1)	USFS	WV	1645	3

Ocala National Forest	USFS	FL	1600	4
Ouachita National Forest	USFS	AR/OK	1583	4
Blackwater River State Forest	FFS	FL	1510	4
Mark Twain National Forest (Unit 2)	USFS	MO	1472	5
Mark Twain National Forest (Unit 1)	USFS	MO	1406	5
Ozark-St. Francis National Forest	USFS	AR	1391	5

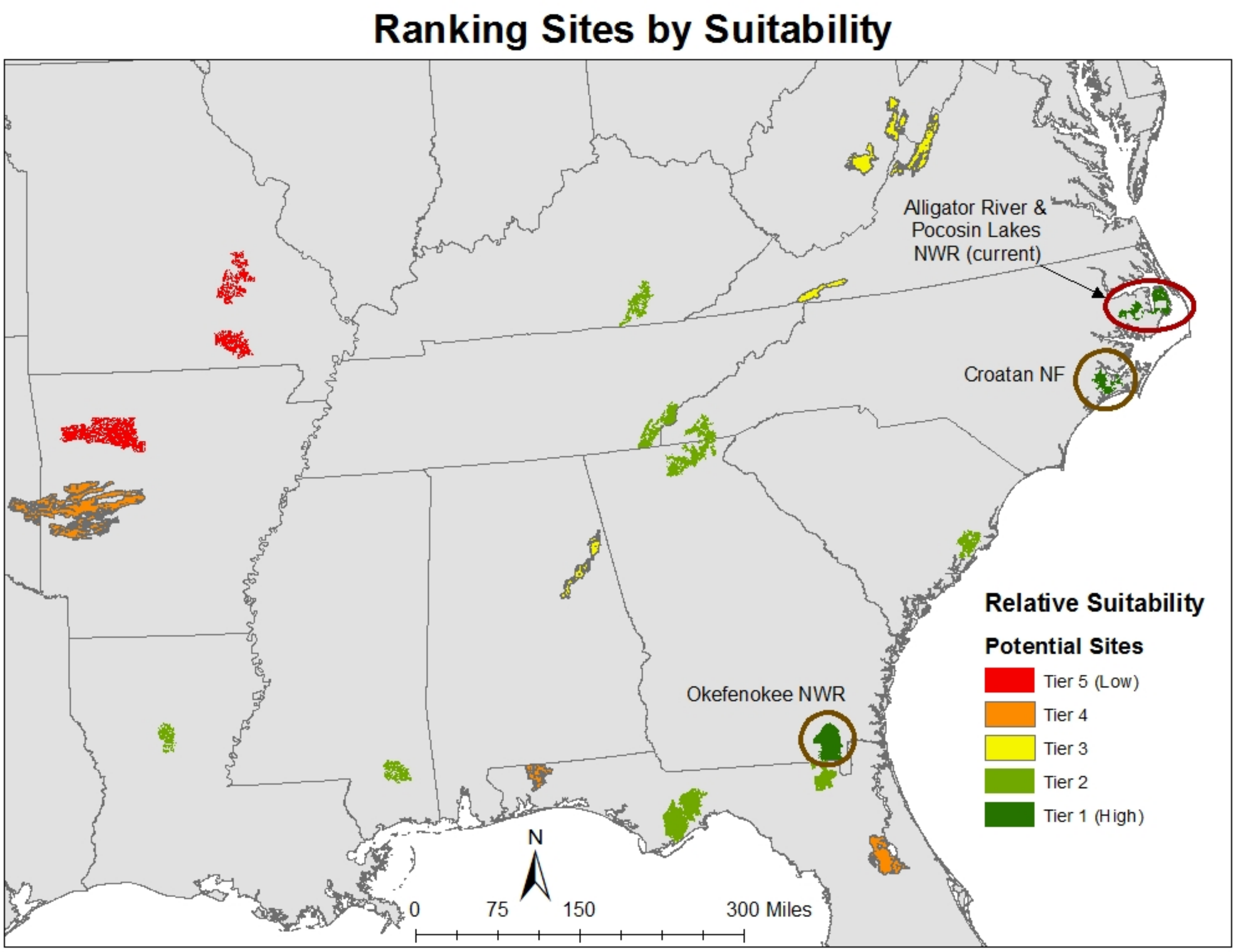

Figure 5. Each of the potential sites ranked by their relative suitability, with the highest scoring sites shown in dark green and the lowest in red. The two top sites are indicated and labeled in the map. The current territory of Alligator River & Pocosin Lakes NWR was also scored, and had the third-highest overall, which would have placed it in Tier 1.

III. Descriptive Statistics

Calculating the Euclidian Distance matrix in R produced a 22x22 matrix comparing each site to all of the other potential reintroduction sites, along with the current site of Alligator River & Pocosin Lakes NWR. The matrix's values (Appendix: Figure 9, Table 12) represent the amount of dissimilarity between any pair of sites. This can be used to look for sites that are roughly comparable across all five of the variables that I analyzed, not just ecologically, and could be a good way to propose similar alternative locations for reintroduction if one area proves to be infeasible.

As an example of this, I set a dissimilarity threshold of 2 and pulled out all of the pairs of sites that fell below this level. These sites can be described as "similar" across all of the measured variables (Table 5).

Table 5. Similar sites based on the Euclidian Distance matrix measuring the distance between sites based on the values of the variables within their buffer zone areas. Sites across rows are considered "similar."

Site	Similar Sites	Similar Sites	Similar Sites
Alligator River & Pocosin Lakes National Wildlife Refuges (NC)	Croatan NF (NC)		
Apalachicola National Forest (FL)/Tate's Hell State Forest (FL)	Osceola NF (FL)	Nantahala NF /Chattahoochee NF (NC/GA)	
Blackwater River State Forest (FL)	Mark Twain NF (1) (MO)	Mark Twain NF (2) (MO)	
Cherokee National Forest (TN)	Nantahala NF /Chattahoochee NF (NC/GA)		
Croatan National Forest (NC)	Alligator River & Pocosin Lakes NWR (NC)		
Daniel Boone National Forest (KY)	Nantahala NF /Chattahoochee NF (NC/GA)		
De Soto National Forest (MS)	Kisatchie NF (LA)		
Francis Marion and Sumter National Forests (SC)	De Soto NF (MS)		
George Washington and Jefferson National Forest (VA)	Monongahela NF (1) (WV)	Monongahela NF (2) (WV)	Mt Rogers NRA (VA)

Kisatchie National Forest (LA)	De Soto NF (MS)		
Mark Twain National Forest (1) (MO)	Blackwater River SF (FL)		
Mark Twain National Forest (2) (MO)	Ouachita NF (AR/OK)	Blackwater River SF (FL)	
Monongahela National Forest (1) (WV)	Monongahela NF (2) (WV)	Mt Rogers NRA (VA)	George Washington and Jefferson NF (VA)
Monongahela National Forest (2) (WV)	Monongahela NF (1) (WV)	George Washington and Jefferson NF (VA)	
Mount Rogers National Recreation Area (VA)	Monongahela NF (1) (WV)	George Washington and Jefferson NF (VA)	
Nantahala National Forest /Chatahoochee-Oconee National Forest (NC/GA)	Cherokee NF (TN)	Daniel Boone NF (KY)	Apalachicola NF (FL) /Tate's Hell SF (FL)
Ocala National Forest (FL)			
Okefenokee National Wildlife Refuge (GA)	Osceola NF (FL)		
Osceola National Forest (FL)	Okefenokee NWR (GA)		
Ouachita National Forest (AR/OK)	Ozark-St Francis NF (AR)		
Ozark-St. Francis National Forest (AR)	Ouachita NF (AR/OK)		
Talladega National Forest (AL)			

Discussion

The collection of results presented here represents the first major recent attempt to comprehensively analyze the entire historic range of the red wolf in order to identify which parcels of federally owned and protected land would be best for the reintroduction of a new population. Previous reintroduction efforts in North Carolina have shown that the wolves can thrive in the wild when given the chance, and as the Fish & Wildlife Service considers the next location where they will attempt to reintroduce wolves this project should serve as a helpful road map.

I. Findings

Okefenokee National Wildlife Refuge and Croatan National Forest stand out as the best choices for red wolf reintroduction, based on the collection of sites analyzed. Their scores in Table 4 are nearly identical and far higher than the rest of the potential new sites, landing them a place in the first tier. These scores represent the mean pixel value in the 30-mile zone surrounding and containing the site in question, after the variables were weighted and summed across the entire study area.

Okefenokee NWR and Croatan NF both scored very highly in the ‘Hunting’ and ‘Livestock’ metrics, but their scores for the ‘Habitat’ metric were in the lowest third of the locations. For the ‘Deer’ variable, Croatan NF was in the top third and Okefenokee NWR was in the middle third, while the reverse was true for the ‘Age’ variable. This similarity in results led to them having comparable final suitability scores, taking the top two spots overall. The component scores for all variables and all sites can be seen in Table 13.

This breakdown of the component variables for the sites, which can be seen visually in Figures 10-14, paints an interesting picture of where red wolf introduction is likely to occur. Croatan NF was found to be similar to the current range of the wolves in Alligator River & Pocosin Lakes NWR, and the closeness of these two sites to Okefenokee NWR based on final suitability scores indicates that they must all possess similar characteristics that makes them a “good” place for red wolves to live.

This seems counterintuitive based on their low scores in the ‘Habitat’ variable, presumably due to their preponderance of swampy, wetlands-dominated land. However, all three of these protected areas compensate for this by being areas with a low likelihood of human conflict. While the landscape conditions may not be ideal for wolves, they are not ideal for agriculture or ranching either, or even for serious development of human settlement and cities. While other areas that contain the grasslands and pine forests that wolves prefer may seem like a better choice, much of this land across the East has been cleared for farms, towns, and cities, leaving few pristine stretches that wolves could thrive in. These trade-offs are fully evident both in the previous choices of FWS to introduce wolves to Alligator River

NWR and in the model's selections for best future sites. If the goal is to avoid human conflict, sites like Croatan, Okefenokee and Alligator River may be the best option.

The tiers that are assigned to the sites in Figure 5 are meant to represent a rough hierarchy of where reintroductions should occur. The sites in the highest tier, as discussed above, would be the best places based on this analysis. However, if circumstances should prevent either of these from being an option, sites in tier 2 such as Kisatchie National Forest in Louisiana would be the next best options, and so on down the line (Table 4). If one site has the characteristics deemed most desirable by the Service but some circumstances should render it no longer viable, the grouping of similar sites in Table 5 provides a guide for possible alternatives that have similar characteristics to those desired in the original site.

II. Scope and Context

The way that the project was structured allows for future efforts to draw from the same data and methodology while adding their own personal beliefs or interests to the models. The expert weights that were used to calculate the final suitability scores contained a wide range and lots of variation, and so these results only represent the suitability for wolves based on an average of these expert views. I believe that by using 10 different experts from academia, non-profits and governmental agencies I was able to capture a wide range of opinions, making the weights representative of the average view of someone who works with red wolves and therefore useful for this project. A different individual though could reconstruct this project and input their own beliefs on the relative importance of these variables, and of the different levels within each one.

Similarly, the results presented here do not represent a guaranteed likelihood of success or failure based on the relative rank of the sites. By virtue of being large, protected federal or state lands within the past range of the red wolf, these potential sites were chosen because they all could theoretically support wolves under the right conditions. The top sites in Table 4 are not certain successes, just as the lowest sites in the table are not doomed to failure.

Local and national conditions that are not captured in this model can have a strong influence on the potential success of a reintroduction, such as a beloved local politician being strongly in favor of the project, or a local industry leader being vocally opposed. These situations are hard to predict or model, although my variables of 'Age', 'Livestock Ownership', and 'Hunting' are an attempt to measure these social conditions through proxies. Future efforts that are focused on any one specific locality could benefit from a close look at the politics or key stakeholders in the region. Ensuring that there will be significant community buy-in is a major key to ensuring a successful reintroduction effort.

One example of local conditions potentially complicating a release that could arise from these results is the potential selection of Croatan NF. Given that the current red wolf reintroduction project is already underway just a short distance to the north along the coast of North Carolina, residents in the area around Croatan NF may already be biased in one direction or another by the heated rhetoric that has occasionally emerged in the state surrounding this topic. Getting a better understanding of potential existing biases may be important and could cause the other top choice of Okefenokee NWR to seem like a safer choice. These sorts of considerations should be taken into account for each site as much as is feasible.

The project also fits in with a growing international movement to "rewild" areas that have been developed or settled for centuries, typically by returning extinct or extirpated animals to their historic ranges.[54] A recent paper on the topic even looked at reintroducing the red wolf, but their analysis was extremely broad and did not have the amount of species-level detail that is included here.[55] Public awareness and support of endangered species issues more broadly could be increased by successful rewilding projects, and this study aims to provide data to increase the likelihood of success for future red wolf reintroductions in particular.

III. Limitations

This study has some inherent limitations that should be accounted for when considering the potential broader applications of the results. The analysis was not conducted with perfect information, as several of the variables required some adjustment of the data or other assumptions.

The deer abundance and range data are from a study that was published in 2008, with data that was gathered by QDMA from state agencies over the years 2001-2005.[56] Therefore the data was not gathered very recently, but given my need for data that covered the entire eastern United States, it was the best available. In addition, the dataset does not include data for the state of Oklahoma, but since the Ouachita National Forest extends from Arkansas into the eastern portion of Oklahoma, I needed to make an estimate for that area. I selected the deer density value that was most common along the western border of Arkansas and applied it to the range around Ouachita NF in Oklahoma, lacking better data.

The greatest challenge with regards to data availability and quality came from locating reliable hunting data. As described in the Methods, there were many inconsistencies between the states and their various reporting systems for white-tailed deer harvest. The lack of county-level data in Mississippi was a

[54] For example: Rewilding Europe, "Rewilding Europe – Making Europe a Wilder Place," accessed April 15, 2018, https://www.rewildingeurope.com/; "Yellowstone to Yukon Conservation Initiative," Cover, accessed April 15, 2018, https://y2y.net.
[55] Christopher Wolf and William J. Ripple, "Rewilding the World's Large Carnivores," *Open Science* 5, no. 3 (March 14, 2018): 172235, https://doi.org/10.1098/rsos.172235.
[56] Adams, Hamilton, and Ross, "QDMA's Whitetail Report."

major issue, as the one candidate site in the state did not have data at the proper scale to truly rate the suitability of its surroundings. Using the average number of deer hunted was a serviceable approximation.

Other issues arose when states do not differentiate between “reported” and “actual” harvest of deer. The adjustments made to data in Georgia, Alabama, and Louisiana brought their reported harvest levels more in line with the expected totals, based on communications with state wildlife officials and those with personal experience hunting in the area.

Finally, it would have been useful to have data on all types of possible red wolf prey, including raccoon, nutria, rabbits and more, but there is little data available on these species. What little information is out there typically does not contain numeric abundancies but is rather just simple presence/absence data. Having a more complete way to estimate prey for red wolves would be beneficial to future studies.

Conclusions

The information contained in this report should serve as guidance for the U.S. Fish and Wildlife Service as they prepare to publish their final decision and rulemaking on the status of the current non-essential experimental wild population of red wolves. This work could allow them to prioritize the potential sites where their reintroduction efforts will have the best chance of succeeding, which benefits everyone involved, from the wolves themselves to the FWS Administrator. The two top scoring sites based on suitability for red wolves were Okefenokee National Wildlife Refuge in Georgia and Croatan National Forest in North Carolina, and therefore these federally protected sites should be the two locations that Wildlands Network advocates for with the Service as the best places to initiate the newest reintroduction effort for the critically endangered red wolf.

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Appendix

```
#using PyPDF2, tabula, and pandas to turn a massive PDF into an Excel sheet
#State of Florida

#importing modules, after installing with pip
import PyPDF2, os, glob, tabula
import pandas as pd

#Create object with PyPDF2, read PDF
PDFReader = PyPDF2.PdfFileReader(open("V:/FINAL_so106/Data/FLDeerReport2015.pdf", 'rb'))
pages = PDFReader.numPages

#list of states that have files in Data folder
statename = "FL"
counter = 15
os.mkdir("V:/FINAL_so106/Scratch/" + statename + "/")

#add pages from imported PDF to Writer, name files, write to Docs folder
for i in range(PDFReader.pages.lengthFunction()):
    PDFWriter = PyPDF2.PdfFileWriter()
    PDFWriter.addPage(PDFReader.getPage(counter))
    counter = i + 17
    filename = "V:/FINAL_so106/Scratch/" + statename + "/" + statename + "Deer_" + str(counter) + ".pdf"
    with open(filename, "wb") as pdffile:
            PDFWriter.write(pdffile)
    if counter == 18:
        break

#just pick FL PDFs to convert
path = "V:/FINAL_so106/Scratch/" + statename + "/"
tabula.convert_into_by_batch(path, output_format="csv")
```

Figure 6. Sample Python script that was used to extract data on white-tailed deer harvest from a state agency's website. The relevant data for this state (Florida) was on two pages of a very long document, requiring a tool to snip out only the desired tables from the rest of the material.

Table 6. List of sources that supplied data on white-tailed deer hunting numbers for each state. Direct hyperlinks available upon request.

State	Responsible State Agency	Year of Data Used	Estimated % Reported (if applicable)
Alabama	AL Department of Conservation and Natural Resources	2017-2018 (through 2/10/18)	35%
Arkansas	AR Game and Fish Commission	2016-2017	
Florida	FL Fish and Wildlife Conservation Commission	2014-2015	
Georgia	GA Department of Natural Resources	2016-2017	58%
Kentucky	KY Department of Fish and Wildlife Resources	2016-2017	
Louisiana	LA Department of Wildlife and Fisheries	2016-2017	50%
Mississippi	MS Department of Wildlife, Fisheries and Parks	2015-2016	
Missouri	MO Department of Conservation	2015-2016	
North Carolin	NC Wildlife Resources Commission	2015-2016	
Oklahoma	OK Department of Wildlife Conservation	2016-2017	
South Carolin	SC Department of Natural Resources	2016-2017	
Tennessee	TN Wildlife Resources Agency	2015-2016	
Virginia	VA Department of Game & Inland Fisheries	2016-2017	
West Virginia	WV Division of Natural Resources	2016-2017	

Red Wolf Reintroduction Variables - Master's Project

Start of Block: Default Question Block

Intro Thank you for helping my Master's Project by agreeing to provide your expertise on red wolves. The variables listed on the next page will all be used to analyze potential reintroduction sites for the wolves within their historic range. Potential sites were identified as being protected lands that met certain criteria and could serve as the source population for reintroduced red wolves. The model will determine which sites are the most likely to succeed, as the goal of reintroduction is to establish a population that will have the best chance of becoming established and eventually leading to the delisting of the species.

All variables that are listed were identified after a thorough search of the literature, and have been found to have some predictive power over the success or social acceptance of wolves.

All input will *not* be associated with your name, and will be presented in the aggregate in any future publications. Thank you again!

-Shane O'Neal

#1 Your Name (for my records only)

____

End of Block: Default Question Block

Start of Block: Block 1

Instructions Please rate each of the following variables from 0-100, where a score of 0 indicates that the variable will have no impact on the survival of introduced wolves and a score of 100 means that this variable has an enormous influence on the chances of success based on current conditions. The variable scores are not cumulative, and each should be rated independently. These seek to understand which factors are the most important in determining the success of reintroduced wolves.

#2 Variables to Rate:

	0 10 20 30 40 50 60 70 80 90 100
Availability of deer for prey (1)	
Habitat/Land Cover Type (2)	
Age of residents in area (3)	
Amount of livestock in area (5)	
Number of hunters in area (6)	

#3 How far away from the protected core area should these variables be analyzed? I have selected a set of 25 protected areas within the historic range that will serve as core areas for the reintroduction, and the distances below are measuring how far away the variables in question will still be relevant to the success of the introduction and establishment of a sustainable population.

- ○ 1 mile (1)
- ○ 5 miles (2)
- ○ 10 miles (3)
- ○ 20 miles (4)
- ○ 40 miles (5)

End of Block: Block 1

Start of Block: Block 2

Thanks Thank you very much for your participation in my survey. If you would like to be sent a copy of the final product, please indicate so below, along with a method of contact or any other comments you may have.

Q6 Would you like to be sent a copy of the final project?

- ○ Yes (1)
- ○ No (2)

Q7 Best method of contact and any further comments.

____

____

____

____

____

End of Block: Block 2

Figure 7. Copy of the expert survey used to elicit weights of variables.

Table 7. Reclassification values for the habitat layer, converting National Land Cover/Land Use Database classifications into suitability scores (1-10).

NLCD Classes:	Suitability:
11- Open Water	1
21- Developed, Open Space	3
22- Developed, Low Intensity	2
23- Developed, Medium Intensity	1
24- Developed, High Intensity	1
31- Barren Land	3
41- Deciduous Forest	8
42- Evergreen Forest	10
43- Mixed Forest	9
52- Shrub/Scrub	5
71- Grassland/Herbaceous	10
81- Pasture/Hay	8
82- Cultivated Crops	7
90- Woody Wetlands	7
95- Emergent Herbaceous Wetlands	5

Table 8. Reclassification values for converting from the abundance levels provided in the QDMA report data into suitability scores (1-10).

Deer Concentration:	Suitability:
Rare/Absent	1
<15/sq mile	2
15-30/sq mile	5
30-45/sq mile	8
>45/sq mile	10

Table 9. Reclassification values for converting the median age in a county into suitability scores (1-10). Class ranges were created using ArcMap Classification method Jenks/Natural Breaks with six classes.

Median Age/County:	**Suitability**:
22.4-31	10
31-36	8
36-39.1	6
39.1-42	4
42-46	2
46-62.7	1

Table 10. Reclassification values for converting the levels of cattle concentration in the FAO Gridded Livestock of the World dataset into suitability scores (1-10). Because most of the study area contained very low levels, the distribution was not even.

Cattle/km^2:	**Suitability**:
0	10
0-25	8
25-50	6
50-75	4
75-100	2
100-6230	1

Table 11. Reclassification values for converting hunting data into suitability (1-10). The number of deer hunted in a season per county was divided into 10 quantiles to form 10 classes.

Deer Hunted/County:	**Suitability:**
0 - 506	10
506 - 965	9
965 - 1315	8
1315 - 1716	7
1716 - 2073	6
2073 - 2471	5
2471 - 2984	4
2984 - 3165	3
3165 - 4020	2
4020 - 9761	1

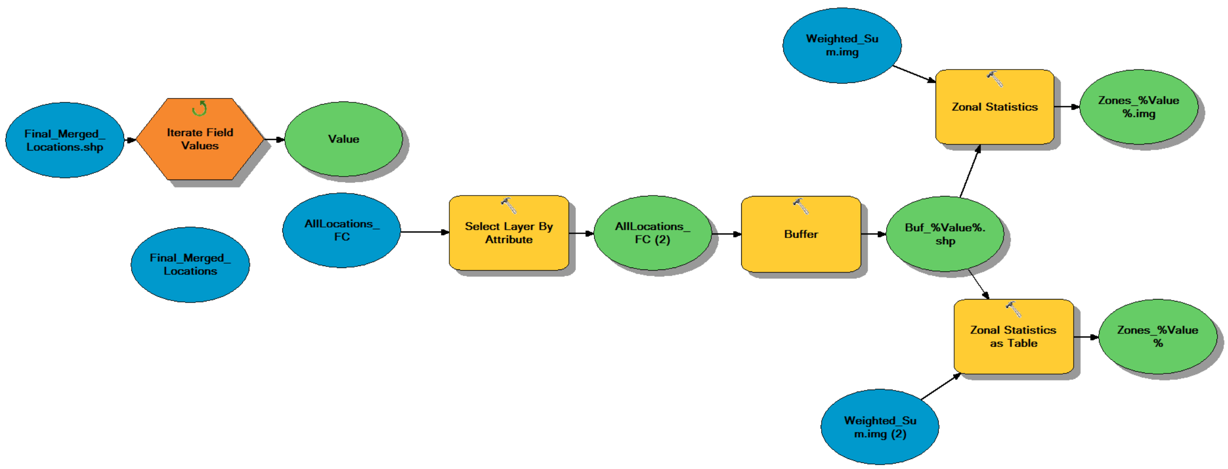

Figure 8. Tool made in ModelBuilder using a Looping Iterator to Iterate through all 21 of the potential reintroduction sites and calculate statistics for each one. This eliminated the issue caused by overlapping zones and considered each buffer zone independently.

	1	2	3	4	5	6	7	8	9	10	11
1	0	3.42390128	4.5382706	2.0731136	2.35112739	6.73173826	4.2940191	7.31849028	4.64028016	3.87708654	3.89362299
2	3.42390128	0	1.64401946	4.83972107	5.35061679	3.96550123	2.83737555	4.30562423	2.6805783	2.2041098	2.74714397
3	4.5382706	1.64401946	0	5.90417649	6.51019969	4.08905857	3.37109774	4.62506216	1.70689777	1.54431214	3.17023658
4	2.0731136	4.83972107	5.90417649	0	1.3903237	8.36557828	4.47854887	8.69674077	5.51733631	4.96956739	4.19670109
5	2.35112739	5.35061679	6.51019969	1.3903237	0	8.78782681	5.45164195	9.0633934	6.2924558	5.64450175	5.27347134
6	6.73173826	3.96550123	4.08905857	8.36557828	8.78782681	0	5.92353779	2.07402989	5.70437551	5.53937722	5.93122247
7	4.2940191	2.83737555	3.37109774	4.47854887	5.45164195	5.92353779	0	5.76960137	2.94648944	3.10618737	0.98402236
8	7.31849028	4.30562423	4.62506216	8.69674077	9.0633934	2.07402989	5.76960137	0	6.07660267	6.03240416	6.07853601
9	4.64028016	2.6805783	1.70689777	5.51733631	6.2924558	5.70437551	2.94648944	6.07660267	0	0.92757749	2.65109411
10	3.87708654	2.2041098	1.54431214	4.96956739	5.64450175	5.53937722	3.10618737	6.03240416	0.92757749	0	2.7092988
11	3.89362299	2.74714397	3.17023658	4.19670109	5.27347134	5.93122247	0.98402236	6.07853601	2.65109411	2.7092988	0
12	4.58904129	2.60595472	3.02473139	5.06004941	6.03041458	5.23782398	0.92773919	5.15740245	2.90735275	3.09885463	1.14341593
13	3.45199942	2.95445426	3.72150507	3.39159255	4.30765598	6.51680904	1.26739891	6.44217355	3.18293889	3.10198324	1.55441307
14	2.48889534	3.06174787	3.70068913	2.86136331	3.94583325	6.39577204	2.66315602	6.96203275	3.30656922	2.96027026	2.12863806
15	1.03865297	3.76625809	5.05120778	2.46329048	2.18920077	6.82585526	4.8703388	7.30314316	5.3524387	4.56832573	4.62104966
16	5.97552508	3.21172851	3.6991891	7.60480769	7.82039002	1.85639435	5.46088821	1.88271081	5.32055448	5.02476865	5.60687079
17	1.68656456	4.46781826	5.52230025	0.66128662	1.75342522	7.96733331	4.25108222	8.36860801	5.19258125	4.60733111	3.86367701
18	3.76546146	3.70178335	5.1260121	4.56794264	5.11369729	5.11409816	4.16349613	5.45780176	5.84245668	5.41910509	4.07325423
19	2.06855022	4.15689788	5.62410882	3.21015576	2.91683047	6.61239745	5.31735837	7.05298518	6.17192839	5.42205681	5.13320563
20	2.71040587	2.3712444	2.68663358	4.14300615	4.3879722	5.92347871	4.0021869	6.42454668	2.7865929	1.92028644	3.70002703
21	4.0254565	3.50653675	3.05447213	5.24027671	5.49418784	6.65140587	4.89923463	7.25470882	2.75635629	2.12393503	4.57101739
22	4.64705283	4.97969879	6.19682177	4.67584217	5.540731	6.57676212	4.29060602	6.83752879	6.48936823	6.23627293	4.16787716

	12	13	14	15	16	17	18	19	20	21	22
1	4.58904129	3.45199942	2.48889534	1.03865297	5.97552508	1.68656456	3.76546146	2.06855022	2.71040587	4.0254565	4.64705283
2	2.60595472	2.95445426	3.06174787	3.76625809	3.21172851	4.46781826	3.70178335	4.15689788	2.3712444	3.50653675	4.97969879
3	3.02473139	3.72150507	3.70068913	5.05120778	3.6991891	5.52230025	5.1260121	5.62410882	2.68663358	3.05447213	6.19682177
4	5.06004941	3.39159255	2.86136331	2.46329048	7.60480769	0.66128662	4.56794264	3.21015576	4.14300615	5.24027671	4.67584217
5	6.03041458	4.30765598	3.94583325	2.18920077	7.82039002	1.75342522	5.11369729	2.91683047	4.3879722	5.49418784	5.540731
6	5.23782398	6.51680904	6.39577204	6.82585526	1.85639435	7.96733331	5.11409816	6.61239745	5.92347871	6.65140587	6.57676212
7	0.92773919	1.26739891	2.66315602	4.8703388	5.46088821	4.25108222	4.16349613	5.31735837	4.0021869	4.89923463	4.29060602
8	5.15740245	6.44217355	6.96203275	7.30314316	1.88271081	8.36860801	5.45780176	7.05298518	6.42454668	7.25470882	6.83752879
9	2.90735275	3.18293889	3.30656922	5.3524387	5.32055448	5.19258125	5.84245668	6.17192839	2.7865929	2.75635629	6.48936823
10	3.09885463	3.10198324	2.96027026	4.56832573	5.02476865	4.60733111	5.41910509	5.42205681	1.92028644	2.12393503	6.23627293
11	1.14341593	1.55441307	2.12863806	4.62104966	5.60687079	3.86367701	4.07325423	5.13320563	3.70002703	4.57101739	4.16787716
12	0	2.08997608	2.99190575	5.16796865	4.96304342	4.74562957	3.9791959	5.5010908	4.18301327	5.07549012	4.21293247
13	2.08997608	0	2.09148273	4.00328615	5.84251658	3.26588426	4.15783598	4.61126881	3.46865968	4.45228031	4.35433118
14	2.99190575	2.09148273	0	3.35735015	6.06248299	2.57645105	3.84212181	4.05387469	3.15263382	4.05779497	4.05582297
15	5.16796865	4.00328615	3.35735015	0	5.89330977	2.2491554	3.78569677	1.29448832	3.14774522	4.52796864	4.89549793
16	4.96304342	5.84251658	6.06248299	5.89330977	0	7.2570104	4.85145339	5.72646488	5.00397842	5.87409568	6.54808369
17	4.74562957	3.26588426	2.57645105	2.2491554	7.2570104	0	4.25469153	3.00413049	3.8260162	4.97869461	4.4412836
18	3.9791959	4.15783598	3.84212181	3.78569677	4.85145339	4.25469153	0	3.12592386	5.18474686	6.6240471	1.97823153
19	5.5010908	4.61126881	4.05387469	1.29448832	5.72646488	3.00413049	3.12592386	0	4.14687834	5.6092602	4.40973922
20	4.18301327	3.46865968	3.15263382	3.14774522	5.00397842	3.8260162	5.18474686	4.14687834	0	1.58164471	6.32181936
21	5.07549012	4.45228031	4.05779497	4.52796864	5.87409568	4.97869461	6.6240471	5.6092602	1.58164471	0	7.65802847
22	4.21293247	4.35433118	4.05582297	4.89549793	6.54808369	4.4412836	1.97823153	4.40973922	6.32181936	7.65802847	0

Figure 9. Euclidian Distance Matrix comparing all 21 potential sites, along with the current site of Alligator River & Pocosin Lakes (22). The values in the matrix represent the dissimilarity between the two sites, with higher numbers representing sites that are “farther apart” in terms of the five variables that were analyzed.

Table 12. Key to the numbered sites in the Euclidian Distance Matrix in Figure __.

Name	Number
Apalachicola NF in FL/Tate's Hell State Forest	1
Talladega National Forest	2
Blackwater River State Forest	3
Cherokee National Forest	4
Daniel Boone National Forest	5
Francis Marion and Sumter National Forests	6
George Washington and Jefferson National Forest	7
Kisatchie National Forest	8
Mark Twain National Forest (1)	9
Mark Twain National Forest (2)	10
Monongahela National Forest (1)	11
Monongahela National Forest (2)	12
Mount Rogers National Recreation Area	13
Ocala National Forest	14
Osceola National Forest	15
De Soto National Forests	16
Nantahala National Forest-NC / Chattahoochee-Oconee National Forest- GA	17
Croatan National Forest	18
Okefenokee National Wildlife Refuge	19
Ouachita National Forest	20
Ozark-St. Francis National Forest	21
Alligator River & Pocosin Lakes National Wildlife Refuges	22

Table 13. Each site's unweighted mean scores for each variable, calculated within the 30-mile buffer zone including and surrounding the site. Scores are scaled from 0-10, with 10 being an ideal situation.

Site	Habitat Scores	Deer Scores	Hunting Scores	Age Scores	Cattle Scores
Alligator River & Pocosin Lakes NWR (*current range*)	6.47	7.16	8.06	2.76	9.77
Apalachicola National Forest (FL)/Tate's Hell State Forest (FL)	7.37	3.36	7.07	4.71	8.52
Blackwater River State Forest (FL)	7.6	4.8	2.85	4.02	8.09
Cherokee National Forest (TN)	7.42	3.08	8.45	3.36	7.82
Croatan National Forest (NC)	6.81	6.95	7.2	4.47	9.47
Daniel Boone National Forest (KY)	7.65	2.74	8.96	4.48	7.32
De Soto National Forest (MS)	7.67	7.42	3.14	6.61	8.24
Francis Marion and Sumter National Forests (SC)	6.69	7.91	2.44	6.07	9.45
George Washington and Jefferson National Forest (VA)	7.81	5.74	5.2	1.92	7.38
Kisatchie National Forest (LA)	7.69	9.05	2.64	5.83	8.07
Mark Twain National Forest (1) (MO)	7.77	3.89	3.05	2.68	7.62
Mark Twain National Forest (2) (MO)	7.86	3.62	3.53	3.37	7.89
Monongahela National Forest (1) (WV)	7.78	5.17	5.16	1.89	8.18
Monongahela National Forest (2) (WV)	7.82	6.18	4.69	2.07	8
Mount Rogers National Recreation Area (VA)	7.67	4.93	5.96	2.33	6.95
Nantahala National Forest /Chatahoochee-Oconee National Forest (NC/GA)	7.63	3.18	8.09	3.42	8.32
Ocala National Forest (FL)	6.51	3.96	6.02	2.72	8.34
Okefenokee National Wildlife Refuge (GA)	7.38	4.59	8.06	6.04	8.65
Osceola National Forest (FL)	7.48	3.63	7.52	5.54	8.2
Ouachita National Forest (AR/OK)	8.01	3.05	4.62	4.81	7.61
Ozark-St. Francis National Forest (AR)	7.82	2	3.52	4.6	7.28
Talladega National Forest (AL)	7.7	5.32	4.33	4.5	8.05

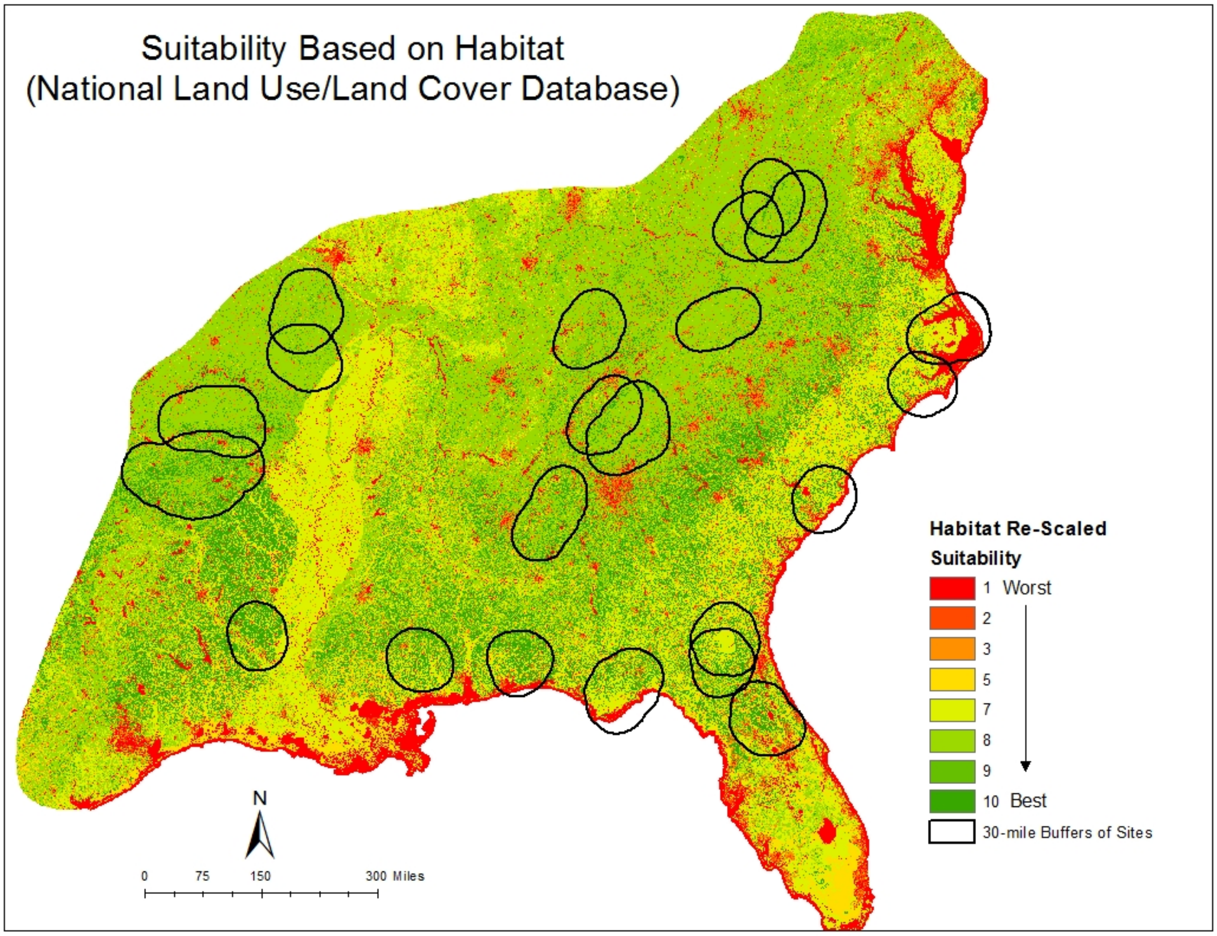

Figure 10. Map of suitability for red wolves based on habitat type per 30-meter by 30-meter pixel, with 1 as the least suitable habitat and 10 as the most suitable.

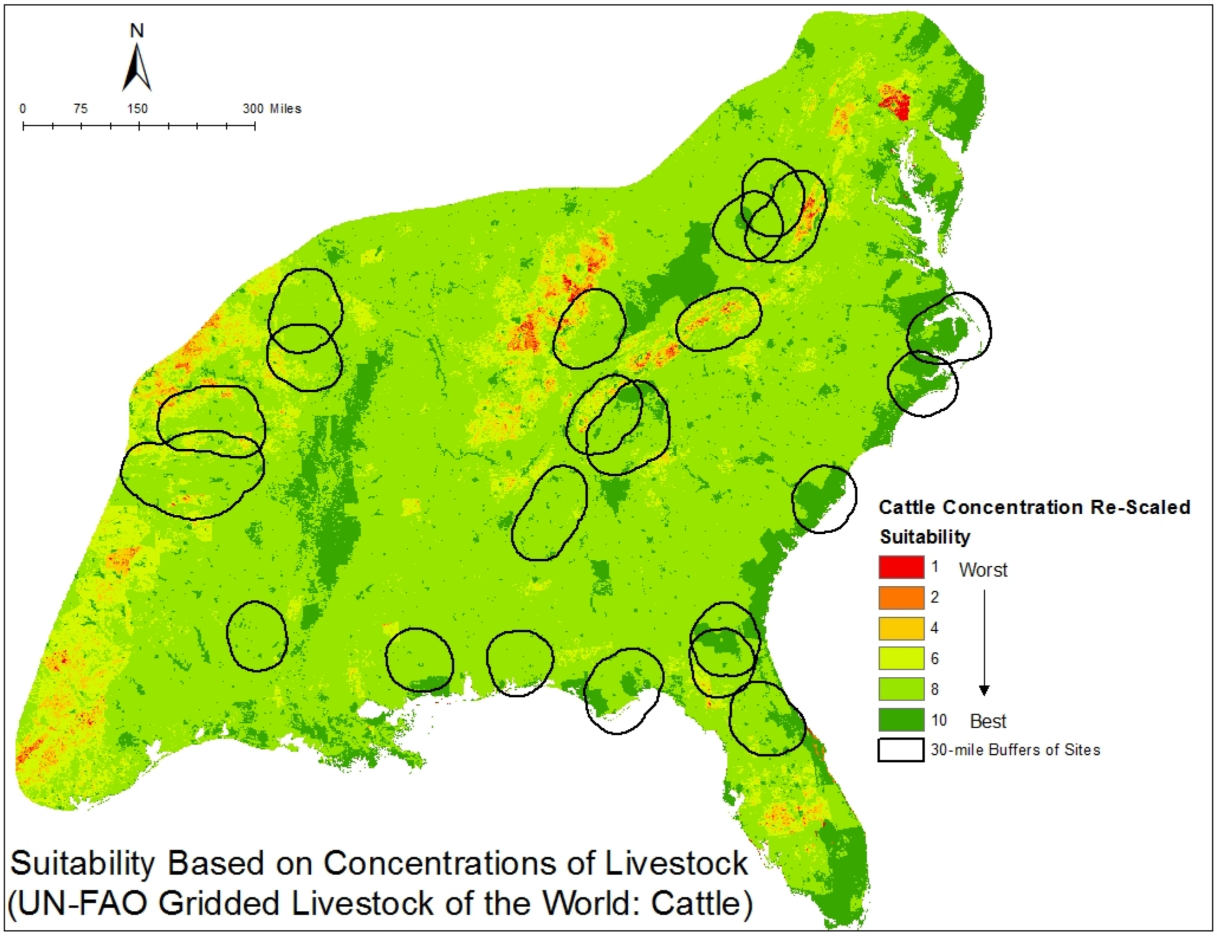

Figure 11. Map of suitability for red wolves based on concentration of cattle per 30-meter by 30-meter pixel, with 1 as the highest concentration of cattle (and therefore the least suitable) and 10 as the lowest concentrations. This represents pressure from livestock owners overall.

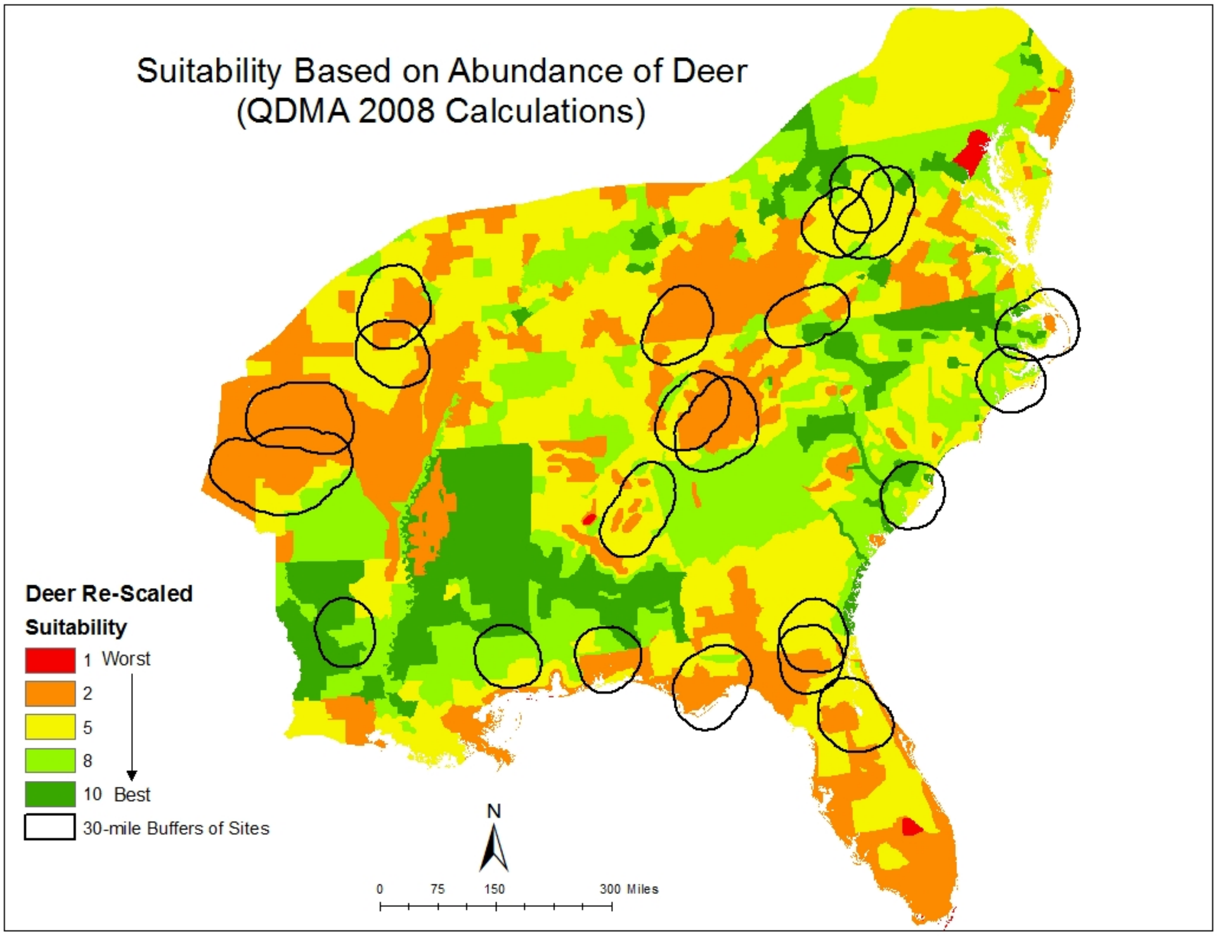

Figure 12. Map of suitability for red wolves based on the abundance of deer, with 1 as the lowest amount of deer and 10 as the highest amount. This represents the availability of prey for the wolves.

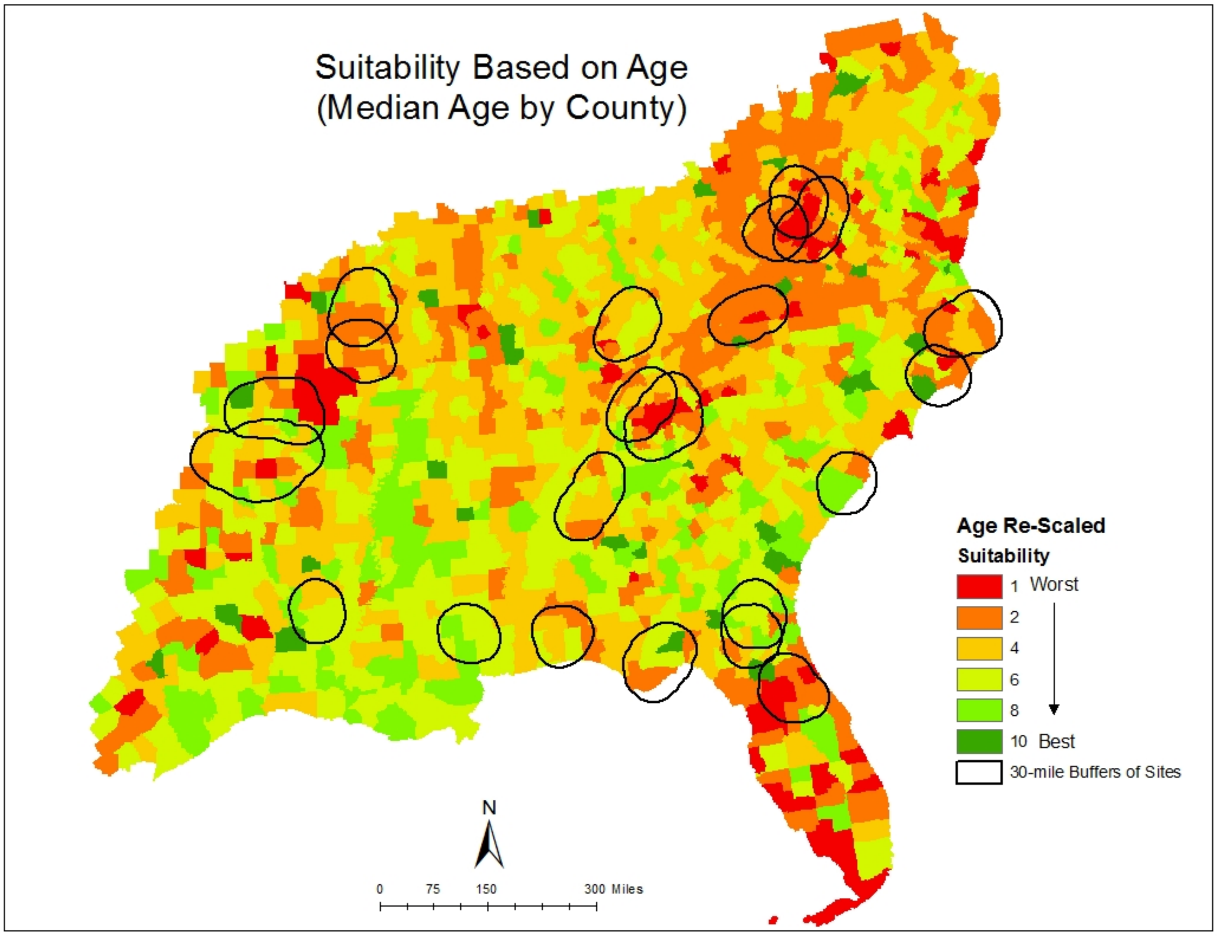

Figure 13. Map of suitability for red wolves based on the median age of residents per county, with 1 as the oldest median ages and 10 as the youngest. The older counties are predicted to express more opposition to the reintroduction of wolves.

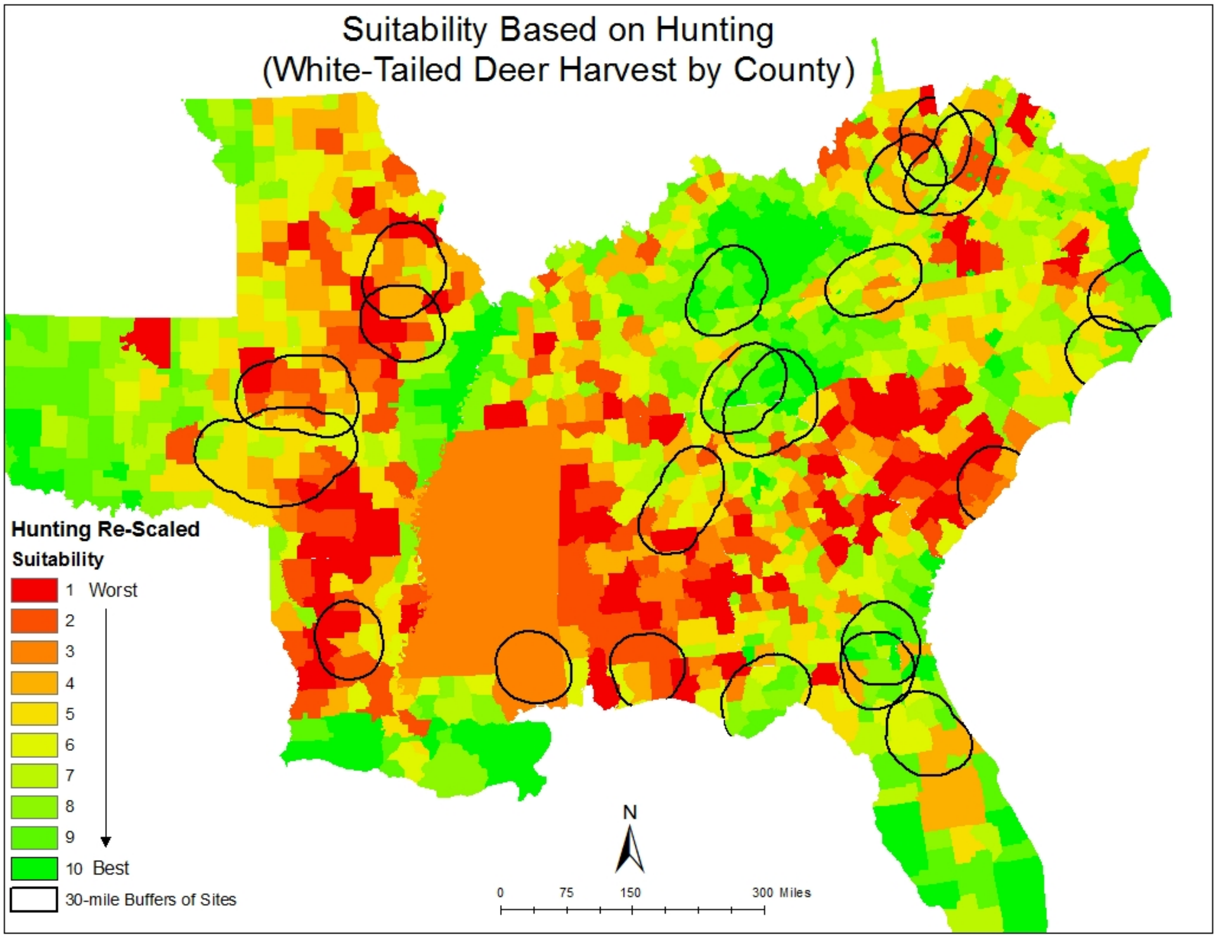

Figure 14. Map of suitability for red wolves based on the amount of hunting of white-tailed deer per county, with 1 as the highest amount of hunting (and therefore the least suitable) and 10 as the lowest levels of hunting. This represents pressure from recreational hunters.