RED WOLF SPECIES STATUS ASSESSMENT

REPORT

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CONTRIBUTIONS

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EXECUTIVE SUMMARY

This species status assessment reports the results of the comprehensive biological status review by the U.S. Fish and Wildlife Service (USFWS) for the red wolf (*Canis rufus*) and provides a thorough account of the species' overall viability and, therefore, extinction risk. The red wolf is a medium-sized canid historically native to the southern United States, but is now limited to a single reintroduced non-essential experimental population (NEP) in eastern North Carolina and captive stock in 43 zoos and nature centers throughout the United States.

We used the best available information to forecast the likely future condition of the red wolf. Our goal was to describe the viability of the species in a manner that will address the needs of the species in terms of **resiliency**, **redundancy**, and **representation**. We considered the possible future condition of the species.

RESILIENCY

Given the very low numbers in the NEP (3 breeding pairs; N approximately 44), without substantial intervention (e.g., releases and management of coyote introgression), extirpation will likely occur within as few as eight years (Faust *et al.* 2016, p. 15). Faust *et al.* (2016, p. 3) suggested that the NEP could avoid extirpation and be viable (<10% chance of extirpation in 125 years) as a population with intervention, which might include reduction of the NEP mortality rate, increase in breeding rates (which would require reducing breeding season mortality), and releases from the Species Survival Plan (SSP) captive population for approximately 15 years followed by releases to maintain genetic health after that. However, the starting value (i.e., number of animals) for the population is now lower (44 wolves) than was initially modeled, and there is now an increased risk of stochastically-driven dynamics given the smaller population size (i.e., variability in the environment could have a stronger effect on the remaining population, than initially projected). All in all, without significant intervention, wild red wolves in the NEP could be extirpated in the near-term.

If interventions described in Faust *et al.* (2016) are carried out, which could produce a viable population on the Albemarle Peninsula, substantial additional efforts and financial resources will be needed to facilitate population expansion in North Carolina. Modelling indicates landscape-level factors that affect habitat (e.g., particularly sea-level rise and increased flooding) will result in substantial changes to the habitat on the peninsula in the next 125 years, which could push wolves further west from where they currently occur. If this happens, they would encounter more development (e.g., Greenville area), as indicated by the urban development model results. Whether their natural mobility as a species will allow the red wolf to locate suitable habitat in a changing landscape is still unclear, but coyotes will likely use the same habitats and are more adaptable with regard to human development and infrastructure. Without sufficient wolf mates on the landscape, hybridization would likely continue to occur and coyotes already vastly outnumber wolves on both the peninsula and areas west of the current NEP so, intensive management and significant additional resources would be necessary.

With regard to the SSP captive population, current gene diversity for the managed population is 88.87% and is equivalent to the genetic diversity of a population descended from only approximately five founders. This is one of the biggest challenges with this species because the current gene diversity is very low. The main objective for the captive population is to maintain this diversity in the long term. Faust *et al*. (2016, p. 3) discussed that "[w]hile the SSP [captive population] has been maintained at a relatively large population size of more than 150 animals for over 20 years, it needs to increase breeding and increase its population size/space to ensure long-term viability and its ability to serve as a strong source for animals to release to the wild."

REDUNDANCY

Redundancy is having sufficient numbers of resilient populations for the species to withstand catastrophic events. The single NEP of red wolves could be extirpated in approximately 8 to 37 years (Faust *et al.* 2016, p. 15). Without new reintroduction sites the species is unlikely to have significant redundancy in the wild. Some level of redundancy is present in captivity because the species is held at multiple facilities throughout the U.S. However, this does not constitute a viable wild population. Therefore, at present and into the future, there is no redundancy of red wolves in the wild.

REPRESENTATION

The SSP captive population represents the genetic fail-safe for the entire population and any future recovery potential for the species. However, only twelve of the original fourteen lines are still represented and Faust *et al.* (2016) provide several scenarios through which the SSP captive population could be expanded, genetic diversity (of the remaining 12 lines) maintained, and future release efforts supported. While any future reintroductions would require a consideration of SSP capacity to support these efforts, it is clear that the SSP captive population has maintained a genetically-diverse stock, within the limits of the remaining 12 founder lines, from which to grow the population and release into the wild.

This report presents the best available scientific information to date on the status and management of the red wolf. This report is expected to be a living document that can be edited and peer-reviewed regularly to keep it current with the best available science. We expect to use this report for future recovery planning activities, management efforts, species status review (i.e., 5-year reviews), and other conservation activities that depend on the most current science.

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PREAMBLE

To evaluate the viability of the red wolf both currently and into the future, we assessed a range of conditions to allow us to consider the species' resiliency, redundancy, and representation (together, the 3Rs). Because the species is already restricted to a single, heavily managed population (redundancy), we first evaluated what would make a single wolf population resilient and what level of representation (genetic diversity) remains. From there, we considered what is possible given current levels of diversity, captive capacity, and numbers, as well as, how the area of the experimental population may change in the future.

Additionally, we evaluated factors affecting the red wolf and what it needs for long-term viability. The primary factors affecting current and future conditions for the species include: (1) adult mortality (including losses to shooting), (2) effects of small population size, and (3) hybridization (i.e., interbreeding) with coyotes and resultant introgression into the red wolf gene pool. We also assessed information relevant to climate change and effects to the Albemarle Peninsula and red wolves. Given our uncertainty regarding sea level rise in the future, we projected future sea level rise at multiple time steps.

Sea level rise data is presented along with Population Viability Assessment (PVA) outputs (as originally described in Faust *et al.* 2016 (entire). This PVA effort evaluated a variety of scenarios for both captive stock and the only remaining wild population. To allow for comparison to PVA results, sea level rise projections are provided at 125 years, although several intermediate projections are also included, along with curves associated with PVA scenario outcomes.

For the purpose of this assessment, we generally define viability as the ability of the species to sustain populations in the wild beyond a biologically meaningful timeframe, in this case, 125 years. We chose 125 years because it is relevant to timeframes considered in previous recovery planning and modeling efforts (USFWS 1990, entire; Faust *et al*. 2016, entire), and because for some recovery scenarios long timeframes are required to achieve genetic and population targets (e.g., set in years past by the recovery program). The outputs of both the PVA and sea level rise assessments could be adjusted should future recovery plan change these target values.

Currently, only one wild population of the species exists and at present, without substantial intervention (e.g., releases and management of coyote introgression), it is likely to go extirpated within decades. Without additional reintroduction sites the species is unlikely to have redundancy in the wild in the future.

CHAPTER 1. INTRODUCTION, DATA, AND ANALYTICAL FRAMEWORK

INTRODUCTION

This report summarizes the results of a species status assessment (SSA) conducted for red wolf (*Canis rufus*). The red wolf was first listed as "threatened with extinction" under the Endangered Species Preservation Act of October 15, 1966 (80 Stat 926; 16 U.S.C. 668aa(c)) on March 11, 1967 (32 FR 4001).). It is currently listed as an endangered species under the Endangered Species Act of 1973 (ESA), as amended (16 U.S.C. 1531 et seq.) The red wolf, is managed in captivity in 43 approved zoos and nature centers throughout the United States (U.S.) and as a single, nonessential experimental population in five North Carolina counties (NEP) (Beaufort, Dare, Hyde, Tyrrell and Washington). A "nonessential" experimental population designation under section 10(j) of the ESA means, on the basis of the best available information, the experimental population is not essential for the continued existence of the species in the wild (an essential population is one whose loss would be likely to appreciably reduce the likelihood of the survival of the species in the wild).

On September 12, 2016, after a two-year program review, the USFWS released a memorandum with recommended decisions on a new path forward for the Red Wolf Recovery Program. The memo committed the USFWS to several actions, including working with our science partners to develop a species status assessment (SSA) by October 2017. Thus, we conducted a SSA to compile the best available data regarding the species' biology and factors that influence the species' viability. The SSA will provide the biological underpinning of the USFWS's forthcoming effort to develop a new Recovery Plan.

The SSA assesses the ability of the red wolf to maintain populations over time (*i.e.*, viability). Our approach for assessing red wolf viability involved 3 stages. In Stage 1, we described the species' ecology in terms of the resiliency, redundancy, and representation (the 3Rs); specifically, we identified the ecological requirements for survival and reproduction at the individual, population, and species levels. In Stage 2, we determined the baseline condition of the species using the ecological requirements identified in Stage 1. That is, we assessed the species' historical and current condition in relation to the 3Rs and identified past and ongoing factors (beneficial and risk factors) that led to the species' current condition. In Stage 3, using the baseline conditions established in Stage 2 and predictions for future risk and beneficial factors, we projected the likely future condition of the red wolf.

This SSA provides: context for the analysis (Chapter 1); the species' historic context and program history is summarized in (Chapter 2); ecology and life history (Stage 1 Chapter 3); current conditions (Stage 2) in Chapter 4, factors affecting the species in Chapter 5; and the future condition and species future viability (Stage 3) in Chapter 6.

AVAILABLE DATA, DATASETS, AND MODELLING EFFORTS

Many modelling efforts have been conducted for the red wolf through the years. Among these are models that provide survival estimates, genetic outcomes, and habitat use and selection. Many of these will be explained in context where necessary throughout the text of this document. For current and future condition characterizations herein, we used models developed specifically for the red wolf including a stochastic, individual-based population model called a Population Viability Assessment (PVA) created by Faust *et al.* (2016, entire) in Vortex 10.1.4.0 software and a population planning document specifically developed for the Red Wolf (*Canis rufus gregoryi*) AZA Species Survival Plan® (Waddell and Long, 2016, entire) Yellow Program using the red wolf studbook database maintained in PopLink 2.4 (Faust *et al.* 2012, entire) and, PMx version 1.3.20160601 software (Ballou *et al.*, 2010, entire; 2015 version), and data obtained from the International Red Wolf Studbook.

Sea level rise and vertical land movement data was derived from the North Carolina Sea Level Rise Assessment Report (2015, pp. v; 16). From these data relative sea level rise (RSLR) was calculated at the local National Oceanic and Atmospheric Administration (NOAA) tidal gauges (particularly relevant, are the gauges at Beaufort, NC, Duck, NC and Oregon Inlet, NC). The RSLR is a combination of the published sea level rise data with the addition of the published vertical land movement data. The RSLR was then averaged from the 3 tidal gauges (i.e., Duck, Oregon Inlet, and Beaufort) that best represent the project area. These data were then converted to future elevations by multiplying the RSLR rate by the target year and subsequent RSLR maps were produced for spatial analysis. Current land elevation data for the project area was derived from LiDAR data collected by USGS in the spring of 2014 for the Sandy LiDAR Project. The data was developed based on a horizontal projection/datum of North Carolina State Plane (NAD 83) and a vertical datum of NAVD1988 (GEOID 12 A). Subsequent RSLR maps were developed utilizing ESRI Arc GIS 10.3.1 software.

To explore potential urbanization on the Albemarle Peninsula, we used the SLEUTH-3r urban-growth model, as modified (Belyea and Terando 2013, entire; Terando *et al.* 2014, entire). Input datasets for the model were produced in ESRI ArcGIS. A process for classifying past urbanized areas was informed by both the 2001 National Land Cover Dataset (NLCD) and the U.S. Census Bureau (USCB) TIGER Line Data (USCB 2011, entire) of local street network information (Terando *et al.* 2014, p. 2).

ANALYTICAL FRAMEWORK

Viability is the ability to sustain populations over time; to do this, a species must have a sufficient number and distribution of healthy populations to withstand changes in its biological (*e.g.*, novel diseases, invasive species, prey availability) and physical (*e.g.,* climate change) environment, environmental stochasticity (*e.g., wet or dry years*), and catastrophes (*e.g.,* hurricanes, fires, and other sources of catastrophic loss) which can affect large or small proportions of the population or breeding individuals simultaneously). Generally speaking, the more resiliency, representation, and redundancy a species has, the more protected it is against the unpredictability of the environment, the more it can tolerate stressors (one or more factors that may be acting on the species or its habitat, causing a negative effect), the better able it is to adapt to future changes, and thus, the more viable it is (Shaffer and Stein 2000, pp. 307-310). The 3Rs framework (assessing the health, number, and distribution of populations relative to frequency and magnitude of environmental stochasticity and catastrophic events across its historical range of adaptive diversity) is useful for describing a species' degree of viability through time.

RESILIENCY

Resiliency is the ability to sustain populations in the face of environmental variation and periodic disturbances. Environmental variation includes normal year-to-year variation in rainfall and temperatures, as well as unseasonal weather events. Disturbances (i.e., discrete events which cause substantial changes to the structure or resources of an ecosystem) are stochastic events such as fire, flooding, and storms. Simply stated, resiliency is having the means to recover from "bad years." To be resilient, a species must have healthy populations that are able to sustain themselves through good and bad years. The healthier the populations and the greater number of healthy populations, the more resiliency a species possesses. For many species, resiliency is also affected by the degree of connectivity among populations and the diversity of ecological niches occupied. Well-connected populations and more generalist behaviors typically make a more resilient population.

REDUNDANCY

Species-level redundancy is the ability of a species to withstand catastrophic events by having multiple populations widely distributed across its range. Redundancy protects species against the unpredictable and highly consequential events for which adaptation is unlikely. In short, it is about spreading the risk. Having multiple populations reduces the likelihood that all populations are affected simultaneously, while having widely distributed populations reduces the likelihood of populations possessing similar vulnerabilities to a catastrophic event. Furthermore, the more populations and the more diverse or widespread that these populations are, the more likely it is that the adaptive diversity of the species will be preserved. Having multiple populations distributed across the range of the species, will help preserve the breadth of adaptive diversity, and hence, the evolutionary flexibility of the species. Given sufficient redundancy, single or multiple catastrophic events are unlikely to cause the extinction of a species. Thus, the greater redundancy a species has, the more viable it will be.

REPRESENTATION

Species-level representation is the ability of a species to adapt to near and long-term changes in the environment; it's the evolutionary capacity or flexibility of a species. Representation is the range of variation found in a species, and this variation--called adaptive diversity--is the source of species' adaptive capabilities. The greater the adaptive diversity, the more responsiveness and adaptable the species will be over time, and thus, the more viable the species is. Maintaining adaptive diversity includes conserving both the ecological diversity and genetic diversity of a species. Ecological diversity is the physiological, ecological, and behavioral variation exhibited by a species across its range. Genetic diversity is the number and frequency of unique alleles within and among populations. By maintaining these two sources of adaptive diversity across a species' range, the responsiveness and adaptability of a species over time is preserved, which increases overall viability.

In addition to preserving the breadth of adaptive diversity, maintaining evolutionary capacity requires maintaining the evolutionary processes that drive evolution (i.e., gene flow, genetic drift, and natural selection). Gene flow is expressed through the physical transfer of genes or alleles from one population to another through immigration and breeding. Gene flow will generally increase genetic variation within populations by bringing in new alleles from elsewhere, but decrease genetic variation among populations by mixing their gene pools (Hendry *et al.*2011, p. 173). Genetic drift is the change in the frequency of alleles in a population due to random, stochastic events. Genetic drift always occurs, but is more likely to negatively affect populations that have a smaller effective population size (N_e; i.e., the size of an ideal population that would result in the same gene frequency or inbreeding rate as the population being considered (Frankham 1995, p. 96) and populations that are geographically spread and isolated from one another. Natural selection is the process by which heritable traits can become more (selected for) or less (not selected for) common in a population based on the reproductive success of an individual with those traits. Natural selection influences the gene pool by determining which alleles are perpetuated in particular environments. This selection process generates the unique alleles and allelic frequencies, which reflect specific ecological, physiological, and behavioral adaptations that are optimized for survival in different environments. Because selection allows a population to adapt towards its phenotypic optimum, high genetic variability promotes persistence under strong environmental change (Chevin *et al.* 2010, p. 2).

CHAPTER 2. HISTORICAL CONTEXT AND PROGRAM HISTORY

Here we provide a summary of the Red Wolf Recovery Program's history. Additional details on program history can be found in USFWS 1990 (entire), Phillips *et al.* 2003 (entire), Stoskopf *et al.* 2005 (entire), and Bartel and Rabon 2013 (entire), and Hinton *et al.* 2013 (entire) and (Wildlife Management Institute (WMI) 2014, entire).

HISTORICAL PERSPECTIVE AND PROGRAM HISTORY

A recent review of available information regarding historic records of red wolves in the U.S. by WMI , concluded that earlier range delineations had been too restrictive and that the historic range of the red wolf encompassed all or parts of five Level II Ecoregions (EPA 2009, unpaginated) including the Mississippi Alluvial and Southeast USA Coastal Plain, Ozark/Ouachita-Appalachian Forests, South Central Semi-Arid Prairies, the Southeastern USA Plains, and the Texas-Louisiana Coastal Plains (see Figure 1). These Ecoregions encompass the southeastern U.S. westward to the Edwards Plateau in Texas, north to the lower Midwest (i.e., southeastern Missouri, southern Illinois) and east into Southern Pennsylvania and extreme southeastern New York (WMI 2016, pp.19, 22-23). Despite this wide historic range, human eradication efforts, in part supported by government eradication programs extirpated the wolf from much of this range (Hinton *et al*. 2013, p. 723). By 1972, the species was reduced to a small coastal area including parts of Liberty, Jefferson, Brazoria, Chambers, Galveston, and Harris Counties in Texas and Calcasieu and Cameron Parishes in Louisiana (designated as red in Figure 1; USFWS 1990, p. 9).

In anticipation of passage of the ESA, the USFWS established a formal recovery plan and a recovery program office in Beaumont, Texas, in 1973. The program set about trapping wild canids in the area mostly via animal damage complaints. The program was tasked with capturing animals, developing methods to differentiate hybrids from pure stock (including evaluating "potential" red wolves already in zoos), establishing a captive breeding program, developing and disseminating information to the public, and evaluating sites and procedures for wild reintroductions. The interim recovery team was formed by the Southwest Region in 1974. (USFWS 1990, pp. 9-10).

To distinguish canids captured (as part of the initial recovery efforts mentioned above) in the population, several characteristics were used including: skull x-rays, electrophoretic and chromosomal analysis, several minimum morphological standards, and knowledge of canids examined from the same area (USFWS 1990, p. 11). It was clear that red wolves had already experienced significant hybridization with local coyotes. From 1973 to 1980, over 400 canids were captured; only 43 met the criteria for inclusion in the breeding/certification program (USFWS 1990, p. 12; Hinton *et al.* 2013, p. 723). Among those 43 individuals; medical problems, shortage of breeding facilities, and short life span led to 15 animals becoming the founding stock (USFWS 1990, p. 12). Of those, eventually 14 remained (Hinton *et al*. 2013, p. 724) and only 12 have living descendants in the captive population today (Faust *et al.* 2016, p. 14). The species was officially declared extinct in the wild in 1980 (Hinton *et al*. 2013, p. 724).

The captive red wolf population had been managed in zoos and partner facilities since 1969 (Faust *et al.* 2016, Executive Summary). Point Defiance Zoo and Aquarium (PDZA) in Tacoma, Washington, partnered with the USFWS and led the effort to develop husbandry techniques and recruit additional cooperating institutions to house wolves in the captive program. The captive program received American Association of Zoological Parks and Aquariums (AAZPA) and Association of Zoos and Aquaria (AZA) approval for a Red Wolf Species Survival Plan (SSP) program (which provides oversight for maintaining a healthy and genetically diverse captive stock) in 1984. By this time, there were approximately 63 individuals in the captive population and the SSP was actively growing the population through the coordinated efforts of PDZA and other partner facilities, making reintroduction efforts possible (https://www.fws.gov/redwolf/captivemanagement.html; Accessed 6/9/2017).

During the early years of red wolf recovery efforts, islands were used to evaluate feasibility of different approaches to reintroduction. Two groups of wild-caught wolves were released onto Bulls Island, a 5,000 acre (2,000 ha) component of the Cape Romain National Wildlife Refuge in South Carolina (Carley 1979, p. 8) to assess various approaches to reintroduction and their merits. "These experiments demonstrated that red wolves acclimated at release sites for 6 months exhibited more restricted movements and higher persistence rates than red wolves released without being acclimated. This finding became the cornerstone of logic that supported the contention that it was feasible to reintroduce red wolves at select mainland sites," (Phillips *et al.* 2003, p. 274).

The first mainland reintroduction effort was initiated in eastern North Carolina at Alligator River National Wildlife Refuge (ARNWR) in 1987 with four males and four females. Over 60 adults were released from 1987-1994 and then by the mid-1990s red wolves in the wild maintained territories, formed packs, and bred successfully (Hinton *et al.* 2013, p. 725). The program initiated a second release in the Great Smoky Mountains National Park, Tennessee, but this was terminated in 1998 due to emigration of wolves to lower elevations with greater prey availability and low pup survival (63 FR 54152; Hinton *et al.* 2013, p. 725).

The red wolf recovery program, including both wild and captive management effort have been in place for over 40 years. Many lessons learned have emerged from the program's history informing canid reintroduction efforts throughout the U.S. For instance, since 2000, an adaptive management program designed to deal with introgression on the Albemarle Peninsula (transfer of coyote genes into the population via hybridization and backcrossing), while rebuilding a wild wolf population has been in implemented (Kelly *et al.* 2000, p. 1). Other areas where protocols have been modified through time to address risks to the species include: handling and release protocols, disease management (USFWS 2012, entire; AZA 2012, entire), genetic management of red wolves in the SSP (e.g., captive stock; Rabon 2014, p. 254; Lockyear *et al.* 2009, p. 227), and recognition of hybrids (Hinton *et al.* 2013, p. 729). Efforts through time have have provided improved success with releases (e.g., acclimation period and use of island sites; Henry and Lucash 2000, p. 5), retained genetic diversity in the captive stock (Lockyear *et al.* 2009, p. 227), and minimized coyote introgression into the population (currently <4% as of 2015; refer to discussion beginning on p. 35 below and Gese and Terletzky 2015, p. 18).

At present, there are 43 facilities participating in the Red Wolf SSP. The SSP fills multiple roles including: (1) coordinate captive breeding and management of red wolves among approved cooperating facilities, (2) maintain records in the red wolf studbook database (captive and wild populations), (3) maximize genetic vigor of the species by selected pairing and breeding, and (4) provide animals in the captive population for reintroduction into the wild. Additionally, the RWSSP coordinates and participates in various approved research projects involving reproductive research e.g. genome resource banking, assisted reproduction, fecal hormone analysis, infertility, contraception, reproductive disease (cystic endometrial hyperplasia), and veterinary medicine, such as vaccine protocols, canid disease, inflammatory bowel disease, nutrition (Waddell 2017b, pers. comm.).

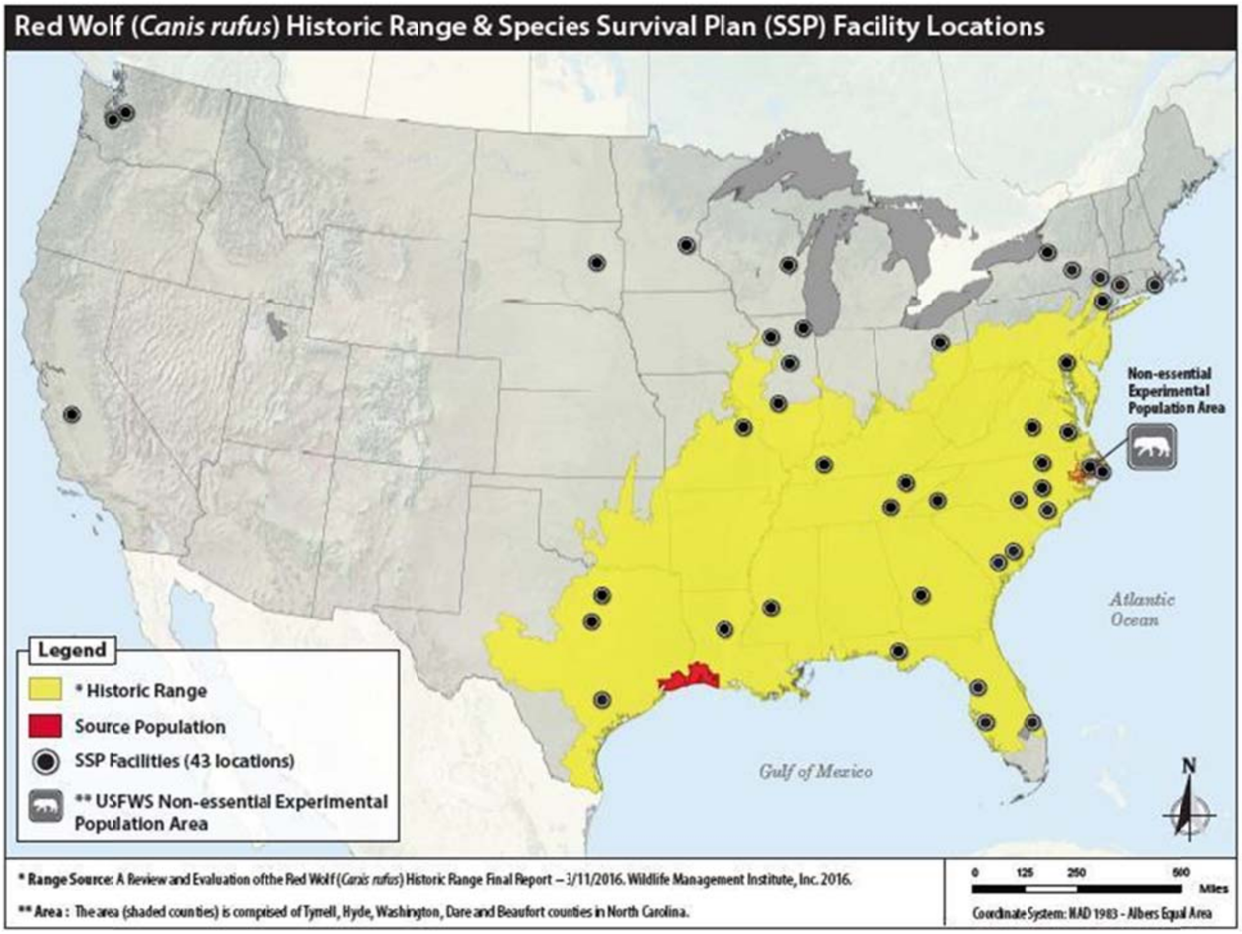


Figure 1: Historic range of the red wolf with locations of SSP facilities, source population area for genetic stock and the location of the Red Wolf Recovery Area in North Carolina.

CHAPTER 3. SPECIES ECOLOGY

In this chapter, we briefly describe the red wolf taxonomy and discuss the species' life history characteristics at the individual, population, and species levels. This is not an exhaustive review of the species natural history; rather, it provides a summary of information available at the time of this writing, and the ecological basis for the SSA analyses conducted in Chapters 4 -7.

SPECIES DESCRIPTION

The red wolf is considered medium-sized for the genus *Canis*, intermediate in size between gray wolf and coyote (Kelly *et al.* 2004, p. 87; Trani and Chapman 2007, p. 441) and weighing between 20.4-28.1 kg (45-62 lbs; Riley and McBride 1972, p. 6); though Paradiso and Nowak 1972, reported variable weights at different locations in the remnant range in Arkansas and Texas ranging from 16 (35.3 lbs) to 41 kg (90.4 lbs; Paradiso and Nowak 1972, p. 1). It has almond-shaped eyes, a broad, light colored muzzle, and a wide nose pad. Coloration is variable, typically cinnamon or brownish with black or gray shading and white around the lips, which extends up the sides of the muzzle (see cover image). A black phase also occurred historically (Kelly *et al.* 2004, p. 87). The muzzle, belly, and throat are whitish-buff and the tail is bushy and tipped with black (Trani and Chapman 2007, p. 441). Large ears and long legs are the two most obvious external features separating the species from both the coyote and gray wolf (Phillips and Henry 1992, p. 597).

TAXONOMY

Red wolves were originally described by Audubon and Bachman (1851) as a subspecies of the gray wolf (*C. lupus rufus*); reasoning supporting this possibility is provided by Lawrence and Bossert 1967, pp. 228-230), Phillips and Henry (1992, p. 597), and Wayne (1995, p. 11). Goldman (1937, 1944) later combined *rufus* with other wolves of the southeastern United States to form the distinct species of red wolf (*C. rufus*) separate from gray wolves (Nowak 1979, p. 25). Support for this designation comes from genetic, morphological, paleontological and other data indicating the red wolf evolved from a common ancestor with the coyote and are separate from gray wolves (e.g., McCarley 1962; Paradiso and Nowak 1971, 1972; Nowak 1979, 1992, 1995, 2002; Henry 1992; Nowak *et al.* 1995; Nowak and Federoff 1996, 1998; Bertorelle and Excoffier 1998; Wilson *et al.* 2000; Hedrick *et al.* 2002; Adams *et al.* 2003; Hailer and Leonard 2008; Chambers *et al.* 2012; Hinton and Chamberlain 2014; Bohling *et al.* 2016; Brzeski *et al.* 2016; Hohlenlohe *et al.* 2017).

With the onset of applied genetic techniques in the 1990s came new hypotheses suggesting the red wolf evolved via hybridization between gray wolves and coyotes (e.g., Wayne and Jenks 1991; Roy *et al.* 1994, 1996; Wayne 1992; Wayne 1995; Wayne and Gittleman 1995; Wayne *et al.* 1998; Reich *et al.* 1999; vonHoldt *et al.* 2011, 2016; Hohenlohe *et al.* 2016). However, there is disagreement about this hypothesis over the timeframe in which hybridization took place; estimates range from as far back as the Pleistocene (10,000 years ago) to as recent as 300 years ago with European settlement (Wayne 1995, pp. 10-11; Roy *et al.* 1996, p. 1421; Reicht *et al.* 1999, p. 143; Hohenlohe *et al.* 2016, p. 2; vonHoldt *et al.* 2016, pp. 7-8).

Genetics studies have also resulted in suggestions that the red wolf and Algonquin wolf are a distinct North American evolved wolf species, the eastern wolf (*C. lycaon*), that evolved from a common ancestor with coyotes (Wilson *et al.* 2000, pp. 2158, 2164; Kyle *et al.* 2006, p. 12; Wilson *et al.* 2012, p. 2328). However, due to a bottleneck associated with captive breeding, the red wolf's contemporary genetic signature has diverged (Rutledge *et al.* 2015, p. 2).

In 2016, an expert workshop was convened to investigate and address key questions related to uncertainty surrounding hybridization and the potential increase in introgression with coyotes and challenges to survival of red wolves. The main contribution of the workshop was the evaluation of competing evolutionary origin hypotheses for the red wolf, specifically whether the red wolf is a listable entity under the ESA (Pacifi and Mills 2016, p. 13). Although the attending experts did not reach consensus on a hypothesis, they did agree that there was a logical and valid path to make a determination that the red wolf is a listable entity under the ESA either as a species (*C. rufus*), a subspecies of DPS of eastern wolf (*C. lycaon*), or a subspecies or DPS of gray wolf (*C. lupus*) (Pacifi and Mills 2016, p. 16).

The debate over the taxonomic status of the red wolf has continued for more than 30 years. Genetic studies present conflicting interpretations and offer various theories on the origin of the red wolf and recommendations on the correct taxonomic status. There are three main theories on the origin of the red wolf: (1) the red wolf originated from ancient hybridization between gray wolves and coyotes, (2) the red wolf originated from recent (post European colonization) hybridization between gray wolves and coyotes, and (3) the red wolf evolved from a common ancestor with the coyote, but is of a lineage divergent from coyotes. Additionally, one of the mammal taxonomy authorities (Wilson and Reeder, Mammal Species of the World Third Edition 2005) does not recognize the red wolf as a distinct species, but does recognize it as a subspecies of gray wolf. Given the fact that the scientific community is not in agreement on the question of red wolf taxonomy, in 2017, the USFWS conducted a review of all the evidence related to red wolf taxonomy. The most recent scientific publications continue to provide conflicting interpretations and support for different theories of origin, specifically theories 2 and 3 above; therefore, USFWS continues to recognize the red wolf as the species *Canis rufus*.

INDIVIDUAL AND PACK-LEVEL ECOLOGY

LIFE SPAN

The median life expectancy of red wolf in captivity is 10.7 years (Waddell and Long 2016, p. 48); in the wild 3.2 (Hinton *et al.* 2016, p. 7). While we do not have a documented life span for red wolves prior to European settlement, Kelly *et al.* (2004, p. 90) stated, "…in the absence of human-induced mortality, red wolves have been documented to have lived in the wild as long as 13 years," (USFWS unpublished).

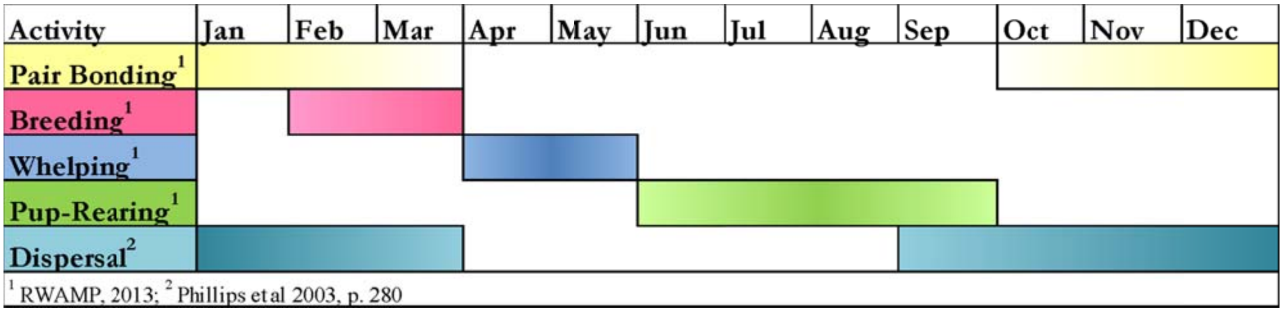
PACK STRUCTURE AND BIOLOGICAL SEASONS

Red wolves normally live in extended family groups or packs, are territorial, and relatively intolerant of conspecifics (Phillips and Henry 1992, p. 596). Typically, packs consist of a breeding pair, which are dominant, and their offspring from prior years (Crawford *et al.* 2001, p. 244; Phillips *et al.* 2003, p. 279). Dispersal usually occurs around two years of age and is not sex-biased (Phillips *et al.* 2003, p. 279).

BREEDING

According to Phillips *et al.* (2003, p. 278) seven of the nine pairs of red wolves in the early stages of the reintroduction began consorting four months before the breeding season. It is generally recognized that pair formation in red wolves begins in the fall and a period of bonding may last several months prior to actual breeding.

The species is seasonally monestrous (experiencing one breeding season per year) and usually reaches sexual maturity by the second year (Phillips *et al.* 2003, p. 273; Crawford *et al.* 2001, p. 244). Gestation is approximately 63 days (add citation) and the average litter size has been reported variably as three to four (Phillips *et al.* 2003, p. 272; Riley and McBride 1972, p. 9) and five (USFWS, 1989, p. 48) pups per litter. Faust *et al.* (2016, pp. 36, 46) used a range with a mean of 4.19. Based on the red wolf studbook database (Poplink 2.4), the mean litter size in the captive population is 4.124 (Waddell 2017, entire, Faust *et al.* 2012, unpaginated).



Activity	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pair Bonding[1]	■	■	■							■	■	■
Breeding[1]		■	■									
Whelping[1]				■	■							
Pup-Rearing[1]						■	■	■	■			
Dispersal[2]	■	■	■						■	■	■	■

[1] RWAMP, 2013; [2] Phillips et al 2003, p. 280

Figure 2: Approximate biological seasons for reproductive and life history events

PAIR FORMATION AND TERRITORY ESTABLISHMENT

Mech and Boitani (2003, p. 2) outlined several ways in which wolves establish new pairs and territories. "In a saturated population, all territories are occupied, so the only local breeding possibilities will be to (1) wait until the established breeding position opens (A) in the natal pack or (B) in a neighboring pack, (2) become an extra breeder within the pack, (3) carve out a new territory from the established mosaic, or (4) usurp an active breeder." Beyond the strategies already described to obtain a breeding position in his or her present population wolves can also initiate a long distance movement in a more or less single direction to locate another population on the landscape (i.e., dispersal; Mech and Boitani 2003, p. 5).

PUP-REARING/COOPERATION

Wolf packs provision pregnant females and after she selects a den site, which are usually located away from the periphery of the pack's territory. Females sometime localize their movements around the den site for several weeks before giving birth (Packard 2003, p. 45). Dens may be located below ground or above ground in nest-like depressions under dense vegetation (Phillips *et al.* 2003, p. 279). Most dens were noted to be in agricultural areas along the sides or tops of brushy windrows in areas with a low water table and friable soils. Red wolf packs contract ranges during pup-rearing (Hinton and Chamberlain 2010, p. 57) and localize their movements around den sites when pups are present (Chadwick *et al.* 2010, p. 303).

Like domestic dogs, wolf pups go through several distinct stages of development, including: the neonatal period (12-14 days) until eyes are open; the transition period when they begin to stand and walk; a socialization period (from about 20-77 days) during which they begin to eat solid food and elicit care from pack members; and a juvenile period (from about 12 weeks to maturity; Packard 2003, pp. 46-48).

Like gray wolf pups, red wolf pups are rarely left alone, indicating that males play a significant role in rearing and that wolves share duties (Hinton 2006, p. ii); in fact, Riley and McBride (1972, p. 10) previously reported that both males and females took part in rearing of young in the remnant population in Texas and Louisiana. In general, non-pup pack members provide assistance in caring for pups (Phillips and Henry 1992, p. 596). Generally, as pups begin to take solid food this is delivered via regurgitation by older wolves. Observations of gray wolves indicate that when wolf pups spot a returning pack member they run up, place there muzzle near the mouth of the pack member, and if the care giver's stomach is full, regurgitation occurs (Packard 2003, p. 48). Therefore, as older wolves forage, they consume meat which is later regurgitated for the breeding female and later for her pups.

Hinton and Chamberlain (2010, p. 75) found that pups were located within 250 m (820.2 feet) of an older pack member 77% of the time. They also found that while older wolves foraged away from the home site more at night (as would be expected), the pups remained near the home sites; therefore, pups were attended more during the day than during the night. They also found that the mean time that wolves were found in agricultural fields was over 98% during pup-rearing in the North Carolina population, which indicated in this population a strong preference for agricultural fields during pup-rearing. Home range sizes appear to gradually increase as pups grow and become large enough to hunt with the pack (Chadwick *et al.* 2010, p. 312).

By three months of age, pups are more likely to follow departing adults and explore around the homesite, around this age they exhibit pouncing behavior. Between 4 and 10 months of age, they can join adults on hunts, even though they are not fully grown. Packard (2003 p. 52) has suggested that having already learned social interactions, juvenile wolves undergo a sort of "hunting school" during this time, developing hunting skills while traveling with the family. Over time they gain experience and use their innate ability to learn quickly and detect complexities to improve their hunting and killing abilities. During this time, they also learn which classes of prey are most vulnerable and where to find them (Peterson and Ciucci 2003, p. 119).

In general, reproduction at ages younger than two are uncommon both in captivity and the wild population (Rabon 2014, p. 254), though instances of wild red wolves breeding have occurred at younger ages (Phillips *et al.* 2003, p. 278). Young wolves often defer breeding while still with the natal pack, however eventually juveniles of both sexes will disperse to form pairs and establish their own territories (Mech and Boitani 2003, pp. 2, 12, 16). Interestingly, one study on lifetime reproductive success for wild males found that lifetime reproductive success (i.e., the number of viable offspring produced over the wolf's lifetime) was lowered via decreased annual recruitment and shorter reproductive lifetime if they had natal helpers (Sparkman *et al*. 2016, p. 9), so there may be a trade-off for males related to staying with the natal pack longer.

DISPERSAL

The primary mechanism for expanding the range of a wolf population is dispersal (Fuller *et al.* 2003, p. 181). Dispersal is likely a response to competition for food and mates (Mech and Boitani 2003, pp. 12-13), but timing and age likely depends on prey abundance, survival of pack breeders, and availability of vacant territories. A representation of dispersal dynamics and how it relates to pack formation can be found in Figure 3. Two types of dispersal are recognized in wolves (Karlin and Chadwick 2012, p. 266). Natal dispersal is movement from the natal pack to the first breeding group, and breeding dispersal is movement by an adult breeder between breeding groups (Gese and Mech 1991, p. 2946; Boyd and Pletscher 1999, p. 1097; Blanco and Cortés 2007, p. 116).

Phillips *et al.* (2003, p. 279) reported dispersal behavior of eight male and ten female red wolves born in the wild eastern North Carolina reintroduction site. They reported an average dispersal age of 27 +/- 9 months for males and 23 +/- 10 months for females with a lack of sex bias among dispersers. Early dispersal of pups was also reported from this study following the disruption of social bonds between pups and adults (Phillips *et al.* 2003, p. 280). While dispersals occurred from September to March, 72% occurred between November and February. The duration of these dispersal events averaged 9 days (range = 1–44 days). Average distance dispersed was 36 +/- 22 km (22.4 +/- 13.6 miles) for males and 45 +/- 58 km (27 +/- 35 miles) for females (note: error is likely large due to small sample size; Phillips *et al.* 2003, p. 280). Nearly 90% of the dispersers traveled south or west and settled in unoccupied areas with abundant prey and good habitat that lacked wolf packs, unlike the areas to their north and east which already had established pack territories (Phillips *et al.* 2003, p. 280).

Karlin and Chadwick (2012, p. 266) found that dispersing red wolves are influenced by their natal habitat type and settle in areas with similar habitat types, (i.e., natal habitat preference induction; Davis and Stamps 2004, p. 411). They found that between 1990 and 1998, agricultural areas were the primary cover type used by wolves for natal and settled home ranges in the five county red wolf management area associated with the NEP and that 71% of pups and 82% of yearling/adults settled in areas dominated by the same land use land cover type as their natal home ranges after dispersal (*Z* = 1.87, *P* = 0.03; Karlin and Chadwick 2012, p. 270). Karlin and Chadwick (2012, p. 268) recorded a total of 79 natal dispersal events for 38 females and 41 males. Straight-line natal dispersal distance averaged 41.0 +/- 17.5 km (25.5 +/- 10.9 miles) from 1990 to 1998 and 34.4 +/- 21.6 km (21.4 +/- 13.4 miles) from 1999 to 2007. This difference was not significant. For females average dispersal distances from 1990-1998 were 36.7 + 8.4 (22.8 + 5.2 miles; *n* = 7), and from 1999-2007, 32.3 + 14.9 (20.0 + 9.3 miles; *n* = 31). For males average dispersal distances from 1990-1998 were 43.8 + 21.3 (27.2 + 13.2l; *n* = 11) and from 1999-2007, 36.6 + 27.0 (22.7 + 16.8 miles; *n* = 30; Karlin and Chadwick 2012, p. 269).

HOME RANGE AND TERRITORY SIZE

However, substantial variability exists in reported home range data for this species for several logistical reasons, as well (Hinton 2006, p. 2; WMI 2014, p. 78). Variability in home range sizes may be derived from differences in population size and health, as well as, lack of systematic data collection for this purpose. Generally, prey biomass explains about 33% of the variation in wolf pack territory size (Mech and Boitani 2003, pp. 21-22). Initially, in Louisiana and Texas data was collected on small populations in “poor health” (Hinton 2006, p. 2; Phillips *et al.* 2003, p. 272). Prior to Hinton’s effort (2006, entire) home range data was not collected systematically or evenly across the reintroduced population because biologists gathered data for various management purposes (WMI 2014, p. 78; Hinton 2006, p. 2).

Phillips *et al.* (2003, pp. 281-282) reported average home range for individuals to be 88.5 km² (34.2 mi²) +/- 18.3 SD km² (7.1 mi²). Pack home ranges varied between 46 and 226 km² (17.8 and 88.2 mi², respectively); it was suspected that this resulted from habitat quality and prey density. Chadwick *et al.* (2010 p. 303) found that home range spatial extents (95% fixed-kernel probability areas) vary by season, reaching maximums in fall and winter (73-121 km² (28.2-46.7 mi²)) and contracting by 40% to 63% during whelping and pup-rearing in the spring. In addition, wolves were found to localize movements around den sites when pups are present (May-September). As pups began to hunt with adults in the fall, the area used by the pack increased (Chadwick *et al.* 2010, p. 312). Hinton (2006, pp. 14-15) found home range size to vary by social rank and life stage of the individual, with pups being significantly smaller (61.5 km² (23.7 mi²)) than juveniles (88.9 km² (34.3 mi²) and adults intermediate between the two (76.1 km² (29.4 mi²). This study found no significant difference between the sexes. Hinton (2006, p. 14) reported that total home range size varied from 59.0 km² (22.8 mi²) to 110.6 km² (42.7 mi²), with a mean of 74.1 km² (28.6 mi²). Hinton *et al.* (2016, p. 1) noted that red wolves maintained spatially stable home ranges that varied between 25 km² and 190 km² (9.7 and 73.4 mi², respectively) on the predominantly agricultural landscape of the Albemarle Peninsula. In contrast, transient red wolves examined for the same study did not maintain home ranges and covered areas ranging from 122 km² (47.1 mi²) to 681 km² (262.9 mi²). Their space use was marked by shifting patterns and spatial instability until individuals established residency (Hinton *et al.* 2016, p. 1). Hinton *et al.* (2016, pp. 13-14) also suggested a role for transients in the maintenance of the population based on this study noting, "that if the red wolf population increases and saturates the Recovery Area, the available space for coyotes would diminish and the number of transient wolves frequenting marginal habitats would increase. In doing so, transient red wolves would likely disrupt coyote territories in marginal habitats while biding for opportunities to acquire territories and mates."

HABITAT USE

The remnant population in Texas and Louisiana was found in fallow fields, bayous, marshes and coastal prairie (Carley 1979, p. 23, Kelly *et al.* 2004, p. 89; Trani and Chapman 2007, p. 443); however Kelly *et al.* (2004, p. 89) noted that, "many agree that this environment probably does not typify preferred red wolf habitat." Paradiso and Nowak (1972, p. 3), suggested it once occurred in open pine forests and bottomland hardwoods, among others. Additionally, Kelly *et al.* (2004, p. 89) noted that "given their wide historical distribution, red wolves probably utilized a large suite of habitat types at one time." Most of these early observations were general, in nature, and do not tell us whether the animals observed were residents or transients, therefore, it is difficult to know whether this habitat was regularly used or being used during dispersal or displacement from a territory.

In North Carolina, reintroduced wolves have used many habitats, including agricultural lands, pine forests, and pocosins (e.g., a wetland found in coastal areas with sandy peat soil and shrubs throughout; Kelly *et al.* 2004, p. 89, Trani and Chapman 2007, p. 443). In the earlier years of the reintroduction effort, they seemed to favor wooded areas for denning, whelping, and rearing pups, edge habitat and roadways for travel, and areas of low human population density for hunting (Hinton 2006, Kelly *et al.* 2004, USFWS 2007). However, more recent studies have revealed that wolves in North Carolina are selecting agricultural areas over other cover types and use secondary roads for travel when human density is low (Dellinger *et al.* 2013, p. 327; Karlin *et al.* 2016, pp. 91, 93). Hinton (2006, p. 18) noted that packs used woodlots mostly in fall and winter and switched to agricultural areas in spring and summer. These wolves left dens early and moved pups to adjacent agricultural fields (Hinton 2006, p. ii). Chadwick *et al.* (2010, p. 312) found that the shift from row-crop agricultural areas to other cover types coincided with intense crop harvest occurring between September and November. Further, Dellinger (unpubl. manuscript, p. 12) found in a study of red wolves from 2007-2010, that home ranges center on agricultural areas, and that wolves radiate out from these areas even in winter, keeping the amount of agricultural area used consistent across seasons.

In Karlin *et al.* (2016, entire) a MaxEnt (machine-learning algorithm) was used to develop a model to estimate habitat suitability for the red wolf based on 4,200 telemetry locations collected on 178 breeder wolves in the recovery population area between 1998 and 2008. Model variables which provided the highest contribution to predicting wolf presence were low human population density (48.5%), secondary road density (34.7%) and agricultural area (10.7%) (Karlin *et al.* 2016, p. 91). Karlin *et al.* (2016) concluded that “red wolves are showing continued high use of agricultural areas over all other land cover types,” (Karlin *et al.* 2016, p. 93).

PREY

Typically, wolves have depended on ungulates (in some form) worldwide (Mech and Peterson 2003, p. 131), as a food source, but red wolves have been documented to use other food sources, as well. Red wolves are opportunistic predators and predate species which offer the best chance for capture (Carley 1979, p. 26). Wolves, in general, are known to focus on vulnerable prey within their territory (Mech *et al.* 1998, p. 111; Peterson and Ciucci, pp. 118-119). In addition, Fuller *et al.* (2003, p. 162) noted that the availability and abundance of food determine the potential for various areas to be inhabited by wolves. In fact wolf numbers according to Fuller (2003, p. 171) are usually limited by ungulate numbers and accessibility, though most of the studies examined therein involved northern North American wolf populations.

The remnant red wolf population in Texas and Louisiana primarily ate small mammals such as rabbits, rodents (e.g., muskrat and cotton rat), and other small animals such as nutria (Paradiso and Nowak 1972, p. 3; Riley and McBride 1972, p. 11; and Shaw 1975, pp. 55-60). Although it is not likely red wolves often preyed on larger animals, they noted earlier reports of predation on deer and wild hogs (Paradiso and Nowak 1972, p. 3). However, it is important to note that deer availability in Louisiana and Texas may have been limited as deer numbers had been reduced drastically throughout the U.S. in the late 1800s as a result of market and subsistence hunting (VerCauteren 2003, pp. 15-16). Depredation of livestock has been noted including sheep and goats in Alabama (Howell 1921, p. 30) and adult cattle on a ranch in Texas (Paradiso and Nowak 1972, p. 3) and occasional predation of newborn calves in the remnant population in Texas and Louisiana (Riley and McBride 1972, p. 10). In the history of the NEP, there have been few confirmed depredations of livestock by wolves; an estimated 5 livestock and 2 pet incidents (Nordsven 2017, pers. comm.).

In other areas and during reintroduction efforts several species have been targeted. Carley (1979, p. 26) reported that fox squirrel (*Sciurus niger*), American coot (*Fulica americana*), and other birds and small mammals were consumed in South Carolina. In North Carolina, after animals were reintroduced to Cades Cove in the Great Smoky Mountains National Park, they were located several times in proximity to cattle, both adults and calves, and one adult male took both a domestic chicken and several turkeys (Phillips *et al.* 1995, p. 166). In eastern North Carolina the primary food sources appear to be white-tailed deer, marsh rabbit, and small rodents in this area (Phillips *et al.* 2003, p. 283; McVey *et al*. 2013, p. 1144), with Phillips *et al*. (2003, p. 283) also noting significant use of raccoons. Though other items have also been consumed including, small mammals, insects, herpetofauna, vegetation, fish, birds, and crustaceans (Phillips *et al.* 1995, p. 163). McVey *et al.* (2013, pp. 1144, 1146) found that white-tailed deer was the only prey species consumed every month, but that consumption of rodents showed seasonal variability with more in the spring, than in the summer. Prey consumption patterns were similar in coyotes during this study and the authors concluded that diets of the two species did not differ significantly in the area of overlap (McVey *et al.* 2013, p. 1146). It is important to note that nearly all red wolf diet studies have been scat analysis studies, therefore, some nuances of resource partitioning (e.g., whether species were killed by canids or scavenged) may be difficult to discern. However, in a later resource partitioning study, Hinton *et al.* (2017 p. 8) found differences in proportions of prey species consumed between the two species and noted that red wolves used deer regardless of season, while rabbit, small mammal and furbearer use differed seasonally. The primary prey of coyotes in this study was found to be rabbits (secondarily deer and small mammals in equal amounts) and coyotes consumed more deer and fewer rabbits from September to February than they did during the growing season of May to August.

While the prey-base of red wolves is highly variable; it does show specific patterns by life stage, pack, and biological season. Juvenile red wolves consume more rodents than adults (Phillips *et al*. 2003, p. 283). Packs showed preference for specific food items (Phillips *et al.* 2003, p. 283). Dellinger *et al.* (2011, entire) analyzed scat of six red wolf packs over a two-year period to explore variation in prey species during pup-rearing. Approximately 66 percent of prey biomass consumed for the six packs consisted of adult white-tailed deer and fawns (Dellinger *et al.* 2011, p. 736). Other prey items used included: small rodents (hispid cotton rat, marsh rice rat, Eastern harvest mouse, and house mouse), large rodents, (nutria and muskrat), rabbits (marsh rabbits and eastern cottontails), raccoons, wild boars (i.e., feral swine), anthropogenic material, and other incidental prey species (e.g., insects) (Dellinger *et al.* 2011, p. 735). All packs primarily consumed mammalian prey (mostly white-tailed deer) during pup-rearing, though packs were variable with regard to secondary and tertiary prey items. The authors also noted that prey items used by packs did not vary across years or reproductive status (Dellinger *et al.* 2011, p. 738). As habitats across the recovery area did not vary greatly, the authors suggested variation was likely due to prey availability within a pack's territory, selection for a particular prey item within the territory, or hunting and foraging skills transmitted across kinship lines, rather than habitat type (Dellinger *et al.* 2011, p. 738). Phillips *et al.* (2003 p. 283) previously noted that there were differences among packs in prey consumption and suggested this was related to distribution and abundance of prey, which was similar to the conclusions of Shaw (1975, abstract) that found that prey importance shifted in relation to availability. Two packs consumed anthropogenic material; one likely due to proximity to a dump and another domestic hogs, likely as a result of a carcass pit within its territory (Dellinger *et al.* 2011, p. 738), though both packs also consumed native prey. The authors concluded that most packs are consuming wild prey almost exclusively during pup-rearing, demonstrating an ability to survive and reproduce in proximity to humans (Dellinger *et al.* 2011, p. 739).

PACK-LEVEL ECOLOGY

TERRITORIES AND COMPETITION

Competition among wolves is a pervasive feature of their ecology both within packs and between them (Mech and Boitani 2003, p. 27). Mech and Boitani (2003, p. 21) noted that in most relatively saturated populations there is only a minor relationship between territory size and pack size (Potvin 1988, p. 1268; Fuller 1989, p. 14; Mech *et al.* 1998, pp. 79-80) because pairs usually establish territories large enough for a full-sized pack at the outset, though where killing by humans is high they may be related (Ballard *et al.* 1987, p. 43; Peterson *et al.* 1984, p. 31; Ballard *et al.* 1997, pp. 15, 39).

Most studies of territories held by packs indicate a degree of overlap among territories (Mech and Boitani 2003, p. 25) and once a territory is established, a wolf pair strongly resists losing it (Mech and Boitani 2003, p. 30).Wolves employ several defensive strategies to defend their territories including howling, scent-marking, and direct attacks (Mech and Boitani 2003, p. 25). Wolves tend to mark the edges of their territories significantly more than the interior and marks tend to last 2 to 3 weeks (Mech and Boitani 2003, pp. 25-26), whereas howling, allows packs to notify neighboring packs of occupation over large distances, as howls can be heard for miles (Mech and Boitani 2003, p. 26). While scent-marking and howling minimize chances of direct conflict between packs, it does occur, usually near territory boundaries or within buffer zones. This intraspecific strife usually results in death. In fact, it is one of most common sources of natural wolf mortality (Mech and Boitani 2003, pp. 26-27). It has been suggested that intraspecific strife largely represents territorial competition that provides opportunity for territorial expansion and eliminates competing breeders (Mech and Boitani 2003, p. 28). In general, wolves will kill smaller canids like coyotes that invade the pack's territory. However, when other potential wolf mates are scarce wolves will interbreed with coyotes (Bohling and Waits 2015, pp. 113-114).

Disruption of social bonds within a pack can result in early dispersal of other pack members (Phillips *et al*. 2003, p. 280). While instances of pairing with a close relative have occurred (Sparkman *et al*. 2012a, pp. 1188-1190), "an array of dispersal, post-dispersal, and pair formation behaviors have the potential to work together to reduce rates of inbreeding, and any associated fitness costs," in red wolves (Sparkman *et al*. 2012a, p. 1193).

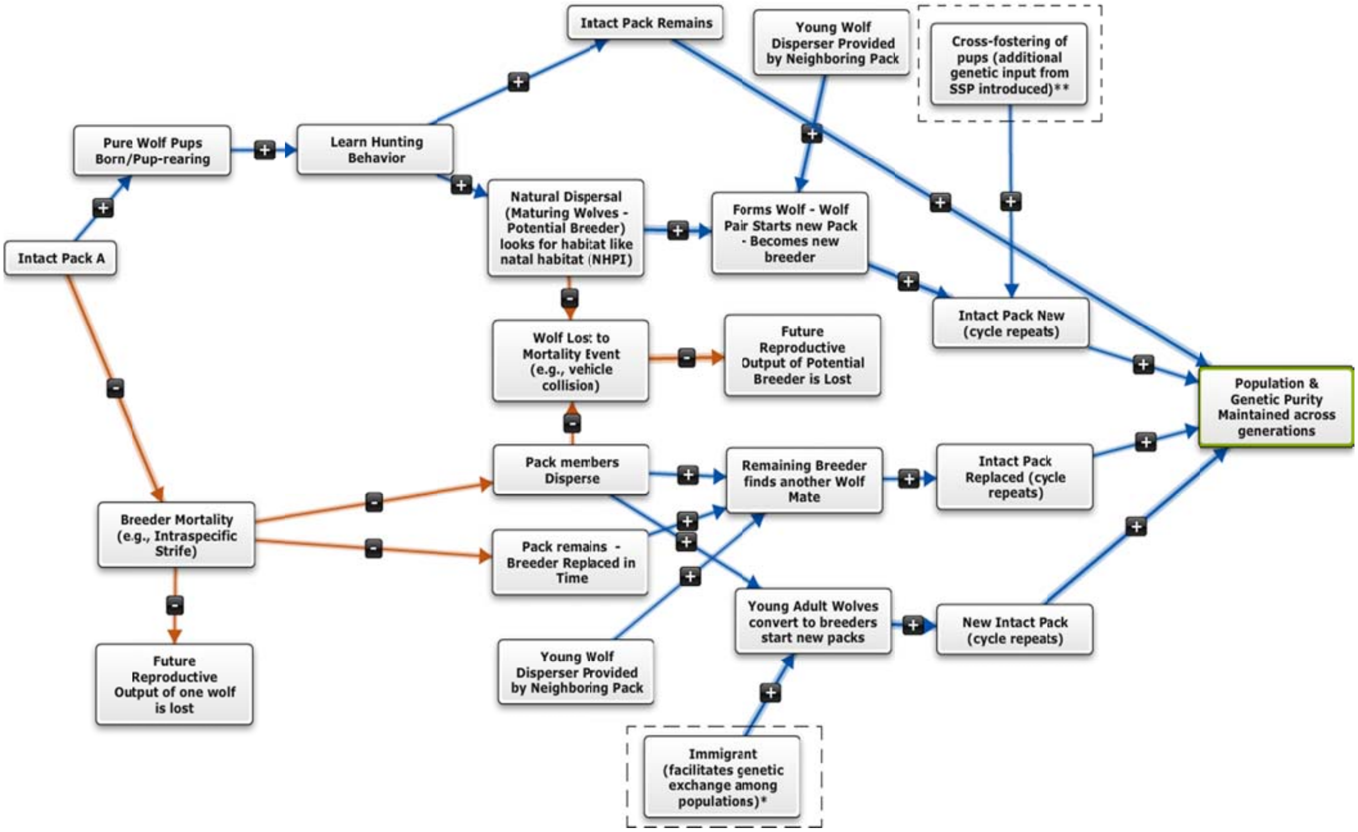


Figure 3: Pack formation and dispersal dynamics in a stable population of wolves *(Notes: *Adult wolves sometimes immigrate into intact packs and some more unusual pack structures do occasionally form, neither is depicted here; **Dashed lines represent opportunities for population to exchange genetic material with outside populations (either naturally or via release from SSP; ***Cross-fostering is the introduction of pups into a non-family litter just after birth).*

POPULATION LEVEL ECOLOGY

Mech and Boitani (2003, p. 6) have noted, "…a wolf population can be viewed as a highly dynamic system in which breeding pairs hold territories and pump out numerous offspring that travel about, criss-crossing the population and striving to gain their own breeding positions. In this flux, each pack tries to hold its position while competing with neighbors that try to expand their territories… with new breeding pairs, local lone wolves, and immigrants that are all trying to leverage themselves into the population structure." As such, a territorial mosaic develops in a well-established wolf population. Each pack competes for resources and space with its neighboring packs and the population is characterized by considerable territorial tension. The natural tendency of packs to expand allows the population to adjust to variations in prey availability (Mech and Boitani 2003, p. 20).

CHAPTER 4. SPECIES' NEEDS FOR VIABILITY AND CURRENT CONDITION

In this chapter, we first review the historical information on the range and distribution of the species. We next review the conceptual needs of the species, including population resiliency, redundancy, and representation, and reduce the likelihood of extinction. Finally we consider the current conditions of the red wolf SSP and wild population, and whether the species has what it needs for viability.

When considering what a wild red wolf population might need for viability, a few modifications have been made to the model for a functioning wolf population (Figure 3), which reflects the lack of nearby populations and the presence of the SSP. For instance, the introduction of pups from the SSP is represented by the block for cross-fostering of pups. Immigration remains in the diagram to show how genetic exchange with other populations occurs naturally on the landscape for wolf populations – however, for red wolf this may actually be replaced with the periodic movement of animals from the SSP into a reintroduced population.

POPULATION VIABILITY MODELING

The first Population Viability Assessment (PVA) for the red wolf was developed following a meeting of USFWS personnel with genetic and demographic specialists in Apple Valley, Minnesota in 1988. The purpose was to develop population goals for red wolf. That effort resulted in a PVA that recommended a captive population of 330 individuals and a wild population of 220 individuals maintained as a metapopulation in order to maintain 80-85% of the heterozygosity in the founder stock for 150 years (USFWS 1990, Preface, pp. 42, 48, and 51), recognizing the ultimate goal and ongoing strategy to slow the loss of genetic diversity that is inevitable in a small and closed populations (Long 2017, pers. comm.). This is particularly challenging given the fact that all wolves in captivity and in the wild are descendants of only 12 of the original 14 founders. In addition to calculating these minimum viable population (MVP) values, it also evaluated demographics of the captive stock and made recommendations for several aspects of the recovery program, including:

- adjusting the founder lineage representation to achieve a target distribution (p. 48) which would allow for an increase in the effective population size (Ne),
- increasing the effective number of founders (i.e., suggesting some founder lineages are over or under-represented in captive stock) (p. 42),
- expanding the captive population (p. 48),
- monitoring a release program for interactions of red wolves with coyotes (p. 53),
- developing a sperm and embryo-banking strategy (p. 53),
- developing a model to predict number of wolves needed at each reintroduction site (p. 53),
- evaluating reproductive physiology and issues of reproduction in captive stock, and enacting several criteria for captive facilities and the captive program (pp. 51, 53).

This first PVA effort provided the baseline goal for genetic diversity used in the 2016 PVA effort provided below (Faust *et al.* 2016, p. 4) and also recommended equalizing the representation of the founder lineages (only 12 out of the original 14 remain) to maximize retention of genetic diversity, which was incorporated into management of the captive stock (USFWS, 1989, pp. 42, 48; Long 2017, pers. comm.).

A red wolf Population and Habitat Viability Assessment (PHVA) workshop was later held in Virginia Beach, Virginia in 1999 (Kelly *et al.* 1999, entire) to "begin developing solutions focused on the technical issues facing recovery of the red wolf," (Kelly *et al.* 1999, p. 4). Forty scientific and management experts in the fields of wolf and coyote biology, wildlife biology and management, captive breeding, genetics, and population modeling were in attendance (Kelly *et al.* 1999, p. 4). This workshop concluded that hybridization with coyotes represented the single largest threat to recovery of red wolf. An initial population viability model was created in Vortex, however, the group felt this did not address the issue of hybridization adequately (Kelly *et al.* 1999, p. 5), so a separate model was created that focused on genetic outcomes (Kelly *et al.* 1999, p. 5).

The basic assumption of the genetic model created at the 1999 PHVA workshop was that as the number of coyotes around the population increased, more mattings between red wolf females and coyotes would occur, effectively removing female wolves as breeders and lowering the proportion of breeding red wolf females in the population. It is important to note that a "successful breeding" for the purposes of the model were between a pair of red wolves, therefore the model projects a "pure" red wolf population (Kelly *et al.* 1999, p. 24). The 1999 model predicted positive population growth (λ) of 1.215 (Kelly *et al.* 1.215). Additionally, Kelly *et al.* (1999, p. 23) predicted the carrying capacity in the North Carolina population as 145 ± (SD = 13).

Mahoney (2011, entire) suggested there were limitations to the Kelly *et al.* (1999) PVA effort and constructed a five-stage model including pups, yearlings, breeding adults, non-breeding adults, and vagrants to more accurately reflect wolf social structure and pack composition. Mahoney's model produced a nearly identical prediction of positive growth in the population as the 1999 model ($\lambda_s =$ 1.212); however, Mahoney (2010, p. 11) noted that the observed population growth was actually reported to be 1.413 (USFWS 2007, [p. 15]). Mahoney's model predicted that carrying capacity in the North Carolina population was approximately 120 individuals (Mahoney 2010, p. 12).

Mahoney noted that the wolf population was estimated to be 115-125 at the time of modeling individuals based on data available (Mahoney 2010, p. 8).

Although much of the PHVA completed by Kelly *et al.* (1999) was based on data from other wolves [(e.g., other canids including Algonquin wolves, Kelly *et al.* (1999, pp. 19-20)] and expert opinion rather than detailed analysis of red wolf data (Faust *et al.* 2016, p. 5), the NEP population did in fact increase as projected in Kelly *et al.* (1999) until 2005, after which it began to decline, a trend that accelerated after 2010.

In 2013, USFWS and the Red Wolf SSP captive breeding program asked Lincoln Park Zoo to create a new PVA team. The goal of this effort was to model viability of the captive stock and the NEP to better comprehend the conditions under which the two populations could persist in the future and how viability would be impacted by movement between the populations. The team first developed an SSP-only population model (Simonis *et al.* 2015) using ZooRisk (Earnhardt *et al.* 2008, entire) software and then developed a stochastic, individual-based model in Vortex 10.1.4.0 software. This constitutes the most recent PVA effort for the species and is the basis of model predictions provided in the future condition section below.

In the Faust *et al.* (2016, p. 7) model, the carrying capacity used for the NEP was 150 (based both on previous maximums seen in the five-county recovery area – though this may not constitute the true ecological carrying capacity) and for the SSP was 225, which is the population size that can be supported with current spaces in the SSP.

RED WOLF SPECIES NEEDS FOR VIABILITY

For the red wolf to maintain viability, its populations, or some portion of its populations, must be resilient. Stochastic events that have the potential to affect red wolf populations include weather events, fires, and disease outbreaks. Resilient red wolf populations occupy habitats of sufficient size to sustain growing, reproducing populations of adequate size to withstand introgression pressure and produce viable offspring which reach maturity and expand the population through the formation of new packs.

Therefore, the general needs of the red wolf for viability (resiliency, redundancy, and representation):

- Adequate Numbers – to establish and maintain pack structures, defend territories, produce viable offspring, and find suitable mates (i.e., sufficient unrelated individuals to prevent selection of heterospecific mates);
- Adequate Habitat – to support multiple packs and provide sufficient resources for packs to complete life history and avoid anthropogenic mortality sources (at a rate which will facilitate population maintenance);
- Genetic Diversity – sufficient captive and wild stock to support genetic diversity goals set out by the recovery team and sufficient capacity within the captive population to support genetic diversity [based on the 12 founder lines] while supporting releases; and

- Multiple Resilient Populations within the historic range – it is generally agreed that multiple populations would be needed to provide for protection from catastrophic loss - though the number necessary will depend on further recovery planning efforts and configuration of sites, their features, and resultant demographic rates may strongly influence these targets.

CURRENT CONDITION OF THE SSP (RESILIENCY)

The population of red wolves in zoos and nature centers consists of 231 (109 males, 122 females) animals at 43 participating facilities (27 AZA, 16 non-AZA) as of July 2017. The population has grown steadily in captivity since the managed breeding program was established in the early 1970's, with a slight plateau in growth in the past ten years as the captive population experienced space constraints. The target population size set for the Red Wolf Species Survival Plan® (RWSSP) by the Canid and Hyaenid Taxon Advisory Group in the 2010-2013 Regional Collection Plan is 200. The long term target population size set by USFWS Red Wolf Recovery Plan for the *ex situ* population is 330. At this time, the SSP population is unable to grow beyond its current size due to space constraints; the SSP needs additional institutions to better support population growth, demographic stability, and retention of genetic diversity.

Current gene diversity for the managed population is 88.87% and is equivalent to the genetic diversity of a population descended from approximately five founders (FGE = 4.49). The Red Wolf Recovery Plan (USFWS, 1989) set the target gene diversity to be retained at 80 – 85% over 150 years. Under current conditions, at a population capacity of 200 and a 0% growth rate, gene diversity can be maintained at or above 85% for less than 18 years and at or above 80% for approximately 43 years. Strategies that may help maintain a high level of gene diversity for a longer period of time include increasing the population growth rate and increasing the proportion of breeders in the population (i.e., ratio of effective population size to census size, Ne/N). Both of these strategies require setting up additional breeding pairs and are thus dependent on an increase in space. Recent population viability analysis modeling (Faust *et al.* 2016) suggests that an increased target size of 330 can help maintain gene diversity at or above 80% for at least 100 years.

CURRENT CONDITION OF THE NORTH CAROLINA POPULATION (RESILIENCY)

Currently, there is only a single wild population of red wolves that occupies a Recovery Area of about 6,000 square kilometers (km) (2,317 m^2) of federal, state, and private lands in Beaufort, Dare, Hyde, Tyrrell, and Washington Counties, on the Albemarle Peninsula of North Carolina, the NEP (Hinton *et al*. 2015, p. 2). At present, 23 wolves are being tracked in the non-essential experimental population in eastern North Carolina, which includes both adults and juveniles. The current population in the NEP is estimated to be 44 individuals, including pups (USFWS 2017, unpublished data).

Considering the conditions of the SSP and NEP, as described, the red wolf is currently not resilient. The single wild population of red wolves is projected to go extirpated in approximately

37 years, but could go extirpated in as few as eight years. The trajectory of the NEP presented in Figure 4 below has continued downward for this population since the completion of the Faust *et al.* 2016 PVA.

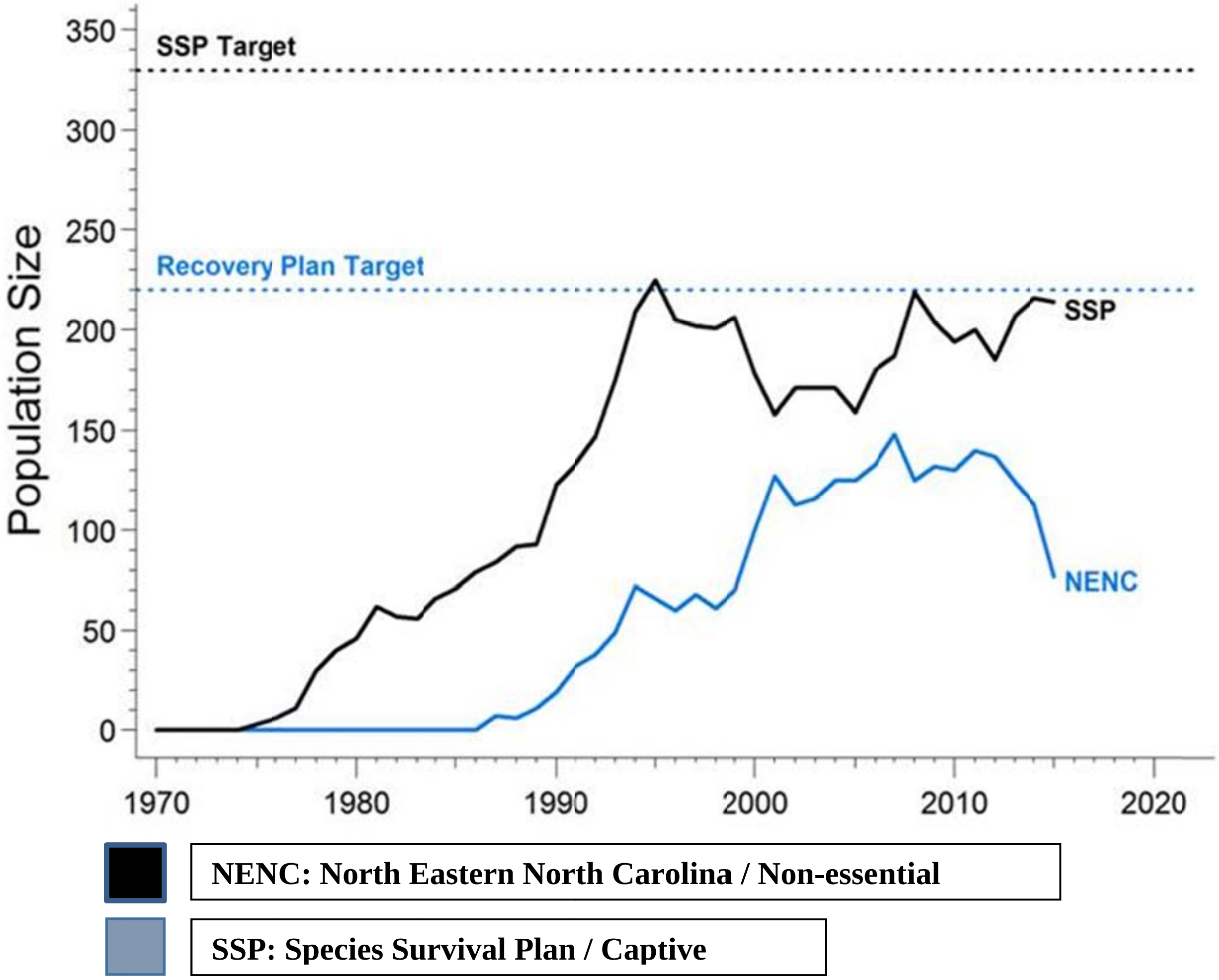


Figure 4: Population size of the SSP and NEP over time (Adapted from Faust *et al.* 2016. "NENC", used by Faust *et al*. 2016, refers to NEP) *Note: that the recovery plan target was for all wild populations, not just the NEP

SPECIES REDUNDANCY AND REPRESENTATION

The red wolf needs to have multiple resilient populations distributed throughout its range to provide for redundancy and representation. The more populations, and the wider the distribution of those populations, the more redundancy the species will exhibit. Redundancy reduces the risk that a large portion of the species' range will be negatively affected by a catastrophic natural or anthropogenic event at a given point in time. As only one wild population exists, and this population is declining, the red wolf currently has no redundancy other than what may be supplied by captive stock held at multiple facilities throughout the U.S.; however, this does not constitute a functioning, wild population. Therefore, the red wolf does not have the adequate numbers or multiple resilient populations needed for the species itself to be resilient and redundant.

Multiple resilient populations contribute to the range of variation found in a species; the more variable a species is, the greater the adaptive diversity and the ability of a species to adapt to changes in the environment. Maintaining adaptive diversity includes conserving the genetic diversity of a species. Current gene diversity for the SSP population is 88.87% and is equivalent to the genetic diversity of a population descended from approximately five founders (FGE = 4.49). Maintaining the genetic diversity remaining for the species would require additional spaces within the captive population and presently only three breeding pairs exist on the ground, so the ability of the wild population to contribute to genetic diversity at the species level is limited both by numbers and because individual wolves do not optimize mate selection for genetic diversity purposes. However, the SSP represents the genetic fail-safe for the entire population and any future recovery potential for the species. All twelve of the original lines are still represented, therefore, it is clear that the SSP effort has maintained a genetically-diverse stock from which to grow the population and release the most diverse animals possible.

CHAPTER 5. FACTORS INFLUENCING VIABILITY

In this chapter, we evaluate the past, current, and future factors that are affecting what the red wolf needs for long-term viability. Those factors that are not known to have effects on red wolf populations, such as overutilization for commercial and scientific purposes, are not discussed in this report. Because of the long history of the red wolf program, negative and positive factors may be discussed together, since many of the proactive measures are the result of lessons learned and research conducted during the program’s history. Since the inception of the recovery program, efforts have been made to maintain the purity of the genetic stock, manage morbidity and mortality dynamics of captive and wild stocks, find best practices to ensure successful releases, and monitor the condition and status of the populations and recovery effort. Captive stock has been cooperatively and adaptively managed since 1984 when the red wolf was approved by the Association of Zoos and Aquariums (AZA) for SSP designation. Since 2000, an adaptive management plan has been used for both the captive stock and the wild population in North Carolina. Below, we explore the factors affecting the species presently and those for which management has resulted in reduction of impact on the species below, as any future recovery efforts may need to consider potential effects with and without management.

Many factors have caused direct mortality in red wolves in North Carolina. Among these, in order of effect, are gunshot, vehicle collision, health-related causes, intraspecific strife, private trappers, management actions, suspected illegal activity, and poison (Figure 5; Hinton *et al*. 2016, entire). While annual survival rates have remained stable, the population has declined since approximately 2005 (refer to the section on Introgression and Anthropogenic Mortality for a detailed explanation below; Hinton *et al*. 2016, p. 9).

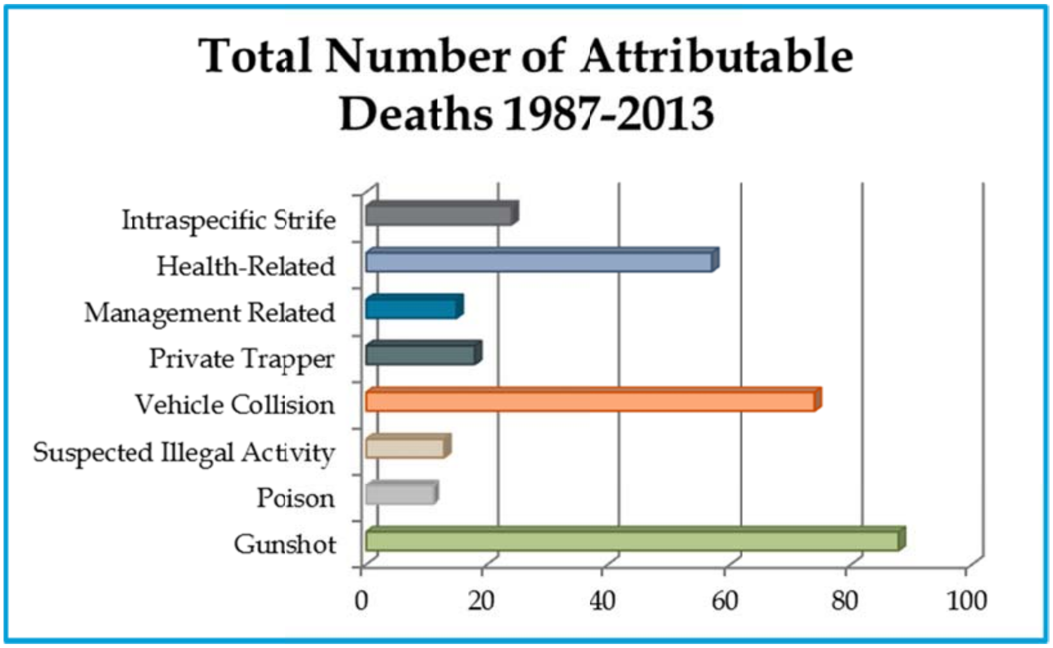


Figure 5: Mortality sources of red wolves in the northeastern North Carolina wild population from 1987-2013 (Adapted from Hinton *et al.* 2016, entire)

In addition to direct mortality, factors which have the potential to affect the genetics and demography of the wild and captive populations still exist, including a limited number of founders, coyote introgression, and pack disruption following the loss of a breeder.

Hinton (2015, p. 10) has suggested that transiency of red wolves (periods when they don't maintain a home range) may facilitate rapid population-level recovery following extensive and drastic mortality events. Fuller *et al.* (2003, pp. 184-185) has suggested for gray wolves, that because of high reproductive potential, wolf populations can tolerate a high level of mortality, though if reproduction cannot fully compensate for high exploitation rates, the population should decline. In addition, Fuller (2003, p. 185) noted for gray wolves if productivity is low or immigration limited then allowable harvest must also be low. Sparkman *et al.* (2011b, p. 5) suggested for the northeastern North Carolina population that, "…in populations such as this where population growth is the desired end of the reintroduction program, these findings suggest that anthropogenic mortality rates substantially lower than 25% are necessary to achieve positive growth rates, particularly at low population density."

SMALL POPULATION SIZE AND FOUNDER STOCK

To better understand the factors affecting red wolves, it is important to start with the founder population and small population effects. Despite capturing over 400 canids in Louisiana and Texas, only 14 animals were used to found the captive program. Of those, only 12 are still represented in the population (Faust *et al.* 2016, p. 5). While early studies found no inbreeding depression in the captive population (Kalinowski *et al*. 1999, p. 1375); recent reviews of the captive population have determined that it is becoming increasingly difficult to avoid inbreeding since no additional founders exist (Waddell and Long 2016, p. 1). This was noted as a potential problem even in the early PVA modeling effort in 1989, which suggested adjustments be made in founder lineage representation to maintain more of the original heterozygosity in the captive population (USFWS 1990, p. 42). Maintaining genetic diversity is important because inbreeding depression could result in a reduction in individual fitness and loss of genetic variability due to genetic drift, which can diminish the ability for populations to adapt to changes in their environment (resiliency; Frankham 2005, p. 131), such as novel diseases.

"Many populations are extirpated or reduced due to deterministic factors like habitat loss, overexploitation, and climate change. However, even when the habitat and conditions are favorable, populations may become extirpated as a result of various stochastic events and natural catastrophes. Random events like drought, floods, and fires exacerbate each other and become more likely to cause extirpation or extinction in small populations," (Shaffer 1981, p. 131). In general, the fewer populations a species has or the smaller its population size, the greater the likelihood of extinction by chance alone (Shaffer and Stein 2000, p. 307).

Another consideration with small populations are Allee effects. An Allee effect is defined as, "a positive relationship between any component of individual fitness and either number or density of conspecifics," (Stephens *et al.* 1999, p. 186). These effects can cause extirpation for small populations when growth rate or some element of individual fitness is related positively to population density or size (Stenglein and Van Deelan 2016, p. 1). This is important to recovering carnivore populations because a minimum number of cooperating individuals is necessary for positive population growth (Stenglein and Van Deelan 2016, p. 1). Social carnivores (like wolves which maintain pack structures) may be particularly vulnerable to Allee effects because of the need for conspecifics for rearing of young and hunting; and because they often exist at naturally low densities (Stenglein and Van Deelan 2016, p. 10). Stenglein and Van Deelan (2016, p. 1) modeled potential Allee effects in a population of gray wolves and estimated that the population crossed the Allee threshold at 4-5 packs comprised of roughly 20 wolves. Further, they suggested this could have resulted from wolves dispersing to areas distant from population centers into vacant territories and then being unable to find mates (Stenglein and Van Deelan 2016, p. 9).

INTROGRESSION AND ANTHROPOGENIC MORTALITY

Coyotes were once restricted to the western United States, but elimination of wolves and landscape changes facilitated their expansion into the southeastern United States, and despite extensive control efforts, they have continued to expand their range (NCWRC 2012, p. 14). Until the 1980's coyotes observed in North Carolina were likely the result of illegal importation and release (NCWRC 2012, p. 14), but as early as 1985 coyote presence was documented in Washington and Beaufort Counties (with visual sightings by residents as early as 1983), two were collected in Tyrrell in 1987, one suspected in Hyde in 1986, and finally in Dare in 2005 (data provided by North Carolina Wildlife Resources Commission 2017). Between 1999 and 2013, the mean number of coyote first captures increased from 4.2 to 34.1 (15% to 51%), while mean red wolf first captures decreased from 20.8 to 10.1 (75% to 34%) (Gese *et al*. 2015, p. 194). Coyotes numbers have continued to increase as evidenced by the continuing harvest of large numbers across the state (see Figure 6 below for recent estimated harvest by hunters in North Carolina). Additional data on coyote harvest specific to the Albemarle Peninsula in recent years is provided in Appendix 4. However, it is important to note, that retrospective molecular genotyping suggested the known number of free-ranging reproductively-intact hybrids alive at any inventory point in the pre-RWAMWP period never exceeded two (Gese *et al.* 2015 p. 198).

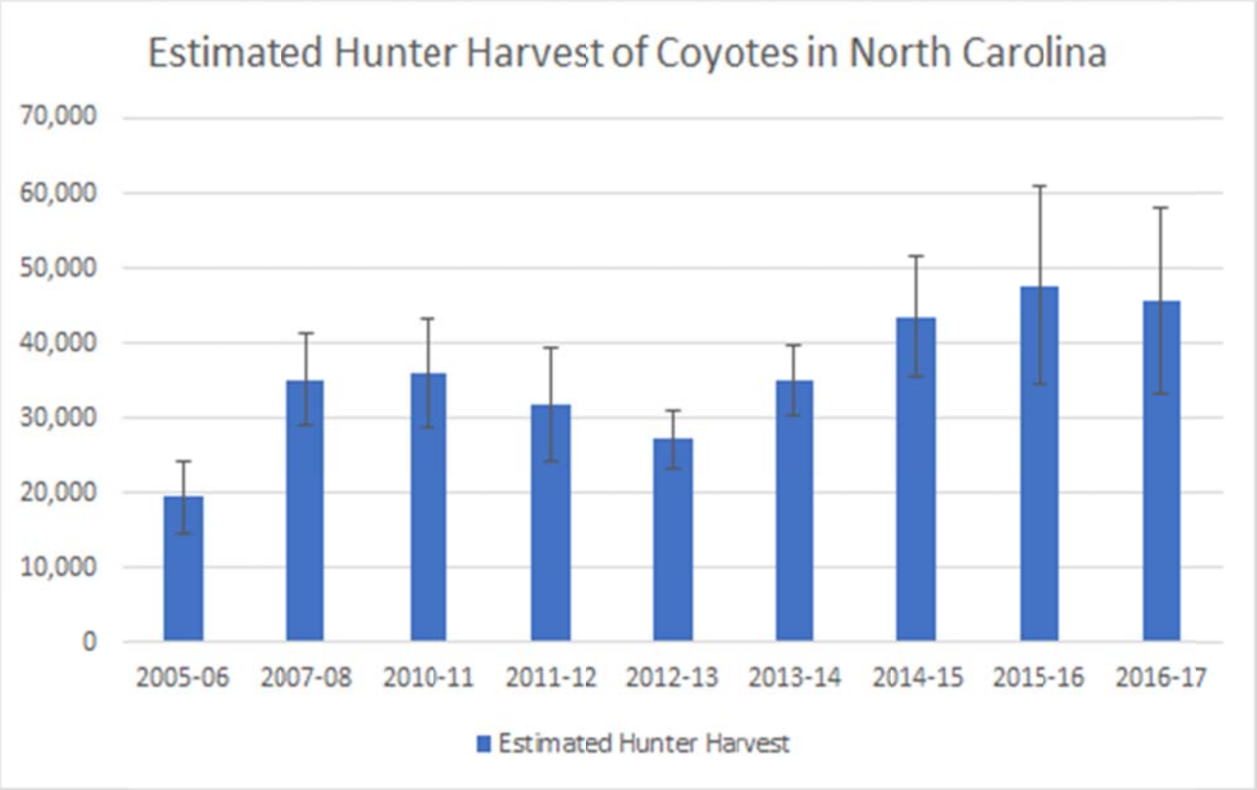


Figure 6: Coyote Hunter Harvest Estimates (with 95% confidence limits) in North Carolina (data provided by the North Carolina Wildlife Resources Commission 2017)

Because the red wolf genetic pool was limited to the lines from only twelve individuals (of the original 14), as coyotes moved into the area there was substantial concern that the population would be swamped by hybridization with coyotes. By 1999 it was recognized as the most immediate threat to the reintroduced population continues to be hybridization with coyotes (Kelly *et al.* 1999, entire). As a result the USFWS adopted a Red Wolf Adaptive Management Work Plan (RWAMWP) to enable learning while reducing or eliminating this threat (Gese *et al*. 2015, p. 193). The RWAMWP is an intensive long-term management plan developed to reduce interbreeding and introgression while simultaneously building the red wolf population. The RWAMWP includes 1) the placeholder concept (removal/sterilization of coyotes and hybrids), 2) the release of red wolves from the captive breeding program, 3) genetic testing of litters, 4) cross-fostering of captive pups born to wild parents, and 5) a public relations effort to promote recovery (Rabon *et al.* 2013, p. 6; Bartel and Rabon 2013, p. 111; Gese *et al*. 2015, p. 200).

Gese *et al*. (2015, p. 200) found the success of the RWAMWP at controlling hybridization and facilitating red wolf recovery to be mixed. They also noted that the number of coyotes and hybrids, and ratio of hybrid to red wolf litters did not decrease which were measures of success, however, the "placeholder" portion of the RWAMWP was found to be an effective way to manage coyote introgression (Gese and Terletzky 2015, p. 18; Gese *et al.* 2015, p. 200). However, the plan has not been successful in providing conditions favorable for red wolf survival mostly due to the fact that it does not addresses anthropogenic causes of mortality (Hinton *et al.* 2016, p. 10).

The RWAMWP describes techniques to capture and sterilize hormonally intact coyotes via vasectomy or tubal ligation, then releases the sterile canid at its place of capture to act as a territorial "placeholder" until the animal is replaced by wild red wolves. Sterile coyotes are not capable of breeding with other coyotes, effectively limiting the growth of the coyote population, nor are they capable of interbreeding with wild red wolves, limiting hybridization events. In addition, the sterile canid will exclude other coyotes from its territory (also supported by Gese and Terletsky 2015, entire). Ultimately, the placeholder coyotes are replaced by the larger red wolves either naturally by displacing the coyote or via management actions (e.g., removal of the coyote followed by insertion of wild or translocated wolves) (Bartel and Rabon 2013, p. 111). During a time in which the number of coyotes and hybrids were increasing and red wolves decreasing due to anthropogenic mortality (Hinton *et al*. 2016, entire; see Figure 5 above), the average ancestry of all known, reproductively intact red wolves and introgressed individuals in the recovery zone in 2014 was 96.5% (< 4% coyote ancestry from introgression since the reintroduction began). No reproductively-intact hybrids were noted at any inventory date from 2004 through 2013 (i.e., all known hybrids were removed or sterilized) (Gese *et al.* 2015 p. 198). Additionally, the number of red wolf litters exceeded hybrid litters each year (Gese *et al.* 2015 p. 200).

Today, despite the large number of coyotes present on the peninsula, hybridization events are relatively infrequent when compared to the number of potential canid parents in the area, and illustrate that some natural processes are operating to limit introgression; though undoubtedly aggressive management of coyotes and hybrids has limited genetic introgression into this population (Bohling *et al.* 2016, pp. 8, 11). With the continued presence of coyotes, hybridization continues to be an ongoing challenge.

The "placeholder concept" is particularly important because in a functional population, the death of a breeder creates a vacancy that would be filled by non-breeding or transient red wolves already in the area (either lone wolves or from neighboring packs) (Hinton 2016, p. 13). Therefore, it is important that there be enough red wolves to fill these vacancies, as they occur and as Hinton (2016, p. 13) noted, "the presence and space use of transients has a profound effect on recovery of red wolves via the ability of transients to replace lost residents and deter coyote encroachment in the Recovery Area."

Another concern with the presence of coyotes is that they are well-adapted to recover from harvest. "Despite intensive control efforts in other states that have had high coyote populations, they continue to thrive. Coyotes are highly adaptable and readily locate near humans. They eat a wide variety of foods, produce a higher than average number of offspring for a predator, and can readily breed with both eastern wolves (e.g., red) and dogs. Many maintain packs, though some are classified as transients and do not maintain territories or show affinities for particular areas (Hinton *et al.* 2015, pp. 1-2). Several studies have shown populations quickly replace lost individuals following substantial control efforts – this may be the result additional food availability allowing for larger litters and release of younger individuals to breed (Gese 2005, p. 281) or abundant coyotes in neighboring areas may quickly fill vacant territories. Whatever the mechanism, it is generally agreed that standard control efforts can increase both birth and survival rates in coyote populations.

Given that coyotes vastly outnumber wolves in eastern North Carolina, they would be more likely to quickly find a conspecific mate and produce a viable litter. At present they are in a much stronger position to recover from anthropogenic mortality in northeastern North Carolina than the NEP red wolves, particularly as it results in loss of breeders.

Recent research has revealed a complex dynamic between coyote introgression and anthropogenic mortality in the NEP on the Albemarle Peninsula. There were over four times the number of red wolf litters compared with hybrid litters between 2001 and 2013, but over half of the hybridization events occurred after one or more breeders was lost from a stable breeding pair (Bohling and Waits 2015, pp. 108, 113). Bohling and Waits (2015, pp. 113-114) went on to explain the relationship between hybrid litters and anthropogenic mortality:

> "…it appears that hybridization events tend to follow the disruption of stable breeding pairs of wolves, frequently due to anthropogenic actions such as gunshot mortality. In this system canids begin establishing pair bonds during a period that corresponds with the onset of hunting seasons for large mammals. The elimination of red wolf breeders during the breeding season forces reproductively active red wolves to quickly locate another mate. A higher percentage of hybrid than red wolf litters were produced by first-time female breeders, which is likely due to the low natural turnover in red wolf breeders from year to year (Sparkman *et al.* 2011,[p. 4])… The inexperience of these animals coupled with the timing of pair dissolution during the breeding season may facilitate selection of a heterospecific mate."

This dynamic is further complicated by timing with critical life history periods. Hinton *et al.* (2016, p. 9) noted that red wolves in eastern North Carolina exhibited reduced survival from October to December and suggested extensive loss of vegetative cover (associated with harvest of crops) reduced refugia for red wolves just prior to a period of elevated human activity (fall and winter hunting seasons). Further, younger wolves likely suffered greater mortality for several reasons, including the overlap of hunting season with the annual period of natal dispersal (described in Karlin and Chadwick 2012, p. 269), unfamiliarity of the areas being traversed, and encountering decreased availability of vegetative cover and human activity for the first time.

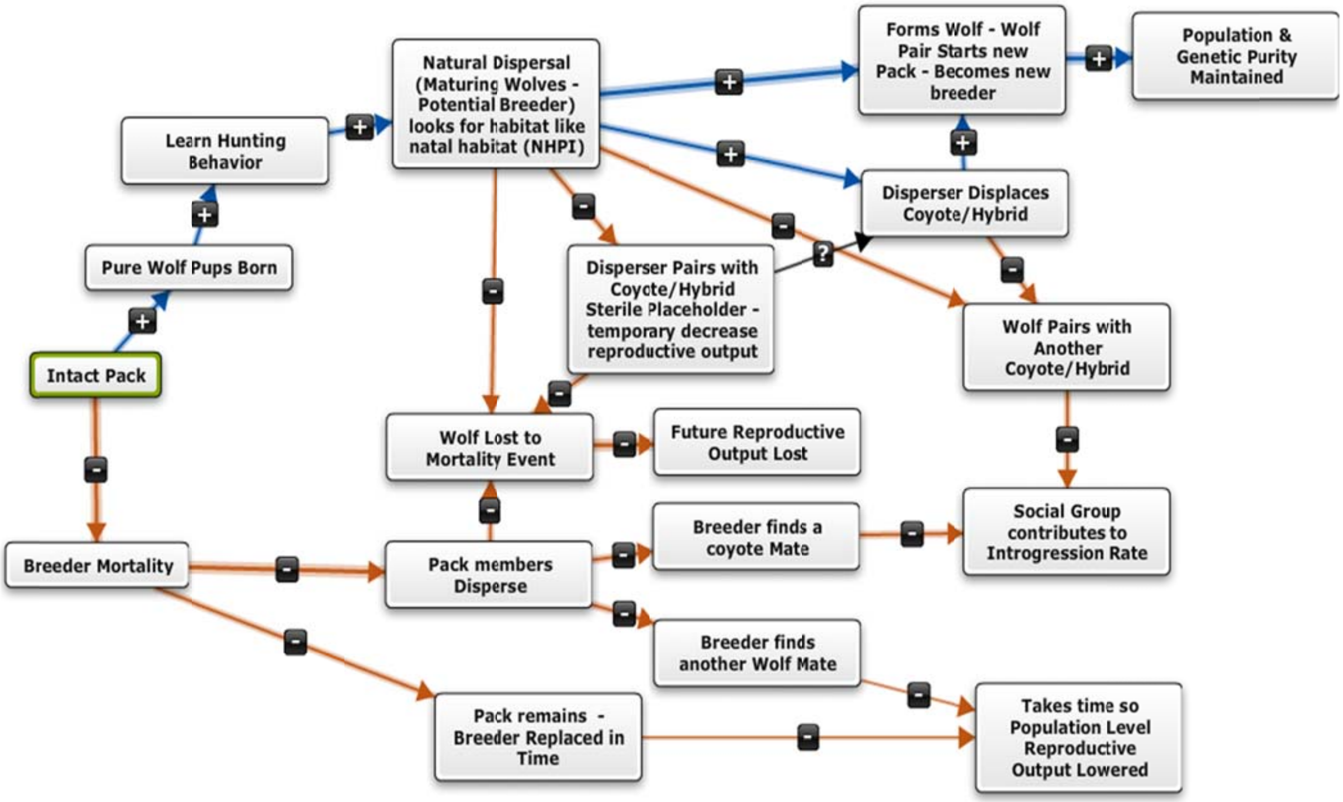
These mortality events resulted in breeder loss and disturbances in pack structure. Hinton *et al.* (2017, p. 174) reported that annual preservation rates of red wolf breeding pairs has declined 34% and replacement rate of all *Canis* breeders by red wolves has declined 30% since the mid-2000s. Hinton described the progression by explaining that early in the red wolf's recovery, when few coyotes were present and anthropogenic mortality was lower, wolves replaced wolves when an animal was lost. Since the early 2000s, however, this, dynamic has changed, with increasing numbers of coyotes and increasing wolf mortality caused by gunshots, coyotes are now replacing red wolves when a breeder is lost (Hinton *et al*. 2017, p.178). As the red wolf population continues to decline, red wolves are unable to find other wolves to form breeding pairs and likelihood of introgression goes up. Therefore, introgression exacerbates already reduced population numbers because the resulting hybrids do not contribute to the maintenance of the population.

As shown in the Figure 7 below, the paths available to establish new pure red wolf packs is only one of many and reproductive output of individuals can be reduced or lost through several possible pathways. Overall, the dynamic that developed has the effect of preventing timely wolf-wolf pair formation and prevents the successful contribution to the population through reproduction and new pack formation – leaving very limited potential to maintain a pure red wolf population in the wild.

It is important to consider several things while examining this diagram of dispersal dynamics. 1) Mech and Boitani (2003, p. 11) describe wolf packs as "dispersal pump(s)" that generate potential wolves to fill the landscape. Red wolves typically replace coyotes or hybrids, therefore a wolf dispersing from another pack could usurp one of these as a breeder converting a pair into a wolf-wolf pair. 2) Progression through steps may take time. Sparkman *et al*. (2011b, p. 3) found that nearly half of the packs disbanded following loss of a breeder and their home ranges remained vacant for 1+ breeding seasons and that replacement of a breeder (if the pack maintains the home range) could take 0-3 breeding seasons, during which time the pack may not contribute to the overall population-level reproductive output. 3) The interventions of the recovery program largely prevent hybrids from being created (via "placeholder efforts") or facilitate the removal of hybrid animals if hybridization occurs; therefore the effect is to minimize the rate of introgression in the NEP. 4) As the population declines the impact of these negative outcomes increases. Also, as breeders and dispersers are lost, fewer potential unrelated wolf mates exist to select from and, therefore, introgression potential increases. Note: It may also be helpful to compare this figure to Figure 3 which diagrams a more functional pack structure and dynamic.

The impact on the population growth rate was explored by Hinton *et al.* (2016, p. 8) which noted that annual population growth rate changed from positive to negative, when analyzing the time periods between 1998 and 2013. Specifically from 1998-2005 the red wolf population in North Carolina increased from approximately 90 to 151 wolves with an average annual growth rate (λ) of 1.12 but from 2005 to 2013, the population decreased from approximately 151 to 103 wolves with an average annual λ of 0.96. The authors concluded that while interventions from the recovery program likely softened the decline, anthropogenic mortality is still affecting population size and growth and that pairings between wolves and coyotes prevent compensation of losses to the wolf population (Hinton *et al.* 2016, p. 10). It is important to note that while Sparkman *et al*. (2011b, p. 4) found strong evidence that anthropogenic mortality was additive, Hinton *et al*. (2016, p. 10) noted that some sort of compensatory mechanism must be operating because as anthropogenic mortality has risen, other sources have declined and the overall survival rate appears stable; though without more wolf-wolf pairs the population cannot compensate losses to mortality on its own.

Figure 7: Dispersal dynamics and issues created by synergistic effects of anthropogenic mortality and coyote introgression in the NC Red Wolf Recovery Area.



VEHICLE COLLISION

In the early years of the northeastern North Carolina reintroduction, most red wolf mortality was the result of vehicle strikes, malnutrition and parasitism, or intraspecific strife (Phillips *et al.* 2003, p. 284). According to Hinton *et al.* (2016, pp. 6-7), vehicle collisions resulted in 34% of all mortality resulting from an anthropogenic source between 1987 and 2013. Gunshot mortality is now the leading source of anthropogenic mortality, though wolves are still being lost to vehicle collision. Overall, anthropogenic mortality sources are combining to affect annual growth and size of the red wolf population in the wild (Hinton *et al.* 2016, p. 10) and these are expected to continue in the future.

MANAGEMENT MORTALITY

Because substantial interaction with animals occurs as part of the recovery effort, attempts have been made to detect the impact of human visits on den abandonment and pup survival. Beck *et al.* (2009, pp. 635-637) reported that interference did not appear to result in increased risk of female abandonment or reduced pup survival in a study of 12 litters. Management efforts since 2009 in North Carolina have increased and no known impact on den abandonment or pup survival have been noted. The most significant negative effect of management on wolves appears to be trap-related mortality (Morse, 2017a, pers. comm.). This includes drowning due to drags getting hung in cancals, equipment malfunction where the drag is separated from the trap, exposure when a sick or weak wolf is captured, and gunshot when a trapped wolf is shot before being checked in the mornings (Nordsven 2017, pers. comm.). Hinton *et al.* (2016, pp. 6-7) found that management-related activities collectively resulted in 7% of the 219 deaths from anthropogenic sources of mortality between 1987 and 2013, overall, less than several other sources, including gunshot (40%), vehicle mortality (34%), and private trappers (8%), but more than poisoning which accounted for 5% (see Figure 5 above).

POISONING AND SUSPECTED ILLEGAL ACTIVITY

Instances of poisoning have been detected in the North Carolina population. Hinton *et al.* (2016, p. 6) reported 11 instances of poisoning (5%) out of 219 deaths attributable to anthropogenic sources. In addition to poisoning, Hinton also described suspected illegal activity. This source of mortality could be best described as an instance where it was clear to researchers the animal had been separated from the collar and would have likely been dead upon its removal (e.g., the collar was found cut from the animal or perhaps collar was recovered with a bullet hole). Suspected illegal activity resulted in the loss of approximately, 13 animals (approximately 6% of anthropogenic mortality) over the period from 1987 to 2013 (Hinton *et al.* 2016, p. 6). Together, these additional intentional anthropogenic sources contributed approximately 11% of mortality to the population between 1987 and 2013.

DISEASES AND PARASITES

WILD POPULATION

Brzeski *et al.* (2016, entire) completed a review of the disease factors affecting the wild population and found several diseases and parasites affecting the population or could in the future. Red wolves are more susceptible to heartworms than coyotes (Brzeski *et al.* 2015, p. 6); however, Kelly *et al.* (2004, p. 89) has suggested that red wolf may have a specific adaptation that allows them to survive heartworm infestation. Although all red wolves during their study tested positive for heartworm, it is not known to be a significant source of mortality, as it is for other canids.

While, the most common ectoparasites found were ticks and biting lice (Brzeski *et al.* 2015, p. 6); mange is also considered an important disease that impacts wild red wolf populations, as it has resulted in the deaths of 18 North Carolina wolves and has been documented in 46 other instances where red wolves were treated and released (Brzeski *et al.* 2015, p. 4). Treatment is difficult in wild animals because it requires administering ivermectin to both the infected animal and those it came in contact with (Bornstein *et al*. 2001, p. 116).

Coyotes may act as a reservoir for diseases and parasites. Coyotes have a richer endoparasite community and interaction with red wolves could result in disease transmission to the population. Small, endangered populations such as red wolves are likely to be immunologically naïve and lack the genetic variation to fend off new diseases. Several diseases are common on the landscape and pose a threat to the wild red wolf population including canine distemper, canine parvovirus, and rabies (Brzeski *et al.* 2015, pp. 6-7).

Climate change may exacerbate vector-borne diseases like Lyme disease, which is transmitted by a tick. The bacteria which causes the disease has been detected in several canids (both red wolves and coyotes) in North Carolina (Brzeski *et al.* 2015, pp. 1, 8).

However, all wild wolves are currently vaccinated for canine distemper, parvovirus, coronavirus, parainfluenza, Leptospirosis, adenovirus, Lyme disease, and rabies whenever they are handled. During processing, blood is collected to bank serum and if disease is suspected, a full lab report is ordered (Morse 2017a, pers. comm.). Brzeski *et al.* (2015, p. 7) concluded that potential negative effects of intervention (e.g., long-term negative evolutionary consequences by weakening selection for immunity) are outweighed by the risk of pathogens (which are particularly virulent viruses, like rabies) and treatable conditions like mange, acting in a very small population.

CAPTIVE POPULATION

Seeley *et al.* (2016 p. 83) reported the results of an effort to monitor mortality in the captive population between 1997 and 2012. Among captive wolves, the leading cause of mortality among neonates were parental trauma, stillbirth, and pneumonia. Juveniles showed very low mortality overall during the period of monitoring. The leading cause of mortality in adults were various neoplasias (abnormal cell growths or cancer), and secondarily gastrointestinal disease (often lesions) (Seeley *et al*. 2016, pp. 83, 87). Other causes of mortality included renal disease, trauma, cardiovascular disease, capture-related mortality, and reproductive disease (e.g., pyometra or uterine infection; Seeley *et al.* 2016, p. 85). Seeley *et al.* (2016 p. 87) also found that earlier reports (e.g., 1992-1996) showed that neonates had higher parasite prevalence, however, the decrease in prevalence was likely due to "increased diligence in prophylactic deworming." Overall, they found increased survivability after the first month of life.

FIRE

While wildfires have been incidentally reported to result in mortality of individual wolves, notably pups (Beck *et al.* 2009, p. 636); it is not known to be, and does not seem to currently be, a significant source of mortality in the population. Prescribed fire could potentially have beneficial habitat related impacts, but could also have detrimental impacts if a den is burned or if the burn is conducted in a way that does not allow wildlife to escape. However, we are not aware of either of these potential detrimental impacts occurring within the NEP (Nordsven 2017, pers. comm.).

HURRICANES AND STORMS

In the wild, hurricanes and storms could result in mortality through mechanisms such as wind intensity or flooding. One male wolf died on Bulls Island shortly after Hurricane Hugo in 1989, while the injuries sustained during the hurricane were suspected, it was unclear what caused his death (M. Morse, 2017b, pers. comm.). Two separate hurricanes (Isabel (2003) and Sandy (2012)) have resulted in three captive red wolf deaths (Bartel and Rabon 2013, p. 111); currently, however, this does not seem to be a significant source of mortality. In the future, climate models largely predict a decrease in tropical cyclone numbers, but an increase in intensity for the strongest storms and increased rainfall rates. In addition, sea level rise will likely contribute to increased storm surge risk, though this is also influenced by other factors, as well. (Walsh *et al.* 2015, p. 65, 77). While there are clear increases in intensity of tropical cyclones in the North Atlantic in the previous few decades, the basin is noted for having substantial variability in activity levels across multiple decades (Walsh *et al.* 2015, p. 69).

Walsh *et al.* (2015, p. 72) noted, "Projections are uncertain on whether relative SST [sea surface temperature] (or tropical storm frequency) in the Atlantic basin will increase during the 21st century under GHG [greenhouse gas] forcing. In addition, the role of tropopause temperature trends in observed changes in the PI [potential intensity] appears unresolved, thus reducing our confidence in future projections of this relationship."

SEA-LEVEL RISE AND POTENTIAL HABITAT INUNDATION

WMI (2014, pp. 40-45) summarized information available at the time of the review on climate change effects to the Albemarle Peninsula and future prospects for red wolves. Recently, additional information has further refined understanding of these effects, which are summarized below.

Locally, the North Carolina coast is experiencing land subsidence and rising water levels due to global sea-level rise (North Carolina Coastal Resources Science Panel (NCCRSP) 2015, p. 5; Center for Natural Hazards Research (CNHR) 2008, p. 3). The local rate of sea level rise varies within North Carolina with two main factors: (1) vertical movement of the Earth's surface (e.g., subsidence) and (2) effects of ocean dynamics (oceanographic influences) (NCCRSP 2015, p. 24). Between 1980 and 2010, the GMSL rise in North Carolina increased to 2.5 +/- 0.5 mm/yr (0.1 +/- 0.02 in/yr); the rate of sea level rise north of Cape Hatteras, where the NEP is located, increased significantly, even while rates in areas south of Cape Hatteras decreased or remained stable (Kopp *et al*. 2015, pp. 700-701).

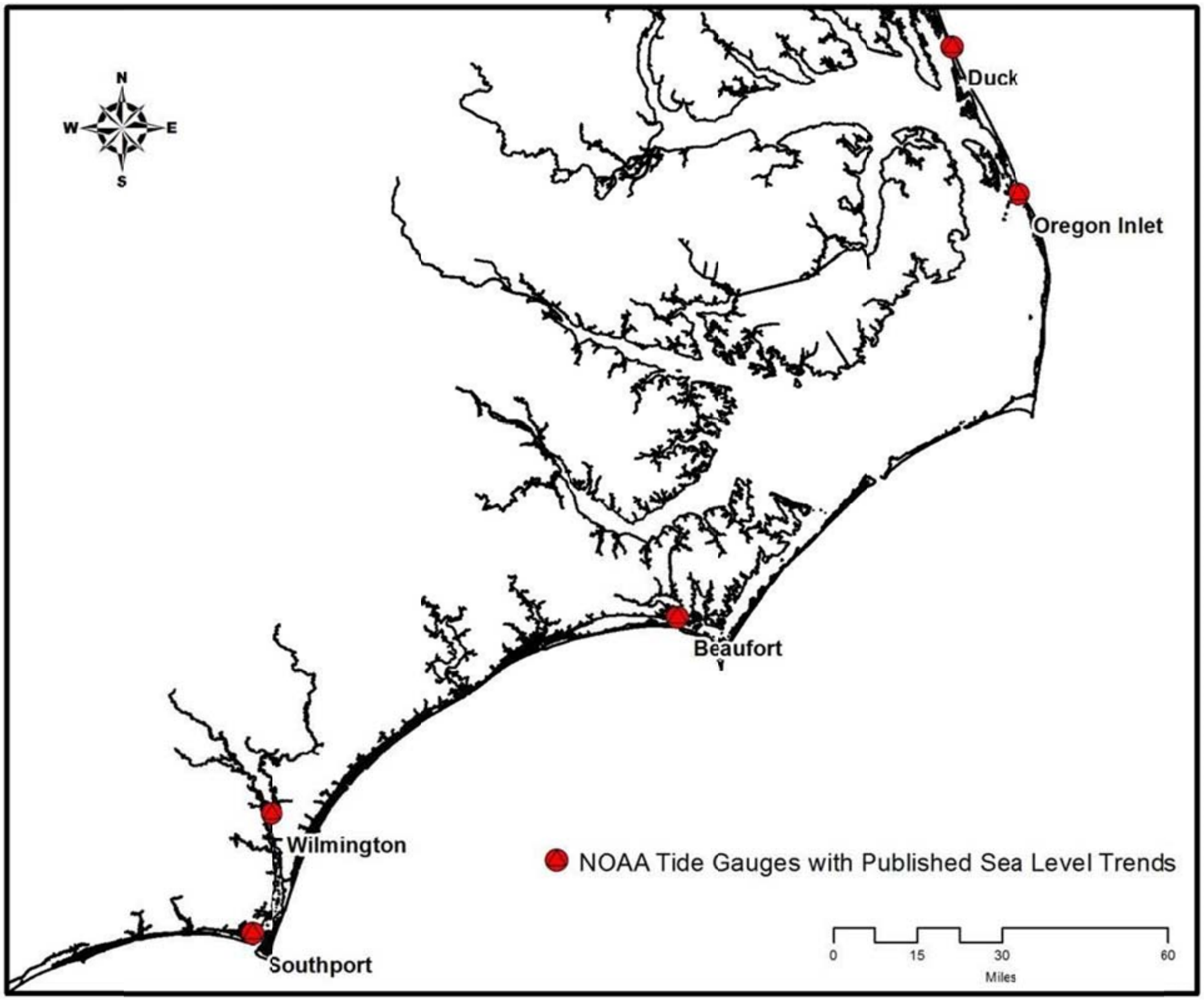


Figure 8. Location of NOAA tidal gauges in North Carolina. Reproduced from NCCRSP 2015, p 12.

Projections of future sea level rise for the NEP were calculated based on the methodology described on p. 10 of this document. In lieu of utilizing the four Intergovernmental Panel on Climate Change (IPCC) projections published in the North Carolina Sea Level Rise Assessment Report (2015): RCP 2.6, 4.5, 6.0, and 8.5, we utilized the empirical data from the NOAA tidal gauges at Duck, Oregon Inlet, and Beaufort (Figure 8) to be conservative in our projections and err on the side of caution; IPCC projections would, in general, result in more substantial flooding. The published vertical land movement (VLM) data and sea level rise data from the NOAA tidal gauges

(Figure 8) were used to determine RSLR at each station within the NEP. The RSLR data was then averaged across the 3 stations to determine the RSLR rate for the area of interest (Table 1).

Table 1. Tidal gauge trend data over several decades (NCCRSP 2015, pp. 12, 15). Lengths are in mm/yr (in/yr). Data used to calculate trends were collected over several years (36, 37, and 61, respectively).

Station	Sea Level Rise Trend	Vertical Land Movement Trend	Relative Sea Level Rise Trend[1]	Mean Relative Sea Level Rise Trend Between Stations[1]
Duck	4.57 (.18)	-1.49 (-0.06)	6.06 (.24)	4.75 (.19)
Oregon Inlet	3.65 (.14)	-0.84 (-0.03)	4.49 (.18)	
Beaufort	2.71 (.11)	-0.99 (-0.04)	3.70 (.15)	

[1] Calculated by USFWS. [2] Sea level rise trend and vertical land movement trend at each gauge were calculated based on data from each gauge during multiple (range 36-61) years prior to 2014.

These data were converted to future elevations by multiplying the mean RSLR rate by the desired target year. This computation assumes that the trends at each gauge will remain the same as historical trends. RSLR 30-year projections (2015-2045) for the NOAA tidal gauges and IPCC RPC lowest and highest scenarios are reported in Table 2 for comparison. The very likely rise at Duck between the years 2000 and 2030 is expected to be 12-33 cm (4.7-13.0 in), with a median of 23 cm (9.1 in); between 2000 and 2050 the rise is expected to be 24-59 cm (9.4-23.2 in) with a median of 41 cm (16.1 in) (Kopp *et al.* 2015, p. 701). This could be abated before the year 2050 by mitigation of greenhouse gases, but only weakly (about 3-6 cm) because sea levels respond slowly to climate forcing; however, reductions in greenhouse gases over the course of the 21st century could significantly affect sea-level rise estimates after 2050.

Table 2. Relative sea level rise 30 year projections determined by NOAA tidal gauges at Duck, Oregon Inlet, and Beaufort compared to the lowest and highest IPCC pathway projections, RCP 2.6 and RCP 8.5 respectively (NCCRSP 2015, p. 25).

Station	NOAA Mean Tidal Gauge Projections + VLM[1] in cm (inches)	IPCC RCP 2.6 Mean + VLM cm (inches)	IPCC RCP 8.8 Mean + VLM cm (inches)
Duck	18.3 (7.2)	18.0 (7.1)	20.6 (8.10)
Oregon Inlet	13.5 (5.3)	16.0 (6.3)	18.5 (7.30)
Beaufort	11.2 (4.4)	16.5 (6.5)	19.1 (7.50)

[1] Projection used by USFWS.

The RSLR projections do not account for storm events, flooding frequency and duration, changes in coastal geomorphology, wind pattern shifts, tidal variations, or man-made alterations. The aforementioned events, while influential to coastal processes, are speculative and could lead to significantly variable outcomes when determining what the landscape may look like in 125 years.

However, while not combined in these projections, flooding could still be a significant issue. As previously noted by WMI (2014, p. 40) the Albemarle Peninsula experiences significant erosion and much of it is less than one meter (3.28 ft) above sea level, while the remaining two-thirds is less than 1.5 meters (4.9) above sea level. In addition, Poulter and Halpin (2007, pp. 12-13) found that the drainage systems (e.g., canals and ditches) in the low near-shore environment would worsen flooding at lower levels of sea-level rise (<0.4 m (1.3 ft)), given the topographical complexity, as they could water to reach areas via ditches which otherwise might not flood.

Recently, NCCRSP updated the 2010 Report and 2012 Addendum on Sea Level Rise in North Carolina. The panel concluded, “If existing conditions continue for the next 30 years, sea level would be expected to rise between approximately 5 – 15 cm (2 and 6 in) across the North Carolina coast, with the highest sea levels expected north of Cape Hatteras. This computation assumes that the trends at each gauge will remain the same as historical trends over the 30-year time frame,” (NCCRSP 2015, p. 16). Regardless of the rate of rise, increased flood events and frequent flooding in low-lying areas should be expected as the sea level rises (NCCRSP 2015, p. 25; Kopp *et al*. 2014, p. 7; Kopp *et al*. 2015, p. 705). Ezer and Atkinson (2014, p. 380) note that the U.S. East Coast (most specifically the coastal area north of Cape Hatteras along the mid-Atlantic) is a “hotspot of accelerated flooding” and that minor flood duration is highly correlated with acceleration in sea level rise. Therefore, both frequency and duration of flood events is expected to worsen with sea level rise.

To calculate the inundated area of NEP, we applied the calculated mean RSLR (Table 1) to the analysis area which returned the area remaining above MSL. The 5 counties that constitute the NEP currently encompass 1,622,152 acres of emergent land. Relative sea level rise projections reduce total emergent lands in the 5 counties from ~1,622,152 acres to ~1,223,806 acres in 125 years representing a 24.5% loss of land above mean sea level (MSL). The East side of the NEP area experiences the most significant effects of RSLR, with respect to inundation, as illustrated by the RSLR maps at current MSL and MSL in 125 years (Figures 9 & 10).

In a 2016 memorandum (see p. 9), the USFWS recommended reducing the focus of the NEP to federal lands within Dare County. To assess the impacts of sea level rise for this potential scenario, we calculated the inundated area of federal lands within Dare County. The federal lands within Dare County account for ~168,943 acres (10.4%) of the emergent land which would be reduced by 44.5% to ~93,828 in 125 years due to RSLR (Table 3) (Figures 11 & 12).

Table 3. Square kilometers (Acres) above MSL (Mean Sea Level) by [1]County, Federal lands, and [2]Outer Banks for the NEP.

Target Year	Beaufort	Beaufort (south of bridge)	Dare	Hyde	Tyrrell	Washington	Federal Lands (Dare County)	Outer Banks
0	1288.9 (318,502)	830.4 (205,203)	730.0 (180,384)	1503.1 (371,412)	994.5 (245,743)	962.1 (237,732)	683.7 (168,943)	255.7 (63,176)
25	1286.8 (317,986)	828.5 (204,721)	719.9 (177,894)	1445.0 (357,062)	985.9 (243,633)	958.4 (236,820)	675.5 (166,912)	252.6 (62,417)
50	1277.3 (315,635)	822.4 (203,218)	693.0 (171,247)	1345.0 (332,366)	951.7 (235,169)	948.2 (234,304)	653.2 (161,399)	245.1 (60,557)
75	1258.3 (310,924)	810.4 (200,256)	622.2 (153,754)	1194.4 (295,141)	841.7 (207,988)	932.6 (230,462)	590.4 (145,882)	228.0 (56,333)
100	1239.6 (306,323)	798.7 (197,357)	510.9 (126,246)	1023.7 (252,965)	704.2 (174,000)	918.3 (226,919)	488.5 (120,711)	208.0 (51,405)
125	1222.0 (301,960)	788.2 (194,768)	394.2 (97,418)	865.9 (213,974)	591.2 (146,132)	905.4 (223,739)	379.7 (93,828)	185.4 (45,815)

[1] County totals are independent of Outer Banks

[2] Outer Bank totals consist of only Dare and Hyde County properties

We recognize that there is a high degree of uncertainty with these projections, especially beyond 50 to 75 years into the future. However, these scenarios are presented here not as certain to occur but as an indicator of possible trend.

Regardless of the pathway of future emissions, Kopp *et al*. (2015, p. 701) indicates that it is virtually certain (*Probability* >0.998) that both Wilmington and Duck will experience a rate of sea level rise over the 21st century and very likely (*Probability* > 0.90) that the rate of that rise will exceed the rate observed during the 20th century. Overall, uncertainty in North Carolina's projected rate of sea level rise comes from two primary sources: oceanographic and Antarctic ice sheet responses to climate change, the former contributing the larger source of uncertainty through most of the century (Kopp *et al*. 2015, p. 702).

Figure 9a. Analysis boundary and current MSL for the NEP area.

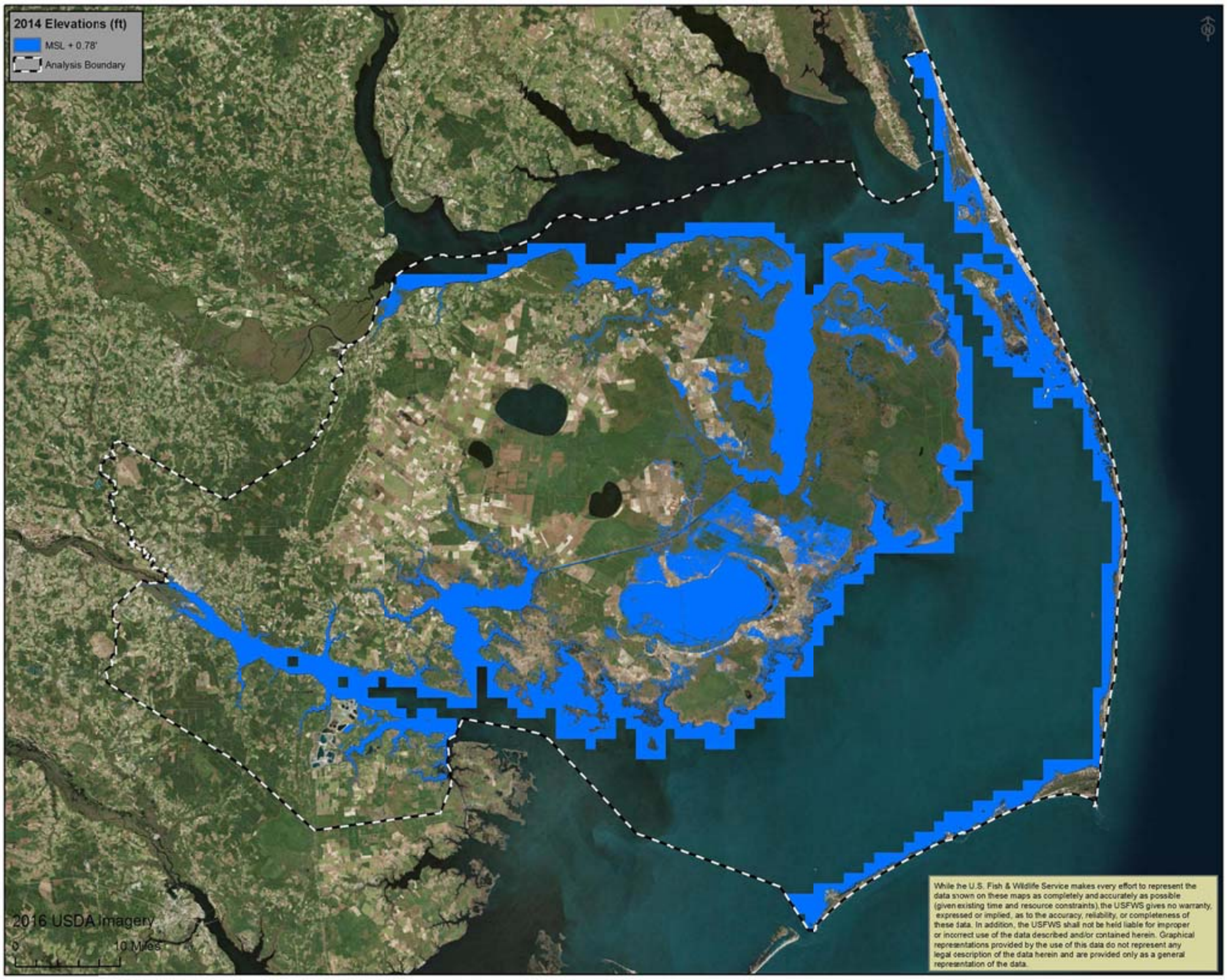


Figure 9b. Analysis boundary at 50 years MSL for the NEP area.

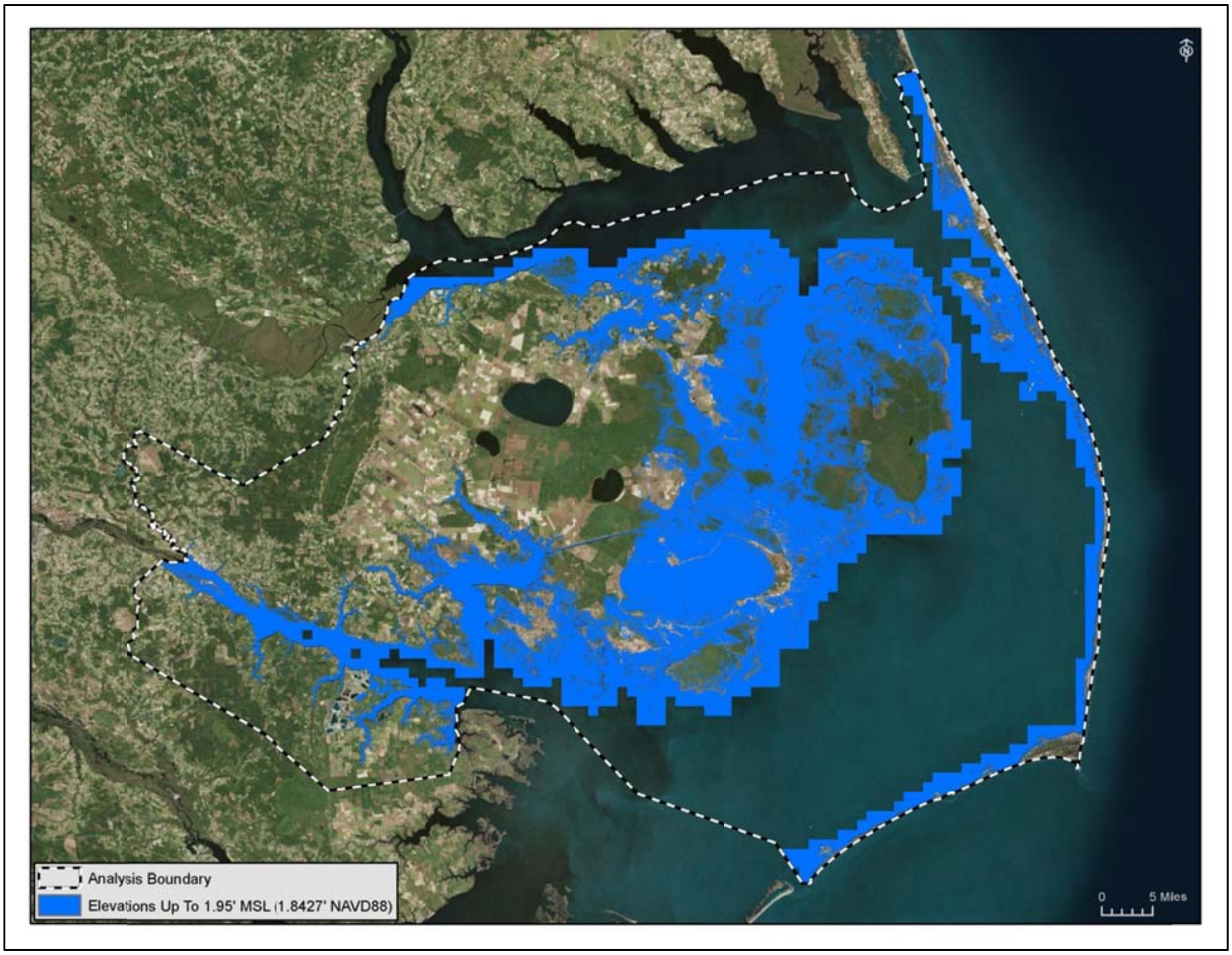


Figure 10. Analysis boundary and MSL in 125 years for the NEP area.

Figure 11. Analysis boundary and current MSL for the federal lands in Dare County.

Figure 12. Analysis boundary and MSL in 125 years for the NEP area.

PUBLIC PERCEPTIONS

A recent survey was conducted by Responsive Management, Inc. (2016, p. *ii*) between July and September 2016 and obtained 2,577 total completed surveys, including 2,420 for landowners and 157 for renters on the Albemarle Peninsula. The survey was done for the North Carolina Wildlife Resources Commission, "to determine the perspectives and views of residents and landowners of the Albemarle Peninsula regarding coyotes and red wolves, the management of those species, and the Red Wolf Recovery Program," (Responsive Management, Inc. 2016, p. *i*).

Results from the survey indicated that 44% of respondents agreed that coyotes were non-native to the peninsula, while only 28% agreed that red wolves were native to North Carolina (Responsive Management 2016, p. viii). When asked whether they agreed or disagreed that there should be more red wolves on the Albemarle Peninsula, 50% of respondents disagreed, while only 21% agreed (Responsive Management, Inc. 2016, p. *iii*). While generally 32% of residents supported and 39% oppose having wild red wolves on the Albemarle Peninsula (Responsive Management, Inc. 2016, p. 253), support was variable under specific scenarios (seventeen were presented). Among these were: it becoming easier to distinguish a wolf from a coyote (51% support), hiring a full-time staff person to engage landowners, answer questions, and resolve problems (53% support), and if landowners could kill a red wolf or coyote at will, without a permit, as long as it was reported (47% support) (Responsive Management, Inc. 2016, p. 253). Respondents were also split on potential futures of the recovery program in the state ranging from termination of the program to expansion with new incentives for landowners (Responsive Management, Inc. 2016, p. 253). Overall, the perspectives were quite varied and demonstrate that both support and opposition for the species and the program exist on the Albemarle Peninsula. It is important to note that specific impressions of subgroups can show different degrees of support or opposition in public opinion studies (meaning all members of a subgroup may not be equally in favor or opposed to a specific position), as illustrated in Bruskotter *et al*. (2007, p. 215, entire).

Although the numbers of coyotes and red wolves in these counties favor seeing and interacting with a coyote, half of all hunters surveyed agreed that red wolves reduce small game levels to unacceptable levels and 38% agreed red wolves reduce deer (*Odocoileus virginianus*) numbers to unacceptable levels. Sixty-four percent of hunters agreed that coyotes reduce small game populations and nearly half (49%) agree they also deplete deer numbers to unacceptable levels (Responsive Management 2016, pp. ix-x).

In another public opinion survey conducted for gray wolves, Treves *et al*. (2013, p. 315) found that over time their 656 survey respondents showed increased agreement with statements about wolves competing with hunters for deer, fear of wolves, and inclination towards poaching a wolf. WMI (2016, p. 90) concluded in the program review completed in 2014, that there was "potential for decreasing support for wolf conservation within the red wolf restoration area and continued negative population impacts from poaching."

CARCASS USE, DUMPING, AND CARNIVORE USE OF AGRICULTURAL AREAS

There is evidence in the literature regarding the use of carcass and garbage dumps and gut piles as food sources for red wolves (Dellinger *et al.* 2011, p. 738). Globally, across numerous studies, predators have been shown to alter home range size and activity in response to a subsidy (anthropogenically-supplied food source) (Newsome *et al.* 2015, p. 5). Red wolves choose habitats similar to their natal habitat (Karlin and Chadwick 2012, p. 266). While we have seen evidence of wolves in North Carolina using a livestock carcass pit, there were no similar features (e.g., large carcass pits) in the surrounding landscape for natal dispersers to select outside of their natal territory. It should be noted that coyotes would also be attracted to concentrations of prey and carcasses and young wolves are often confused with coyotes.

In general, wolves avoid direct interaction with humans, particularly where they are hunted or harassed. Agricultural areas in eastern North Carolina have provided deer herds and small mammal populations such as rodents, raccoons and rabbits, with a ready food source for many years. For the past two decades wolves have used these concentrations of prey and some packs have focused their annual activities near agricultural areas on the peninsula. While these areas provide ready prey and potentially carcasses of both deer and livestock, they also increase the likelihood of interaction with humans, which increases risk of human-wildlife conflict and further interaction with coyotes. Like the gray wolf (and as was seen in the GSMNP) availability of livestock may increase human-wolf conflict as wolves are drawn into areas of vulnerable prey.

DEVELOPMENT

At present, development does not appear to have contributed to declines in red wolf populations in this area (refer to map depicting development levels in 2010 on pp. 67-68 below). Development potential in the future may become more relevant if habitat is limited by another factor (e.g., SLR), which drives wolves into areas more heavily used by humans or in areas where the “placeholder” strategy is not implemented to limit introgression with coyotes.

“Coyotes readily adapt to suburban and urban environments once thought unsuitable and they exhibit great plasticity in their behavior and diet… They are naturally wary of people and will avoid areas in which threats are perceived. They will also become acclimated to humans in the absence of threats, such as hunting and trapping, and in areas where typically unnatural food, such as pet food, garbage and unsupervised small pets, are readily available,” (NCWRC 2012, p.15). One study found coyote densities were eight times higher (2.4 -3.0 individuals/km^2) in an area with more urban and residential cover than an area with <2% urban and residential coverage, when 14-25% of food items were anthropogenic in origin (Fedriani 2001, p. 329). Their adaptability and plasticity in using resources associated with human-dominated areas could favor their continued presence in urban and residential areas.

Although competition and hybridization, and resulting introgression, with coyotes are substantial concerns for the survival of red wolves, we note that red wolves can and often do outcompete coyotes for the best available habitat. Red wolves are larger and stronger. Evidence on the

Albermarle Peninsula has shown many red wolf packs, when left alone, sustained themselves quite well without coyote introgression and with minimal, if any, management interference.

SUMMARY

While a variety of factors have resulted in documented mortality to red wolves, the primary factors affecting the future viability are anthropogenic mortality (in wild populations), introgression (in wild populations), and inbreeding depression (captive and wild populations). In addition, in time, sea level rise may limit available habitat on the Albemarle Peninsula and development could limit further westward expansion.

It is important to emphasize that many factors affecting the species in North Carolina have been managed through various management strategies (see discussion on pp. 13-14, 34-35) within the recovery program (either in the NEP or the SSP). The interventions have been implemented to maintain purity of the genetic stock and ensure survival of wolves both in the SSP and the NEP. However, some factors have proven particularly difficult to control. The RWAMWP (USFWS 2013, entire) appeared in 2015 to be effectively limiting genetic introgression (< 4% coyote ancestry from introgression since the reintroduction began) into the red wolf population, though hybridization is seen as an ongoing challenge (Gese *et al.*, 2015, pp. 191, 200).

At present, in the North Carolina NEP, the birth rate is not sufficient to overcome the losses to mortality. This situation is further aggravated by introgression, which effectively reduces births of pure red wolves. There are now insufficient unrelated red wolves to replace lost breeders and therefore, the population cannot recover from their losses and overcome mortality resulting in a steadily declining population.

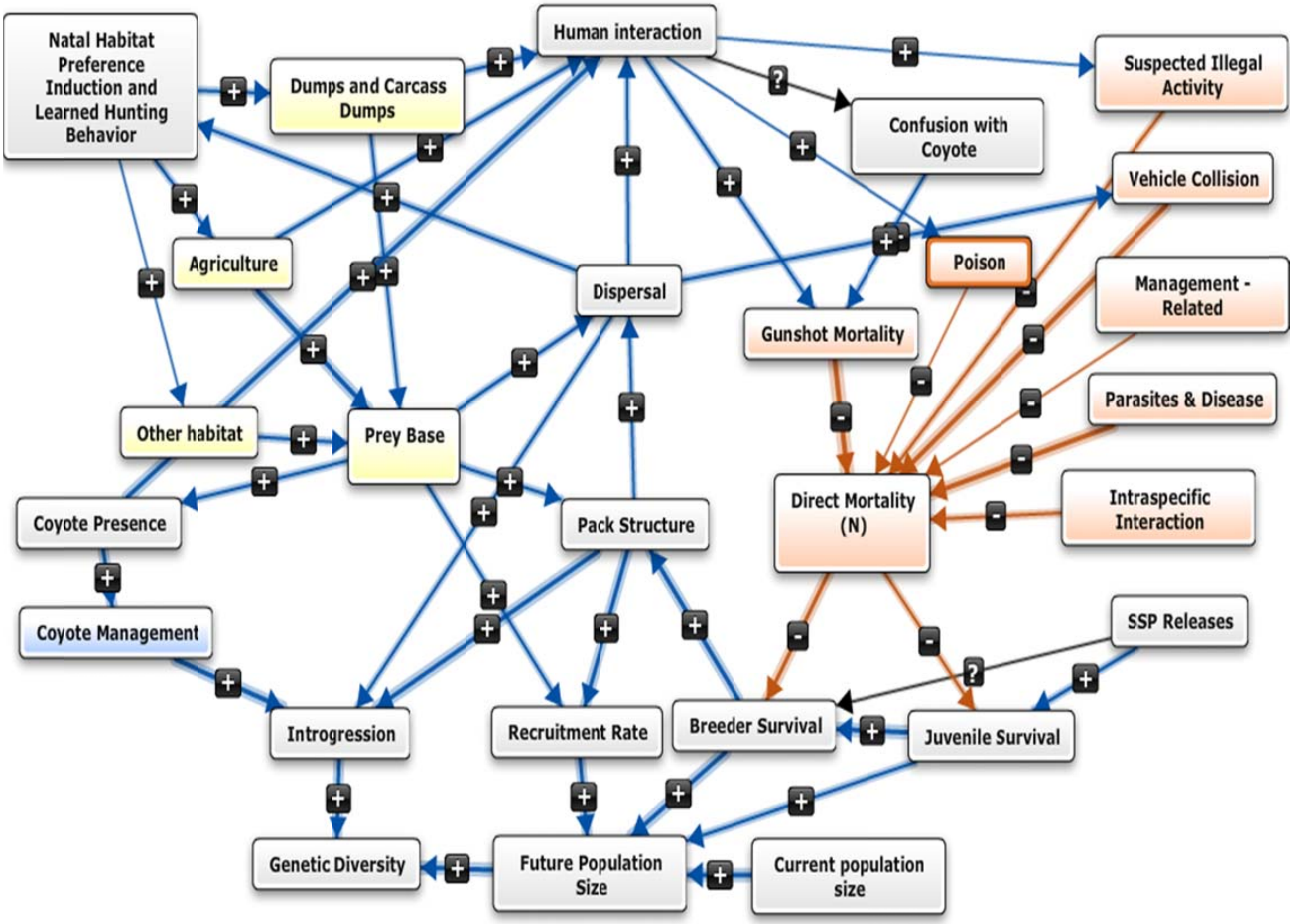


Figure 13: Factors affecting red wolf population resiliency.

CHAPTER 6. SPECIES VIABILITY

We have considered what the red wolf needs for viability and the current condition of those needs (Chapters 3 and 4), and we reviewed the factors that are driving the historical, current, and future conditions of the species (Chapter 5). We now consider what the species' future conditions are likely to be.

INTRODUCTION

Despite attempts to re-establish the species at several locations, the reintroduction effort initiated in eastern North Carolina in 1987 with four males and four females is the only remaining wild population. The extant population is affected by a variety of factors, but most importantly, anthropogenic mortality and coyote introgression, which act synergistically to further reduce an already very small population (approximately 44 individuals).

Faust *et al.* (2016, p. 5) defines the two subpopulations in the model as the SSP (captive stock) and NEP (reintroduced population located in North Carolina). As noted previously, the model was created using Vortex 10.1.4.0 software, which is a widely-used population viability assessment tool. "The model is individual-based, meaning it tracks every animal (current and future) in the population over time. After being initiated with the starting population, the model steps through an annual event cycle (e.g., births, transfers between subpopulations, deaths, aging, censusing) for all individuals" (Faust *et al.* 2016, p. 5). For both subpopulations, each animal is individually identified and tracked using an electronic database (Studbook) maintained using PopLink 2.4. This database contains both the genetic history and demographic information of the population (i.e., births, deaths, transfers between zoos or from the captive stock to the wild, and pedigree back to the original founders (Waddell 2015, [entire; herein a reference to the report generated from the Poplink 2.4 Studbook software cited elsewhere in the document as Faust *et al.* 2012, entire]). USFWS databases provided additional information on the NEP subpopulation. The Vortex model was parameterized using data from those datasets (Faust *et al.* 2016, pp. 5-6).

In the Faust *et al*. 2016 model (p. 7), the NEP carrying capacity of 150 was based on "… a previous estimate by USFWS (Kelly *et al*. 1999) of the potential number of individuals that could be held at the original reintroduction site of Alligator River National Wildlife Refuge if the population had access to the whole landscape of the 5-county NEP area. In the past the maximum estimated population size was 148 individuals, and when at that size there was not strong observed intraspecific competition or density-dependent effects, so the population was likely not truly at ecological K [(K meaning carrying capacity; ecological K meaning the maximum number of wolves the environment could sustain indefinitely) Gese *et al*. 2015; Hinton *et al*. in review)]. However, for the model 150 was chosen as a cap that the population would likely not be able to exceed." The carrying capacity used for the SSP was 225, which was noted as the population size that could be supported with spaces in the SSP at the time the modelling was done.

Typically, a PVA is run many times because any one simulation (which incorporates random events) may be an anomaly, either higher or lower than the median value of many model runs. The PVA completed by Faust *et al.* (2016, entire) used 1000 iterations (or runs of a model scenario) and reported mean values for genetic diversity (GD), inbreeding coefficient (F), and number in the population at 125 years (N), as well as probability of extirpation and the probability of maintaining 80% GD (i.e., based on the % of the 1000 iterations that hit those thresholds (extirpation, or final GD>80%)). It is important to note that 1000 iterations were found to be enough to achieve stable, repeatable results and calculate variance for each scenario. There was variability associated with these values because of the stochastic nature of the model dynamics and this variability reflects a range of possible future outcomes for a model scenario (Faust *et al.* 2016, p. 13). To look at effects of single or groups of parameters, most parameters are held constant, while one or more of the parameters are manipulated.

CAVEATS TO THE ANALYSIS:

The PVA used starting population sizes as of 1 January 2015, but the wild population experienced subsequent declines. Therefore, the following summaries of model outputs are qualified by explaining that qualitatively, the outcomes and trajectories reported are still expected and useful in comparing between different scenarios, but given the smaller population size an increased risk of stochastically-driven dynamics. Specific model runs would be expected to vary more widely around the projection lines established by the model. In addition, spatial and pack dynamics values aren’t addressed specifically in the model, and there could be more variation driven by these factors if population sizes and dynamics change further at low numbers of packs. J. Simonis noted that based on experience with multiple previous modeling efforts that the strength of interventions modeled in the PVA would be expected, even at presently lower population numbers, to be enough to overcome the noise (variation) in each projection and would achieve the same overall trajectories as reported in the existing model report (J. Simonis 2017b, pers. comm.).

Overall, due to the impact of anthropogenic mortality and the continuing increase in mortality rate of wild red wolves, all model scenarios that involve the NEP would now be expected to result in shorter times to extirpation or slightly lower projected population sizes. As numbers decline in the wild population and breeders are lost, remaining breeders have increasing difficulty finding suitable (i.e., red wolf) mates, resulting in increasing introgression by coyotes and a resultant loss of red wolf genes in the wild.

Certainly additional, more complex modeling could be useful, however there are trade-offs in all modelling efforts between realism and predictive capability. Vital rates associated with the wild population were used for projections (of NEP outcomes) and while not all sources of uncertainty were incorporated (e.g., pack structure effects), many were (e.g., environmental variation, catastrophes, proportion of females in the breeding pool, female breeding success, litter size, and offspring sex ratio). In addition, many scenarios were run to compare potential management choices to each other and model validation efforts were made to ensure input values and model setup were valid (Faust *et al.* 2016, pp. 6-12). The overall goal of this modelling effort was to predict outcomes for the metapopulation (i.e., species) both in terms of overall numbers and genetic outcomes. Vortex was an appropriate choice for this effort. As noted by Feiburg and Ellner (2000, p. 2046) PVA models “may be useful for comparative evaluation of different management scenarios via computer simulation.” Therefore, as noted, by Faust *et al*. (2016, p. 4) it may be most appropriate to, “compare between scenarios (e.g. relative to each other) rather than as absolute predictions of what will happen." The timeframes used in the model were guided by the 1990 recovery plan which stated a goal of maintaining 80% genetic diversity in 150 years (125 years from the start of the model), but are appropriate to this species for several reasons: this species has a multiple year life-span; not all adults in the population breed each year; with low population numbers interventions may take decades to result in viability of populations, and these are not point estimates, but trajectories, which have been run long enough to achieve stability and report variances. We acknowledge significant uncertainty exists about the future (e.g., will carrying capacity of the peninsula change due to human land use or habitat loss), especially over these timeframes, but this modeling effort which was conducted prior to the development of the SSA constitutes the best available science and an appropriate modeling tool for the scenarios of interest to the SSA development team.

SCENARIOS:

Faust *et al.* (2016, entire) modeled a wide variety of scenarios related to the SSP and NEP including a baseline scenario that includes no releases, recovery on federal lands only, termination of the NEP, increases in the SSP capacity, and various changes to NEP demographics among others. These scenarios provide substantial insight into possible futures of the SSP and the only wild population.

In general, various scenarios explored a range of conditions by considering differing levels of: movement of wolves between SSP and wild population, mortality rates, the fraction of females given the opportunity to produce a litter (% breeding), and SSP capacity. Some parameters do not change in most model runs. These values often represent either best practices established over program history or in the field (e.g., genetic management in the SSP) or parameters associated with the biology of red wolves and data collected over the history of the program (e.g., litter size, sex ratio of offspring, reproductive system, effects of inbreeding on demographic parameters). Some of the parameters which remain constant in most scenarios (except model validation scenarios) include: rate of catastrophes affecting the NEP (2.9% annually with 50% reduction in survival in NEP); model timeframe (125 years); initial population (SSP = 201; NEP = 74); reproductive system (i.e., long-term monogamy); carrying capacity of the NEP (N=150), among others (Faust *et al.* 2016, pp. 6-8). For a full explanation of all model parameters considered and detailed descriptions of each scenario and its parameter values, please refer to Faust *et al.* 2016 (entire). Here we summarize and explore several scenarios presented in their analysis, for detailed descriptions of each model scenario refer to Appendix 2.

BASELINE SCENARIO

Under the baseline scenario, the NEP and SSP are uncoupled and no further releases to the wild occur. This scenario gives us a picture of what happens without the SSP's input to the remaining wolves on the ground in North Carolina. Faust *et al.* (2016, pp. 15-17) projected that the NEP would reach extirpation P(E) = 100% in a median time of 37 years, though some iterations were extirpated in as few as eight years (refer to Figure 14 below). Based on a carrying capacity of 225, the SSP as modeled was able to maintain its current population size and have a 65.7% chance of maintaining the recovery goal of 80% GD, which would have to be carried by the SSP since the NEP is expected to go extirpated in the near-term.

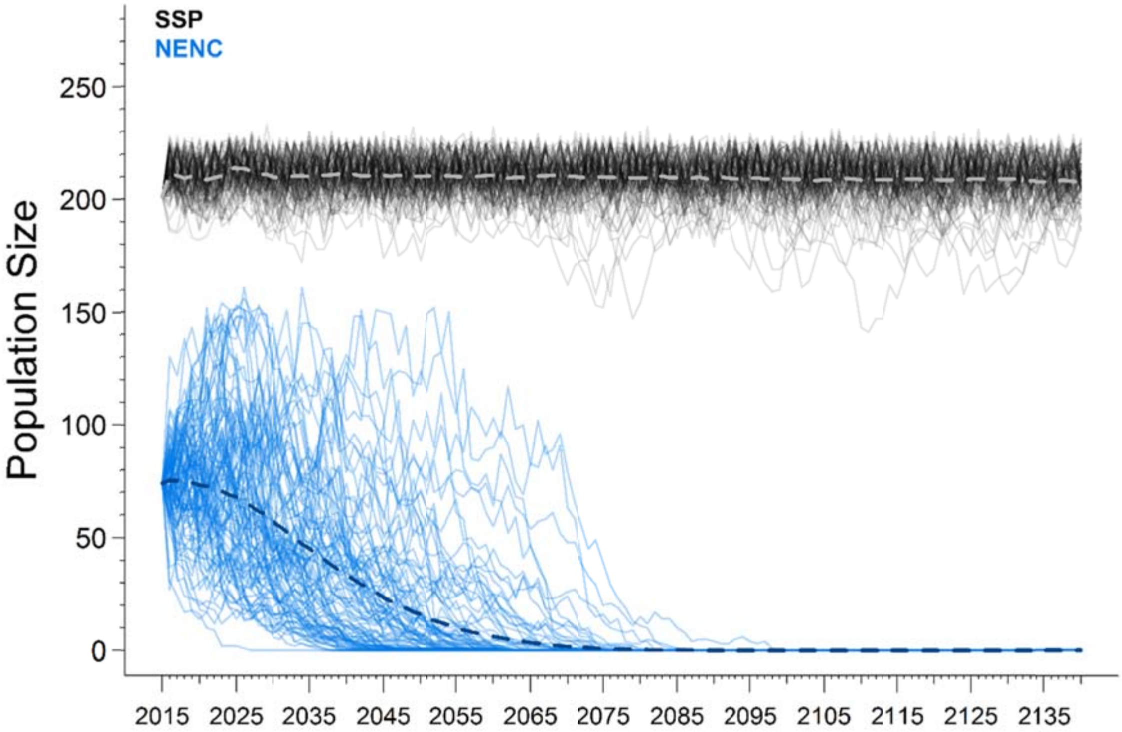


Figure 14: Baseline PVA model results for a sample of 100 iterations. Dashed line represents the mean model trajectory over 1000 iterations (reproduced from Faust *et al.* 2016, p. 15; "NENC," used by the authors, refers to NEP).

SCENARIOS WHICH ALTER DEMOGRAPHICS OF THE NEP

Present growth of the NEP is limited because birth rates are not overcoming mortality rates. Several scenarios examined by Faust *et al.* (2016) examined improving vital rates to explore whether growth of the population was possible, even in the absence of releases from the SSP. According to their modelling effort, improvements to mortality rates and reproductive rates could potentially slow the decline, but would need significant adjustment to ensure persistence of the population in the future. While changes to mortality rates have the greatest impact of any single variable on outcomes (greater than reproductive rate and coyote impact); changes to mortality and reproductive rates would not guarantee a sustainable population (refer to Figures 15 and 16 below) due largely to the long-term effects of inbreeding depression (Faust *et al.* 2016, p. 18).

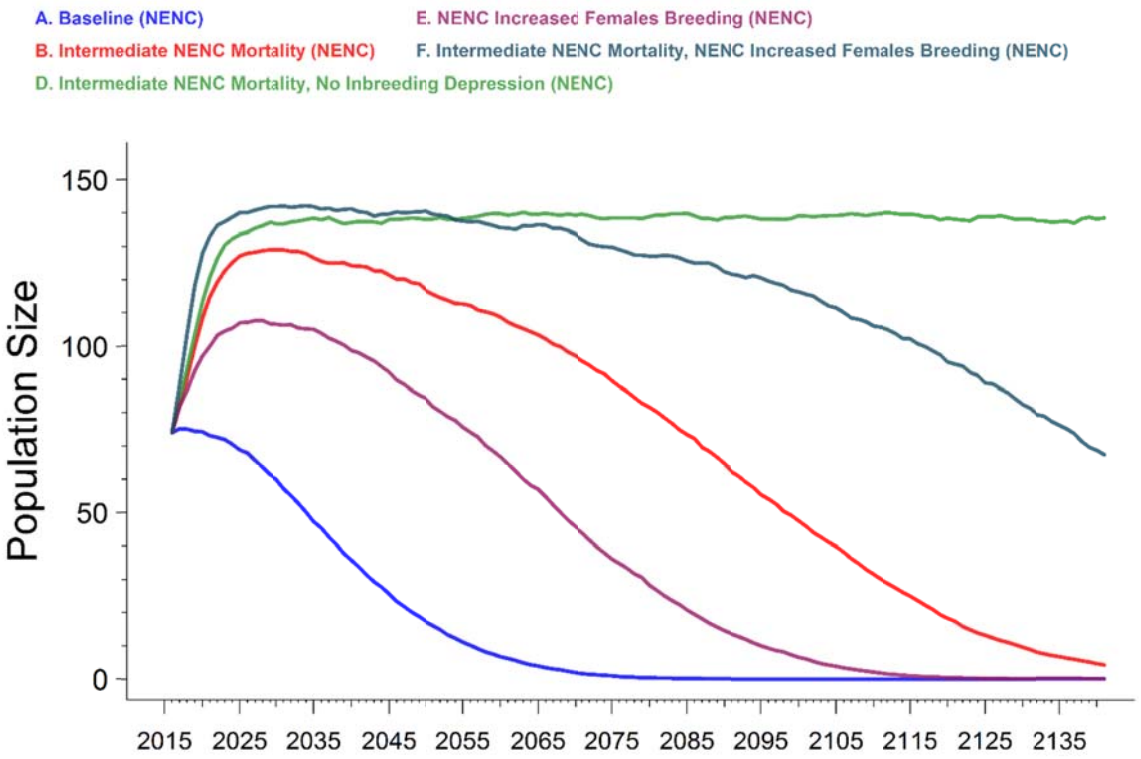


Figure 15: Projected Mean Population Size of NEP with Various Demographic Rate Changes (reproduced from Faust *et al*. 2016, p. 18; “NENC,” used by the authors, refers to NEP)

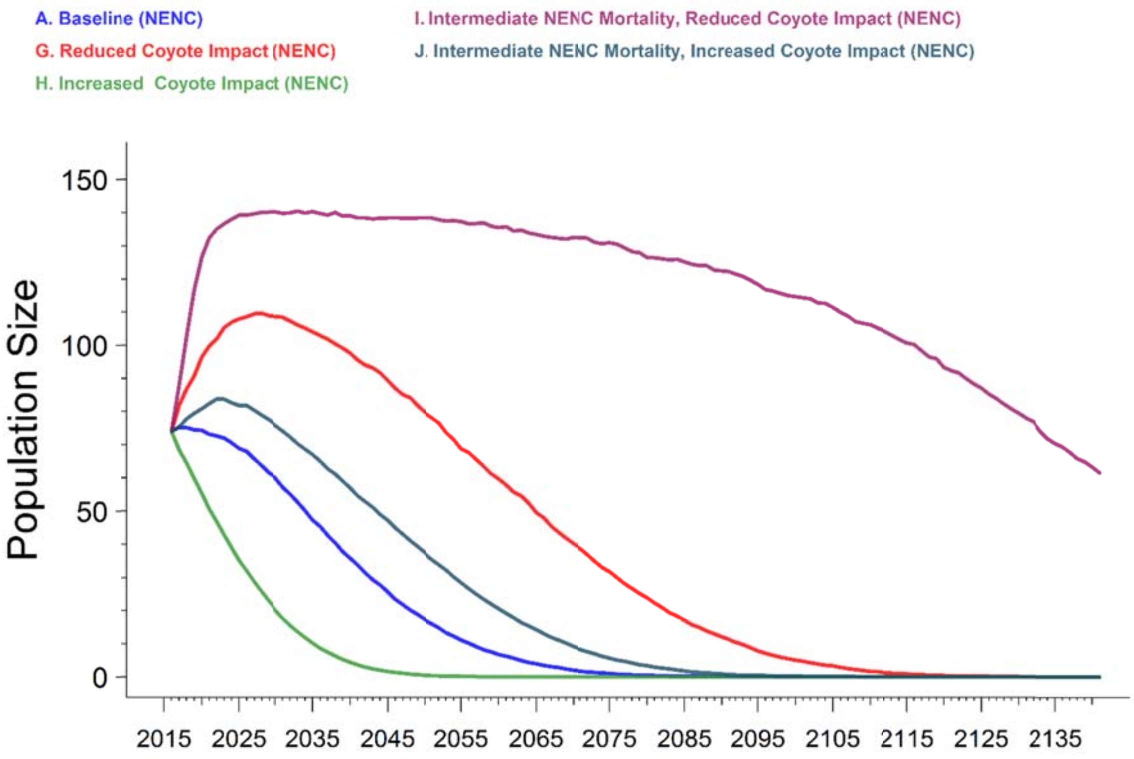


Figure 16: Projected Mean Population Size of the NEP with Coyote Impacts and Various Demographic Rate Changes (reproduced from Faust *et al.* 2016, p. 19; "NENC," used by the authors, refers to NEP)

SCENARIOS WHICH ALTER SSP PARAMETERS (NO RELEASES)

Additional space and improved breeding rates within the SSP have the potential to improve genetic and demographic outcomes. The SSP needs to increase births to avoid a decline. Increased breeding could create a demographically stable population. Increasing the population to 330 or 400 does not result in different demographic outcomes, but would improve genetics, raising the probability of reaching the genetic target P(80GD) from 65.7% (current carrying capacity of 225) to 80% (at 330) or 88.5% (at 400). Increasing capacity while improving breeding success from 19% of paired females being successful to 25% would further improve P(80GD) to 88.3% at 330 spaces or 91.3% at 400 spaces and would further lower inbreeding values from an F = 0.1477 ± 0.0459 (330 spaces) to 0.1426 ± 0.0423 (400 spaces) (Faust *et al.* 2016, p. 20).

It should be noted that a carrying capacity for the SSP of 400 was modeled as it represented "a round number large enough to ensure (with >95% prediction probability) that the SSP population would be larger than 330 individuals in the year 2140," (which was the target set by the 1990 recovery plan (USFWS 1990, entire)), (Simonis 2017a, pers. comm.).

SCENARIOS WHICH PROVIDE RELEASES AT CURRENT CAPACITY

Releasing 3-4 animals per year to the NEP would allow the wild population to avoid extirpation, but is not enough alone to create a viable population without other changes (refer to Figure 17 below).

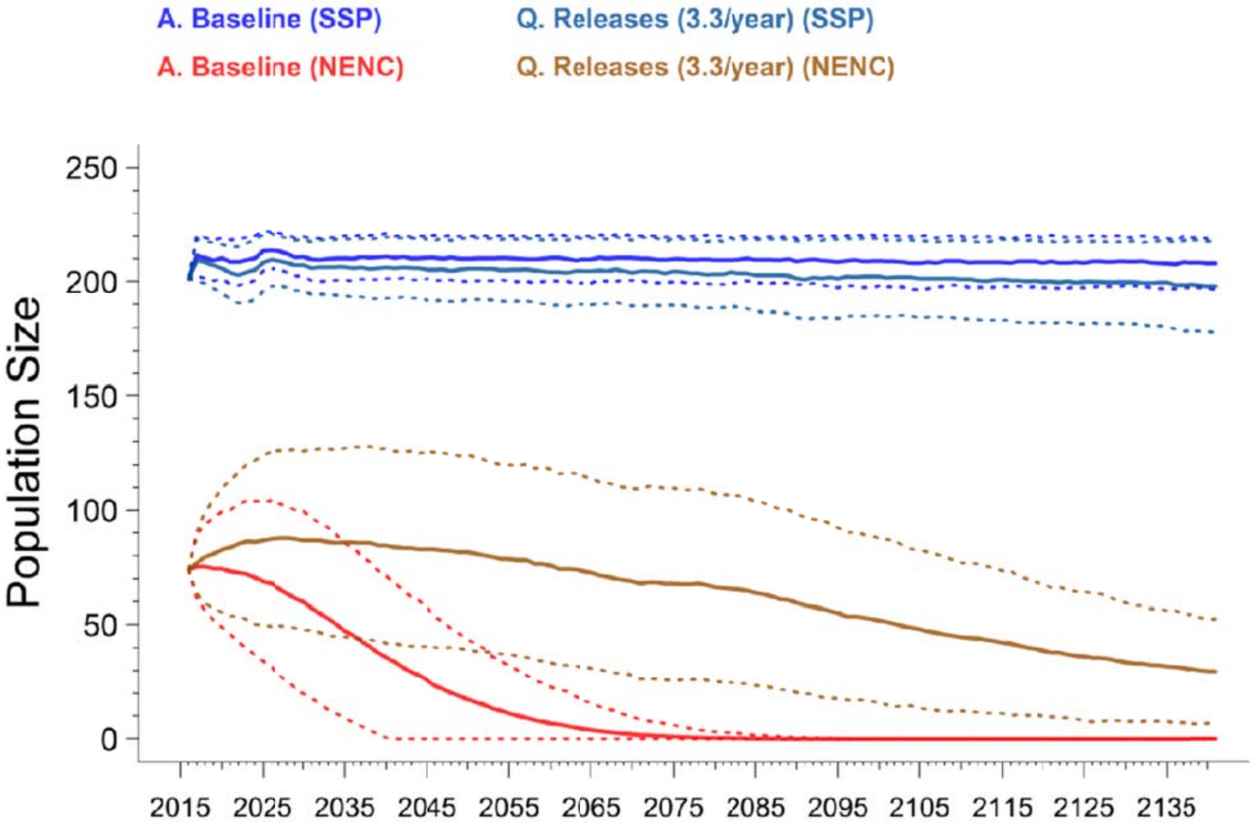


Figure 17: Projected Mean Population Sizes for the SSP and NEP with Releases at Current Capacity (reproduced from Faust *et al.* 2016, p. 21; "NENC," used by the authors, refers to NEP) *Means are represented by solid lines; dashed lines illustrate one standard deviation in each direction (minimum at 0) across 1000 iterations of the model.

SCENARIOS WHICH GROW CAPACITY OF THE SSP AND PROVIDE RELEASES

Several scenarios evaluated different levels of capacity (number of spaces) in the SSP, with regard to providing for annual releases (using average number from 2005-2014). Under the scenarios which just grew capacity (refer to Figure 18 below), "[NEP] still experiences a demographic drag on its population as inbreeding starts to accumulate under these scenarios, which translates into the differences in population size; that drag is much less if the SSP is larger with more breeding," (Faust *et al.* 2016, p. 24).

In general, adding space to the SSP allows it to retain higher GD while providing for releases, as well as remaining demographically strong. In fact, adding space and increasing breeding to 25% allows the SSP to retain the highest GD and be the strongest source population for the NEP. It should be noted that it would be difficult to grow the captive population while providing for releases without increases in breeding success (Faust *et al.* 2016, p. 22).

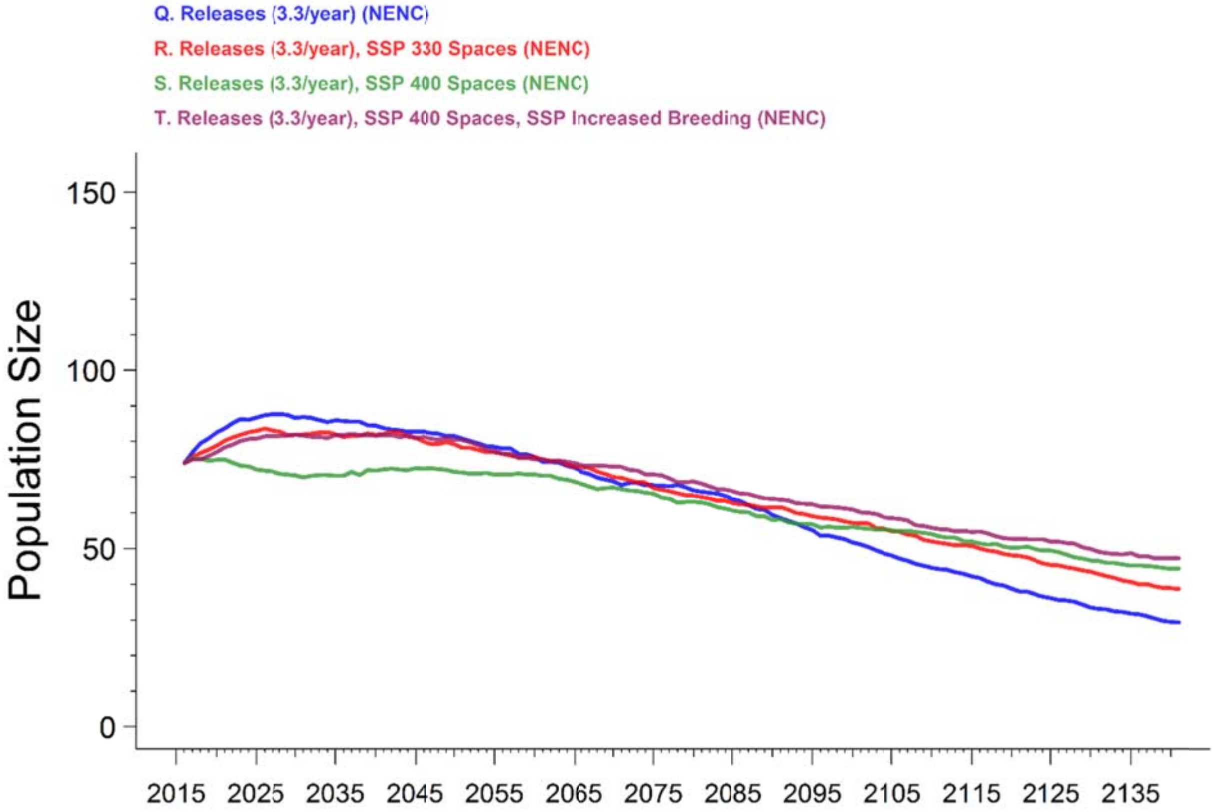


Figure 18: Projected Mean Population Size of NEP with 3.3 Releases/Year and Changes to SSP Capacity (reproduced from Faust *et al.* 2016, p. 24; "NENC," used by the authors, refers to NEP)

SCENARIOS WHICH PROVIDE FOR RELEASES AND IMPROVE DEMOGRAPHICS OF THE NEP

Several scenarios were evaluated which changed mortality rates in the NEP or the timing of mortality to increase breeding, while providing for releases. In general, each of these assumed 3.3 animals released per year, but one also considered a reduction in NEP mortality, one modeled increased NEP breeding, one looked at both of these, and two looked at these with intense releases in the first 15 years and then intermittently (i.e., every 5 and 20 years, respectively) afterwards.

The first three scenarios (releasing 3.3 animals annually combined with decreased mortality, improved breeding or both) would ultimately create a sustainable wild population in the NEP with approximately 100 or more individuals (refer to Figure 19 below). Additionally, changes in mortality have a greater impact than changes to breeding in these scenarios. The probability of achieving a GD of 80% ranged from 56.6 to 66.7% across these scenarios (Faust *et al.* 2016, pp. 24-25). The latter scenarios, which provide for intense release periods, can improve NEP demographics and provide for average population sizes ranging from 110 – 140 at 125 years (as compared to ~67 under scenario F without releases, with P(E) of 16.5%) and nearly eliminate the chance of extirpation (Faust *et al.* 2016, p. 26).

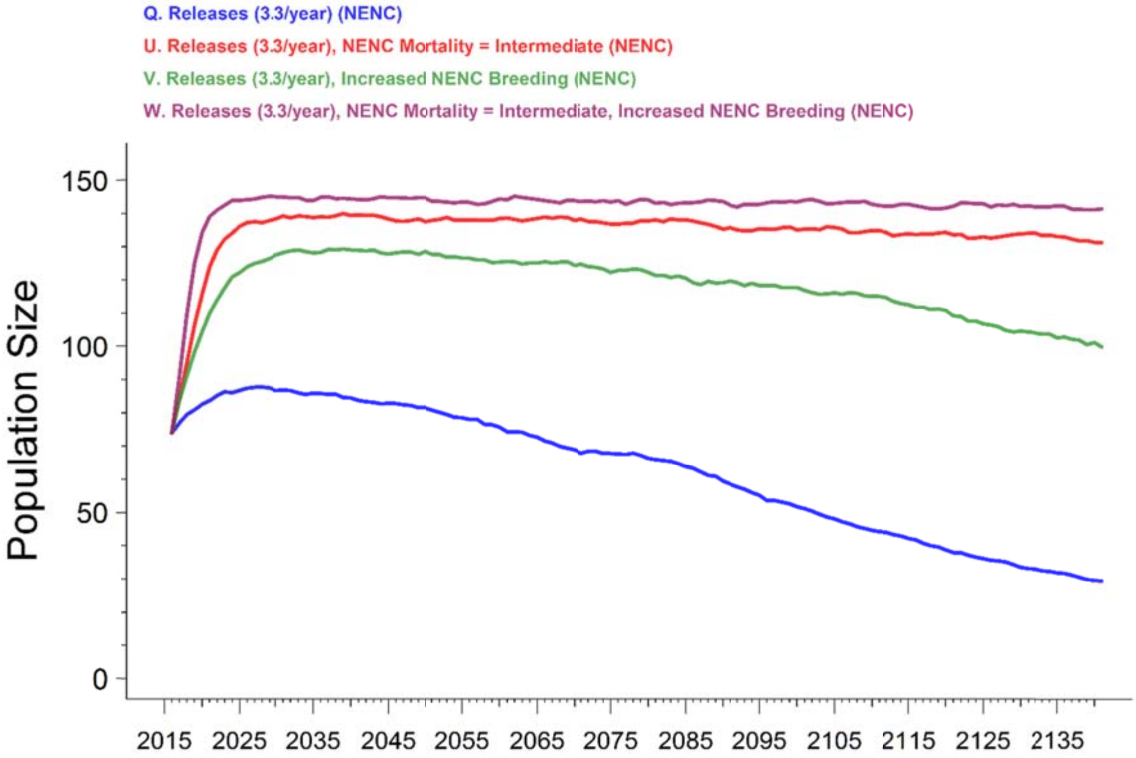


Figure 19: Projected Mean Population Size with 3.3 Releases/Year and Improvements to NEP Mortality and Breeding Rates (reproduced from Faust *et al.* 2016, p. 25; "NENC," used by the authors, refers to NEP)

Scenarios which Provide for Releases, Add capacity to the SSP and Improve Demographics of the NEP

Two scenarios explored improving vital rates in the NEP (e.g., approximately 20% reduction in annual mortality and shift in when it occurs to improve breeding success to 70%) and increased space (400 spaces) and breeding (% females producing a litter increases from 19 to 25%) in the SSP. Overall, these scenarios resulted in the highest GD and the most improvement in demographics for the NEP. These scenarios represent the highest probability of maintaining 80% GD for 125 years of the scenarios modeled (Faust *et al.* 2016, pp. 10-12 and 25-26).

SCENARIOS WHICH BRING WILD ANIMALS INTO THE SSP

Reintegrating wild NEP wolves back into the SSP would not have a large impact on demographics of the SSP; genetically, the benefits of reintegrating NEP genes into the SSP might have a more substantial impact on the SSP, but much of that "extra" benefit would not be captured unless SSP population size was increased. In fact, if the NEP program is terminated, larger SSP capacity would be important to ensure the species' genetic health is not permanently worsened. If additional spaces are not available, cryopreservation of genetic materials should be an important avenue for making sure NEP genes are captured, with investments in the research needed to utilize those genes via assisted reproduction (Faust *et al.* 2016, p.20).

RECOVERY ON FEDERAL LANDS ONLY

In this hypothetical scenario, the NEP carrying capacity (K) would be reduced to 25 given estimates of the number of territories that could be supported on federal land within Dare County; coyote impact would be increased (define per Scenario H); SSP would provide one animal every other year for release; the initial population would be reduced to 14 animals, including 8 adults, 2 juveniles, and 4 pups (Faust *et al.* 2016, p. 11). Overall, this scenario has a "severe demographic and genetic future," and "would not result in a viable population."

"After a severe bottleneck in the first 15 years of the model as the existing animals die off, any population survival is simply because the scenario includes releasing 1 animal every other year from the SSP. Even with this, 67.1% of iterations ended with extirpation. The scenario had a median TE [time to extirpation] of 14 years; this represents the time to first extirpation, although some iterations that went extirpated could be restarted by releases." (Faust *et al.* 2016, p. 27)

SUMMARY

The Faust *et al.* 2016 PVA concludes that multiple scenarios would result in less than a 10% probability of extirpation for the NEP (Figure 20 below; detailed descriptions of scenarios are available in Appendix 2). Among these were several that would anticipate releases of 3.3 animals per year from the SSP. Several of these also modeled a change in either demographics of the NEP (e.g., mortality rate or increased breeding), an increase in SSP capacity, or both.

C	NEP mortality = SSP mortality
D	NEP mortality = Intermediate, no inbreeding depression
Q	Movement (3.3 every year)
R	Movement (3.3 every year), SSP 330 spaces
S	Movement (3.3 every year), SSP 400 spaces
T	Movement (3.3 every year), SSP 400 spaces, SSP 25% breeding
U	Movement (3.3 every year), NEP mortality = intermediate
V	Movement (3.3 every year), NEP increased breeding
W	Movement (3.3 every year), NEP mortality = intermediate, NEP increased breeding

X	Movement (3.3 per year for 15 years then every 5 years), NEP mortality = intermediate, NEP increased breeding
Y	Movement (3.3 per year for 15 years then every 20 years), NEP mortality = intermediate, NEP increased breeding
AA	Movement (3.3 every year), SSP 400 spaces, SSP 25% breeding, NEP mortality = intermediate
BB	Movement (3.3 every year), SSP 400 spaces, SSP 25% breeding, NEP mortality = intermediate, NEP increased breeding

Figure 20: Scenarios in which the NEP had less than 10% probability of extirpation as modeled by Faust *et al*. 2016 (figure reproduced from Faust *et al*. 2016, p. 28; we note that the authors use "NENC" rather than NEP, as shown here).

Twenty-two of the modeled scenarios were capable of maintaining genetic diversity of the metapopulation as a whole at greater than 80% (Figure 21 below). Among these were: scenarios which lowered mortality in the NEP; increased SSP capacity; brought wolves into the SSP and increased SSP capacity to 330; release scenarios which changed SSP parameters; release scenarios which altered NEP vital rates; release scenarios which increased SSP capacity and moved more animals; and scenarios which represented combinations of these elements.

C	NEP mortality = SSP mortality
D	NEP mortality = Intermediate, no inbreeding depression
F	NEP mortality = intermediate, Increased females breeding NEP
I	NEP mortality = intermediate, reduced coyote impact
L	SSP 400 spaces
M	SSP 330 spaces, SSP 25% breeding
N	SSP 400 spaces, SSP 25% breeding
P	Capturable wolves brought into SSP, SSP 330 spaces
S	Movement (3.3 every year), SSP 400 spaces
T	Movement (3.3 every year), SSP 400 spaces, SSP 25% breeding
X	Movement (3.3 per year for 15 years then every 5 years), NEP mortality = intermediate, NEP increased breeding
Y	Movement (3.3 per year for 15 years then every 20 years), NEP mortality = intermediate, NEP increased breeding
AA	Movement (3.3 every year), SSP 400 spaces, SSP 25% breeding, NEP mortality = intermediate
BB	Movement (3.3 every year), SSP 400 spaces, SSP 25% breeding, NEP mortality = intermediate, NEP increased breeding
4B	Capturable wolves brought into SSP, SSP 400 spaces
4E	Movement (young, 4.5 per year), SSP 330 spaces
4F	Movement (young, 4.5 per year), SSP 400 spaces
4G	Movement (young, 4.5 per year), SSP 400 spaces, SSP 25% breeding
4I	Movement (3.3 per year for 15 years then every 10 years), NEP mortality = intermediate, NEP increased breeding

4J	Movement (3.3 per year for 25 years then every 5 years), NEP mortality = intermediate, NEP increased breeding
4K	Movement (3.3 per year for 25 years then every 10 years), NEP mortality = intermediate, NEP increased breeding
4L	Movement (3.3 per year for 25 years then every 20 years), NEP mortality = intermediate, NEP increased breeding

Figure 21: Scenarios which had greater than 80% chance of hitting that benchmark at the metapopulation level (reproduced from Faust *et al.* 2016, p. 30; we note that the authors use "NENC" rather than NEP, as shown here)

Faust *et al*. (2016, p. 30) note that:

> "These modeling scenarios highlight that red wolves will be a conservation-reliant species, requiring population management: all red wolves will need to be treated as a metapopulation, with occasional movement between the SSP and [NEP], and perhaps other populations if they are established, to manage declining gene diversity given its small founding population (Goble *et al.* 2012 [pp. 869-870]). However, with [NEP] demographic changes and releases, maintaining a functioning wild population is possible. This is a key example of a species that can be best preserved by the "One Plan" approach, where all populations, captive and wild, are considered under an integrated plan for species conservation (Byers *et al*. 2013, [p. 4])."

Maintaining genetic diversity at greater than 80% in the NEP was achieved by only two scenarios which necessitated changes to NEP, annual releases for 125 years, and increases to SSP capacity and breeding. Overall, the species as a whole can achieve the 80% GD threshold more easily than the NEP (Faust *et al.* 2016, pp. 28-29). Increasing the SSP capacity to 400 spaces increases the probability of achieving genetic diversity of 80% (P(80GD)) from 65.7% (Baseline Scenario) to 88.5%. In addition to this, reproductive improvements are recommended to avoid demographic decline in the SSP. In fact, both populations are small and are expected to see rising inbreeding levels, which have already been detected. Managing the population as a metapopulation (transferring genetic material in both directions) may help maximize genetic diversity (Faust *et al.* 2016, pp. 29-30).

LANDSCAPE FACTORS WHICH COULD IMPACT FUTURE POPULATIONS

Climate change may exacerbate vector-borne diseases like Lyme disease, which is transmitted by a tick. The bacteria which causes the disease has been detected in several canids (both red wolves and coyotes) in North Carolina (Brzeski *et al.* 2015 pp. 1, 8). However, at present vaccinations for this disease are provided, as well as canine distemper, parvovirus, coronavirus, parainfluenza, Leptospirosis, adenovirus, and rabies whenever they are handled (M. Morse 2017a, pers. comm.).

SLR PROJECTIONS

The Albemarle peninsula is expected to be impacted by sea level rise and climate change. Our RSLR projections forecast an approximate 24% loss off emergent land in the 5 county NEP. The eastern portion of Albermarle peninsula will experience the most dramatic effects of inundation in the 125 year projection (Figure 12). Additionally, low lying areas are expected to have increased flooding events and hydroperiods (NC SLR 2015, p. 25; Kopp *et al*. 2014, p. 7; Kopp *et al*. 2015, p. 705). Inundation of habitat and frequent flooding or change in habitat type on the eastern side of the Peninsula could drive red wolves to move further west from their current NEP to find upland habitat and into areas already occupied in large numbers by coyotes, which are outside the area with sterile coyote placeholders and would undoubtedly facilitate further hybridization (without significant intervention), which would result in further introgression of coyote genes in the red wolf gene pool.

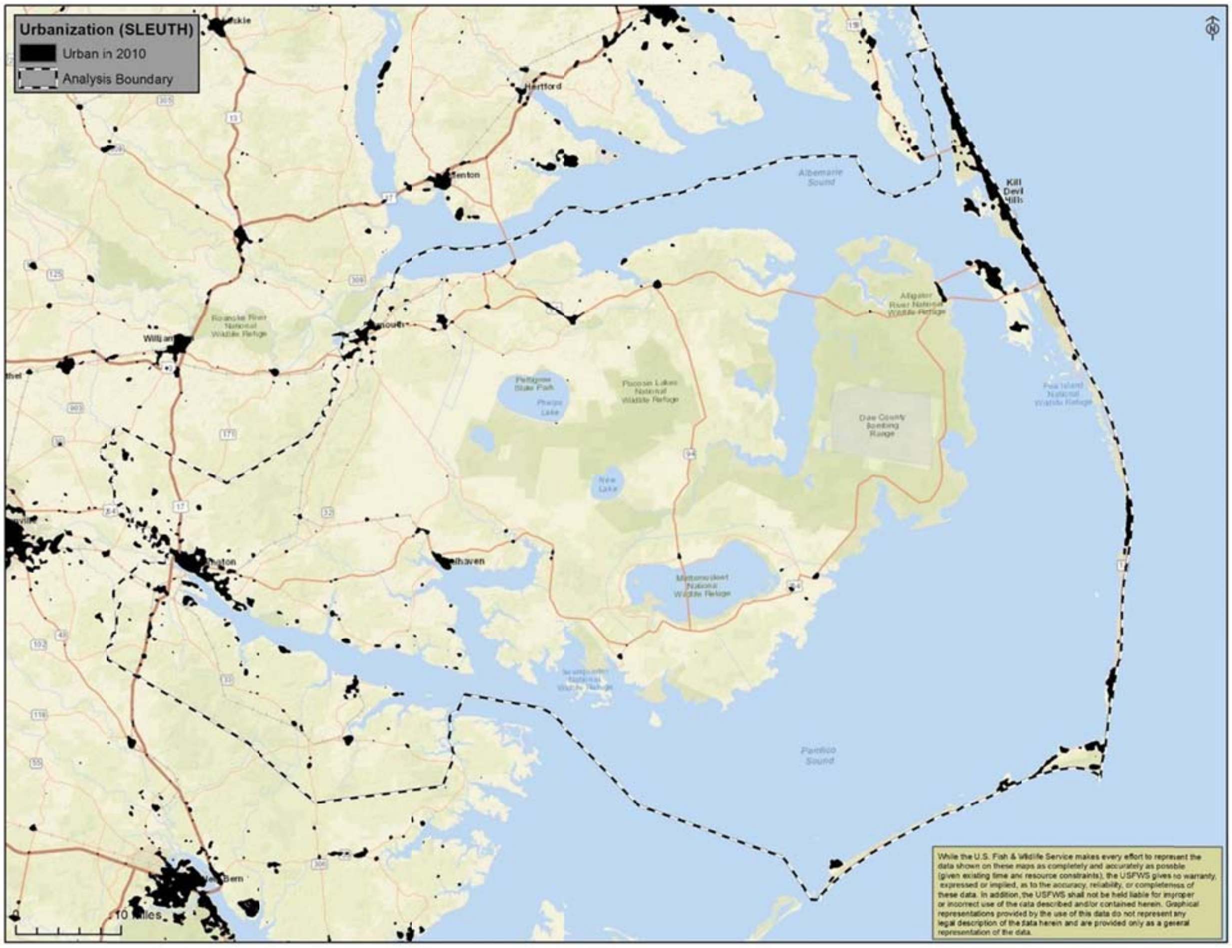
Although highly mobile, the westward dispersal of the wolf has its own challenges. Predicted urbanization and associated anthropogenic factors that favor coyotes (Gese *et al.* 2015, p. 200) as well as the possible habitat fragmentation and the subsequent reduction in dispersal corridors (Terando *et al.* 2014, p. 1) will increase the difficulty of wolves retreat from projected RSLR.

LAND DEVELOPMENT

Urban growth projections were created using the SLEUTH (Slope, Land use, Excluded, Urban, Transportation and Hillshade) model, named for the model input datasets and the evolutionary product of the Clarke Urban Growth Model (Belyea and Terando 2013, entire). This model uses land cover change modeling, cellular automata (a model approach where landscape is divided into a grid of cells), and terrain mapping to predict urban growth (Jantz *et al*. 2009, entire; Belyea and Terando 2013, entire). SLEUTH provides urban growth projections which are useful across a range of applications; including wildlife habitat analysis, conservation planning, and land cover dynamics analysis. SLEUTH incorporates four growth rules (Spontaneous Growth, New Spreading Centers, Edge Growth and Road-Influenced Growth) to model the rate and pattern of urbanization SLEUTH incorporates four growth rules (spontaneous growth, new spreading urban centers, edge growth around existing urban areas, and road-influenced growth). In addition to simulating outward growth of existing urban areas, the model also projects new centers of urbanization and growth along transportation corridors (Terando *et al.* 2014, p. 2; Belyea and Terando 2013, entire). The model is trained using past urbanization patterns, as the most relevant scenario of growth in the Southeast (a fast-growing region), is the “Business-as-Usual” scenario, in which the net effect of growth is commensurate with growth in the past (Terando *et al.* 2014, pp. 1-2). Once the right parameter values are isolated for the growth rules, the model is run in prediction mode, producing one urban growth cycle per year, producing a GIF image with an annual probability of urbanization for each pixel (Belyea and Terando 2013, entire). The SLEUTH model covers nine states at 60-m resolution, reflecting fine-scale changes in habitat-connectivity (Terando *et al.* 2014, p. 2). While it does not explicitly account for demographic and economic drivers of growth, the model has shown utility in predicting urban growth patterns over its 15-year evolution (Terando *et al.* 2014, p. 2).

While urbanization has a variety of effects on ecosystems, it will likely also influence the ability of species to respond to climate change, by creating movement barriers for species that cannot survive in cities and corridors for species that can (Terando *et al.* 2014, p. 1). The spreading development frontier indicates increasing connectedness in the Southeast and favorable conditions for urban-adapted species, while other species will experience reduced habitat area and increased difficulty in migration and dispersal (Terando *et al.* 2014, p. 7). In addition, particularly relevant to red wolf, the largest conversion in land cover type in the Southeast for the next 50 years, is from agricultural to urban land use (Terando *et al.* 2014, pp. 4-5). It is important to note that global warming scenarios will be, "superimposed on or act synergistically with urbanization scenarios," (Terando *et al.* 2014, p. 7).

While development is not anticipated to be a substantial issue for red wolves on the peninsula, it was evaluated in the context of presenting a potential barrier to dispersal in the face of increased flooding and sea level rise. The level of urbanization as reported by the SLEUTH model are provided in Figure 22 below, while the projected probability of growth at 2100 from SLEUTH model projections for the peninsula are provided in Figure 23.



While the U.S. Fish & Wildlife Service makes every effort to represent the data shown on these maps as completely and accurately as possible (given existing time and resource constraints), the USFWS gives no warranty, expressed or implied, as to the accuracy, reliability, or completeness of these data. In addition, the USFWS shall not be held liable for improper or incorrect use of the data described and/or contained herein. Graphical representations provided by the use of this data do not represent any legal description of the data herein and are provided only as a general representation of the data.

Figure 22: Level of urban growth in 2010 as reported by the SLEUTH model (BAU) (refer to pp. 8, 60-63 for information on the SLEUTH model)

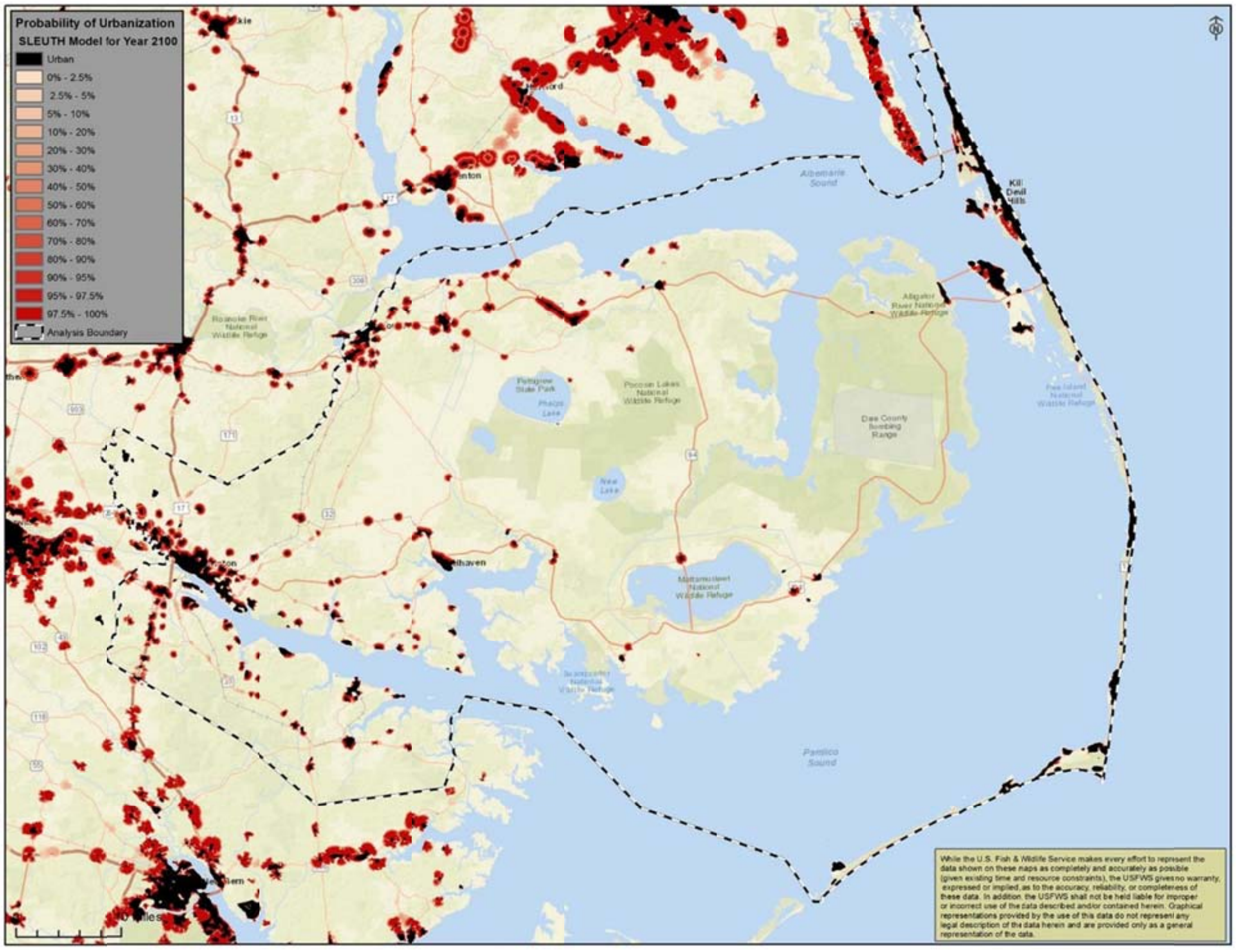


Figure 23: Projected urban growth at 2100 based on the SLEUTH model (BAU).

The eastern portion of the peninsula is not anticipated to experience extensive growth, however, selected locations in Washington and Beaufort counties, as well as areas to the west from their current NEP (particularly near Greenville, NC) could see higher rates of growth over time.
In the case of red wolves, as the combined maps of sea-level rise and projected urban growth above illustrate, habitat will be lost on the Albemarle Peninsula, some of it irreparably (e.g., open water) over the next 125 years. How individual wolves or packs may respond to this loss of habitat to the East is uncertain. However, it is clear as noted by WMI (2014, p. 3), "…climate change impact models indicated that significant portions of the current restoration area on Albemarle Peninsula would succumb to sea level rise. Accordingly, over the long term, current federal lands will not provide sufficient habitat for red wolves in the restoration area."

Areas on private lands to the west of Federal lands will also be affected. While the wolf is a highly mobile species, which readily expands into available habitat, particularly when concentrations of prey and absence of other predators co-occur, wolves are already dispersing in westerly directions on the peninsula and encountering substantial numbers of coyotes. "Anthropogenically-driven habitat changes continue to favor coyotes because of their ability to colonize areas in closer proximity to human activity," (Gese *et al.* 2015, p. 200). In the face of sea level rise and other land use changes, the area used by red wolves will shift and will invariably include a smaller proportion of federal lands.

FUTURE RESILIENCY

Given the very low numbers in the NEP (3 breeding pairs; N approximately 44), without substantial intervention (e.g., releases and management of coyote introgression), extirpation will likely occur within as few as eight years (Faust *et al.* 2016, p. 15). While, Faust *et al.* (2016, p. 3) suggested that the NEP could avoid extirpation and be viable (<10% chance of extirpation in 125 years) as a population with intervention, which might include reduction of the NEP mortality rate, increase in breeding rates (which would require reducing breeding season mortality), and releases from the Species Survival Plan (SSP) captive population for approximately 15 years followed by releases to maintain genetic health after that. The starting value (i.e., number of animals) for the population is now lower (44 wolves) than was initially modeled, and there is now an increased risk of stochastically-driven dynamics given the smaller population size (i.e., variability in the environment could have a stronger effect on the remaining population, than initially projected). All in all, without significant intervention in the NEP could go extirpated in the near-term.

If interventions described in Faust *et al.* (2016) are carried out which could produce a viable population on the Albemarle Peninsula, substantial additional efforts and financial resources will be needed to facilitate population expansion in North Carolina. Modelling indicates landscape-level factors that affect habitat (e.g., particularly sea-level rise and increased flooding) will result in substantial changes to the habitat on the peninsula in the next 125 years, which could push wolves further west from where they currently occur. If this happens, they would encounter more development (e.g., Greenville area), as indicated by the urban development model results. Whether their natural mobility as a species will allow the red wolf to locate suitable habitat in a changing landscape is still unclear, but coyotes will likely use the same habitats and are more adaptable with regard to human development and infrastructure. Without sufficient wolf mates on the landscape, hybridization would likely continue to occur and coyotes already vastly outnumber wolves on both the peninsula and areas west of the current NEP, so intensive management and significant additional resources would be necessary.

With regard to the SSP captive population, Current gene diversity for the managed population is 88.87% and is equivalent to the genetic diversity of a population descended from only approximately five founders. This is one of the biggest challenges with this species because the current gene diversity is very low. The main objective to the captive population is to maintain this diversity in the long term. Faust *et al.* (2016, p. 3) discussed that "[w]hile the SSP [captive population] has been maintained at a relatively large population size of more than 150 animals for over 20 years, it needs to increase breeding and increase its population size/space to ensure long-term viability and its ability to serve as a strong source for animals to release to the wild."

FUTURE REDUNDANCY

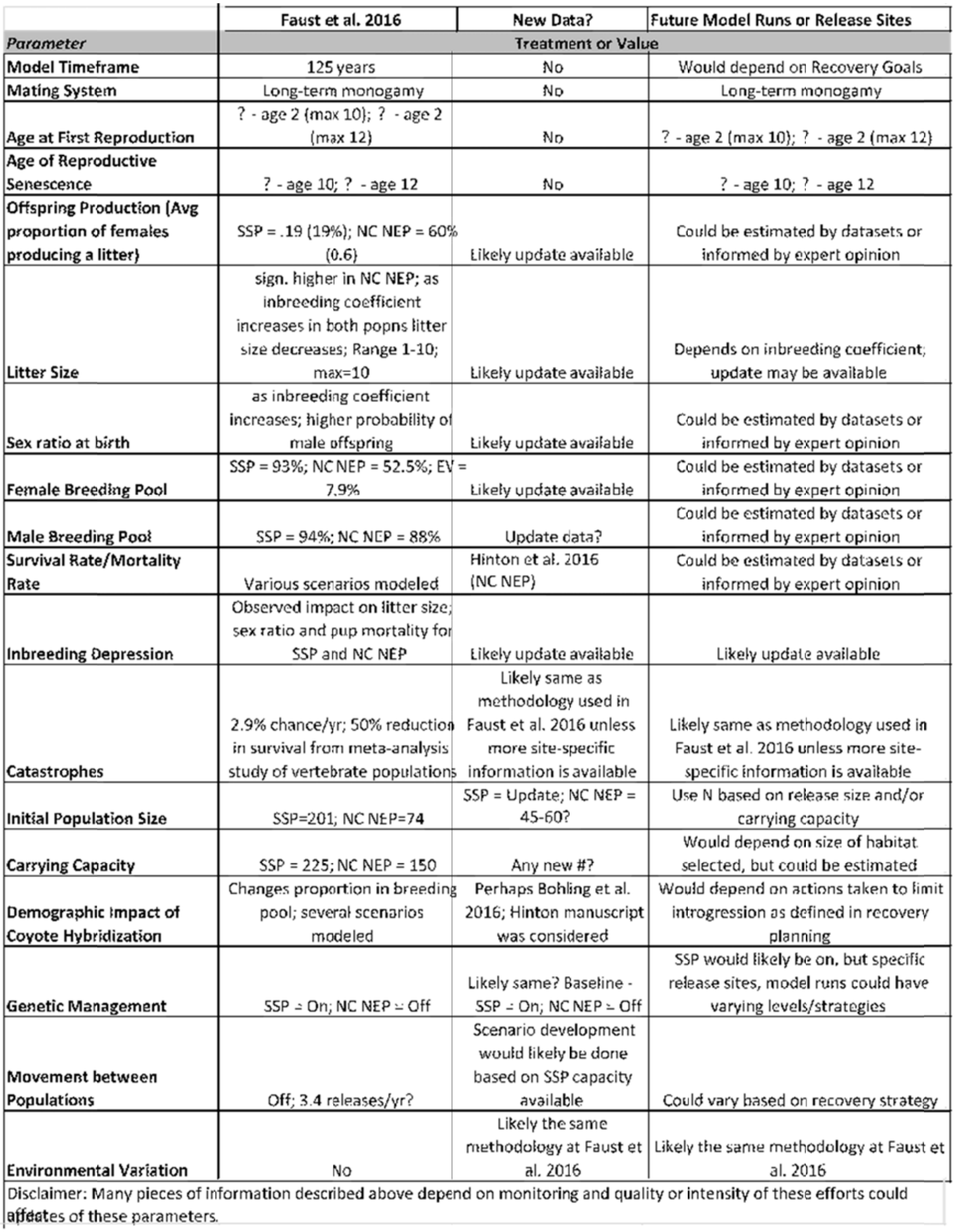
Redundancy is having sufficient numbers of resilient populations for the species to withstand catastrophic events. The single NEP of red wolves could go extirpated in approximately 8 to 37 years (Faust *et al.* 2016, p. 15). Without new reintroduction sites the species is unlikely to have significant redundancy in the wild. Some level of redundancy is present in captivity because the species is held at multiple facilities throughout the U.S. However, this does not constitute a viable wild population. Therefore, at present and into the future, there is no redundancy of red wolves in the wild.

FUTURE REPRESENTATION

The SSP captive population represents the genetic fail-safe for the entire population and any future recovery potential for the species. Twelve of the original fourteen lines are still represented and Faust *et al.* (2016) provide several scenarios through which the SSP captive population could be expanded, genetic diversity (of the remaining 12 lines) maintained, and future release efforts supported. While any future reintroductions would require a consideration of SSP capacity to support these efforts, it is clear that the SSP captive population has maintained a genetically-diverse stock, within the limits of the remaining 12 lines, from which to grow the population and release into the wild.

NEXT STEPS

The results of this Species Status Assessment will be used to update the current Red Wolf Recovery Plan and provide a basis for future recovery planning efforts. The Population Viability Analysis framework and model (Faust *et al.* 2016, entire) has the capacity to consider additional scenarios and sites making it a useful tool should future reintroductions need to be evaluated for their contribution to species-level genetic diversity or project resiliency of individual potential reintroductions (Faust *et al.* 2017, pers. comm.). Should additional sites be selected for further evaluation of reintroduction potential, several pieces of information may be particularly helpful in evaluating them using the PVA and other tools. To help inform this process, Table 4 below explains parameter values used in Faust *et al.* (2016), where new information may exist to inform these values, and where information might originate to inform them for future projections if new release sites or additional model runs are needed. In addition, peer reviewers have suggested efforts might be made to model pack dynamics and wolf-coyote interactions more explicitly. We acknowledge that this may be very useful in better understanding how pack dynamics influence population demographics and introgression in the future. Future modeling efforts may incorporate more complex biological or ecological elements of this system to further improve future projections.



	Faust et al. 2016	New Data?	Future Model Runs or Release Sites
Parameter	Treatment or Value		
Model Timeframe	125 years	No	Would depend on Recovery Goals
Mating System	Long-term monogamy	No	Long-term monogamy
Age at First Reproduction	? - age 2 (max 10); ? - age 2 (max 12)	No	? - age 2 (max 10); ? - age 2 (max 12)
Age of Reproductive Senescence	? - age 10; ? - age 12	No	? - age 10; ? - age 12
Offspring Production (Avg proportion of females producing a litter)	SSP = .19 (19%); NC NEP = 60% (0.6)	Likely update available	Could be estimated by datasets or informed by expert opinion
Litter Size	sign. higher in NC NEP; as inbreeding coefficient increases in both popns litter size decreases; Range 1-10; max=10	Likely update available	Depends on inbreeding coefficient; update may be available
Sex ratio at birth	as inbreeding coefficient increases; higher probability of male offspring	Likely update available	Could be estimated by datasets or informed by expert opinion
Female Breeding Pool	SSP = 93%; NC NEP = 52.5%; EV = 7.9%	Likely update available	Could be estimated by datasets or informed by expert opinion
Male Breeding Pool	SSP = 94%; NC NEP = 88%	Update data?	Could be estimated by datasets or informed by expert opinion
Survival Rate/Mortality Rate	Various scenarios modeled	Hinton et al. 2016 (NC NEP)	Could be estimated by datasets or informed by expert opinion
Inbreeding Depression	Observed impact on litter size; sex ratio and pup mortality for SSP and NC NEP	Likely update available	Likely update available
Catastrophes	2.9% chance/yr; 50% reduction in survival from meta-analysis study of vertebrate populations	Likely same as methodology used in Faust et al. 2016 unless more site-specific information is available	Likely same as methodology used in Faust et al. 2016 unless more site-specific information is available
Initial Population Size	SSP=201; NC NEP=74	SSP = Update; NC NEP = 45-60?	Use N based on release size and/or carrying capacity
Carrying Capacity	SSP = 225; NC NEP = 150	Any new #?	Would depend on size of habitat selected, but could be estimated
Demographic Impact of Coyote Hybridization	Changes proportion in breeding pool; several scenarios modeled	Perhaps Bohling et al. 2016; Hinton manuscript was considered	Would depend on actions taken to limit introgression as defined in recovery planning
Genetic Management	SSP = On; NC NEP = Off	Likely same? Baseline - SSP = On; NC NEP = Off	SSP would likely be on, but specific release sites, model runs could have varying levels/strategies
Movement between Populations	Off; 3.4 releases/yr?	Scenario development would likely be done based on SSP capacity available	Could vary based on recovery strategy
Environmental Variation	No	Likely the same methodology at Faust et al. 2016	Likely the same methodology at Faust et al. 2016
Disclaimer: Many pieces of information described above depend on monitoring and quality or intensity of these efforts could affect estimates of these parameters.			

Table 4: Data Updates and Needs for Future Model Runs

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APPENDICES

APPENDIX 1: SUMMARY OF FACTORS AFFECTING THE SPECIES AND MANAGEMENT EFFORTS

Factor Affecting the Species	Timeframe (Past (P), Current (C), Future (F))	Likelihood of threat occurring	Impact to Species (life stage/mechanism)	Area(s), Stages of Impact	Extent of Populations Affected?	Proactive Management?	Exacerbated or Synergistic with another Factor?
Introgression (Faust *et al* 2016)	P, C, F	Very High	All; Reproduction; Recruitment Rate	NEP; potential future sites	Only wild; all potential ones	Yes; placeholder effort, Adaptive Management Plan	Habitat loss; gunshot mortality (Bohling and Waits 2015), coyote management efforts
Habitat loss NEP – climate change	F	Projections could be done	Increased dispersal; Pack movement inland	NEP	Affected areas of NEP	No	Possibly change human interaction, unclear.
Human Shooting (Hinton *et al* 2016) –	P, C, F	Very High	Adults; Juveniles; Population -Survival Rate	NEP; potential future sites	Only wild; all potential ones	Yes; education, legal protection	Yes; disrupts social structure, incr. introgression; disproportionate <4 year
Inbreeding Depression	P, C, F	Very High	Individual Fertility; Population Recruitment rate	NEP; potential future sites	Affects NEP	Yes; captive management and releases	Yes; shooting mortality and introgression?
Disease outbreaks	P, C, F	See rates used in Faust *et al* 2016	All life stages	NEP; potential future sites?	Could happen in NEP; could happen in SSP, but likely would manage	Yes; vaccination program	coyote presence; yes vector-borne affected by climate change
Hurricanes	Past, Current, Future	See rates used in Faust *et al* 2016	All life stages	NEP; potential future sites?	NEP – yes; SSP -no	No; minor so far	Possibly climate change – dynamics complicated
Fire	Past, Current, Future	See rates used in Faust *et al* 2016	All life stages	NEP; potential future sites?	NEP – yes; SSP unlikely	No; minor so far	No
Vehicle Collision	P, C, F	Very High	Juveniles/Adults	NEP; specific areas?	NEP	No or Yes; signage on roadways, wildlife underpasses	?
Management	P	Low	Release animals only	NEP; Release Areas	NEP; Release Areas	Yes; SOP (Protocols)	No
Private Trapper	P	Low	Release animals only	NEP; Release Areas	NEP; Release Areas	Yes; SOP (Protocols), trapping regulations,	No or Yes; local trapping efforts, fox pen activity

						education and incentive programs	

APPENDIX 2: DETAILED DESCRIPTION OF MODEL SCENARIOS REPRODUCED FROM FAUST *ET AL*.

*Note: The authors use “NENC” rather than NEP, as shown below; scenarios derived from Faust *et al*. 2016 (p. 9-12)

Label	**Scenario Name**	**Description**
A	Baseline	SSP and NEP populations uncoupled (separate, no releases) with baseline demographic rates as described above
		NEP population - demographic rate changes (survival, reproduction)
B	NEP mortality = intermediate	NEP mortality rates are decreased to “intermediate” levels, calculated as the midpoint value between the SSP and NEP rates, for age classes 1-16 (Table A3). Anthropogenic mortality is the leading cause of death for red wolves (Hinton *et al.* 2015*)*. Evidence suggests that anthropogenic mortality in the population is additive rather than compensatory (Sparkman *et al.* 2011b), suggesting that if human-caused mortalities were reduced, the overall mortality rates for the population would be lower. USFWS managers also suggest that in the population’s early history there were management and health-related issues which, with experience, are now better managed; this is supported by the decreasing trend in per capita mortality over time (Appendix 1, Fig. A8). Although the mortality values used in this scenario are hypothetical, they generally represent a scenario in which anthropogenic (and other) mortality sources are reduced but not reduced to levels as low as the captive SSP population.
C	NEP mortality = SSP mortality	NEP mortality rates are decreased to SSP mortality rates for age classes 1-16 (Table A3).
D	NEP mortality = Intermediate, no inbreeding depression	NEP has intermediate mortality rates + elimination of inbreeding depression's impact on offspring sex ratio, infant mortality, and litter size as described in scenario DD.
E	Increased females breeding NEP	% NEP females breeding increased to 70% based on the highest breeding rates observed in the past, when in 2003-4 the population had 71.4% of females in wolf-wolf pairs (Table A2). We hypothesize that these rates can be achieved again by shifting mortality. Over the history of the population, the timing of mortality in the year has shifted such that in more recent years, mortality (primarily anthropogenic) has occurred fall through winter (i.e. in the fall hunting

		season), which corresponds to red wolf pre-breeding and breeding season (See Fig. A9; Hinton *et al.* 2015, Hinton *et al.* in review, Bohling and Waits 2015). When mortality occurs during this time of year, wolves do not have time to form a new pair bond naturally or via USFWS management actions, disrupting reproduction for the season. If late season, anthropogenic mortality is reduced allowing wolves more time to repair if a mate is killed, higher breeding rates should be achievable (Hinton *et al.* 2015). While shifts in the timing of mortality would support the increased breeding rate modeled here, the actual mortality rates in this scenario remain unchanged.
F	NEP mortality = intermediate, Increased females breeding NEP	NEP has intermediate mortality rates + increased % females breeding. This scenario represents ideal management of demographic rates, where anthropogenic mortality is reduced to the point that overall mortality is reduced, and observed mortality is less concentrated in the pre-breeding and breeding seasons, resulting in higher % females breeding.
G	Reduced coyote impact	% NEP males in the breeding pool was increased to **100%**, assuming no males are mated with coyote females. % NEP females in breeding pool was increased to **68.8%**, based on the average annual rate of wolf-canid pairs (i.e. pairs with either a wolf or coyote are replaced by pairs with only wolves) that have been observed 2000-2014 (Table A4). If all wolves were able to make wolf-wolf pairs, reproduction would increase. We hypothesize that these effects might take place if the wolf population was large enough that wolves outcompeted coyotes for breeding partners or territories, and/or if the coyote population was managed through a placeholder approach (Gese *et al.* 2015, Gese and Terletzky 2015, Bohling *et al.* 2016).
H	Increased coyote impact	Assumes that if the coyote population increases or if coyotes are less managed to avoid impacts on the wolf population, then wolf breeding would be further negatively impacted as coyotes would more frequently pair with wolves. To simulate this, we took the average rate of male and female wolves in wolf-coyote breeding pairs (12% and 16.3%, respectfully) and doubled those rates (to 24% and 32.6%); this reduces the % NEP males entering the (wolf) breeding pool from 88% to **76%** and females entering the breeding pool from 52.5% to **36.2%**. This reduces the breeding pool (of wolf-wolf pairs), which limits the genetic population dynamics as well (fewer pairs have offspring).
I	NEP mortality =	NEP population has intermediate mortality rates + increased breeding rates as in Scenario G.

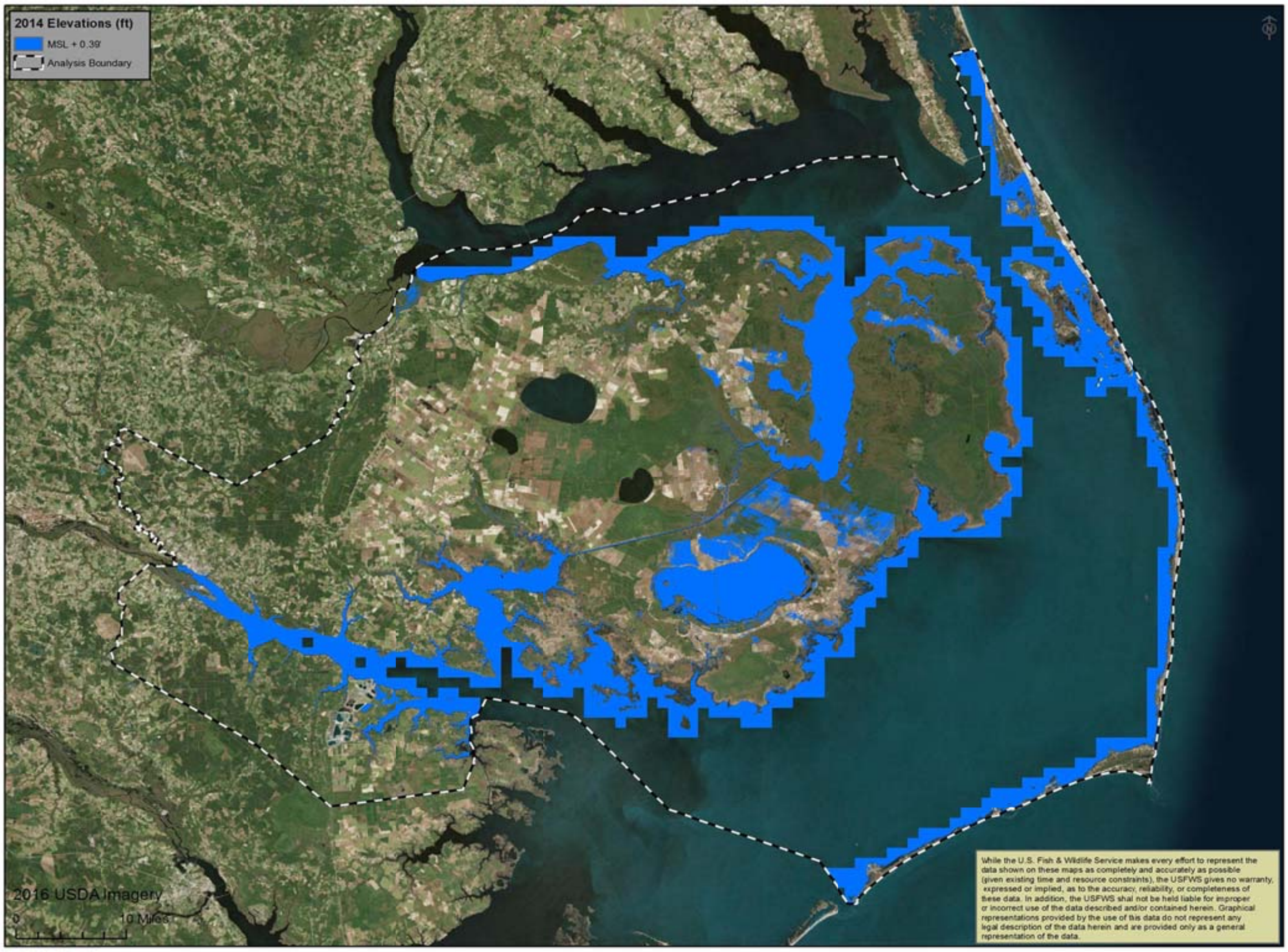
	intermediate, reduced coyote impact	
J	NEP mortality = intermediate, Increased coyote impact	NEP population has intermediate mortality rates + decreased breeding rates decreased as in Scenario H.
SSP - increased space and breeding		
K	SSP 330 spaces	SSP carrying capacity increased to 330 based on the target set in the 1990 Recovery Plan (USFWS 1990).
L	SSP 400 spaces	SSP carrying capacity increased to 400 based on previous modeling work (Simonis *et al.* 2015b)
M	SSP 330 spaces, SSP 25% breeding	SSP carrying capacity increased to 330 + % females producing a litter increased from 19% to 25%. Although the percentage of paired females that successfully breed with their recommended mate in the SSP has achieved a maximum of 34.6% (Table A1), population managers consider this to be overly optimistic for a sustained period of time (Waddell, personal communication). In discussions with population managers, the PVA team decided that 25% was a reasonable, if challenging, value to achieve on an annual basis (Waddell, personal communication).
N	SSP 400 spaces, SSP 25% breeding	SSP carrying capacity increased to 400 + % females producing a litter increased from 19% to 25%
NEP individuals brought into SSP		
O	Capturable wolves brought into SSP	Based on an assessment by FWS staff, 32 individuals of the 74 wolves in the NEP at the start of the model could be captured (Harrison, pers. comm.). This scenario assumes that these individuals are moved immediately into the SSP population before the model simulation begins and are subsequently subjected to SSP demographic rates, but the SSP remains at the baseline level of space (225)
P	Capturable wolves brought into SSP, SSP 330 spaces	Bring in the 32 individuals + increase SSP carrying capacity to 330
P	Capturable wolves brought into SSP, SSP 330	Bring in the 32 individuals + increase SSP carrying

	spaces	capacity to 330
Release scenarios - Releases Only		
Q	Movement (3.3 per year)	Release younger SSP wolves into NEP at a rate of 3.3 animals per year, which is based on the average release rate from 2005-2014. Animals are released with these age distributions: 60.6% 0-year olds, 33.3% 1-year olds, and 6% 2-5-year olds (matching age distribution of releases from 2005-2014, Fig. A6), representing primarily a pup-fostering approach. The model randomly selects animals within the given age class range as long as there are individuals available for release. Releases only occur in years when the SSP population size was at least 80% of the SSP's K. Released individuals are then subject to all NEP demographic rates.
Release scenarios - Releases + SSP changes		
R	Movement (3.3 per year), SSP 330 spaces	Releases as in Scenario Q + SSP carrying capacity is increased to 330.
S	Movement (3.3 per year), SSP 400 spaces	Releases as in Scenario Q + SSP carrying capacity is increased to 400.
T	Movement (3.3 per year), SSP 400 spaces, SSP 25% breeding	Releases as in Scenario Q + SSP K = 400 + % females in the SSP producing a litter increased to 25%
Release scenarios - Releases + NEP demographic rate changes		
U	Movement (3.3 per year), NEP mortality = intermediate	Release as in Scenario Q + decreased mortality in the NEP population as in Scenario B.
V	Movement (3.3 per year), NEP increased breeding	Release as in Scenario Q + increased breeding in the NEP population as in Scenario E.
W	Movement (3.3 per year), NEP mortality = intermediate, NEP increased breeding	Release as in Scenario Q + decreased mortality + increased breeding in the NEP population as in Scenario F.

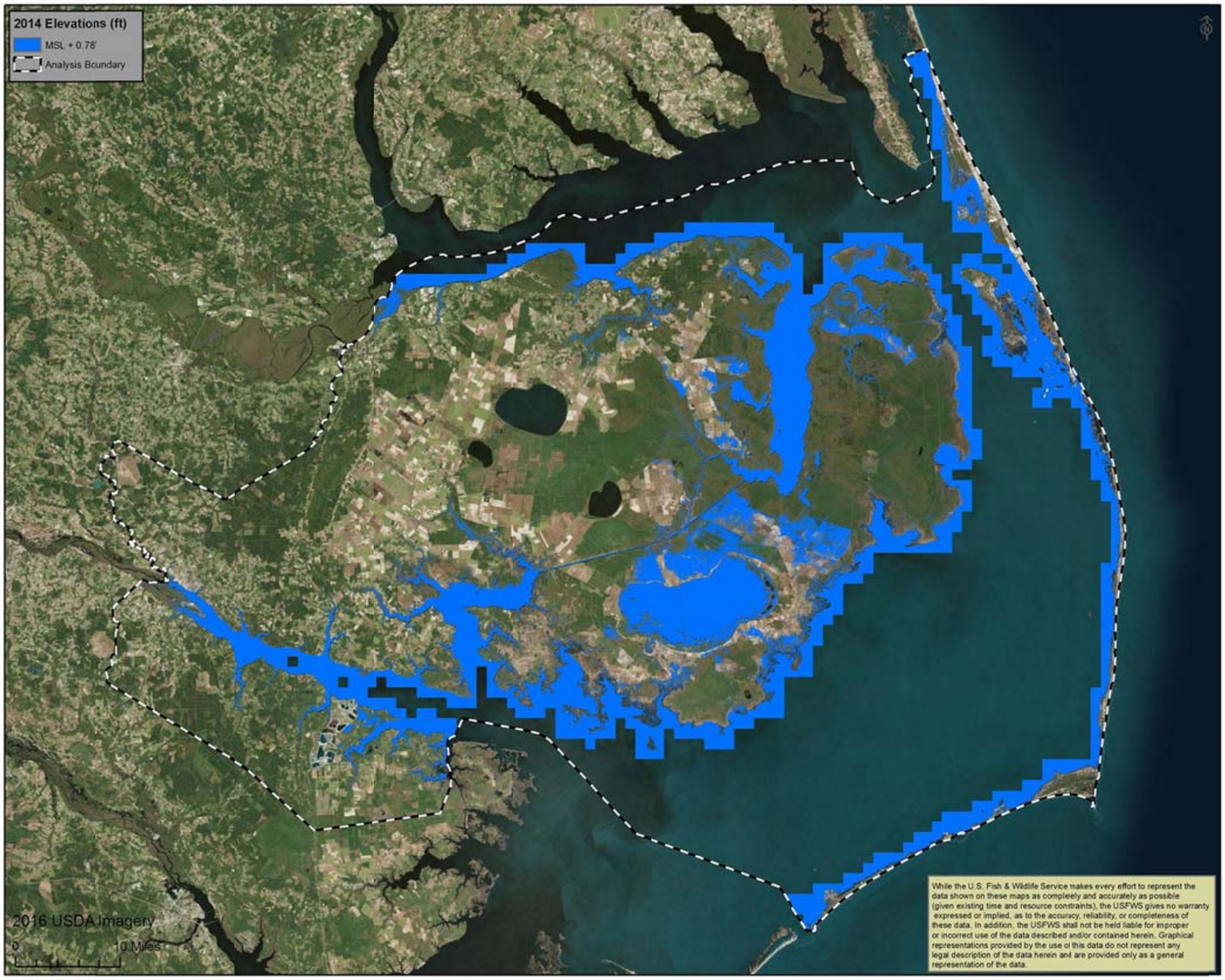
X	Movement (3.3 per year for 15 years then every 5 years), NEP mortality = intermediate, NEP increased breeding	Release young animals, 3.3 per year for 15 years and then 3.3 every 5 years from year 16 to 125. NEP mortality = intermediate and increased females breeding as in Scenario F.
Y	Movement (3.3 per year for 15 years then every 20 years), NEP mortality = intermediate, NEP increased breeding	Release young animals, 3.3 per year for 15 years and then 3.3 every 20 years from year 16 to 125. NEP mortality = intermediate and increased females breeding as in Scenario F.
Z	Recovery on federal lands only	Hypothetical effects of only using federal lands for NEP recovery, scenario includes: Increased coyote impact on reproduction as in Scenario H; NEP K reduced to 25 based on estimates of numbers of territories available on federal land; Release 1 animal every other year from the SSP; Initial NEP reduced to 14 animals (8 adults, 4 pups, 2 juveniles)
Release scenarios - Releases + SSP + NEP changes		
AA	Movement (3.3 per year), SSP 400 spaces, SSP 25% breeding, NEP mortality = intermediate	Release as in Scenario Q + 400 SSP spaces + increased SSP breeding (as in scenario M) + decreased NEP mortality
BB	Movement (3.3 per year), SSP 400 spaces, SSP 25% breeding, NEP mortality = intermediate, NEP increased breeding	Release as in Scenario Q + 400 SSP spaces + increased SSP breeding (as in scenario M) + decreased NEP mortality + increased NEP breeding

NEP & SSP populations parameter sensitivity testing		
CC	No BSR bias	Offspring sex ratio (birth sex ratio, or BSR) set as 50% males (no bias due to inbreeding).
DD	No inbreeding	Remove future inbreeding effects. Use parameter values based on each population's median current inbreeding level, such that offspring sex ratio = 48.8% male, litter size is a Poisson distribution with a mean of 3.97 for the SSP and 4.64 for the NEP, and first year mortality is 37.7 for the SSP and 47.4 for the NEP. See Appendix 1 for more details.
EE	No genetic management of SSP	For the SSP population, stop genetically managing by mean kinship and allow individuals to be paired and given a breeding recommendation randomly regardless of their mean kinship.
FF	SSP Current Number of Pairs	For the SSP, restrict reproduction to reflect the current number of pairs that are being made within existing space (rather than allowing Vortex to make enough pairs to "breed to K”). Over the past three years, the SSP has recommended an average of 29.3 breeding pairs (Table A1). In the model, this is implemented by allowing the first 29 paired females to have a 19% probability of breeding success and, beyond that, pairs have a 0% probability of breeding success.
GG	No Environmental Variation in any demographic parameters	For the NEP only, evaluate the impact of EV on model results by setting all EV values to 0

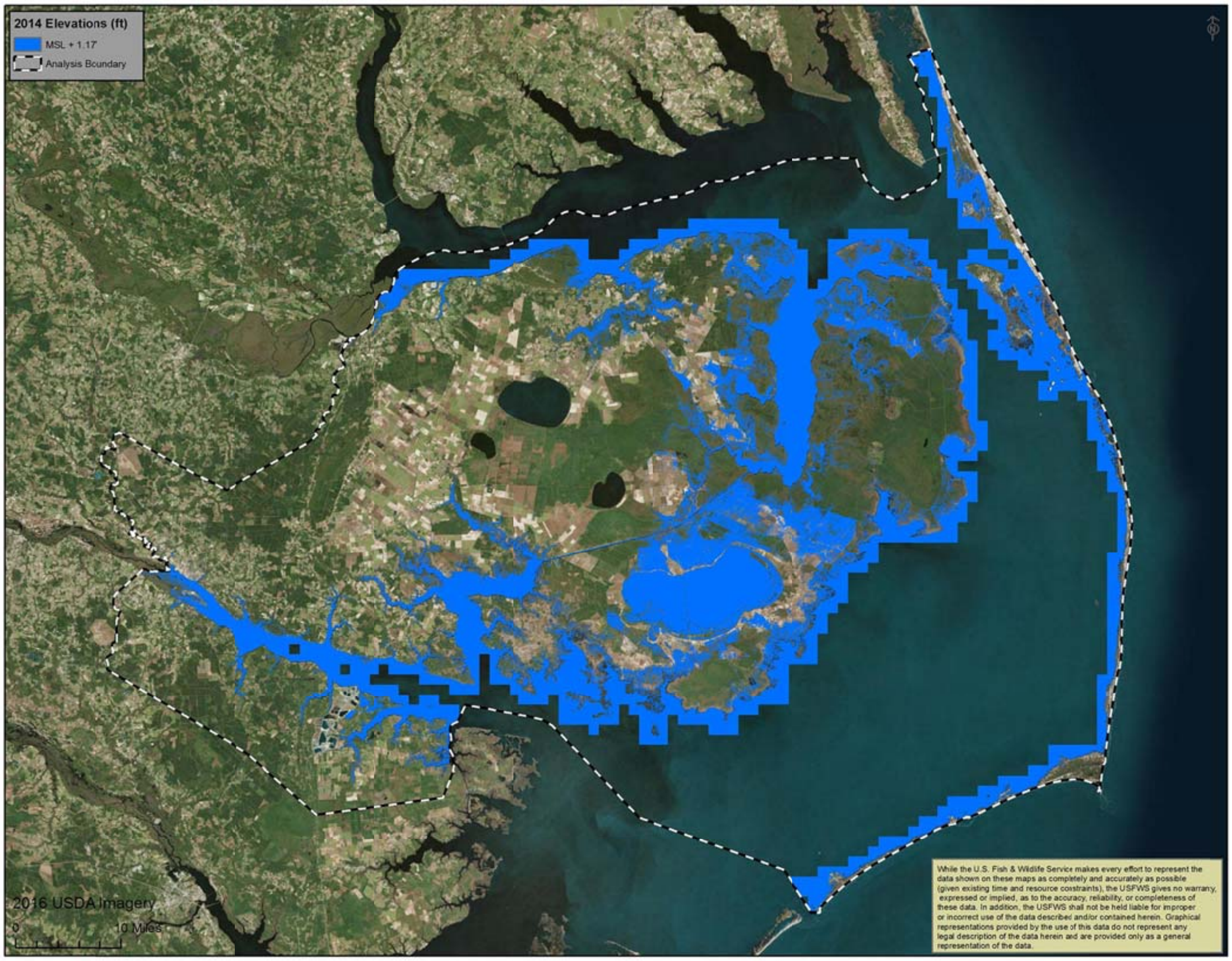
APPENDIX 3: MAPS SHOWING INTERMEDIATE TIME STEPS FOR SEA LEVEL RISE ON THE ALBEMARLE PENINSULA



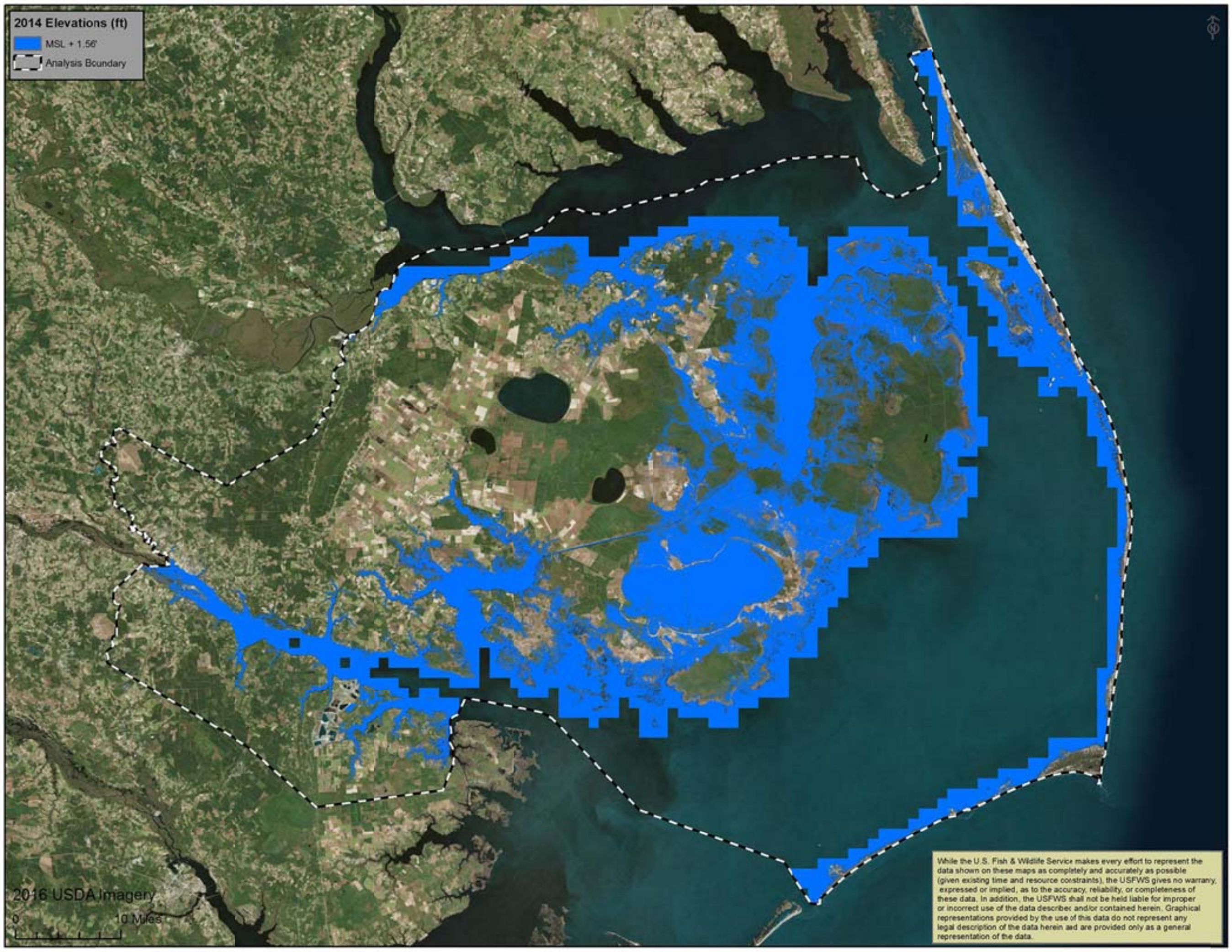
Appendix 3, Map 1: MSL at 25 years for the NEP.



Appendix 3, Map 2: MSL at 50 years for the NEP.



Appendix 3, Map 3: MSL at 75 years for the NEP.



Appendix 3, Map 4: MSL at 100 years for the NEP.

APPENDIX 4: ADDITIONAL DATA ON COYOTE REMOVALS ON THE ALBEMARLE PENINSULA AND THE STATE OF NORTH CAROLINA (NCWRC 2017 DATA)

ALBEMARLE PENINSULA DATA

Estimated Hunter Harvest of Coyotes on the Albemarle Peninsula by Year

Year	n*	Total Harvest	Confidence Limits (+)	PSE**	% of harvest taken incidentally***
2010-11	8	632	643	0.519	7.69%
2011-12	19	670	327	0.249	27.86%
2012-13	10	324	340	0.535	0.00%
2013-14	8	331	551	0.849	0.00%
2014-15	7	214	218	0.520	0.00%
2015-16	9	351	384	0.558	14.29%
2016-17	9	195	191	0.500	33.33%

Notes: *"n" denotes the number of survey respondents; **PSE is the percent standard error (a measure of precision), and ***% harvest taken incidentally records that coyotes were not the primary target animal (e.g., coyote may have been taken while hunters were hunting deer, for instance); 95% confidence limits are large, likely due to the small number of survey respondents used to generate the estimate

Estimated Trapper Harvest on the Albemarle Peninsula by Year

Year	n*	Est. Total Harvest in AP	Confidence Limits (±)	PSE**
2012-13	27	307	212	0.352
2013-14	17	190	119	0.321
2014-15	21	297	176	0.302
2015-16	14	88	37	0.218
2016-17	19	265	126	0.243

Notes: *"n" denotes the number of survey respondents; **PSE is the percent standard error

STATEWIDE DATA

Estimated Trapper Harvest in North Carolina by Year

Year	**n**	**Est. Trapper Harvest**	**Confidence Limits (±)**	**PSE**
2012-13	504	5,419	917	0.086
2013-14	558	6,951	1,141	0.084
2014-15	516	7,611	1,605	0.108
2015-16	434	7,643	1,451	0.097
2016-17	474	6,337	958	0.077

Notes: *"n" denotes the number of respondents; **PSE is the percent standard error