USING GEOGRAPHIC INFORMATION SYSTEMS TO EXAMINE RED WOLF HOME RANGE AND HABITAT USE IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK

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To the Graduate Council:

I am submitting herewith a thesis written by Harry Ford Mauney entitled "Using Geographic Information Systems to Examine Red Wolf Home Range and Habitat Use in the Great Smoky Mountains National Park." I have examined the final electronic copy of this thesis for form and content and recommend it be accepted in partial fulfillment of the requirements for the degree of Masters of Science, with a major in Environmental Science.

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DEDICATION

This thesis is dedicated to my parents, Harry Mauney and Rosamary Mauney. I owe my work ethic, determination, endurance, and skills as an outdoorsman to my father. I thank my mother for encouraging my investigations of the natural world as a child, the freedom she gave me in expressing myself, and her undying support of my pursuit of higher education.

I will always remember the insects in the jars.

My parents gave me the freedom to follow my dreams and the will to achieve them.

I will never forget that.

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ABSTRACT

A Geographic Information System (GIS) analysis was conducted to determine home range and habitat use patterns of the reintroduced red wolf (*Canis rufus*) in the Great Smoky Mountains National Park (GSMNP). To facilitate this GIS analysis, the original telemetry data was first converted from obsolete file formats into a contemporary database. When spatial movement patterns of animals are analyzed with regard to habitat characteristics, habitat use patterns may be revealed.

In order to ascertain gender-based home range and core area size differences, home range and core areas were determined for 16 of 31 red wolf datasets (9 male, 7 female). A fixed kernel analysis with least squares cross validation was used to determine home range (95%) and core areas (50%) from location estimate datasets with outliers removed (5%). I determined the mean value for the 95% home range of adult male wolves ($n = 4$) to be 18.44 km^2 +/- 5.29 (mean +/- SE), and the mean value of adult female wolves ($n = 3$) to be 18.98 km^2 +/- 5.53. I compared the dependent variables of home range (95%) and core area (50%) size of 7 adult wolves (3 females, 4 males) and found no significant gender-based difference in male and female home range and core area size using a Studentized t-test (t (5) = 0.078, $p > 0.05$, two-tailed).

The GIS based use-availability analysis examined location estimates with respect to three habitat attributes: aspect, slope, and land cover. Individual home range (95%) estimates were used to independently define the available habitat of individual red wolf datasets. The independent variable, individual wolves, and three dependent variables, aspect, slope, and land cover were tested using *Chi* square tests for goodness of fit ($\alpha = 0.05$). Individual red wolf datasets displaying habitat use significantly different from random were further examined and assigned individual habitat use values (+, 0, -). These values were established by comparing observed and expected habitat use values for each habitat classification within each habitat attribute for each individual wolf dataset. Individual red wolf habitat use values were then examined in an attempt to detect overall habitat use trends among the non-random datasets within each of the three habitat attributes.

In the absence of comparative red wolf home range and habitat use data, the results of three eastern coyote studies were used to make comparisons. I used eastern coyote studies from Vermont, south-central Georgia, and the GSMNP. Red wolf home range estimates were similar but slightly larger than home range estimates for Vermont and Georgia coyotes. Habitat use patterns of male and female red

wolves in the GSMNP were similar and that habitat usage suggested a habitat preference. The null hypothesis that red wolf utilization of aspect is proportional to its availability within their 95% home range was rejected for 4 of 16 wolves (3 females, 1 male). There were no trends in aspect use detected. The null hypothesis that red wolf utilization of slope is proportional to its availability within their 95% home range was rejected for 10 of 16 wolves (6 females, 4 males). There was no difference detected between male and female red wolf utilization of habitat in respect to slope. Male and female red wolves utilized habitat with slopes less than 20% greater than expected and utilized habitats with greater than 20% slope less than expected. The null hypothesis that red wolf utilization of land cover is proportional to its availability within their 95% home range was rejected for 8 of 16 wolves (5 females, 3 males). Red wolf habitat use was greater than expected for the land cover classifications of pasture and deciduous forest. Red wolf habitat use was less than expected for the land cover classifications of evergreen forest and mixed forest.

Home range comparisons between the two species indicated the red wolf had a slightly larger home range size than eastern coyotes. A larger red wolf home range may be a function of the difference in body size and diet of the two species. The coyote is a highly adaptive generalist, while the red wolf may be more of a specialist. Habitat use patterns of the red wolf were also similar to GSMNP, Georgia, and Vermont coyotes in that all used deciduous forest greater than statistically expected. Habitat use patterns varied between canids occurring in the GSMNP and those occurring in Vermont and Georgia for pastures or open areas. Red wolves and GSMNP coyotes utilized pastures diurnally, while coyotes in Vermont and Georgia were active in open areas and field nocturnally. Temporal differences in habitat use inside and outside the GSMNP may be directly related to hunting pressure. The GSMNP provides canids protection from the hunting pressures which may come to bear on coyotes in Vermont and Georgia.

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CHAPTER I
INTRODUCTION

General

The red wolf (*Canis rufus*) is one of the first endangered species to attract recovery attention by the U.S. Fish and Wildlife Service (FWS) (U.S. Fish and Wildlife Service 1989). This secretive species once ranged over the majority of the eastern half of the United States. The historical range of the red wolf encompassed the area to the southeast of a line drawn from New York to East Texas (U.S. Fish and Wildlife Service 1989; Choate *et al.* 1994). Red wolf numbers began to rapidly decline during the 19th and 20th centuries because of increased levels of persecution and habitat modification resulting from European settlement (U.S. Fish and Wildlife Service 1989; MacDonald and Sillero-Zubiri 2004). The red wolf was persecuted because it was perceived as a threat to humans and livestock. Interest in the ecology of the species was limited to deriving a more efficient way of eliminating the wolf. Government bounty programs were very effective at reducing red wolf numbers (U.S. Fish and Wildlife Service 1989). Red wolves were not as wary as coyotes and more readily approached the poisoned baits and trap sets of bounty hunters (Paradiso and Nowak 1972; U.S. Fish and Wildlife Service 1989). By the late 1960's, the few remaining red wolves were restricted to marginal habitats in forested bottomlands and coastal marshes of the Gulf Coast region in east Texas and southwest Louisiana (Riley and McBride 1972; U.S. Fish and Wildlife Service 1989). Coyotes (*Canis latrans*) began to move into areas left vacant by the removal of red wolves. In an attempt to stabilize the diminishing population, the FWS listed the red wolf as an endangered species, giving it protected status under the Endangered Species Preservation Act of 1967 (U.S. Fish and Wildlife Service 1989). As populations continued to decline, it became increasingly difficult for red wolves to locate conspecifics during the breeding season. As a result, the red wolves began to hybridize with the growing coyote population.

In late 1973, the red wolf gained further protection under the Endangered Species Act (ESA) (U.S. Fish and Wildlife Service 1989). An interim recovery team was appointed in late 1974 that soon thereafter received official sanction by the FWS (U.S. Fish and Wildlife Service 1989). In early 1974, Carley (1975) informed the United States Fish and Wildlife Service that a "wolf-coyote hybrid swarm" spreading eastward from central Texas imperiled the remaining purebred red wolves. In 1975, the FWS determined that the only way to save the red wolf was to remove all remaining animals from the wild (U.S. Fish and Wildlife Service 1989).

The red wolf was extirpated from much of its original range prior to the early 1920's. This extirpation prevented the documentation of red wolf geographic range and habitat usage within their historical range (U.S. Fish and Wildlife Service 1989). Complete ecological profiles would have been beneficial to the species recovery efforts, but at the time of removal, long-term research was not feasible. The urgency of the small and rapidly diminishing populations constrained research efforts to techniques used in the identification of the red wolf or techniques essential to the captive breeding phase of the species recovery plan (U.S. Fish and Wildlife Service 1989). These studies included sonographic analysis of canid vocalizations, electrophoretic and chromosomal analysis techniques, x-ray techniques for identifying live canids based on skull morphology, and evaluation of internal and external parasites of canine populations within the red wolf range (U.S. Fish and Wildlife Service 1989).

Trapping efforts from 1973 through 1980 yielded over 400 prospective canids (U.S. Fish and Wildlife Service 1989). They were evaluated for entry into a breeding certification program as probable red wolves based on morphological characteristics considered unique to the red wolf (U.S. Fish and Wildlife Service 1989). Of those 400 animals, only 43 were selected for a breeding certification program (U.S. Fish and Wildlife Service 1989). The screening of the offspring of these 43 canids, in combination with inadvertent mortalities, reduced the number of canids considered "pure" red wolves to 14 individuals. These 14 wolves served as the founding stock for the captive breeding program based out of Point Defiance Zoo in Tacoma, Washington (U.S. Fish and Wildlife Service 1989).

The red wolf readily reproduced in captivity, and by 1987 the captive population had reached levels sufficient to attempt a reintroduction. The FWS initiated a red wolf reintroduction effort at the 404,685 hectare (1,000,000 acres) Alligator River National Wildlife Refuge (ARNWR) on the coast of North Carolina. The reintroduction was quickly considered a success (Phillips 1993). It was soon determined that the ARNWR would not support the 220 red wolves proposed by the recovery plan (U.S. Fish and Wildlife Service 1989; Phillips 1993). In addition to potential genetic troubles, the geographic location of ARNWR posed a unique problem. Hurricanes frequently made landfall along North Carolina's outer banks, and any single population of "at-risk" animals might be destroyed by such a large-scale environmental perturbation (Phillips 1993). The potential loss of the entire wild red wolf population to inbreeding depression or a stochastic natural disaster motivated the FWS to begin the search for a second reintroduction location (Phillips 1993).

By 1990, the Great Smoky Mountains National Park (GSMNP) emerged as the place that could provide the appropriate habitat needed for a second red wolf population. The GSMNP was located within the heart of the original range of the red wolf. The GSMNP consisted of 211,621-ha (521,621 acres) and was connected to 225,005 ha (556,000 acres) of the Cherokee National Forest in Tennessee and 254,951ha (630,000 acres) of the Nantahala National Forest in North Carolina. The total acreage of federally owned lands potentially available to the reintroduction effort was approximately 691,577 ha (1,708,924 acres).

If any reintroduction were to be a success, it would need room for potential expansion. However, in the design stages of the reintroduction, the stipulation was made that any red wolf leaving GSMNP property was to be captured and returned to the park. Expansion of the reintroduction project to the adjacent National Forest Service lands would be addressed if and when necessary.

One of the reasons the FWS conducted the initial removal of the red wolf had been the potential loss of the species through hybridization with coyotes (Carley 1975; U.S. Fish and Wildlife Service 1989). Coyotes had not established dense populations along the coast of North Carolina; therefore, this was not an issue at the start of the ARNWR reintroduction. In the GSMNP, however, the exact densities of the coyote were not known. This needed to be assessed prior to the release of captive red wolves. In order to accomplish this task, a radio-telemetry study was performed on coyotes to determine their relative abundance, movements, and habitat use within the park (Crawford 1992). In addition, no red wolf life history information was established prior to their removal from the wild (U.S. Fish and Wildlife Service 1989). Therefore, the FWS had no information on which to base assumptions about the initial movements and habitat requirements of the red wolf in the Appalachian Mountains. It has been noted that despite widespread variation, comparative analysis indicates that there is remarkable consistency in the way many diverse carnivores adapt to and utilize their habitat (Beckoff *et al.* 1984). Considering this, Crawford's (1992) coyote telemetry study provided FWS biologist the best available information about the potential for hybridization, the possible movements of newly released red wolves, and the intricacies of obtaining radio-telemetry locations in the mountainous terrain.

Releases occurred at three different locations within park boundaries: Cades Cove, Tremont, and Elkmont. The GSMNP reintroduction effort began in November 1991with an experimental phase (year 1) that began with the release of a mated adult pair and two pups at the Cades Cove release site on Forge Creek. The wolves quickly settled into a stable pattern of movements within the Cove. The experimental phase was relatively problem-free, thus the decision was made to begin a full-scale reintroduction beginning in October 1992 (Lucash and Crawford 1993). The initial release of the full-scale reintroduction consisted of two adult pairs with pups. After that, red wolf pairs were released annually in the spring. Unlike the ARNWR reintroduction, the GSMNP reintroduction was hampered by frequent adult and pup mortality.

Adult wolf mortality during the reintroduction resulted from various causes including ethylene glycol poisoning, interspecific aggression, intestinal blockage, progressive retinal atrophy, gunshot wounds, and automobile collisions. No single factor contributed to a majority of the adult wolf mortalities that occurred during the 1992-1997 releases (Lucash and Crawford 1993, 1994, 1995, 1996, 1997, 1998).

Determining the causes of red wolf pup mortality was more difficult than for adult animals. In order to more closely monitor pup survival and determine the source of pup mortality, biologists implanted radio-transmitters in wolves too young to be fitted with collars (less than 6 months). Biologists were often unable to capture the complete litter for implantation with radio-transmitters and were forced to rely on visual monitoring of pup survival (Lucash and Crawford 1993, 1994, 1995, 1996, 1997, 1998). Wolf pups less than 6 weeks old were presumed dead when biologists repeatedly failed to locate them with adult wolves. Biologists considered pup survival unlikely without the protection of the adults. Recovery of red wolf pup carcasses was difficult at best. Carcasses were scavenged and subject to high rates of decomposition. The necropsies of recovered pup carcasses most often indicated that Parvovirus was the cause of death (Lucash and Crawford 1993, 1994, 1995, 1996, 1997, 1998). Interspecific aggression by coyotes represented the other confirmed source of red wolf pup mortality (Lucash and Crawford 1993, 1994, 1995, 1996, 1997, 1998). Pup movements were closely tied to those of their parents. Attempts to locate "missing" pups were continued until survival could be confirmed via the fall and winter trapping sessions. FWS biologist used these trapping sessions to confirm pup survival, to attach radio-collars to surviving offspring, and to collect basic body morphology measurements (Lucash and Crawford 1993, 1994, 1995, 1996, 1997, 1998).

After repeated reintroduction attempts at the three GSMNP study areas, it was determined that any red wolf population within the GSMNP would have to be perpetually managed. In late 1998, the FWS and National Parks Service (NPS) halted the reintroduction and all free-ranging wolves were removed from the GSMNP. The inability of wolves to establish home ranges within the park and extremely low pup survival were given as the reasons for the stoppage of the reintroduction effort (Henry 1998).

Biologists often neglect to analyze data collected during unsuccessful reintroductions to determine potential reasons for failure. Dodd and Seigel (1991) issued a warning to Species Recovery teams that failure to determine causative factors involved in failed reintroductions doom them to repeat their errors. Teunissen van Mannen *et al.* (2000) did employ data collected during the GSMNP reintroduction effort to develop a predictive model to determine habitat suitability for future reintroductions, but no analysis was done to specifically determine habitat usage of the GSMNP wolves.

Recent technological advances have increased computer processor speeds and have enhanced the power of analytical software such as home range estimators and Geographic Information Science (GIS). Combining GIS and Kernel home range estimators may prove to be valuable wildlife management tools that allow detailed investigation into habitat usage (Taulman and Seaman 2000; Selkirk and Bishop 2002). Tools developed in GIS offer the wildlife manager the ability to perform large-scale statistical analyses in a fraction of the time that was once necessary. GIS and Kernel home range estimation techniques were just beginning to be utilized during the closing years of the red wolf reintroduction. Applying the latest versions of GIS and Kernel based utilization distributions to the GSMNP red wolf reintroduction "legacy" data may expose trends that could not be detected at the time of the project. As a former member of both the GSMNP and ARNWR reintroduction teams, I chose to model the habitat use of endangered red wolves released into the Great Smoky Mountains National Park using GIS and telemetry locations obtained during the attempted reintroduction in 1991-1998. I believe combining my first hand knowledge of the intricacies of red wolf reintroduction efforts with GIS technology will yield basic information about the species' ecology and information applicable to existing and any future red wolf reintroduction efforts.

Study Areas

Three release sites were used for the GSMNP red wolf reintroduction. They were 1) the Cades Cove study area, 2) the Tremont study area, and 3) the Elkmont study area (Figure 1). Red wolves were released from acclimation pens located within each of the three study areas.

Cades Cove Study Area

The Cades Cove study area consisted of a 2,752-ha (6,800 acres) valley near Townsend, Tennessee (Figure 2). Approximately 1300 vehicles a day visited Cades Cove to travel the 11-mile loop road (Lucash and Crawford 1993). Cades Cove was comprised of large areas of open grassland and pastures broken by wood lines and woodlots. It supported 500 cattle on 324-ha (800 acres) of pasture under lease to a cattle operation located within the center of the Cades Cove loop road during the entire reintroduction period (Lucash and Crawford 1993). Cades Cove was considered the best location for reintroducing the red wolf based on prey populations, ability to acquire telemetry locations, and ease of access. Cades Cove had white-tailed deer (*Odocoileus virginianus*) population densities that ranged from 0.20 to 0.55 deer/ha (Wathan and Neu 1989). These white-tailed deer densities were the highest within the GSMNP (Bill Stiver, National Parks Service, personal communications). Numerous maintenance roads and fields within the Cove area provided vehicle, horseback, and foot access for visual and telemetry based monitoring of wolf movements and activities. The majority of the releases that occurred during the GSMNP reintroduction were from acclimation pens located near Forge Creek in the Cades Cove study area (Lucash and Crawford 1993, 1994, 1995, 1996, 1997, 1998).

Forge Creek Acclimation Pens

In late 1990, two 23m^2 (250ft^2) acclimation pens were constructed at the head of a small tributary to Forge Creek 2.6 km southeast of the Cable Mill on Forge Creek Road near the southwest corner of Cades Cove. The Forge Creek area was comprised of numerous small-interconnected drainages separated by low gaps under the continuous canopy of mixed mesophytic forest.

Cooper's Branch Management Pens

In late 1996, two 23m^2 (250ft^2) management pens were constructed along Cooper's Branch near the Cades Cove ranger station. These pens were used to hold free-ranging wolves for short periods of captivity. Short-term captivity was necessary to administer annual vaccinations and to facilitate veterinary examinations. The management pens also served as a temporary holding area for animals not destined for release. These particular animals were associated with the captive breeding program and were being transferred between captive breeding facilities.

Tremont Study Area

In June of 1992, two $23m^2$ ($250ft^2$) pens were constructed approximately 8km (5 miles) east southeast of Cades Cove and 2km (1.2 miles) south-southeast of the Great Smoky Mountains Institute at Tremont along a tributary of the Middle Prong of the Little River (Figure 3). The pens were located in the Thunderhead Prong drainage basin. The area consisted of a moderately sloped central valley that varied in width. Smaller tributaries formed smaller fingerlike glens extending outward from its centerline. The area had a mixed mesophytic forest overstory and a relatively open understory with patches of mountain laurel (*Kalmia latifolia*) and members of the genus *Rhododendron* dispersed along the creek beds. In terms of distance from centers of human activity, the Tremont study area was the most remote of the three study areas. Hiking trails along Thunderhead Prong drainage received a relatively low number of human visitors. Individuals hiking in this remote area were usually NPS employees, experienced hikers, or local trout fishermen.

Elkmont Study Area

The Elkmont study area was located 18km (11.2 miles) east of Cades Cove and 6km (3.7 miles) southwest of GSMNP headquarters at Sugarlands along Jakes Creek south of Elkmont Campground (Figure 4). The Elkmont pens were erected in January 1994 in close proximity to a small pasture 0.2 km (0.1 miles) from the historic Civilian Conservation Corps cabins to the south of Elkmont campground. Only two of the cabins were still occupied. Despite its close proximity to the campground, historic cabins, and hiking trails, this site also received limited human visitation. This location was chosen primarily for the ease of access to the pens.

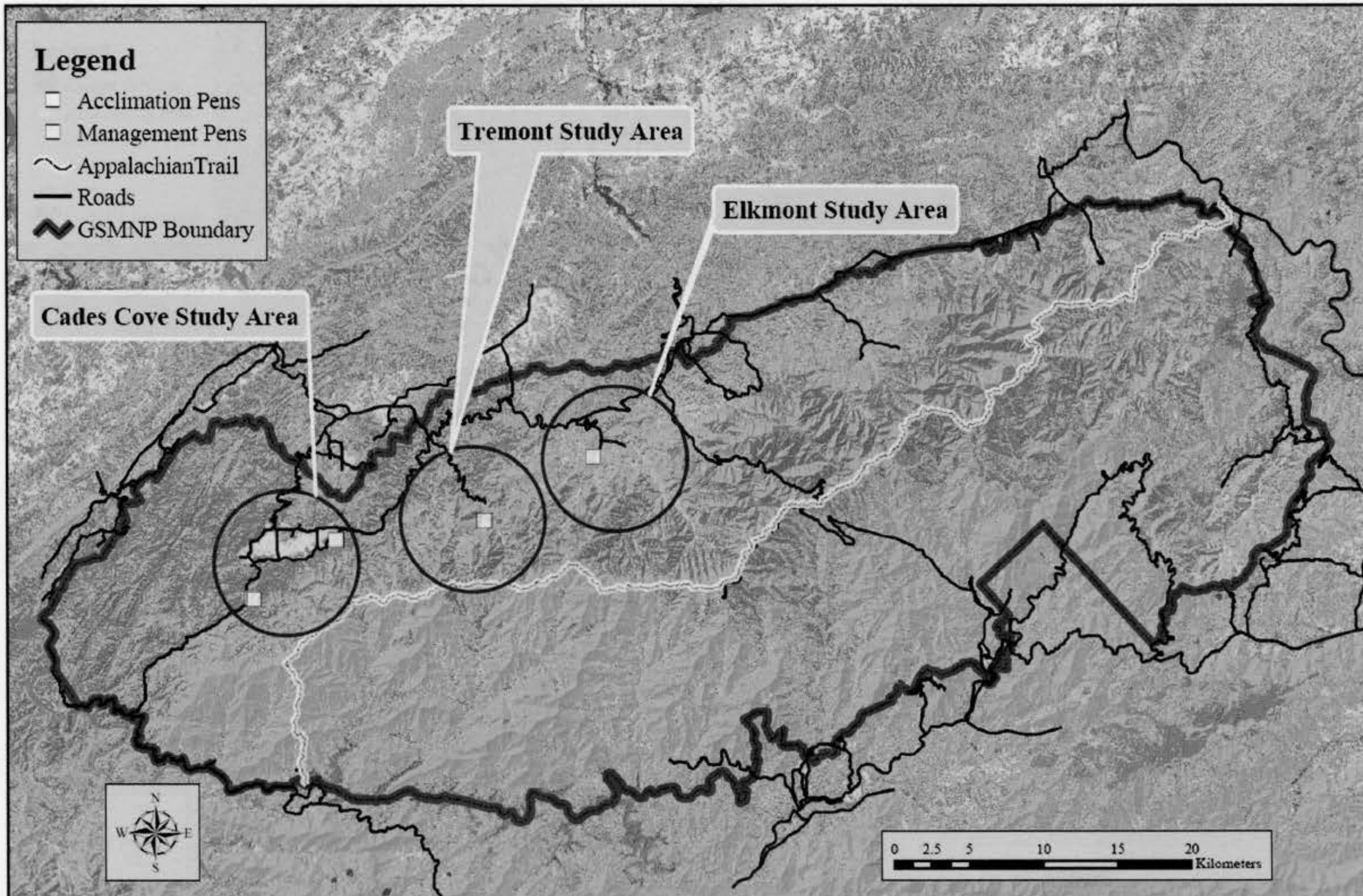

Figure 1. General location of the three study areas (red circles) within the park and the position of the acclimation pens (white squares).

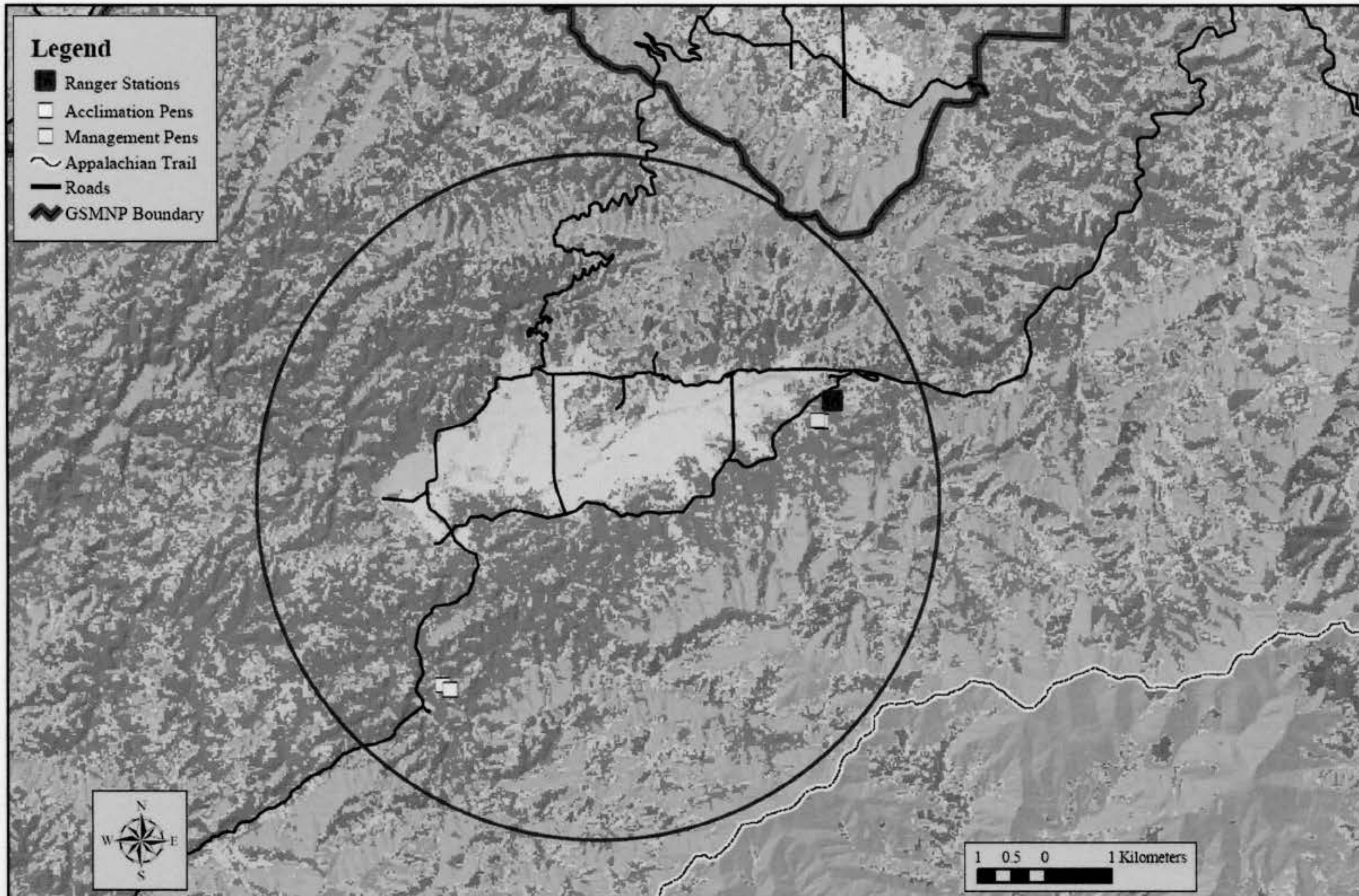

Figure 2. Cades Cove Study Area general location (red circle) and the position of the Forge Creek acclimation pens (white square) and the Cooper's Branch management pens (yellow square).

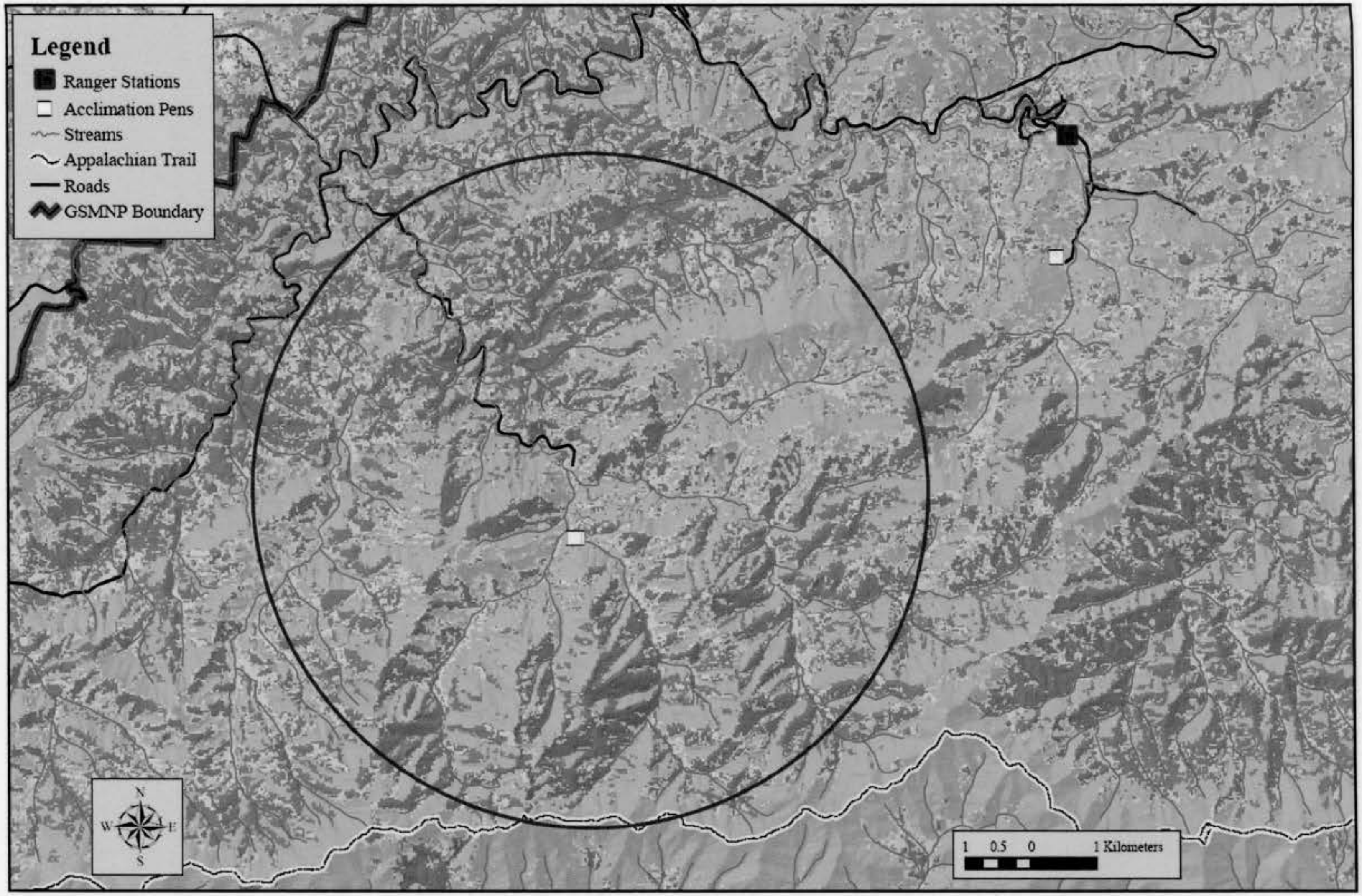

Figure 3. Tremont Study Area general location within the park and its position in relation to the Appalachian Trail and the park boundary.

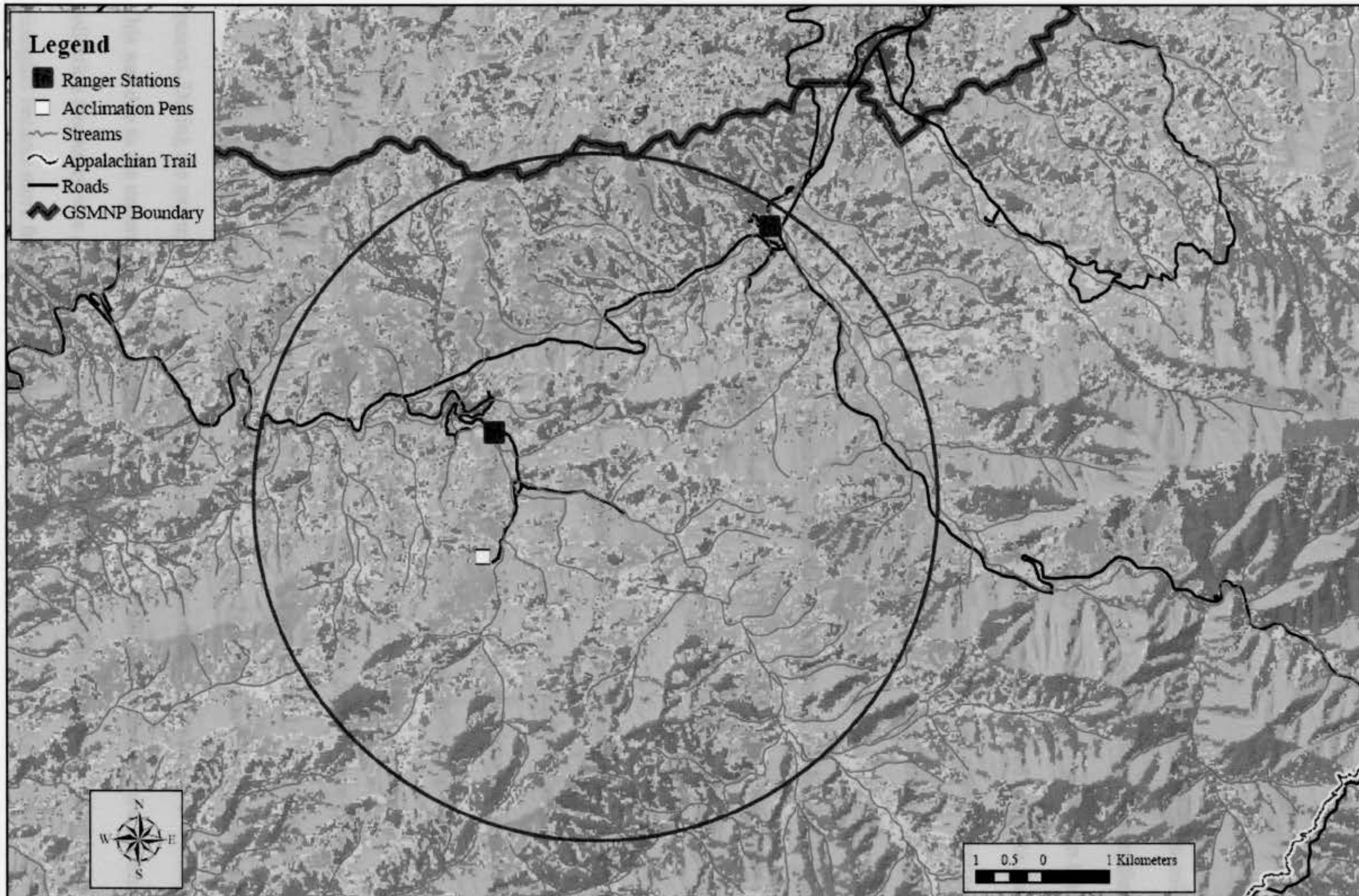

Figure 4. Elkmont Study Area general location within the park and its position in relation to the park boundary. Elkmont ranger station (left), and NPS Headquarters at Sugarlands ranger station (right).

CHAPTER II
METHODS

Location Data

Data Collection

Approximately 2,851 location estimates were compiled from 31 datasets for 27 radio-collared red wolves (11 female and 16 male). FWS biologists and NPS technicians, including myself, were the primary collectors of red wolf location data used in this analysis. Telemetry locations were recorded in Universal Transverse Mercator (UTM) coordinate system format on data sheets and transcribed into data files using MSDos 3.1© software (Wilson *et al.* 1996). Locations of radio-collared red wolves were determined using receivers (Telonics, Mesa, AZ and Wildlife Materials, Inc., Carbondale, IL) with 8-element antennas (Hy-Gain Electronics, Lincoln, NE) mounted on 40 ft (12.2 m) stationary masts, RA-2A and RA-14 2-element hand-held antennas (Telonics, Mesa, AZ), 5-element vehicle mounted antennas, and by aerial locations from fixed wing aircraft. Collection data consisted of station location, azimuth, time, date, signal strength, animal disposition (moving/stationary), and position location (based on visual sighting and estimated using topographic maps or telemetry data).

Position location data were derived from 1) individual data collectors estimating their point locations on 1:24,000 topographic maps, and/or 2) by batch calculation in TELEM88 based on individual wolf azimuth and station location data (Coleman and Jones 1988). Position locations based on visual sightings by ground tracking individual red wolves were estimated on topographic maps and the coordinates determined with a transparent UTM grid-coordinate tool. Point location estimates with error polygons with a radius greater than a 150m were rejected. All the original datasets were processed with TELEM88© to output position estimates in 5-digit easting and 6-digit northing UTM coordinates.

The data collection frequency was varied throughout the 7-year reintroduction project for various reasons. During the experimental release period (1991-92), location data were collected at 6-hour intervals. This was due to the uncertainty of the initial movement patterns of the wolves in their new habitat. The data collection frequency was gradually decreased to once daily after wolf movements stabilized and the biologists became more familiar with animal movement trends. The frequency of data collection increased during 1994 when the livestock operator in Cades Cove began to suspect wolf predations of calves. At that time, monitoring of Cades Coves free-ranging wolves was increased to once every four hours in order to determine the exact source of the calf predations. Frequency in data collection was also increased 1) during the wolf reproduction season (in order to establish den locations) and 2) when wolves roamed outside park property. Though periods of increased monitoring did occur, the standard protocol for telemetry collection was once daily for the Cades Cove study area and once every other day for Elkmont and Tremont study areas.

Data Transformation

The original data were received from the FWS service in electronic text file format. These files were imported into a Microsoft Access© database and edited for incomplete entries and formatting errors. Erroneous entries consisted of descriptive text output generated by TELEM88© that 1) contained no location information, or 2) represented a duplicate entry. The original UTM coordinates were converted from 5 digit easting and 6 digit northing format to 6 digit easting and 7 digit northing format to facilitate conversion to GIS point shapefiles. This conversion had no significant impact on the data analysis.

Dataset Selection Criteria

In determining which datasets to utilize for the habitat analysis, several factors were considered: standard dataset size criterion for statistical analysis (30 samples), length of sampling period, sequential nature of datasets, characteristics indicative of asymptotic datasets, and management practices influencing habitat selection. The first dataset selection criterion required that the following information be present for each dataset: wolf id, time, date, northing and easting coordinates

The second criterion was that each dataset must consist of greater than 50 location estimates. Kernel estimates of home range have been shown to reduce sampling error with an increase in sample size (Seaman *et al.* 1999). There was no analytical method for determining the appropriate sample size for non-parametric home range estimators because they have no associated variance estimator (White and Garrot 1990). It has been suggested that between 100 and 300 locations were necessary for Minimum Convex Polygon home range estimators to display asymptotic characteristics (Beckoff and Mech 1984, Laundré and Keller 1984, Harris *et al.* 1990). Kernel based home range estimators using Least Squares Cross Validation applied to datasets containing less than 50 locations have been shown to overestimate home range size (Seaman *et al.* 1999). Datasets used in this model would be limited to those sets containing greater than 50 locations in order to prevent the overestimation of available habitat.

The third criterion was that each dataset must be collected on an animal that was free-ranging for at least 6 months. Due to FWS management practices, only wolves that established relatively stable movements within park boundaries were allowed to remain free-ranging. Datasets collected for wolves under the FWS movement constraints over long periods (>6 months) should theoretically contain a larger number of habitat use samples within the home range. This should result in a better representation of red wolf habitat utilization within the GSMNP. Location data collected for less than six months may not adequately sample wolf activity within all of its 95% home range. Datasets collected over a period in excess of a year were considered subject to errors when trying to define a seasonal home range due to changes in the home range across the seasons (Garshelis 2000). Red wolf habitat use data was generally collected once daily at approximately the same time of day. The frequency and duration of data collected on red wolves limited the model resolution to the detection of general trends in red wolf habitat utilization. For the purposes of this study, datasets needed to be greater than 6 months in duration to be useful in the detection of trends across seasons.

The fourth criterion was that each dataset must be continuous or unbroken by a length period of captivity. Per management policy in place at the time, wolves exhibiting wide-ranging movements outside park boundaries for great distances or extended periods were considered transient wolves. Transient behavior was not considered representative of an animal with a stable home range. Transient behavior was consistent with dispersing animals that were unable to establish a territory (Gese *et al.* 1988a, 1988b). FWS personnel attempted to encourage transient wolves to establish home ranges on park property by returning them to captivity at their original release site for a short period (less than 1month) and then re-releasing them. If transient movements persisted after the first capture and release, the wolf was paired with a new mate at another release site for a longer period (greater than 1month) for future release. If, after several acclimation attempts, transient wolves were unable to establish a home range within the GSMNP, they were either transported to ARNWR for release or placed in the captive breeding program.

The movements of transient wolves on private land often brought them in close proximity to anthropogenically modified habitat such as cattle farms, rural homesteads, and urban rental and housing developments. Areas outside of the park contained land cover types that were either absent from or proportionally underrepresented within the park. Habitat use data collected for wolves regularly traveling outside park boundaries were considered a potential source of bias. Point locations of dispersing wolves could represent habitat use influenced by human avoidance behaviors, anthropogenic food sources, and/or the restricted availability of land cover undisturbed by human development. In order to reduce bias from data collected on animals exhibiting transient movement, it was decided to limit data used in my use-availability modeling effort to animals with continuous datasets.

Resultant Datasets

The data collected during the reintroduction effort consisted of 47 telemetry files for 27 individual wolves. Of the 47 files, twelve contained duplicate datasets and were excluded from further processing. Four partial datasets were merged with other data to create continuous release datasets. The resulting 31 files for 27 individual were incorporated into a Microsoft Access© database and converted to point file format in GIS. This allowed further examination based on the predetermined analysis criteria.

Of the remaining 31 files, three datasets did not meet the greater than 6 months release length criteria. Nine datasets contained less than 50 wolf position locations. Three datasets were excluded from the analysis because they were interrupted by greater than 1 week of captivity. The remaining 16 datasets (9 female, 7 male) represented 12 wolves (7 female, 5 male). Eleven (6 female, 5 male) of the 16 datasets were for adult wolves and five (3 female, 2 male) contained position locations for juveniles (greater than 6 months of age) associated with a family group. Four of the five juvenile wolves were subsequently released as adults resulting in adult red wolf datasets used in this analysis. Datasets used in the analysis ranged in size from 56 to 312 positions and consisted of 2036 total location estimates.

Geographic Information Systems

Home Range Estimation

There are several home range estimation techniques available to wildlife researchers. Convex polygon and harmonic mean analysis (HMA) programs such as TELEM88© and HOMERANGE© have been used frequently in black bear research (Ackerman *et al.* 1990, Teunissen van Manen 1994). Convex polygon methods are sensitive to sample size. When using the convex polygon technique to estimate home range size, datasets may consist of to few location estimates to generate an asymptotic home range or contain outliers that result in the overestimation of home range size (Beckoff and Mech 1984, Laundré and Keller 1984, Harris *et al.* 1990, Teunissen van Manen 1994). The HMA home range estimation method has been shown to have little bias but lacks precision (Boulanger and White 1990).

Fixed-Kernel home range estimators with Least Squares Cross Validation (LSCV) to determine the Normal Bivariate Kernel Smoothing Factor (h) provides the least bias in home range estimates when compared to five other non-parametric home range estimators (Seaman and Powell 1996). LSCV produced home range estimates with the least amount of bias when compared with other methods of selecting a smoothing parameter (Seaman *et al.* 1999, Gitzen and Millspaugh 2003). Location data used in the Kernel method produce utilization distributions (UD) that estimated the proportional usage of different areas within the home range (Taulman and Seaman 2000). The 50% core area computed by fixed kernel analysis was determined by a contour interval in which the density of locations is greater than expected (Worton 1989).

ArcCatalog© was used to generate point shapefiles for the 16 wolf datasets used in this analysis. All point shapefiles were batch processed using ArcToolbox© to assign an NAD 1983 Transverse Mercator Zone 17 projection as suggested by Wilson *et al.* (1996). Individual red wolf location point shapefiles were added to a new view in ArcView 3.3© where outliers were removed to the 5 percent level via HMA. Fixed-Kernel home range estimation using LSCV to determine the Normal Bivariate Kernel Smoothing Factor and default output cell size (70) was then used to generate the red wolf 95 percent (home range) and 50 percent (core) probability of use polygons in the ArcView 3.3© Animal Movement extension v2.0© (Figure 5). The single 95/50% polygon shapefile was separated into two shapefiles consisting of one 95% home range and one 50% core polygon. The 95% and 50% polygons area, perimeter, acreage, and hectare values were calculated using the X-Tools Pro extension v1.0© in ArcMap 8.3©. The 95% polygon area represents an area in which there is a 95% probability of locating the animal at any given time. The 50% polygon area represents an area in which there is a 50% probability of locating the animal at any given time. The 50% polygon represents an area of greater usage, as the density of location estimates within the 50% polygon is greater than those in the 95% home range.

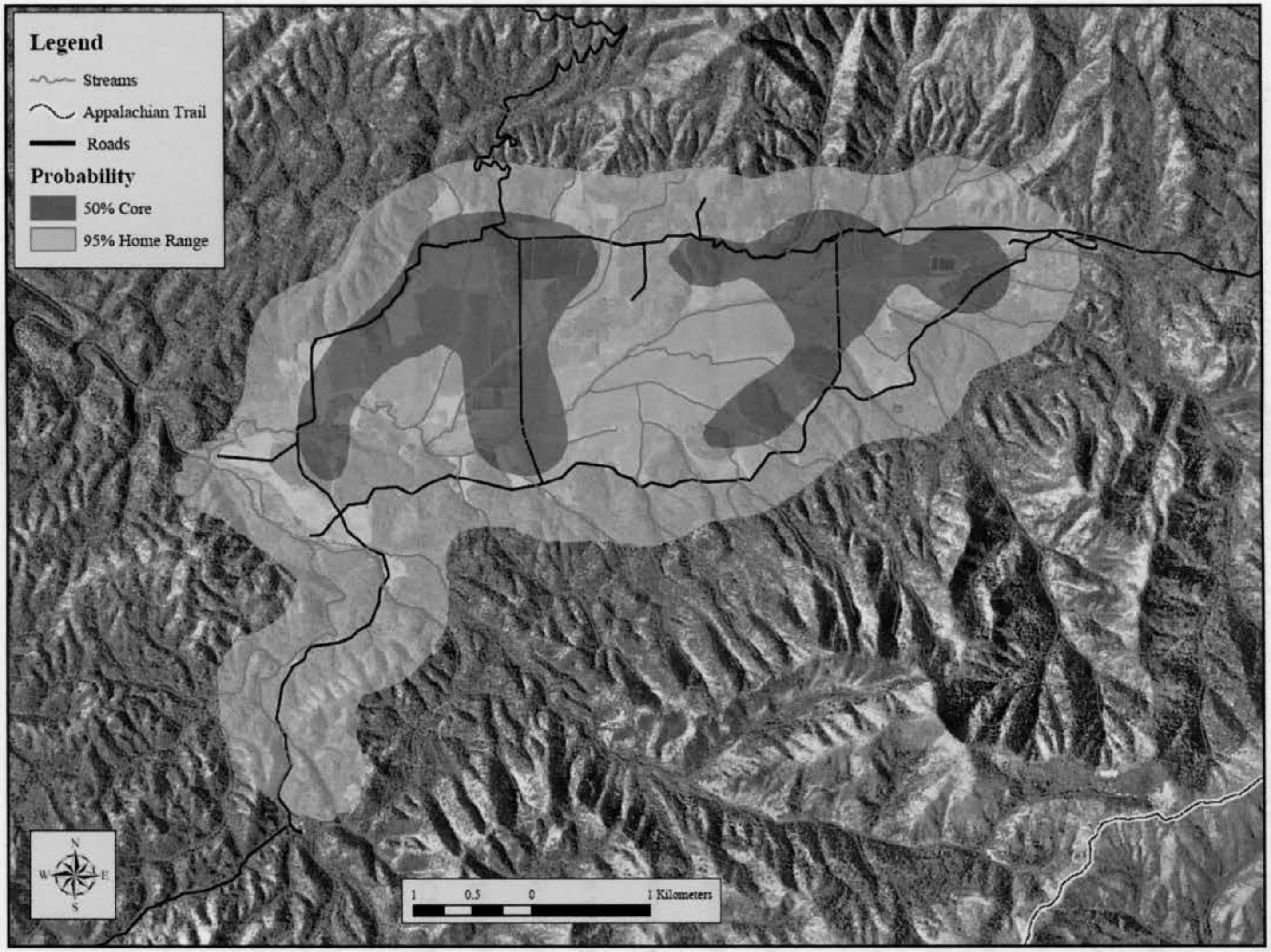

Figure 5. Fixed-Kernel estimation of 95% home range (light blue) and 50% core (dark blue) probability polygons overlaid on color infrared imagery.

Digital Elevation Model

United States Geological Survey (USGS) 10m digital elevation model (DEM) quarter quadrangles with geographic coordinates system North American Datum (NAD) 1927 projections for Tennessee (Blockhouse, Cades Cove, Calderwood, Gatlinburg, Hartford, Jones Cove, Kinsel Springs, Mount Guyote, Mount le Conte, Richardson, Waterville, and Wear Cove) and for North Carolina (Graham, Haywood, Jackson, Bryson City, Bunche's Bald, Clingman's Dome, Cove Creek Gap, Dellwood, Luftee Knob, Noland Creek, Silers Bald, Smokemont, Tapoco, Thunderhead Mountain, Tuskegee, and Whittier) were downloaded from the Geocomm GIS data clearinghouse (http://www.geocomm.com). The USGS Digital Elevation Model (DEM) data files are digital representations of cartographic information in a raster form. DEMs consist of a sampled array of elevations for a number of ground positions at regularly spaced intervals. These digital cartographic/geographic data files are produced by the USGS as part of the National Mapping Program. Quarter quadrangles making up each county were joined to form quadrangles using the raster mosaic function in ArcMap 8.3©. The raster mosaic process was then used to join the mosaic county quadrangles within each state forming a single DEM for each state. The raster mosaic process was applied to these mosaic state DEMs to form single 10m DEM for the entire GSMNP region (Figure 6). UTM coordinates systems provided the best resolution for wildlife studies due to the zone specific projections (Wilson *et al.* 1996). The regional DEM projection was then transformed from its original GCS NAD 1927 Transverse Mercator projection to a NAD 1983 Transverse Mercator Zone 17 projection using ArcToolbox© to ensure the accuracy. ArcMap 8.3© Spatial Analyst was used to perform aspect and slope analysis of the 10m DEM of the entire GSMNP region.

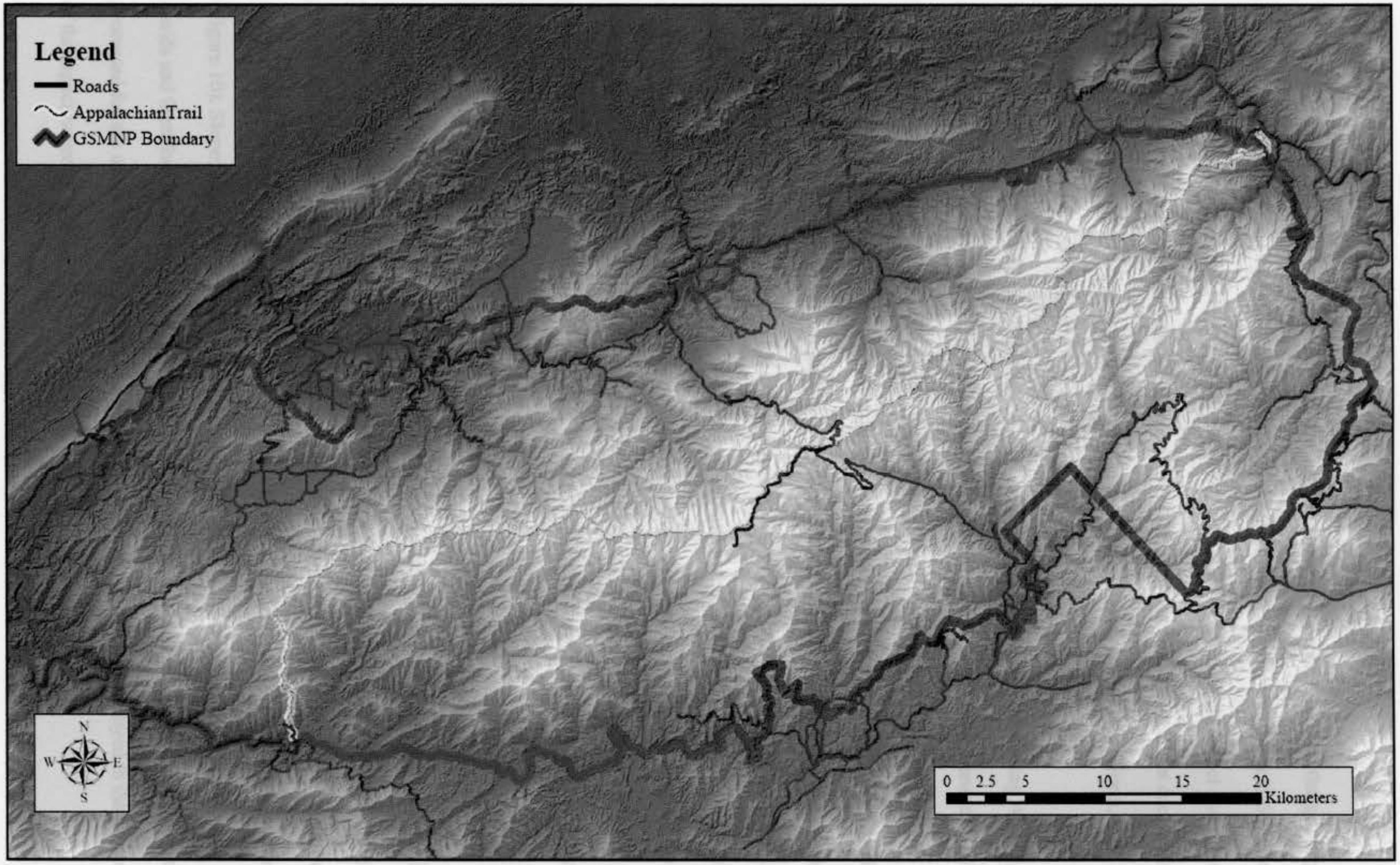

Figure 6. Ten meter digital elevation model (DEM) of the GSMNP. Major roads are depicted by thin solid black lines, the GSMNP boundary by a thick solid black line, and the Appalachian trail by a solid yellow line with a black hashed stripe.

Aspect Surface Analysis

The Spatial Analyst© extension in ArcMap 8.3© was used to generate a 10m X 10m grid aspect analysis raster based on the GSMNP DEM. The GSMNP aspect analysis raster was, by default, calculated using eight aspect classifications N, NE, E, SE, S, SW, W, and NW. Including eight aspect classifications in the use-availability analysis was deemed too detailed for this analysis. Therefore, it was decided to reclassify the aspect analysis raster to 4 classifications representing the cardinal points (North, East, South, and West) using ArcMap 8.3© Spatial Analyst (Figure 7).

The reclassified aspect raster was then converted to polygon shapefile format using ArcMap 8.3© Spatial Analyst. The aspect shapefile projection was then transformed to a NAD 1983 Transverse Mercator Zone 17 projection format using ArcToolbox©. The resulting aspect shapefile was then clipped with the 95% probability red wolf home range polygons using Geoprocessing wizard in ArcMap 8.3©. The clipping process uses the 95% polygon like a cookie cutter to clip the aspect polygons within the 95% home range (Figures 8 & 9). The table attributes of the GSMNP aspect shapefile included: polygon id, grid code, perimeter (m) and area (m^2). These table attributes are retained in the database file (dbf) of the shapefiles generated from the clipping process. The table statistics (perimeter, area, acres, and hectares) for the 95% clipped aspect shapefile were calculated using the X-Tools Pro extension v1.0 in ArcMap 8.3©. The sixteen 95% clipped aspect polygon Microsoft EXCEL© database files (.dbf) were then compiled in a 95% clipped aspect Microsoft EXCEL© Workbook (.xls) for statistical analysis.

Slope Surface Analysis

ArcMap 8.3© Spatial Analyst was used to generate a 10m X 10m grid slope analysis raster based on the GSMNP DEM. The GSMNP slope analysis raster was generated with ten classifications ranging from 0 to 90 percent. The slope analysis raster was reclassified from the 10-classes of the original slope analysis raster to four classes: 0-20 percent, 20-40 percent, 40-60 percent, and greater than 60 percent slope (Figure 10). Slopes of greater than 60 percent were considered too steep for extensive utilization for large canids and therefore were grouped into one class. The slope raster was converted to shapefile format and processed for the use-availability analysis using the GIS processing protocols employed in the processing of the aspect raster.

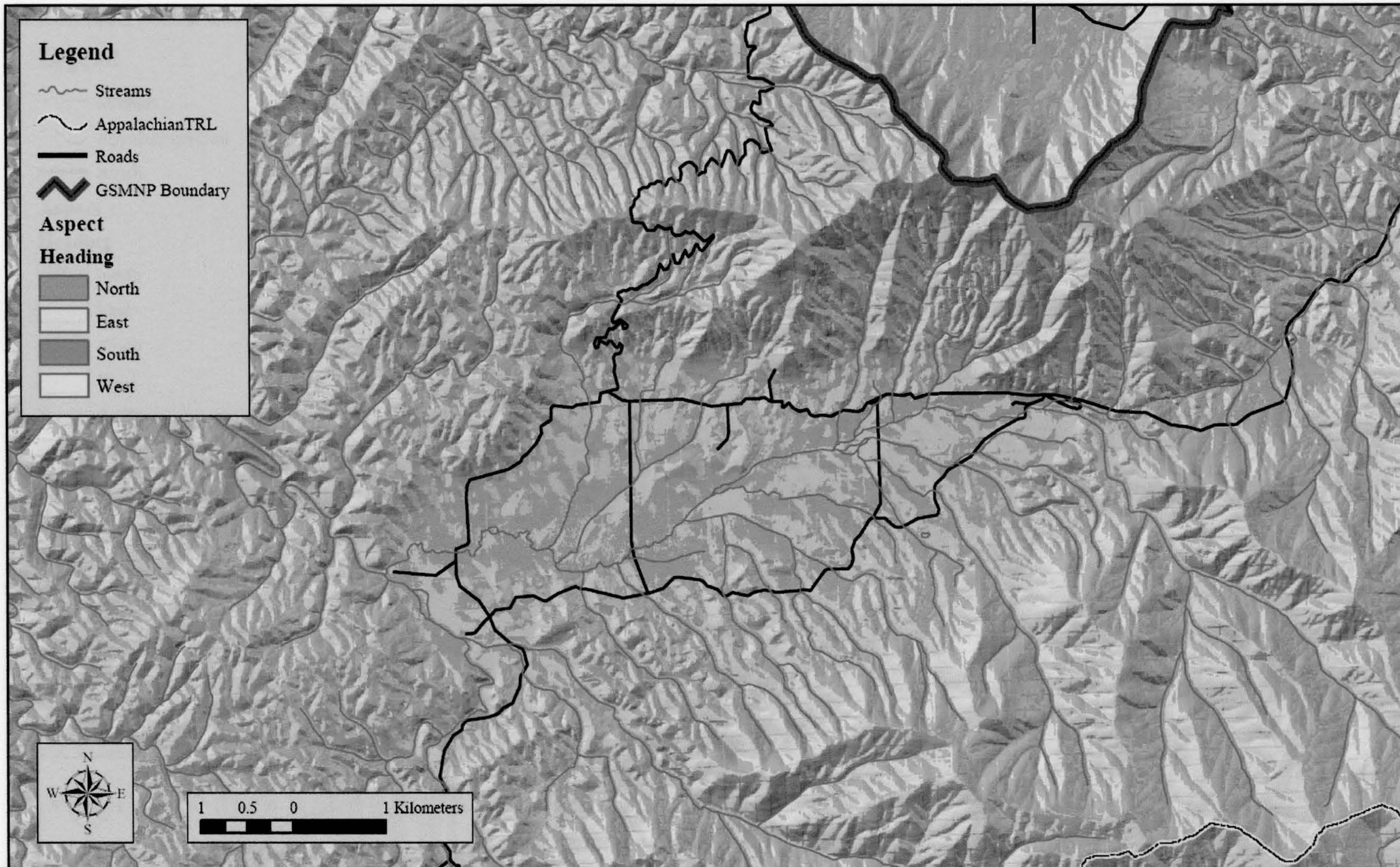

Figure 7. Four classification aspect analysis of Cades Cove study area generated from the GSMNP 10 meter DEM using ArcMap 8.3© Spatial Analyst©.

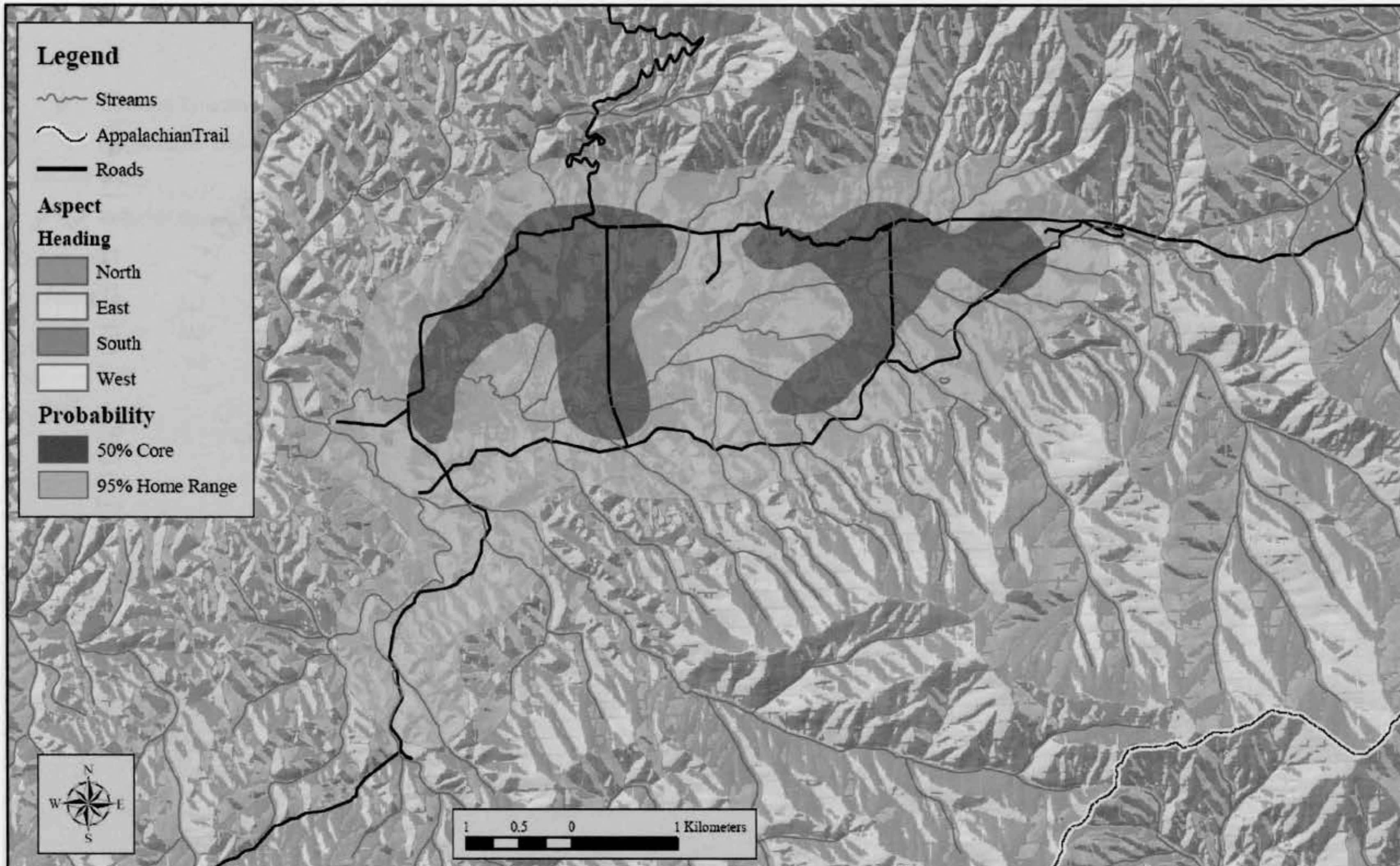

Figure 8. Aspect analysis polygon overlaid with wolf 95% home range and 50% core area polygons.

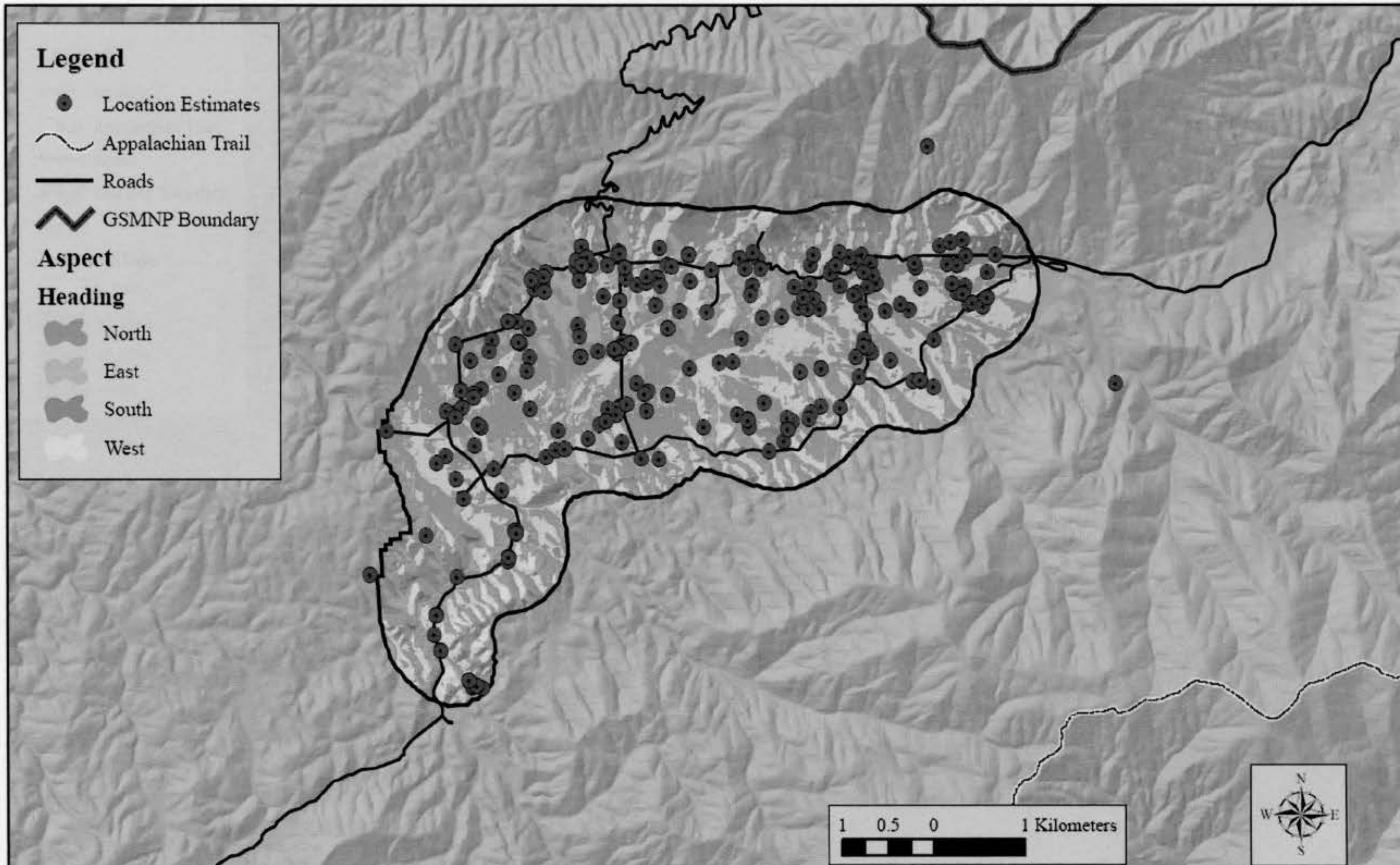

Figure 9. Aspect polygon clipped with wolf 95% home range polygon overlaid with wolf point locations.

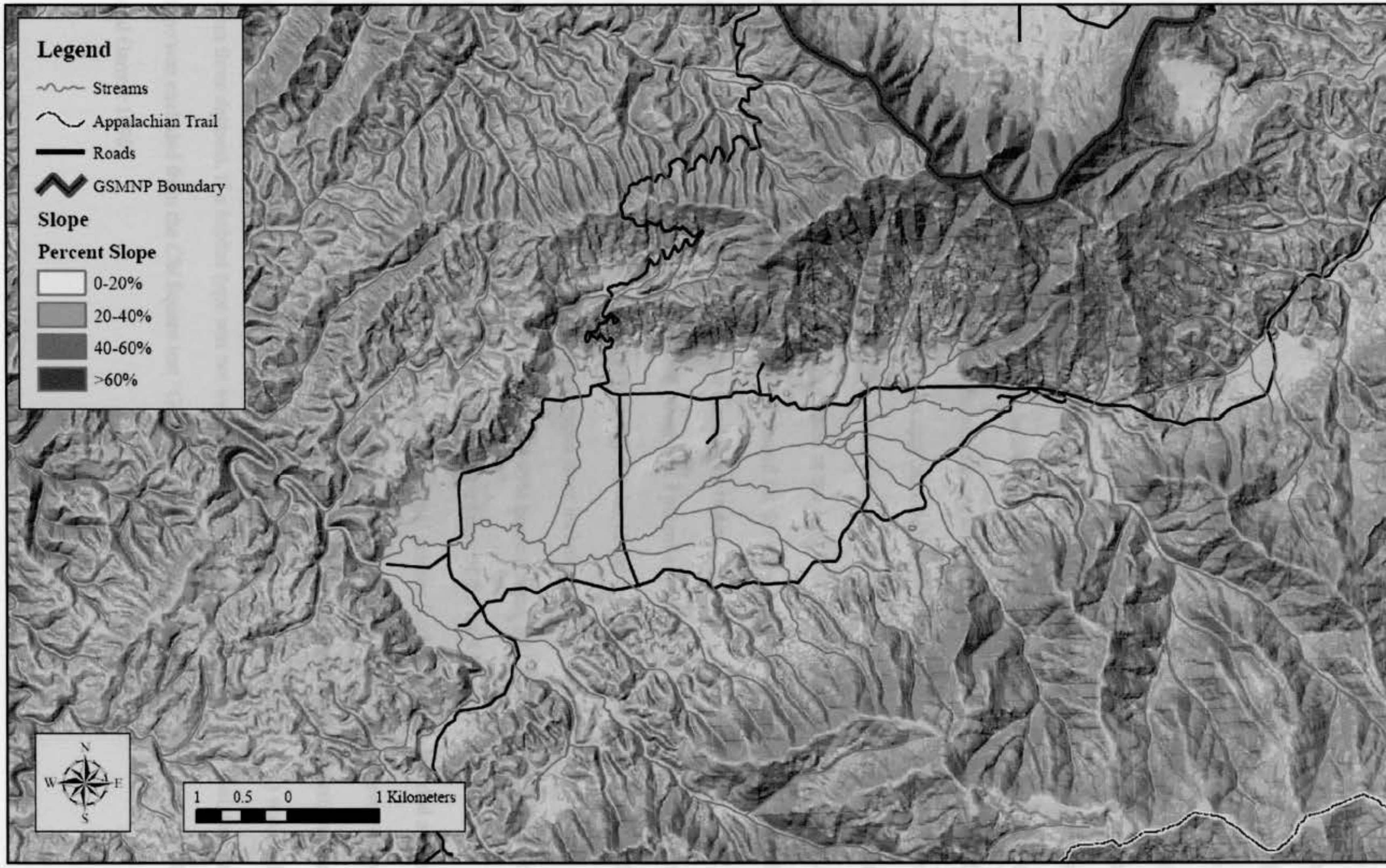

Figure 10. Slope analysis of Cades Cove study area generated using ArcMap 8.3© Spatial Analyst©.

National Land Cover Dataset Analysis

A GSMNP region National Land Cover Dataset (NLCD) raster in Albers Conical Equal Area map projection and NAD 1983 geographic coordinate system was downloaded from the USGS National Land Cover Project website (http://landcover.usgs.gov/nationallandcover.asp). The thirty-meter resolution 1992 NLCD was generated using 1992 satellite imagery and intended for use at a scale of 1:100,000 (Vogelmann *et al.* 2001). The 1992 NLCD classification is currently the most accurate source of land cover information for the United States (Wayne *et al.* 2004). Errors in use-availability analysis may occur when attempting to use the thirty-meter resolution NLCD at a scale below 1:100,000. It has been suggested that NLCD data accuracy should be confirmed on a site-specific scale using high-resolution imagery (Wayne *et al.* 2004). The average map scale used in this analysis was approximately 1:40,000. In order to determine if the NLCD was appropriate for use in this analysis, one meter resolution color infrared imagery (CIR) was overlaid with the NLCD and its accuracy confirmed at the 1:40,000 scale (Figures 11 & 12). The NLCD raster was converted to shapefile format and processed for the use-availability analysis using the GIS processing protocols used for the aspect raster and slope raster.

Of the 12 NLCD classification land cover types potentially available to red wolves, eight were well represented in the three study areas (Figure 13). Of the 12 habitat types potentially included within individual wolf home ranges, only four habitat types were included in all 16 datasets. Eight datasets contained all 12 NLCD land cover types within wolf 95% home ranges. NLCD land cover types that were excluded from wolf home ranges represented small percentages of the total NLCD land cover types available within the respective study area. Urban/recreational grasses (code 85) were excluded as available habitat from nine datasets. Emergent herbaceous wetlands (code 92) were excluded from seven datasets. Open water (code 11), Low intensity residential (code 21), Commercial/industrial/transportation (code 23), and Row crops (code 82) each were excluded from four datasets. Woody wetland (code 91) was excluded from three datasets. If a habitat type was not included within the home range of an individual, that habitat type was excluded from the *Chi* Square test "Goodness of Fit" for that individual (Neu et al. 1974; White and Garrott 1990).

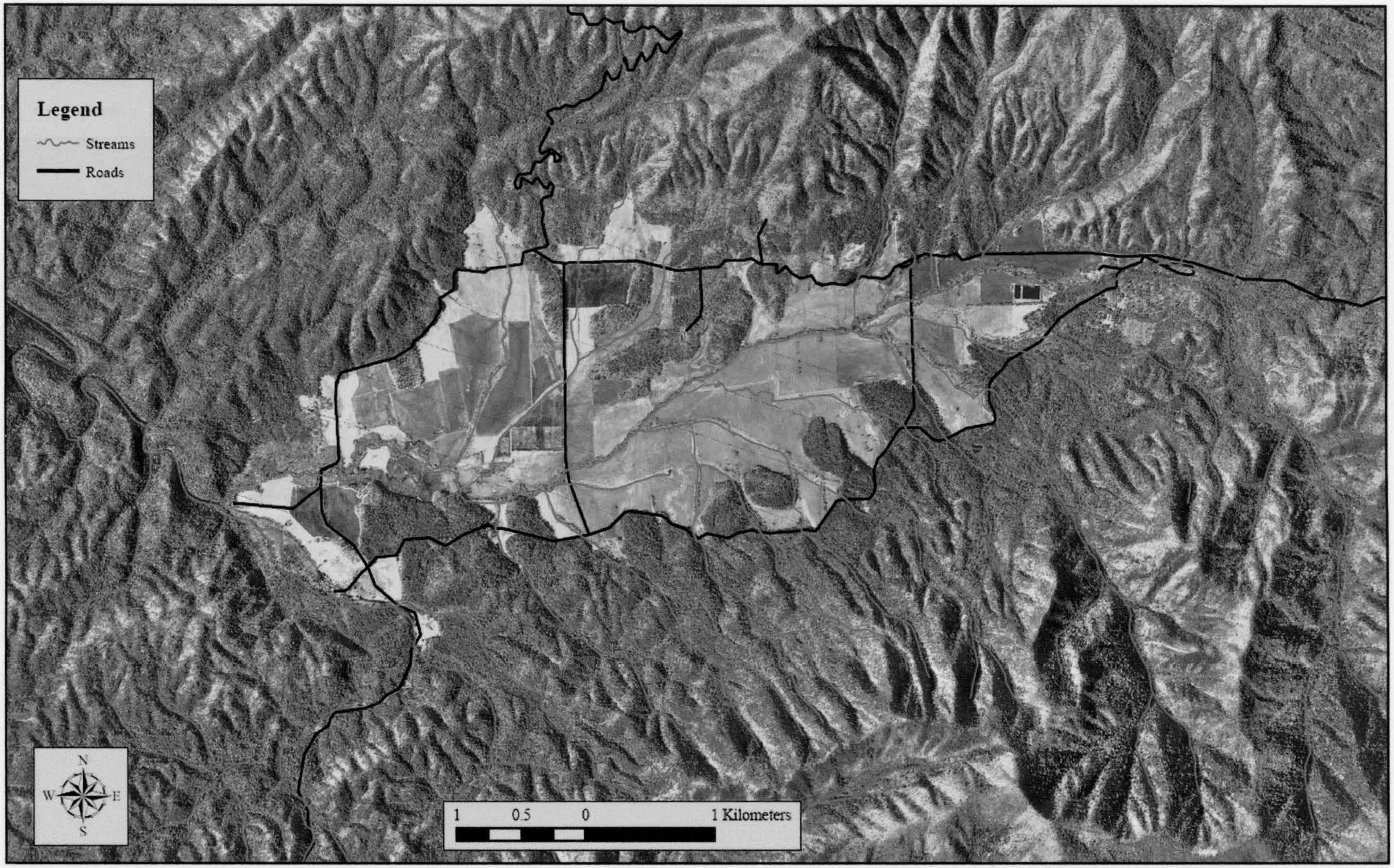

Figure 11. Color infrared imagery of Cades Cove study area used to visually inspect the accuracy of the NLCD for its use in the use-availability analysis.

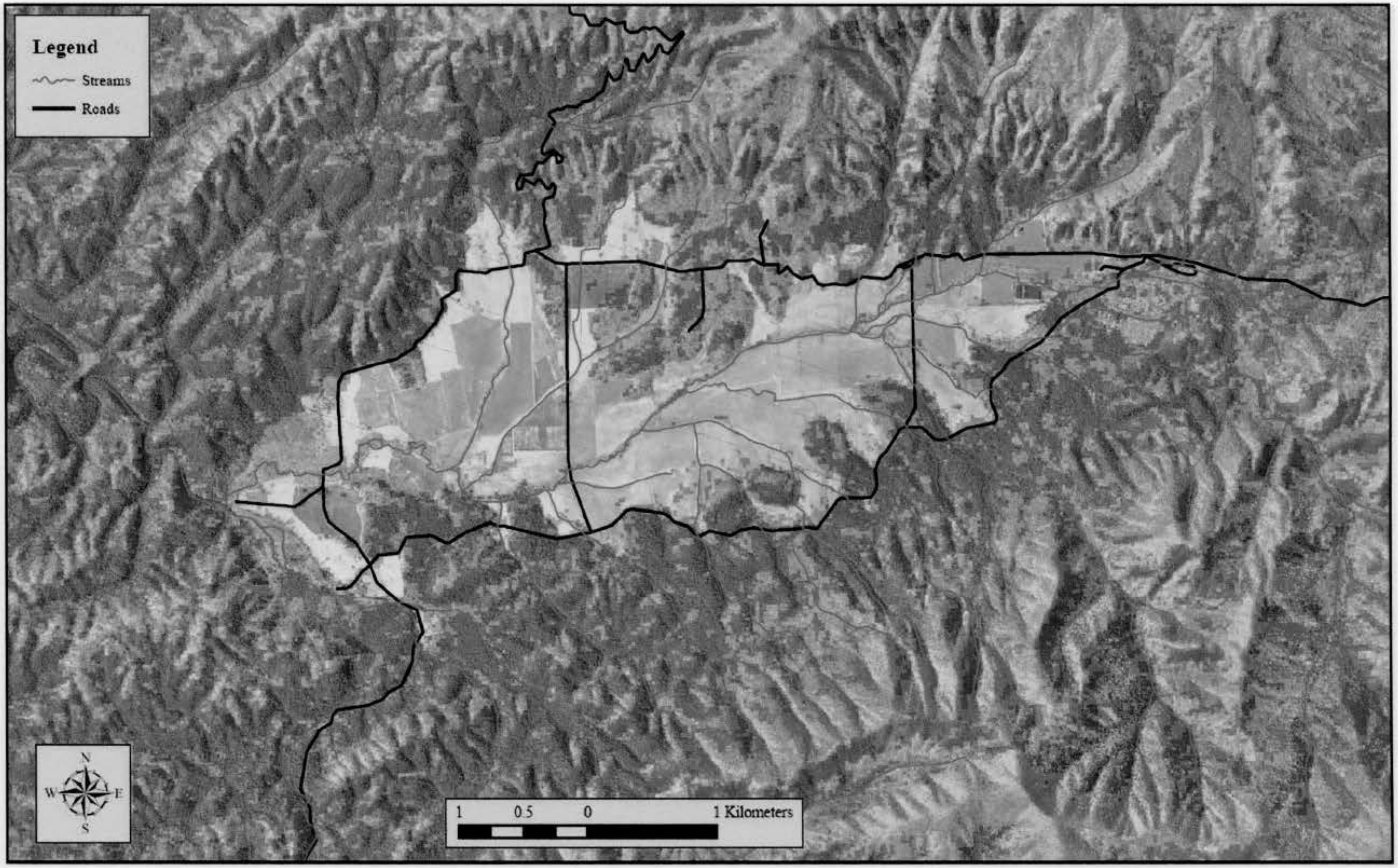

Figure 12. NLCD land cover raster (50% transparent) overlaid on color infrared imagery for accuracy evaluation at a 1:40,000 scale.

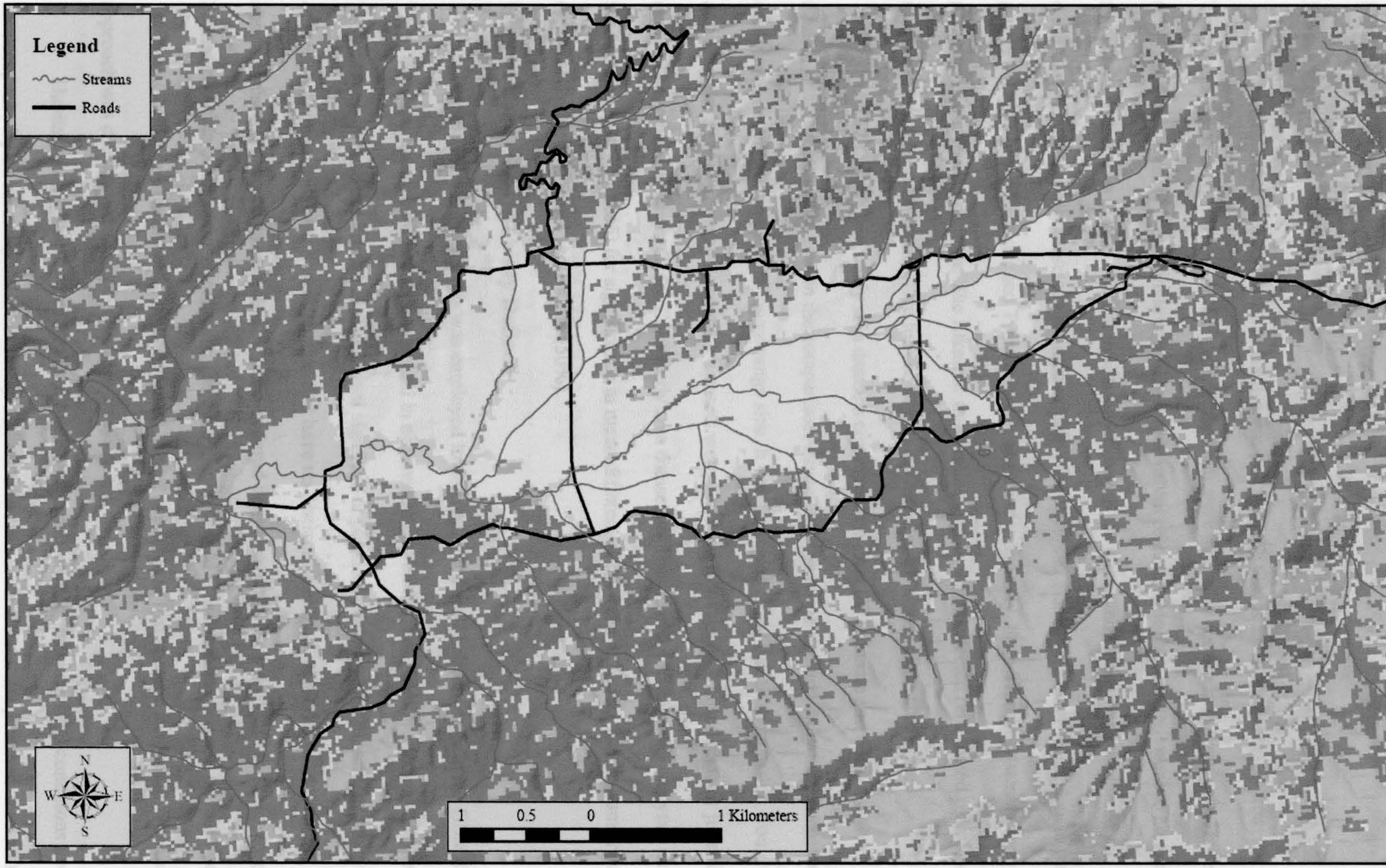

Figure 13. The NLCD land cover raster representing the Cades Cove study area.

Statistical Analysis

Home Range

Sixteen datasets from the three study areas (12 from the Cades Cove study area, 2 from the Tremont study area and 2 from the Elkmont study area) were evaluated for use in the analysis. Home range (95%) and core areas (50%) of male and female red wolves released into the GSMNP were to be tested for significant differences in size. Habitat availability between the three study areas was considered too dissimilar to compare all datasets in a single or pair-wise analysis. There were insufficient data to perform proper analysis of the Elkmont and Tremont study areas independently. Both Tremont datasets were generated from female animals. The Elkmont study area datasets were collected on a mated pair. Home range size comparison was therefore limited to data collected at the Cades Cove study area.

The 12 Cades Cove study area datasets contained use-data for 6 female and 6 male wolves. Only adult animal datasets were used in the comparison. Juvenile home range size and daily movements were considered dependant on parental home range size. It was therefore likely that their inclusion would bias any analysis. Three female and two male datasets were excluded from analysis based on their juvenile status. The remaining seven Cades Cove study area datasets (3 female and 4 male) were analyzed using a Studentized t test ($\alpha = 0.05$) for significance in mean differences between male and female home range (95%) and male and female core areas (50%).

Habitat Use and Availability Defined

A use-availability analysis was employed to determine red wolf habitat usage in the GSMNP. Three common approaches have been applied in use-availability analysis of wildlife species (Garshelis 2000). One approach used data based on visual sightings or physical evidence (tracks, scat, or other signs of presence) of animals of the same species that have no distinctive individual markings. A second approach used location data collected on radio-collared individuals and compared it to the percentages of habitat available to the entire population. The third approach used location data collected on radio-collared individuals and compared it to the percentages of habitat available to that specific individual. The third approach was chosen as the template for this analysis.

Habitat has been defined as a type of place with a collection of resources and conditions necessary for occupancy by an animal (Hall *et al.* 1997). Habitat selection is considered the presence of an animal in any habitat type. Presence within any given location has been the result of a choice made by that animal. Several methods have been utilized to define the habitat available to a study animal in use-availability models.

Previous carnivore use-availability models have used numerous techniques to define available habitat. Maximum distance traveled from the center of activity was used in a study of black bear in the GSMNP (Teunissen van Manen 1994). Composite available habitat areas defined by pooling of a group of individuals and designating an area that encompassed all home ranges were used by Johnson (1980). In a use-availability study of coyotes, habitats within a 95m radius of telemetry locations were used to determine habitat preference/avoidance (Holzman *et al.* 1992). Recent coyote use-availability modeling efforts have used an adaptive kernel estimate of the 95% home range estimate to define available habitat (Chamberlain *et al.* 2000; Grinder and Krausman 2001; Atwood and Weeks 2003). Seaman and Powell (1996) suggest that fixed kernel analysis provides the most accurate home range estimates. Whereas MCP home range estimates result in similar total area estimates, fixed kernel analysis give a more accurate depiction of the contours of the home range boundary and habitat utilized by the individual wolf. Therefore, a fixed kernel estimation of home range was used in this analysis to reduce the errors associated with estimation of available habitat.

For the purposes of this analysis, available habitat was determined on an individual dataset basis. Available habitat was defined as all habitat types contained within the 95% home range of each individual (Chamberlain et al. 2000; Grinder and Krausman 2001). Habitat use was defined as the presence of a wolf position location within a habitat type based on telemetry locations. Only point locations occurring within individual wolf 95% home ranges were used in determining observed use values.

The removal of point file outliers to the 5 percent level prior to fixed kernel analysis of home range resulted in the exclusion of some points from individual wolf use-availability analyses. Of the 16 datasets consisting of 2036 total point locations, a total of 90-point locations (4.4 percent of total) fell outside of the areas considered available habitat (Figure 14). This did not appreciably influence the analysis as the determination of randomness of habitat use was done on an individual basis. Less than five percent of the total point locations for any given dataset occurred outside of their respective 95% home range.

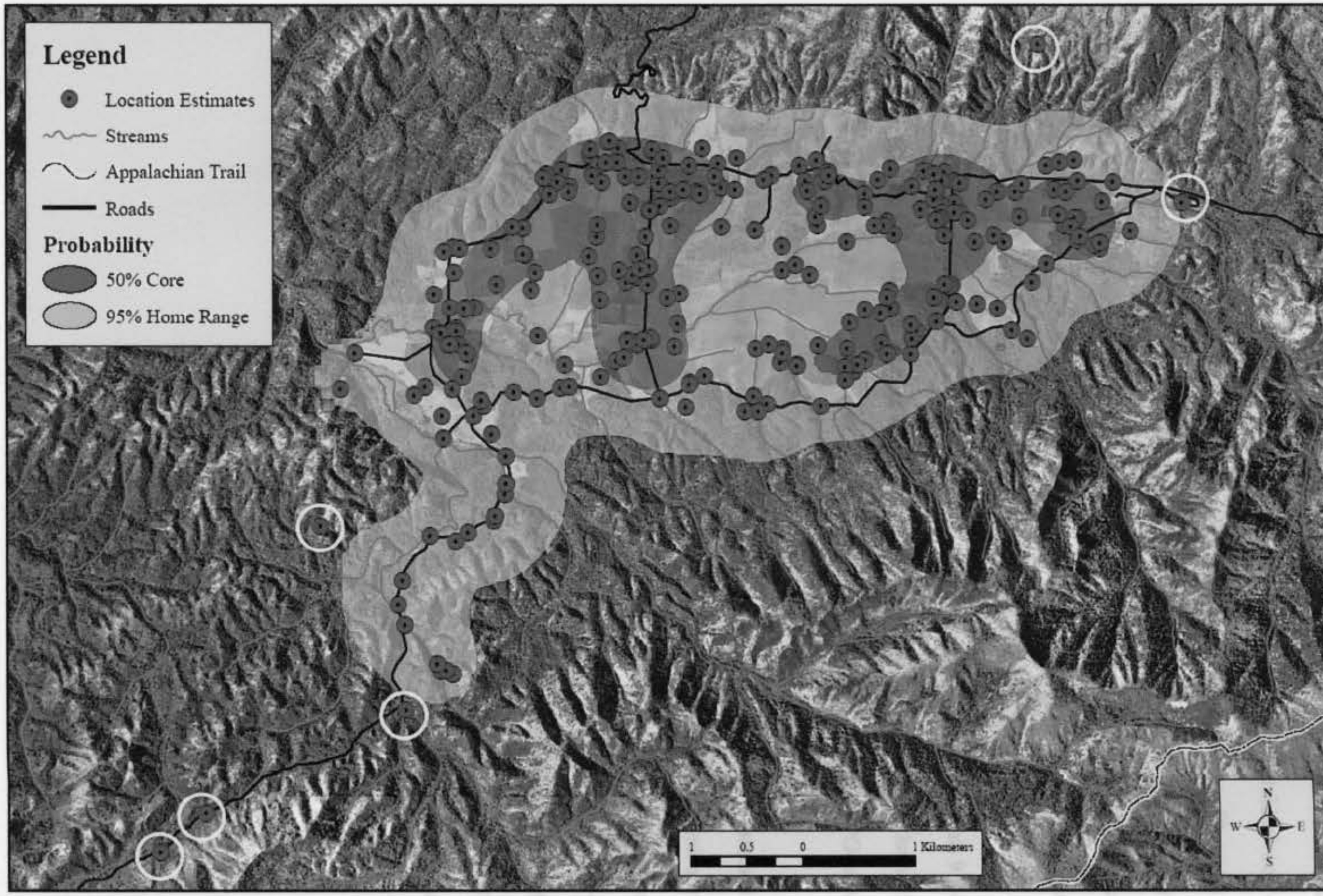

Figure 14. Male red wolf location estimates (pink dots) overlaid on 95% home range and 50% core polygons. The six point locations in yellow circles outside the 95% home range are excluded from use-availability analysis.

Habitat Use

Three habitat attributes (land cover, aspect, and slope) were considered in the use-availability analysis based on individual wolf third order selection of habitat (Johnson 1980). Individual wolf datasets were tested for randomness in habitat type use within their respective 95% home range. Observed habitat use values were determined by overlaying the individual wolf point locations on the respective 95% home range polygons containing land cover, aspect, or slope habitat attribute information. The number of point locations that occurred within each habitat type within each use-availability attribute was documented as the observed habitat use values for land cover, aspect, and slope. Individual wolf expected values were calculated taking the percentage of area of each habitat type occurring within that individuals 95% home range and multiplying it by the total number of point locations occurring within that individuals 95% home range (Figure 15). Observed and expected values were then used to perform a *Chi* Square "Goodness of Fit" test ($\alpha = 0.05$) to determine if habitat use was random (White and Garrot 1990).

Individual wolf datasets that resulted in a rejection of the null hypothesis were examined to determine trends in habitat type use of the group for each of the three use-availability analysis attributes. The observed and expected values of each habitat type within each individual wolf dataset were empirically compared to determine if use was greater or less than expected. A positive, negative, or neutral (+, -, 0) numerical value based on the differences in the observed and expected use values was determined for each habitat type occurring in each individual wolf dataset. The individual habitat type numerical values (+, -, 0) were then compared across all individual datasets to determine if the group's usage of each habitat type was greater or less than expected.

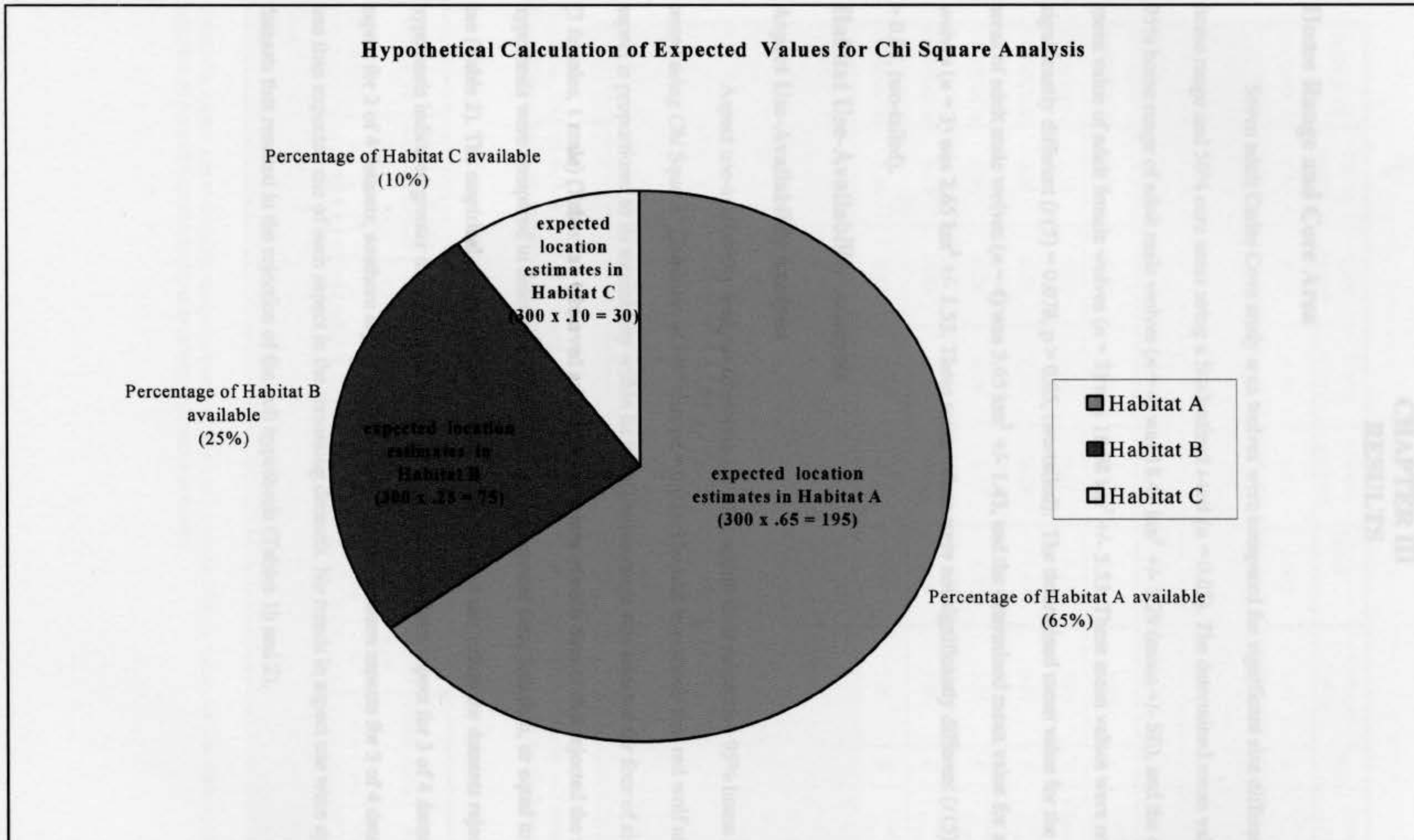

Figure 15. Total number of location that occurred within the 95% home range was equal to 300. The percentage of each habitat type (a, b, or c) that a home range is comprised of are used to estimate the percentage of the total number of locations (within the home range) that would occur in each habitat type (a, b, and c) if randomly distributed. These values are referred to as expected values.

CHAPTER III
RESULTS

Home Range and Core Area

Seven adult Cades Cove study area wolves were compared for significant size difference in 95% home range and 50% core areas using a Studentized t-test ($\alpha = 0.05$). The determined mean value for the 95% home range of adult male wolves ($n = 4$) was 18.44 km^2 +/- 5.29 (mean +/- SE), and the determined mean value of adult female wolves ($n = 3$) was 18.98 km^2 +/- 5.53. These mean values were not significantly different ($t(5) = 0.078$, $p > 0.05$, two-tailed). The determined mean value for the 50% core areas of adult male wolves ($n = 4$) was 3.65 km^2 +/- 1.43, and the determined mean value for adult female wolves ($n = 3$) was 2.65 km^2 +/- 1.53. These mean values were not significantly different ($t(5) = -0.468$, $p > 0.05$, two-tailed).

Habitat Use-Availability Analysis

Aspect Use-Availability Analysis

Aspect use-availability analysis of wolves ($n = 16$) within their respective 95% home range were tested using *Chi* Square "Goodness of Fit" tests ($\alpha = 0.05$). The null hypothesis that red wolf utilization of aspect is proportional to its availability within its (95%) home range was rejected for four of sixteen wolves (3 females, 1 male) (Table 1a). Observed and expected values of each dataset that rejected the null hypothesis were compared to determine if habitat usage was greater than, less than, or equal to expected use (Table 2). The empirical comparison of observed and expected use values for datasets rejecting the null hypothesis indicated greater than expected use of habitat with a northern aspect for 3 of 4 datasets, eastern aspect for 2 of 4 datasets, southern aspect for 3 of 4 datasets and western aspects for 3 of 4 datasets, with less than expected use of each aspect in the remaining datasets. No trends in aspect use were apparent in datasets that resulted in the rejection of the null hypothesis (Tables 1b and 2).

WOLF ID	North Aspect	East Aspect	South Aspect	West Aspect	Total	Critical Value	Ho	Study Area	Sex
341M92CA	0.52	6.83	1.68	1.57	10.60	7.81	R	Cades Cove	Male
378F92CA	2.92	4.76	1.02	3.85	12.55	7.81	R	Cades Cove	Female
468F94TA	6.16	2.74	5.68	5.55	20.13	7.81	R	Tremont	Female
642F96CA	0.57	0.09	6.42	2.27	9.35	7.81	R	Cades Cove	Female
538M92CP	0.44	4.32	0.08	1.47	6.31	7.81	F	Cades Cove	Male
538M96EA	2.13	0.62	1.23	0.22	4.21	7.81	F	Elkmont	Male
539M92CP	3.24	0.53	3.65	0.19	7.60	7.81	F	Cades Cove	Male
539M96CA	1.06	0.24	0.00	0.35	1.65	7.81	F	Cades Cove	Male
641M96CA	0.11	2.85	0.50	0.00	3.46	7.81	F	Cades Cove	Male
781M96CA	1.84	0.55	0.10	0.05	2.54	7.81	F	Cades Cove	Male
303F91CA	0.92	1.35	0.15	0.07	2.49	7.81	F	Cades Cove	Female
467F91CP	0.12	4.05	0.01	1.36	5.54	7.81	F	Cades Cove	Female
468F92CP	0.03	1.02	0.45	1.61	3.12	7.81	F	Cades Cove	Female
541F92CP	0.11	0.34	0.03	0.27	0.74	7.81	F	Cades Cove	Female
541F96TA	0.10	1.40	4.28	0.83	6.60	7.81	F	Tremont	Female
565F96EA	1.33	1.27	0.63	0.60	3.83	7.81	F	Elkmont	Female

Table 1a. *Chi* square test results for aspect use-availability analysis ($\alpha = 0.05$) (females in gray and males in white). The null hypothesis (Ho) is indicated as either rejected (R) or failed to reject (F) for each of the 16 datasets.

WOLF ID	North Aspect Obs.	North Aspect Exp.	East Aspect Obs.	East Aspect Exp.	South Aspect Obs.	South Aspect Exp.	West Aspect Obs.	West Aspect Exp.	Study Area	Sex
341M92CA	65	71	32	51	100	88	108	96	Cades Cove	Male
378F92CA	46	58	27	41	79	71	93	76	Cades Cove	Female
468F94TA	29	16	19	13	6	15	8	18	Tremont	Female
642F96CA	28	24	23	22	14	27	35	27	Cades Cove	Female

Table 1b. Aspect use-availability analysis observed (Obs.) and expected (Exp.) values for *Chi* square tests resulting in rejection of the null hypothesis (females in gray and males in white).

WOLF ID	North Aspect	East Aspect	South Aspect	West Aspect	Study Area	Sex
341M92CA	+6	-19	+12	+12	Cades Cove	Male
378F92CA	-12	-14	+8	+17	Cades Cove	Female
468F94TA	+13	+6	+7	-10	Tremont	Female
642F96CA	+4	+1	-13	+8	Cades Cove	Female

Table 2. Differences between observed and expected values for aspect use-availability resulting in the rejection of the null hypothesis (females in gray and males in white). Aspect habitat types: North, East, South, and West.

Slope Use-Availability Analysis

Slope use-availability analysis of wolves ($n = 16$) within their respective 95% home range were tested using Chi Square "Goodness of Fit" tests ($\alpha = 0.05$). The null hypothesis that red wolf utilization of slope is proportional to its availability within its (95%) home range was rejected for ten of sixteen wolves (4 male, 6 females) (Table 3a). The empirical comparison of observed and expected use values for datasets rejecting the null hypothesis indicated greater than expected use of 0-20% slope for 10 of 10 datasets (Tables 3b & 4). The empirical comparison of observed and expected use values for datasets rejecting the null hypothesis indicated less than expected use of habitat with 20-40% slope for 7 of 10 datasets, 40-60% slope for 9 of 10, and greater than 60% slope for 8 of 10 datasets (Tables 3b & 4).

There was no difference detected between male and female red wolf utilization of habitat in respect to slope. Male and female red wolves utilized habitat with slopes less than 20% greater than expected and utilized habitats with greater than 20% slope less than expected.

WOLF ID	0-20% Slope	20-40% Slope	40-60% Slope	>60% Slope	Total	Critical Value	Ho	Study area	Sex
341M92CA	10.68	13.64	10.75	5.81	40.87	7.81	R	Cades Cove	Male
538M92CP	16.94	18.07	10.74	3.90	49.64	7.81	R	Cades Cove	Male
539M92CP	2.94	8.21	0.60	0.02	11.76	7.81	R	Cades Cove	Male
781M96CA	1.16	2.96	6.62	3.40	14.14	7.81	R	Cades Cove	Male
378F92CA	11.33	13.80	11.21	5.82	42.16	7.81	R	Cades Cove	Female
467F91CP	5.78	0.23	4.56	4.38	14.95	7.81	R	Cades Cove	Female
468F92CP	3.32	7.78	0.84	1.69	13.64	7.81	R	Cades Cove	Female
468F94TA	29.73	7.86	10.76	15.36	63.72	7.81	R	Tremont	Female
541F92CP	1.23	1.15	5.93	0.43	8.74	7.81	R	Cades Cove	Female
565F96EA	5.96	0.50	4.77	1.74	12.97	7.81	R	Elkmont	Female
538M96EA	3.73	0.03	1.55	0.31	5.62	7.81	F	Elkmont	Male
539M96CA	0.25	0.81	0.03	0.00	1.09	7.81	F	Cades Cove	Male
641M96CA	0.10	0.06	1.69	1.20	3.05	7.81	F	Cades Cove	Male
303F91CA	0.83	0.35	0.27	2.15	3.59	7.81	F	Cades Cove	Female
541F96TA	2.28	0.73	0.27	0.56	3.84	7.81	F	Tremont	Female
642F96CA	0.54	0.00	1.87	1.53	3.94	7.81	F	Cades Cove	Female

Table 3a. *Chi* square test results for slope use-availability analysis ($\alpha = 0.05$) (females in gray and males in white). The null hypothesis (Ho) is indicated as either rejected (R) or failed to reject (F) for each of the 16 datasets.

WOLF ID	0-20% Slope Obs.	0-20% Slope Exp.	20-40% Slope Obs.	20-40% Slope Exp.	40-60% Slope Obs.	40-60% Slope Exp.	>60% Slope Obs.	>60% Slope Exp.	Study area	Sex
341M92CA	273	224	22	47	8	24	2	9	Cades Cove	Male
538M92CP	150	107	7	30	4	18	2	7	Cades Cove	Male
539M92CP	103	87	8	21	8	11	4	4	Cades Cove	Male
781M96CA	47	40	26	19	4	13	2	7	Cades Cove	Male
378F92CA	223	178	16	39	5	20	1	8	Cades Cove	Female
467F91CP	41	28	12	14	3	10	0	4	Cades Cove	Female
468F92CP	48	37	5	16	14	11	2	5	Cades Cove	Female
468F94TA	31	12	26	15	5	19	0	15	Tremont	Female
541F92CP	147	134	16	21	1	8	2	3	Cades Cove	Female
565F96EA	33	22	41	37	15	26	7	11	Elkmont	Female

Table 3b. Slope use-availability analysis observed (Obs.) and expected (Exp.) values for *Chi* square tests resulting in the rejection of the null hypothesis (females in gray and males in white). Slope habitat types: 0-20% slope, 20-40% slope, 40-60% slope, and >60% slope.

WOLF ID	0-20% Slope	20-40% Slope	40-60% Slope	>60% Slope	Study area	Sex
341M92CA	+49	-25	-16	-7	Cades Cove	Male
538M92CP	+43	-23	-14	-5	Cades Cove	Male
539M92CP	+16	-13	-3	0	Cades Cove	Male
781M96CA	+7	+7	-9	-5	Cades Cove	Male
378F92CA	+45	-23	-15	-7	Cades Cove	Female
467F91CP	+13	-2	-7	-4	Cades Cove	Female
468F92CP	+11	-11	+3	-3	Cades Cove	Female
468F94TA	+21	+11	-14	-15	Tremont	Female
541F92CP	+13	-5	-7	-1	Cades Cove	Female
565F96EA	+11	+4	-11	+4	Elkmont	Female

Table 4. Differences between observed and expected values for slope use-availability analysis resulting in the rejection of the null hypothesis (females in gray and males in white).

National Land Cover Dataset Use-Availability Analysis

Land cover use-availability analysis of wolves (n =16) within their respective 95% home range were tested using *Chi* Square "Goodness of Fit" tests ($\alpha = 0.05$). The null hypothesis, that red wolf utilization of land cover habitat types is proportional to its availability within its (95%) home range, was rejected for eight of sixteen wolves (3 male, 5 females) (Table 5). The empirical comparison of observed and expected use values for datasets rejecting the null hypothesis indicated greater than expected use of habitat type 41 (Deciduous Forests) for 5 of 8 datasets, 81 (Pasture/Hay) for 6 of 8 datasets, and 91 (Woody Wetland) for 4 of 8 datasets (Tables 6 & 7). The empirical comparison of observed and expected use values for datasets rejecting the null hypothesis indicated less than expected use of habitat type 42 (Evergreen Forest) for 6 of 8 datasets and 43 (Mixed Forest) for 6 of 8 datasets (Tables 6 & 7).

Male and female red wolves utilized all land cover habitat types similarly except deciduous forest and woody wetlands. Males utilized deciduous forest greater than expected and females utilized deciduous forest less than expected. Male red wolves utilized woody wetlands greater than expected for 2 of 3 datasets and less than expected for 1 of 3 datasets. Female red wolves utilized woody wetlands greater than expected for 2 of 5 datasets, less than expected for 1 of 5 datasets, and as expected for 2 of 5 datasets. Overall, red wolf (male and female) habitat use was greater than expected for the land cover classifications of pasture for 6 of 8 datasets and deciduous forest for 5 of 8 datasets and less than expected use of evergreen forest for 6 of 8 datasets and mixed forest for 6 of 8 datasets.

WOLF ID	NLCD 11	NLCD 21	NLCD 23	NLCD 41	NLCD 42	NLCD 43	NLCD 81	NLCD 82	NLCD 85	NLCD 91	NLCD 92	Totals	Critical Value	Ho	Study Area	Sex
341M92CA	0.03	0.01	0.08	0.48	8.67	8.15	12.34	9.10	0.01	17.63	0.07	56.57	18.31	R	Cades Cove	Male
538M92CP	0.01	0.01	0.04	0.42	12.84	1.70	15.58	372.80	0.01	2.91	30.30	436.60	18.31	R	Cades Cove	Male
539M92CP	84.55	0.00	0.02	1.51	4.68	0.48	2.54	0.04	NA	0.61	0.03	94.68	16.92	R	Cades Cove	Male
303F91CA	NA	0.00	0.02	1.52	0.01	1.12	0.00	37.47	0.00	0.38	0.02	40.53	16.92	R	Cades Cove	Female
378F92CA	0.02	0.01	0.06	1.05	6.80	9.14	11.87	0.07	0.00	12.95	0.05	42.03	18.31	R	Cades Cove	Female
467F91CP	0.00	0.00	0.01	7.14	0.00	1.62	11.00	108.85	0.00	0.06	0.01	128.69	18.31	R	Cades Cove	Female
468F94TA	0.00	NA	0.01	9.29	0.18	5.54	3.71	NA	NA	0.32	NA	19.05	12.59	R	Tremont	Female
541F92CP	40.61	NA	0.06	0.41	2.84	0.15	2.59	0.05	NA	2.81	0.04	49.56	15.51	R	Cades Cove	Female
538M96EA	NA	NA	NA	1.74	0.91	1.60	0.06	NA	NA	NA	NA	4.31	9.49	F	Elkmont	Male
539M96CA	NA	0.01	NA	0.21	0.29	0.12	0.04	0.07	NA	0.87	0.05	1.66	14.07	F	Cades Cove	Male
641M96CA	0.03	NA	0.05	0.39	0.05	1.43	3.03	NA	NA	1.30	NA	6.29	12.59	F	Cades Cove	Male
781M96CA	0.01	NA	0.01	0.31	1.21	0.08	2.61	0.01	0.00	2.69	NA	6.93	15.51	F	Cades Cove	Male
468F92CP	0.00	0.00	0.01	3.61	1.19	6.50	1.76	0.01	0.00	1.80	0.01	14.90	18.31	F	Cades Cove	Female
541F96TA	0.01	0.02	0.01	0.51	0.04	0.25	1.02	0.07	NA	NA	NA	1.93	14.07	F	Tremont	Female
565F96EA	NA	NA	NA	0.49	2.13	0.00	0.06	NA	NA	NA	NA	2.67	7.81	F	Elkmont	Female
642F96CA	NA	0.01	NA	0.00	0.61	0.28	1.05	0.03	NA	1.51	NA	3.48	12.59	F	Cades Cove	Female

Table 5. *Chi* square test results for land cover use-availability analysis ($\alpha = 0.05$) (females in gray and males in white). The null hypothesis (Ho) is indicated as either rejected (R) or failed to reject (F) for each of the 16 datasets.

WOLF ID	NLCD 11 Obs.	NLCD 11 Exp.	NLCD 21 Obs.	NLCD 21 Exp.	NLCD 23 Obs.	NLCD 23 Exp.	NLCD 41 Obs.	NLCD 41 Exp.	NLCD 42 Obs.	NLCD 42 Exp.	NLCD 43 Obs.	NLCD 43 Exp.	NLCD 81 Obs.	NLCD 81 Exp.	NLCD 82 Obs.	NLCD 82 Exp.	NLCD 85 Obs.	NLCD 85 Exp.	NLCD 91 Obs.	NLCD 91 Exp.	NLCD 92 Obs.	NLCD 92 Exp.
341M92CA	0	0	0	0	0	0	27	24	91	124	30	50	129	95	1	0	0	0	27	12	0	0
538M92CP	0	0	0	0	0	0	16	14	41	71	22	29	70	44	4	0	0	0	9	5	1	0
539M92CP	1	0	0	0	0	0	13	9	37	53	22	19	47	37	0	0	NA	NA	3	5	0	0
303F91CA	NA	0	0	0	0	0	4	7	40	40	18	14	24	24	1	0	0	0	2	3	0	0
378F92CA	0	0	0	0	0	0	24	19	73	99	22	41	105	75	0	0	0	0	21	10	0	0
467F91CP	0	0	0	0	0	0	0	7	28	28	6	10	20	10	1	0	0	0	1	1	0	0
468F94TA	0	0	NA	NA	0	0	38	23	19	21	5	14	0	4	NA	NA	NA	NA	0	0	NA	NA
541F92CP	1	0	NA	NA	0	0	9	11	47	60	23	25	79	66	0	0	NA	NA	7	4	0	0

Table 6. Land cover use-availability analysis observed (Obs.) and expected (Exp.) values for *Chi* square tests resulting in the rejection of the null hypothesis. NLCD habitat type codes: 11-Open water, 21-Low intensity residential, 23-Commercial/Industrial/Transportation, 41-Deciduous forest, 42-Evergreen forest, 43-Mixed forest, 81-Hay/Pastures, 82-Row crops, 85-Urban/Recreational Grasses, 91-Woody wetlands, and 92-Emergent herbaceous wetlands.

WOLF ID	NLCD 11	NLCD 21	NLCD 23	NLCD 41	NLCD 42	NLCD 43	NLCD 81	NLCD 82	NLCD 85	NLCD 91	NLCD 92
341M92CA	0	0	0	+3	-33	-20	+34	+1	0	+15	0
538M92CP	0	0	0	+2	-30	-7	+26	+4	0	+4	+1
539M92CP	+1	0	0	+4	-16	+3	+10	0	NA	-2	0
303F91CA	NA	0	0	-3	0	+4	0	+1	0	-1	0
378F92CA	0	0	0	+5	-26	-19	+30	0	0	+11	0
467F91CP	0	0	0	-7	0	-4	+10	+1	0	0	0
468F94TA	0	NA	0	+15	-2	-9	-4	NA	NA	0	NA
541F92CP	+1	NA	0	-2	-13	-2	+13	0	NA	+3	0

Table 7. Differences between observed and expected values for land cover use-availability analysis resulting in the rejection of the null hypothesis (females in gray and males in white).

CHAPTER IV
DISCUSSION

Introduction

A comparison of the present studies findings with that of historical examinations of the red wolf ecology is difficult at best. The eastern subspecies of the red wolf (*Canis rufus floridanus*) which would have inhabited the GSMNP was extirpated from the southern Atlantic states by the early 1920's (U.S. Fish and Wildlife Service 1989). A complete historical account of the ecology of wild red wolf populations is nonexistent (Paradiso and Nowak 1972). Subsequently, the removal of the red wolf from the wild by the FWS preceded the documentation of their home range and habitat use within the species' original range. Comparative analysis indicates that there is remarkable consistency in the manner in which diversely adapted canids utilize their habitat (Beckoff *et al.* 1984; McDonald Sillero-Zubrini 2004). Therefore, I looked to natural history data available in the literature for the eastern coyote in order to make comparisons with red wolf data from the GSMNP study.

In order to strengthen the validity of the comparisons, studies were selected based on the habitat in which the study was conducted, the time frame in which the study was conducted, and the home range estimation techniques utilized by the study. Comparison studies were conducted in Vermont (Person and Hirth 1991), Georgia (Holzman *et al.* 1992), and the GSMNP (Crawford 1992). The Vermont and Georgia studies were conducted in habitats that were present within the GSMNP study areas though independently neither study area was representative of the GSMNP as a whole. The time at which the comparison studies were conducted (1991-92) also provided the effect of a broad based (interstate) sample of coyotes from various areas of the eastern United States at a time when they were still establishing their populations. This maximized the validity of the comparisons as both the red wolf and coyote were establishing populations in the unfamiliar habitat of the eastern United States during the course of their study.

All of the comparison studies utilized MCP home range estimation techniques. Though this provided uniformity in the home range data among the comparison studies, the GSMNP red wolf study used the fixed kernel method to derive home range estimates. Different methods of determining home range and data sampling regimens are often the source of variation in home range size estimates between studies (Laundré and Keller 1984). The MCP provides a crude estimate of home range derived by connecting the outermost point locations of a dataset and is therefore sensitive to outlying position estimates (Powell 2000). The MCP ignores all information given by interior points (Powell 2000). Fixed kernel home range estimates are utilization distributions that are sensitive to the varying density of point locations within a dataset (Worton 1989). Application of the two methods to the GSMNP red wolf data resulted in similar home range area estimates. The difference between fixed kernel and MCP home range estimates is the shape of the boundary. The two methods produce home range estimates with radically different shapes. The fixed kernel home range technique delivers a more precise representation of area utilization or home range boundary than the MCP technique. I considered it inappropriate to revert to the older and less accurate MCP estimation methods in order to provide uniformity in the comparison of home range size. The fixed kernel technique were utilized in the comparisons because they provide the most accurate home range estimates currently available and any variation in regard to home range area between the MCP and fixed kernel estimates would be minimal.

Home Range

Adult female red wolf 95% home range estimates (18.98 km^2) were slightly larger than those of adult males (18.44 km^2) but did not differ significantly. In contrast, adult male red wolf 50% core area estimates (3.65 km^2) were slightly larger than estimates for the females (2.65 km^2), yet again the differences were not significant.

The 95% home range estimates for adult GSMNP red wolves were much larger than adult male coyote home range estimates ($mean_{males}$ = 7.6 km^2), slightly larger than the mean adult home range estimates ($mean_{adult\ coyotes}$ = 15.7 km^2), but much smaller than adult female coyote home range estimates ($mean_{females}$ = 27.9 km^2) of the Georgia study (Holzman *et al*. 1992). Red wolf home range estimates were similar to but slightly larger than the home range estimates for adult coyotes in the Vermont study ($mean_{males}$ = 17.5 km^2, $mean_{females}$ = 18.7 km^2, $mean_{adult\ coyotes}$ = 17.9 km^2) (Person and Hirth 1991). Neither the GSMNP red wolf nor the Vermont coyote study (Person and Hirth 1991) reported any significant difference between male and female home range size. The Georgia study did report a significant difference between male and female home range size, but they indicated their small sample size for female coyotes made any inferences about sex-specific home range size difficult (Holzman *et al*. 1993).

GSMNP red wolf home range estimates were much smaller than mean 95% MCP home range estimate for GSMNP coyotes (mean $_{males}$ = 256.8 km^2) (Crawford 1992). Previous coyote studies have associated large home range size with transient/nonresident animals exploring a new habitat (Gese *et al.* 1988a; Person and Hirth 1991; Kalmer and Gipson 2000). One of the three GSMNP coyote home ranges (18.2 km^2) fell within the size range of the GSMNP red wolf and Vermont coyote, while the other two GSMNP coyote home ranges were much larger. This was expected as the coyote had only begun to establish populations in the GSMNP at the time of the Crawford (1992) study (Wathan and Neu 1989). Natural immigrations of coyotes would likely consist of lone transient coyotes investigating new areas. Though the red wolf was also in the initial stages of establishing populations in the park, their densities were artificially bolstered via the release of mated pairs (just prior to whelping) or entire family groups. Furthermore, the standard practice of releasing of whelping pairs and family groups aided in localizing red wolf movements to within the park boundaries (U. S. Fish and Wildlife Service 1989; Lucash and Crawford 1993). Crawford (1992) did not exclude transient animals from the home range analysis. The inclusion of transient coyotes in the calculation of a mean estimate may explain the large mean home range size of GSMNP coyotes.

In general, the GSMNP red wolf had a 95% home range size that was slightly larger than that of Georgia and Vermont coyotes. The larger home range size of the red wolf in the GSMNP may be a function of the proportionally larger body size that would aid in the taking of larger prey species. Lone GSMNP red wolves have been observed taking adult white-tailed deer (personal observation). Red wolf consumption of medium to large prey was supported by scat analysis data collected to determine food habits of the red wolf at ARNWR (Phillips 1993) and the GSMNP (Lucash and Crawford 1993). Lucash and Crawford (1993) determined that white-tailed deer (*O. virginianus*), raccoon (*Procyon lotor*), rabbit (*Sylvilagus floridanus*), rodents, and vegetation occurred in GSMNP red wolf scats 41.0, 33.3, 10.3, 9.0, and 9.0 percent of the time respectively (Lucash and Crawford 1993). The procurement of medium to large prey would require traveling greater distances in order to pursue and capture mobile prey species, thereby necessitating an increased home range size. Coyotes on the other hand, are generalists and take advantage of any available food source (Bekoff 1978; McDonald and Sillero-Zubiri 2004). The eastern coyote diet consists of small mammals (*Peromyscus* and *Microtus*), eastern cottontail (*S. floridanus*), snowshoe hare

(*Lepus americanus*), woodchuck (*Marmota monax*), muskrat (*Ondatra zibethicus*), white-tailed deer (*O. virginianus*), livestock, dump refuse, various fruits and berries (Bekoff 1978). The presence of white-tailed deer in the diet of Maine coyotes is attributed to nonpredation sources such as deer killed by hunters or starvation during the winter (Bekoff 1978). GSMNP coyotes have been observed eating insects, vegetation, feces, and decomposing carcasses (Chris Lucash, U.S. Fish and Wildlife Service, personal communication; personal observation). The smaller body size and more varied diet of the coyote reduce the amount of travel involved in obtaining the nutrition needed to survive and reproduce.

Habitat Use

Aspect

The red wolf use-availability analysis did not reveal any preference in aspect. The red wolf might be expected to utilize aspect seasonally to optimize their energetic requirements. Seasonal movements between elevations and aspects have been observed in other mammalian species as a method of maximizing thermoregulatory efficiency (Porter and Gates 1969). For example, red wolves might utilize habitat with a northern aspect to escape the heat of the summer or habitat with a southern aspect to take advantage of a warmer microclimate or radiant solar heating in the winter. Habitat productivity and species richness are known to vary with aspect (Waide *et al.* 1999). An aspect with a higher productivity may foster a greater abundance of small mammalian consumers. The lack of a discernable preference in aspect may reinforce the assertion that red wolves rely on larger prey items for their nutritional needs.

Data collection by the FWS in the red wolf restoration program was set up for monitoring wolf movements and establishing the presence or absence of individual red wolves within park boundaries. Monitoring of GSMNP red wolves was adapted to address specific management needs during the restoration. The monitoring frequency of GSMNP wolves was increased for female wolves suspected of being pregnant during the whelping season, wolves ranging outside of the GSMNP boundary for extended periods, and for wolves implicated in livestock predation. The increased monitoring and data collection was not applied to a significant portion of the population nor was it done in a uniform manner with respect to particular seasonal periods. In cases of increased monitoring during whelping, location data collection was not uniform across a twenty-four hour period and was only applied to female wolves that were likely to be pregnant. Monitoring was increased to 3-4 times daily during daylight hours with no predefined or uniform sampling regimen. Additionally, not all location estimates were recorded on data sheets as they were used primarily to determine if the female had moved or where the den site might be located. Ultimately, the data collection that took place in the GSMNP restoration was management oriented as apposed to research oriented. Any seasonal preferences in aspect derived from the analysis of partitioned GSMNP data would be unreliable, due to irregularities in the data collection regimen. A reliable seasonal habitat use analysis would require data collected 6-8 times daily for 6-8 week-long samples during a series of predetermined seasonal periods. In the absence of the GSMNP red wolf population, it is impossible to apply a research oriented sampling regimen that would precisely define seasonal habitat use of GSMNP red wolves and therefore not possible to determine if there are seasonal differences in aspect use.

Slope

In general, GSMNP red wolves used habitats with slopes less than 20% greater than expected and utilized habitats with greater than 20% slope less than expected. The usage of the GSMNP habitat in relation to slope by the red wolf as determined by the present study and by the coyote as determined in Crawford's study (1992) indicated a greater than expected use of habitat with less than 20% slope.

The increased energetic expenditure associated with travel on steep slopes was considered to be a factor in the red wolves' less than expected utilization of habitat with a greater than 20% slope. Animals traveling between resources would be expected to optimize their energetic expenditure by traveling along the most energy efficient route. White-tailed deer have been documented to conserve energy by utilizing land with low slopes and areas with reduced snow depth (Moen 1976). Game trails in the more steeply sloped areas of Cades Cove will follow the gradient of a stream or the contour of the ridge and pass through a low gap as opposed to crossing the ridge at its steepest slope (personal observation). In the GSMNP black bear, white-tailed deer, wild boar, wild turkey *(Meleagris gallopavo)*, red wolves, coyotes, and bobcats (*Lynx rufus*) utilize the gentle gradients of designated hiking trails, unmaintained man-ways, and abandoned roadbeds in the GSMNP (personal observation). Traveling on game and hiking trails allows predators such as the red wolf to move quietly and efficiently in their search for prey. As most trails and travel ways generally follow a gentle gradient, it would be expected that any use availability analysis of slope would result in the indication of a greater use of gentle slopes.

Another factor that could influence red wolf utilization of slopes greater than 20% could be the change in land cover that occurs with a change in slope. The bottomland of Cades Cove consists of open fields broken by woodlots, ideal habitat for white-tailed deer. Slope rapidly increases beyond the reaches of Cades Coves' bottomland areas. Deer densities drop as you travel outside Cades Cove and the associated open field and woodlot habitat (Bill Stiver, National Parks Service, personal communication; personal observation). Decreased deer densities may be due to the differences in land cover, as the land cover associated with Cades Cove is not representative if the majority of the GSMNP (Whitaker 1956). Mixed oak forests dominate the slopes of the southern Appalachian Mountains, whereas mesophytic forests containing a diverse group of species occur on rich cove sites in the Appalachians (Day *et al.* 1988). The steep slopes surrounding Cades Cove were subject to clear-cut logging and timber removal for agriculture until the parks formation in the 1930's (Lambert 1960). Steep slopes increase the potential for erosion and loss of topsoil and nutrients (Kalisz 1986). This may contribute to a reduction in primary productivity and the densities of prey species. Reduced prey densities in habitat with a greater than 20% slopes was expected to influence utilization of these areas by red wolves and coyotes. Wolves traveling in areas with gentler slope expend less energy. They also increase their ability to spot prey and conspecifics in the more open habitat.

Land Cover

In general, GSMNP red wolves were located in deciduous forests, pastures, and woody wetlands with greater than expected frequency; however, they were located in evergreen forests and mixed forests less than expected. Land cover use by the Georgia coyote populations (Holzman *et al.* 1992) was similar. Habitat classified as deciduous forest in my study and the GSMNP coyote study (Crawford 1992), as bottomland hardwood forest by the Georgia study (Holzman *et al.* 1992), and as hardwood forest by the Vermont study (Person and Hirth 1991) are similar habitat types. The use of hardwood/deciduous forest habitat types was greater than expected in all studies. The greater than expected use of hardwood/deciduous forest by the red wolf and coyote (Vermont, Georgia, and GSMNP) suggests a preference in canids for hardwood/deciduous forest types.

Red wolves utilized land cover habitat classified as mixed forests less than expected, while coyotes in Georgia (Holzman *et al.* 1992) used habitat classified as pine-hardwood forests greater than expected. The Georgia study sites contained a larger percentage of pine than either the Vermont or GSMNP study sites. Person and Hirth (1992) reported that transient coyotes in Vermont were located in softwood/pine stands more frequently than resident coyotes. Resident coyotes most frequently located in hardwood forest in the Vermont study (Person and Hirth 1992). The presence of coyotes of lower social standing (transient) in softwood/pine forest supports the assertion that pine forests are not the preferred habitat for coyotes. Regardless of preference, habitat use is heavily influenced by habitat availability, as canids have been noted to adapt to and utilize whatever habitat is available.

The greater than expected use of hardwood/deciduous forest by red wolves and coyotes (Vermont and GSMNP) may be a function of availability as deciduous forests were the predominant forest type in the GSMNP and Vermont studies. The Georgia coyote study had two study sites with varied land cover compositions, but in general, they contained more pines than either the Vermont or GSMNP study sites. The forested habitat of Georgia study site 1 consisted of 31% mixed pine-hardwood forest, 23% pine plantations, and 16% hardwood forest (Holzman *et al.* 1992). The forested habitat of Georgia study site 2 consisted of 23% bottomland hardwood forest, 10% mixed pine-hardwood forest, and 9% planted pines (Holzman *et al.* 1992). The greater than expected use of mixed pine-hardwood by Georgia coyotes is most probably an adaptation of their lifestyle to the available habitat.

The use of pastures/hay by red wolves in my study and of pastures, agricultural areas, and old fields by coyotes in the Georgia study (Holzman *et al.* 1992) was greater than expected. Person and Hirth (1991) indicated that there were no differences in nighttime and daytime habitat use. However, the Vermont coyotes (Person and Hirth 1991) were observed moving in open areas greater than expected and resting in open areas less than expected. All GSMNP red wolf home ranges in the Cades Cove study area were centered over large open areas (pastures) as they were in the Vermont coyote study (Person and Hirth 1991). In the Georgia study (Holzman *et al.* 1992), coyotes increased their activity in pastures, agricultural areas, and old fields at night. Though analysis of nocturnal versus diurnal usage was not performed on the GSMNP red wolf data, the vast majority of the red wolf telemetry locations were collected diurnally. This would indicate that the red wolf readily utilized open areas during daylight hours. Paradiso and Nowak (1972) noted personal communications indicating the red wolf would rest in weedy fields, grass, or brush pastures, often bedding down among a herd of cattle during daylight hours. In addition, the large body size and long legs of the red wolf would appear to be advantageous in stalking prey in open fields, as the added height would increase the line of sight of the red wolf in tall grass. The red wolf has been observed standing on its hind legs to investigate sounds in high grass or brushy areas (Paradiso and Nowak 1972).

The protection from human persecution provided by the GSMNP may have contributed to the red wolves diurnal use of open areas within Cades Cove. Crawford (1992) suggested that the absence of hunting pressure in the park contributed to the diurnal use of open areas by GSMNP coyotes. The GSMNP setting provided for high levels of passive interactions between humans and wildlife. Passive interactions have increased the levels of tolerance of wildlife in the GSMNP to the presence of humans. Black bear (*Ursus americanus*) and white-tailed deer exhibit extreme tolerance to human activity in the GSMNP, while wild boar (*Sus scrofa*) avoid humans and open areas (Bill Stiver, National Parks Service, personal communication; personal observation). The wild boar is the only animal in the GSMNP that has experienced substantial hunting pressure, as it is the subject of a continuous population control effort by GSMNP service personnel (Bill Stiver, National Parks Service, personal communication; personal observation). This negative reinforcement of human/animal interactions and the resultant avoidance behavior exhibited by the wild boar further supports the conclusions of Crawford (1992), Holzman *et al.* (1992), Person and Hirth (1991). Finding of this study indicate that canids prefer open habitat although they may avoid them during daylight hours to avoid negative interactions with humans.

Red wolf use of woody wetlands in the GSMNP was greater than expected. Woody wetlands represented a small percentage of all habitat types available to the red wolf. This habitat type occurred predominately along Abrams Creek and its tributaries that radiate out from the centerline of the cove. These waterways are dry and/or shallow seasonally, which makes them excellent travel corridors and ambush points. These travel corridors consist of edge habitats that are commonly associated with increased levels of floral and faunal diversity (Sharitz *et al.* 1992). These riparian zones also provide cover for stalking and ambushing prey. Woody wetlands along the riparian buffer zones along Abrams Creek and its tributaries would also offer seclusion from the loop road through Cades Cove and the numerous visitors that frequent the Cades Cove area. Though canids within the GSMNP show some tolerance to the presence of humans, they do not tolerant of close contact. Any species of wildlife has its limits when it comes to human presence, but canids are especially wary of humans and often need cover or a place of seclusion in which to rest.

Application of Analysis Techniques

The present study is the first attempt to conduct a *post hoc* analysis of the failed reintroduction of red wolves in the GSMNP. Such analyses are a critical element for management of all species, but are especially important to the management of an endangered species for which we have no life history information. The failure to perform an analysis of life history data collected during a reintroduction may reduce the success of current and future reintroductions through the repetition of mistakes (Dodd and Seigel 1991). As is too often the case, data collected from reintroduction efforts that is not immediately utilized in an analysis and can languish in desk drawers. If not for the efforts of dedicated biologists, any possible benefits to future reintroductions from the analysis of legacy data are lost.

Analysis of legacy data is more effective if those performing the analysis have first hand knowledge of the fine points of the reintroduction. This first hand knowledge is even more beneficial to the *post hoc* analysis of a reintroduction involving a species that has been removed from the wild for a substantial period. Animals that have been reared for several generations in captivity may have been influenced behaviorally by exposure to their human caretakers. In order to reduce the effects of long-term captivity, captive bred pairs of red wolves were released on island propagation sites prior to whelping in order to minimize human contact with their pups (U. S. Fish and Wildlife 1989). These "wild" raised pups were then used in the reintroduction efforts at ARNWR and the GSMNP. Though the GSMNP red wolves were products of the island propagation technique, some of those released displayed an inappropriate level of tolerance to humans. Having a first hand knowledge of the release animals and their individual behavioral characteristics, such as transient behaviors, aided in establishing dataset selection criteria (e.g. uninterrupted datasets) that eliminated them from this analysis. Furthermore, having a first hand knowledge of the activities and behaviors of release animals allows the researcher to incorporate observations made in the field that aid in the documentation of a species' life history and the development of future research directions.

Though the GSMNP red wolf analysis revealed some general habitat use trends, further investigation into red wolf home range and habitat use is warranted. Seasonal trends in habitat usage are likely to be important in properly managing reintroduced populations of endangered species. However, seasonal analyses were not attempted in the present study. Partitioning of the GSMNP red wolf data would reveal only a limited amount of useful information about seasonal home range and habitat use patterns. The limitations of the data lie in the data collection regimen. The majority of the once daily location estimates were taken between sunrise and sunset. This limits the resolution of the datasets to long term or general diurnal trends. In order to appropriately assess red wolf seasonal habitat use, location estimates would need to be taken 6-8 times daily over 6-8 weeks during a series of predetermined seasonal periods such as breeding, pup rearing, and non-pup rearing. The once daily diurnal sampling of the GSMNP red wolf datasets provide a view of habitat use for one instant during the animals daily habitat usage pattern. This would be insufficient to accurately describe the seasonal habitat usage patterns of the species. On the other hand, home range estimation requires fewer location estimates. Therefore, partitioning the GSMNP data might be expected to reveal some useful information about seasonal home range distributions. Never the less, I believe such seasonal home range estimates derived from the partitioning of the existing GSMNP data would have to be invested with limited confidence, as they would reveal little to nothing about the nocturnal movements of the red wolf.

Again, intensive monitoring is needed to appropriately define red wolf home range and habitat usage. The acquisition of this type of data is impossible as all red wolves were removed from the GSMNP at the close of the reintroduction. However, the application of fixed kernel home range estimates and the use-availability analysis to the GSMNP data has revealed weaknesses in the sampling regimen applied to the GSMNP population. The application of intensive seasonal sampling to the ARNWR red wolf populations in combination with analysis techniques utilized in the GSMNP may enhance the ability of the biologists to apply the findings of the present study to the current adaptive management plan for ARNWR.

In 1999, biologists at ARNWR recognized that the growing coyote population in the region was encroaching on the existing red wolf population from the west. In response to the growing threat of hybridization a Population and Habitat Viability Assessment (PHVA) was held in order to develop a revised red wolf recovery plan (Kelly *et al.* 1999). One product of the red wolf PHVA was an adaptive management plan that set out to determine what portion of the current red wolf range was coyote free

(Kelly 2000). After the coyote free zone was established, FWS biologists were to expand their monitoring efforts westward applying techniques to reduce coyote/red wolf interaction.

Currently, the red wolf adaptive management plan is heavily dependent on monitoring hybridization along the red wolf population's western boundary. Fixed kernel home range estimates would define the home range boundaries of coyotes and red wolves along the western extent boundary with the highest degree of accuracy currently available. The percentage of home range overlap and level of interspecific social interaction between canids could be accurately determined using the precisely defined home range boundaries. Biologists could then determine the areas in which red wolves and coyotes have the highest levels of territorial overlap. Once target areas are defined, biologists can trap individual canids, attach radio collars, and take tissue samples to determine the genetic lineage of the canids. Biologists can remove radio-collared coyotes and/or hybrids mated with red wolves prior to the breeding season and simultaneously insert purebred red wolves as replacement mates. This bolsters purebred red wolf densities along the zone of interspecific social interaction. Maintaining a high density of purebred red wolves along the area of interspecific contact decreases the potential for hybridization by reducing potential interactions between red wolves and coyotes/hybrids. This also increases the rate of expansion of the red wolf population into areas formerly occupied by coyotes and the size of the purebred red wolf core population, while pushing coyotes westward away from the core population area.

The loss of a large core red wolf population and the established social hierarchy with other wild canids along the border of their original range was considered key in the extirpation of the red wolf from the wild (U. S. Fish and Wildlife Service 1989). If a large enough red wolf core population could be established, the red wolf/coyote social hierarchy might be reestablished. By increasing the ability of biologists to monitor and manage the wild population via the application of the home range and habitat use analysis techniques refined in the analysis of the GSMNP legacy data, we can increase the likelihood for the success of the restoration effort.

Unfortunately, the lack of life history information due to the loss or removal of a species from the wild is common especially in the case of carnivores. Utilizing management data to develop life history information and refine analysis techniques could be beneficial to, but not limited to, endangered species with limited life history information such as the Black-footed Ferret (*Mustela nigripes*) or Mexican wolf

(*Canis lupus baileyi*). The application of fixed kernel analysis home range estimation and the use-availability technique utilized in the GSMNP red wolf study could be applied to the management of various species such as White-tailed deer, Black bear, Wild boar, or Eastern turkey. As habitat and resources vary on a regional and local scale, home range and habitat use analysis using these techniques could reveal variations in a species' resource utilization that would improve the management capabilities of regional wildlife managers. The regional habitat usage of a species could be used to develop a land management plan designed to improve the quality of wildlife habitat, and to optimize the population density of a target species. Management data, regardless of the status of a species, should regularly be examined in order to improve the quality and quantity of life history information available for any species.

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