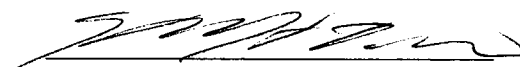
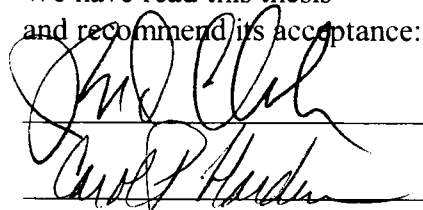


To the Graduate Council:

I am submitting herewith a thesis written by Roger Tankersley, Jr. entitled "Black Bear Habitat in the Southeastern United States: A Biometric Model of Habitat Conditions in the Southern Appalachians." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.


Kenneth H. Orvis, Major Professor

We have read this thesis
and recommend its acceptance:


Two handwritten signatures, one above the other, on a line.

Accepted for the council:


Associate Vice Chancellor
and Dean of The Graduate School

BLACK BEAR HABITAT IN THE SOUTHEASTERN UNITED STATES:
A BIOMETRIC MODEL OF HABITAT CONDITIONS IN THE
SOUTHERN APPALACHIANS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Roger Tankersley, Jr.

December, 1996

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DEDICATION

To my wife, Christine, whose faith in me gave me faith in myself.

And to all of those who are brave enough
to try and make a life out of rolling stones uphill

The development of civilization and industry in general has always shown itself so active in the destruction of forests that everything that has been done for their conservation and production is completely insignificant in comparison.

—Karl Marx (1818–83), German political theorist, social philosopher.

We, the generation that faces the next century, can add the ... solemn injunction
“If we don’t do the impossible, we shall be faced with the unthinkable.”

—Petra Kelly (1947–92), German Green Party founder.

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I want to thank all the guys at work, Dennis Yankee, Karl Hermann, Matt Emerson, and Jim Wickham, for their assistance with computer problems and long days; I've never met a group of people who could talk for so long about nothing, and still manage to get everything done. Thanks to Charles Lafon for braving the fierce Alabama wilderness with me; we were nearly overrun with armadillos and eastern reticulated death rats, and if not for the skill of Alabama map-makers we may not have made it. I want to thank my parents, Roger and Phyllis Tankersley, for never telling me that I couldn't; their love and support made me who I am, and I still wake up at night hearing 'You can if you think you can!' Lastly I wish to thank my wife, Christine, for being patient and understanding, for getting me in gear when I needed it, and for following me to Tennessee in the first place.

ABSTRACT

In order to assess regional patterns of black bear (*Ursus americanus*) habitat use in the southern Appalachian region, I developed regional biometric models of habitat use based on habitat variables identified by F.T. van Manen and M.R. Pelton for Tellico Ranger District, Cherokee National Forest (CNF). The locally-focused Tellico model was based on an analysis of radio telemetry data collected from 1978–1983 by students of Dr. Pelton at the University of Tennessee. The CNF model identified important variables associated with bear habitat use, such as proximity to human activity sites, elevation, and overstory vegetation. Removing highly localized variables such as understory vegetation and stand age richness, which could not be measured at a broad regional scale, I developed models that reflect landscape-level habitat use probability for black bears. Using the recently completed Southern Appalachian Assessment database, these models were applied to the Southern Appalachians, revealing the relative probability of suitable habitat for male and female bears in spring, summer, fall and year-round habitat conditions.

The habitat suitability maps show a clear pattern of upland habitat areas with high use probabilities around the Great Smoky Mountains in Tennessee, and the George Washington and Jefferson national forests in Virginia. High probability habitat areas were also identified on private lands, many adjacent to areas of public ownership. These probability maps are based on a model developed on National Forest land, in an area with abundant suitable habitats. Areas with a high relative probability of suitable habitat at this regional scale should be interpreted as optimum habitat, distinguishable from areas of moderate habitat quality. A regional perspective is important because it provides information on the distribution of habitat outside known bear population areas, and also evaluates the fragmentation of occupied areas. Identifying these suitable habitat patterns is another step in establishing a regional conservation program that insures the survival of black bears in the Southeast.

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Chapter I

Introduction

General Problem Statement

The increasing fragmentation of forested wildlife habitats in the southern Appalachians has led to a cooperative effort between state and federal agencies to conserve biodiversity in the region. The human population of the region is concentrated in the valley areas; these areas provide highly productive farmland, as well as the low relief preferred for development of roads and urban areas. As a result, wildlife species dependent on contiguous forest cover have been relegated to the more rugged, upland areas of the Appalachians that fall mainly under public ownership. These areas collectively comprise the Southern Appalachian Bioreserve, and represent one of the richest enclaves of species diversity on earth. In the face of an expanding human population, forest wildlife species will require sound regional management planning that helps to conserve the overall condition of remaining forested areas in the Southeast. The combination of human environmental exploitation and species richness warrants a regional evaluation of habitat conditions to help future land managers address the management of species diversity within a regional landscape context.

To conserve and maximize the biodiversity of the southern Appalachians, it is important to concentrate on maintaining and enhancing the gene pools of individual species; healthy populations of individual species are the key to diverse ecological assemblages. Maintaining a diverse biota at a regional scale depends on the availability of

suitable habitat areas that can support large, viable populations. Species such as the black bear (*Ursus americanus*), which require extensive tracts of land to maintain a stable population, are especially important to biodiversity — management of large, contiguous habitat areas for bear is likely to provide habitat for numerous other wildlife species. A population that can survive indefinitely requires an effective population — the portion of the population that is actually reproducing, also known as a deme — that is large enough to insure genetic diversity (Lande and Barrowclough 1987). Black bears require an estimated 80,000 hectares to maintain an effective population (M.R. Pelton, from Rudis and Tansey 1995), and it is unlikely that any single new populations will be established in the eastern U.S. Managing the existing metapopulation, which consists of several geographically separated sub-populations, is a more attainable conservation goal (Rudis and Tansey 1995). Creating genetic links between populations will strengthen existing populations, and planned reintroductions may establish new sub-populations, increasing the size of the metapopulation. Metapopulation management will also help maintain biodiversity by targeting many areas of different sizes and different habitat characteristics.

The black bear is a highly adaptable species which once occupied nearly all of North America (Figure 1). The fragmentation of forested areas and lowland habitats has greatly reduced the range of the black bear, until it now occupies only a fraction of its historic range (Figure 2). In the Southeast, bears inhabit only five to ten percent of their former range (Figure 3), predominantly public lands managed by federal agencies such as the U.S.D.A. Forest Service and the U.S.D.I. National Park Service (Maehr 1984). The

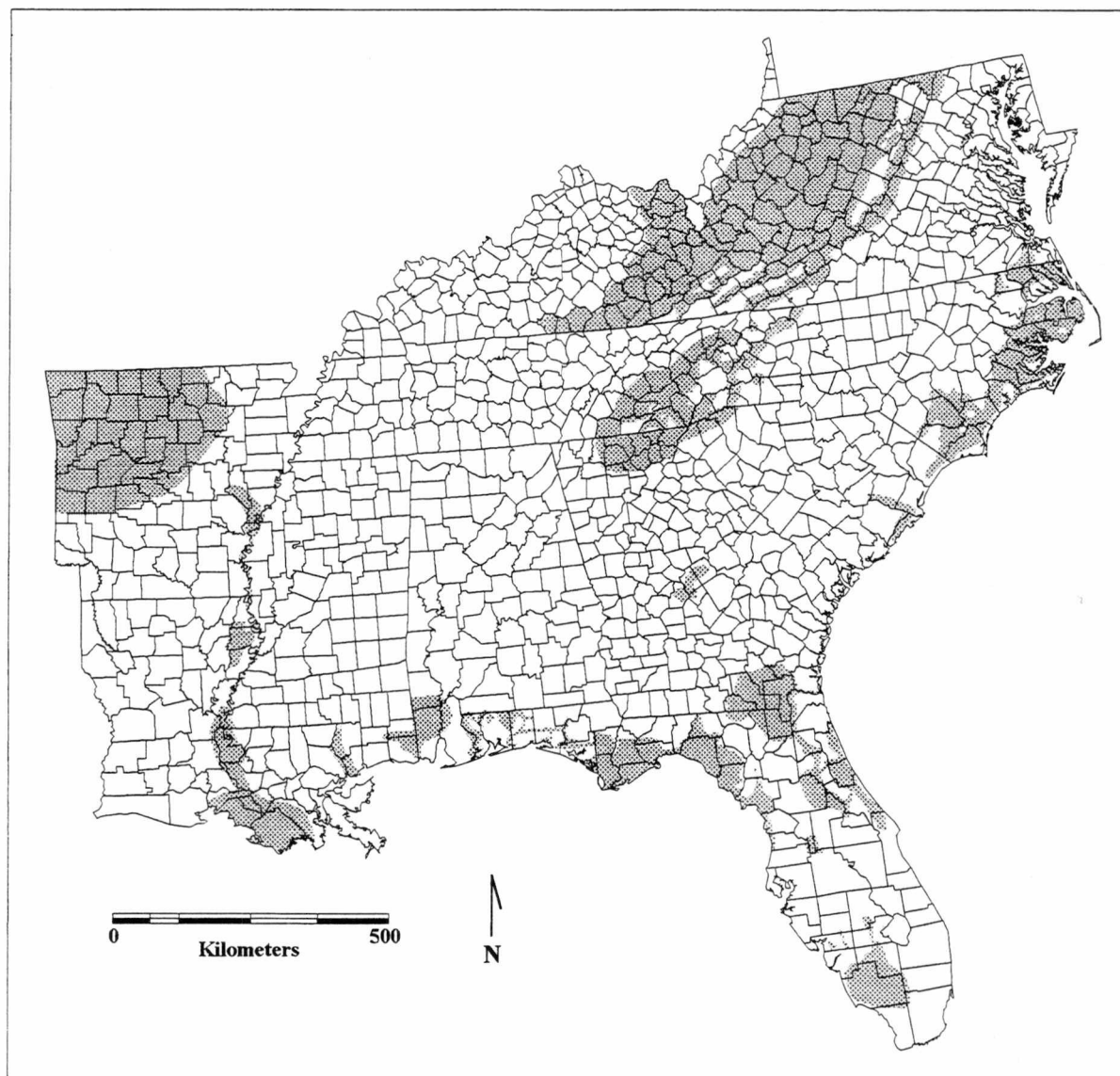
Figure 1: Historic distribution of black bear in North America. From Pelton and van Manen, in press. Used with permission.



Figure 2: Current black bear distribution in North America. From Pelton and van Manen, in press. Used with permission.



Figure 3: Current black bear distribution in the southeastern United States. Pelton and van Manen, in press. Used with permission.



southeastern population is divided between two remaining habitat types: mountainous regions and coastal areas (Pelton 1985). The mountainous habitat is distributed along the length of the southern Appalachians, and represents most of the remaining contiguous forest cover in the Southeast. Bears use this rugged habitat more by default than by preference; human exploitation has removed nearly all the contiguous forest from the Appalachian valleys. Over the past 200 years, human settlements and agricultural land use have created a human-dominated landscape matrix that isolates and fragments wildlife habitat areas. The remaining forest areas are separated by unsuitable habitat into 'islands' of intact forest ecosystems, fragmenting both the remaining suitable habitat and wildlife populations. Studying the arrangement and composition of these areas identifies habitats and populations requiring special attention in land-use management plans.

To insure the survival of a black bear population in the southern Appalachians, it is important to evaluate the present distribution of suitable habitat areas. Bears are large-bodied, opportunistic, intelligent and wide-ranging mammals that are capable of occupying a wide range of habitat types (Schoen 1990). Bears occupy extensive home ranges to meet their habitat requirements: in the Southeast, male home ranges cover 31–155 square kilometers, and female ranges cover 5–16 square kilometers (Clevenger 1986). Large home range sizes and the ability to use many habitat types place the black bear in direct conflict with human disturbance and development in the region. The stability and distribution of the black bear population can therefore be used as a proxy for the overall condition of forested areas in the region; evaluating the distribution of available habitat areas for black bear effectively reveals patterns of overall forest condition. Human

development pressures affect all species in the region, and a well studied, environmentally sensitive species such as the black bear is useful in evaluating human impacts on forest habitat conditions in the southern Appalachians. Given the severity of human impacts in the Southeast, it is remarkable that any viable populations of black bears remain; this fact makes their study even more imperative.

The fragmentation of bear habitat in the Southeast necessitates the management of black bear as a metapopulation. Lande and Barrowclough (1987) define a metapopulation species as "a species whose range comprises geographically distinct patches interconnected through patterns of gene-flow, extinction, and recolonization." Although black bears are not historically a metapopulation species (given that bears once occupied all of North America), human disturbance has forced bears to occupy fragmented habitat areas that are separated by unsuitable habitat. This organization of bears into geographically separated habitats has created a metapopulation in the southern Appalachians.

While fine scale habitat studies reveal important information about the biological requirements of bears, it is imperative to place these biometric evaluations in a regional context. Metapopulation management depends on reliable information about regional habitat conditions. To evaluate habitat quality on such a large scale, a regional habitat model must be developed, either by using bear occurrence data covering the entire region, or by extrapolating a site-specific model to a regional scale. Numerous fine scale studies identifying bear habitat requirements are available, and since many of these requirements

are met at a coarse spatial scale over large areas (Clark and van Manen 1993), it is reasonable to base a regional habitat evaluation on a fine scale modeling effort.

Regional Context

The area of focus for this study is the Southern Appalachian Man and the Biosphere (SAMAB) Southern Appalachian Assessment (SAA). SAMAB is a member of UNESCO's Man and the Biosphere (MAB) coalition, an international organization dedicated to the preservation of biotic diversity through the establishment of biosphere reserves (Tangley 1988). Placing ecological systems in the context of a human dominated landscape, the interagency SAA stresses the importance of regional land management plans in preserving the biotic diversity of the Southeast. While a great deal of information is available concerning public lands in the southern Appalachians, the SAA is important because it also provides information concerning private lands, which make up 84% of the land area (Hermann 1996). Privately owned lands dominate the region and surround publicly managed forested environments; land owners must therefore play a significant role in regional conservation efforts. It is important for conservation initiatives to move toward integrated management plans encompassing private lands, so that a biosphere reserve can be maintained in the southern Appalachians.

A regional viewpoint is shared by the Southern Appalachian Black Bear Study Group (Bear Study Group), which sees the southern Appalachian bear population as a shared resource between several states (Clark and Pelton 1996). The Bear Study Group

was formed in 1990, growing out of the Tri-State Black Bear Study founded in 1974 and including Tennessee, North Carolina and Georgia. Today, the Bear Study Group also includes South Carolina, the National Park Service, and the U.S. Forest Service; Virginia and West Virginia have expressed an interest in joining the group (Clark and Pelton 1996). The regional view taken by the Bear Study Group is an important step toward an integrated management plan for bear conservation in the southeastern United States. Evaluating regional habitat patterns will facilitate regional management plans by establishing a baseline of current habitat conditions across the region.

While many studies on black bear habitat requirements in the Southeast exist (i.e. Beeman and Pelton 1980, Beringer 1986, Brody 1984, Garner 1986), none have attempted to evaluate habitat conditions for the region as a whole. Most studies have centered on the Great Smoky Mountains National Park (Carr 1983), the adjacent Cherokee National Forest (Clevenger 1986), or the Shenandoah National Park (Williamson and Whelan 1983). These studies have provided a wealth of habitat data on black bears, and the long term research at the University of Tennessee (which began in 1968) has revealed temporal fluctuations and patterns that would not be apparent over shorter time scales (van Manen 1994). A regional examination would place well known bear populations in a black bear habitat 'landscape' and reveal regional patterns of habitat conditions, including linkages between populations that were unidentified, or uninhabited areas that are suitable for bear reintroduction or range extension. A regional perspective could also be used to guide management practices in existing habitats; the development of

a new road that bisects existing habitat could be judged not only in a local context, but also from a regional population management perspective.

Habitat Studies and Geographic Information Systems

The study of wildlife-habitat relationships implicitly assumes an ability to understand habitat suitability by evaluating physical and biological variables. Furthermore, there is an underlying assumption that a subset of important habitat variables can be measured and evaluated to illuminate complex interactions between an organism and its surroundings. Habitat studies have become essential during the twentieth century as the need for scientific management has increased (Morrison et al. 1992). Concepts such as the multi-dimensional niche account for the complexity of environmental conditions that define suitable habitat for a species; the definition of habitat conditions as the intersection of numerous environmental gradients recognizes the complexity of ecological processes (Hutchinson 1957). The key to developing a successful habitat model lies in the ability to correctly identify, measure, and classify environmental variables in such a way that habitat suitability is revealed from a subset of the actual environmental conditions (Morrison et al. 1992). Human abilities define this subset; humans can only gather and analyze variables that reflect our perception of the natural world. So while scent, vision, experience, and other factors may be important in a bear's perception of the landscape, humans must rely on measurable proxies like understory vegetation to evaluate habitat conditions. Established techniques and numerous field studies, particularly on

black bear in this region, have identified measurable environmental variables that may reveal regional habitat patterns.

The development and refinement of Geographic Information System (GIS) technology within the past two decades has provided a new venue for habitat models. GIS is designed for the collection, storage, manipulation, and analysis of data that includes geographic location as an important component of the analysis (Aronoff 1993). Implicit in this definition is the spatial analysis of landscape components; various layers of information can be combined to reveal regions of coincidence between multiple environmental variables. The spatial arrangement of these regions can be evaluated to reveal patterns in metapopulation distributions, and to identify locales that will be affected by future human population growth. In addition, the ability to combine large spatial datasets within a single analysis framework may reveal processes not directly under consideration, such as the effect of topography on vegetation distributions or the influence of human barriers on otherwise continuous habitat areas.

Black bears are especially suitable for GIS habitat analysis due to this species' large home range and coarse use of habitat components. Bears seem to respond to gross changes in habitat conditions, and these changes can be identified in a GIS using environmental variables measured by humans. While bears do respond to micro scale habitat conditions, it has been possible to predict bear habitat use by examining only broad scale variables (e.g. Rudis and Tansey 1995, Agee et al. 1989). Many of the common data layers available (i.e. roads, forest cover types, elevation, urban areas) are significant to black bear ecology, and GIS enables wildlife biologists to study complex patterns over

large spatial scales (Clark et al. 1993). This type of regional habitat modeling is currently not feasible using intensive ground sampling at all locations. Using a GIS enables researchers to examine the landscape in different ways; the best habitat model can be developed by selecting a combination of variables that most reliably quantifies habitat conditions.

Approach and Scope

Management of black bears in the Southeast depends on our understanding of habitat distribution patterns across the SAA region, which in turn may lead to an understanding of metapopulation dynamics of the Appalachian population. In addition to a basis in wildlife biology, this thesis is founded on the study of the spatial distribution of biotic components in the environment; this study can be easily referred to as biogeography (Haring et al. 1992). The integration of physical variables into a recognizable entity, here called a suitable habitat area, is a spatial statistics exercise that relies on geographic principles.

Regional habitat modeling represents the integration of wildlife biology and landscape ecology within a geographic framework. The interaction of biotic and abiotic processes can be organized into the study of landscape ecology, which examines the distribution and configuration of environmental patterns across large regions (Forman 1995). Landscape ecology helps in understanding the complex patterns created by the interaction of zoogeographic distributions and environmental gradients; studying black

bears as members of environmental patches distributed across the region provides an understanding of habitat distribution and metapopulation organization. Hierarchy theory may also play a role in black bear habitat analyses, by identifying regional scale variables which influence the observed variations in habitat conditions (Allen and Starr 1982). A fine scale model necessarily focuses on local conditions in the habitat study area; at a broader scale, we lose site of specific selection decisions made by bears, and begin to see bears as members of forest patches. These patches are distinguishable from unsuitable habitat using broad scale variables that reflect gross differences in habitat conditions, such as land cover or elevation. Successful extrapolation of a fine scale model to a broad scale study area depends on the ability of the researcher to identify variables measurable at both scales. These variables serve as a kind of 'bridge' between the two modeling efforts, providing a scientific basis for habitat variable selection at a broad scale.

As part of the Southern Appalachian Assessment, Jim Wentworth of the U.S. Forest Service and I have developed a potentially-suitable-habitat model for black bear. This model is not statistical, but is based on empirical data published in the bear research literature, using forest cover, patch size, proximity to major highways, and road density to identify potentially suitable habitat. Such a broad habitat evaluation provides general information on where black bears are likely to thrive; more importantly, it helps to identify areas that are almost certainly unsuitable. This type of general habitat evaluation is the basis for land management initiatives by the Forest Service and other agencies; it is important to evaluate the validity of the model outputs, particularly since it is a part of the SAA database, which is available to the public and to management agencies.

F.T. van Manen and M.R. Pelton have developed a statistical biometric black bear habitat use model for the Cherokee National Forest (CNF) in Tennessee. Their model is based on numerous variables representing habitat conditions in terms of food supply, isolation from human-altered land cover, elevation, and other variables important to bear survival (van Manen and Pelton in press). Parameters for these model variables were developed from a statistical analysis of five years of radio telemetry data collected by the University of Tennessee Wildlife and Fisheries department. These telemetry data represent actual bear habitat use patterns, and help in determining environmental characteristics of suitable habitat areas.

This thesis focuses on developing regional scale biometric models by extrapolating appropriate attributes of van Manen and Pelton's model from the Tellico Ranger district, CNF, to the entire SAA area. The purpose of the project is two-fold: 1) To evaluate the southeastern United States highland areas and reveal landscape-level habitat patterns through the use of regional models. This study represents the first application of a biometric model to the entire SAA region, and significant patterns may be revealed that have implications for metapopulation management. 2) To assess the accuracy of Wentworth and Tankersley's SAA model, which is typical of the types of models the Forest Service uses in implementing management plans over large areas. All areas identified in the regional model should be contained within the broad areas defined in the SAA model.

The ultimate goal is to determine the feasibility of regional scale habitat suitability assessments based on existing GIS datasets. This approach is important because it avoids

the often prohibitive expense of ground-based habitat assessments that cannot be attempted over such broad spatial scales. Furthermore, the ability to assess habitat areas using existing data will allow more frequent and reliable assessments, resulting in a constant monitoring and updating of conservation plans.

Chapter II

Background

Habitat Studies

Within the framework of scientific conservation biology, habitat studies are key tools for the evaluation and conservation of species in a given environment. The scientific study of habitat conditions began in the 1930's as scientists such as H.L. Stoddard (1931) and Aldo Leopold (1933) sought to expand wildlife populations by manipulating habitat conditions. Wildlife was viewed as a crop which needed management to insure the continued abundance of game species. Wildlife managers such as Leopold realized that "science had accumulated more knowledge of how to distinguish one species from another than of the habits, requirements, and interrelationships of living populations" (1933). Leopold was calling for the systematic study of wildlife-habitat relationships, so that management could begin to focus on natural components that contributed most to the abundance of species.

Habitat studies in the latter half of the twentieth century have begun to encompass non-game species threatened by human population expansion. Legislation such as the Wilderness Act (1964), the National Environmental Policy Act (1969) and the Endangered Species Conservation Act (1973) necessitate the evaluation of habitat areas in a systematic manner that can be repeated (Grumbine 1992). Scientific habitat evaluations must attempt to identify a few measurable variables that reflect habitat suitability. Those

variables must be measurable at other locations across the earth's surface to reveal regional, continental, and ultimately global patterns in wildlife habitat conditions.

The definition of habitat has changed in recent years, and continues to be refined due to new concepts in ecology and wildlife biology. In its simplest sense, habitat represents the area of the earth where an organism lives (Weaver and Clements 1938). This definition allows the researcher to identify the physical characteristics that define suitable habitat for the organism of interest. Such a wide open view of a species' habitat does not aid in identifying critical components of the natural environment, because the habitat variables measured may have little to do with the life history requirements of an organism.

Dividing habitat into biotic and abiotic components helps to separate environmental systems (e.g. geomorphic and climatological processes) from biological interactions between species (D. Buehler, Univ. of Tenn., pers. commun.). Habitat studies must focus on all aspects of the environment, both physical and biological, while considering how each of these factors affects the life history requirements of the organism. A functional definition for a species' habitat is "an area with the combination of resources and environmental conditions that promotes occupancy by individuals of a given species (or population) and allows those individuals to survive and reproduce" (Morrison et al. 1992). From this viewpoint, habitat components are those physical or biological qualities that not only *identify* a habitat area, but also *functionally determine* suitable habitat areas by defining the physical and biological constraints acting on the species of interest. Some researchers further define habitat as being either "primary" or "secondary," depending on

its importance in the life history of the species (Harris 1984). While this refinement may help to rank habitat areas in order of importance, it does little to improve the functionality of Morrison's definition as a basis for habitat studies.

Using the above definition of habitat, it is possible to identify the geographic range an organism occupies within its ecological community. The concept of the ecological niche is a useful tool for organizing information about measurable components of an organism's habitat. Hutchinson's (1957) definition of an n -dimensional hypervolume combined several existing concepts of the ecological niche, representing niche as the intersection of n independent variables that defines the geographic location of the highest population density for a given species. Van Horne (1983) correctly noted that an individual species' abundance does not necessarily indicate optimum or even suitable habitat conditions; bearing this in mind, however, the niche concept is still useful in identifying combinations of ecological parameters that define a species' habitat. Potential habitat should be considered in the broader context of population demographics and longer time scales, which may help to further define what may be considered optimum habitat and identify those environmental variables that most constrain the species..

Modeling Wildlife Habitat

Once the physical and biological factors affecting a species' distribution and abundance at a particular location are identified, it is possible to develop predictive models that quantify habitat conditions at other locations. A habitat model is a descriptive or

mathematical representation of the relationship between a wildlife population and its habitat. Models fall into two broad categories: empirical models, which are based on field collected data about species occurrences and habitat conditions; and theoretical models, which may be more fully mathematical in nature, representing habitat relationships in an abstract manner (Morrison et al. 1992). Empirical models reveal more about actual wildlife–habitat relationships, and are more useful in management. The models developed in this study are empirical; the SAA model is based on the experience of field experts, and the adapted van Manen model is based on radio telemetry data that reveals actual ground locations of bears. Empirical models are based on the assumption that the researcher is measuring variables that are actually determining habitat selection, or that represent proxies for other variables perceived by the organism. It is impossible to truly measure how another species views the environment; instead, we must rely on carefully structured studies that associate a species' occurrence with quantifiable variables.

The key to developing a successful habitat model lies in the accurate abstraction and aggregation of the system being studied (Bunnell and Tait 1981). Since model development always involves a simplification of the system under study, the elements chosen to represent the complexities of the wildlife–habitat relationship should reveal as much as possible, while remaining manageable from a sampling perspective. To achieve this, models must evolve from a thorough understanding of the system or phenomena being represented; the “concepts guide the researcher when he is looking for facts; they provide the matrix in which facts are embedded” (Margenau, from Bunnell 1973). Modeling in this context becomes a method of examining the facts and focusing the

researcher's attention on established relationships within a structured framework, identifying physical properties or geographic regions that are critical to the species being studied.

Considering that many habitat studies are based on a multidimensional evaluation of the ecological niche, multivariate statistical techniques are useful in analyzing habitat conditions. Common methods for habitat modeling are principal components analysis, canonical correlation analysis, multiple linear regression, discriminate analysis, and logistic regression (Morrison and O'Neil 1992). These techniques are all capable of weighting habitat parameters to reflect the importance of various habitat components. Multivariate techniques have the added advantage of revealing correlations between variables, which may reveal habitat relationships that were not considered in the model development.

Past habitat modeling efforts have been largely based on techniques developed by federal management agencies such as the U.S. Fish and Wildlife Service (USFWS) and the U.S. Forest Service (USFS). The USFWS Habitat Evaluation Procedures (HEP) are used extensively to evaluate the effects of land management alternatives on habitat quality and distribution (Flood et al. 1977). Using a selected group of species that rely on different habitat types and successional stages, HEP models identify the amount and quality of remaining habitat under several different management plans. The USFS Habitat Suitability Index (HSI) models are widely used by federal agencies and research scientists (Schamberger and O'Neil 1982). These models indicate habitat suitability as the geometric mean of several habitat components, each corresponding to a life history stage of the species; the resulting index ranges from 0–1, representing habitat quality as a

function of species presence, abundance, or distribution (Morrison et al. 1992). HSI models have been developed for a variety of species, including black bear (Rogers and Allen 1987); many of these have been tested by the USFS.

Nearly all habitat modeling and evaluation research has focused on fine scale patterns of habitat use and selection; these studies provide invaluable data on the actual habitat use characteristics of black bear throughout the world, and particularly in eastern North America. While these studies are essential to understanding the complex interactions between bears and their environment, few studies have applied this information to a regional study area. This thesis is the next step in determining the continental biogeographic distribution of bears in North America; by building on past research efforts at the local scale, it is possible to identify patterns in environmental variables that define the biogeography of bears in a forested ecosystem. Although applying an extrapolated fine scale model to a regional GIS database represents a new methodology in bear research, this procedure is firmly based on past research efforts that have identified habitat needs for bears in the southern Appalachians.

Geographic Information Systems and Habitat Modeling

Geographic Information Systems (GIS) present an excellent platform for the development and application of habitat models. Inherent in the definition of GIS is the ability to automatically or manually update a spatial database, and to combine existing data layers into new geographic data (Fisher and Lindenbergh 1989). This flexibility means that

habitat models may be modified and re-evaluated relatively quickly as new data become available. GIS also facilitates the recursive modeling, since many alternatives can be examined in a short time using the same dataset. Bearing in mind that reality consists of mostly unmeasured operational factors, GIS models can bring us much farther in habitat studies than can qualitative philosophies about habitat relationships (Zonneveld 1990). Habitat measures identified through an iterative model development and selection process may more accurately represent habitat conditions over a broad spatial range; they will certainly identify the best sub-group of model variables perceivable to humans. This iterative process would be difficult using purely qualitative techniques, because the importance of individual variables would be unclear.

There are generally two approaches to representing habitat data in a GIS format: vector topology, which represents features using arcs and polygons; and raster data, which represents habitat factors using grid cells. In both methods, the spatial information is represented using homogeneous units, and combinations of units convey the spatial distribution of data across the landscape (Aronoff 1993). In the vector data model, homogeneous units are represented using points, lines and polygons which are topologically related to one another; that is, each feature encodes its spatial relation to every other feature. In the raster approach, the cells are the homogeneous features, and carry spatial data implicitly by their placement within the raster grid. Given that the spatial variability of habitat conditions is the desired information in habitat modeling, the raster approach is generally more applicable; habitat conditions can be represented as a continuous cover variable, rather than as discrete polygons or lines (Aronoff 1993).

While linear features such as roads may be somewhat distorted in shape, the ability to evaluate habitat as a surface map more than compensates for the slight errors in linear feature placement. I used raster data for the models presented in this thesis.

GIS techniques are especially useful for black bear habitat evaluations, since many of the broad scale habitat factors (roads, forest cover, elevation, human disturbance) are available in most land management GIS databases (Clark and van Manen 1993). Black bears are also habitat generalists and use habitat components at a coarse geographic scale; this means that fewer variables and lower resolution may be adequate to evaluate habitat conditions, compared to habitat specialists which may require highly detailed datasets (Donovan et al. 1987). Several recent bear habitat studies have incorporated GIS techniques for the analysis of habitat variables. Grizzly bear sightings (Agee et al. 1989) and habitat use (Gaines et al. 1994) in the northern Cascades range were evaluated in a GIS using habitat factors such as vegetation cover and human disturbance. Williamson and Whelan (1983) developed a computer-based habitat map of Shenandoah National Park; although this was not a true GIS application, it represents an early attempt to organize habitat data within a computer mapping format. Clark et al. (1993) developed a multivariate biometric habitat model for the Arkansas highlands; bear telemetry data were regressed against broad scale habitat variables. Van Manen (1995) also used a telemetry correlation approach in the Great Smoky Mountains National Park, and subsequently in the Cherokee National Forest (van Manen and Pelton, in press); the Cherokee model is the basis for the research presented in this thesis. This thesis represents one of the first efforts to expand bear habitat evaluations from a local to a regional level; earlier models

based on localized conditions provide the theoretical foundation for broader scale modeling research.

Landscape Ecology

Landscape ecology is the study of the relationships between ecological patches across a region, identifying patterns that define the landscape as an ecosystem rather than simply an aggregation of smaller systems (Zonneveld 1990). Observing many small adjacent systems across a landscape, the patterns may at first appear to be simple combinations of ecosystems, defining a regional ecosystem that is nothing more than the sum of its parts. Landscape ecologists believe that regional ecosystems have qualities that define them as unique systems, with measurable variables that affect ecosystem processes across the landscape and within embedded ecosystems. Identifying these variables reveals larger processes that determine the distributions of plants and animals at continental and global scales.

A key component of landscape ecology is evaluation of the spatial distribution of plants, animals, and abiotic ecosystem components; this evaluation can also be called biogeography, or geoecology (Troll 1950 cited in Zonneveld 1990). There are essentially three dimensions of landscape ecology: topological, emphasizing ecological relationships between biological entities within a landscape patch regardless of the scale of the evaluation; chorological, emphasizing the distribution of patches and their connectivity through corridor areas; and geospheric, the study of relationships at continental and

global scales (Neef 1967 cited in Zonneveld 1990). This thesis incorporates both the topological and the chorological components; regional patterns of habitat areas are evaluated while keeping the ecological relationships between habitat variables in focus. Therefore patches are seen as relatively homogeneous units, but the ecological make-up of individual patches is considered.

Metapopulation studies and theories are based on the landscape ecology principles of connectivity, dispersion, and patch dynamics. A group of populations distributed over several habitat patches is called a metapopulation only if there is interchange among the populations (Opdam 1991). Wide-ranging species such as black bear are likely to be organized in a metapopulation due to their ability to cross unsuitable habitat areas and their need for large home ranges. The interconnectedness of several small populations provides a regional stability to the population, even when local populations experience wide fluctuations due to locally unstable conditions (Johnson et al. 1992). While a stable — in fact growing — population of black bear exists in Great Smoky Mountains National Park, the stability of that population may rely on the regional patterns of genetic transfer, extinction, and recolonization typical of a metapopulation species. The first step in evaluating the metapopulation dynamics of black bear in the SAA region is to identify the spatial arrangement of bear habitat areas across the landscape. That is the purpose of this thesis.

Landscape ecology also focuses on selecting an appropriate scale for various ecological evaluations. Many of the components described above — dispersion, the interconnectedness of patches, and metapopulation dynamics — must necessarily be

studied at large spatiotemporal scales (Noss and Harris 1986). It is difficult, if not impossible, to gather reliable data about black bear occurrences over an area as large as the SAA region. Furthermore, much of the land is privately owned, which may preclude habitat studies in many locations. An extrapolation approach to regional habitat studies — developing broad scale models using information gathered from fine scale efforts — deals with these issues. Extrapolation methods have been used to study gray wolf habitat in the Great Lakes Region (Mladenoff et al. 1995) and grizzly habitat in the northwest (Agee et al. 1989).

Researchers generally agree that there is no one appropriate scale for all ecological analyses (Meentemeyer 1989; Allen et al. 1987; Hamel et al. 1986). When moving from one scale to another some general guiding principles can be found in hierarchy theory. The most obvious effect of changing scale from a local to a regional extent is the loss of detailed habitat information (Wiens 1989). For example, fine scale habitat variables that drive actual resource procurement within a habitat patch are unlikely to be measurable over large areas. Fine scale studies examine an ecological plane, or level of organization, where biotic factors (such as the location of individual feeding sites) are highly important in determining habitat suitability. As the extent of the study area increases, these fine scale biotic variations become less important. The resulting loss of detail refocuses the study onto a different scale of ecological organization: the study has moved from within a forest patch, where individual food items and the distribution of plant species dictate resource use, to a regional view which sees the species as one component of a forested habitat patch.

As one continues to move upward through broader ecological planes of organization, the overall constraints on the system become more apparent, until finally at a regional scale habitat conditions may be determined by one or two broad environmental variables. These various planes of organization are hierarchical in nature, with processes in one plane affecting processes in both higher and lower planes (Allen et al. 1987). A regional view is necessary for metapopulation studies, since viewing habitat areas internally reveals little about nearby patches that may be suitable for dispersal (Allen et al. 1987). The stability of a metapopulation depends more on the organization of suitable habitat patches across the landscape than on subtle differences within individual habitat patches.

There are two approaches to developing a regional view: aggregation of smaller systems into larger systems, or identification of larger systems which actually control the fine scale distributions (Meentemeyer 1984). My research takes the aggregation approach — I have changed the extent of the study area while maintaining the grain size (the actual examination units) of van Manen's fine scale model. This higher ecological level is simply an aggregation of local habitat conditions into large scale habitat patterns, and is not built upon larger systems that may be driving habitat selection. However, an examination of the distribution patterns identified in this study may reveal larger systems — like the effect of topography on forest area distribution — that are determining habitat patterns across the region. If this is true it may be possible to examine even larger areas, with a change in both grain size and extent, and quantify habitat distribution with reasonable accuracy.

Black Bear Biology and Habitat Requirements

Black bear habitat requirements have been thoroughly studied in the Southeast, particularly by students at the University of Tennessee under M.R. Pelton (for examples, see Garshelis 1978, Quigley 1982, Brody 1984, Clevenger 1986, Coley 1995). This volume of research stems largely from the direction provided by the Southern Appalachian Black Bear Study Group. Bear habitat studies have identified several variables that contribute to bear habitat quality, including physical (elevation, topography), biological (vegetation, community structure) and cultural (roads, urban areas, and campsites) components of the landscape (van Manen 1995). Combinations of these variables define bear habitats in forested areas; more importantly, they are variables that can be identified and measured by humans.

Bears are habitat generalists that rely on several different food sources in the Southeast; this flexibility in food sources allows bears to inhabit many different habitat types. Their diet is predominantly berries and nuts, with blackberries, blueberries and other soft-mast species providing food for the spring and summer seasons (Pelton 1982). Oak acorns provide the high energy needed to prepare bears for denning; during fall months, it is not uncommon for bears to gain 0.5–1 kilograms (1 to 2 pounds) of fat per day in preparation for winter (Pelton 1982). All of these food sources are most easily found in continuous forest cover with relatively dense understory vegetation.

After food availability, human disturbance probably places the greatest restriction on bear habitats. Bears typically occupy remote areas characterized by rough terrain, which gives them protection from human disturbance and over-harvest; however, bears

can exist in close proximity to humans if ample escape cover is present (Pelton 1982). Forest fragmentation is the most damaging effect of human land development; forested habitats become reduced in size and isolated from each other. Roads pose a special problem to bears, both through direct mortality of bears attempting to cross improved roads, and through increased human access to remote habitat areas along unimproved roads (Beringer et al. 1990). Interstate highways have been shown to be substantial barriers to bear movements, and can isolate populations that are geographically close but that cannot connect across the highway corridor (Wooding and Maddrey 1994).

Roads pose a complex research problem, since not all roads degrade bear habitat areas; unimproved roads with little human traffic, such as gated forest service roads, may actually facilitate bear movements (Pelton 1982). In a region as large as the SAA study area, similar roads may affect habitat quality in different ways. Roads that cut through otherwise remote forest areas may affect suitability more than those that run along the edge of a forest patch. Other factors, such as local hunting regulations, may also play a role. The effects of roads on black bear habitat quality continue to be studied, and it is possible that no clear relationship will emerge that is applicable to a region as large as the SAA. From a regional viewpoint, roads represent areas with relatively higher human occupation than areas without roads, effectively serving as a proxy for human use areas that are unsuitable bear habitat.

Black bears and other members of the genus *Ursus* have some of the lowest reproductive rates among terrestrial vertebrates (Bunnell and Tait 1981). They are a classic *K*-selected species, exhibiting slow reproductive maturity, prolonged reproductive

cycle, and small litter sizes (Eiler et al. 1989). These reproductive traits make suitable den selection imperative, since cubs are born during denning season and their survival is dependent on the mother's ability to maintain homeothermy and conserve energy (Johnson and Pelton 1981). The most common den sites are in depressions under fallen trees, boulders, and tree roots, and within standing tree cavities. In the Southeast dens must be relatively enclosed to keep out winter rains; rain can flood bear dens, and wet conditions make it more difficult to retain body heat and conserve energy (Clark and Pelton 1996). As habitat areas continue to decline in both number and quality, den sites may become a limiting factor in bear population sizes, since the reproductive capability of the species is dependent on suitable dens. Currently den sites are plentiful in the southern Appalachians, and are not regarded as a limiting factor in determining habitat suitability.

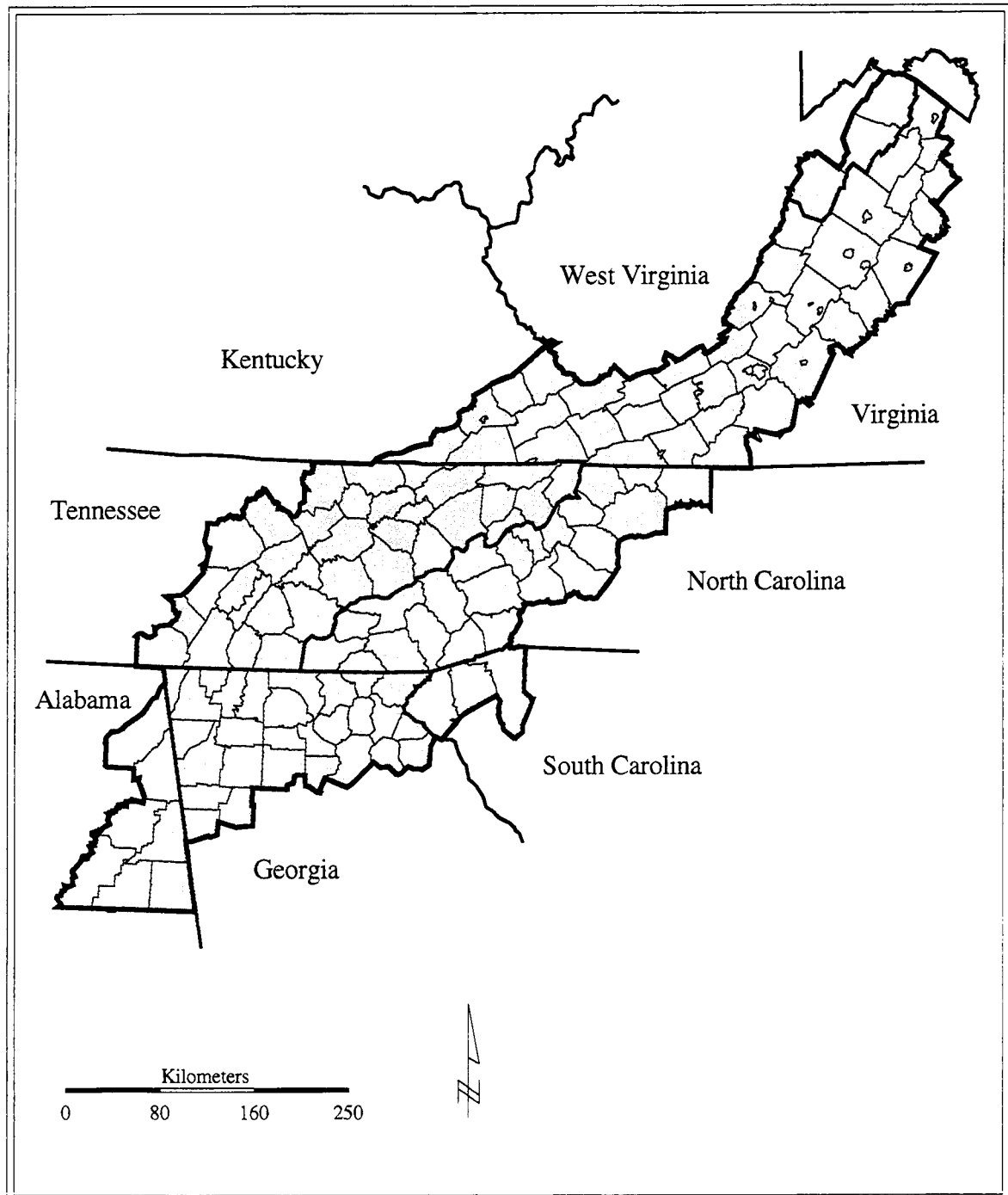
Chapter III

Study Area

The Southern Appalachian Assessment (SAA) study area covers 15,150,000 hectares (37,400,000 acres, 57,426 square miles) in the southeastern United States. It encompasses 135 counties in portions of seven states (Figure 4), stretching from northern Virginia to northern Alabama. Government leaders in the early twentieth century recognized the Appalachians as a valuable national resource, and worked to preserve the biological and historical heritage of the region. Their work resulted in the establishment of seven National Forests and three National Parks in the southern Appalachians, forming the largest contiguous block of public lands east of the Mississippi (SAA summary report). Management decisions by a few federal agencies determine land management practices for many ecosystems, providing a unique opportunity for biological conservation. Climatic variations, topographic features, and human land use history combine to create a complex landscape of cover types and species' distributions. Patterns of disturbance and forest regeneration continue to change across the region, affecting the distribution of species requiring forested habitat.

The southern Appalachian ecosystem is one of the most diverse in the world, due largely to its humid-subtropical climate that provides a long growing season, year round precipitation, and mild winters. Situated near the continental edge of North America, the Appalachians experience weather patterns strongly influenced by the presence of the warm Gulf of Mexico to the south, the Azores High to the east, and the effect of the Rocky

Figure 4: Southern Appalachian Assessment Study Area



mountains, to the west, on the jet stream. The southern Appalachians receive abundant precipitation; most variations in soil moisture are caused by landform properties such as aspect and topographic position. Climatic conditions vary north to south with changes in latitude, due to differences in the intensity of solar radiation and the position of the polar front. Alabama has milder winters and warmer summers than the northern sections of the study area. This latitudinal gradient produces variations in climatic conditions that affect the distribution of plant and animal species across the landscape. Black bears are able to adapt to nearly all habitat conditions across the region; the diversity of plant and animal communities, including both hard and soft mast species, insures that an abundant food supply is available nearly year round.

The latitudinal climatic gradient is magnified by topographic differences in the region. Rising suddenly from the Piedmont province, the Blue Ridge mountains dominate the eastern portion of the study area, with elevations ranging from 610–1,800 meters (2,000–6,000 feet). Variations in climatic and physical conditions support a diverse biota, with many species occupying the edge of their natural range. Subtle differences in environmental gradients (such as soil moisture, temperature, and topographic position) allow many different species to co-exist in close proximity. Shenandoah and Great Smoky Mountains (GRSM) National Parks lie in the Blue Ridge province; GRSM is part of a recognized Biosphere Reserve within Unesco's Man and the Biosphere Program, emphasizing the importance of the Blue Ridge province in the southern Appalachians (Tangley 1988). The complex patterns of environmental conditions along the Blue Ridge

help to make the southern Appalachians one of the most diverse regions of the United States.

To the west of the Blue Ridge lies the Ridge and Valley province. A majority of the SAA area's six million people live in these lowland valley areas (Hermann 1996).

Croplands and pastures are the dominant land cover types in the great valley. Although some forested areas remain, they are highly fragmented by roads and human altered land-cover types. While some wildlife species have adapted to this human-dominated environment, most species have been forced into the more mountainous regions to the east and west; the valley effectively separates these two regions. Human landscape features like interstate highways are sometimes crossed by highly mobile species, but it is unlikely that any significant migration takes place across the valley. It is unknown if this isolation is sufficient to cause biological speciation (the formation of two new species from a single species due to genetic drift that causes subtle biological differences, preventing them from interbreeding) in an adaptable and mobile species such as the black bear. It certainly affects the transfer of genetic material within the regional population (Wilson 1992). Complex interactions between wildlife populations across the landscape are not fully understood, and more studies are needed concerning the effects of human-altered landscapes on species movements. While bears do cross the ridge and valley province, the valley is considered a significant barrier to black bear movements in the SAA region, and contributes to the metapopulation configuration of the black bear population.

To the west of the Ridge and Valley province lies the Cumberland plateau, characterized by the sudden rise of mountains and ridges from the valley floor. The

topography of the plateau is generally more rugged than the great valley, but less mountainous than the Blue Ridge province; consequently the plateau has more human development than the Blue Ridge, but retains many large areas of contiguous forest cover. More mesic forest conditions dominate, and temperature and rainfall patterns are relatively consistent across the plateau region. This section of the study area enhances the diversity of the region by retaining many species that are unable to survive without contiguous forest cover. The plateau is less rugged than the Blue Ridge, allowing easier access to humans and consequently greater alteration of ecological conditions; historically there has been significant coal mining and logging pressure, preventing the development of the complex ecosystems found in the Blue Ridge.

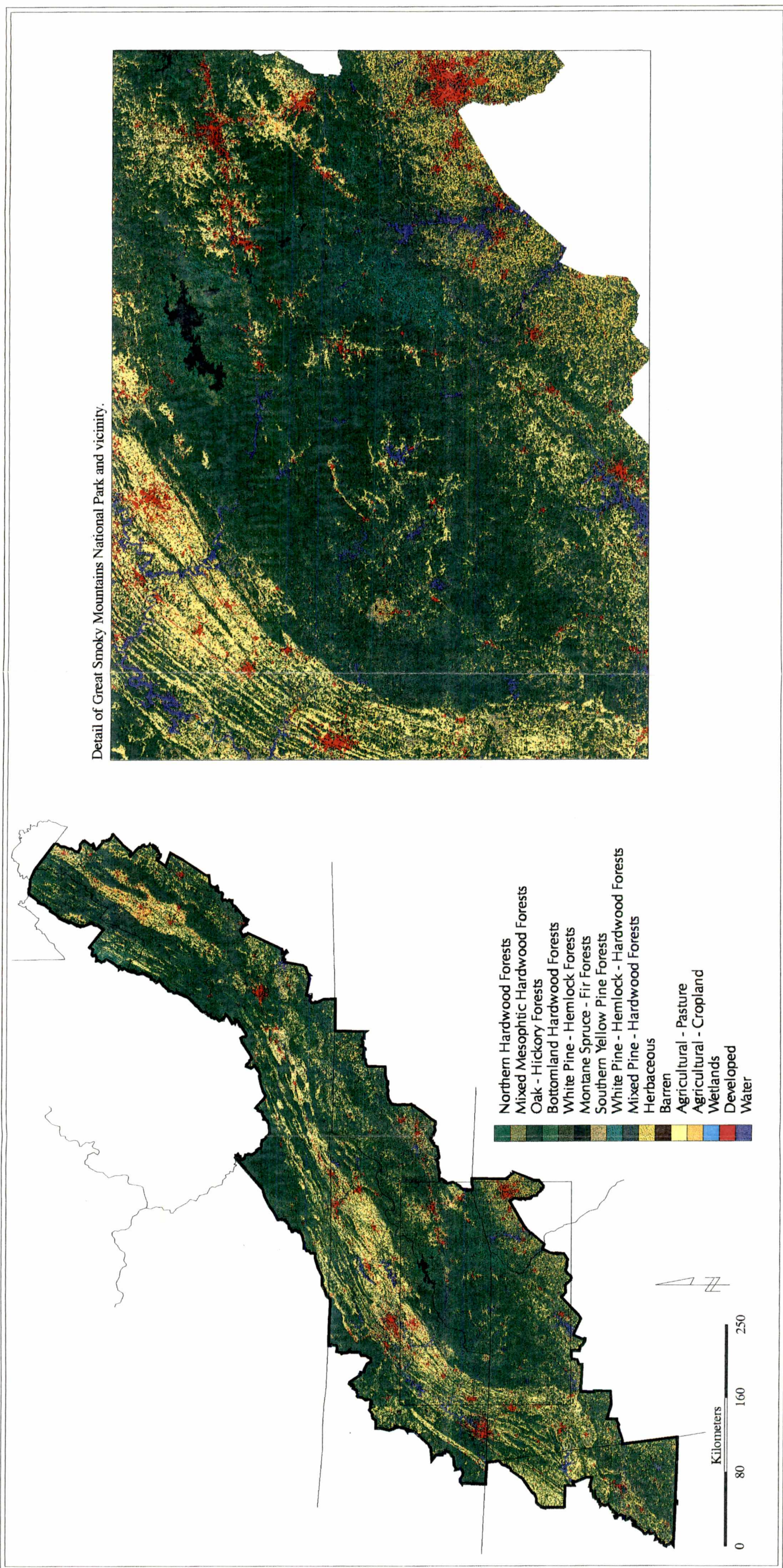
While forest cover on the plateau is more fragmented than forests in the Blue Ridge, black bear and other habitat generalists may find abundant and unoccupied suitable habitat by occupying small habitat areas that lie near larger areas of contiguous forest. This hypothesis is being tested by a repatriation of black bears into Big South Fork National Recreation Area, which lies in the Cumberland plateau province on the Tennessee and Kentucky border (van Manen 1991). Big South Fork is a large area located near the Daniel Boone National Forest in Kentucky that may be able to support a bear population. A bear population located in Big South Fork could expand into the Daniel Boone NF; the juxtaposition of these two forested regions should allow bear populations to expand and contract in response to population fluctuations caused by changing habitat conditions. Although most of the plateau is privately owned, making habitat management programs developed by public agencies difficult to carry out, the

discovery of suitable habitat areas may warrant further evaluation. The lack of public ownership in the plateau section of the study area means that future management initiatives there must involve private landowners.

Human land use history has shaped the SAA region, and may have been the most important factor in determining the present distribution of forest cover shown in Figure 5, as well as the locations of stable populations for wide-ranging species like black bear. In the two hundred years prior to 1930, most of the virgin forest cover in the southern Appalachians was cleared by settlers for homesteads, heating, and to provide land for agriculture (Van Doren 1955). Old growth forests of chestnut, beech, oak, and hickory were cleared, removing an important food source for bears in the region (Clark and Pelton 1996). The most extensive logging and habitat destruction occurred from 1900–1930, when forests were cut for railroad construction, mining timbers, and charcoal. Early successional stages associated with forest clearings were probably beneficial initially, with shade-intolerant species like blackberry (*Rubus* spp.) providing an abundant food source. Benefits for wildlife species were short lived, as continued clearing relegated forested habitats to a fraction of the southern Appalachians.

Clearing the forests had the destructive and longer lasting effect of allowing human settlers to occupy areas of prime wildlife habitat, converting much of the land to agricultural fields unsuitable for most species. Accompanying this land alteration was a period of unchecked wildlife exploitation; species such as wolves (*Canis rufus*) and panthers (*Felis concolor*) were hunted to regional extinction, and black bears were forced to occupy rugged upland forests (Connelly 1968). Since these areas are relatively less

Figure 5: Southern Appalachian Assessment Land Cover
Derived from Landsat Thematic Mapper Data (1990 – 1994) by Pacific Meridian Resources, Inc.



productive than lowland ecosystems, bears often returned to the valley to feed on crops and livestock (Clark and Pelton 1996). Farmers responded by using all available means to eliminate bears from the Southeast, rewarding hunters with bounties in most of the southern Appalachian states. Humans indirectly influenced forest conditions by introducing a blight to the American Chestnut in the early 1900's; this species dominated the southern Appalachian forests, and provided a stable food supply for bear and other species (Clark and Pelton 1996). The blight spread quickly through the region, aided by the expansion of the human population. Chestnuts were soon eliminated from all forested areas, and bears were forced to rely on inconsistent acorn crops; bear demographics today are affected by wide fluctuations in annual acorn production (Pelton 1996).

Land use practices began to change during the 1930's and 1940's. Eroded and degraded farmlands were abandoned as many families moved to more fertile land in the west, or were relocated in the development of a public land base. These abandoned farmlands reverted to forest cover and, as the forests matured, bear populations began to increase (Clark and Pelton 1996). Perhaps even more important was the expansion of the National Park Service and the U.S. Forest Service land holdings in the region. Land purchases were beginning to protect large stands of new and old growth forest; fragmented forest patches began to merge into large forest regions that could support bear populations. For black bear, the most significant land acquisition was the establishment of the Great Smoky Mountains National Park. The 212,000-hectare (524,000-acre) park was relatively undisturbed, and represented a core habitat of old growth hardwoods for black bears. The trend of reforestation and public land acquisition has continued through

the latter half of the century, and stable black bear populations are present in both the northern and southern sections of the SAA area.

Today much of the southern Appalachians has returned to forest cover; in the SAA region, over 70% of the land cover is in forests (Hermann 1996). While this is encouraging, over 25% of the land is altered by human land use, with 20% of the land used for agriculture and 5% developed as urban areas (Hermann 1996). In numerical terms, 5% seems like a small amount; in reality, it means that over 750,000 hectares (1,850,000 acres) is covered by southern Appalachian cities and towns. In addition to simply destroying forested habitat areas, urban landscapes affect the remaining forest habitats by placing human-altered landscapes close to forested regions. As the forests become less isolated from human disturbance, habitat conditions become unsuitable for many wildlife species, including black bear. In the SAA region, over 80% of all land is within 4 kilometers (2.5 miles) of human development, and 96% is within 8 kilometers (Hermann 1996). Land use practices today are reversing the 60-year trend of increasing forest cover; as the human population in the region continues to grow, forests are again being cleared, and the remaining forested habitats are being affected by the proximity of human development.

The distributions of wildlife species in the lowland ecosystems are largely determined by human disturbance, and human altered habitat conditions are beginning to spread into the upland regions. Societal preferences are affecting wildlife habitat, as more individuals seek to leave urban landscapes and establish homes in rural settings. With these new homes come new roads that fragment habitats and further decrease the isolation

of forested areas. Roads are virtually everywhere in the southern Appalachians; 99% of the SAA region is within 4 kilometers of an improved road. Even more remarkable, only 16% of the region is more than one kilometer away. Although the ecological effects of roads are not fully understood, they allow human access to nearly all sections of the southern Appalachians, increasing the chances for human development in forested habitats. Habitat conditions across the entire SAA study area are threatened; even protected lands like the GRSM are affected by development pressure on their boundaries.

The SAA provides a unique opportunity to examine the distribution of wildlife habitat in a region historically altered by humans. Studying the current habitat conditions may identify locations where local management practices, such as closing roads or preventing the construction of new ones, can have a significant impact on wildlife species. The diversity of ecological communities allows us to examine the effects of human disturbance on many different species, and may give us insight into the future of wildlife populations in a human-altered global ecosystem. Although the southern Appalachians have been significantly affected by human land-use, the region is relatively healthy in comparison to the rest of the eastern United States. Examining habitat distributions in the Southeast may help us to understand how a growing human population can co-exist with other animal populations, or if co-existence is possible at all.

Chapter IV

Methods

General

To examine the regional distribution of black bear habitat in the southeastern United States, I developed regional biometric habitat models based on models initially developed by F.T. van Manen and M.R. Pelton for the Tellico Ranger District, Cherokee National Forest, Tennessee. The Tellico models predict male and female bear habitat use in spring, summer, and fall, as well as overall habitat conditions. The regional models were applied to the SAA GIS database in the ARC/INFO GRID raster environment (Environmental Systems Research Institute, Redlands, Ca.). The development of regional habitat models in this thesis builds on the more localized study of van Manen and Pelton.

The Tellico Ranger District is predominantly forest covered, and is typical of suitable upland black bear habitat. There are private holdings within and adjacent to Tellico that include human development sites and improved roads. This juxtaposition of forested habitat with human disturbance areas reflects the conditions found throughout the forested environments of the SAA study area. Extrapolating fine scale models to a regional extent is a deductive approach to wildlife habitat studies, wherein known habitat requirements are evaluated over a large area by examining the spatial distribution of habitat factors (Stoms et al. 1992). While some variables important to bear biology (understory vegetation, forest stand age) cannot easily be measured over a large

geographic region, other relatively coarse scale variables can serve as proxies for actual habitat conditions.

Tellico Ranger District Models

The regional biometric models developed in this thesis are based on the biometric models developed by van Manen and Pelton for the Tellico Ranger District, Cherokee National Forest. My regional perspective places the earlier work in a broader context, and demonstrates the ability to model broad scale patterns using variables which are important at both the local and the landscape scale; therefore a discussion of van Manen and Pelton's methodology is necessary to clarify my work on developing the regional models. The Tellico models were based on 3,289 bear locations collected during three studies from 1978–1983 using radio–telemetry tracking of captured and collared bears (van Manen and Pelton, in press). Bear locations were estimated using the “loudest signal method” (Springer 1979), a triangulation technique that reduces error in locational data. Telemetry location error was mitigated by calculating error polygons for individual bears, and rejecting those locations where three or more radio bearings did not fit within a circle with a radius of 150 meters (van Manen and Pelton, in press). Compiling the three studies yielded 5,023 locations of 42 individual bears; of these, 2,231 female locations and 1,070 male locations passed the selection criteria, yielding the sub–group of 3,289 locations. This sub–group was used in the local scale habitat analyses, and later to evaluate the variables used in the regional–scale models.

Van Manen and Pelton developed a GIS database containing 15 habitat variables associated with bear locations (Appendix A). They performed habitat analyses in a vector environment using ARC/INFO (Environmental Systems Research Institute, Redlands, Ca.), with a minimum mapping unit based on Forest Service Continuous Inventory of Stand Condition (CISC) stand polygons (U.S. For. Serv. 1988). The CISC data contain information concerning forest condition, stand age, and management history; other data, such as topography, were added to the database from other sources (see van Manen and Pelton, in press). Habitat analyses used the 3,289 bear locations and an equal number of random locations representing habitat areas that were available to bears.

To reveal seasonal variations in habitat use, van Manen and Pelton divided the telemetry locations into three periods representing distinct changes in the diet and activity of bears. The seasonal definitions were based on food and activity studies in the southern Appalachians during the same time period the locations were collected. Although forest conditions may have changed during the past 16 years, the number of locations insures that gross habitat changes in one area will not dominate the dataset. For the seasonal analysis, spring was defined as the period from 1 April through 15 June, summer as the period from 16 June through 15 September, and fall as the period between 16 September and 15 December (van Manen and Pelton, in press).

Van Manen and Pelton conducted univariate analyses on all variables in the GIS database using logistic regression (SAS Inst., Inc. 1990, PROC LOGISTIC). Logistic regression techniques can reveal useful biological data by distinguishing between known and random bear locations (van Manen and Pelton, in press). Logistic regression

attempts to separate random locations from known locations, represented as 0 or 1, respectively. The resulting equation reflects the ability of a data variable to separate the two, and may reveal the significance of a model variable in quantifying known bear locations. As each variable is logistically regressed against the locational data, it becomes clear which parameters consistently reflect black bear habitat use, and which variables are unable to distinguish between actual and random bear locations. Not only does this reduce the number of variables selected, it also insures that the model parameters selected are the most useful for evaluating habitat conditions. Variables whose univariate tests had P -values < 0.25 were considered candidates for multivariate habitat use analysis. For females, the authors included all variables except understory vegetation richness; for males, they used all variables except slope, stand age, and stand age richness.

After evaluating each variable individually, van Manen and Pelton used a model selection procedure to determine the best subset of variables for explaining the variations in the locational data. The selected models were those whose variable combinations consistently minimized the difference between computed and actual probability values of bear habitat use. Several individual variables exhibited no significant differences among their variable classes in χ^2 goodness of fit tests, and classes for these variables were pooled before being submitted to the model selection procedure. For overstory vegetation type, van Manen and Pelton combined bottomland, mixed mesophytic, and northern hardwoods into one class; white pine/hemlock/hardwood and white pine/hemlock were combined into another. For females, the authors combined the slope aspect classes northeast, southeast, and northwest; for males, southwestern, southeastern,

and northeastern were pooled. The computerized model selection procedure allowed the authors to evaluate literally thousands of model combinations, insuring that the best fitting combination was selected.

The Akaike's Information Criterion (AIC) was used to select the variable subset that best described bear habitat use (Akaike 1973). AIC is an information based method for identifying an optimal statistical model; the procedure helps to select the model that provides the best explanation for variances in the data, while penalizing models that have excessive parameters and violate the principle of parsimony. The AIC value was calculated for each model combination using the PROC LOGISTIC procedure of the Statistical Analysis System (SAS Institute, Inc., 1990); values were calculated for 12,951 female models and 4,095 male models. Van Manen and Pelton used the same variable set in each season and in their overall evaluation, assuming that seasonal variations are better reflected by changing parameter values than by several models with different variables. The results of van Manen and Pelton's logistic regression analysis of the variables can be found in Appendix A (Tables A2 and A3); the models they developed provide the most accurate representation of bear habitat use in Tellico Ranger District.

Using parameter estimates from the best fitting models, van Manen and Pelton calculated the relative probability of bear habitat use in a given area based on the habitat characteristics of that location, using equation 4.1 (Hosmer and Lemeshow 1989):

$$P = \frac{e^{g(x)}}{1 + e^{g(x)}} \quad (4.1)$$

where $g(x)$ is the logit transformation (Equation 4.2), consisting of the sum of parameter estimates for nominal variables and the parameter estimates for continuous variables times their observed values (van Manen and Pelton, in press).

$$g(x) = \beta_0 + \beta_1 X_{1i} + \dots + \beta_k X_{ki} \quad (4.2)$$

The parameter estimates are given either a positive or negative value, indicating whether a location variable was used more or less than expected based on the selected variable; the value of the parameter indicates the magnitude of the relationship. If the resulting probability (Equation 4.1) value is near 1.0, the probability of use is greater than expected; if it is near 0, the probability of use is less than expected. A value of 0.5 indicates that the specified habitat type is used in proportion to its availability. When this model is applied to the entire Tellico Ranger District, it reveals probability of use patterns that may separate high quality habitat from less suitable areas. Since it is unknown whether the locations actually support a bear population, the values do not represent actual bear habitat use, but rather a relative ranking of habitat conditions based on the model parameters. The probability of use seems to be a reasonable estimate of habitat suitability.

It is important to note that the probability values are relative to the sample area, and represent comparisons with random locations in a highly suitable forested environment (Tellico Ranger District) during a defined time period. Therefore areas identified as having optimal habitat conditions by the regional model will be those locations most like high-use areas in Tellico; the variable set and parameter values were derived from statistical analysis using bear locational data there, and reveal habitat preferences of bears living on national forest lands. If a different model development area was chosen, a different model would emerge; it is

assumed, however, that mountainous habitats for black bear are similar enough that habitat quality can be assessed over a broad scale using measurements taken at a local scale.

Therefore a model developed in another forested mountain habitat should generally identify the same variable subset, while a model developed in coastal regions of the Southeast may identify variables not even considered in montaine habitats. The CNF is recognized as an optimum habitat area for bear in the southern Appalachians, and it is reasonable to classify habitat conditions in other forested areas by their similarity to conditions there. Locations with a high relative probability for habitat use at the regional scale should be interpreted as optimum habitat, which the regional biometric model is able to distinguish from locations with moderate habitat quality based on the model variables. Other areas certainly contain suitable habitat, but the environmental conditions defining suitability at those locations are different from the conditions in the CNF.

Development of Regional Scale Models

To develop regional scale models of the entire SAA region, I began with the variable set defined by van Manen and Pelton and selected variables that were measurable over large areas. In order to evaluate habitat conditions for the entire SAA area, it was necessary to remove highly localized variables that could not be measured at the regional scale, and that were not available in the SAA database. For males, understory vegetation type was removed from the fine scale model. The remaining variables were then evaluated using AIC, and the best new models were selected for each of the seasonal variations and for year-round

conditions. Since it was important to use the best combination of the selected landscape scale variables, land-form index was also removed; when this index was included without understory vegetation type, the AIC score revealed that the model was less accurate than a separate model with both variables removed. For females, stand age richness was eliminated from the fine scale model. Using the resulting variable subset, I evaluated the regional models using the AIC goodness of fit statistic to determine whether the regional scale model was capable of determining habitat use at the local scale. It was important to evaluate the fit of the model to the Tellico data to insure that the habitat conditions determined at the regional scale did in fact reflect habitat conditions and use patterns in the model development area. While these regional models may not provide the best fit at the local scale, they do represent the best estimate of habitat conditions at a regional scale, based on the available black bear habitat use data.

In order to apply the regional biometric models the SAA area, habitat variables were evaluated in the ARC INFO GRID raster GIS (Environmental Systems Research Institute, Redlands, Ca.), using the recently completed SAA database (Hermann 1996). A raster environment allows the user to calculate habitat use probability values for each minimum mapping unit area (here 90 by 90 meter pixels), revealing complex patterns that may have a significant impact on habitat suitability. The variables are represented by separate data layers, or "coverages," organized as numerical grids; each 90 by 90 meter grid cell corresponds to a location on the earth's surface, and locations in separate coverages match exactly. The logistic parameter value, calculated for each variable using AIC and based on Tellico bear locations, is multiplied by the actual variable value; the results are summed and stored in a new coverage

representing $g(x)$ in the logit transformation equation (Equation 4.2). Habitat use probability is then calculated for each cell using Equation 4.1; this process is repeated for males and females in each season, each represented by a new coverage. The final product is a set of eight habitat suitability maps, based on habitat use probabilities, reflecting relative habitat use at a regional scale for male and female bears in all seasons.

After determining a variable subset and variable parameter values for use in the regional models, it was necessary to manipulate many of the data sources to prepare them for use in the models. Most of the variables in both the male and female models were derived from other datasets using specialized commands in GRID; only overstory vegetation type had existed as a completed input coverage before work on this thesis began. Each of the proximity values (proximity to streams, roads, and human activity sites) was calculated with the EUCDISTANCE function in GRID. I rasterized the linear features, converting stream and road locational data from a vector data source into a raster data layer. These rasterized linear coverages, as well as the urban land cover class from the landcover data, were used as inputs in the Euclidean distance calculations; the result is a set of grids in which every cell has a value representing the distance to the nearest road, stream, or human activity site. The respective parameter estimates were then applied to these distances to create input grids for the $g(x)$ equation (Equation 4.2).

Aspect was calculated with the ASPECT function of GRID using a digital elevation model (DEM) as the input data layer. Elevation is represented in a DEM (here a 3-arc second DEM) by interpolated values on a coordinate grid cell; these values are digitized from U.S. Geological Service 1:250,000 topographic maps (Hermann 1996). For example, the DEM

used for this analysis had a single elevation value at every 3 seconds of latitude by 3 seconds of longitude grid cell location; these values collectively represent elevation as a continuous surface. The ASPECT function in GRID simply evaluates the directional and elevational change within the DEM on a cell by cell basis, and determines the cardinal direction that each cell is facing. Particular aspect values can then be selected and assigned the appropriate parameter value. Van Manen and Pelton determined that female bear locations exhibited a significant relationship to elevation only if a logistic growth function was applied to the elevation value (van Manen and Pelton, in press). Elevation for the female models ($elev_f$) was calculated using equation 4.2:

$$elev_f = elev * \frac{1600 - elev}{1600} \quad (4.2)$$

where $elev_f$ is represented by a logistic growth function with 1,600 meters as the maximum elevation. This transformation is used to obtain a linear relationship between elevation and female bear locations. Likewise, distance to improved roads (RO) was squared for use in logistic regression analysis for female bears, again to obtain a linear relationship.

I calculated overstory vegetation richness for the male models using a "sliding window" technique. This technique evaluates several pixels at a time within a "neighborhood" and returns the number of different pixel values in the analysis window. The entire SAA study area was processed by sliding the analysis window across the landcover data layer. The GRID function FOCALVARIETY was used with a window size of 3 by 3 pixels; 9 pixels were evaluated in each window to determine the number of different cover types present, and this value was stored in a new data layer. The resulting coverage provides the needed measure of

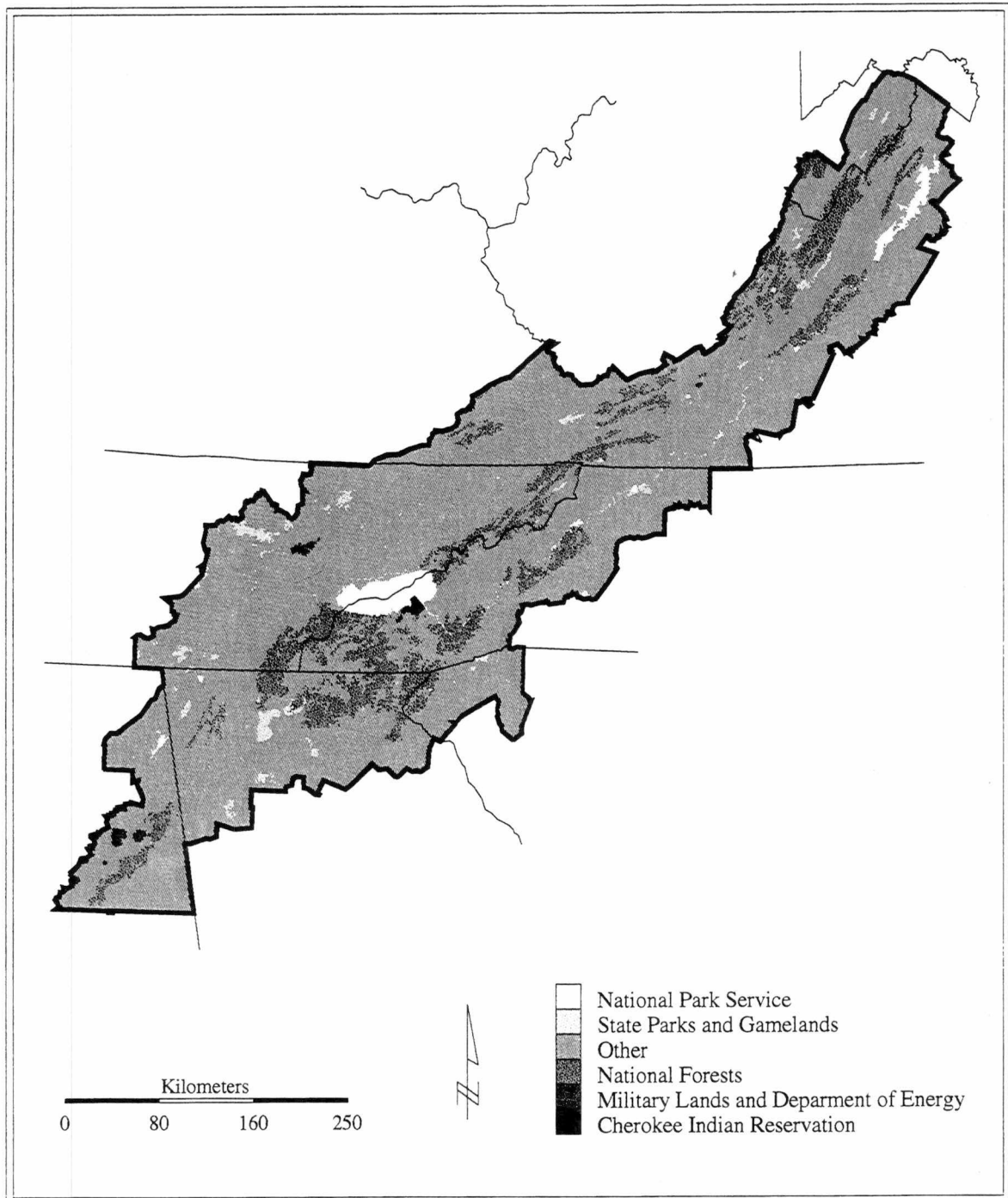
overstory vegetation richness, to be combined with the other data layers in the logit transformation.

After developing all the necessary data layers, I performed the logit transformation using the GRID function EXP, which calculates the base e exponent for an input grid value. Input grid coverages for males and females in all seasons contain the $g(x)$ value determined for each location using the variable data layers. The result is a set of eight coverages with values ranging from 0–1.0, representing the relative probability of bear habitat use at each cell location. This probability translates roughly to habitat suitability at the landscape scale; by ranking habitat locations, the model identifies habitat areas that are relatively better habitat in comparison to other locations. Each cell in the various maps represents the habitat conditions in a 0.8 hectare area on the earth's surface; these areas collectively create a surface of habitat suitability that characterizes the landscape in terms of bear habitat conditions. Coverages were summarized over the entire SAA region, as well as by land ownership class (Figure 6). Ownership of individual habitat areas were used to distinguish locations that are already protected by federal agencies from those that occur on privately owned lands.

Evaluation of Model Accuracy

Bear location data are not available for the entire SAA region; therefore model accuracy was assessed mainly through the opinion of experts in the field. Basing the regional model on variables identified in the fine scale model developed by van Manen and Pelton provides the

Figure 6: Southern Appalachian Assessment Land Ownership



main accuracy assurance; the fine scale model is the result of many years of intensive study by bear experts at the University of Tennessee. The present day distribution of bears in the Southeast (Figure 3) was also used to evaluate the regional model. This distribution map was based on data collected through questionnaires sent to bear biologists and researchers across the region (Pelton and van Manen, in press). Although this is a somewhat qualitative measure of bear distributions based on the individual biologists' ability to assess black bear habitats, it is the most accurate distribution map available, and is a tangible representation of expert opinions across the study area. If most of the high probability areas fall within the known bear range, the model has performed well. High probability locations that do not fall within the known range are not necessarily errors, however; habitat suitability does not indicate presence or absence, and these areas may represent unoccupied habitat that is suitable for the reintroduction of a bear population.

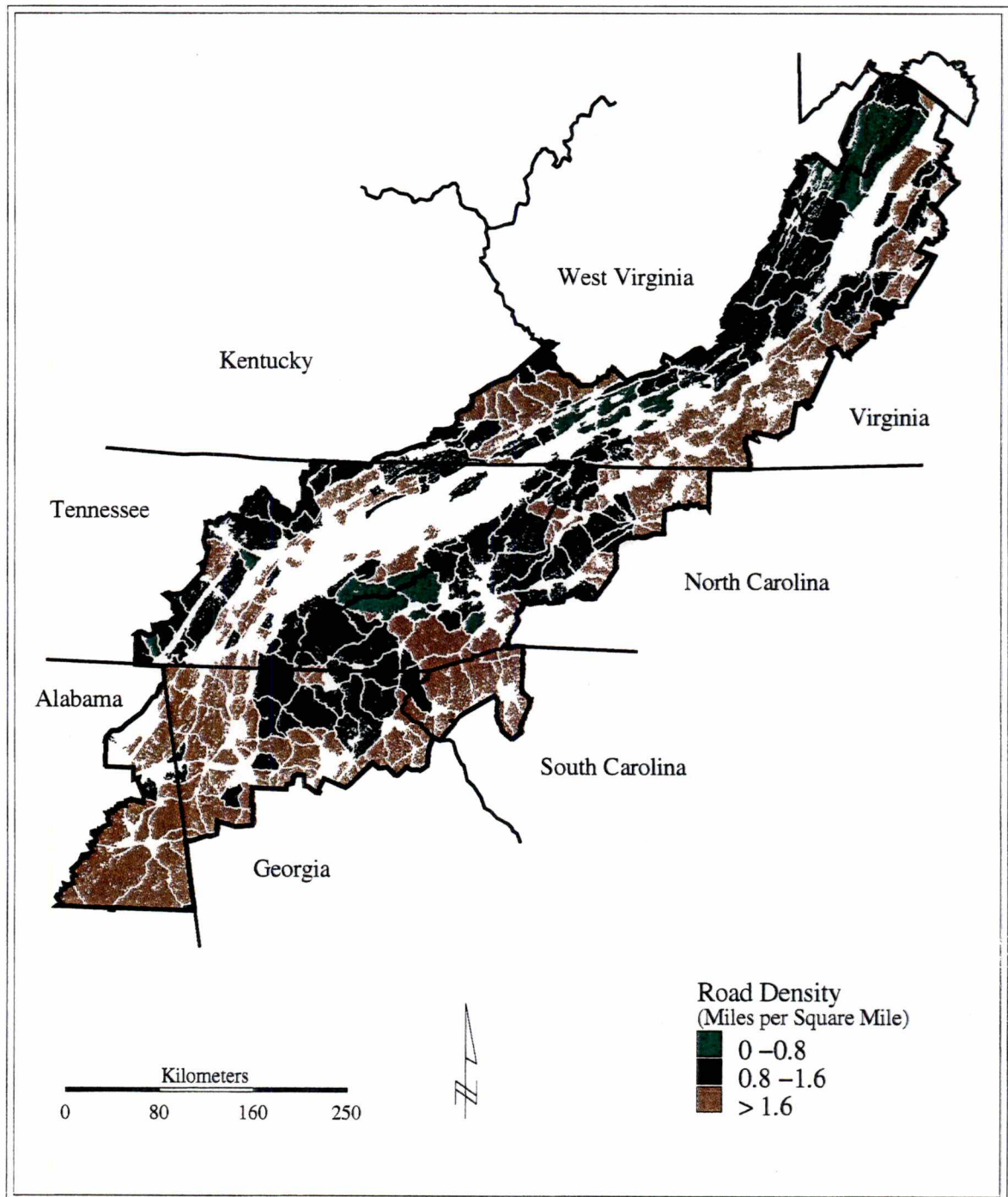
To further evaluate the model results, I conducted field examinations at an area of high use probability that lies outside the known range of bears in the Southeast. Field examinations concentrated on consistent model reflection of gross habitat differences that would certainly affect the suitability of habitat for black bear. Since quantitative measurements of habitat variables in the field were beyond the scope of this thesis, I relied on qualitative judgments of gross habitat conditions to assess habitat conditions. I was judging overall forest condition based on factors such as relative stand age and composition, relative isolation from roads and human activity areas (assessing sight and sound as well as simple distance), and overall environmental conditions such as air pollution and forest

senescence. In addition, I attempted to assess human use of the area, such as logging, that could not be measured using remote data.

Evaluation of the SAA Potential Habitat Model

The SAA black bear potential habitat model was developed for the SAA Plant and Animal team as a broad evaluation of potential habitat conditions. To assess the accuracy of this model, I overlaid the extrapolated male and female overall habitat suitability models onto the SAA model coverage (Figure 7). The SAA model does not reflect seasonal variations in habitat, so comparisons to seasonal habitat suitability would be inappropriate. As with the extrapolated regional models, the main accuracy test is simply a visual evaluation of the landscape patterns; the broad scale organization of bear habitat areas should be generally consistent between the SAA model and the regional models. The SAA model is meant to provide a general overview of habitat conditions; areas identified as highly suitable in the SAA model should contain locations identified as high probability areas in the Tellico models. Since land management agencies such as the Forest Service are evaluating habitat conditions using parameters similar to the SAA model, it is important to assess the model's ability to reflect habitat suitability; this assessment will help to determine if the model is suitable for use in future forest management plans.

Figure 7: Southern Appalachian Assessment Potential Black Bear Habitat.
 Shaded regions represent suitable habitat stratified by road density.
 White regions inside the study area represent unsuitable habitat.



Chapter V

Results

General

The regional models developed in this thesis are able to distinguish high quality habitats from areas of marginal quality across the SAA area, as evidenced by a relatively high correlation with the southeastern distribution map. Furthermore, from what experts know of black bear habitat areas in the region, the habitat probability maps present a reasonable picture of the black bear habitat landscape. The female and male overall habitat use maps (Plates 1 and 2, in pocket) show a regional pattern of upland habitat, with the highest quality areas appearing near ridgelines in Tennessee, North Carolina and Virginia. The regional models were applied to all forested areas of the SAA region below 1600 meters elevation. These areas are similar to Tellico Ranger District, and include the forested habitat conditions evaluated by the fine scale model. I did not feel confident in the model's ability to predict habitat conditions for other land cover types, or above 1600 meters; similar areas are not present in Tellico, and were not considered in the selection of habitat variables. Although valley locations were excluded from the study area (they are not forest covered) they were evaluated before they were excluded, using all variables other than forest cover. None of the valley regions received a probability of use score greater than 0.3 for males or females. This is consistent with the fact that the model was developed for forested upland environments, and is not suitable for evaluating habitat in

other cover types. Although further study may be necessary to evaluate model accuracy at individual locations, the models overall have performed quite well in identifying broad scale habitat differences, as they were designed to do.

Female Black Bear Habitat Suitability

Logistic regression analysis of the Tellico model variables identified six variables for use in the female habitat use probability models: overstory vegetation type (OV); proximity to streams (ST); elevation ($ELEV_f$); aspect (ASP); proximity to improved roads ($RO \cdot RO$), squared to provide a linear correlation; and proximity to human activity sites (HA). These variables were used as inputs for the $g(x)$ equation (Equation 4.2), and their corresponding parameter values are found in tables B.1–B.4 in Appendix B (overall, spring, summer, and fall models, respectively). For the categorical variables OV and ASP, the parameter values were substituted for the landcover classification; for the continuous variables ST, $ELEV_f$, RO^2 , and HA, parameter values were multiplied by the actual locational value for the habitat variable. The logistic transformation was then computed using Equation 4.1; the result represents the relative probability of habitat use by female black bears in each of the models, at every map unit location across the study area. Taken together, these values can be used to create habitat use maps that reveal patterns of habitat use in the SAA area.

For discussion purposes, I will refer to any probability value over 0.5 as suitable habitat, or high quality habitat; this denotation implies that locations with a high use

probability are the most suitable habitat locations. All habitat locations are classified according to conditions in Tellico Ranger District, an area known to support a healthy bear population, and I assume that high use locations contain the most suitable habitat. This assumption is not based on biological data regarding presence or absence of bears; it is simply a convenient way of discussing the relative rankings of habitat areas with regard to the habitat variables used in the models. Areas classified with a habitat suitability less than 0.5 may contain usable habitat conditions, but these areas represent relatively poorer habitat than locations with values greater than 0.5.

The overall female habitat suitability map (Plate 1, in pocket), shows a clear correlation between upland habitat and high probability of use values in both the southern and northern sections of the study area. Located on the border of North Carolina and Tennessee, GRSM is identified as suitable habitat; the presence of a growing bear population in GRSM supports the model classification. The area south of GRSM, the Cherokee National Forest, is also identified as suitable; this would be expected, since the model was developed in that area. Western Virginia has a large amount of suitable habitat identified by the model; this is the location of George Washington National Forest (GWNF), an area known to contain a healthy bear population. The forested lowland regions contain almost no suitable habitat, reflecting the level of human disturbance in the lowland region of the southern Appalachians. Suitable habitat conditions are concentrated in the Blue Ridge mountains in the southern section of the study area, and in the Allegheny highlands west of the great valley in the northern section of the study area. The seasonal probability maps, found in Appendix C, show patterns similar to the overall map.

Although there are small shifts in habitat suitability from season to season, the general regions of suitable habitat remain the same.

A summary graph of female habitat suitability probability (Figure 8) shows that a majority of the SAA region falls below 0.5 probability of use, indicating that most locations are lower quality habitat for female bears. Only 7% of the study area is classified with a use probability greater than 0.5. The distribution of higher use probability habitat is similar between seasons, with a general downward trend in the amount of habitat as use probability increases. The distribution of habitat probabilities above 0.5 by ownership class is shown in Figure 9. A majority of the higher quality habitat is controlled by private owners ('other' in Figure 9) and the U.S. Forest Service (USFS). While the National Park Service (NPS) controls a relatively low amount of the high use probability habitat in the SAA region, most of this habitat is contiguous, and falls in the GRSM and Shenandoah National Park in Virginia. Figure 10 shows the percentage of each ownership class that is high quality habitat; although the 'other' ownership class has many locations classified 0.5 or higher, these locations represent a small percentage of the total land area under private ownership. The NPS and USFS, by comparison, have a relatively high percentage of their land base classified as high probability for use habitat. Nearly all of the known bear populations exist on or adjacent to land managed by these two agencies.

Figure 8: Summary of female black bear regional habitat use probability.

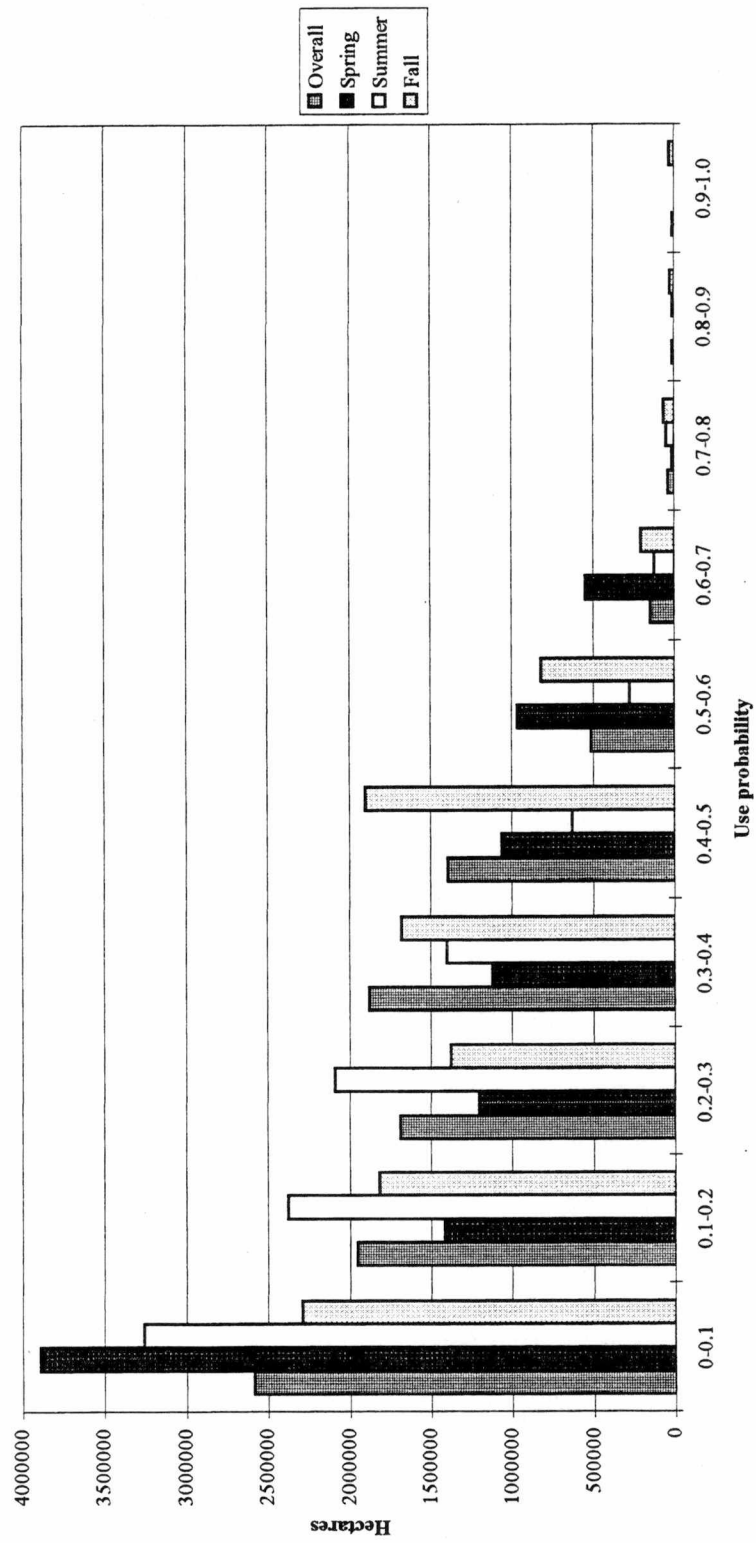


Figure 9: Female habitat use probability over 0.5 classified by ownership. All seasons.

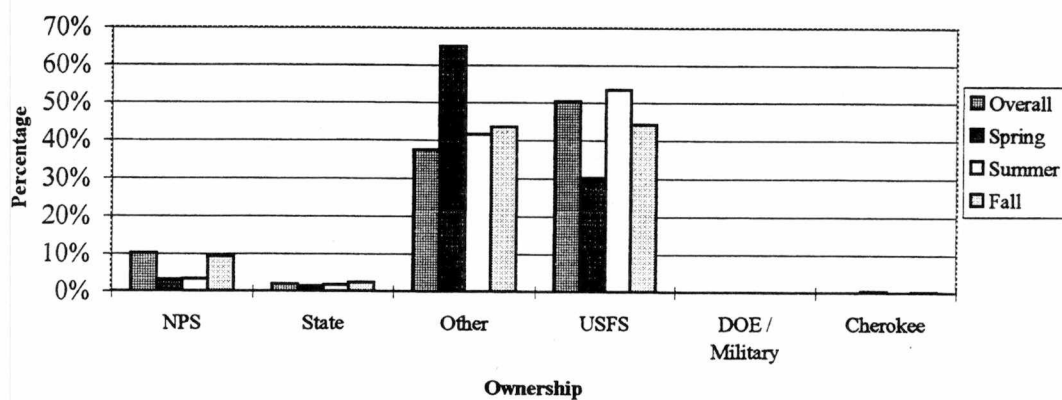
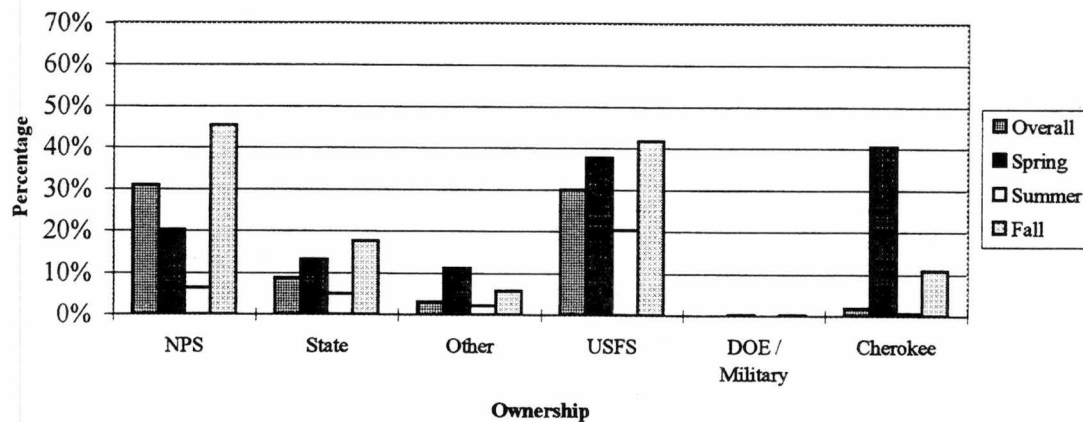


Figure 10: Amount of land base in female habitat use probability over 0.5 classified by ownership. All Seasons.



Male Black Bear Habitat Suitability

Logistic regression analysis for male bears identified six habitat variables from the broad scale variable subset for inclusion in the use probability models: overstory vegetation type (OV); overstory vegetation richness (OVR); proximity to streams (ST); aspect (ASP); proximity to improved roads (RO); and proximity to human activity sites (HA). As with the female models, these variables and their parameter estimates (Tables B5–B8 in Appendix B) are used to compute $g(x)$ for the use probability models. The resulting distribution of habitat use probabilities reveals patterns of relatively higher quality habitat.

The patterns of high use probability habitats for males is similar to the female distribution; upland forests in the northern and southern sections of the regions have the largest contiguous blocks of suitable habitat (Plate 2, in pocket). The GRSM and GWNF are highlighted, along with the Jefferson National Forest in southwest Virginia. North of the Sequatchie Valley in Tennessee, the Catoosa Wildlife Management area is highlighted. While this area does not currently contain a bear population, it is near the Big South Fork National Recreation Area, where a black bear reintroduction project is currently underway. The higher quality habitat areas identified in the upland forest regions are likely able to support a bear population, although not all locations are presently occupied.

A notable difference between the male and female models is the suitable habitat identified in and around Talledega National Forest (TNF) in northern Alabama. It is classified with a high use probability only in the male models, and has not recently supported a black bear population. Field examination of the sites helped to determine

whether they are truly suitable, or simply an over-extension of the model. The lowland areas east of Cheaha and Horn mountains are managed for logging by private timber companies and individual land owners. These locations have few improved roads, and are relatively isolated from human activity sites. Intensive logging practices, however, probably make those locations unsuitable as bear habitat, due to the overwhelming human presence and lack of forest cover in the area. The predominance of pine forest types may also reduce habitat suitability for bears, by displacing oak forests which provide a winter food supply for black bears.

Horn mountain, approximately 48 kilometers south of Cheaha, is a Wildlife Management Area. It is not managed for timber, and the ridgetops are dominated by medium aged hardwood and mixed pine-hardwood forest types. Horn mountain is a significant feature in the topography of TNF; it rises over 300 meters from the valley floor. There are no human activity sites nearby, and no improved roads cross the WMA; there are several unimproved dirt roads, but they are nearly impassable in vehicles without four wheel drive. All of these factors appear to combine to make Horn Mountain WMA a potentially suitable habitat area for bears. The area receives heavy hunting pressure, however, and a significant temporary population of hunters is present in the fall. Although hunters may represent a significant human presence at certain times of the year, it is unknown whether bears in the region could adapt to the hunting pressure, as they have done in many locations across the Southeast.

The distribution of male bear habitat across the SAA region is shown in Figure 11. As with the females, the amount of habitat steadily decreases as use probability increases.

Although values in the male habitat use maps cannot be compared with values from the female maps — they are two different models, with different parameters — it is interesting to note that there are fewer locations in the 0–0.1 probability class for males than for females, and significantly more locations above 0.5. These variations may be the result of differences in habitat preferences, reflecting differences in the ways male and female bears perceive and use their habitat.

Ownership patterns for males center on private landholders and USFS lands, with distributions similar to females (Figure 12). State owned lands are slightly more important for males than females, with around 35% of state managed land receiving a high probability score (Figure 13). Ownership patterns are relatively consistent between seasons; there are no drastic shifts in male black bear habitat suitability from one ownership class to another as seasonal conditions change.

Habitat in the Current Southeastern Bear Range

I compared the regional model results to the current southeastern range map for black bear (Figure 3), representing the opinion of experts in the field. The geographic distribution of high use probability areas within the Southeastern bear range boundary is shown for males in Figure 14, and for females in Figure 15. Over 60% of the suitable habitat for males and females was consistently mapped within the southeastern range map

Figure 11: Summary of male black bear regional habitat use probability.

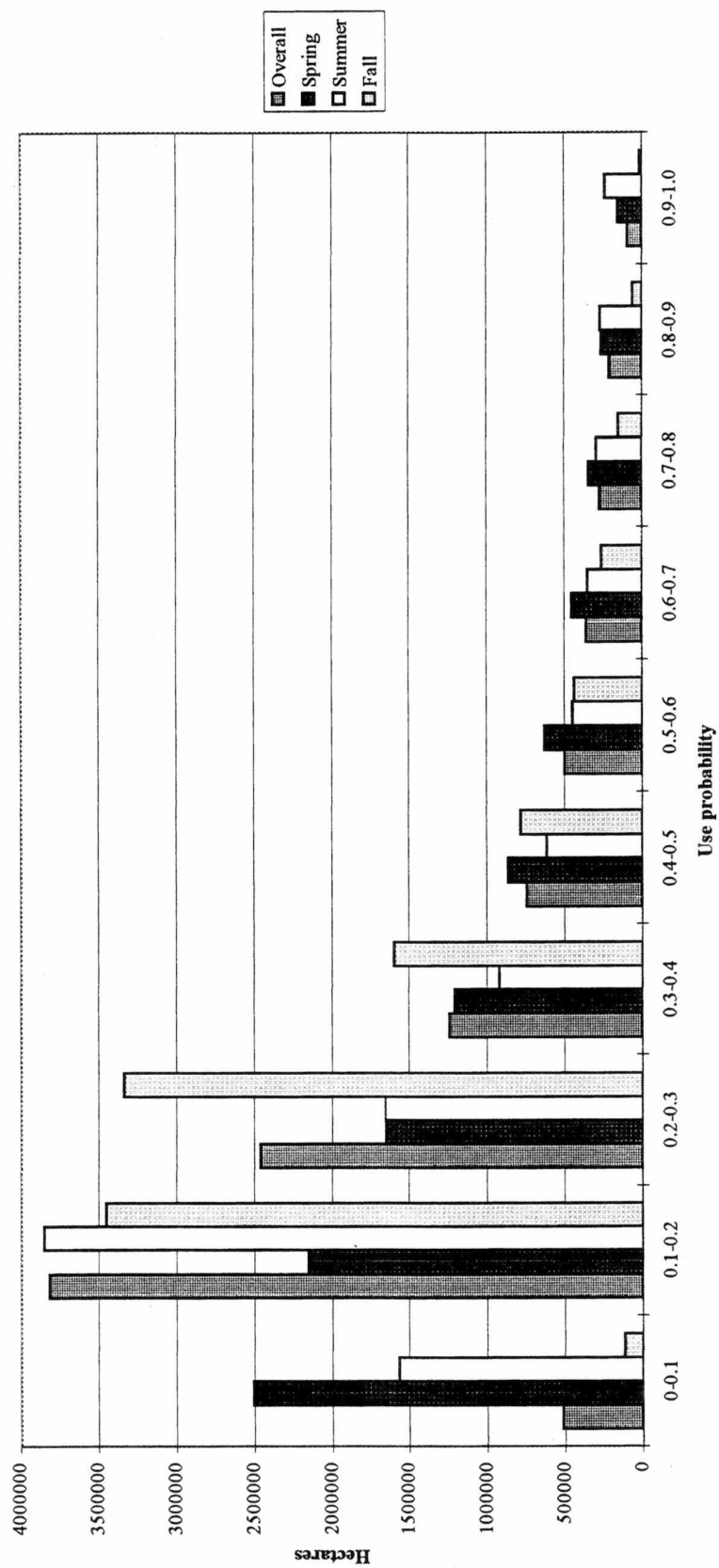


Figure 12: Male habitat use probability over 0.5 classified by ownership. All models.

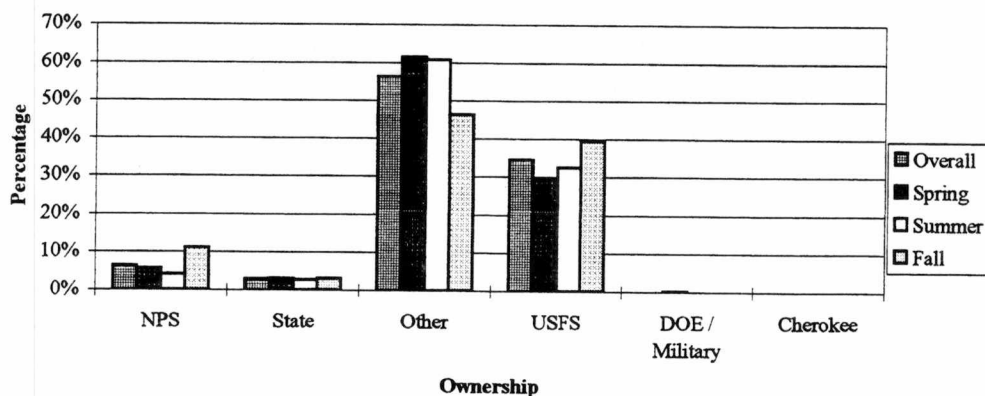
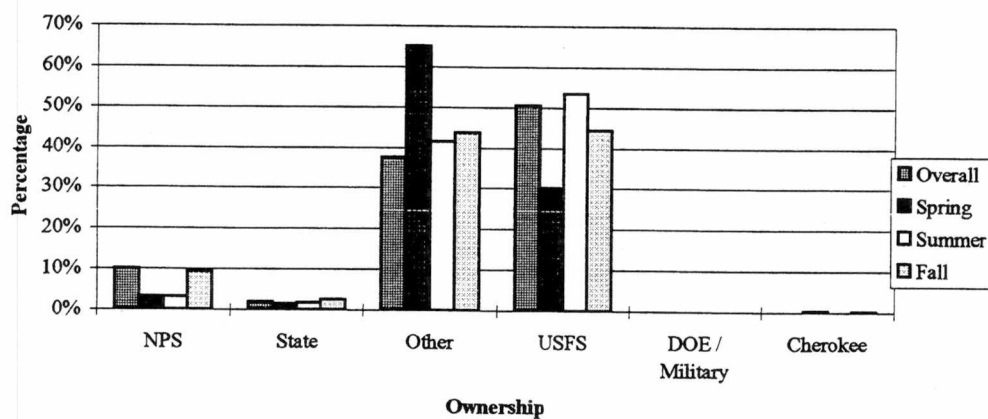


Figure13: Amount of land base in male habitat use probability over 0.5 classified by ownership. All models.



(Figure 16), with female locations approaching 90%. The ability of the model to identify areas within the known range of bear occurrences is a reasonable accuracy assessment; if the model was consistently misrepresenting habitat conditions, the classification percentage would be much lower. Suitable locations outside the range map are not necessarily misclassifications; they may represent suitable habitat that is currently unoccupied. The percentage of areas for males may increase significantly if the Alabama locations are removed, supporting the hypothesis that this upland forest model may not be applicable to habitat conditions in Alabama.

Evaluation of the SAA Potential Habitat Model

To evaluate the accuracy of the SAA model, I overlaid the regional male and female overall habitat suitability maps onto the SAA potential habitat map. The purpose was to determine if the SAA model is capable of delineating low, medium, and high classes of habitat suitability; distinct classes would indicate that the SAA model is accurately reflecting habitat conditions for black bears based only on a few, broad scale variables. Figures 17 and 18 indicate that this is not the case; the SAA model was unable to differentiate low, medium, and high classes of use probability. Each of the three classes follows the general trend of suitable habitat, and there is no clear separation of the potential habitat model classes.

Although the SAA model is unable to quantitatively reflect habitat conditions in the region, a visual comparison of the map (Figure 6) to the habitat suitability maps for

Figure 14: Male black bear overall habitat use probability shown with southeastern range boundary.

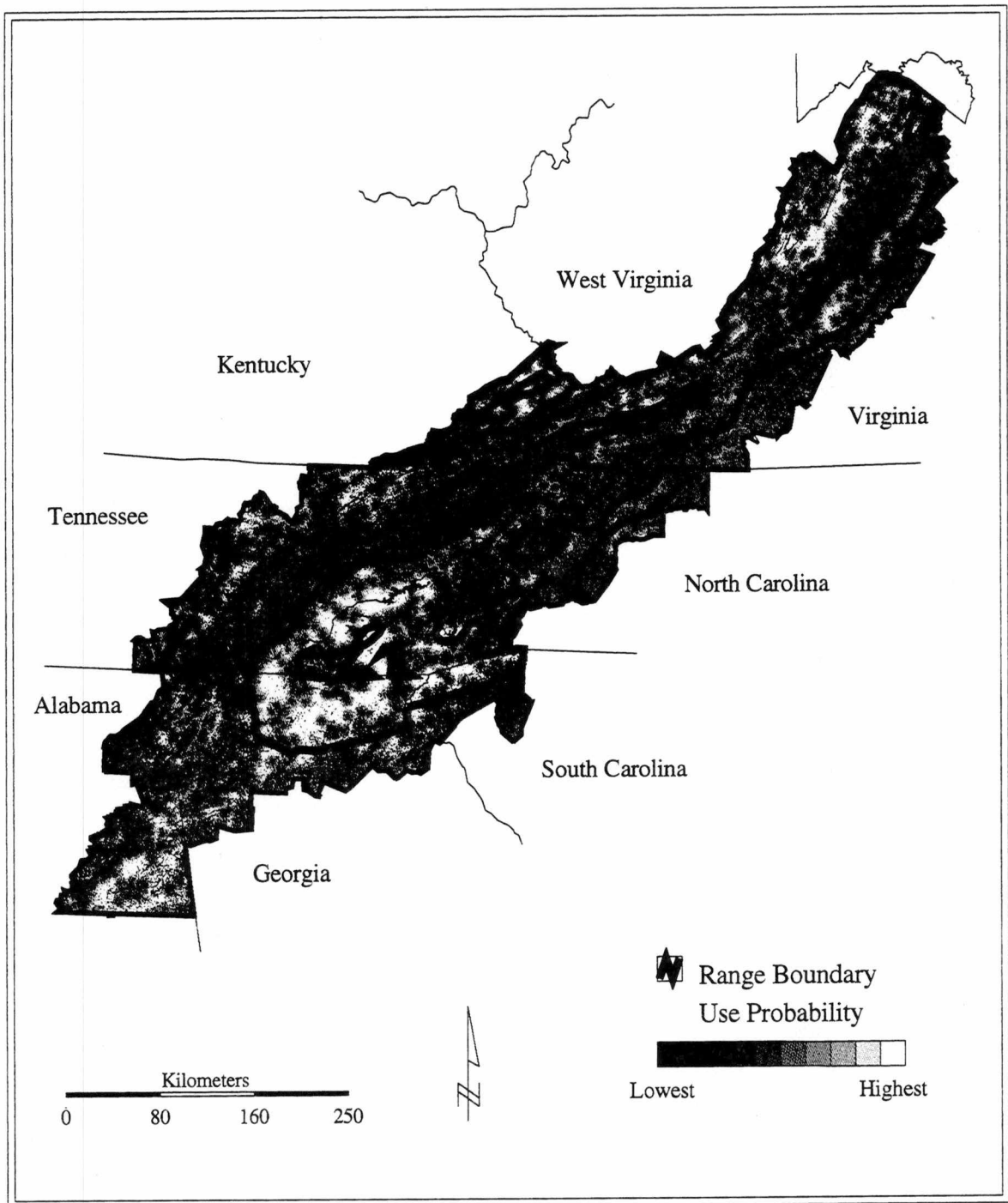


Figure 15: Female black bear overall habitat use probability shown with southeastern range boundary.

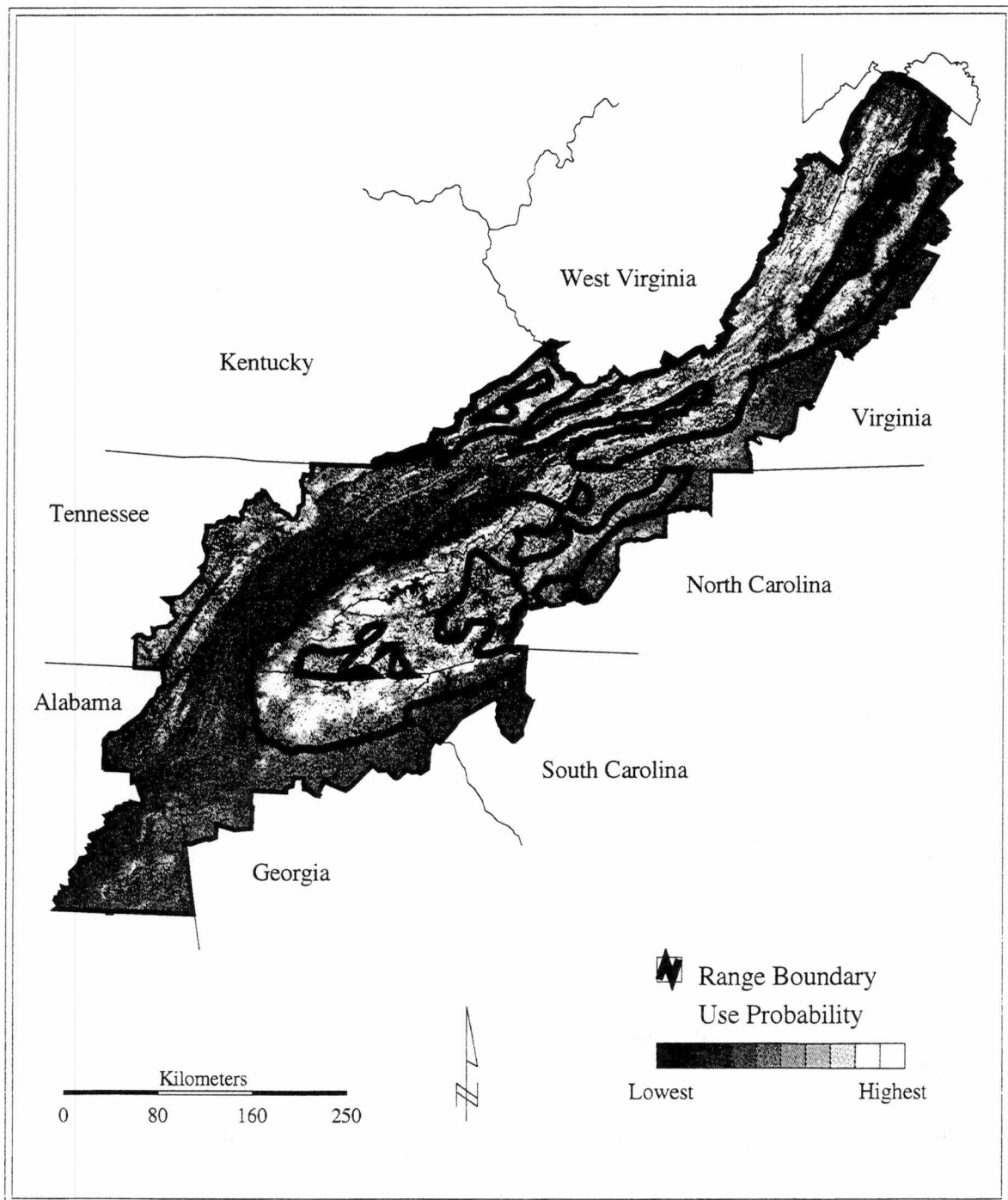
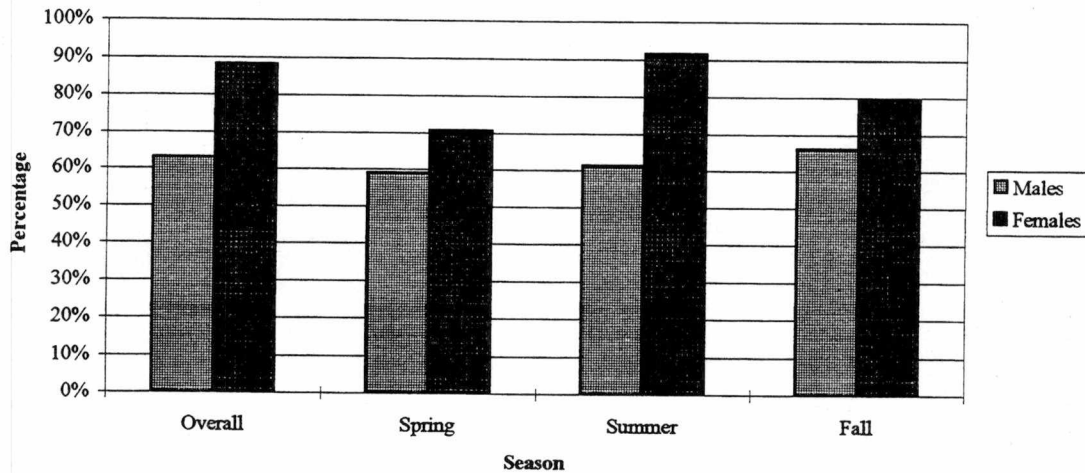


Figure 16: Male and female bear habitat use probability over 0.5 within the southeastern range map areas.



males and females (Plates 1 and 2, in pocket) shows that the broad habitat patterns are similar. Highland regions in the northern and southern halves of the study area are delineated as highly suitable in all three habitat representations, and the low and medium classes of road density in the SAA model collectively cover most of the middle to high use probability locations. So while the SAA potential habitat map should not be used as a representation of actual habitat conditions, it does provide an accurate 'first look' at the region by identifying broad scale patterns in habitat suitability. This result was expected, since many of the more important habitat variables for bear (forest cover, location of roads) were used in both the regional and SAA models.

Figure 17: Male habitat use probability classified by the SAA potential habitat model.

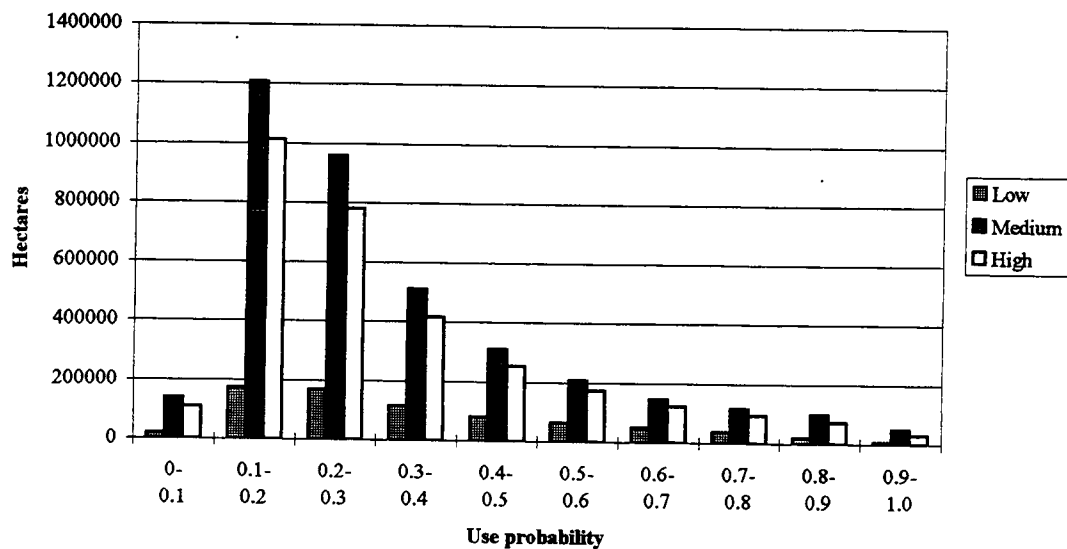
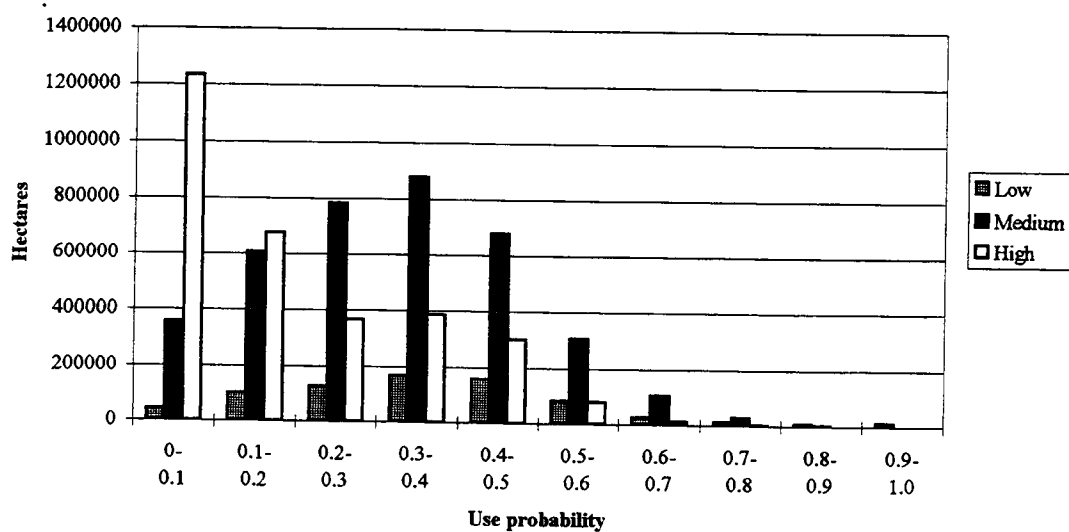


Figure 18: Female habitat use probability classified by the SAA potential habitat model.



Chapter VI

Discussion

Model Performance

Both the male and female models seem capable of evaluating habitat quality at a regional scale. By using a model which ranks each mapping unit against all others, I was able to identify locations where the integration of important environmental variables has created high quality habitats that insure the survival of bears in the region. My concentration on broad scale measures of habitat quality highlights entire forest tracts across the SAA area, revealing geographic distribution patterns that are undetectable when surveying smaller areas one at a time. The ability of the models to quantitatively rank habitat areas is supported by the relatively good fit with the southeastern distribution map.

The relatively strong predictive power of the models supports the hypothesis that black bears respond to regional habitat patterns: although fine scale variables are important in daily activities for bears, their distribution across the landscape is ultimately determined by broad scale habitat conditions. Within segments of the broad patterns, numerous fine scale variables (such as disturbance history, food supply, and microclimatic differences) determine local habitat quality, ultimately driving local habitat use by bears within forest patches. Presently these fine scale conditions cannot be evaluated at the regional scale; remote sensing equipment is unable to detect fine scale patterns, and

intensive ground sampling is prohibitively expensive. While future capabilities and innovative sampling techniques may one day allow us to comprehensively examine entire regions, presently we must rely on extrapolations and broad measures of habitat suitability. This statement is not meant to imply that fine scale studies and model development are not important; without locally developed habitat models, the regional models would be impossible. Conservation and management of bears in the southern Appalachians rests solidly on the integration of both scales into a comprehensive analysis of black bear habitat and population distribution.

The foundation of the regional scale models is a model developed on National Forest land, in an area that lies at the high end of the habitat suitability spectrum. Therefore areas identified as suitable habitat at the regional scale should be interpreted as optimal habitats that resemble optimal locations within the model development area, which can be distinguished from areas of moderate habitat quality. By developing the models using data from Tellico Ranger District, I have included geographically distinct relationships that may be unique to the southern section of the study area. Developing the model in Shenandoah National Park, for example, would have resulted in different variables and parameter values, and ultimately a different picture of the landscape. This geographic distinction may explain why Shenandoah is ranked relatively lower than other habitat areas in both the male and female models, and yet contains one of the strongest bear populations in the region. Although no truly quantitative measure of model accuracy is available, experts who have seen the maps believe the models to be reasonably accurate in identifying suitable habitat for bears across the SAA region. The current distribution

map (Figure 3) is a physical representation of expert opinion, and the habitat suitability maps consistently identify habitat areas within the present black bear range.

Based on comparisons with the southeastern distribution maps and discussions with experts in the field, the female models more accurately depict current habitat conditions in the SAA area. Using habitat probability scores above 0.5 as a break point in habitat quality, over 70% of the female high quality habitat falls within the current black bear range in each of the seasonal models and the overall model (Figure 16).

Classification accuracy is over 90% in the female summer model. For males, classification accuracy never rises above 60%; although the male models still do a reasonable job of identifying high quality habitat, they are not as accurate as the female models. Habitat models are usually validated using population density estimates gathered through extensive field work or bait station studies; a sample of the population is statistically extrapolated to provide an estimate of the actual population density in a given area. Since locational data is not available for the entire SAA region, it is reasonable to use a comparison to the distribution map as an accuracy assessment; while a few well studied and documented populations would be a more reliable assessment, regional patterns can be judged based on the entire range of the species. Expert opinion is based on knowledge gathered from many different areas over a long time period, and provides a reasonable picture of habitat conditions across the SAA area. In essence, the regional habitat models are reflecting knowledge gathered by field researchers; organizing that knowledge in a biometric model helps to identify new and interesting patterns of habitat suitability, leading possibly to future field studies in previously unconsidered locations.

There are several explanations for the disparity in accuracy between the male and female models. In developing the models, there were considerably more female bear telemetry locations (2,234) than male locations (1,070), which would have statistical significance in selecting model variables and identifying model parameters. Increasing the number of sample points when developing biometric models increases the robustness of the statistical analysis by providing a clearer picture of habitat use. The male models are based on a smaller sample of the habitat conditions at Tellico Ranger District, and therefore are less capable of identifying similar conditions at a regional scale.

Another explanation may be found in van Manen and Pelton's analysis of home range size based on telemetry locations (van Manen and Pelton, in press). They found that male home range sizes were 1.5 times greater than females in the Tellico Ranger District, indicating that males spend much more time traveling than females. The reproductive fitness of male black bears is dependent on their ability to fertilize many females, and van Manen and Pelton found that male home ranges often encompass many female ranges. If a correlation between female locations and male home ranges can be established, future male models may be able to incorporate female habitat use as an indicator of reproductive capability. Although reproductive success is essential to the overall health of the population, it is not a particularly important life requisite for individual males. Therefore many of the telemetry locations may be located in lower quality habitats which are used for travel rather than for shelter or foraging, decreasing the ability of the models to identify high quality habitat important for the survival of male bears. Females, on the other hand, spend most of their time simply meeting life

requirements (food, shelter, water) for themselves and their cubs; therefore female telemetry locations may be more biologically significant than male locations. This hypothesis is supported by the spatial arrangement of telemetry locations within home ranges for both males and females. The female locations are generally more clustered, indicating a tendency to occupy higher quality habitat to sustain their health and reproductive fitness, while male locations are often widely dispersed throughout their home range (van Manen and Pelton, in press). This tendency for travel makes it more difficult to model habitat use preferences for males, because reproduction and dispersal are not directly linked to habitat selection.

Although travel areas may be relatively less important for the survival of individual male bears, those areas are probably crucial to the stability of the population as a whole. The social and demographic structure of black bears is likely very complex, and the movement of males across the landscape is possibly an organizing element of black bear populations; this species may depend on an interlocking social structure that requires males to establish home ranges that encompass many female home ranges. So while modeling male habitat use may be more difficult, it may be just as important to model male travel corridors, which represent links that stabilize the regional population. It is important to remember that black bears are not historically a metapopulation species. In the recent past, bears occupied the entire North American continent (Pelton and van Manen, in press), and their populations were free to expand and contract across the landscape without human interference. Today, bear habitats are severely restrained by the presence of human activity centers and altered landscapes; researchers may be witnessing

the habitat use and population fluctuations of a species struggling to cope with a suddenly restricted distribution. There is no way to determine how long the effects of habitat restriction may last in a wide ranging species such as black bear, and researchers are faced with the fact that what we consider normal behavior and distribution patterns may reflect the recent history of habitat fragmentation and reduction. We should be careful not to base management decisions for long range bear conservation plans on a single snapshot of habitat use and availability, but to also consider social behavior, population dynamics, and demographics.

The seasonal models of both males and females are unable to reflect seasonal fluctuations in habitat selection by black bears. This may be because the models are too coarse to capture food choices by individual bears, and so they cannot detect changes in feeding habits from season to season. Although the seasonal maps do show slight shifts in the location of suitable habitat (see the seasonal maps in Appendix C), the general patterns remain the same. Since seasonal changes in the diet of black bears have been shown to affect habitat selection (Eagle and Pelton 1983), the inability of the model to reflect those changes may also indicate that variables other than food supply define broad patterns of suitability at a regional scale. Human activity sites and roads, for example, may force bears into certain locations; seasonal dietary shifts must then be accommodated within these remote areas delineated by human disturbance. In an undisturbed landscape, or a finer resolution model, more evident shifts in habitat use may occur as bears move freely across the region in response to seasonal fluctuations in food availability. Based on the seasonal maps produced here, it appears that seasonal changes in diet do not affect the

large scale distribution of suitable habitat across the SAA region, although these changes may dictate habitat selection within individual areas.

My field work in northern Alabama was another important part of the model validation. This location was identified as relatively high use habitat for male bears, yet it lies outside the known range for bears in the east. Since one goal of this thesis research is to identify new habitat areas, the northern Alabama site could not be dismissed as an inaccuracy of the model. Site visits allowed me to perceive habitat qualities — such as relative isolation from noise and the amount and kinds of human use — that remotely sensed data have difficulty reflecting. Given the level of human use in Talledega National Forest (TNF), and the adjacent Cheaha Mountain State Park, the area is probably not comparable to more optimal habitats near the GRSM or upland forests in Virginia. Habitat conditions in northern Alabama, particularly Horn Mountain WMA, are similar to many locations farther north; bears once occupied northern Alabama, and the area could possibly support a bear population in the future if management practices change. The fact that the area is identified only in the male models, however, raises questions about the true suitability of the site. As discussed earlier, those models may be reflecting lower quality habitat conditions used for travel between home ranges. This is not to say that management practices could not facilitate the reintroduction of bears in northern Alabama. In fact, the decline of remote forests in Alabama (Rudis 1991) lends a sense of urgency to the protection of remote forest areas there, and these models may help to prioritize conservation efforts aimed at restoring forest conditions suitable for black bears.

While the SAA potential habitat model is unable to accurately stratify the habitat conditions of the regional biometric models into high, medium, and low classes of habitat quality, it does provide a general guide to the location of prime habitat areas. It is important to note that the SAA model was a first step developed to identify patterns in *potential habitat*, reflecting large scale patterns in habitat condition. The habitat delineated by the SAA model may be seen as the possible extent of bear habitat areas based on forest cover and human disturbance; all other factors held constant, bears may be able to inhabit all of the low and medium road density areas. The biometric models are the next step in quantifying regional habitat conditions, and they improve on the SAA model by evaluating habitat conditions based on a wider range of habitat variables. While forested areas located in the SAA low to medium road density classes may not currently be suitable for bears (according to the biometric models) they may represent locations where modest changes in management practices could significantly improve habitat quality for bears. A manager responsible for land within one of these two classes should consider the possibility of improving bear habitat conditions; other areas are unsuitable due to high road densities, and would require extensive management to return them to suitable habitat conditions. The SAA model reflected very broad scale habitat conditions, and the biometric models further refine the definition of habitat conditions by including more variables and viewing the landscape as a surface rather than as a collection of habitat areas.

Application of the Models to Other Regions

The biometric habitat models presented in this thesis were developed specifically for forested environments in the southern Appalachians; they reflect habitat suitability in a clearly defined setting, and should be used cautiously in other cover types or regions. While similar forested areas may exist elsewhere, forest conditions alone do not drive the models; bear habitat suitability in the SAA region may reflect conditions that are undetectable to humans and are unique to the study area. The variable sets serve as proxies for specific habitat conditions that include the effects of human land use history, bear demographics, and other variables and combinations of variables that define the habitat conditions found in the southern Appalachians today. Using the models outside the region, the researcher may neglect to account for specific interactions in the new location, and place too much confidence on the results of a model produced under different environmental conditions. The models could be used in other regions to take a broad 'first look' at habitat conditions in forested locations; transferring knowledge gained in one region to other regions is an important function of habitat suitability models. While it may be inappropriate to assume that a model developed in one region can accurately identify suitable habitat elsewhere, the models may be used in other locations, provided that some sort of testing is used to insure the accuracy of the model results. The patterns in the model output may provide valuable insight for starting habitat evaluations in other regions, even if they only identify areas of contiguous forest undisturbed by humans.

Human perceptions of bear habitat may be inadequate to describe the actual environmental conditions affecting habitat selection by bears. Bears have more highly developed eyesight and sense of smell than humans, and consequently may have a wider range of perception. A human researcher in the field is unable to judge a habitat patch seen across an open area of unsuitable habitat; humans can evaluate the condition of the forest edge through sight, but can tell nothing of the forest interior conditions without actually traveling to the site. A bear may be able to perceive habitat conditions based on smell or sound, and base its habitat selection on an evaluation of environmental conditions at many different locations. Furthermore, bears spend a lifetime inhabiting the forested locations that humans visit for only a few hours or days at a time; it is likely that bears respond to subtle differences in habitat conditions perceivable only after extensive exploration and immersion in forested environments. Bears may also pass behavior patterns and knowledge from generation to generation; if this is true, we are actually trying to understand habitat use patterns developed over a generational time scale. Since we are unsure exactly how bears perceive or select habitat, we must rely on our ability to measure proxies for habitat use factors; these proxies may not represent the actual selection criteria used by bears, but they allow us to do a credible job of predicting habitat suitability based on habitat factors perceivable to human senses and sensors.

In the southern Appalachians, many of the habitat variables used to evaluate the probability of bear habitat use are related to human disturbance. Proximity to roads and human activity sites reflect the bears' avoidance of human altered landscapes, but the relationship is not simple. In some cases bears were actually attracted to locations near

roads, possibly due to edge effects creating early successional conditions that provide abundant food supplies in spring and summer. In all cases bears avoided human activity sites. These habitat relationships are important in the Southeast, but may be less important in areas with a smaller human population. In the north Cascades of Washington, 68% of the 2,600,000 ha North Cascades Grizzly Bear Ecosystem (NCGBE) has no open roads; bear responses to roads in that area would certainly differ from bear reactions to roads in the SAA region (Gaines et al. 1994). Other study areas have no open roads (Schooley 1994), and bear habitat selection reflects natural factors such as forest stand condition. Black bears in Japan are threatened mainly by mast crop failures in shrinking forest environments; roads have not been considered in habitat analyses there (Hazumi and Maruyama 1986). In regions with a dense human population and established settlements — such as Yellowstone National Park — bears exhibit human avoidance behavior similar to bears in the southern Appalachians (Mattson et al. 1986). Although bear behavior is likely to be similar in all human altered landscapes, each region is unique, and should be evaluated separately.

Other habitat variables (aspect, elevation, overstory vegetation richness) are also location-specific, and unmeasured interactions between variables are likely to affect habitat selection. These intercorrelations are caused by local interactions between environmental variables, which may be affected by human disturbance in the region; extrapolation from this region to other regions may not carry or reflect the unique relationships between habitat components and human disturbance history. In the Tellico Ranger District, elevation is particularly suspect as an artifact of CNF physiography and

human disturbance history. Bear use at different elevations may be related to vegetation richness, distance from human activity, the boundary of the CNF, or various other habitat conditions that are uniquely correlated with elevation in the Tellico. Unique relationships may also exist between other habitat components; since these relationships are difficult to quantify (if we recognize them at all), it is necessary to rely on proxies of habitat use to reveal suitable habitat at other locations.

It may be unreasonable to assume that a single model can be used to produce a fine scale picture of habitat use in a region as large as the SAA study area. Although a minimum mapping unit of 90 meters may seem adequate for site specific evaluations, the precision of the data will not support fine scale analyses; localized variables are simply not accounted for by the regional models. Current modeling technology cannot easily reflect micro scale changes in habitat use at a regional scale; future models may reflect local responses to habitat conditions at many locations within a large study area, analyzing habitat suitability at each location independently. Rather than using study sites to develop extrapolated models of habitat suitability, it may be possible to develop regional scale models that rank habitats based on environmental conditions measured at many different locations. This type of meta-habitat model could reveal how bear habitat preferences change across large areas in response to spatial patterns created by environmental gradients, topography, and human disturbance. Researchers and managers could then develop management plans that account for local variations in habitat use across a complex landscape, effectively managing a regional black bear metapopulation.

Metapopulation Management

The spatial arrangement of high quality habitat throughout the region suggests that black bears are organized as a metapopulation in the southern Appalachians. Although it is unknown whether all the habitat locations identified are occupied, we do know that many isolated areas support bear populations, and are separated from one another by unsuitable habitat. Furthermore, areas identified as less suitable habitat in these biometric models may in fact contain suitable habitat conditions that are capable of supporting a bear population, but are different from the conditions in Tellico Ranger District. The metapopulation configuration of habitat areas in the SAA study area reinforces the genetic stability of the regional population through heterogeneity of genetic material and habitat conditions; it also raises questions about the connectivity between habitat patches, a key component of a true metapopulation (Lande and Barrowclough 1987). While bears have been known to travel distances over 100 kilometers, even across heavily populated human areas like the Shenandoah valley (Fies et al. 1986), it is unclear whether there is sufficient connectivity between populations to guarantee adequate genetic transfer. It is likely that the current sub-populations do interact, creating a metapopulation configuration that helps to maintain the strength of individual sub-populations in the region.

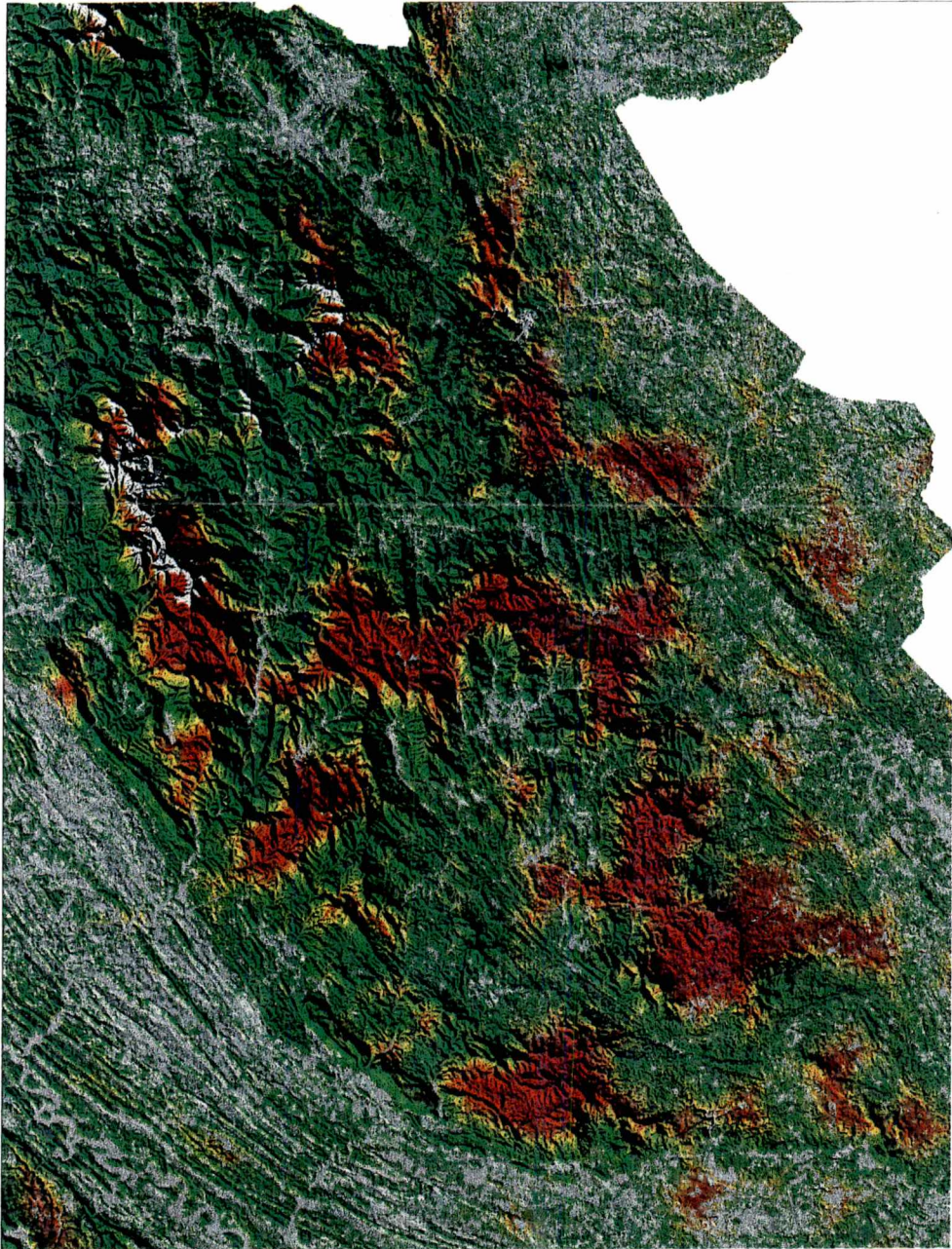
Habitat fragmentation is a serious threat to the continued existence of black bear populations in the southern Appalachians. The male and female habitat suitability maps (Plates 1 and 2, in pocket) both reflect serious fragmentation of habitat, even around core areas such as GRSM. Although fluctuations in annual food crops and other habitat

components have an effect on bear populations, bears are ultimately dependent on the existence of diverse ecosystems that help to stabilize food supplies from year to year. These ecosystems rely on species diversity to provide stability and resiliency to ecological processes; habitat fragmentation is the most serious threat to species diversity in the southern Appalachians, and consequently to the ecological systems essential to the stability of a regional bear population (Wilcox and Murphy 1985). Given that habitat fragmentation currently threatens the biodiversity of the region, it may be reasonable to use black bear habitat as a measurable index of forest fragmentation. High quality habitat is likely found in areas of lower habitat fragmentation.

Relatively high use habitat in the SAA region is surrounded by privately owned lands that are vulnerable to human population pressure and development. Island biogeography theory (MacArthur and Wilson 1967) states that extinction rates are a function of island size and isolation from a large source area; suitable habitat areas in the southern Appalachians can be viewed as 'islands' within a sea of private ownership, which is often correlated with human disturbance. The region around GRSM (Figure 19) illustrates the isolation of USFS and NPS lands caused by private ownership; this pattern is repeated around most of the suitable habitat in the region. While the habitat located in and around GRSM is connected in several places along the ridgetops, other areas in the SAA region are totally isolated. It is important to begin to plan corridors between habitat islands in the southern Appalachians; even private lands that are currently forest covered are vulnerable to development, and corridors will be necessary to protect the genetic viability of the regional metapopulation.

Figure 19: Illustration of Island Biogeography Theory, Great Smoky Mountains and Vicinity.

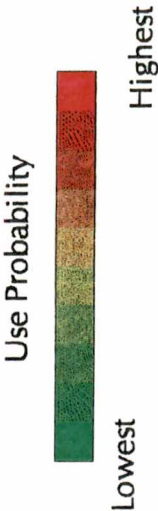
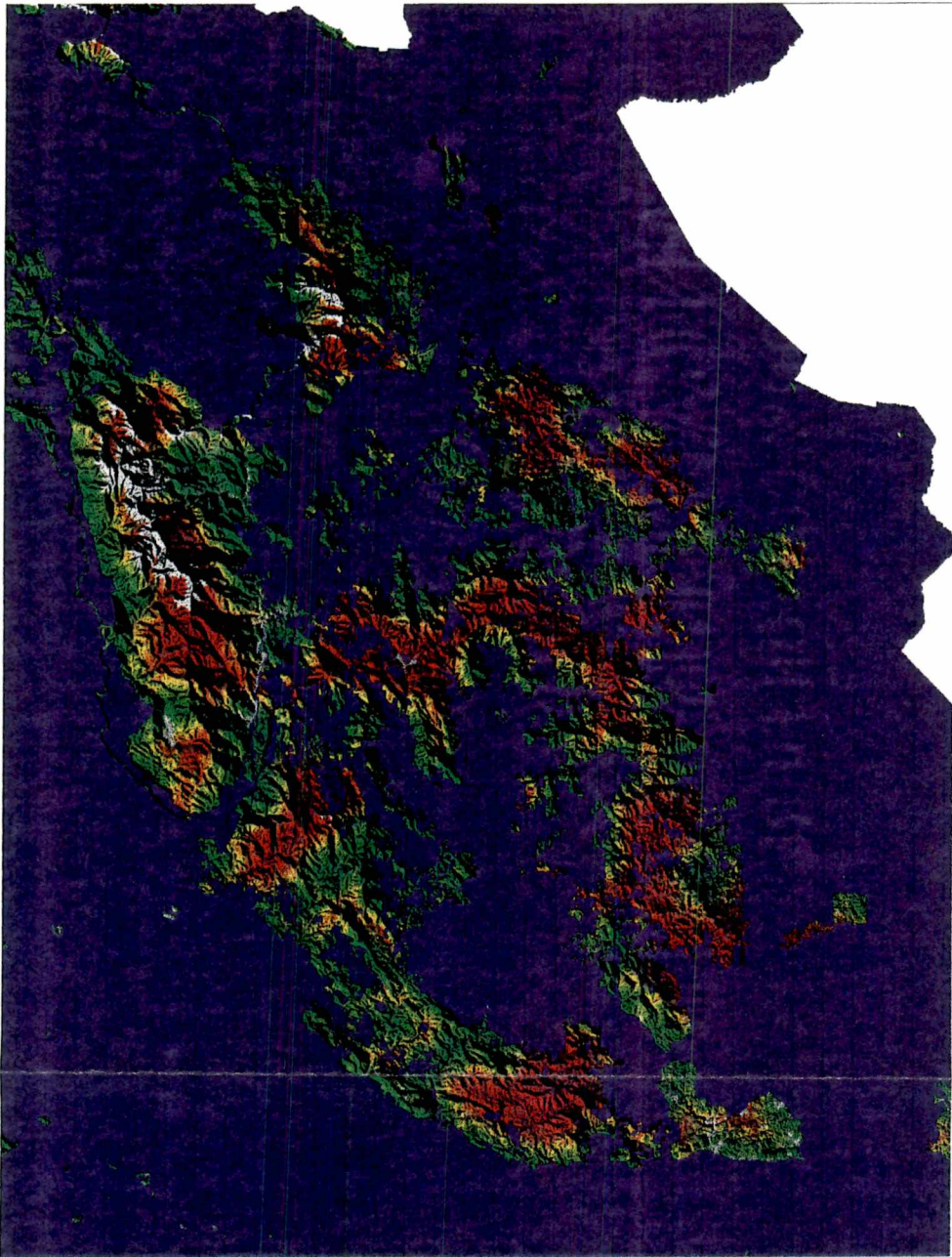
A: Male black bear habitat use, shown with topography.



scale 1 : 1,500,000



B: Male black bear habitat use, shown in an 'ocean' of private ownership lands.



Chapter VII

Management Implications and Future Research

Implications for Management

The regional habitat suitability models provide a landscape scale perspective for fine scale habitat evaluations and management plans; management units such as USFS forest stands can be evaluated within a broad scale context, and the effects of management decisions on the regional metapopulation can be assessed. Land management agencies such as the Forest Service have begun to evaluate their land management practices not only on a local scale, but on a regional scale that considers the consequences of habitat alteration across the southern Appalachians. We can no longer afford to view different management agencies as entities unto themselves; regional cooperative projects like the Southern Appalachian Assessment must be used to guarantee the stability of the Appalachian ecosystem, and the preservation of biodiversity in the region. Regional models like those developed in this thesis are one tool for use in a regional approach to biodiversity conservation.

The SAA potential habitat model will be available to all management agencies in the SAA Plant and Animal Team technical report; the Forest Service is referencing that and other SAA reports as it updates its land management plans. While the potential habitat model does not reflect specific habitat use patterns, it does identify locations where bear habitat could exist in the absence of human disturbance; such guidelines are useful to

managers attempting to understand local patterns within a regional context. The SAA model was validated at a coarse scale by the habitat suitability models; the general patterns of potential habitat were similar to the biometric patterns of habitat suitability. However, the current models are a definite improvement over the SAA model, and may be more useful to managers making decisions regarding bear habitat conservation. Validation of the SAA model was important, since it is available to the public and may be used in land management plans by various government agencies, but the new models are a refinement of the SAA model and should be used in its place.

Regional cooperation and landscape-level planning are goals of the Southern Appalachian Black Bear Study Group. In order to manage bear populations across the region, the Bear Study Group must have accurate data on the locations of existing populations and unoccupied suitable habitat areas. While these data can be gathered through ground-based efforts, it is difficult to field-check an entire region; even if resources were available to carry out intensive sampling, remote regions not known to contain bears could be overlooked. Regional scale habitat modeling provides a basis for landscape-level planning by evaluating habitat conditions at a broad scale in a short time period. This regional perspective can help guide future management decisions by highlighting areas where field investigations are needed.

Regional Conservation at a Local Scale

While GIS modeling efforts help to further theoretical research on habitat conditions and their distribution, models should also focus on providing information to local land managers who will actually implement wildlife conservation plans. Getting this information to the "hands-on" managers will improve wildlife management efforts by providing a regional context for localized conservation plans; it will also make the models themselves more accurate and reliable, as feedback from individuals with an intimate knowledge of the land is incorporated into newer models. It is important to move beyond the current system, which develops land management recommendations based on the work of a few individuals, and then dictates those plans to local managers. Successful conservation and management plans in the future will likely require cooperation at many levels of management organization: local plans will be implemented within a regional planning perspective, so that each may benefit from the other.

Regional studies like this thesis must provide land managers with information that is useful at a local scale, while maintaining an overall regional perspective. Placing individual projects in a broad scale organizational framework will insure that land managers are working towards regional preservation when effecting local management plans. The southern Appalachians provide an excellent opportunity for this type of management: lands in private ownership surround the public lands defining the protected areas of a biosphere reserve, and the region must be managed as a whole. In addition, the federal and state management agencies responsible for the public lands already have an

established infrastructure to manage at both the local and the regional scale; organizations such as SAMAB strive to place local decisions in a regional context.

Future Research

The model results from this thesis are one step in understanding the actual metapopulation dynamics of the southern Appalachian bear population. By identifying the distribution of suitable habitat across the landscape, I have provided a starting point for future studies of habitat use that account for regional movement patterns and the dispersal of sub-populations. Since dispersal in black bear populations is mainly dependent on sub-adult males that are driven from the best habitat by dominant males (Rogers 1987), the male suitable habitat map (Plate 2) may provide a basis for the study of dispersal patterns among the regional population. Field studies should focus on determining which areas have sustainable populations and how the metapopulation organizes itself across the landscape through time. It may be possible to identify one or two habitat locations with stable bear populations that are absolutely essential to the stability of the regional population; stable habitat areas such as these serve as a population source for other locations. Individuals from these locations may dominate the genetics of the regional population, particularly if individuals in marginal habitats are not reproducing. If most dispersing bears come from a few distinct habitat areas, those areas must be preserved to guarantee the survival of bears in the region.

A few habitat areas were identified that currently do not have resident bear populations; these locations represent opportunities for field research to determine whether the model has truly identified new habitat, or whether these results are simply model errors. The habitat areas identified west of the great valley in Tennessee are of particular interest in light of the repatriation project in Big South Fork; they may be locations to which the new bear population can expand, and should be evaluated to determine whether conservation plans are needed. Although the habitat identified in Alabama is most likely an anomaly of the model, the remoteness of the Horn Mountain WMA may warrant a closer study of habitat conditions; this area should be seen as a relatively low priority in current black bear management, but future land use changes could perhaps create a large area of suitable habitat. There are many other areas that should be examined in the field, particularly those on private lands adjacent to publicly managed habitat.

The primary focus of this thesis was to determine whether a regional biometric model could be developed by extrapolating a fine scale habitat model to a broad scale, and then applying that model to an existing database. After evaluating the model results and examining the Alabama location in the field, I believe that it is possible to evaluate large areas using regional models that are based on local habitat evaluations; this depends on the species and the homogeneity of habitat conditions, but models for habitat generalists like black bear can provide reasonable results. With more GIS datasets being developed every day, it may soon be possible to examine conditions over most of the United States, especially in the east. The reduction in government spending for land management

agencies means that larger areas must be managed by fewer individuals; the ability to use existing datasets to accurately assess habitat quality and other environmental conditions will be invaluable in this new era of land management. Researchers can use the approach developed in this thesis to evaluate black bear habitat conditions in other regions using established GIS databases, or to examine habitat suitability for other species in the southern Appalachians.

The future management of wildlife species in a human dominated landscape depends on the ability of land managers to understand regional habitat patterns, so that metapopulations can insure the survival of individual species, and guarantee the preservation of biodiversity at a global scale. Models are simply one component of a comprehensive conservation plan that includes the development of theories and the implementation of management practices at a local scale. While regional examinations are essential to the process, they are not more important than the study of fine scale interactions within habitat patches. Habitat conditions are not based on simple interactions that can be easily studied and manipulated; they are the sum of many complex processes that functionally determine the habitat quality of individual locations and entire regions. As Aldo Leopold stated in his recently discovered *Standards of Conservation*, "when it comes to actual work on the ground, the objects of conservation are never axiomatic or obvious, but always complex and usually conflicting" (from Callicott, 1990). Scientific observation and modeling may help to reduce the complexity and conflicts of management decisions, but it is up to humans to synthesize information from all scales into sound management practices that help insure the survival of species like black bear.

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Appendices

Appendix A:

GIS Data Layer Inputs and Statistical Results of Tellico Models

Table A1. Geographic information system (GIS) variables for analysis of black bear habitat use, Tellico Ranger District, Cherokee National Forest, Tennessee, 1978-1983. From van Manen and Pelton, in press.

Variable Code	Variable Name	Variable Type	Data Type	Explanation	Source
Y	Y	Dependent	Binomial	1) bear location 2) random location	Univ. Tenn. database
OV	Overstory Vegetation Type	Independent	Nominal	1) bottomland, mixed mesophytic, and northern hardwood 2) oak/hickory 3) other pine/hardwood 4) southern yellow pine 5) white pine/hemlock/hardwood, white pine/hemlock	U.S. For. Serv. CISC ^a
OVR	Overstory Vegetation Richness	Independent	Continuous	Number of overstory vegetation types within 270 m radius	GIS manipulation of U.S. For. Serv. CISC
UV	Understory Vegetation Type	Independent	Nominal	1) herbaceous 2) shrub-good wildlife food 3) shrub-poor wildlife food 4) tree 5) more than 1 layer (herbaceous, shrubs, or trees)	U.S. For. Serv. CISC
UVR	Understory Vegetation Richness	Independent	Continuous	Number of understory vegetation types within 270 m radius	GIS manipulation of U.S. For. Serv. CISC
ST	Proximity to Streams	Independent	Continuous	Meters	U.S. For. Serv. GIS
EL	Elevation	Independent	Continuous	Meters	U.S. Geol. Survey DEMs
AS	Aspect	Independent	Nominal	1) northeast 2) southeast 3) southwest 4) northwest	GIS manipulation of U.S. Geol. Survey DEMs

Table A1. (Cont.).

Variable Code	Variable Name	Variable Type	Data Type	Explanation	Source
SL	Slope	Independent	Continuous	Degrees	GIS manipulation of U.S. Geol. Survey DEMs
LFI	Land Form Index	Independent	Continuous	See McNab (1990, 1993a, 1993b)	GIS manipulation of U.S. Geol. Survey DEMs
TM	Timber Management	Independent	Nominal	1) no regeneration harvest 2) regeneration harvest ^b	U.S. For. Serv. CISC
SA	Stand Age	Independent	Continuous	Age of timber stand	U.S. For. Serv. CISC
SAR	Stand Age Richness	Independent	Continuous	Number of stands of different ages within 270 m radius ^c	GIS manipulation of U.S. For. Serv. CISC
TR	Proximity to Trails and 4WD Roads	Independent	Continuous	Meters	U.S. For. Serv. GIS
RO	Proximity to Improved Roads	Independent	Continuous	Meters	U.S. For. Serv. GIS
HA	Proximity to Human Activity Sites	Independent	Continuous	Meters	Identified from U.S. Geol. Survey 1:24,000 maps

^a Continuous Inventory of Stand Conditions.^b Includes: clearcut, seed-tree cut, shelterwood cut, thinning, removal, ranger sale, group selection, and individual tree selection.^c Age classes: 1-7 years, 8-22 years, 23-37 years, and ≥ 38 years. Age classes were defined based on the combined characteristics of height, number of saplings, and basal area of saplings from unpublished vegetation data collected by Bartlett and Buehler, Univ. Tenn., Knoxville).

Table A2. Results of univariate logistic regression analysis of habitat use of female black bears, Tellico Ranger District, Cherokee National Forest, Tennessee, 1978-1983. From van Manen and Pelton, in press.

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	P-value
Overstory Vegetation Type				
1) <i>bottomland, mixed mesophytic, and northern hardwood</i>	0.0322	0.0672	0.22	0.6325
2) <i>oak/hickory</i>	0.1440	0.0536	7.22	0.0072
3) <i>other pine/hardwood</i>	0.0845	0.0593	2.03	0.1539
4) <i>southern yellow pine</i>	-0.2685	0.0623	18.58	2.E-05
5) <i>white pine/hemlock/hardwood, white pine/hemlock</i>	0.0078	0.0840	0.01	0.9259
Overstory Vegetation Richness				
	-0.0465	0.0358	1.68	0.1945
Understory Vegetation Type				
1) <i>herbaceous</i>	0.3201	0.0795	16.20	6.E-05
2) <i>shrubs-good wildlife food</i>	-0.0993	0.1022	0.94	0.3315
3) <i>shrubs-poor wildlife food</i>	-0.1616	0.2488	0.42	0.5160
4) <i>trees</i>	0.1851	0.0930	3.96	0.0466
5) <i>more than 1 layer (herbaceous, shrubs, or trees)</i>	-0.2443	0.1498	2.66	0.1028
Understory Vegetation Richness				
	-0.0408	0.0377	1.17	0.2789
Proximity to Streams				
	-0.000427	0.000256	2.78	0.0956
Elevation				
	0.0147	0.00197	55.44	1.E-13
Aspect				
1) <i>northeast, southeast, northwest</i>	0.1203	0.0371	10.49	0.0012
2) <i>southwest</i>	-0.1203	0.0371	10.49	0.0012
Slope				
	0.0106	0.00469	5.11	0.0237
Land Form Index				
	2.1388	0.5957	12.89	0.0003

Table A2. (Cont.).

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	P-value
Timber Management				
1) <i>no regeneration harvest</i>	-0.0876	0.0313	7.84	0.005
2) <i>regeneration harvest</i>	0.0876	0.0313	7.84	0.005
Stand Age	0.00477	0.00167	8.15	0.0043
Stand Age Richness	0.0954	0.0564	2.86	0.0906
Proximity to Trails	0.00014	0.000074	3.65	0.0562
Proximity to Improved Roads	2.252E-8	1.989E-8	1.28	0.2574
Proximity to Human Activity Sites	0.00017	0.000024	50.54	1.E-12

Table A3. Results of univariate logistic regression analysis of habitat use of male black bears, Tellico Ranger District, Cherokee National Forest, Tennessee, 1978-1983. From van Manen and Pelton, in press.

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	P-value
Overstory Vegetation Type				
1) <i>bottomland, mixed mesophytic, and northern hardwood</i>	-0.1565	0.1078	2.11	0.1466
2) <i>oak/hickory</i>	0.0795	0.0966	0.67	0.4110
3) <i>other pine/hardwood</i>	0.2124	0.1114	3.63	0.0566
4) <i>southern yellow pine</i>	-0.0228	0.0936	0.05	0.8076
5) <i>white pine/hemlock/hardwood, white pine/hemlock</i>	-0.1126	0.1246	0.81	0.3663
Overstory Vegetation Richness				
	0.1856	0.0585	10.06	0.0015
Understory Vegetation Type				
1) <i>herbaceous</i>	0.5669	0.0942	36.19	2.E-09
2) <i>shrubs-good wildlife food</i>	0.6990	0.1503	21.64	3.E-06
3) <i>shrubs-poor wildlife food</i>	-1.1478	0.2191	27.44	2.E-07
4) <i>trees</i>	0.0562	0.1175	0.22	0.6326
5) <i>more than 1 layer (herbaceous, shrubs, or trees)</i>	-0.1743	0.1572	1.22	0.2676
Understory Vegetation Richness				
	-0.0956	0.0573	2.79	0.0948
Proximity to Streams				
	-0.00059	0.000432	1.87	0.1717
Elevation				
	0.00699	0.00133	27.53	2.E-07
Aspect				
1) <i>southeast, southwest, northwest</i>	0.2193	0.0689	10.13	0.0015
2) <i>northeast</i>	-0.2193	0.0689	10.13	0.0015
Slope				
	-0.00719	0.00750	0.92	0.3378
Land Form Index				
	1.1023	0.9382	1.38	0.2400

Table A3. (Cont.).

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	P-value
Timber Management				
1) <i>no regeneration harvest</i>	-0.0952	0.0583	2.66	0.1027
2) <i>regeneration harvest</i>	0.0952	0.0583	2.66	0.1027
Stand Age	-0.00109	0.00269	0.16	0.6865
Stand Age Richness	0.0877	0.0949	0.85	0.3555
Proximity to Trails	0.00066	0.000134	24.54	7.E-07
Proximity to Improved Roads	-0.000116	0.000057	4.07	0.0437
Proximity to Human Activity Sites	0.00036	0.000031	135.53	3.E-31

Appendix B:

Regional Model Parameters and Goodness of Fit Statistics

Table B1. Results of logistic regression analysis of overall regional model variables for female black bears. Tellico Ranger District, Cherokee National Forest, Tennessee, 1978-1983.

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	P-value
Intercept	-5.8190	0.8472	47.17	0.0001
Overstory Vegetation Type (OV)				
1) <i>bottomland, mixed mesophytic, and northern hardwood</i>	-0.0596	0.0706	0.7124	0.3987
2) <i>oak/hickory</i>	0.0776	0.0565	1.8904	0.1692
3) <i>other pine/hardwood</i>	0.0742	0.0625	1.4094	0.2352
4) <i>southern yellow pine</i>	-0.2288	0.0643	12.6700	0.0004
5) <i>white pine/hemlock/hardwood, white pine/hemlock</i>	0.1366	0.0891	2.3490	0.1254
Proximity to Streams (ST)	-0.00103	0.000282	13.3645	0.0003
Elevation (ELEV _i)	0.0137	0.00236	33.67	0.0001
Aspect (ASP)				
1) <i>northeast, southeast, northwest</i>	0.0903	0.0386	5.47	0.0193
2) <i>southwest</i>	-0.0903	0.0386	5.47	0.0193
Proximity to Improved Roads (RO * RO)	4.64E-8	2.101E-8	4.87	0.0272
Proximity to Human Activity Sites (HA)	0.0001	0.000028	12.835	0.0003

Table B2. Results of logistic regression analysis of spring regional model variables for female black bears. Tellico Ranger District, Cherokee National Forest, Tennessee, 1978-1983.

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	P-value
Intercept	-8.7907	4.2275	4.3239	0.0376
Overstory Vegetation Type				
1) bottomland, mixed mesophytic, and northern hardwood	-0.0720	0.2419	0.0884	0.7662
2) oak/hickory	0.1598	0.1999	0.6392	0.1692
3) other pine/hardwood	0.1450	0.2343	0.3828	0.2352
4) southern yellow pine	-0.0762	0.2212	0.1188	0.0004
5) white pine/hemlock/hardwood, white pine/hemlock	-0.1566	0.3319	0.2227	0.1254
Proximity to Streams	-0.00143	0.00105	1.8683	0.0003
Elevation	0.0225	0.0120	3.499	0.0001
Aspect				
1) northeast, southeast, northwest	0.4929	0.1461	11.37	0.0193
2) southwest	-0.4929	0.1461	11.37	0.0193
Proximity to Improved Roads	6.60E-6	1.157E-7	0.4305	0.0272
Proximity to Human Activity Sites	0.0001	0.000112	0.0035	0.0003

Table B3. Results of logistic regression analysis of summer regional model variables for female black bears. Tellico Ranger District, Cherokee National Forest, Tennessee, 1978-1983.

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	P-value
Intercept	-6.1496	1.3862	19.68	0.0001
Overstory Vegetation Type				
1) bottomland, mixed mesophytic, and northern hardwood	-0.0769	0.1073	0.5143	0.4733
2) oak/hickory	0.2080	0.0389	6.1440	0.0132
3) other pine/hardwood	0.2180	0.0947	5.2997	0.0213
4) southern yellow pine	-0.2453	0.0947	6.7089	0.0096
5) white pine/hemlock/hardwood, white pine/hemlock	-0.1038	0.1388	0.5596	0.4544
Proximity to Streams	-0.00124	0.000417	0.0029	0.0029
Elevation	0.0132	0.00386	0.0006	0.0006
Aspect				
1) northeast, southeast, northwest	0.0335	0.0567	0.3481	0.5552
2) southwest	-0.0335	0.0567	0.3481	0.5552
Proximity to Improved Roads	-4.05E-8	3.95E-8	1.0496	0.3056
Proximity to Human Activity Sites	0.000194	0.000045	19.0081	0.0001

Table B4. Results of logistic regression analysis of fall regional model variables for female black bears. Tellico Ranger District, Cherokee National Forest, Tennessee, 1978-1983.

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	P-value
Intercept	-5.6309	1.1480	24.0598	0.0001
Overstory Vegetation Type				
1) bottomland, mixed mesophytic, and northern hardwood	-0.0556	0.1034	0.2894	0.5906
2) oak/hickory	-0.0487	0.0840	0.3358	0.5623
3) other pine/hardwood	-0.0274	0.0910	0.0907	0.7633
4) southern yellow pine	-0.2469	0.0968	6.4980	0.0108
5) white pine/hemlock/hardwood, white pine/hemlock	0.3786	0.1282	8.7176	0.0032
Proximity to Streams	-0.00076	0.00042	3.3002	0.0693
Elevation	0.0141	0.00321	19.2532	0.0001
Aspect				
1) northeast, southeast, northwest	0.0640	0.0577	1.2293	0.2675
2) southwest	-0.0640	0.0577	1.2293	0.2675
Proximity to Improved Roads	1.016E-7	2.931E-8	12.0073	0.0005
Proximity to Human Activity Sites	0.000041	0.000039	1.1012	0.2940

Table B5. Results of logistic regression analysis of overall regional model variables for male black bears. Tellico Ranger District, Cherokee National Forest, Tennessee, 1978-1983.

Variable (Variable Code)	Parameter Estimate	Standard Error	Wald χ^2	P-value
Intercept	-2.1826	0.3142	48.2705	0.0001
Overstory Vegetation Type (OV)				
1) bottomland, mixed mesophytic, and northern hrdwd.	-0.3293	0.1189	7.6747	0.0056
2) oak/hickory	0.0043	0.1060	0.0016	0.9677
3) other pine/hardwood	0.2165	0.1218	3.1589	0.0755
4) southern yellow pine	0.0957	0.1028	0.8669	0.3518
5) white pine/hemlock/hardwood, white pine/hemlock	0.0128	0.1387	0.0085	0.9267
Overstory Vegetation Richness (OVR)	0.2078	0.0663	9.8342	0.0017
Proximity to Streams (ST)	-0.00095	0.000487	3.8219	0.0506
Aspect (ASP)				
1) southeast, southwest, northwest	0.1395	0.0750	3.4552	0.0631
2) northeast	-0.1395	0.0750	3.4552	0.0631
Proximity to Improved Roads (RO)	-0.0001	0.000064	2.4997	0.1139
Proximity to Human Activity Sites (HA)	0.000389	0.000032	145.5127	0.0001

Table B6. Results of logistic regression analysis of spring regional model variables for male black bears. Tellico Ranger District, Cherokee National Forest, Tennessee, 1978-1983.

Variable (Variable Code)	Parameter Estimate	Standard Error	Wald χ^2	P-value
Intercept	-1.6833	1.1140	2.2830	0.1308
Overstory Vegetation Type (OV)				
1) bottomland, mixed mesophytic, and northern hrdwd.	-1.1098	0.5109	4.7175	0.0299
2) oak/hickory	-0.0459	0.4044	0.0129	0.9096
3) other pine/hardwood	0.8064	0.4928	2.6780	0.1017
4) southern yellow pine	0.1712	0.3888	0.1938	0.6598
5) white pine/hemlock/hardwood, white pine/hemlock	0.1781	0.5381	0.1095	0.7407
Overstory Vegetation Richness (OVR)	0.1955	0.2280	0.7357	0.3911
Proximity to Streams (ST)	-0.00392	0.00204	3.6708	0.0554
Aspect (AS)				
1) southeast, southwest, northwest	0.3321	0.2469	1.8086	0.1787
2) northeast	-0.3321	0.2469	1.8086	0.1787
Proximity to Improved Roads (RO)	-0.0001	0.000269	0.1503	0.6983
Proximity to Human Activity Sites (HA)	0.000377	0.000125	9.1877	0.0024

Table B7. Results of logistic regression analysis of summer regional model variables for male black bears. Tellico Ranger District, Cherokee National Forest, Tennessee, 1978-1983.

Variable (Variable Code)	Parameter Estimate	Standard Error	Wald χ^2	P-value
Intercept	-2.3509	0.4745	24.5448	0.0001
Overstory Vegetation Type (OV)				
1) <i>bottomland, mixed mesophytic, and northern hrdwd.</i>	-0.4893	0.1715	8.1439	0.0043
2) <i>oak/hickory</i>	-0.0247	0.1560	0.0251	0.8742
3) <i>other pine/hardwood</i>	0.2650	0.1739	2.3228	0.1275
4) <i>southern yellow pine</i>	0.1159	0.1473	0.6191	0.4314
5) <i>white pine/hemlock/hardwood, white pine/hemlock</i>	0.1331	0.2022	0.4334	0.5103
Overstory Vegetation Richness (OVR)	0.0763	0.0964	0.6276	0.4282
Proximity to Streams (ST)	-0.00065	0.000727	0.7879	0.3747
Aspect (AS)				
1) <i>southeast, southwest, northwest</i>	0.2236	0.1114	4.0306	0.0447
2) <i>northeast</i>	-0.2236	0.1114	4.0306	0.0447
Proximity to Improved Roads (RO)	-0.00044	0.000109	16.0624	0.0001
Proximity to Human Activity Sites (HA)	0.00052	0.00005	107.3701	0.0001

Table B8. Results of logistic regression analysis of fall regional model variables for male black bears. Tellico Ranger District, Cherokee National Forest, Tennessee, 1978-1983.

Variable (Variable Code)	Parameter Estimate	Standard Error	Wald χ^2	P-value
Intercept	-2.1896	0.4862	20.2835	0.0001
Overstory Vegetation Type (OV)				
1) bottomland, mixed mesophytic, and northern hrdwd.	-0.0029	0.1859	0.0002	0.9876
2) oak/hickory	-0.0357	0.1624	0.0484	0.8258
3) other pine/hardwood	0.0022	0.1923	0.0001	0.9910
4) southern yellow pine	0.1463	0.1608	0.8276	0.3630
5) white pine/hemlock/hardwood, white pine/hemlock	-0.1098	0.2154	0.2600	0.6101
Overstory Vegetation Richness (OVR)	0.3558	0.1048	11.5356	0.0007
Proximity to Streams (ST)	-0.00073	0.000723	1.0212	0.3122
Aspect (AS)				
1) southeast, southwest, northwest	0.0301	0.0750	0.0633	0.8013
2) northeast	-0.0301	0.1195	0.0633	0.8013
Proximity to Improved Roads (RO)	-0.000196	0.000093	4.4733	0.0344
Proximity to Human Activity Sites (HA)	0.000242	0.000049	24.7650	0.0001

Appendix C:
Seasonal Regional Habitat Use Probability Maps

Figure 20: Male black bear habitat use probability: spring.

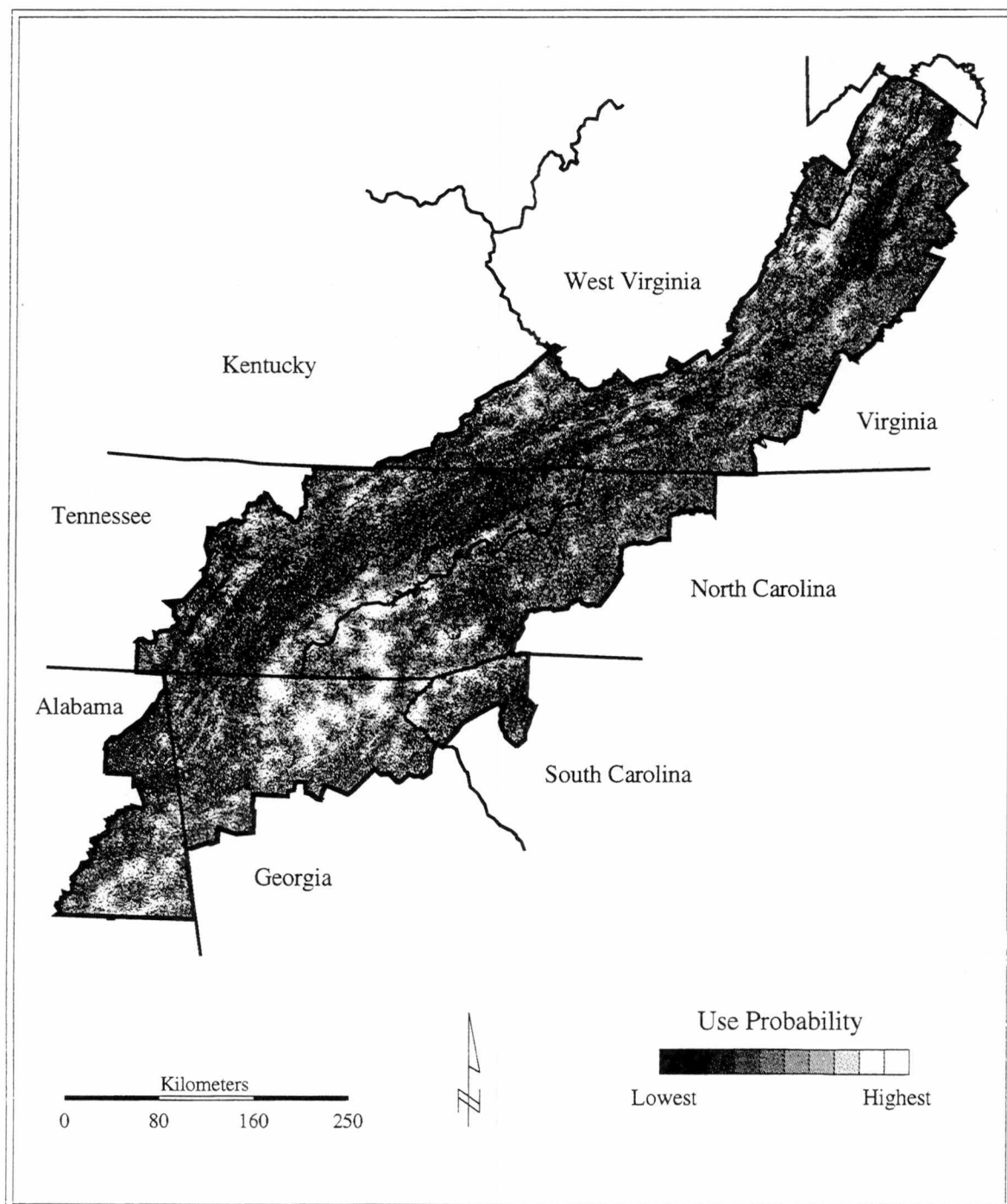


Figure 21: Male black bear habitat use probability: summer.

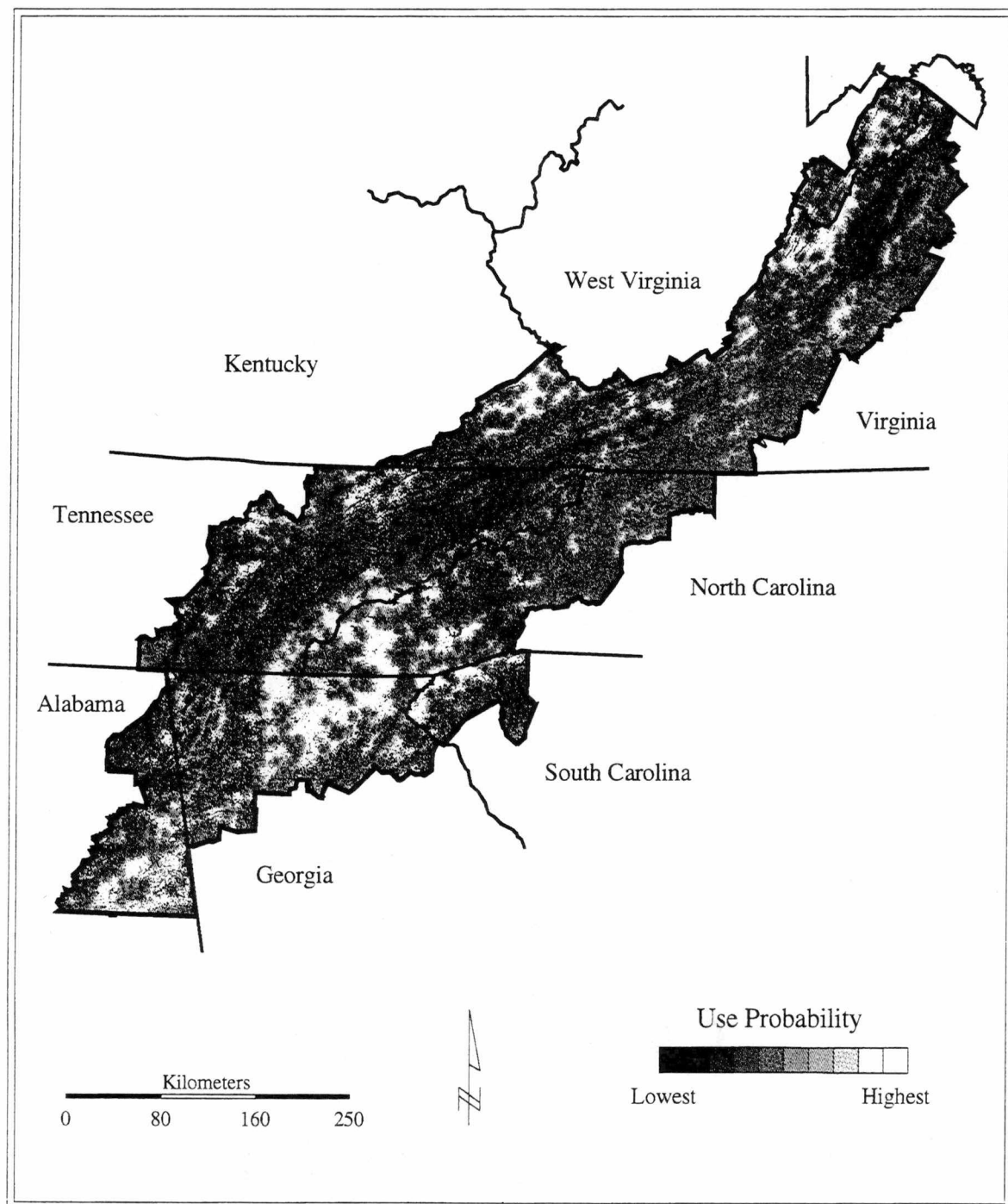


Figure 22: Male black bear habitat use probability: fall.

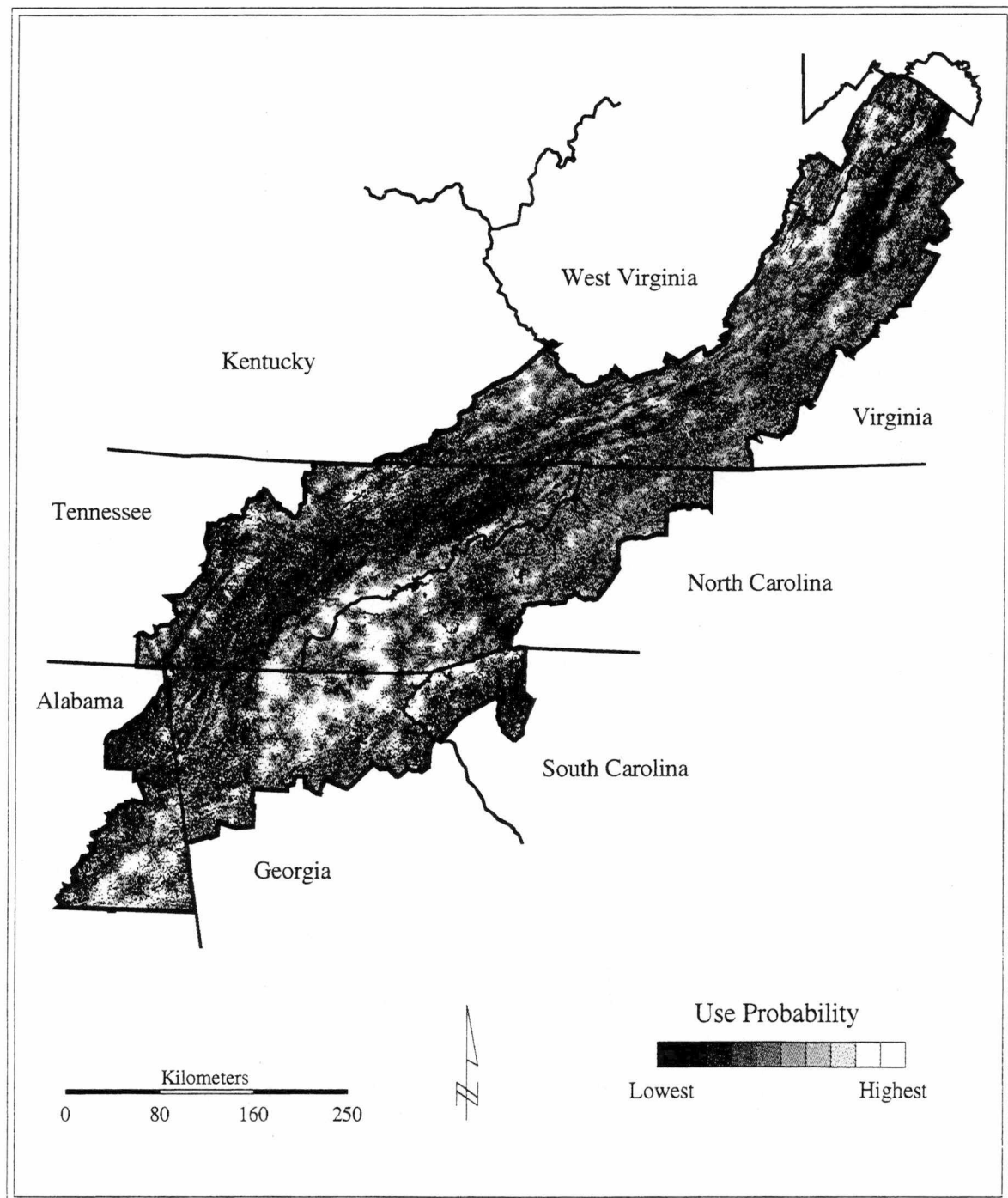


Figure 23: Female black bear habitat use probability: spring.

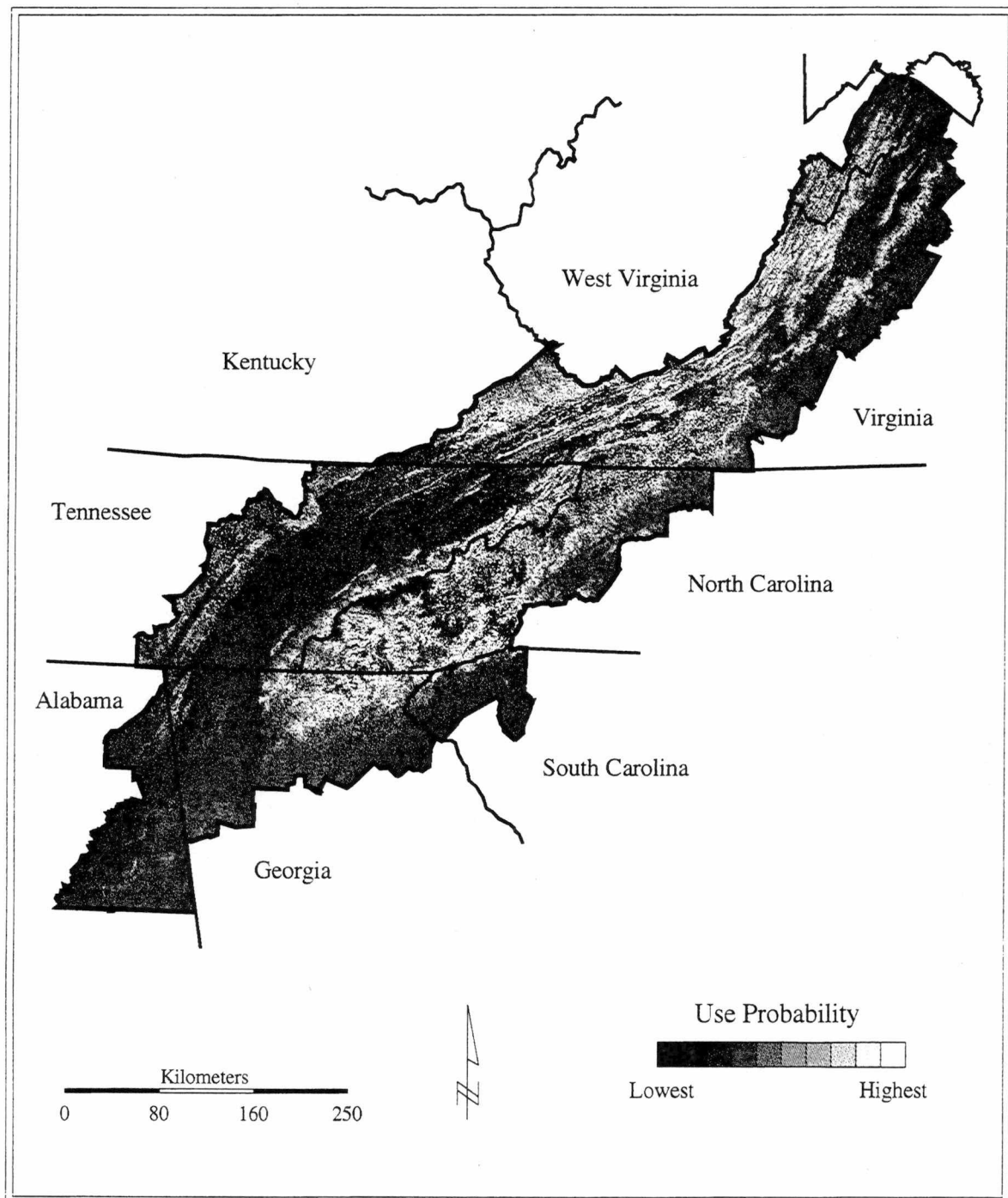


Figure 24: Female black bear habitat use probability: summer.

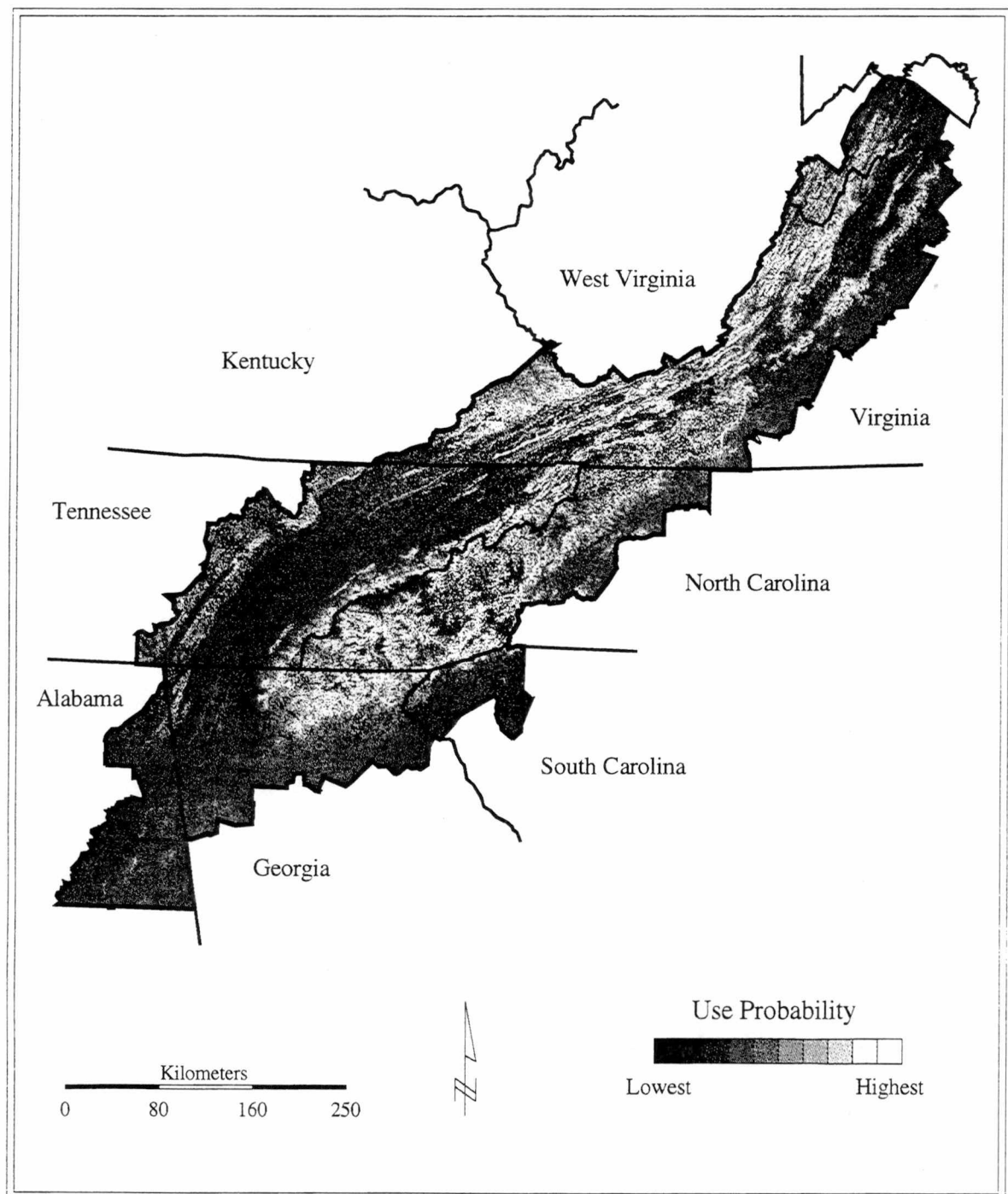
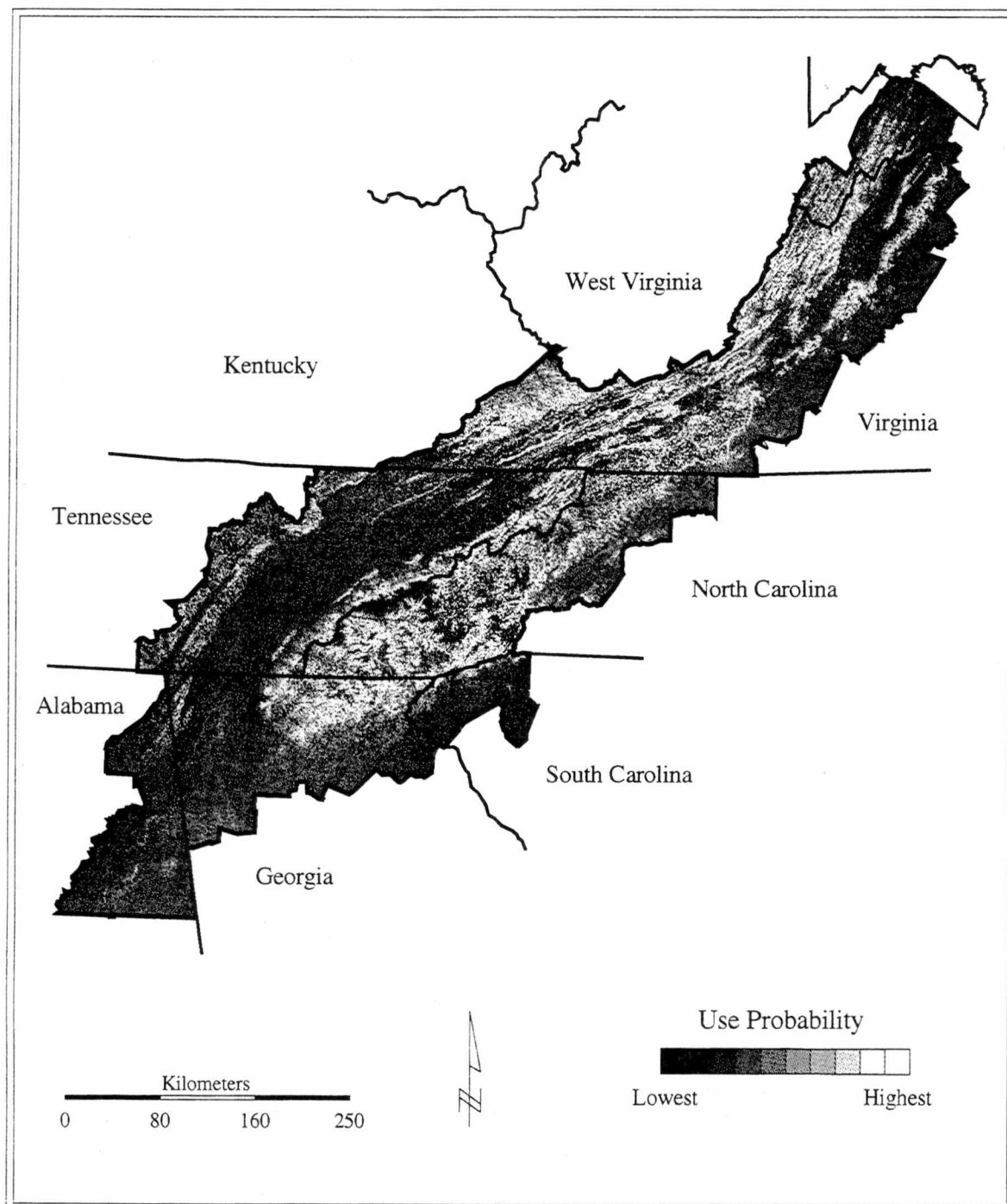


Figure 25: Female black bear habitat use probability: fall.



VITA

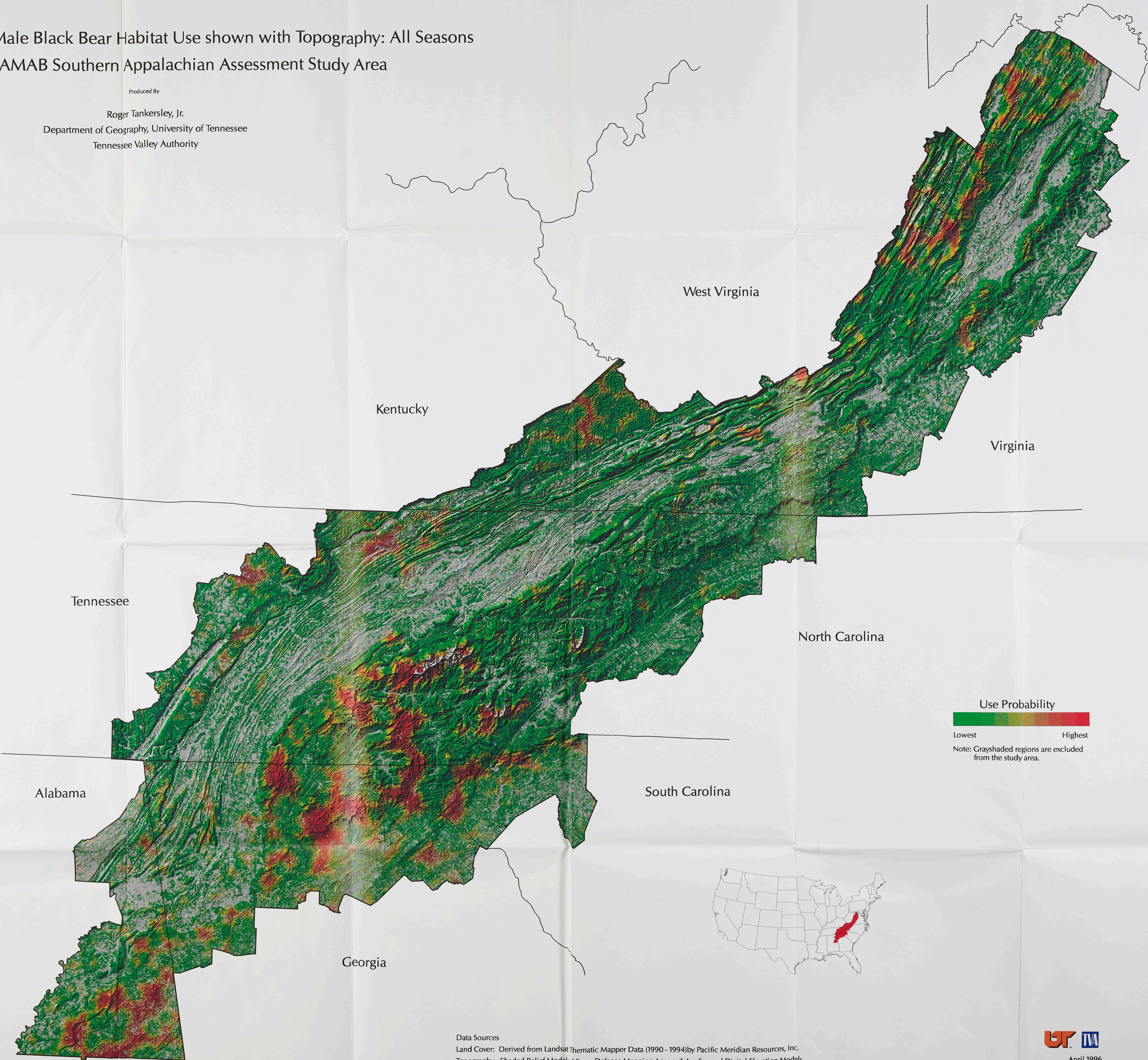
Roger Tankersley, Jr. was born in California, but was thankfully raised in southwest Virginia. He graduated first from Blacksburg High School in 1990, then from James Madison University, Harrisonburg, Virginia in 1994 with a B.S. in Geography. That same year he started his masters research at the University of Tennessee, also in Geography, and was rewarded the M.S. degree in December, 1996.

He and his wife, Christine, live in north Knoxville, and it looks like he will be going back for more punishment as he takes on the Ph.D. starting Spring 1997, again in Geography.

Male Black Bear Habitat Use shown with Topography: All Seasons
SAMAB Southern Appalachian Assessment Study Area

Produced By

Roger Tankersley, Jr.
Department of Geography, University of Tennessee
Tennessee Valley Authority



Use Probability



Note: Grayshaded regions are excluded from the study area.

Data Sources
Land Cover: Derived from Landsat Thematic Mapper Data (1990 - 1994) by Pacific Meridian Resources, Inc.
Topography: Shaded Relief Modeled From Defense Mapping Agency 3 Arc Second Digital Elevation Models
Model development assistance provided by Frank T. van Manen, Department of Forestry, Wildlife and Fisheries, University of Tennessee
Map template provided by Karl A. Hermann, National Biological Service



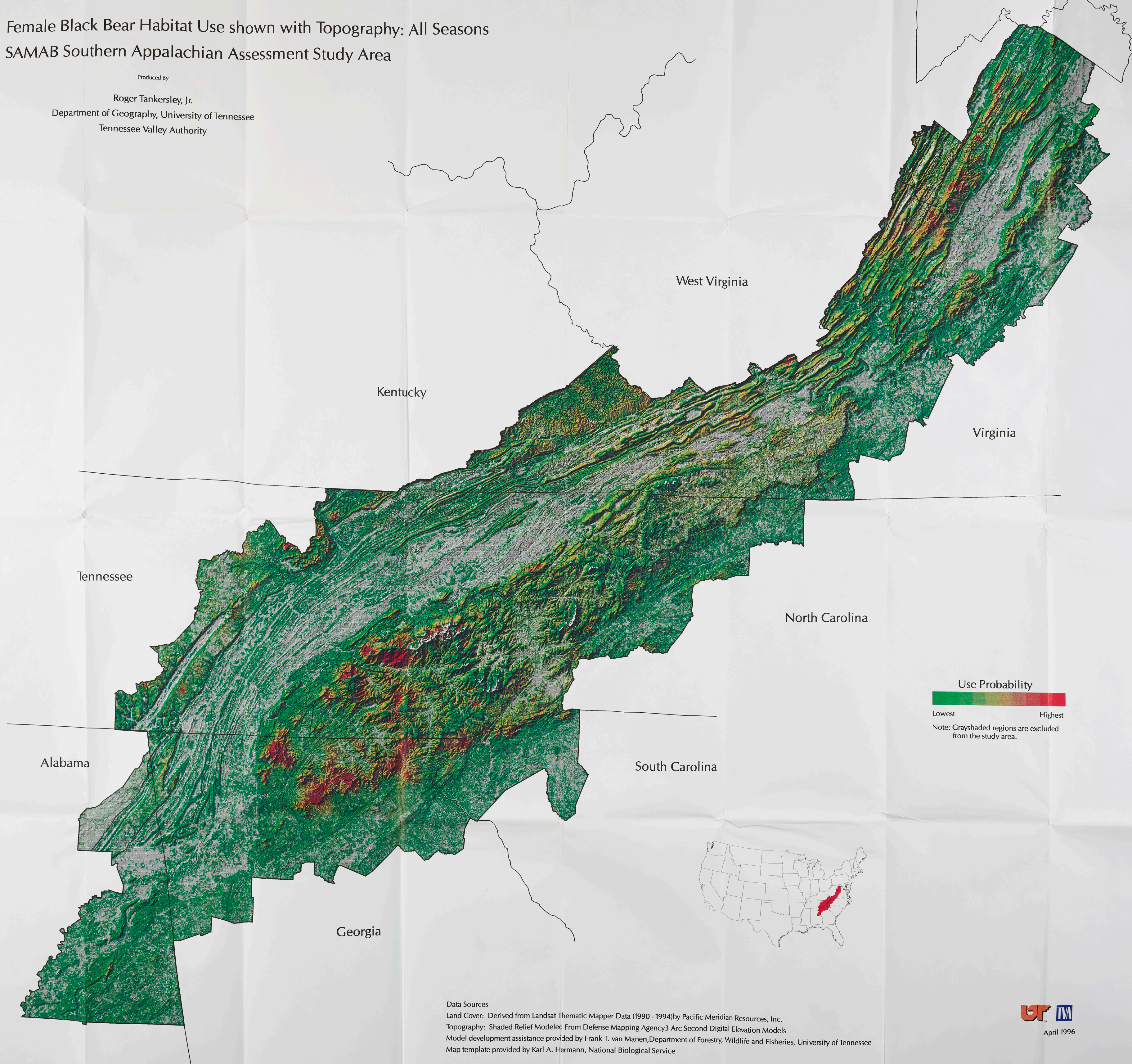
April 1996

Female Black Bear Habitat Use shown with Topography: All Seasons

SAMAB Southern Appalachian Assessment Study Area

Produced By

Roger Tankersley, Jr.
Department of Geography, University of Tennessee
Tennessee Valley Authority



Use Probability



Lowest

Highest

Note: Grayshaded regions are excluded from the study area.

Data Sources

Land Cover: Derived from Landsat Thematic Mapper Data (1990 - 1994) by Pacific Meridian Resources, Inc.

Topography: Shaded Relief Modeled From Defense Mapping Agency 3 Arc Second Digital Elevation Models

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April 1996