8-2003

A landscape assessment to identify potential elk restoration sites in Arkansas

Rebecca Lyn Telesco

To the Graduate Council:

I am submitting herewith a thesis written by Rebecca Lyn Telesco entitled "A landscape assessment to identify potential elk restoration sites in Arkansas." I have examined the final electronic 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 Wildlife and Fisheries Science.

Frank T. van Manen, Major Professor

We have read this thesis and recommend its acceptance:

Joseph D. Clark, Lisa I. Muller, Shih-Lung Shaw

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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A LANDSCAPE ASSESSMENT TO IDENTIFY POTENTIAL ELK RESTORATION SITES IN ARKANSAS

A Thesis

Submitted for the

Master of Science Degree

University of Tennessee, Knoxville

Rebecca Lyn Telesco

August 2003

ACKNOWLEDGMENTS

I would like to extend my appreciation to the many agencies who participated in this study. Financial support was provided by the Arkansas Game and Fish Commission (AGFC), the U. S. Geological Survey, and the University of Tennessee, Knoxville. The AGFC, U.S. National Park Service Buffalo National River, and personnel at the U. S. Forest Service Ozark-St. Francis National Forest and Ouachita National Forest provided data and logistical support. The interest, cooperation, and support of those agencies and their personnel throughout the study were fundamental to its success.

Special thanks to my committee members for making this thesis possible. My major advisor, Dr. Frank van Manen, has been a valuable mentor and a friend. I profited from the personal interest and extra time he gives to all his graduate students and their research studies. Dr. Joseph Clark provided essential input on study design, modeling, and statistical analyses, as well as helpful comments on early drafts of the thesis. Dr. Shih-Lung Shaw gave helpful theoretical and technical GIS support, and I benefited from Dr. Lisa Muller's expertise in ungulate ecology and management. The support of my committee throughout the process led to a sound research study and to my growth as a scientist.

I am indebted to the help of many people from the AGFC, National Park Service, and Ozark-St. Francis and Ouachita national forests in Arkansas. I was pleased to work regularly with Michael Cartwright, Elk Coordinator for the AGFC, who provided helpful input as well as administrative and logistical support throughout the study. He also provided much needed assistance in acquiring and digitizing 12 years of aerial survey data for elk. The enthusiastic support of National Park Service biologist Sammy Lail was essential to the success of the field study. Thanks to Mike Cartwright, Sammy Lail, Mark Baron, Eddie Linebarger, and Bob McAnally for arranging time in their busy schedules to meet and assess elk-human conflict potential in Arkansas. I also appreciate the assistance of Jennifer Herner-Thogmartin, Jim McCoy, Tammy Hocut, Larry Hedrick, and Diana Angelo for supplying data and providing GIS technical advice.

My fellow students at UT have been a continual source of support, friendship, and good times. Thanks to Laura Thompson, Kim Asmus, Kent Hersey, Cindy and Benny Thatcher, Brandon and Meaghan Wear, Jason and Heather Kindall, Steve and Jennifer Dobey, Katie Settlage, Andy Edwards, and Jenny Fiedler. Thanks especially to Cindy Thatcher for answering my numerous daily GIS questions, and for her camaraderie on similar aspects of our study designs. My field validation was a great success due to the hard work of technicians Roy Smith, David Telesco, and Laura Thompson.

Allison, Brad, and Kylie Smith have been fantastic friends and supporting neighbors. They have been a constant reminder to myself and my husband that there is life outside of graduate school. Thanks Kylie, for the permanent smile I wear in your presence.

Finally, I would like to thank my husband, David Telesco, for all his love and encouragement over the past 8 years. Over the course of this study, he has enthusiastically assumed the roles of loving husband, fellow student, field technician, research consultant, and friend. And thanks to our family, the Mikkelsens, the Beans, the Telescos, and the Torluccis for their endless encouragement, love, and guidance.

ABSTRACT

The Arkansas Game and Fish Commission (AGFC) is considering translocation to expand its established elk population. I conducted a feasibility study that identified potential restoration sites in Arkansas to reduce the probability of reintroduction failure. I developed 2 landscape-scale predictive models using geographical information system (GIS) technology to identify potential elk restoration sites in Arkansas, one to identify suitable elk habitat and the other to assess the potential for elk-human conflict. I assessed winter habitat for elk using empirical data consisting of 239 elk-group locations collected from helicopter surveys in the Buffalo National River area. Those surveys were conducted by the AGFC in February–March, 1992–2002. A suite of 9 habitat variables were developed to characterize the habitat and landscape conditions associated with those elk-group locations. Variables were generated at multiple spatial scales, representing different orders of habitat selection, so that I could select the most appropriate scale to evaluate each variable. From those data, I then applied the Mahalanobis distance statistic to evaluate winter habitat suitability in Arkansas based on 90- x 90-m pixels. Lower Mahalanobis distance values indicated a greater similarity to the habitat conditions associated with the elk-group locations. More suitable elk habitat was associated with areas of high landscape heterogeneity, heavy forest cover, and gentle sloping ridge tops and valleys in western and northwestern Arkansas, where human population and road densities also were relatively low. Areas of intensive agriculture in the Mississipppi River Delta generally were least suitable. I tested model performance by recording the frequency of occurrence of elk scat within 19 fixed-width transects surveyed in March

2002. Linear regression analysis indicated that the frequency of scat occurrence increased with decreasing mean Mahalanobis distance values ($F = 9.65$, $P = 0.039$). Those results suggest that elk presence was more likely in areas predicted by the model to be more suitable habitat. Finally, I assessed the potential for elk-human conflict in Arkansas with a GIS adaptation of the Analytical Hierarchy Process. Five elk experts in Arkansas ranked the relative importance of 8 criteria that could influence the potential for elk-human conflict in a series of pairwise comparisons. Those rankings were then applied in a weighted linear summation of 8 variables representing those criteria, resulting in a single map delineating the relative potential for elk-human conflict. Public land forage availability was determined to have the strongest influence on the potential for elk-human conflict, contributing 33% to the overall conflict potential, followed by human population growth rate (22%) and the amount of private land in row crops (18%). Elk-human conflict potential in Arkansas ranged from 0.14 to 0.72 ($\bar{x} = 0.54 \pm 0.009$). Conflict potential was classified as low (≤0.49), medium (0.49– 0.59), and high (>0.59), representing intervals of 6 standard deviations from the mean conflict potential value for radio-locations of nuisance elk cows. I combined contours of those conflict potential intervals with the winter habitat suitability model to identify regions where suitable elk habitat corresponded with low potential for elk-human conflict. Those regions mainly were associated with public lands in western and northwestern Arkansas. Large, contiguous patches of suitable habitat within areas of low elk-human conflict potential tended to correspond with public and private land boundaries in northern and northwestern Arkansas. The combined map provides a tool for natural resource managers to identify and rank potential elk restoration areas in Arkansas.

TABLE OF CONTENTS

CHAPTER PAGE

LIST OF TABLES

LIST OF FIGURES

FIGURE PAGE

FIGURE PAGE

FIGURE PAGE

CHAPTER I

INTRODUCTION

Prior to European settlement, approximately 10 million elk, or wapiti (*Cervus elaphus*), inhabited North America (Seton 1927). Six elk subspecies ranged from sub-arctic Canada to northern Mexico and from the Pacific coast to the Atlantic coast (O'Gara and Dundas 2002; Fig. 1). Bartram observed that Eastern elk (*C. e. canadensis*) were abundant prior to European settlement, but their numbers began to decline by the late 1700s (Van Doren 1955:62). As European settlement expanded west, the decline of elk continued, mainly because of large-scale habitat loss, unregulated hunting, and competition with domestic livestock (Christensen 1998, O'Gara and Dundas 2002).

By 1922, only about 90,000 elk remained, the majority inhabiting population reserves located in Yellowstone National Park in Wyoming, Olympic National Park in Washington, and the Tule Elk Reserve in California (Bryant and Maser 1982). Two subspecies, Eastern elk and Merriam's elk (*C. e. merriami*), were extirpated and only a few isolated populations of the Manitoban subspecies (*C. e. manitobensis*) remained in central Canada (Bryant and Maser 1982). In the early 1900s efforts were initiated to restore and protect elk populations, including strict hunting regulations, public land acquisition, habitat restoration, and elk translocations. As a result, an estimated 1 million elk occupy an expanding range within their historic distribution (Christensen 1998; Fig. 2).

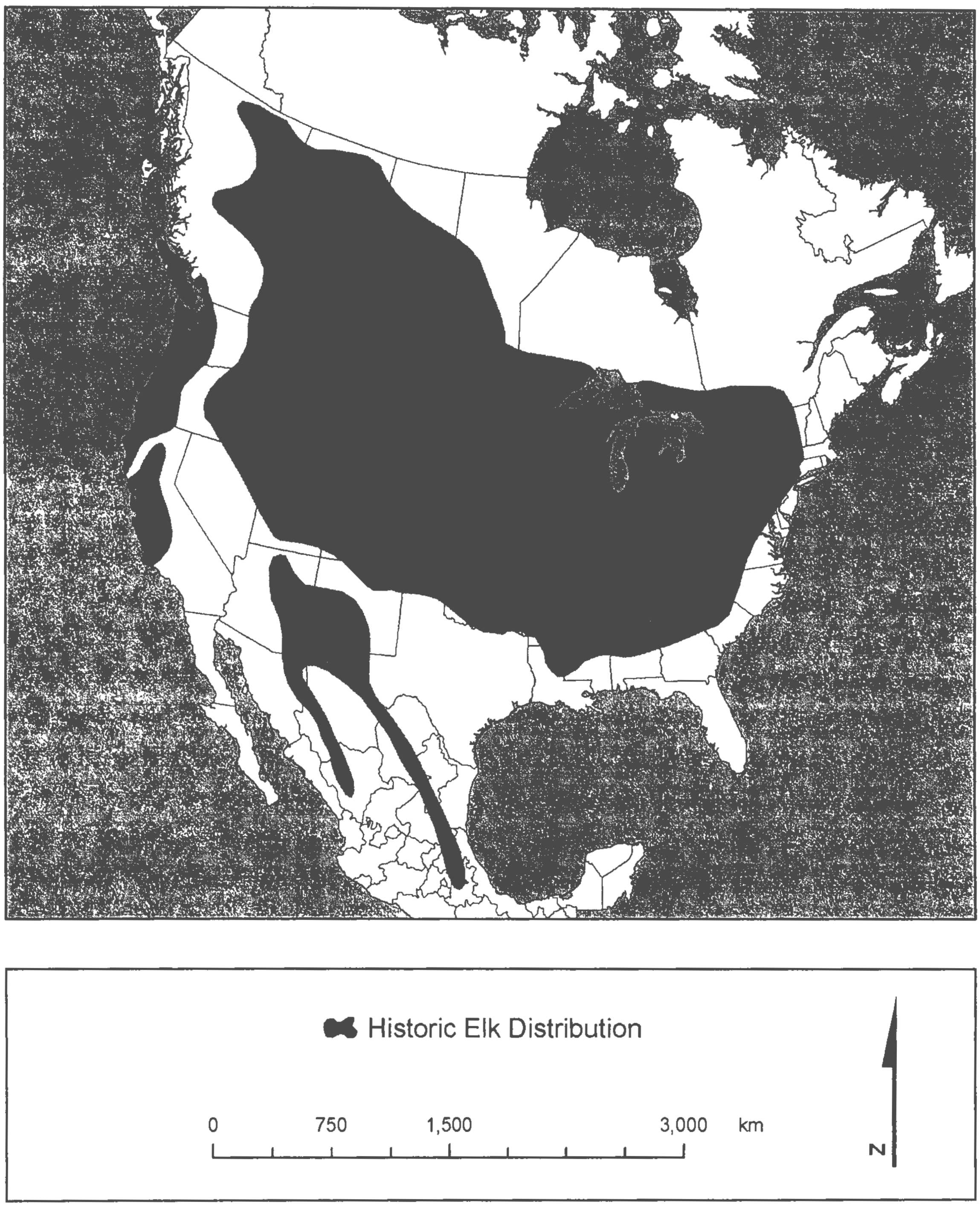

Fig. 1. Historic distribution of North American elk, redesigned from Bryant and Maser (1982)

Fig. 2. Distribution of North American elk, modified from Bryant and Maser (1982) to represent recent elk reintroductions.

ELK RESTORATION EFFORTS

Reintroduction has been an important tool for the restoration of elk populations (Witmer 1990). Although most reintroduction efforts in the western United States have resulted in re-established populations and expansion of elk range, most reintroduction attempts in the plains and eastern states have failed (Witmer 1990, Maehr et al. 2001). The primary causes of those failures included lack of available habitat or poor habitat quality, elk-human conflicts, overharvesting, and disease (Witmer 1990, Thorne et al. 2002).

Reintroduction efforts in the eastern and plains states have resulted in established elk populations in Arkansas, Michigan, North Dakota, Pennsylvania, Oklahoma, South Dakota, and Texas (Fig. 2). With the exception of South Dakota, where the elk population is >5,000, the elk populations in those states are relatively small, ranging from 300 to 1,000 animals (O'Gara and Dundas 2002). Several of those populations are restricted from further growth or range expansion by conflicts on adjacent private lands (O'Gara and Dundas 2002). There has been a resurgent interest in reintroducing elk to the East in recent years, largely due to the efforts of the Rocky Mountain Elk Foundation. Since 1995, elk have been released at sites in Kentucky, North Carolina, Tennessee, and Wisconsin. In addition, wildlife management agencies in Illinois, Missouri, New York, and Virginia have recently considered elk reintroductions.

STUDY JUSTIFICATION

Elk reintroductions require careful planning to reduce potential conflicts between elk management objectives and other land use objectives. Witmer (1990) recommended the use of feasibility studies to increase the success of elk reintroductions. Establishment of viable elk populations requires restoration sites that are sufficient in size and habitat quality and have low potential for disease transmission (Witmer 1990). Because elk are a wide-ranging species with generalized habitat requirements, selecting sites for elk reintroduction is best accomplished at a landscape scale (Edge et al. 1987, Turner et al. 1993, Cooperrider 2002).

Landscapes in the East often contain a complex mosaic of land ownerships and land uses, where human densities are high and public lands tend to be small and fragmented. In addition to meeting biological requirements of elk, elk-human conflict issues should be assessed. Those issues include human access to elk herds, elk damage to private property, competition with domestic livestock, and public attitudes towards elk (Witmer 1990, Lyon and Christensen 2002). Maehr et al. (2001) stressed the importance of assessment studies to avoid potentially large personnel and equipment costs, and loss of public trust associated with reintroduction failures.

The AGFC is considering the establishment of additional elk herds in Arkansas to enhance recreational opportunities (e.g., sport hunting, elk viewing) and support nationwide recovery efforts. However, to reduce the probability of reintroduction failure, the AGFC chose to conduct a feasibility study, including landscape-scale evaluations of elk habitat suitability and elk-human conflict potential. Therefore, my research objective was to identify potential reintroduction areas for elk in Arkansas based on an integrated assessment of (1) suitable landscape characteristics and (2) the reduced potential for elk-human conflict.

CHAPTER II

HISTORY OF ELK IN ARKANSAS

Historical records indicate that elk in Arkansas persisted no later than the 1840s (Cartwright 1991). Unregulated hunting and habitat loss associated with European settlement likely were the ultimate causes of the extirpation of elk in the state. However, a lack of archaeological records and accounts by early explorers indicates that elk may have been scarce or declining prior to settlement; one possible explanation for an earlier elk decline may be a change in Native American land-use practices. The regular and uncontrolled use of fire by Native Americans heavily impacted the structure of southern forests, creating prairies and savannahs in areas with poor soils (Dickson 2001*a*). Those frequent fires and abandonment of agricultural sites resulted in a mosaic of openings and successional stages beneficial to elk (McCabe 2002). As Native American populations declined from exogenous diseases, the amount of forest openings and prairies also declined. Those landscape changes, coupled with increased hunting pressure as Native Americans acquired firearms, may have precipitated elk population declines before European settlement (McCabe 2002).

HISTORIC DISTRIBUTION

The historic distribution of elk (e.g., the distribution immediately prior to European exploration) in Arkansas should be examined to ensure that elk are reintroduced within their native range. However, because few records exist, published elk distribution maps for Arkansas have been inconsistent. One account by

Featherstonhaugh (1835) indicates that elk were present in northeast Arkansas in 1834; it appears to be the only written record of elk in Arkansas from early explorations of the region. O'Gara and Dundas (2002) presented a distribution map of elk based on fossils from the Late Holocene (4,000–500 years before present). That map indicated that elk were present in northwest Arkansas and south along the border of Arkansas and Oklahoma at least 500 years ago.

Variations in mapping the historic elk distribution may have resulted from the amount of inference used in creating the distribution maps, based on accounts in surrounding states. Both Murie (1951) and O'Gara and Dundas (2002) present relatively conservative distribution maps (Fig. 3). However, both authors proposed that elk may have had a wider distribution in the state than reported in the literature. Conversely, distribution maps by Hall (1981) and Bryant and Maser (1982) present a much wider elk distribution in Arkansas (Fig. 3). Those maps showed an historic elk distribution extending south into central Louisiana. Similarly, Sealander and Heidt (1990) stated that prior to settlement, elk were abundant throughout most of Arkansas.

Records of elk in states surrounding Arkansas indicate abundant and wide-ranging populations to the North and Northeast. According to early explorers G. W. Featherstonhaugh, S. C. Turnbo, and H. R. Schoolcraft, elk once were abundant throughout Missouri and continued to exist in southern and southeastern Missouri throughout the 1800s (Featherstonhaugh 1835, Keefe and Morrow 1994, Rafferty 1996). Elk also were common throughout Tennessee, remaining in the bottomlands of West Tennessee into the mid-1800s (Rhoads 1897 *in* O'Gara and Dundas 2002). However, elk apparently were less common and more scattered in states to the East, South, and West of

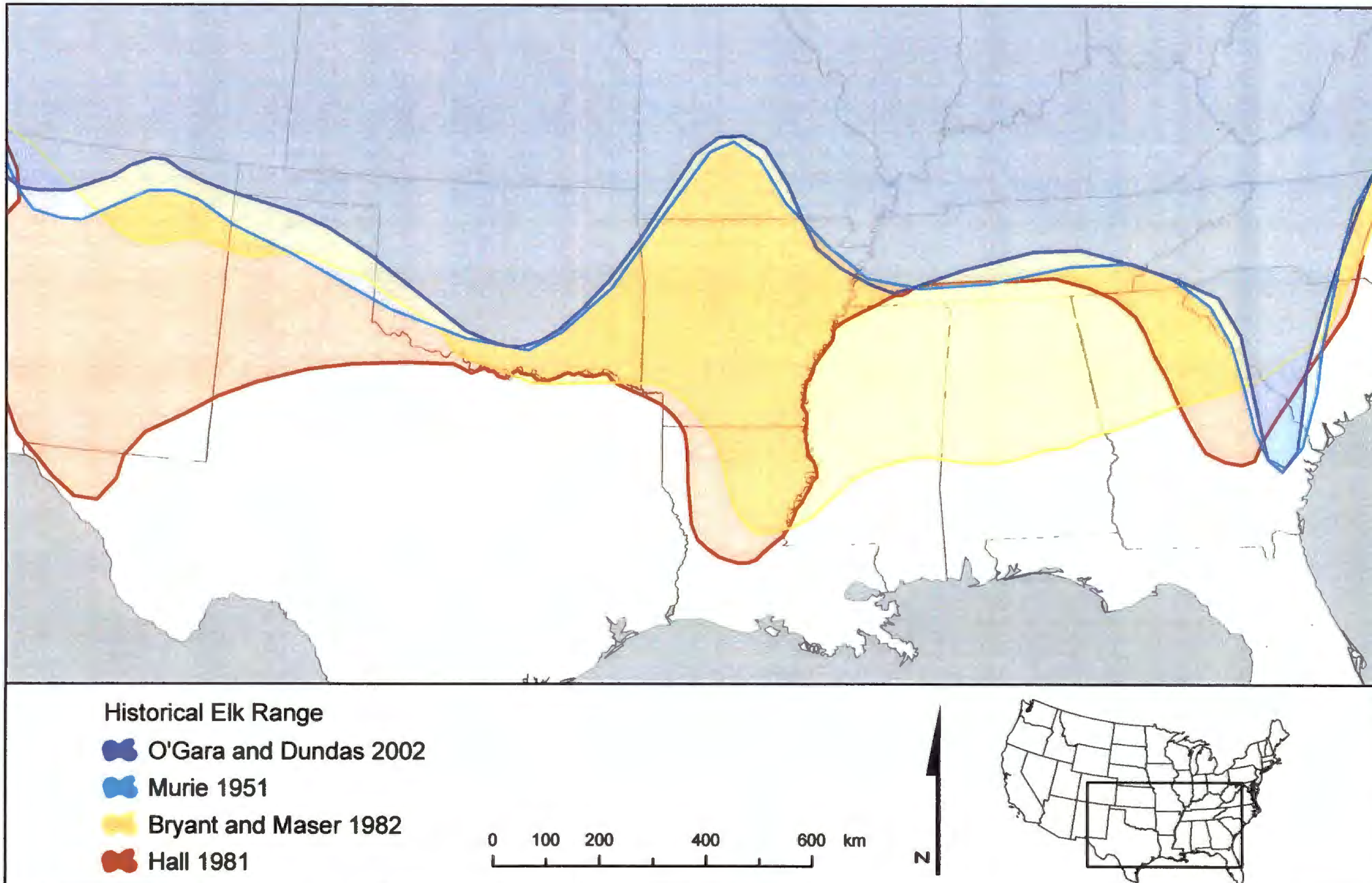

Fig. 3. Historical distributions of elk in Arkansas and surrounding states (Murie 1951, Hall 1981, Bryant and Maser 1982, O'Gara and Dundas 2002).

Arkansas. Two records exist of elk occupying northern Louisiana in the mid 1800s; researchers generally agree that northern Louisiana was the southern boundary of elk distribution (Murie 1951, Hall 1981, Bryant and Maser 1982, O'Gara and Dundas 2002). However, Hays (1871) stated that elk were present from Canada to the Gulf prior to the arrival of European settlers. Elk apparently had a scattered distribution in Oklahoma, with records in the Wichita Mountains and in Alfalfa County (north-central Oklahoma) in the mid to late 1800s (O'Gara and Dundas 2002). Little to no records exist for elk occurrence in eastern Texas and Mississippi.

In reviewing the historical accounts and archaeological records for Arkansas and surrounding states, it seems likely that elk had a larger historical range in Arkansas than described by Murie (1951) and O'Gara and Dundas (2002). Northern Arkansas is ecologically similar to southern Missouri (Bailey 1980) and there are no obvious geographic barriers between the states. Because evidence indicates that elk were abundant in the Missouri Ozarks and western Tennessee, elk likely also occurred in the northern regions of Arkansas. Therefore, I chose the distributions depicted by Hall (1981) and Bryant and Maser (1982) to represent the native range of elk in Arkansas.

Despite discrepancies in describing the native elk range, Arkansas was likely at or near the southern edge of historic elk distribution in North America. Although North American elk have a wide habitat tolerance, elk did not occupy humid regions in the Southeast (Skovlin et al. 2002). Extreme habitat conditions at the boundary of a species range can result in variable populations, which may offer an additional explanation for the scarcity and rapid decline of elk in Arkansas at the time of settlement (Wolf et al. 1996).

ELK REINTRODUCTION ATTEMPTS

Two attempts have been made to reintroduce elk in Arkansas since their extirpation. In 1933, the U.S. Forest Service translocated 11 Rocky Mountain elk from the Wichita Mountains Wildlife Refuge in Oklahoma to Franklin County, Arkansas. By the mid 1950s, the subsequent elk population disappeared, presumably due to illegal hunting, natural mortality, and loss of habitat (Cartwright 1998).

In 1981, the AGFC, in cooperation with the National Park Service, released 105 elk from Colorado and 7 from Nebraska near the Buffalo National River in Newton County. That population has gradually increased in number and distribution. In 2002, the herd consisted of approximately 450 elk, or 1 elk/300 ha (M. Cartwright, AGFC, unpublished report). Elk have been reported in 14 counties in northwest Arkansas, with the core of the elk range located in Newton, Searcy, Boone, and Carroll counties (Fig. 4).

Elk primarily inhabit public lands along the upper and middle sections of the Buffalo National River and within the Gene Rush Wildlife Management Area. However, the increasing elk population has led to a range expansion into neighboring private lands. The AGFC began receiving complaints of nuisance elk from private landowners in the early 1990s (Cartwright et al. 1998). Those landowners primarily experienced damage to pastures and hay meadows (Herner-Thogmartin 1999). Herner-Thogmartin (1999) found that some elk inhabited private land year-round and predicted that nuisance activity would continue to increase as the elk population grows. The AGFC instituted a limited hunt during the fall of 1998, resulting in a harvest of 17 elk (Cartwright 2001). Beginning in 1999, the state expanded its elk hunting program on private land in an effort to reduce elk-human conflicts. From 1998 to 2002, 131 elk were harvested.

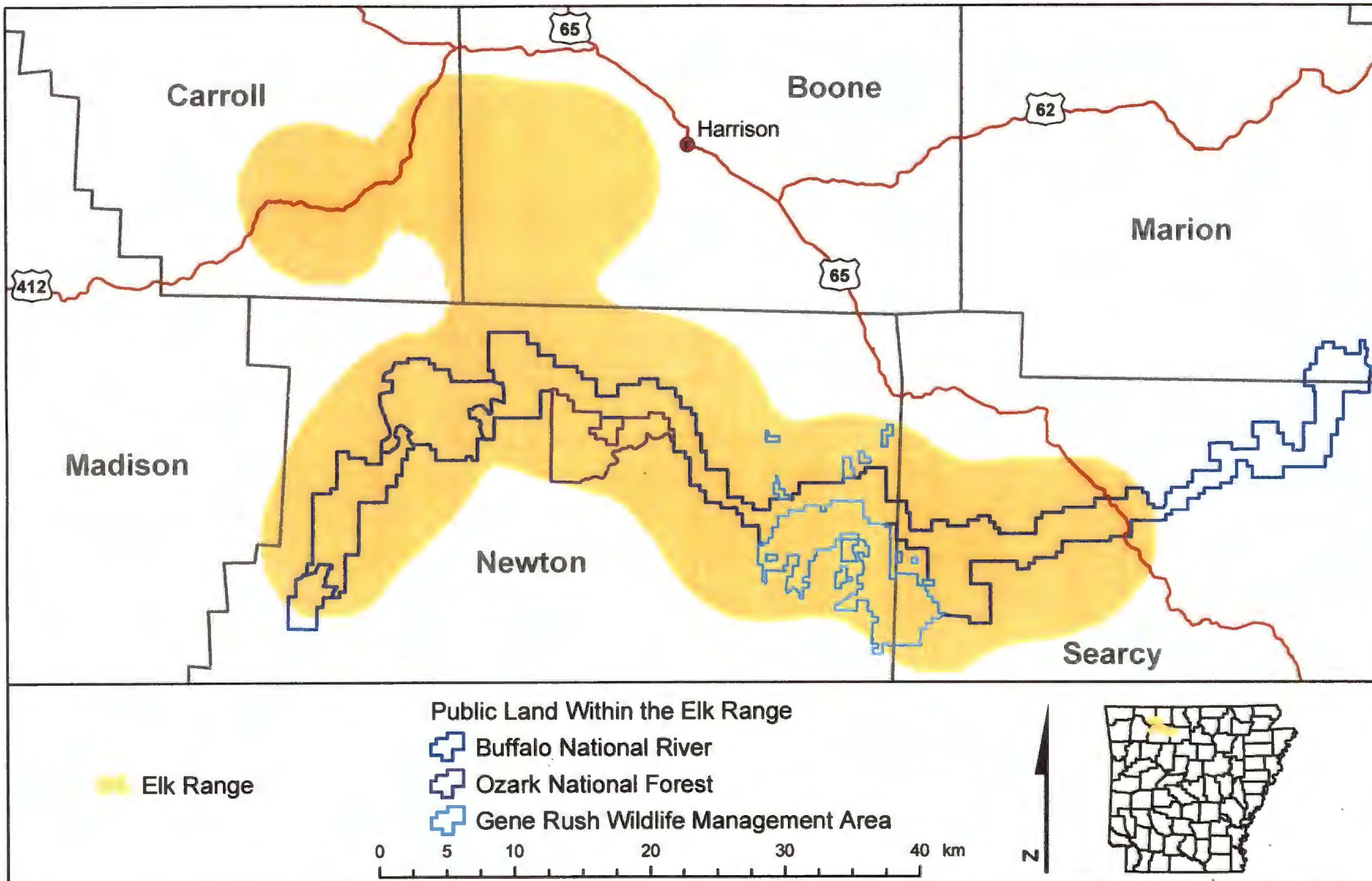

Fig. 4. Current range of elk in Arkansas based on a 99% fixed kernel estimate of aerial survey locations and confirmed elk sightings by the Arkansas Game and Fish Commission, 1992–2002.

CHAPTER III

STUDY AREA

Located in the southeastern United States (33° N – 36° 30' N latitude, 89° 41' W – 94° 42' W longitude), Arkansas shares its borders with the state of Missouri to the North, Tennessee and Mississippi to the East, Louisiana to the South, and Oklahoma and Texas to the West. Arkansas is 418 km long and 386 km wide, with an area of approximately 137,740 km^2. Major river systems in Arkansas include the Mississippi River and its tributaries, including the Arkansas, Ouachita, Red, and White rivers; the Mississippi River forms the eastern border of Arkansas. Arkansas has a temperate climate, productive soils, and a complex physiography, resulting in a wide diversity of ecosystems and wildlife communities. The highlands of western and northern Arkansas are part of the Interior Highlands, which extend into southern Missouri and eastern Oklahoma; the lowlands of eastern and southern Arkansas are part of the Gulf Coastal Plain, which extends from Texas to Georgia (Foti 1974).

INTERIOR HIGHLANDS

Bailey (1980) defined 5 ecoregion provinces for Arkansas; the Eastern Broadleaf Forest (Continental), Ozark Broadleaf Forest-Meadow, and Ouachita Mixed Forest-Meadow provinces comprise the Interior Highlands in Arkansas (Fig. 5). The Interior Highlands have a complex topography of rolling hills and low mountains with steep, narrow valleys caused by erosion from swift-moving rivers (Foti 1974). The Eastern Broadleaf Forest Province has rolling hills of elevations $\leq$500 m, which resulted from

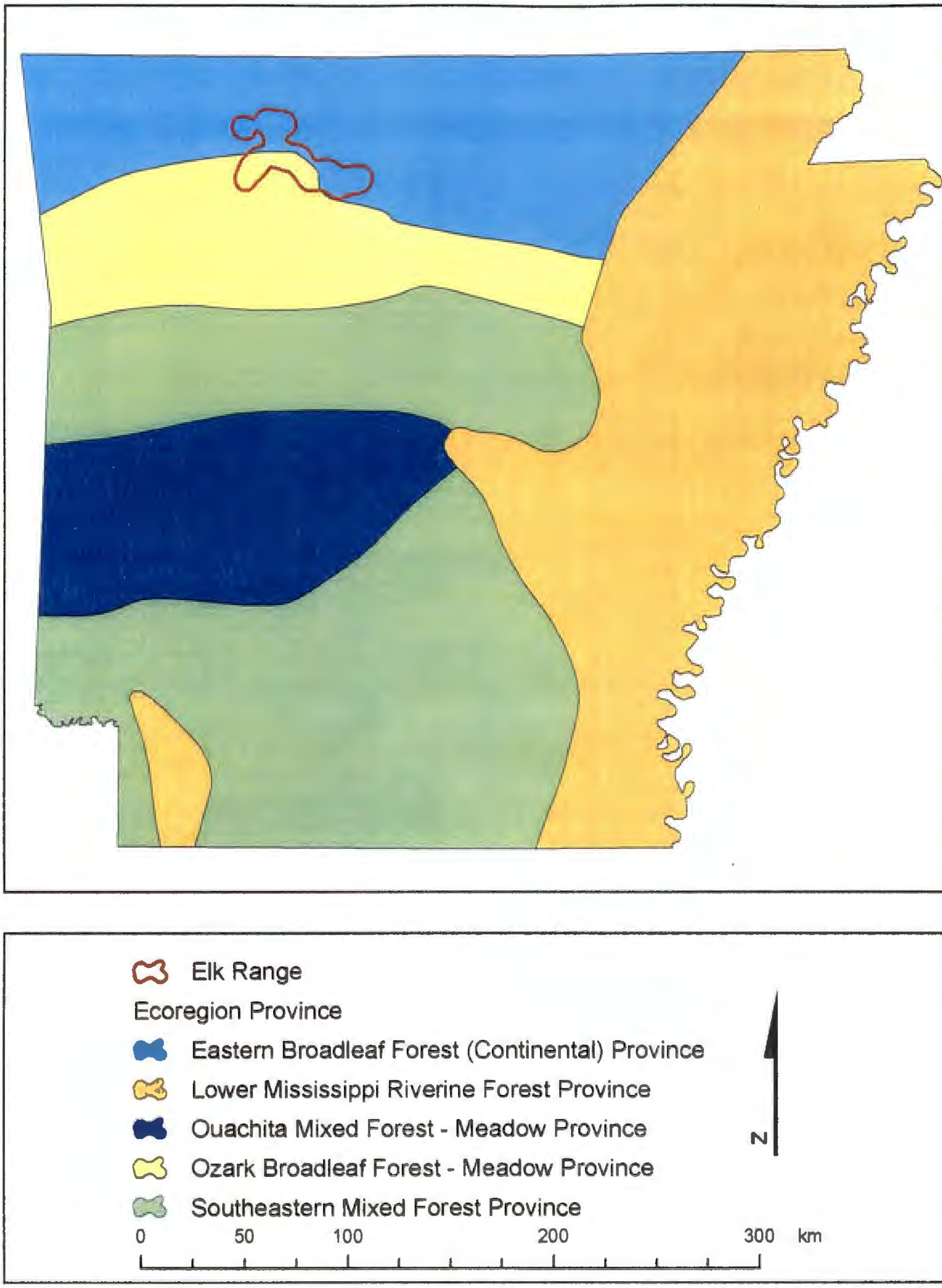

Fig. 5. Ecoregion provinces of Arkansas (Inventory and Monitoring Institute 2001).

doming of basement rock to form the Ozark Plateau (Bailey 1980). The Ozark Broadleaf Forest-Meadow and Ouachita Mixed Forest-Meadow provinces are more mountainous, with narrow ridgetops and higher elevations of ≤800 m. The Arkansas River Valley separates the Ozark Highlands from the Ouachita Mountains. The mountains in the Ouachita Mixed-Forest Meadow Province are 30 million years older than the Ozarks and were created through extensive folding and faulting (Foti 1974). A range of long east-west ridges was created by erosion and gorge cutting of sedimentary rock. Soils in the Interior Highlands are medium–fine textured, consisting of Alfisols and Ultisols to the North and Entisols and Ultisols to the South (Bailey 1980). Average annual temperatures in the Interior Highlands generally are mild, ranging from 13–16 C^{o} in the Eastern Broadleaf Forest Province to 17 C^{o} in the Ouachita Mixed Forest-Meadow Province (Bailey 1980). Precipitation tends to be highest in spring and lowest in summer, ranging from 51–102 cm in the northern Interior Highlands and averaging 105 cm in the mid to southern Interior Highlands (Bailey 1980).

The Interior Highlands mark the western limit of deciduous forests in North America. The region generally consists of large tracts of dense oak-hickory forests to the North and mixed pine-hardwood forests to the South. Approximately 25% of the land is in pasture or cropland (Soil Survey Staff 1981). Pastureland mainly consists of introduced grasses and legumes, although some small native prairies still exist, including Indian grass (*Sorghastrum* spp.), little bluestem (*Schizachyrium scoparium*), and dropseeds (*Sporobolus* spp.). Principal crops are corn, small grains and hay for livestock.

The Eastern Broadleaf Forest Province primarily consists of oak-hickory and oak-hickory-pine forests interspersed with patches of oak savannahs and prairies. Dominant tree species include white oak (*Quercus alba*), red oak (*Q. rubra*), black oak (*Q. velutina*), bitternut hickory (*Carya cordiformis*), and shagbark hickory (*C. ovata*). The well-developed understory includes flowering dogwood (*Cornus florida*), sassafras (*Sassafras albidum*), and hophornbeam (*Carpinus caroliniana*).

The Ozark Broadleaf Forest-Meadow Province mostly consists of forest tracts on federal lands and farm woodlots (Soil Survey Staff 1981). Forests are predominantly oak-hickory, with shortleaf pine (*Pinus echinata*) and eastern red cedar (*Juniperus virginiana*) growing on disturbed sites, shallow soils, and southern and western aspects. Big bluestem (*Andropogon gerardii*), switchgrass (*Panicum virgatum*), Indian grass, and little bluestem grow under medium to open forest canopies. *Uniola* spp., wildrye (*Elymus* spp.), and low panicums (*Dichanthelium* spp.) grow under heavier canopies.

The pre-settlement landscape in the Ouachita Mixed Forest-Meadow Province was dominated by open forests, large prairies, and rocky glades consistent with frequent fire disturbance (Foti and Glenn 1991). Today, forests are dense and consist of shortleaf pine-hardwood forests. White oak, black oak, red oak and hickory dominate the overstory, with loblolly pine (*Pinus taeda*) and shortleaf pine contributing 40% of the cover. About 25% of the region is in the Ouachita National Forest. Commercial logging and recreation are the major land uses.

The current elk range overlaps the Eastern Broadleaf Forest Province and the Ozark Broadleaf Forest-Meadow Province (Fig. 5). Encompassing approximately 1,367 km^2, the elk range is located within Boone, Carroll, Newton, and Searcy counties (Fig. 4). White oak-mixed hardwood forests cover approximately 50% of the forested landscape, followed by mixed pine-hardwood (36%) and post oak (10%) forests (Gorham 2001).

GULF COASTAL PLAIN

The Southeastern Mixed Forest and Lower Mississippi Riverine Forest provinces comprise the Gulf Coastal Plain in Arkansas (Fig. 5). Unlike the Interior Highlands, the Gulf Coastal Plain has gentle topography formed by sluggish to standing water bodies consisting of numerous rivers, marshes, lakes, and swamps. During the Cretaceous period, lowlands of the Southern Mixed Forest Province were submersed by the Gulf of Mexico. As a result, the flat plains of that region consist of gentle topography with a gravelly surface and elevations ranging from 30 to 300 m (Foti 1974). The Lower Mississippi Riverine Province differs physically and biologically from the plains of the Southern Mixed Forest Province. The land is mainly flat and near sea level, with a gently sloping broad floodplain (Foti 1974). However, Crowley's Ridge, untouched by river erosion and featuring a thick mantle of loess, reaches up to 168 m above sea level. The ridge is long (320 km) and narrow (0.8–19 km), oriented in a southerly direction beginning in northeast Arkansas. Soils in the Southern Mixed Forest Province are comprised of Ultisols, Alfisols, and Vertisols. Soils in the Lower Mississippi Riverine Province are deep, medium textured, and generally are poorly drained; they consist of Inceptisols, Alfisols, and Vertisols. Summers in the Gulf Coastal Plain are hot and humid and winters are mild, with an average annual temperature of 15–21 C^{o}. Precipitation is heavier than in the Interior Highlands, averaging 102–153 cm annually; autumn is the driest season.

Most large forest tracts in the Southern Mixed Forest Province are owned by corporations or are in public ownership as national forests; lumber and pulpwood production are major industries. Pine-hardwood mixed forests comprise the dominant woody vegetation. Loblolly pine, shortleaf pine, and other southern yellow pines provide half of the overstory vegetation. Oak, hickory, gum, red maple (*Acer rubrum*), and winged elm (*Ulmus alata*) dominate the deciduous overstory. American beautyberry (*Callicarpa americana*), greenbrier (*Smilax* spp.), hawthorns (*Crataegus* spp.), berry vines, and Japanese honeysuckle (*Lonicera japonica*) comprise the woody understory. The region is characterized by a variety of grasses and forbes. Common crops include corn, grain, soybeans, oats, peanuts, rice, hay, and vegetables.

Bottomland forest once covered much of the landscape in the Lower Mississippi Riverine Province but the majority has been cleared for crops. The bottomland deciduous forest is represented by a diversity of species adapted to wet, poorly drained soils, including ash (*Fraxinus* spp.), elm, cottonwood (*Populus deltoides*), sugarberry (*Celtis occidentalis*), sweetgum, water tupelo (*Nyssa aquatica*), bald cypress (*Taxodium distichum*), and a variety of oaks. Vines are prolific in riparian zones. Herbaceous growth consists of switchgrass, little bluestem, Indian grass, Florida paspalum (*Paspalum floridanum*), plumegrass (*Saccharum* spp.), sedges, and rushes. Vegetation on Crowley's Ridge is reminiscent of the hardwood forests of the Ozarks. Major crops include rice, soybeans, cotton, and wheat. Because of the flat, poorly drained soils, control of surface water is of major concern to agricultural production (Soil Survey Staff 1981).

LAND USE

After the Louisiana Purchase in 1803, the human population in Arkansas (then part of the Missouri Territory) rapidly increased, primarily because of the growth of the cotton industry in the southeastern United States. Cotton plantations dominated the

Mississippi Delta by the 1820s. During that time, natural resources were heavily exploited, hunting was unregulated, and many wildlife species declined or became extinct. The Interior Highlands were intensely logged by the late 1800s, removing the last large tracts of virgin timber in the eastern United States (Smith and Neal 1991).

Attempts to regulate natural resource exploitation began in the early 1900s and public lands were established. After the Civil War, human population growth in Arkansas steadied. The cotton industry failed during the Great Depression; by the end of World War II, farming in Arkansas was diversified to include beef and dairy cattle, poultry, soybeans, and tobacco. Although timberland generally increased, bottomland hardwoods continued to be rapidly converted to cropland (Dickson 2001*b*).

Despite increasing human development in recent years, conservation efforts have led to the designation of additional public lands. Currently, about 87% of the state is privately owned; the remaining 13% is primarily federally owned public land (Table 1). In contrast, public lands comprise 25% of the current elk range (Table 1). Arkansas currently has 2 national forests, 5 national parks, 10 national wildlife refuges, and 88 state wildlife management areas (Fig. 6). Public lands within the current elk range include the Buffalo National River, Gene Rush Wildlife Management Area, and Ozark-St. Francis National Forest; most elk sightings (74%) are reported from those lands. As of 1999, 52% of the land in Arkansas was forested, 42% was cropland, and 2% was urban (Gorham 2001). The primary crop was soybeans (1.46 million ha), followed by rice, hay, and cotton (National Agricultural Statistics Service 2001).

Table 1. Comparison of land ownership in Arkansas and in the current elk range in northwest Arkansas (modified from Smith et al. 1998).

	State of Arkansas		Elk range	
Ownership	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)
Military reservation	543	0.4	0	0
National forest	10,153	7.3	34	2.5
National park	417	0.3	239	17.5
National wildlife refuge	893	0.7	0	0
Private	120,454	87.3	1,028	75.2
State	1,387	1.0	66	4.8
U.S. Army Corps of Engineers	4,088	3.0	0	0
Total	137,935	100	1,367	100

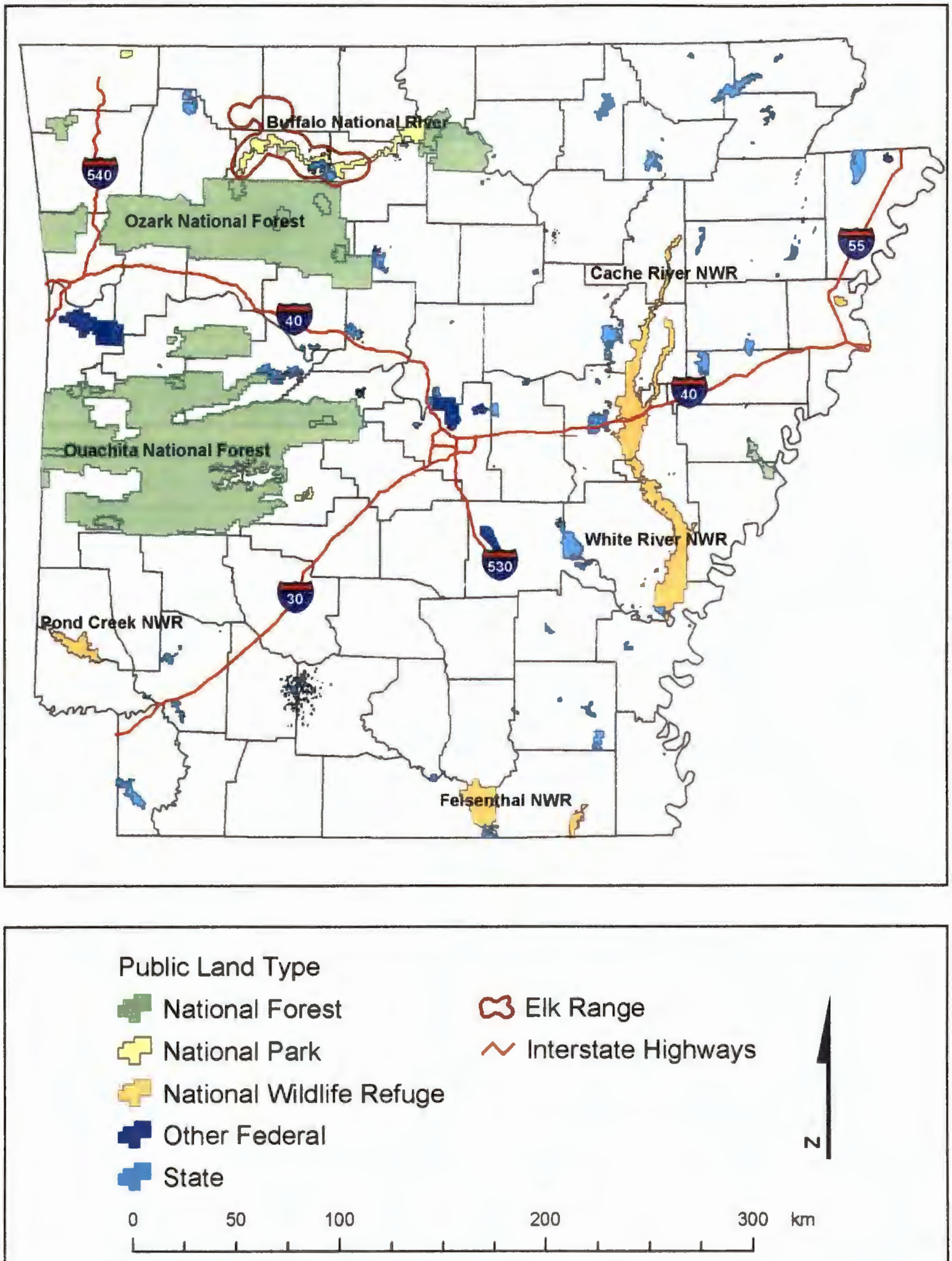

Fig. 6. Ownership of public land in Arkansas (Lower Mississippi Valley Joint Venture 2001).

CHAPTER IV

METHODS

Advances in computer and GIS technology have resulted in a rapid evolution of habitat selection models from subjective, univariate resource selection functions to empirical, multivariate models. Those advanced models can better represent the spatial and temporal complexities of wildlife-habitat relationships, and can be applied over large spatial extents (Clark et al. 1993, Dettmers et al. 2002). Most multivariate habitat models are conceptually similar. A suite of variables is selected to characterize habitat based on empirical data (e.g., field observations) or expert knowledge. In GIS-based models, each variable is represented as a map layer, or theme. A multivariate modeling technique is applied to those layers to assess habitat conditions over a specified spatial extent relative to the habitat conditions of the source data. When performed in a GIS, the result is a map of habitat suitability for the given extent. General assumptions of those models are that source data are representative of habitat use for the targeted species or population, map layers representing habitat measures are sufficiently accurate, and observed habitat-use patterns reflect future habitat use (Clark et al. 1993, Corsi et al. 2000). Methods of creating predictive habitat models with GIS have been designed and tested for a wide variety of plants and animals, including elk (e.g., Eby and Bright 1985, Van Deelen et al. 1997, Didier and Porter 1999, Johnson et al. 2000). I developed 2 predictive models, one to identify suitable elk habitat and the other to assess the potential for elk-human conflict.

ELK HABITAT MODEL

I used the Mahalanobis distance statistic to assess elk habitat suitability. Mahalanobis distance is a proven technique that has been used to predict habitat use of black bears in Arkansas (Clark et al. 1993), occurrence of eyrie sites for peregrine falcons (*Falco peregrinus*; Bockoven 1999), and occurrence of rare plants and trees within the southern Appalachians (van Manen et al. 2002). The multivariate procedure is empirically derived; a dataset representing "ideal" habitat is sampled to create a surface of statistical distances from this ideal (Alldredge et al. 1998). Similar distance values can suggest similar habitat potential for different habitat configurations (Knick and Rotenberry 1998).

Mahalanobis distance offers several advantages over other commonly used modeling techniques, such as logistic regression, classification and regression trees (CART), and discriminant function analysis. In a comparison of the performance of those 4 techniques, Dettmers et al. (2002) found that Mahalanobis distance and logistic regression were the best techniques for general habitat modeling. Unlike those other methods, Mahalanobis distance does not require both presence and absence points, thus avoiding potential biases because of false negatives (Clark et al. 1993). Another important advantage of Mahalanobis distance is that available habitat does not need to be delineated; such delineations often are subjective and can heavily influence the outcome of models (Knick and Rotenberry 1998). Finally, because Mahalanobis distance values are the sum of squares of uncorrelated, standardized distance scores, correlated variables are adjusted for, and distributional assumptions do not have to be met (Clark et al. 1993).

Assumptions of the technique are that animals distribute themselves in optimal habitats, and that optimal habitat is present in the landscape (Knick and Rotenberry 1998). Although Mahalanobis distance models currently lack an effective method of model selection (Dettmers et al. 2002), the technique is robust to the number of variables because weak or unimportant variables contribute little to the distance calculations. A major limitation of the modeling technique is that habitat configurations outside the sampled distribution of predictor variables are negatively valued by the model, even if those configurations represent suitable habitat (Knick and Rotenberry 1998). However, the ability to predict outside of a range of values poses a limitation to empirical habitat modeling in general, and can be reduced by creating and applying the model at the appropriate scale and extent.

I created an elk habitat model based on the Mahalanobis distance technique to evaluate landscape conditions for elk in Arkansas by (1) selecting and compiling a dataset of elk locations from the current elk population; (2) developing landscape variables at multiple scales to describe elk habitat; (3) selecting a suite of landscape variables that best characterize habitat of the elk locations (model selection); (4) generating the model using the Mahalanobis distance technique; and (5) testing the model with independent field data.

Empirical Data

I designed the habitat model using elk location data previously collected on the Buffalo National River elk population. From 1991 to 2002, the AGFC conducted annual helicopter surveys during February–March along the Buffalo River and surrounding private lands. Although the primary purpose of those surveys was to monitor population numbers and composition, the locations of elk groups also were recorded. The AGFC conducted surveys each winter for consistency and because of improved visibility due to a lack of foliage. The improved visibility increased the number of elk observed and reduced the potential bias of different detection rates in fields and forests.

Elk seasonally alter habitat use to meet different physiological, biological, and behavioral requirements (Irwin and Peek 1983, Edge et al. 1987, Skovlin et al. 2002). Elk in Arkansas do not migrate, but exhibit differences in seasonal movements (Herner-Thogmartin 1999). Although an ideal dataset would span all annual seasons to incorporate those differences, a winter (February–March) habitat model supports my research objectives. Limited forage availability and reduced nutritional quality of forage in winter can heavily impact elk survival, particularly for calves that are unable to amass adequate nutritional stores during the previous autumn (Cook 2002, Skovlin et al. 2002). A lack of native winter forage in Arkansas causes elk to seek alternative sources of nutrition, such as fertilized, cool season pastures on private land, thereby increasing the potential of elk-human conflicts (M. Cartwright, AGFC, personal communication).

The annual surveys consisted of 4 routes, incorporating the core of the current elk range (M. Cartwright, AGFC, personal communication; Fig. 7). The current range of elk was delineated based on a 95% fixed-kernel distribution, calculated with the Animal Movements extension (Hooge and Eichenlaub 1997) in ArcView® GIS (ESRI, Redlands, California, USA). Elk locations used in the calculation included aerial survey locations and locations of elk sightings confirmed by AGFC biologists from 1991 to 2002. Three routes were flown on public lands along the Buffalo National River, and the fourth

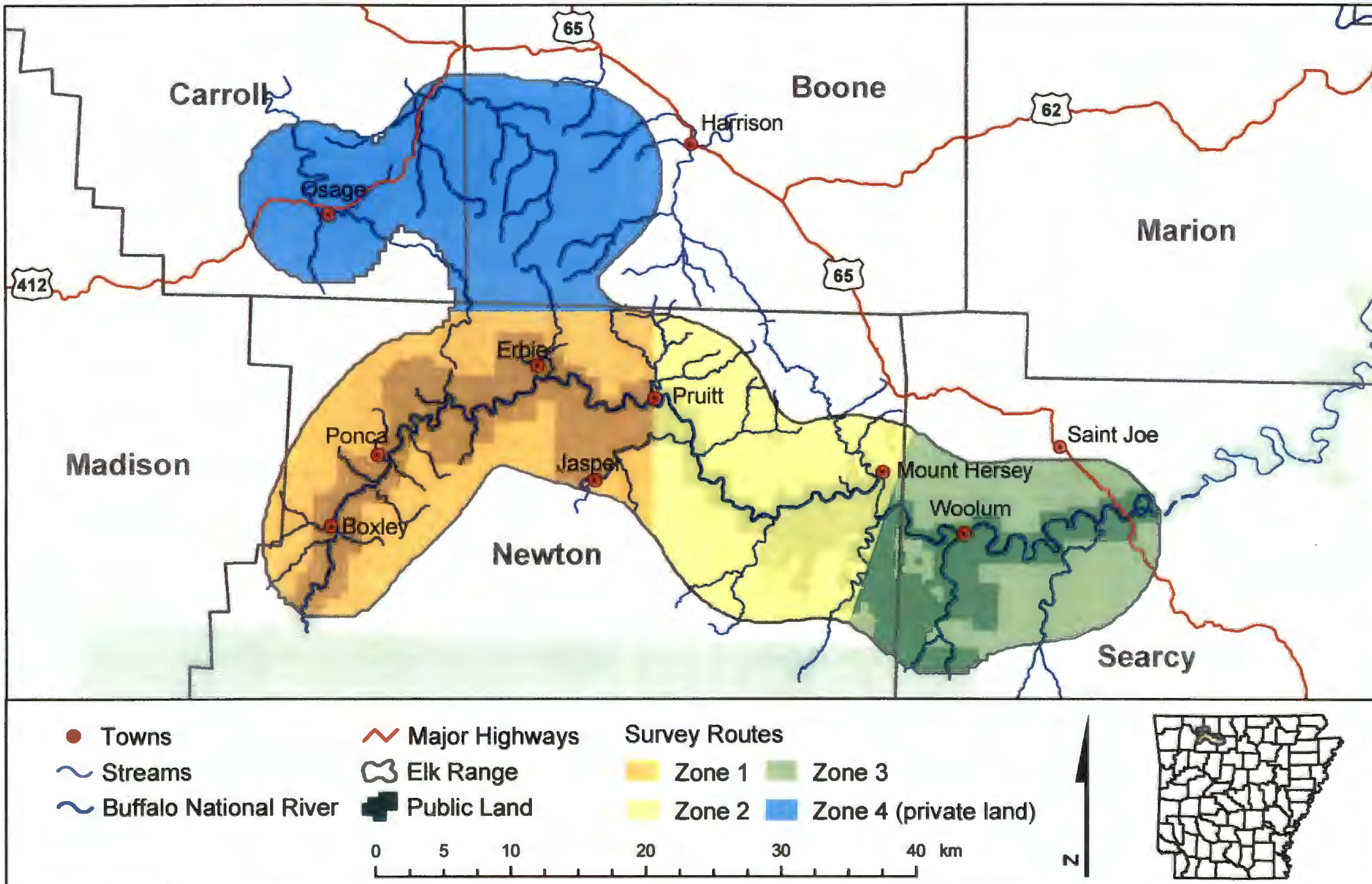

Fig. 7. Approximate areas covered by survey routes used for helicopter surveys of elk conducted by the Arkansas Game and Fish Commission in the Buffalo National River area, Arkansas, 1991–2002.

encompassed private lands northwest of the river. Only 4 observers were used over the 12-year period, reducing the amount of observer variation among surveys.

Each survey route was flown on a different morning. Surveys began at dawn, and continued for approximately 2–3 hours (M. Cartwright, AGFC, personal communication). Although the surveys concentrated on fields, observers also searched for elk in forests along the flight path. The 3 survey routes over public land followed the same flight pattern. The observer was flown over a section of the Buffalo National River, following the course of the river. The survey then continued over public land north and south of the river in the same section, and finally over any fields that may not have been visible during the flight path (M. Cartwright, AGFC, personal communication). The private land area within the elk range was too large (>1,000 km^2) to be completely surveyed within a 2- to 3-hour period. Consequently, the survey route over private land varied, but typically included areas where elk were observed in past years, areas with reports of elk presence, and a random flight search during any remaining time (M. Cartwright, AGFC, personal communication).

Data Preparation

Elk locations were counted by group rather than by individuals to avoid bias due to group size. Group dynamics are influenced by many aspects of elk ecology and behavior, including habitat quality and availability, but also season, time of day, weather, age, sex, security, social interactions, and breeding status (Clutton-Brock 1982, Geist 2002, Skovlin et al. 2002). Clutton-Brock (1982) suggested that red deer groups may vary in size and composition by the hour. Thus, I could not assume that herd size was directly related to habitat quality.

Results from previous studies indicate that bull and cow elk may use habitat differently (Clutton-Brock 1982, Unsworth et al. 1998, Geist 2002). Although the sex and age of each elk were sufficiently determined, I did not consider sex or age effects for the habitat analysis. Analysis of group composition based on Spearman's rank coefficient and scatter plots indicated no clear delineation of sex or age groups. In addition, differences in habitat selection between bulls and cows may be apparent at local scales but not at the broad scales used in my analysis.

The helicopter surveys resulted in 256 group locations over the 12-year period, of which I included 239 in the model to represent locations of habitat selected by elk (Fig. 8). I excluded all 9 elk groups from the 1991 elk survey because the survey methodology differed from subsequent years. I excluded 8 additional locations, each of a single elk that appeared unhealthy and displayed erratic behavior, because those locations likely did not represent selection of optimal habitat. Using Terrain Navigator software (Maptech®, Greenland, New Hampshire, USA), I digitized all 239 elk-group locations onto a 1:100,000 seamless topographic map of Arkansas. Those locations were then imported into ArcView® GIS and checked for accuracy.

Data Quality

The location error of the survey locations varied depending on the method used during the surveys to record the locations. Elk locations from the helicopter surveys were plotted on maps or described in writing. Observers plotted 178 of the elk-group locations

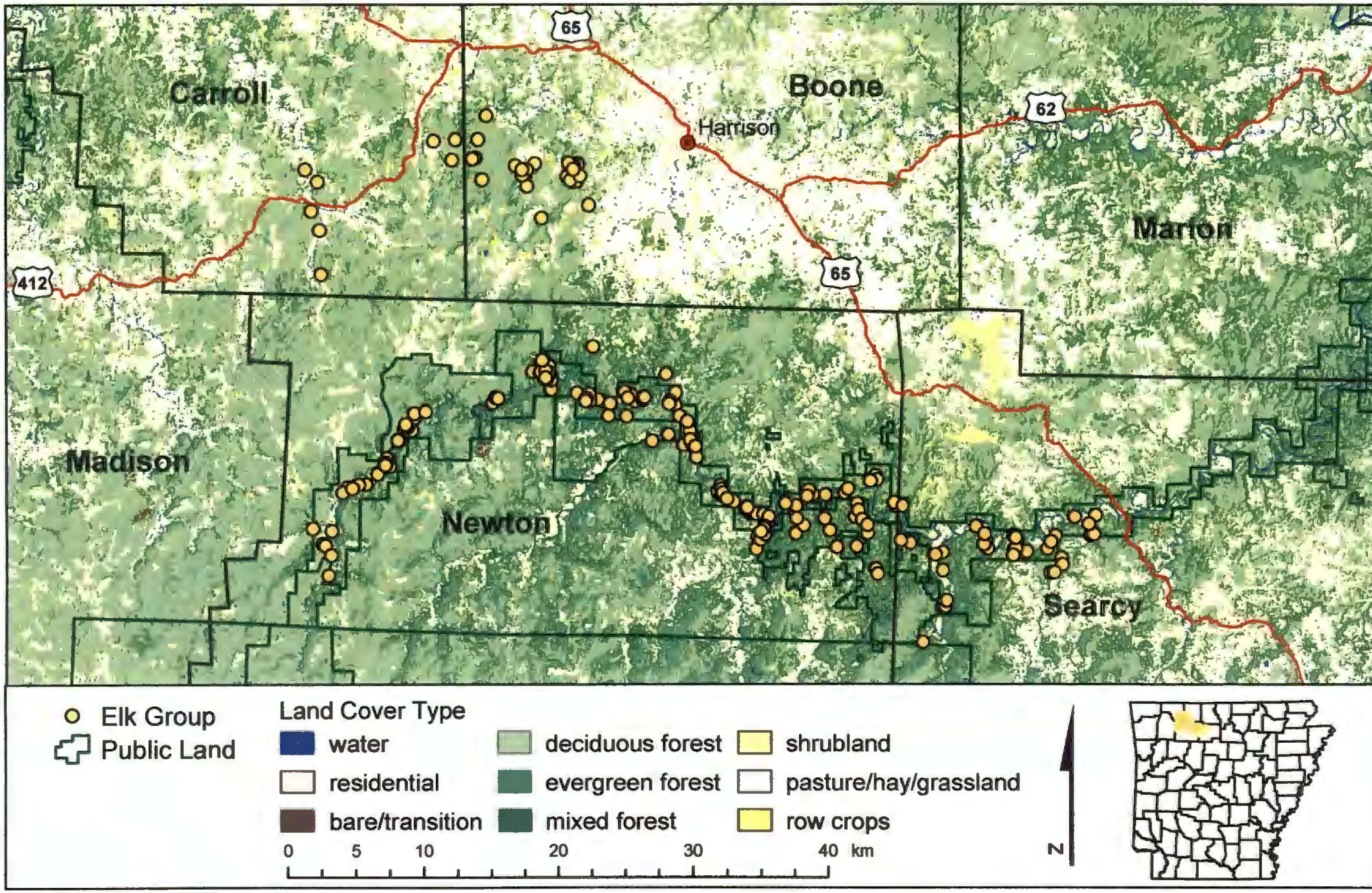

Fig. 8. Locations of elk groups based on helicopter surveys conducted by the Arkansas Game and Fish Commission in the Buffalo National River area, Arkansas, February–March, 1992–2002.

onto paper maps. Those maps consisted of copies of National Park Service maps and U.S. Geological Survey topographic maps at various scales; the smallest map scale was approximately 1:126,720. Most of the plotted locations were accompanied by brief written descriptions of the locations.

Observers recorded the other 61 locations as written descriptions only. The detail of the descriptions ranged from specific sites to general regions. I plotted 15 locations that had specific site descriptions. M. Cartwright (AGFC), an observer on many of the elk surveys, plotted the remaining 46 locations based on the site descriptions and his recollection. The locations plotted by M. Cartwright were recalled over a span of 12 years; hence, they may have a greater observer bias than the locations plotted during the surveys. However, including those locations in the dataset increased the number of observations on private land from 38 to 56. Because landscape conditions on public land may differ from conditions on private land, additional sampling of private land would create a more representative habitat model of all land ownerships. Therefore, I determined the effect of including those locations by comparing the cumulative distributions of the Mahalanobis distance values of the elk locations for models generated with and without the 46 locations (Kolmogorov-Smirnov test, PROC NPAR1WAY; SAS Institute 2000). I used Levene's test to determine if the data met the assumption that variances are homogeneous (PROC GLM; SAS Institute 2000).

Although I could not determine the spatial error associated with the elk locations, biologists who conducted the surveys were confident that elk locations plotted on maps were placed in the correct fields (M. Cartwright, AGFC, personal communication). I considered the average length of improved fields where elk were located (250 m) as an estimate of mean location error.

Habitat Variables

Many factors influenced the identification and selection of variables to characterize elk habitat, including the quality and availability of spatial datasets, spatial scale, previous studies of elk habitat use, and variable performance (McGarigal and Marks 1995, Haines-Young and Chopping 1996, Turner et al. 2001). I began the selection process by identifying factors that influence elk habitat use based on scientific literature and information collected on the current Arkansas elk herd (Table 2). For elk, those factors fall under the following general components: cover, forage, spatial configuration of cover and forage, landform, climate, special requirements (e.g., calving sites, migration), and human disturbance (Roloff 1997, Skovlin et al. 2002). I chose not to consider variables representing climate or special habitat requirements. Snow depth can be an important factor in elk habitat selection and can trigger elk migration (Skovlin et al. 2002). However, snow depths great enough to affect elk habitat use (generally >40 cm; see review by Skovlin et al. 2002) are uncommon in Arkansas and have a short duration.

Spatial Data Sources

Four sources of spatial data were used to create landscape measures that represent each elk habitat element. Those data sources were selected based on their currency, quality, and their consistent, regional extents. Source maps and subsequent calculations

Table 2. Summary of habitat components measured in elk habitat models.

	Habitat components							
Reference (chronological order)[a]	Cover	Forage	Spatial	Landform	Climate	Human/roads	Special[b]	Other[c]
Scharpf et al. 1986	x	x			x			
Wisdom et al. 1986	x	x	x			x		
Edge et al. 1987	x	x	x	x		x		x
Turner et al. 1993		x	x					
Roloff 1997	x	x	x			x	x	
Van Deelen et al. 1997	x	x	x			x		
Unsworth et al. 1998	x			x		x		
Cooper and Millspaugh 1999	x	x	x	x		x		
Didier and Porter 1999	x	x	x			x		
Jost et al. 1999		x						
Johnson et al. 2000	x	x	x	x		x		x
Missouri Dept. of Conservation 2000	x	x				x		
Lehmkuhl et al. 2001	x	x		x	x			
Hutchinson et al. 2002			x		x	x		x

[a]This table represents a sample of common elk habitat modeling studies, not a complete list. Roloff (1997) presents a similar summary of common elk habitat models for Rocky Mountain and Roosevelt elk, 1976–1991.
[b]Includes breeding and post-breeding events.
[c]Includes water, soils, and interspecific avoidance.

were converted to grids with a 90- x 90-m resolution, and projected into North American Datum 1983 (NAD83), Universal Transverse Mercator (UTM) Zone 15 North.

Land Cover.--Measures of elk forage, cover, and the spatial configuration of land-cover types were calculated from 1992 National Land Cover Data (NLCD; Vogelmann et al. 2001; Fig. 9). The land-cover data were derived from Landsat thematic mapper imagery from the early 1990s, and mapped at a 30- x 30-m resolution (Vogelmann et al. 2001). I elected to use the 1992 NLCD instead of more recent land-cover data. During the period of data collection (1991–2002), many improved fields (e.g., wildlife openings, food plots) were established within the Buffalo National River and Gene Rush Wildlife Management Area in an effort to improve elk habitat on public lands (S. Lail, National Park Service, personal communication). Because of those changes, land-cover conditions at the end of the survey period would not apply to elk-group locations observed early in the survey period, and vice versa. However, by using the 1992 data, I was able to digitize the locations of new fields to update the original land-cover data with ArcGIS® software (ESRI, Redlands, California, USA). I used the 1992 NLCD to sample 1992–1996 location and the updated NLCD to sample 1997–2002 locations.

The NLCD was developed with a hierarchical land-cover classification system of 21 land cover types (Table 3). I combined the 21 land-cover types into fewer classes to achieve a relative distribution of cover classes within the elk range that was comparable with the rest of the state. Various landscape measures were derived from one or both of 2 classification schemes: forage/cover and natural types.

The forage/cover classification was designed to assess basic habitat requirements in the landscape (Table 3). The forest category represented cover habitat, comprising all

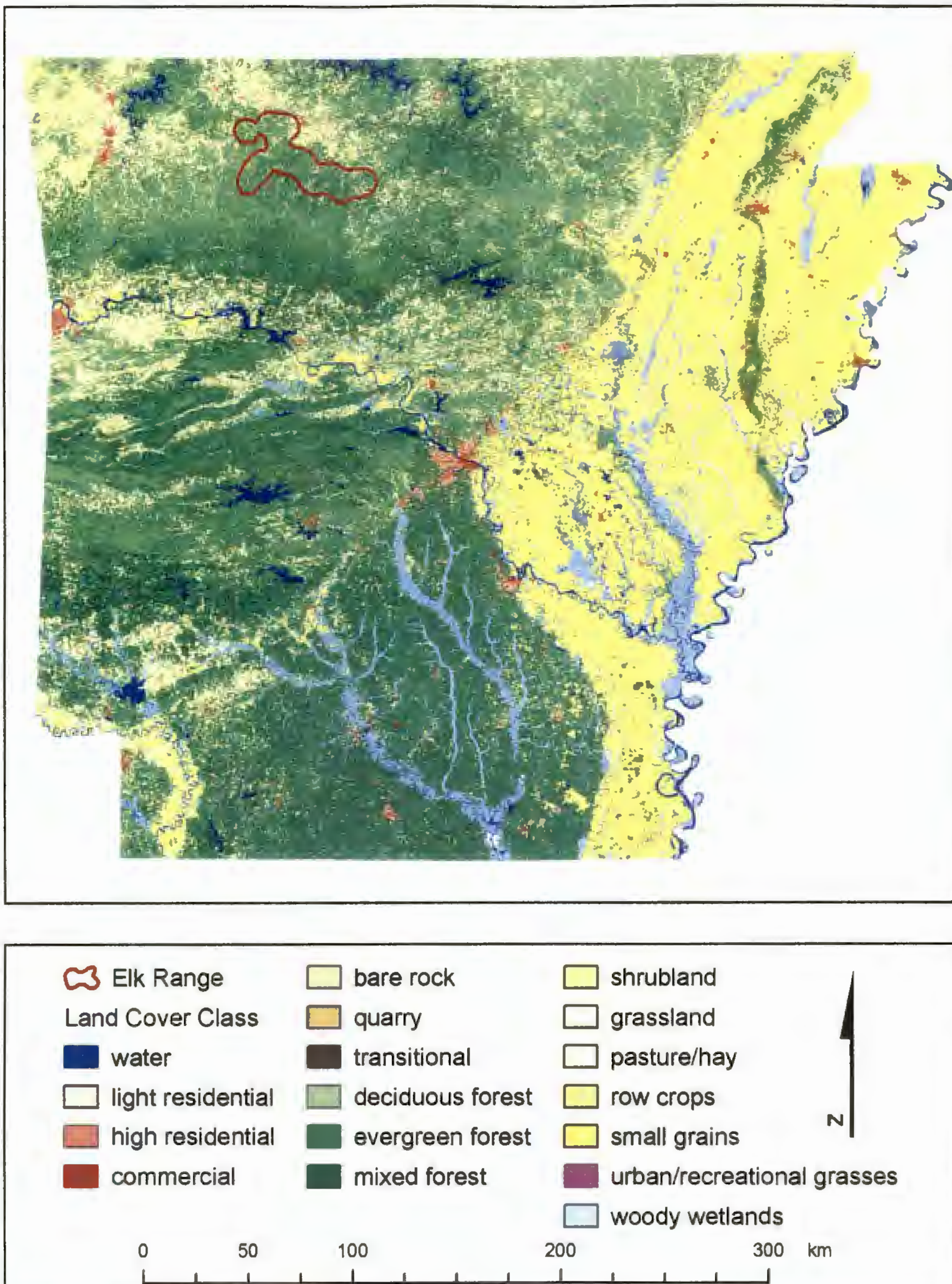

Fig. 9. National Land Cover Data for Arkansas, 1992 (Vogelmann et al. 2001).

Table 3. Original land-cover types of the 1992 National Land Cover Data (NLCD) and classifications used to calculate variables for characterizing elk habitat in Arkansas.

NLCD cover type (reference number)	Forage/cover classification	Natural types classification
Open water (11)	o[a]	Open water
Perennial ice/snow (12)	o	o
Low intensity residential (21)	o	o
High intensity residential (22)	o	o
Commercial/industrial/transportation (23)	o	o
Bare rock/sand/clay (31)	o	o
Quarries/strip mines/gravel pits (32)	o	o
Transitional (33)	o	o
Deciduous forest (41)	Forest	Deciduous forest
Evergreen forest (42)	Forest	Evergreen forest
Mixed forest (43)	Forest	Mixed forest
Shrubland (51)	o	Shrubland
Orchards/vineyards/other (61)	o	o
Grasslands/herbaceous (71)	o	Herbaceous
Pasture/hay (81)	Field	Herbaceous
Row crops (82)	o	Crop
Small grains (83)	o	Crop
Fallow (84)	o	o
Urban/recreational grasses (85)	o	o
Woody wetlands (91)	o	Wetlands
Emergent herbaceous wetlands (92)	o	Wetlands

[a]Other

upland forests; bottomland forests were excluded because little exists within the elk range compared with the rest of the state, and bottomland forests in southern Arkansas often are flooded in winter. The field category represented foraging habitat, comprised of the pasture/hay cover type (Table 3). Grasslands and row crops were not included because of their rarity within the elk range. Recent openings created by clearcuts and other silvicultural treatments also were not included in the forage class because spatial data were not available. Thus, the field class is a conservative estimate of winter elk forage in Arkansas. The remaining NLCD land-cover types were grouped as "other" (i.e., excluded from calculations, but considered part of the total landscape area).

The natural types classification was designed to assess elk habitat based on landscape heterogeneity and configuration and to calculate landscape measures that perform better with a greater number of cover classes. I classified cover types that have little value to elk, such as residential areas and bare ground, as other and used it as the background class for all calculations. Remaining cover types retained their original description except for rare types, which were grouped into broader categories (Table 3).

Landform.--I characterized landform by calculating the mean percent slope from the U.S. Geological Survey National Elevation Dataset (NED; Gesch et al. 2002; Fig. 10). The NED was developed to provide accurate and consistent elevation data for the coterminous United States at 1:24,000 scale. The dataset was primarily constructed from U.S. Geological Survey 7.5-minute Digital Elevation Model (DEM) quadrangles at a 30- x 30-m resolution. Several methods were used to reduce artifacts in the existing data, creating an improved dataset for calculating landform derivatives, such as slope (Gesch et al. 2002).

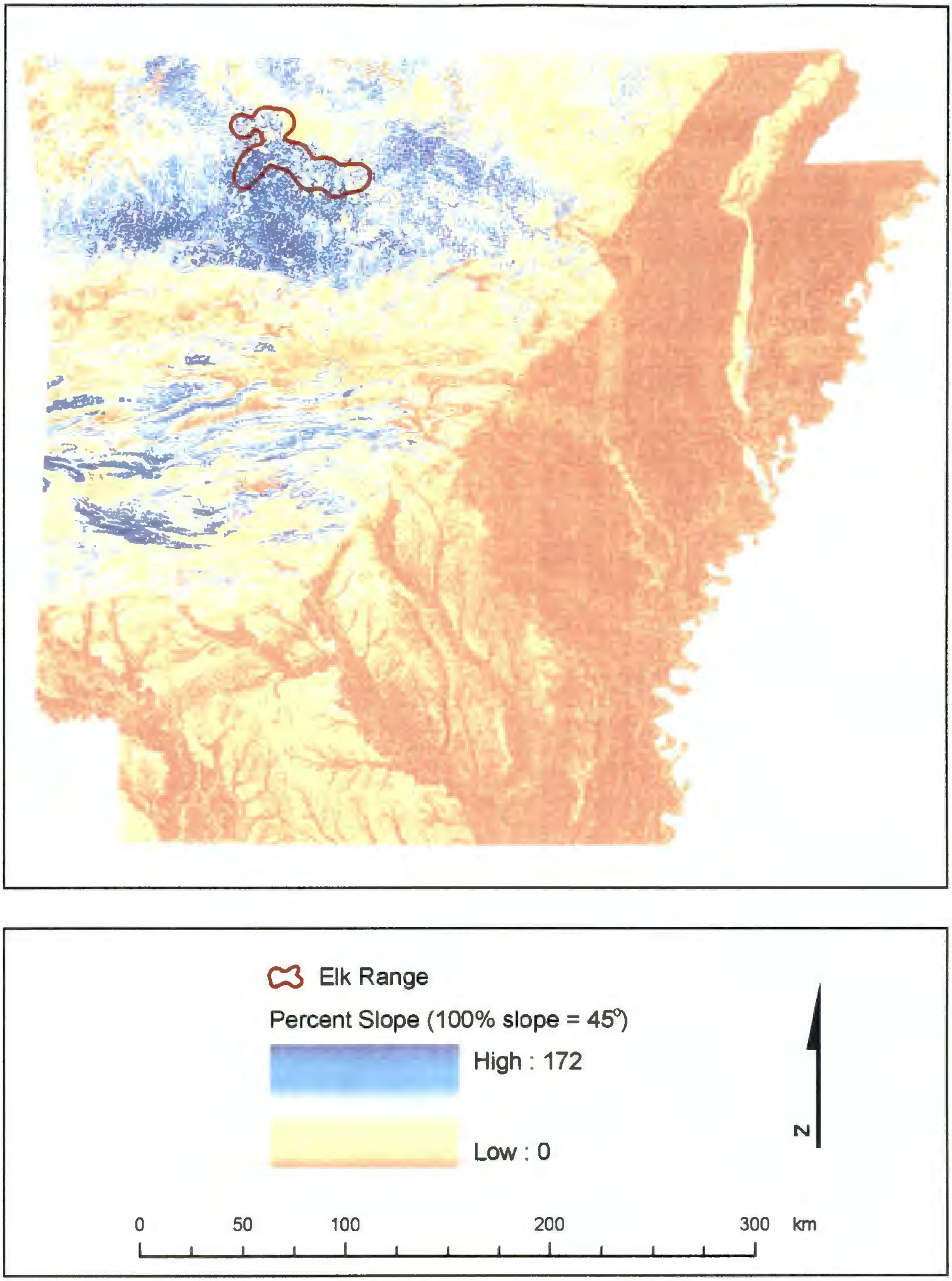

Fig. 10. U.S. Geological Survey National Elevation Dataset for Arkansas, 1999 (Gesch et al. 2002).

Human Disturbance.--I derived a base map of human density from 2000 Census block data (U.S. Census Bureau 2001; Fig. 11). Census blocks are the smallest units in a hierarchical set of census data tabulation. Those areas are generally small (e.g., city block bounded by streets), but can be large and irregular, particularly in rural areas. I combined total population data for each census block with U.S. Census Bureau TIGER®/Line polygon files of census block boundaries. Human density (people/ha) was calculated by dividing the population in each block by the area of the block polygon. Finally, I converted the vector data to raster data. I also created a layer of paved roads in Arkansas from 2000 Arkansas Highway and Transportation Department data that were classified as interstate highways, heavily traveled national highways, and heavily traveled state highways (Fig. 12).

Model Scale

Like the selection of source maps and appropriate classification schemes, the spatial scale at which landscapes are processed strongly affects the outcome and interpretation of landscape measures (O'Neill et al. 1996, Riitters et al. 1997, Turner et al. 2001). Equally important, elk may select habitat at multiple spatial scales, so the best scale to measure habitat use may be variable dependent. For example, edge availability may be more important for local foraging movements, whereas forest density may be more important at the home range scale.

I used methods described by Riitters et al. (1997) to create and incorporate landscape measures at multiple scales, based on "moving window" analyses in GIS. A circular window sized to represent a particular scale of measurement was placed over a

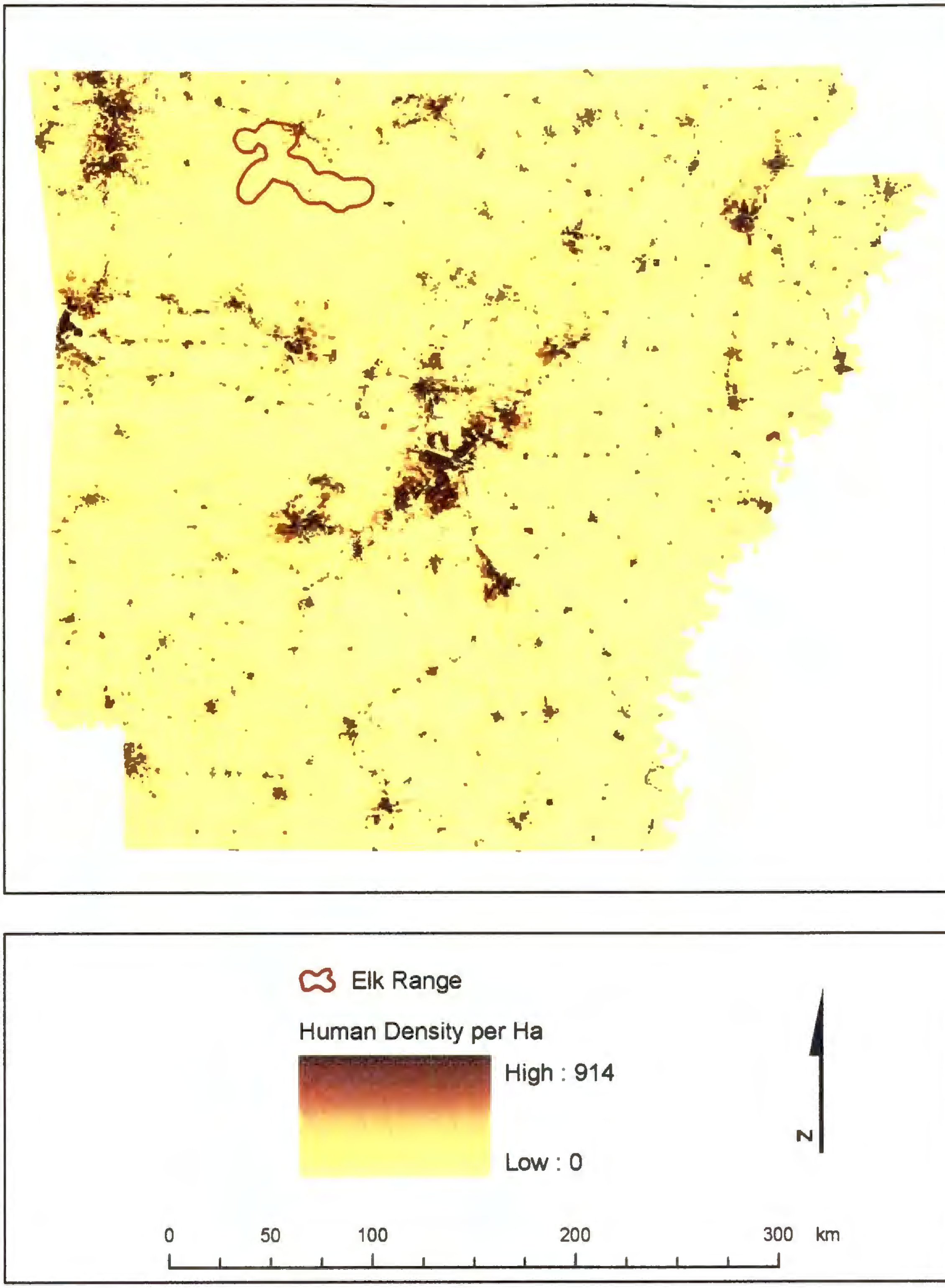

Fig. 11. Human density (number of people/ha) in Arkansas, 2000 (census block data; U.S. Census Bureau 2001).

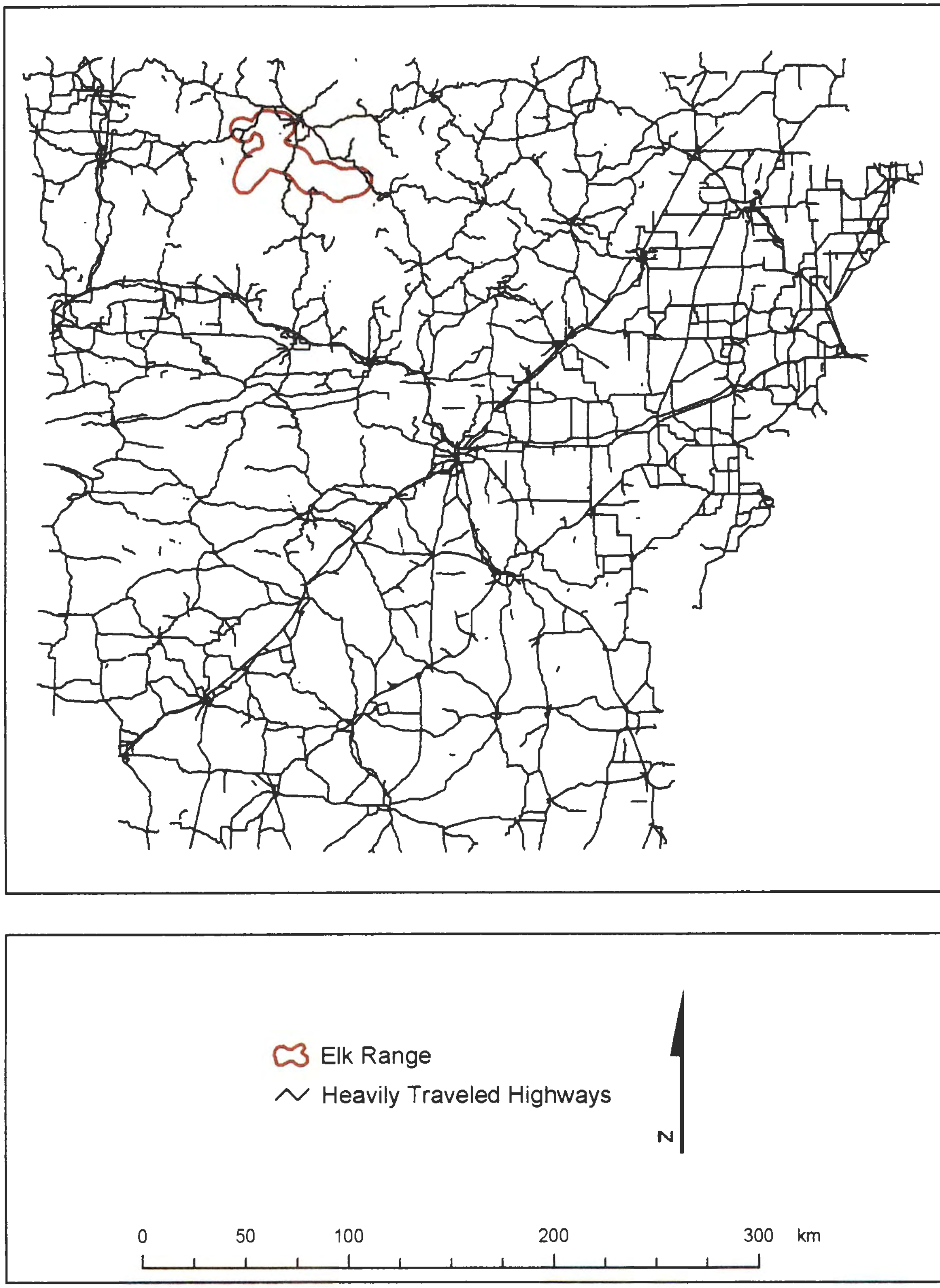

Fig. 12. Heavily traveled highways in Arkansas, from the Arkansas Highway and Transportation Department, 2000.

GIS grid to measure a landscape feature. The area within the window defined the landscape for calculating a landscape measure. The value of the landscape measure was calculated for the window and placed in the center pixel. That window was then moved across the entire GIS grid, one pixel at a time. The process resulted in a new grid in which the value of each pixel characterizes the habitat for an area equal to the window scale. I repeated the process for multiple window sizes so that each landscape measure could be calculated at multiple scales. Thus, when selecting the suite of variables for designing the habitat model, I was able to choose the most appropriate scale to represent each landscape measure.

I identified 4 scales based on telemetry data collected on nuisance elk in Arkansas (Herner-Thogmartin 1999) and from the 1992–2002 aerial survey locations; those scales loosely represent the order of habitat selection described by Johnson (1980; Fig. 13). The radii of the 4 windows were 250 m, 1,600 m, 3,000 m, and 5,000 m. The mean interlocational distance moved by radio-collared nuisance elk in Arkansas located every 2 hours during a 24-hour period was 230 m (Herner-Thogmartin 1999). However, that distance likely is smaller than the potential error associated with the aerial survey locations. Thus, the 250-m radius window (approximately 0.2 km^2) represents local habitat selection while accounting for locational error. The window size based on a 1,600-m radius represents both mean annual and mean winter home range sizes (approximately 8 km^2) of the radio-collared elk (Herner-Thogmartin 1999). The 3,000-m radius window approximates the size of the largest mean seasonal home range (spring; approximately 30 km^2), representing the smallest area required by elk to acquire adequate resources (Herner-Thogmartin 1999). Finally, the 5,000-m radius window represents the

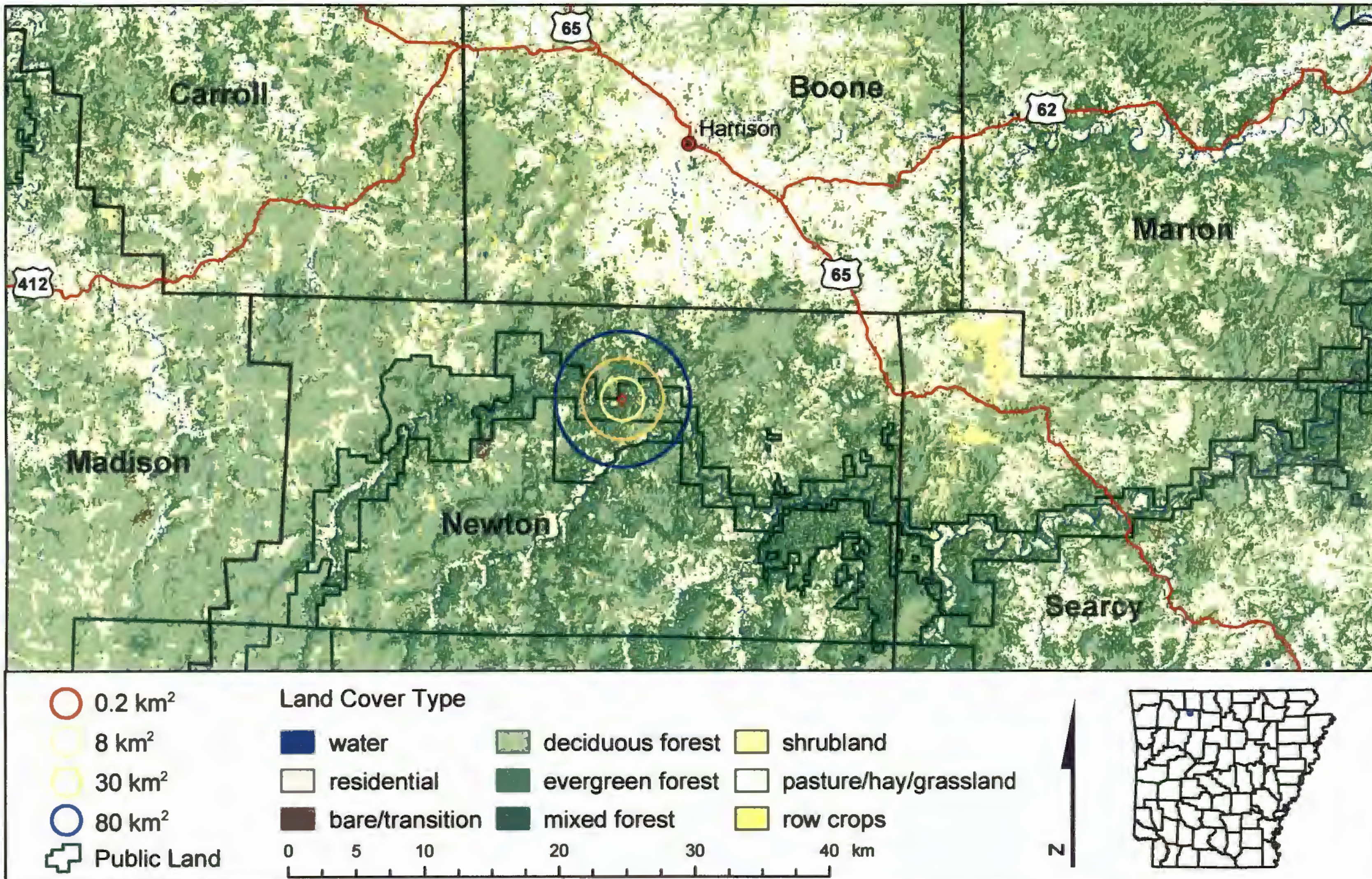

Fig. 13. Examples of 4 window sizes used during the moving window analysis to generate landscape measures at multiple scales, representing different orders of elk habitat selection. Buffalo National River area, Arkansas, is shown for reference.

total amount of core area used within the elk distribution on public land in Arkansas (approximately 80 km^2; 30% fixed-kernel distribution of all aerial survey locations).

Landscape Measures

I considered broad-scale, continuous measures to represent the full range of landscape conditions in Arkansas while being sensitive enough to detect elk habitat use (Haines-Young and Chopping 1996). For example, Johnson et al. (2000) and Unsworth et al. (1998) found aspect to be a significant predictor of elk habitat. However, although aspect may be an appropriate measure for areas with topographic relief (e.g., the highlands of northwest Arkansas) it would not be a suitable measure of landform for the entire extent of Arkansas. Landscape measures selected to characterize elk habitat should also be appropriate for the chosen measurement scales (i.e., window sizes) and modeling technique (Turner et al. 2001).

Forage and Cover Measures.--The quality and availability of forage and cover are widely recognized as critical components of elk habitat (Table 2). Elk diets primarily consist of grasses, forbs, shrubs, hard and soft mast, and woody browse (Cook 2002). Dominance of those forage types in the diet depend on species availability and phenology, and seasonal nutritional requirements (Jost et al. 1999). As such, elk forage can be found in a variety of forested and grassland habitats but elk in Arkansas primarily use openings that provide grasses and forbs for forage (Cartwright et al. 1998). Forest cover provides thermal protection, by modifying temperature extremes, and security to hide from predators, particularly in areas of high human use (Wisdom et al. 1986, Skovlin et al. 2002). The quality and type of cover a forest provides depends on forest type and stand structure.

I considered 3 measures of landscape composition to evaluate the quality and availability of forage and cover. Those measures all were calculated using Fragstats software (McGarigal et al. 2002). I used a measure of land-cover class density (PLAND) to determine the proportion of the analysis window comprised of forage and cover classes (Appendix A). The quality of forage and cover habitat could not easily be quantified on a broad scale. However, because elk are adaptable to a variety of habitats, I assumed that a landscape with increased diversity of land-cover types would be more likely to contain high-quality cover and forage (Didier and Porter 1999). Simpson's diversity index (SIDI; Appendix A) is an easily interpretable measure of diversity that is relatively insensitive to rare class types (McGarigal and Marks 1995). I also calculated Simpson's evenness index (SIEI; Appendix A). Whereas SIDI considers both richness (number), and evenness (distribution of area) of land cover types, SIEI only considers evenness. SIDI and SIEI approach 0 when the analysis window is comprised of a single class, and 1 when diversity or evenness is at a maximum.

Spatial Configuration Measures.--Elk use of available habitat components, such as forage and cover, may largely depend on the configuration of those components in the landscape (Roloff 1997). Many studies have shown that elk use ecotones (i.e., regions of juxtaposition between vegetation types) more than the interior of a patch (Hanley 1983, Wisdom et al. 1986, Roloff 1997, Johnson et al. 2000, Skovlin et al. 2002). Ecotones between forests and open fields have a greater diversity and quantity of forage, and reduce the distance between forage and security cover (Hanley 1983, Wisdom et al. 1986, Skovlin et al 2002). Large ungulates are likely to travel increased distances and select habitat at larger spatial scales when those patches are clumped (O'Neill et al 1988, Turner et al. 1993). The amount of edge is influenced by the area and density of patches, and their shape complexity.

Landscape ecologists have developed many broad-scale landscape measures to quantify landscape patterns over large regions (McGarigal and Marks 1995, Haines-Young and Chopping 1996, Turner 2001). I used several landscape measures to characterize elk habitat throughout Arkansas, including patch density (PD), edge density (ED), perimeter-area ratio (PARA), fractal dimension (FRAC), percentage of like adjacencies (PLADJ), contagion (CONTAG), and an interspersion and juxtaposition index (IJI; Appendix A).

I used PD to calculate the number of forest and field patches within the analysis window. Maximum PD is limited by the number of pixels in the analysis window; therefore, maximum PD for a window is reached when every pixel is a different patch type. Previous elk habitat models have used distance to edge as a measure of ecotone use (Wisdom et al. 1986, Roloff 1997, Johnson et al. 2000). However, because of the coarse scale at which elk locations were plotted, I could not determine the exact placement of elk groups relative to patch edges. Instead, I calculated ED, or the length of edge for forest and field patches divided by the total area within the analysis window.

I used several shape complexity measures to quantify patch compactness. PARA is easily interpreted; the longer the perimeter of a patch compared with its area, the more complex the shape. However, PARA varies with patch size, decreasing with increasing area for patches with the same shape (McGarigal and Marks 1995). In contrast, FRAC measures shape complexity independent of patch size. The theory behind fractal dimension is complex (Mandelbrot 1983), and is based on the idea that a continuous range of values exists between points, lines, and planes. Fractals represent the concept that for many patterns, unseen details are revealed with increasing resolution (Turner 2001). For example, the length of a coastline increases with increasing map resolution because more complexity is revealed. Fractal dimension as a measure of patch shape has a scale from 1 to 2, approaching a value of 1 for shapes with simple perimeters, and 2 for shapes that are highly complex. I used the area-weighted mean over all patches to determine PARA and FRAC within a given analysis window (Schumaker 1996).

PLADJ, CONTAG, and IJI all are measures of contagion and interspersion. PLADJ determines the percentage of neighboring pixels of the same patch type, resulting in a measure of patch aggregation. Therefore, PLADJ is a measure of dispersion (i.e., the spatial distribution of patches) and not interspersion (i.e., the placement of patch types relative to other patch types; McGarigal and Marks, 1995). PLADJ approaches 100 as patches become increasingly aggregated. CONTAG is a measure of both dispersion and interspersion, and is inversely related to edge density (McGarigal and Marks 1995). CONTAG approaches 100 when patches are maximally aggregated and minimally dispersed. Finally, IJI is a measure of interspersion that increases as patches are more equally adjacent to each other. IJI can only be calculated for landscapes with >2 land cover classes.

Landform Measures.--Topographic features such as elevation, slope, terrain, and aspect can influence elk habitat use (Unsworth et al. 1998, Skovlin et al. 2002). However, I only considered measures of slope as a potential habitat variable; elevation and aspect measures were not as applicable to the entire extent of Arkansas. Generally, elk select for gentle to moderate slopes (<40%), exhibiting differences in slope use among seasons and years (Edge et al. 1987, Unsworth et al. 1998, Skovlin et al. 2002). I calculated mean percent slope (SLOPE) in a window using the Neighborhood Statistics tool in the Spatial Analyst extension of ArcGIS® (Appendix A).

Human Disturbance Measures.--Human development adversely affects elk habitat use because of disturbance (e.g., human access to remote areas, vehicular traffic) and range restriction (Skovlin et al. 2002). Human population is an indicator of the relative amount of human development in a landscape. Also, studies have demonstrated that elk proximity to roads depends on road size and traffic volume, with elk selecting habitats away from larger, more heavily traveled roads (Cooper and Millspaugh 1999, Johnson et al. 2000). Both road density of heavily traveled roads (ROAD) and mean human density (HUMAN) were calculated for the 4 window sizes with ArcGIS® (Appendix A).

Model Selection

I limited the variables generated to those that made biological sense for elk and were appropriate for the assumptions and limitations of the landscape measures. As a result, I generated 66 different variables based on the 13 landscape measures (Table 4). I used a combination of methods to determine the best suite of variables to include in the elk habitat model. Variables with high variation among elk-group locations were immediately eliminated, showing no apparent trend for habitat selection. Additionally, some variables were eliminated because they produced large areas of no data values, severely reducing the extent of the model, or because they had no clear interpretation.

Table 4. Variables calculated to characterize elk habitat in Arkansas based on landscape measure, analysis window size, and land-cover classification.

		Window area (km^2)			
Acronym	Landscape measure	0.2	8	30	80
PLAND	Percent landscape	A[a]	A	A	A
SIDI	Simpson's diversity index	C	C	C	C
SIEI	Simpson's evenness index	C	C	C	C
PD	Patch density	AB	AB	AB	B
ED	Edge density	AB	AB	AB	AB
PARA	Perimeter-area ratio, area-weighted mean	AB	AB	AB	B
FRAC	Fractal dimension, area-weighted mean	AB	AB	AB	AB
PLADJ	Percent of like adjacencies	-	C	-	-
CONTAG	Contagion	ABC	AC	C	BC
IJI	Interspersion-juxtaposition index	-	C	C	C
SLOPE	Mean percent slope	D	D	D	D
HUMAN	Mean human density	E	E	E	E
ROAD	Road density	F	F	F	F

[a]Variables were calculated from the following map sources and classification schemes:
A = Derived from National Land Cover data using the forest/cover classification; separate calculation for each class in the landscape (i.e., forest and field).
B = Derived from National Land Cover data using the forest/cover classification; measured over all classes in the landscape except "other" (i.e., forest or field).
C = Derived from National Land Cover data using the natural type classification; measured over all classes in the landscape except "other".
D = Derived from the percent slope source map.
E = Derived from the human density source map.
F = Derived from the heavily traveled highways source map.

Riitters et al. (1995) found many landscape measures are highly redundant, and that 6 classes of landscape measures explained most variation in a landscape. Although the Mahalanobis distance model is unaffected by correlated variables, I did not include correlated measures (e.g., edge density, contagion, and percent of like adjacencies) in the model at the same scale and land cover classification. I further reduced correlation among variables by only including one window scale for each variable.

I used SPSS Answer Tree® (SPSS Inc. 1998) software to select the best model from the remaining set of variables with a CART analysis. CART models attempt to uncover structure in a dataset through a series of hierarchical binary classifications similar to a taxonomic key. A decision rule in the CART model splits the data into increasingly homogenous groups that best explain variation in the dependent variable (Anderson et al. 2000). CART models are easily interpreted, make no distribution or relationship assumptions for the dependent variables, and are robust against outliers (Anderson et al. 2000). I performed the CART analysis by first generating 239 random locations within a 1,600-m area (representing winter home range) around all elk-group locations, using the Animal Movement extension (Hooge and Eichenlab 1997) in ArcView® GIS. I used Arc/Info® GRID (ESRI, Redlands, California, USA) to sample each habitat variable for the elk-group and random locations. Each split in the CART model was designed to homogenize groups of random and actual elk locations based on the sampled values for each habitat variable.

I then performed a principal components analysis on the correlation matrix of the sampled set of variables selected for the habitat model to determine the variation explained by each variable. Principal components were rescaled to component loading vectors to compare the relative contribution of each variable across vectors. Component loading vectors were examined for eigenvalues ≥ 1.

Model Generation

The Mahalanobis distance statistic is a measure of dissimilarity between pixel values representing "ideal" habitat characteristics and the remaining pixel values in a landscape (Clark et al. 1993). For this study, the ideal characteristics for each habitat variable were defined by the elk-group locations. Mahalanobis distance (D^2) is represented by the following equation:

$$D^2 = (\underline{x} - \underline{\hat{u}})'\Sigma^{-1}(\underline{x} - \underline{\hat{u}}),$$

where $\underline{x}$ is the vector of habitat values for each pixel in a grid layer, $\underline{\hat{u}}$ is the mean vector of habitat values for the elk-group locations, and Σ^{-1} is the inverse covariance matrix, estimated from the elk-group locations. A lower D^2 value of a pixel indicates a greater similarity between that pixel and ideal habitat. I calculated $\underline{\hat{u}}$ and Σ^{-1} with PROC MEANS and PROC DISCRIM in SAS® (SAS Institute 2000) based on the habitat characteristics measured for each elk-group location. I then calculated Mahalanobis distance in Arc/Info® GRID for each 90- x 90-m pixel.

Model Evaluation

I assessed the model's ability to predict elk habitat based on the elk location data and on independent data. I used the Kolmogorov-Smirnov test to compare cumulative frequency distributions of D^2 values for the elk-group and the random locations. I also used the cumulative frequency distribution of the elk-group locations to determine the range of D^2 values that identify ideal elk habitat.

Testing predictive models with independent data is the most robust method of assessing model fit, particularly when the observations are collected using different survey methods (Power 1993). I tested the elk habitat model based on elk pellet-group surveys within the current elk range in Arkansas. Pellet-group surveys are commonly used to assess habitat use of large ungulates (Neff 1968, Loft and Kie 1988, Edge and Marcum 1989, Wemmer et al. 1996, Weckerly and Ricca 2000). Pellet-group surveys are based on the assumption that elk pellet groups are highly detectable and that their locations represent suitable elk habitat. Weckerly and Ricca (2000) found that elk scat were apparent (detection rate = 95.6%) during their plot census study.

I conducted a fixed-width transect survey to collect pellet-group locations; the surveys are relatively easy to conduct and are more efficient than plot censuses. The fixed-width transect survey was more appropriate than a line transect survey because the probability of detecting sign decreased quickly within a short distance from the transect line, particularly in areas with tall undergrowth. The fixed-width method also reduced the chance of detection bias towards large groups because fixed-width transects assume a 100% probability of detection of scat within the transect (Burnham et al 1980), whereas observers on line transects are more likely to detect scat at a distance if many piles are present.

Test Data Collection

Field testing occurred in March, the month when the majority of aerial survey locations were collected. Surveys were conducted from March 17–March 23, 2002 and from March 28–March 31, 2002. The surveys were conducted on public land within the current elk distribution; Route 65 marked the eastern boundary of the study area (Fig. 14).

I conducted a small pilot study within the experimental elk herd range in Great Smoky Mountains National Park, and determined that 100% detection was consistently achieved within 1.5 m of observers. To increase transect width while maintaining a perfect detection rate, observers walked transects in pairs, resulting in a total transect width of 6 m. Studies suggest limiting the number of observers to minimize the effects of observer bias (Wemmer et al 1996, Weckerly and Ricca 2000); 6 observers (3 pairs) conducted the survey. Observers recorded survey paths and locations of all elk scat within the transects using global positioning system (GPS) units (Garmin International, Olathe, Kansas, USA).

I allocated observer effort by stratifying the survey area into 3 zones based on the amount of elk use indicated by the aerial elk surveys (Caughley 1977; Fig. 14). The high use zone included areas that contained a large number of aerial survey locations. The moderate use zone contained areas that had a large number of aerial survey locations from earlier years, or that had a moderate number of locations in recent aerial surveys. The limited use zone included areas that rarely contained elk locations. The moderate use zone was sampled with 1.5 times the intensity of the limited use zone, and the high use zone was sampled with 3 times the intensity of the limited use zone, thereby

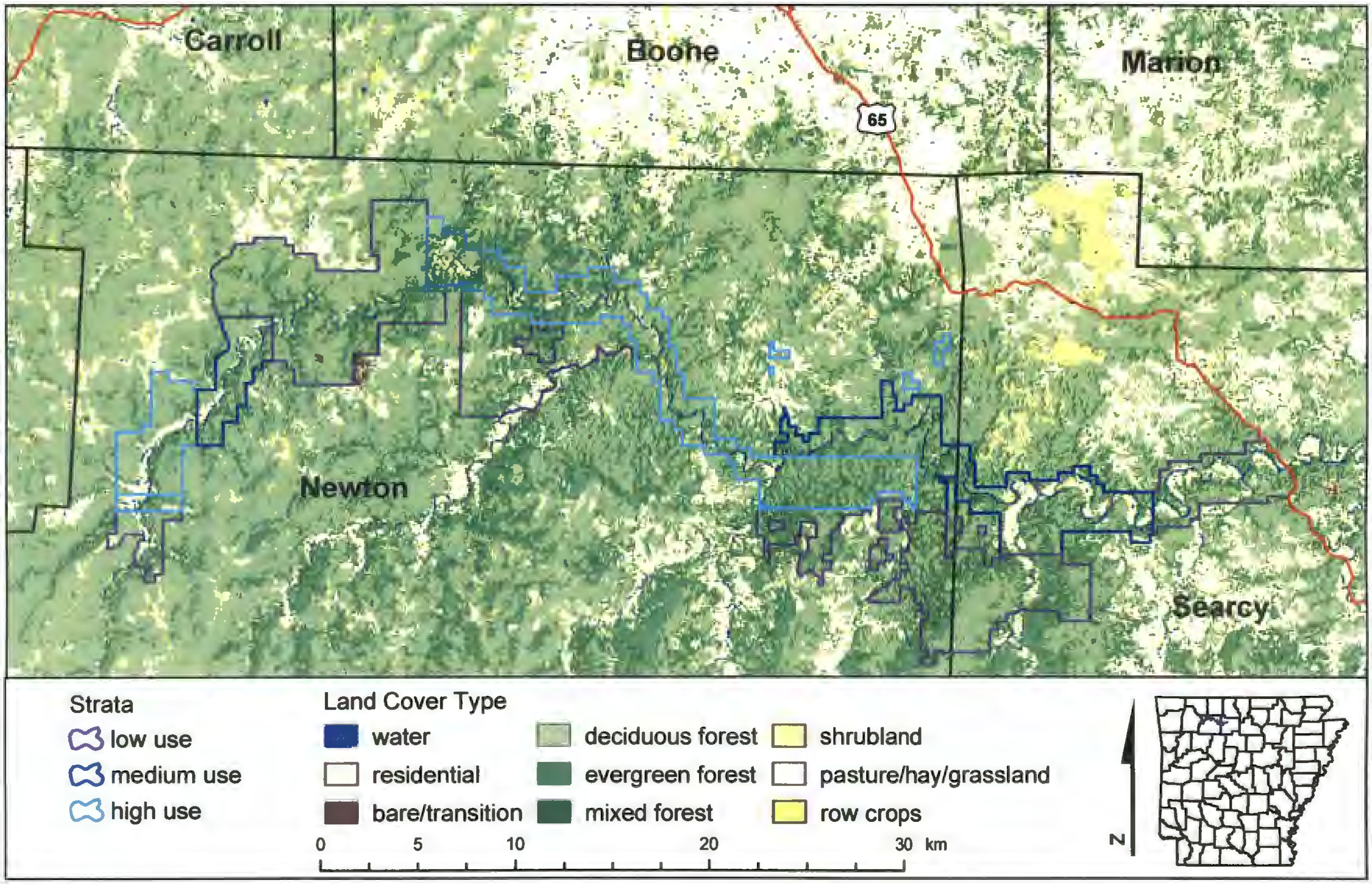

Fig. 14. Stratification of study area into low, medium, and high elk-use areas for fixed-width transect surveys of elk pellet-groups, Buffalo National River area, Arkansas, 2002.

maximizing effort in areas where sign detection was most likely. Placement of transects within the strata was systematic, rather than random, to reduce the amount of time spent locating the start of transects, to maximize the distance between transects, and to maximize coverage of the survey area (Caughley 1977). Transect grids were designed in ArcView® GIS by overlaying a grid of 1- x 1-km cells over the study area; selected cells were >1 km apart to prevent spatial autocorrelation (Weckerly and Ricca 2000). Thus, each transect was 4 km in length, although actual transect lengths varied due to geographical barriers (i.e., cliffs, large bodies of water) and private land boundaries.

Test Data Analysis

Transect paths were digitized to a 90- x 90-m grid in ArcGIS®. Pixels along each transect that contained ≥1 pellet group were identified as presence points; the remaining cells along each transect were considered absence points. A simple linear regression was performed with NCSS statistical software (Hintze 2001) to determine if a relationship existed between the mean D^2 value for each transect and the frequency of presence points. I examined residual plots from the regression for violations of normality and constant error variance. I also tested for normality of residuals using the D'Agostino Omnibus test and by examining the normal probability plot. If nonconstant variance was detected for an appropriate linear relationship, I used weighted least-squares regression to obtain parameter estimates with minimum variance (Neter et al. 1996).

ELK-HUMAN CONFLICT MODEL

When empirical data are not available, predictive models may be designed based on information from expert opinion or scientific literature. I developed a model to assess elk-human conflict potential in Arkansas using an adaptation of the analytic hierarchy process (AHP). A multi-criteria decision tool developed by Saaty (1980), AHP has widespread applications in business and increasingly in natural resource management (Schmoldt et al. 2001). The analytic hierarchy process was developed as a simple method to assign numeric values to subjective components of a decision. The numeric comparison of factors allows for more objective decisions, particularly when criteria are difficult to quantify. The process begins with a hierarchical decomposition of a goal into subordinate criteria that characterize the goal. Those criteria are evaluated in pairwise comparisons, ranking the relative importance of 2 criteria at a time for every possible comparison within each hierarchical level. The pairwise rankings are normalized to weights that are applied to evaluate a set of alternatives (Saaty 1980). Because criteria are prioritized one pair at a time, decision makers do not have to reason on a multivariate level. Objectivity is further increased when experts ranking the criteria are unaware of the final alternatives being considered in the decision.

The popularity of AHP is partly due to its easy integration with other approaches (Schmoldt et al. 2001). Recently, AHP has been combined with GIS as a tool for land-use planning, biodiversity conservation, and habitat suitability predictions (Eastman et al. 1995, Itami and MacLaren 2001, Clevenger et al. 2002). In a GIS application of AHP, GIS map layers representing the criteria are multiplied by normalized weights generated from the pairwise comparisons (Itami and Maclaren 2001, Clevenger et al. 2002).

Similar to a habitat suitability index model, a single suitability map is created from the weighted linear combination of layers.

I developed a model to rank elk-human conflict potential throughout Arkansas by (1) selecting and hierarchically arranging criteria that have the potential to influence elk-human conflict; (2) developing landscape variables at the appropriate scale to measure those criteria; (3) using expert knowledge to rank pairwise comparisons of the criteria and generate normalized weights; (4) generating the model by weighting the landscape variables, and (5) calibrating the model using independent telemetry locations from nuisance elk.

Decision Hierarchy

There is no set method to establishing a hierarchy of objectives and associated criteria (Saaty 1980). I used a review of scientific literature and documentation of landowner complaints near the Buffalo National River elk herd to develop a hierarchy of criteria that may influence the potential for elk-human conflict. After creating an extensive list of possible criteria from that initial review, I first eliminated redundant criteria. The criteria that were retained were the simplest to define and interpret, which is important to increase clarity of the pairwise comparisons. Secondly, I selected only criteria that could be derived from existing spatial data. Thus, criteria such as public attitude were excluded from the model. Finally, because some characteristics defining conflict potential and suitable elk habitat were similar, I measured those factors in a different manner for the elk-human conflict model. For example, road density of heavily traveled roads was measured in the habitat suitability model to assess the effect of road disturbance on habitat use. For the elk-human conflict model, road density of all road types was included as a measure of human access. I established a hierarchy to group the remaining criteria into levels and sublevels (Fig. 15). Those criteria fell into 2 overall categories: land ownership and human development.

The Missouri Department of Conservation (2000) suggested that reduced availability of private land within an elk range would reduce potential conflicts. Availability of private land can be measured in terms of total area and shape complexity of private land patches. The Missouri Department of Conservation (2000) also suggested that movements of elk onto private land could be minimized by increased availability of elk forage on public land. Openings have been created within the current elk range in Arkansas to limit movements of elk onto private land for forage (Cartwright et al. 1998). Finally, damage to private crops and pastures by elk has been identified as a source of conflict in numerous studies, particularly in feasibility studies for eastern states (Van Deelen et al. 1997, Didier and Porter 1999, Missouri Department of Conservation 2000, Lyon and Christensen 2002). Thus, the land ownership factors I included were private land area, private land shape complexity, the amount of forage on public land, and private land use (Fig. 15).

I included projected human population growth as a factor for human development because it indicates the future rate of development and thus the potential for increased conflict issues, both from damage by elk and disturbance to elk by increased human access. Lyon and Christensen (2002) suggested that human access is the most significant constraint to elk habitat and elk habitat management. Access to elk range is facilitated by the density of roads open to vehicular traffic. The avoidance of all road types by elk

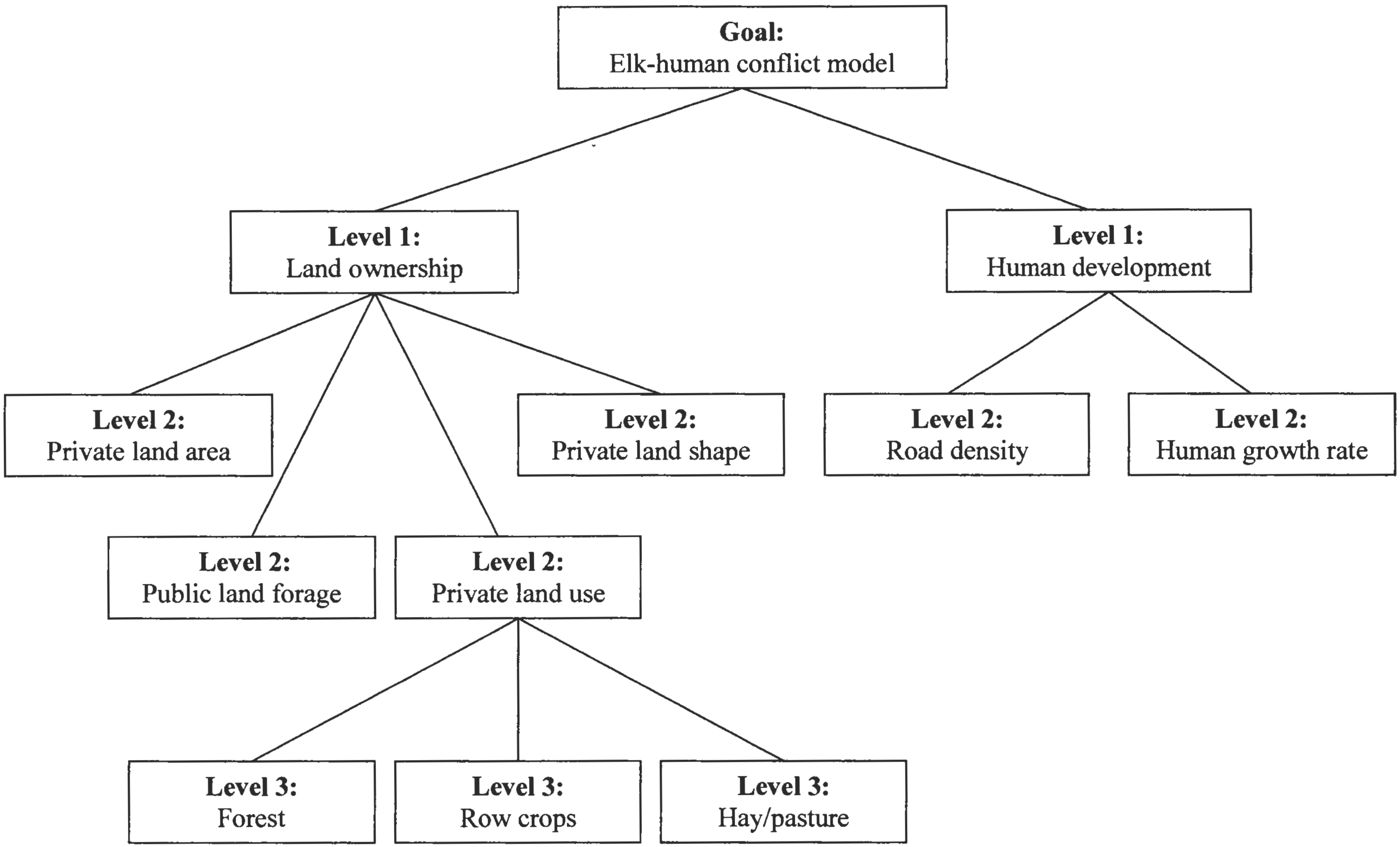

Fig. 15. Analytic hierarchy for an expert-assisted model to determine elk-human conflict potential in Arkansas.

has been well documented (see Lyon and Christensen 2002) and road density has been included as a measure of elk-human conflict in several feasibility studies in eastern states (Van Deelen et al. 1997, Didier and Porter 1999, Missouri Department of Conservation 2000). Therefore, I included road density as a variable in the elk-human conflict model.

Conflict Variables

After identifying criteria that characterize elk-human conflict and constructing the hierarchy, I developed landscape-scale variables to represent those criteria. Similar to the elk habitat model, I identified appropriate map sources, measurement scales, and landscape measures.

Spatial Data Sources

Four sources of map data were used to create the landscape measures that represent the criteria in the expert-assisted model. Like the source maps used in the elk habitat model, those data sources were selected based on their currency, quality, and their spatial extents. Source maps and derived landscape measures were converted to GIS grids with a 90- x 90- m resolution, and projected into NAD83, UTM zone 15 North.

Land Cover.--Land use and forage availability were calculated from 1999 Land-use/Land-cover (LULC) data for Arkansas (Gorham 2001; Fig. 16). Those data were generated for 3 seasons (spring, summer, and fall) by the Center for Advanced Spatial Technologies at the University of Arkansas for the Arkansas Soil and Water Conservation Commission to provide digital land-cover maps focusing on agricultural use in Arkansas. Landsat Thematic Mapper 5 (TM5) imagery was the primary data

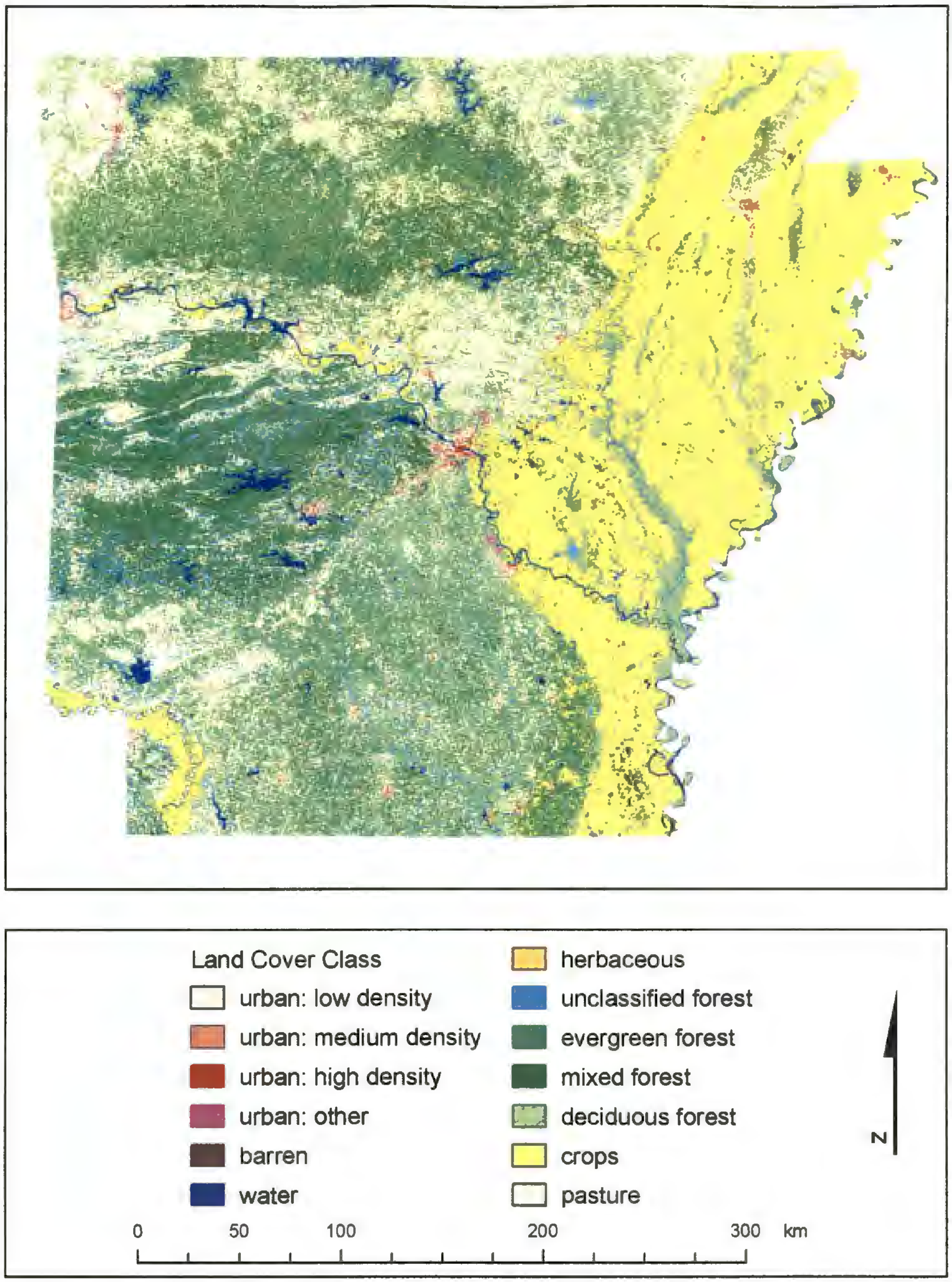

Fig. 16. Arkansas Land-use/Land-cover data, 1999 (Gorham 2001).

source for producing the dataset. Forest classes were the same as those identified in the 1992 Arkansas Gap Analysis Project land cover data (Smith et al. 1998). Forests that appeared between 1992 and 1999 were identified as "forest unclassified". Extensive ground-truthing was completed for agricultural classifications but not for non-agricultural categories. However, average classification accuracy for crops was 87.7%. Therefore, I elected to use the 1999 LULC for the elk-human conflict model rather than the 1992 NLCD because the 1999 data were better suited to determine future potential of elk-human conflicts. Additionally, the agricultural focus of the 1999 LULC provided more accurate measures of private land use.

The LULC data for Arkansas were classified according to 44 land cover types, which I reclassified into 4 broad classes: forest, row crops, pasture, and other. The forest class included all forest types as described by Gorham (2001). Row crops consisted of soybeans, rice, cotton, sorghum/corn, and fallow/seedbed/bare soil. Pasture consisted of warm-season and cool-season pastures. The remaining cover classes were classified as other.

Land Ownership.--Land ownership criteria were derived from the Land Stewardship dataset created for the Arkansas Gap Analysis Project in 1996 (Smith et al. 1998; Fig. 17). The Arkansas Gap Analysis Project represented the first attempt to create an accurate, comprehensive inventory of all public lands in Arkansas. To create the statewide land ownership map, data were either digitized or reprojected into NAD83 UTM Zone 15 N at the 1:100,000 scale. I used Land Stewardship data instead of more recent land ownership data because the data identify private land inholdings within

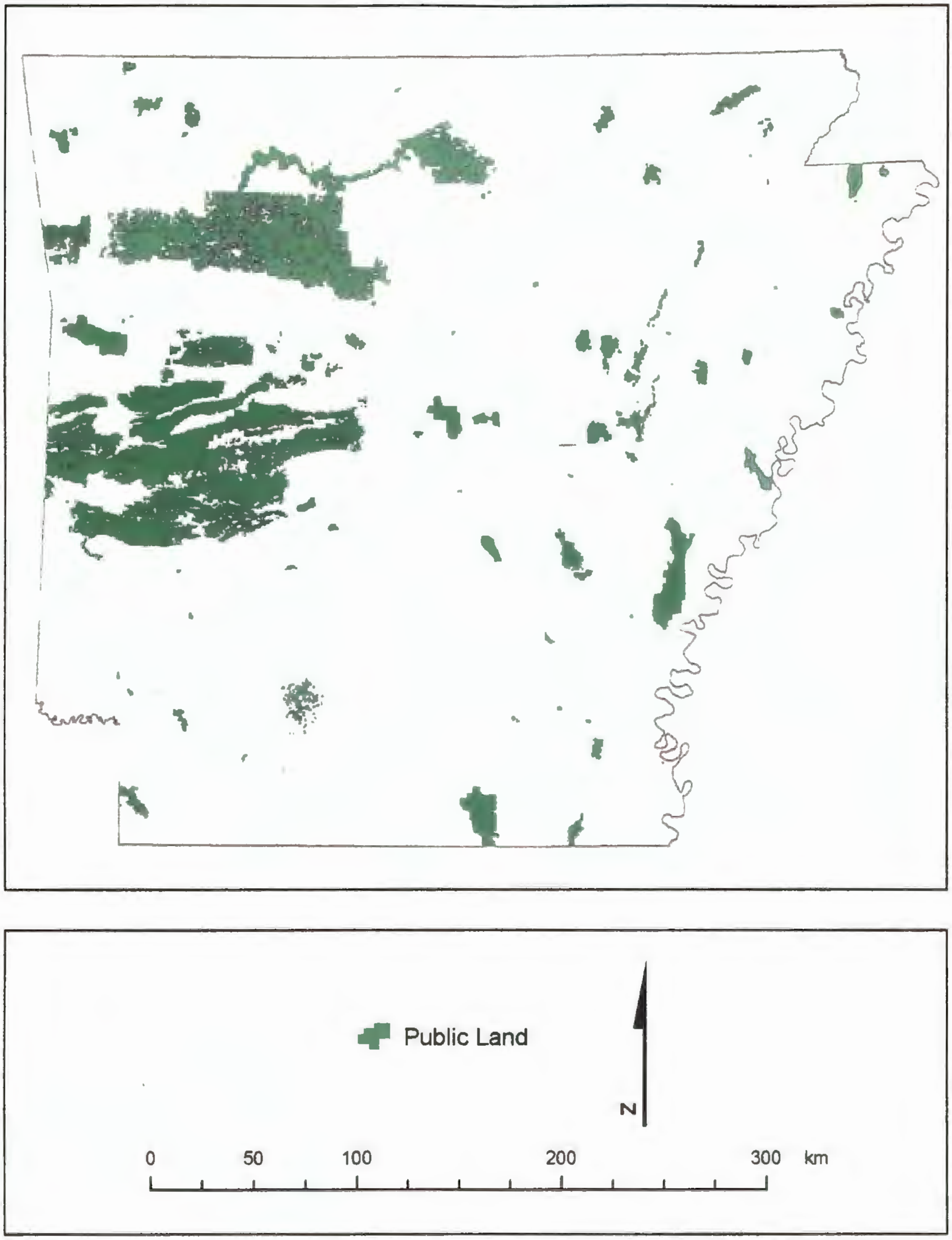

Fig. 17. Public land ownership in Arkansas, 1996 (Smith et al. 1998).

public land boundaries. The land ownership polygons were converted to a grid of public and private ownership.

Human Population Growth.--I derived change in human density from 1990 Census and 2000 Census block group data (U.S. Census Bureau 1991, U.S. Census Bureau 2001; Fig. 18). Census block groups generally are comprised of 3–4 census blocks and are relatively homogenous in size. For each census period, I combined the total population for each block group with U.S. Census Bureau TIGER®/Line polygon data of block group boundaries. GIS grids of human density per block group were created for 1990 and 2000 census data based on the same methods used to create the source map of human density for the elk habitat model. The 2 density maps were subtracted to determine the change in human density over the 10-year period.

Road Density.--I calculated road density from the same 2000 AHTD data used in the elk habitat model. Because all roads were included in the model, no reclassification of road types was necessary (Fig. 19).

Model Scale

The potential for elk-human conflict exists at a broad scale. Sites identified for elk reintroduction should have a low potential for elk-human conflict range-wide. The current elk range in Arkansas is approximately 1,367 km^2, but elk primarily use 305 km^2 of public land (i.e., Buffalo National River and Gene Rush Wildlife Management Area) within the elk range. I used a 10,000-m radius window in a moving window analysis to generate each conflict variable, representing a minimum area of approximately 300 km^2 needed to support a viable population of reintroduced elk (Fig. 20).

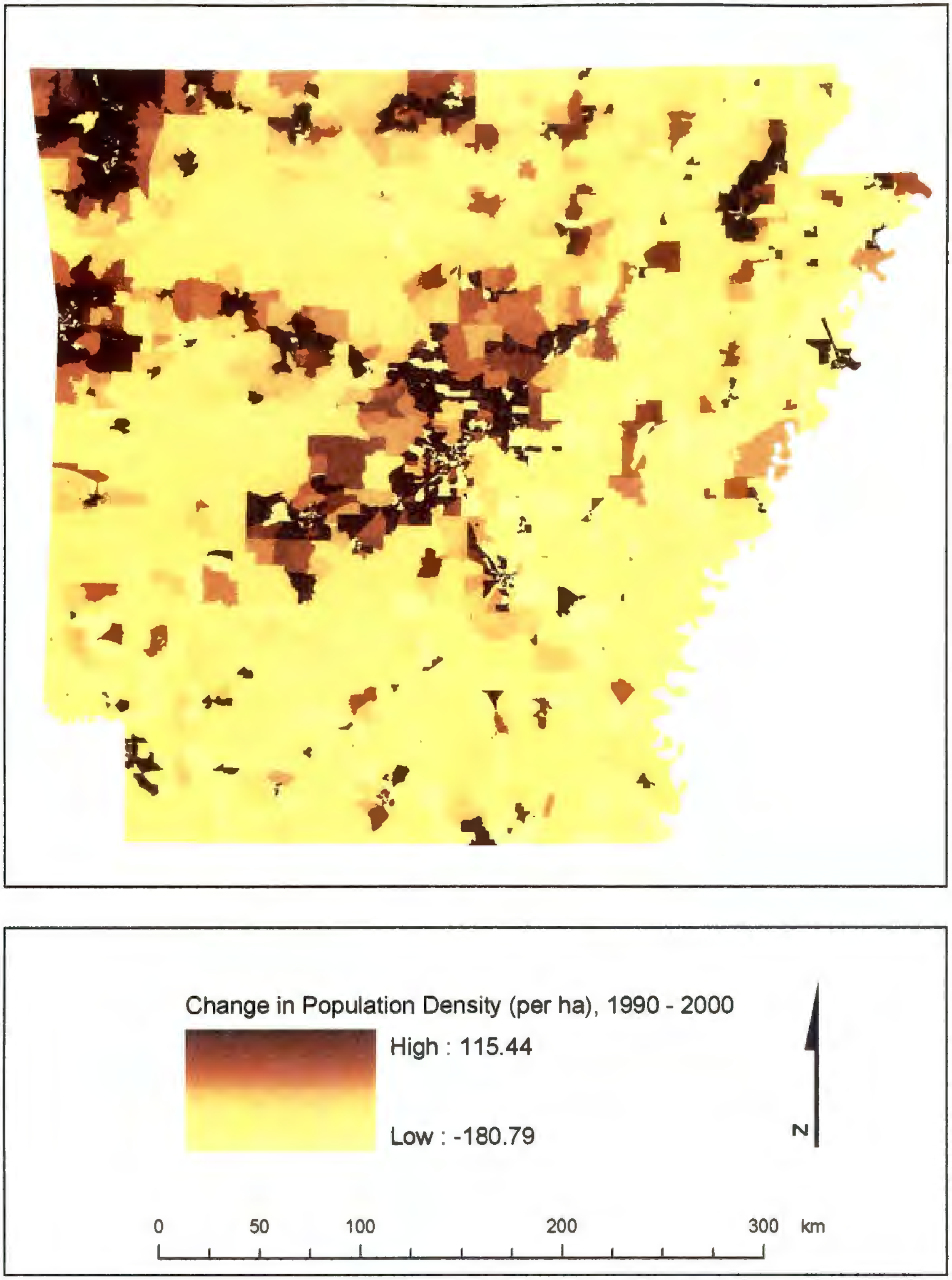

Fig. 18. Change in human density (number of people/ha) within census block groups in Arkansas, 1990–2000 (U.S. Census Bureau 1991, U.S. Census Bureau 2001).

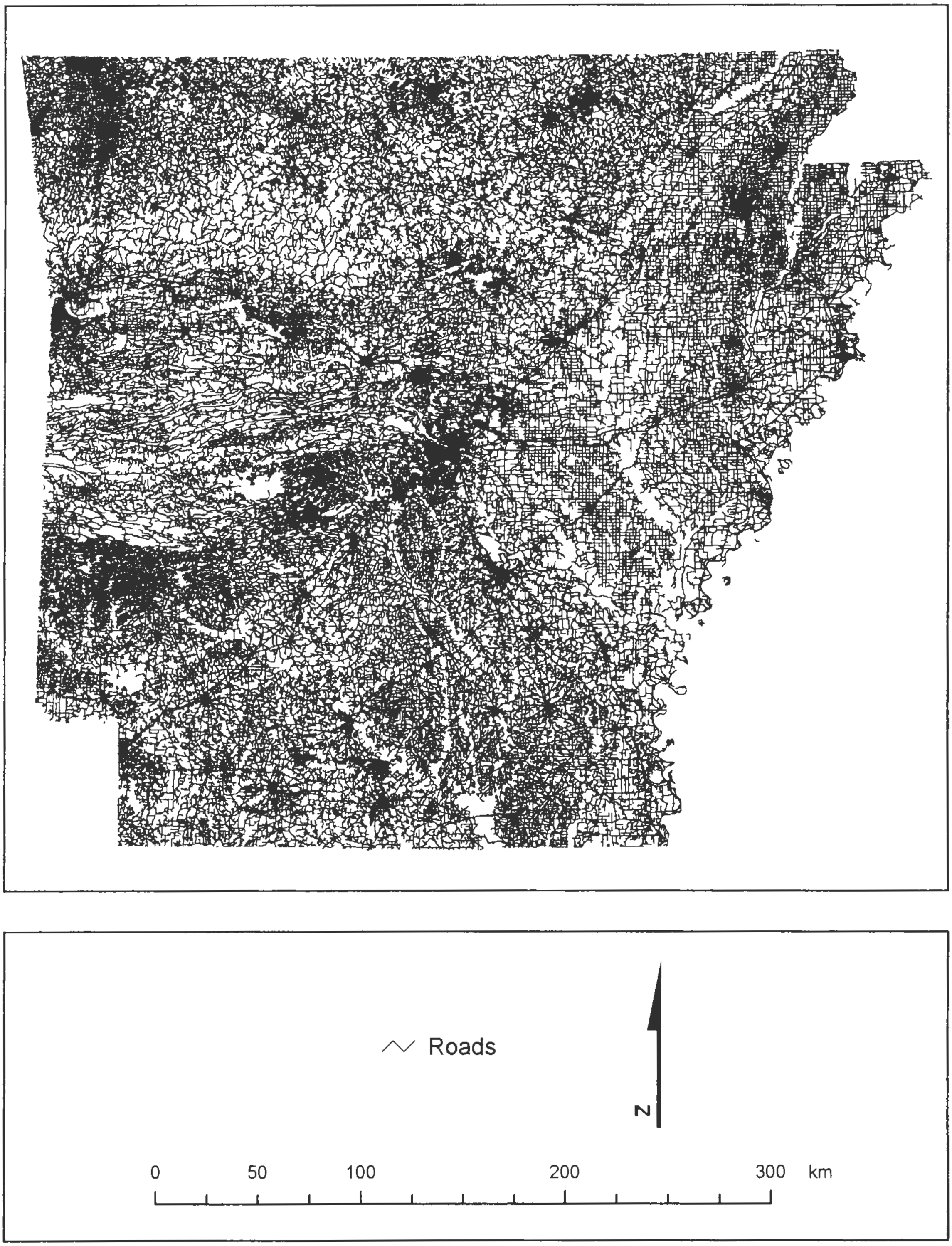

Fig. 19. Roads in Arkansas, from the Arkansas Highway and Transportation Department, 2000.

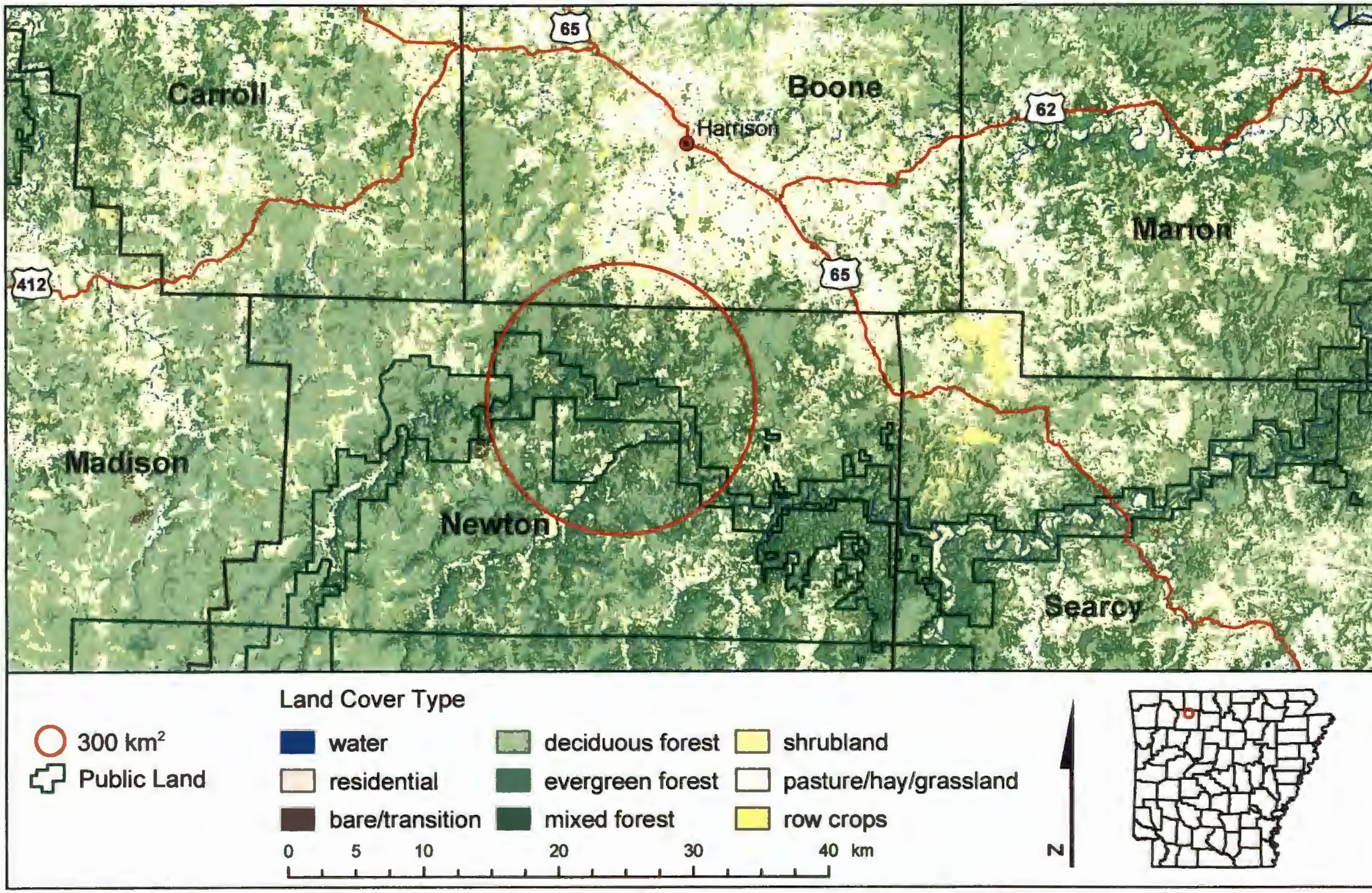

Fig. 20. Example of the window size used to generate landscape metrics during the moving window analysis, representing minimum area necessary for a successful elk reintroduction. Buffalo National River area, Arkansas, is shown for reference.

Variable Calculation

Digital map layers representing elk-human conflict variables were derived in a similar manner to those derived for the elk habitat model. Private land area and private land shape were generated in Fragstats from the public land dataset using the PLAND and ED functions, respectively (Appendix A). I overlaid the classified 1999 LULC with land ownership to delineate land use on public and private land (forest, pasture, row crop). Percent land use for each class was calculated using the PLAND function in Fragstats. Both mean change in human density and road density of all roads in Arkansas were calculated from their respective source maps in ArcGIS®, using the Spatial Analyst extension.

Prior to weighting the criteria, I ensured that all variable layers were positively correlated with increasing elk-human conflict. The only variable among the criteria with an inverse relationship to increasing elk-human conflict was forage availability on public land. Therefore, I transformed that variable by calculating the inverse (1/PLAND).

Each variable was scaled to a consistent range of values (Eastman et al. 1995) to sum the weighted criteria. I standardized each variable to a 0–1 linear scaling:

$$x_i = (R_i - R_{min})/(R_{max} - R_{min}),$$

where R is the original pixel value for a habitat variable, *min* is the minimum pixel value in the range of all values, and *max* is the maximum pixel value in the range of all values.

Criteria Weights

The model criteria were weighted based on pairwise comparisons. I designed an expert opinion survey that was completed in March 2003 by a group of 5 biologists

(Appendix B). Those biologists were actively involved in managing the current Arkansas elk population. I chose to have the comparisons completed by group consensus rather than averaging individual responses because in a group dynamic, active discussion ensures that everyone has the same understanding of the criteria and how they relate to the goal.

The experts were asked to complete the pairwise comparisons by ranking the relative importance of each set of 2 criteria to increasing the potential for elk-human conflict. Ranks were selected from an integer scale ranging from 1 to 9 (Saaty 1980). For variables A and B, a value of 1 indicates equal importance of A and B, 3 indicates A is weakly more important than B, 5 indicates A is strongly more important than B, 7 indicates A is very strongly more important than B, and 9 indicates A is absolutely more important than B. If B is more important than A, then the relative importance of A is the reciprocal of the rank value. For example, if road density was deemed more important than human growth rate by a value of 2, then human growth rate would be more important than road density by a value of 1/2. Although the ranking procedure was subjective, a group consensus helped to calibrate subjective rankings among the experts (i.e., the experts attained a common perspective on values such as "more important", and "strongly more important").

I used Web-HIPRE, an internet-based program for multi-criteria decision analysis, to create pairwise comparison matrices of the survey results (Mustajoki and Hämäläinen 1999). Because inconsistencies may arise within the comparison matrix based on the subjective rankings of the paired comparisons, Saaty (1980) developed a consistency ratio, which evaluates the probability that the matrix values were randomly generated. Ideally, an acceptable consistency ratio should be <0.10 (Saaty 1980). Web-HIPRE calculates the consistency ratio as the matrix is completed. Saaty (1980) demonstrated that the principal eigenvector of the paired comparison matrix represents prioritized weights of each criterion that sum to one. Those weights were calculated from the comparison matrix in program Web-HIPRE.

Model Generation

The variables were combined to produce a map of elk-human conflict potential by multiplying each pixel value in a variable layer by its respective weight, and summing the results across all variables. The weight of each variable used in that function is the product of the weights of each criterion along the hierarchical path. For example, if human disturbance received a weight of 0.5, and road density received a weight of 0.25, then the road density layer would be multiplied by a weight of 0.125 (i.e., 0.5 x 0.25) in the weighted linear summation. The resulting map values range from 0 to 1, with increasing values indicating increased potential for elk-human conflict.

Model Calibration

No independent data were available to test the elk-human conflict model. However, I calibrated the model to identify ranges of values representing acceptable, moderate, and unacceptable levels of elk-human conflict, based on telemetry locations of nuisance elk inhabiting private lands within the current elk range in Arkansas (Herner-Thogmartin 1999). Herner-Thogmartin (1999) collected telemetry locations on 6 cow elk associated with nuisance activity from fall 1997 to fall 1998. Because the home ranges of

2 elk were primarily established within Buffalo National River boundaries (Herner-Thogmartin 1999), they were excluded from the calibration.

The 324 locations collected on the remaining 4 elk were sampled to determine the overall mean and standard deviation of the elk-human conflict scores associated with the nuisance elk. Those elk locations were assumed to represent a moderate level of elk-human conflict. Although property damage caused by nuisance elk has been documented on private lands (Herner-Thogmartin 1999), its severity has not restricted elk use. The conflict map was calibrated based on standard deviations from the mean elk-human conflict score: values <6 standard deviations from the mean (low potential), values within 6 standard deviations of the mean (moderate potential), and values >6 standard deviations from the mean (high potential). Contours representing levels of potential elk-human conflict were overlaid with the winter elk habitat model to identify areas with suitable landscape characteristics and a low potential for elk-human conflict.

CHAPTER V

RESULTS

ELK HABITAT MODEL

Model Selection

I included the 46 recently plotted elk locations in the model, for a total of 239 elk-group locations. Seven variables best explained the variation in the elk-group locations and random locations in the CART analysis (Fig. 21). The CART model had a misclassification rate of 9.4%. Of the 7 variables, I included 6 in the Mahalanobis distance model (Appendix C). I excluded contagion of all natural cover types (80-km^2 window) because it was negatively correlated with perimeter-area ratio of all natural types at the 8-km^2 scale (PARA8; r = -0.67) and because the range of values in the state were not well represented within the elk range. I included 3 additional variables in the Mahalanobis distance model because they are known to be biologically important to elk: percent forest, 30-km^2 scale (PLAND30); fractal dimension of forest and field, 8-km^2 scale (FRAC8); and road density, 8-km^2 scale (ROAD8; Appendix C).

Correlations among the variables were moderate to low ($|r| < 0.59$). In general, landscape pattern variables exhibited less variation among the sampled elk-group locations than the human disturbance variables (Table 5). Of the landscape pattern variables, PAR8, FRAC8, and fractal dimension of forest, 30-km^2 scale (FRAC30) exhibited the least amount of variation. The principal components analysis indicated that the first 4 eigenvalues of the correlation matrix were $\geq$1 and explained 75% of the variation in the data; hence, I examined the elements of the first 4 component loading

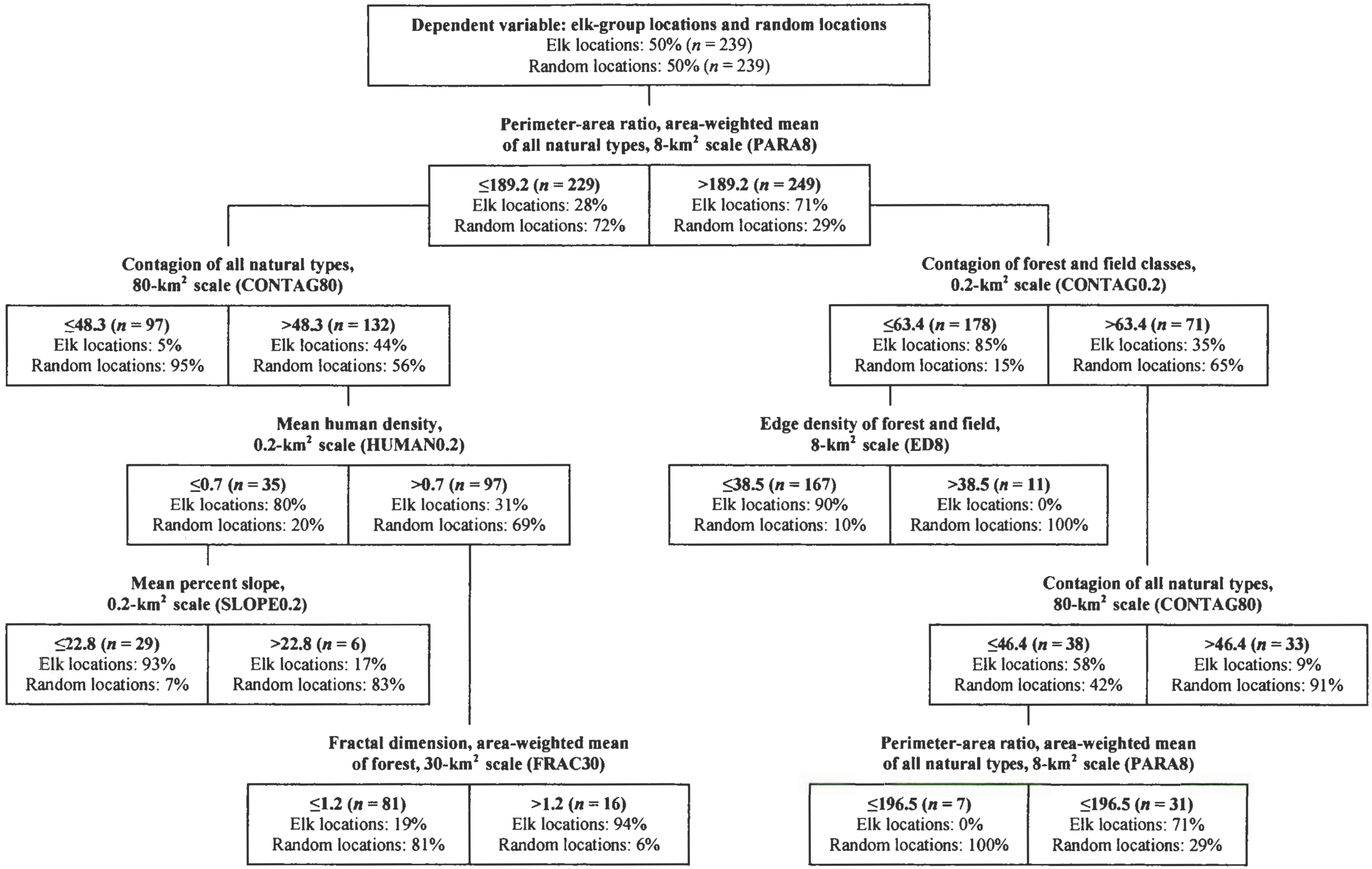

Fig. 21. Classification and regression tree (CART) analysis of habitat variables to characterize elk habitat use in Arkansas, 1992–2002.

Table 5. Mean ($\bar{x}$), coefficient of variation (CV; %), and range (R) of habitat variables included in the winter elk habitat model for elk-group locations in the Buffalo National River area, Arkansas, 1992–2002.

			Elk-group locations		
Variable[a]	Land class(es)	Scale (km^2)	$\bar{x}$	CV	R
PLAND	Forest	30	84.2	10.4	51.7 – 95.4
ED	Forest and field	8	20.3	43.5	0.1 – 40.0
PARA	All natural types	8	198.3	18.0	74.7 – 245.7
FRAC	Forest	30	1.2	2.6	1.1 – 1.2
FRAC	Forest and field	8	1.1	2.1	1.0 – 1.2
CONTAG	All natural types	0.2	43.0	88.9	0.1 – 100.0
SLOPE	–	0.2	12.8	55.4	0.9 – 43.8
HUMAN	–	0.2	0.0	169.9	0.0 – 0.5
ROAD	–	8	0.0	339.8	0.0 – 0.6

[a]See Table 4 and Appendix A for a definition of the variables.

vectors to determine the relative contribution of each variable (Table 6). Edge density of forest and field at the 8-km^2 scale (ED8), FRAC30, FRAC8, and PLAND30 showed strong relationships with the first principal component, explaining 29% of the variation. Mean human density at the 0.2-km^2 scale (HUMAN0.2), contagion of forest and field at the 0.2-km^2 scale (CONTAG0.2), and PARA8 had strong relationships with the second principal component, explaining 22% of the variation. Mean percent slope at the 0.2-km^2 scale (SLOPE0.2), PLAND30, and FRAC8 showed strong relationships with the third principal component, explaining 13% of the variation. Finally, ROAD8, CONTAG0.2, and SLOPE0.2 showed strong relationships with the fourth principal component, explaining 11% of the variation. Because all 9 habitat variables contributed to characterizing elk habitat, I retained all those variables in the Mahalanobis distance model.

Model Generation

Mahalanobis distance (D^2) values in Arkansas ranged from 0.3 to 6.2 x 10^6 ($\bar{x}$ = 561.8 ± 14,609.1; Figs. 22 and 23). D^2 values for the elk-group locations ranged from 0.8 to 84.7 ($\bar{x}$ = 9.0 ± 8.2). Ninety percent of the elk-group locations had D^2 values ≤15; these values indicate more suitable winter habitat for elk (Fig. 24).

Model Evaluation

A random sample of 239 D^2 values, generated within a 1,600-m area around the original elk-group locations, ranged from 1.7 to 64.6 ($\bar{x}$ = 13.7 ± 9.8). A Kolmogorov-Smirnov test indicated that the cumulative frequency distributions of D^2 values for the

Table 6. Principal component loading vectors of habitat variables associated with elk-group locations in the Buffalo National River area, Arkansas, 1992–2002.

		Component loading vectors			
Variable[a]	Scale (km^2)	1	2	3	4
PLAND	30	-0.7	-0.5	0.4	-0.1
EDB	8	0.8	-0.1	-0.3	-0.0
PARA	8	0.4	-0.7	0.2	0.1
FRAC	30	0.8	0.3	0.1	0.2
FRAC	8	0.8	-0.2	0.4	-0.0
CONTAG	0.2	-0.3	0.6	-0.3	0.4
SLOPE	0.2	-0.2	0.4	0.7	0.3
HUM	0.2	0.3	0.7	0.3	-0.1
ROAD	8	0.0	0.4	0.1	-0.8

[a]See Table 4 and Appendix A for a definition of the variables.

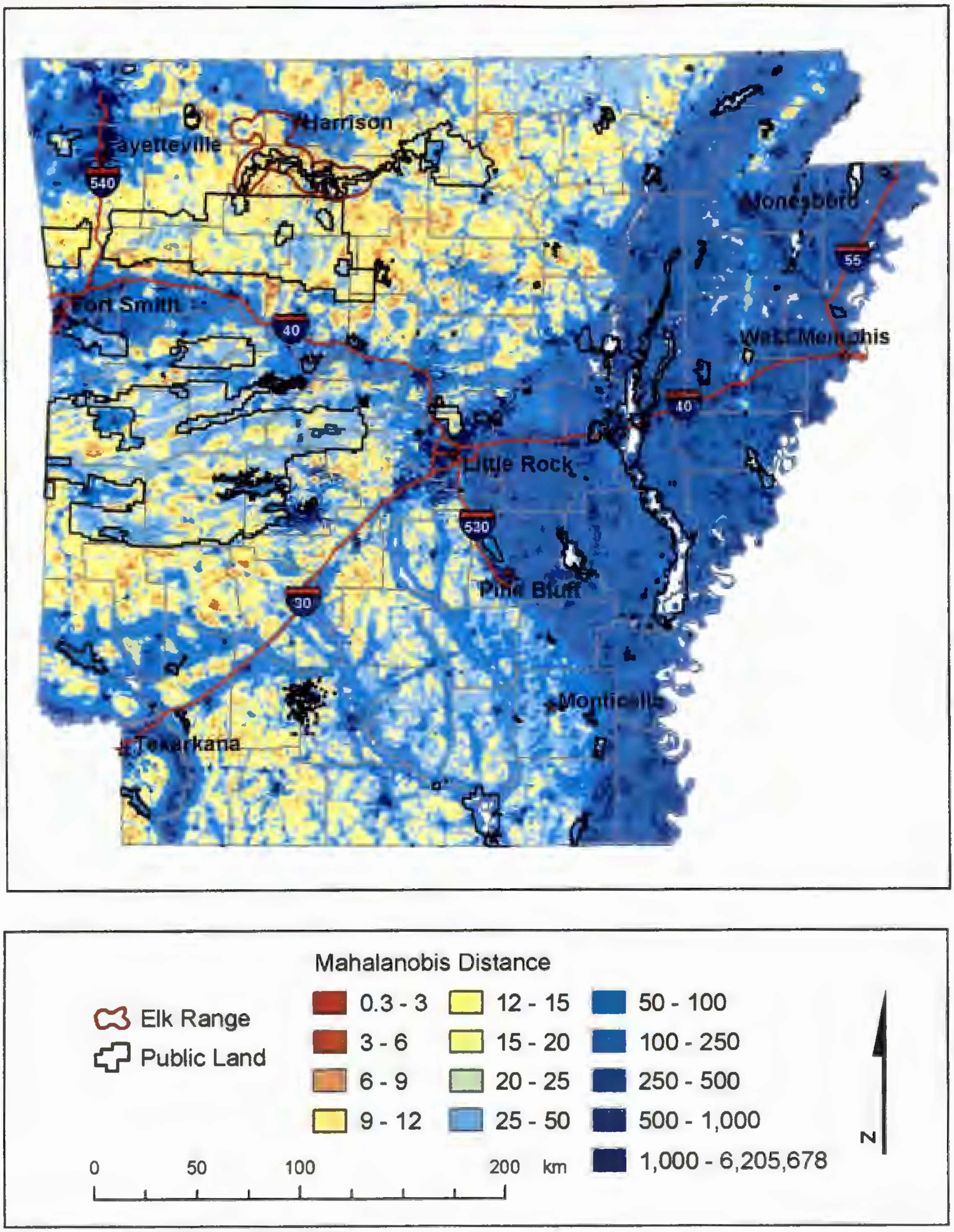

Fig. 22. Suitability of winter elk habitat in Arkansas based on a Mahalanobis distance model of elk-group locations collected in the Buffalo National River area, Arkansas, 1992–2002. Mahalanobis distance values <15 indicate suitable elk habitat.

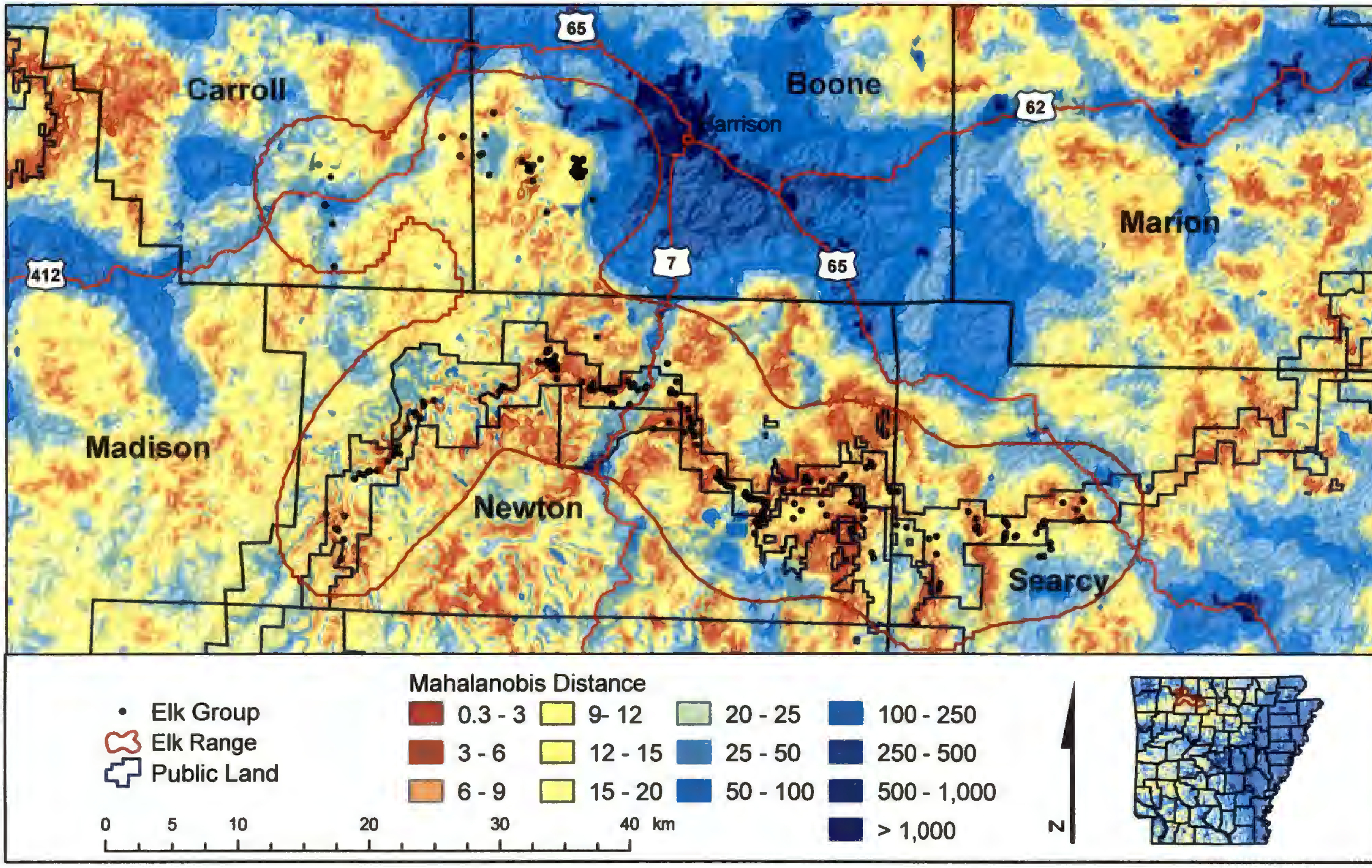

Fig. 23. Suitability of winter elk habitat within the current elk range in Arkansas based on a Mahalanobis distance model of elk-group locations collected in the Buffalo National River area, Arkansas, 1992–2002. Mahalanobis distance values <15 indicate suitable elk habitat.

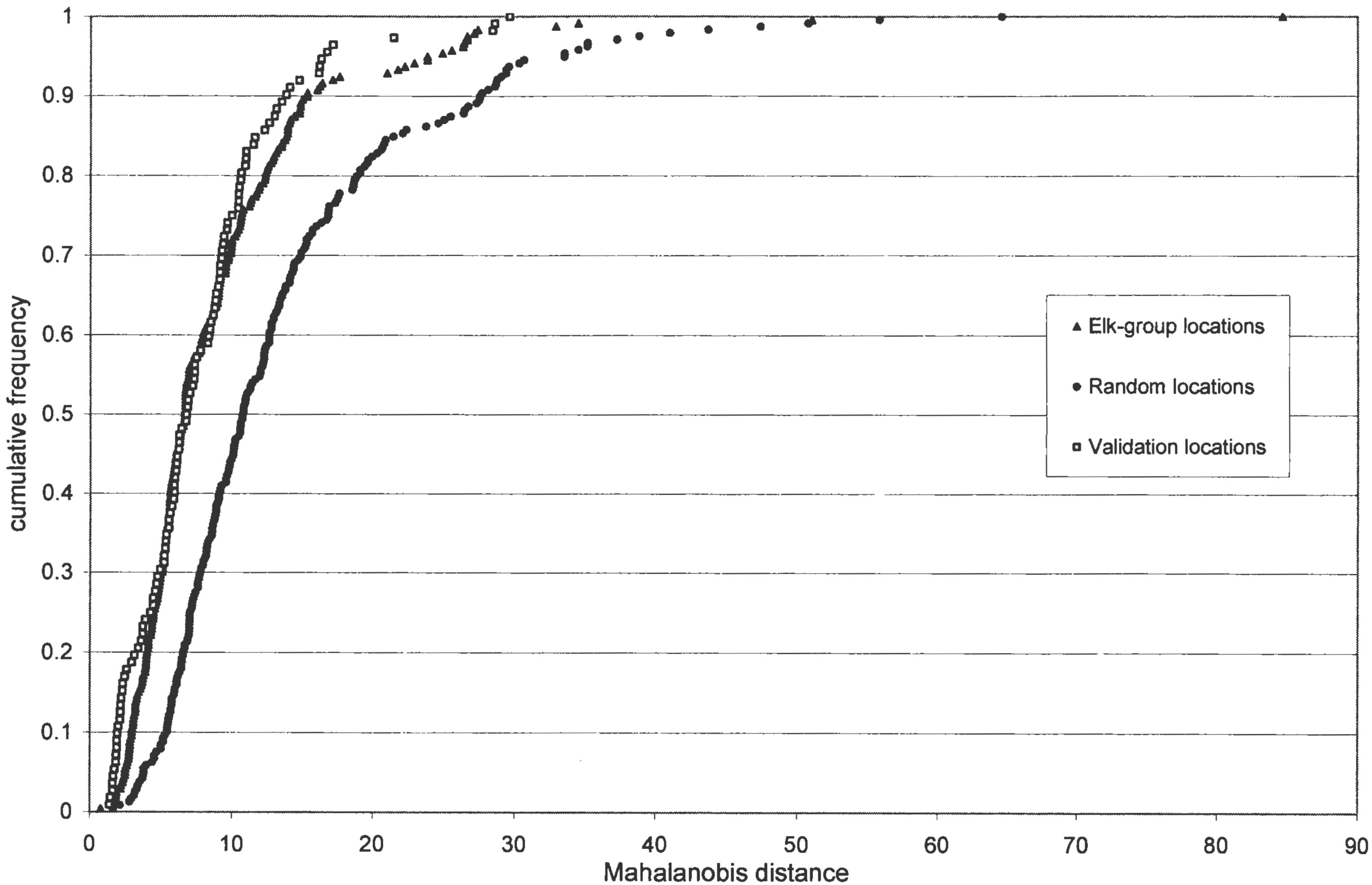

Fig. 24. Cumulative frequency distributions of Mahalanobis distance values for elk-group locations used to design the model, random locations, and locations of pellet-groups used to test the model.

random locations and the original elk-group locations differed ($D = 0.34$, $P \leq 0.001$), suggesting that elk habitat selection differed from random.

Independent test data were collected along 19 transects (75 km; Fig. 25). Mean transect length was 3.98 ± 1.0 km. Total transect lengths covered were 12.9 km, 20.5 km, and 40.4 km in low, moderate, and high use areas, respectively (1:1.60:3.15 ratio). A total of 481 scat locations were recorded, with a range of 0–120 per transect. Elk pellet-groups were present in 112 of 919 pixels within the transects. Mahalanobis distance values for those 112 pixels ranged from 1.4 to 29.6 ($\bar{x} = 7.8 \pm 5.4$). Ninety percent of the presence pixels had distance values ≤13.8 (Fig. 24). A Kolmogorov-Smirnov test indicated that the cumulative frequency distributions of D^2 values for the independent test points and the original elk-group locations did not differ ($D = 0.13$, $P \leq 0.166$).

Residual plots for the regression analysis of the test data indicated a non-constant error variance. Therefore, I used weighted-least squares regression to determine the linear relationship between the frequency of 90- x 90-m pixels containing elk scat and the mean Mahalanobis distance values for each transect. Examination of the weighted residual plots indicated constant error variances. The regression analysis indicated that the frequency of scat occurrence increased with decreasing mean Mahalanobis distance values, or increasing habitat suitability ($F = 9.65$, $P = 0.039$; Fig. 26). Although R^2 is not easily interpretable for a weighted least-squares regression, based on the unweighted regression, the equation explained ≥23.6% of the variation. For any 10-point decline in Mahalanobis distance, the frequency of elk scat occurrence increased by 2.

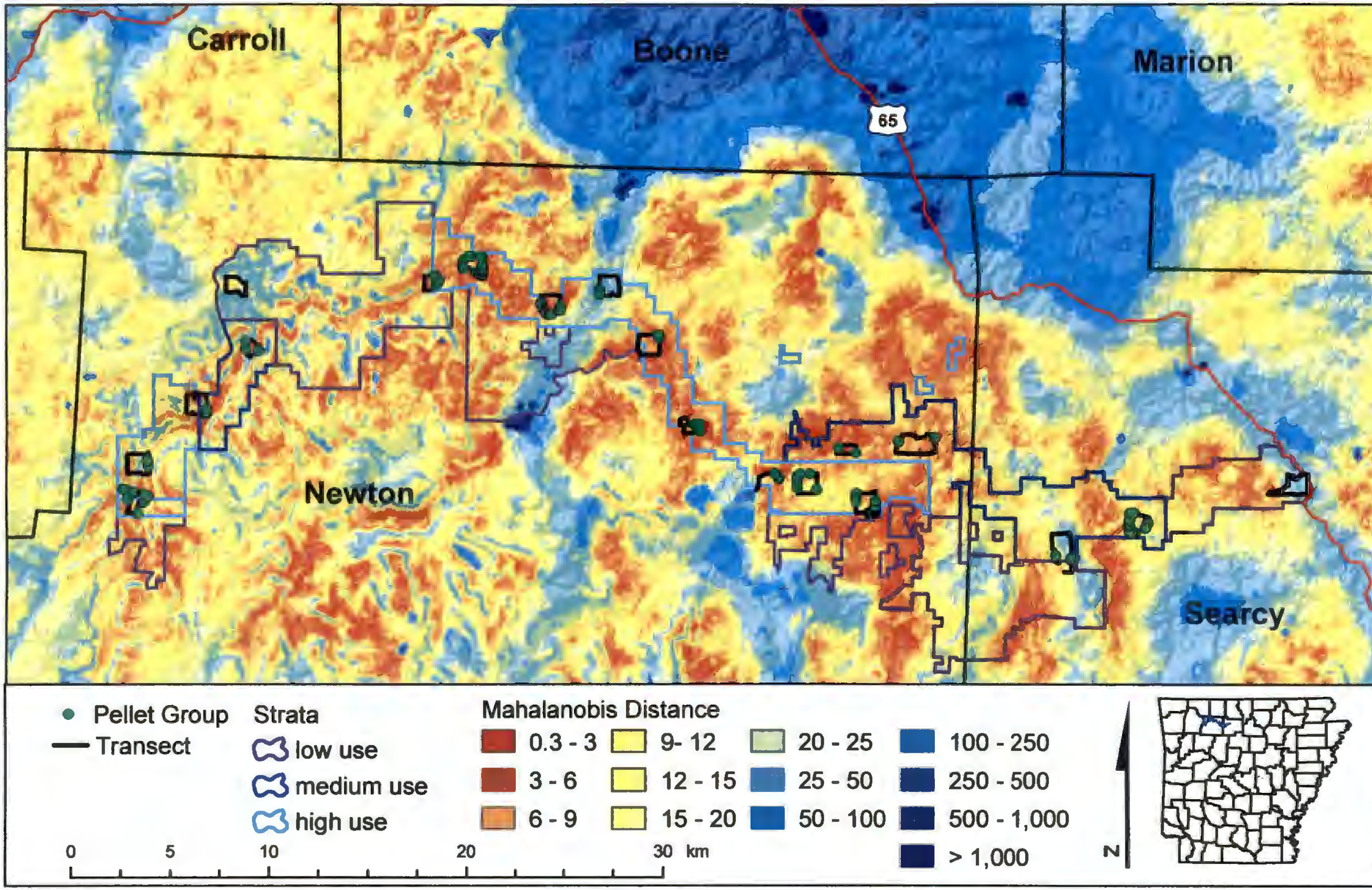

Fig. 25. Locations of fixed-width transects and elk pellet groups observed on public lands within the elk range in the Buffalo National River area, Arkansas, March 2002. Mahalanobis distance values <15 indicate suitable elk habitat.

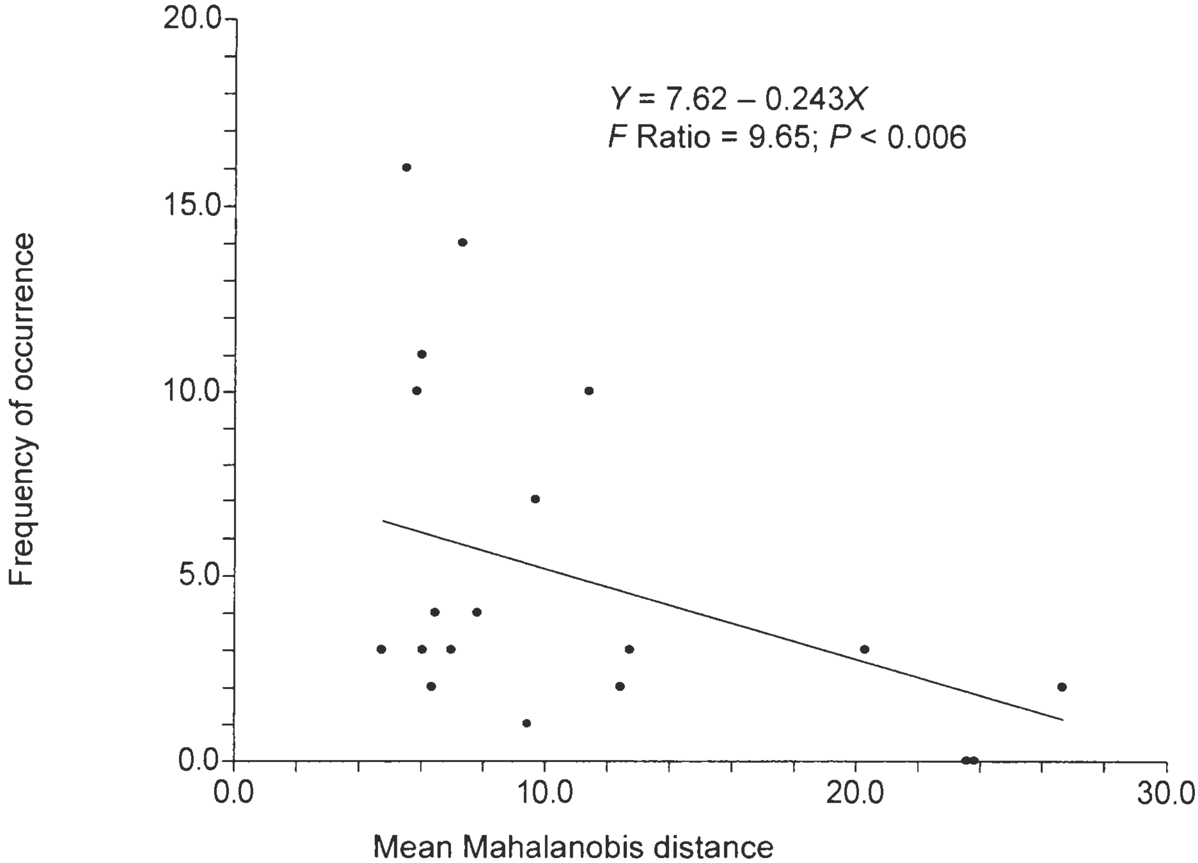

Fig. 26. Weighted least-squares regression of the frequency of pixels in a transect with observed pellet groups and the mean Mahalanobis distance score for all pixels in the transect, Buffalo National River area, Arkansas, March 2002.

ELK-HUMAN CONFLICT MODEL

Criteria Weights

The expert group completed the opinion survey in approximately 1.5 hours. The experts always agreed on which variable of each pair was more important; most discussions related to assigning the degree of importance. The 4 sets of paired comparisons reflecting the hierarchical structure resulted in 4 paired comparison matrices, with consistency ratios <0.18 (Table 7).

According to the relative weights assigned to the criteria within each hierarchical branch and sublevel, the experts ranked land ownership as having a stronger relative influence on the potential for elk-human conflict (0.75) than human development (0.25; Fig. 27). Among criteria characterizing land ownership, public land forage availability and private land ownership were determined to have a stronger influence (0.44 and 0.41, respectively) than private land area (0.12) and shape of private land (0.04). Among land use types, row crops were determined to have the strongest influence on elk-human conflict potential (0.60) compared with hay/pasture land (0.35) and forest land (0.06). Finally, among criteria characterizing human development, projected human growth rate (0.88) was considered more important than road density of all road types (0.13).

Model Generation

Public land forage availability was determined to have the strongest influence on the potential for elk-human conflict, comprising 33% of the overall conflict potential, followed by human growth rate (22%) and the amount of private land in row crops (18%; Table 8). Road density, edge density of private land patches, and the amount of private

Table 7. Paired-comparison matrices and associated consistency ratios completed by a group of 5 elk experts in Arkansas, March 2003, for (A) land ownership and human development main criteria, (B) land ownership sub-criteria, (C) private land use sub-criteria, and (D) human development sub-criteria.

(A)

		LO	HD
Land ownership	LO	1	1/3
Human development	HD	3	1
Consistency ratio = 0.00			

(B)

		AR	SH	FO	US
Private land area	AR	1	6	1/6	1/5
Private land shape	SH	1/6	1	1/8	1/8
Public land forage	FO	6	8	1	1
Private land use	US	5	8	1	1
Consistency Ratio = 0.18					

(C)

		FR	HA	RC
Private land forest	FR	1	1/7	1/9
Private land hay	HA	7	1	1/2
Public land row crop	RC	9	2	1
Consistency Ratio = 0.07				

(D)

		PG	RD
Population growth	PG	1	7
Road density	RD	1/7	1
Consistency Ratio = 0.00			

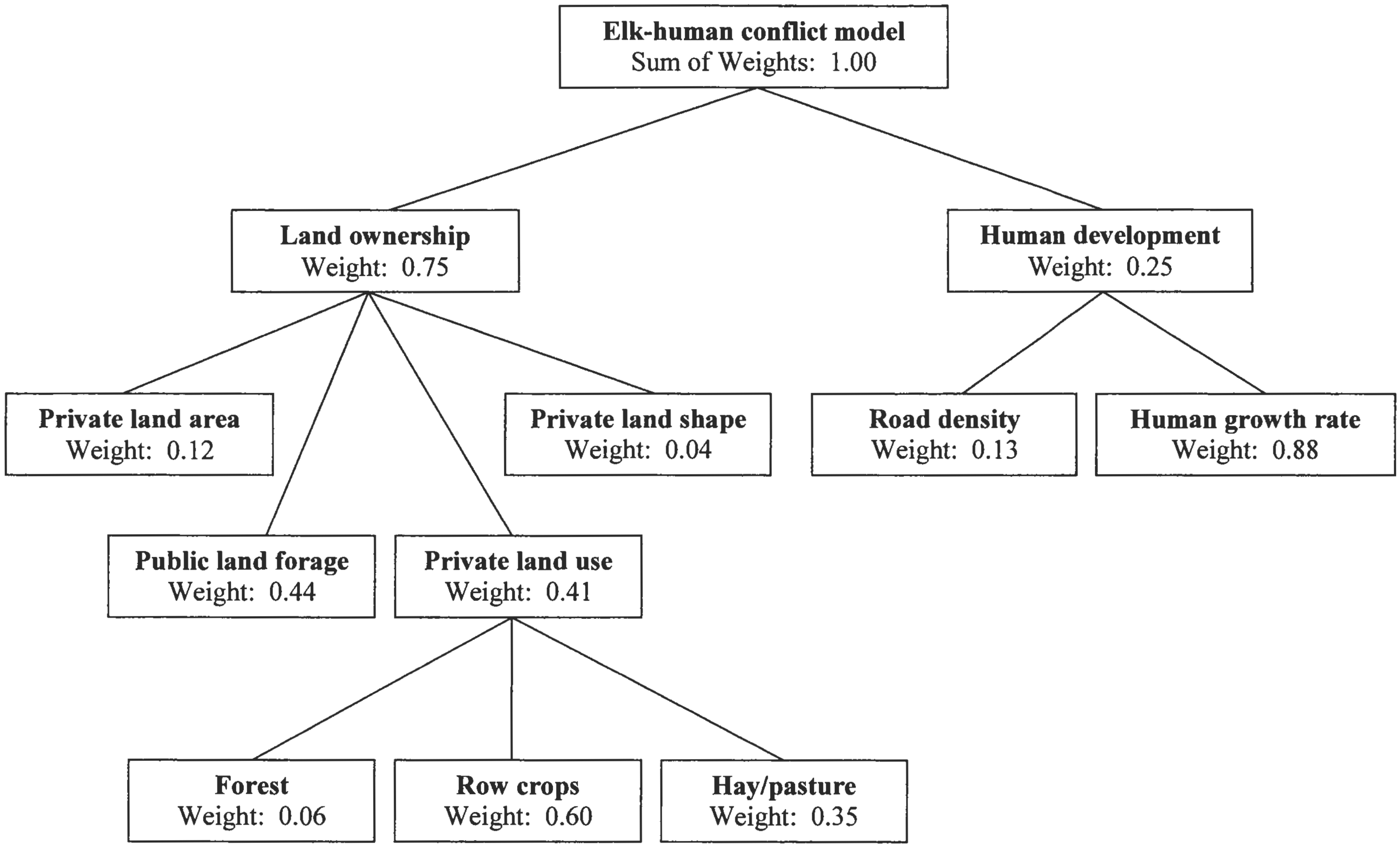

Fig. 27. Weights assigned to each criterion in the elk-human conflict hierarchy, based on an expert-opinion survey of 5 elk experts in Arkansas, March 2003.

Table 8. Ranked weights assigned to each variable in the model of elk-human conflict potential for Arkansas, based on an expert-opinion survey of 5 Arkansas elk experts, March 2003. Weights are ordered by importance.

Variable	Ranked weight
Amount of public land forage (%)	0.33
Human growth rate (people/km^2)	0.22
Amount of private land in row crop (%)	0.18
Amount of private land in pasture (%)	0.11
Relative private land area (%)	0.09
Road density of all roads (m/km^2)	0.03
Edge density of private land patches (m/ha)	0.03
Amount of private land in forest (%)	0.02
Total	1.00

land in forest had little influence on elk-human conflict potential (≤3% each). Elk-human conflict potential in Arkansas ranged from 0.14 to 0.72 ($\bar{x}$ = 0.54 ± 0.57; Fig. 28).

Model Calibration

Elk-human conflict values for the telemetry locations of 4 nuisance cow elk ranged from 0.53 to 0.55 ($\bar{x}$ = 0.54 ± 0.009). Eleven contours with intervals of 0.054 were created, representing 6 standard deviations (0.009 x 6) from the mean conflict potential value for the nuisance cow locations (Fig. 29). I considered values ≤0.49 to be areas of low elk-human conflict potential. Values from 0.49 to 0.59 were considered areas of moderate elk-human conflict potential. I considered values >0.59 to be areas with high potential of elk-human conflict. Generally, areas of low conflict potential were within public land boundaries, with conflict potential decreasing closer to the interior of the public land area (Fig. 28). Fifty-one percent of the current elk range consisted of low elk-human conflict potential.

I combined the conflict potential contours with the winter elk habitat model to map sites where suitable winter habitat corresponded with low elk-human conflict potential (Fig. 29). Large and contiguous patches of suitable winter habitat within areas of low elk-human conflict tended to correspond with public and private land boundaries.

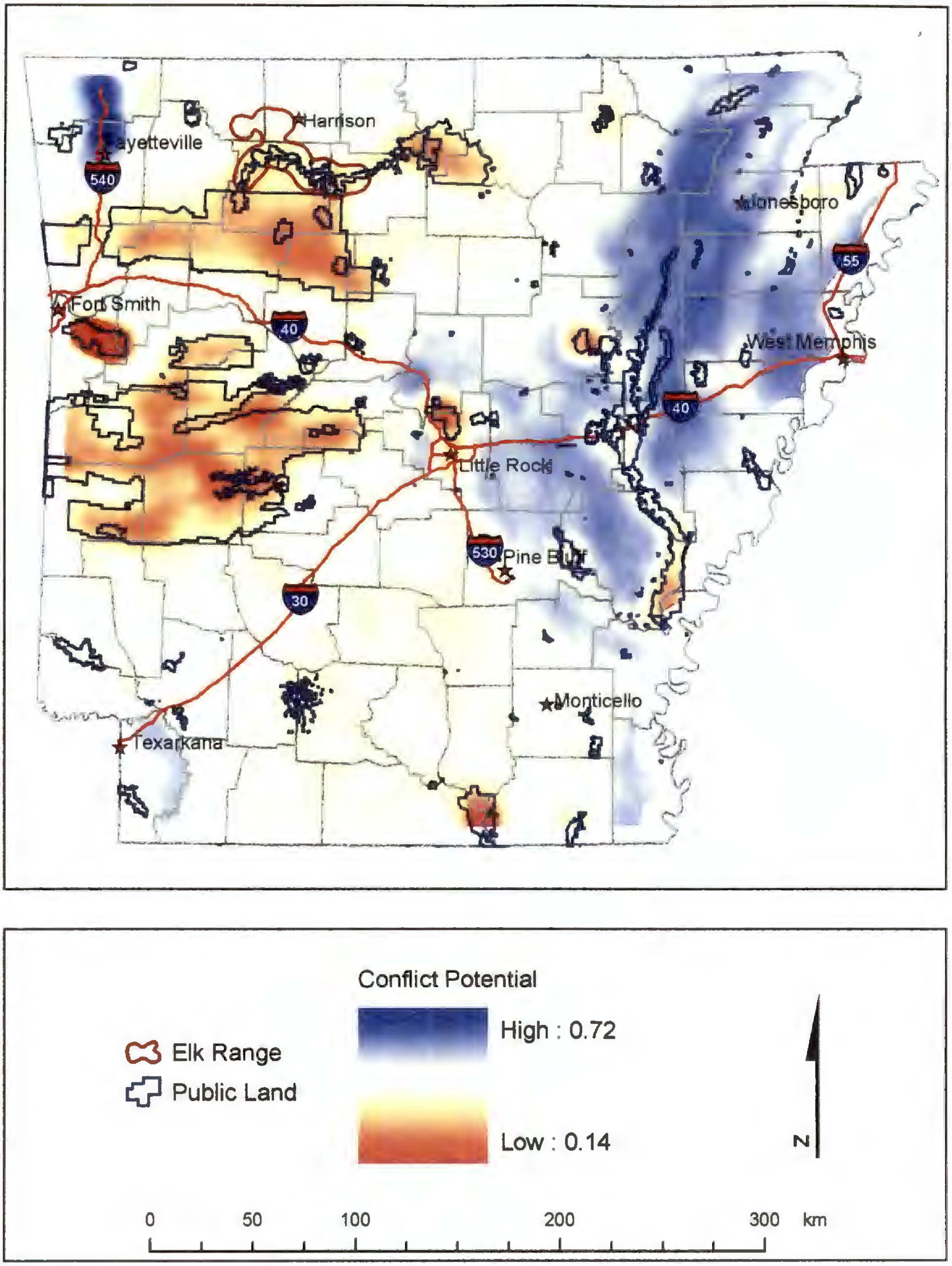

Fig. 28. Index of elk-human conflict potential in Arkansas, based on an expert-opinion survey of 5 Arkansas elk experts to create a linear summation of weighted landscape characteristics.

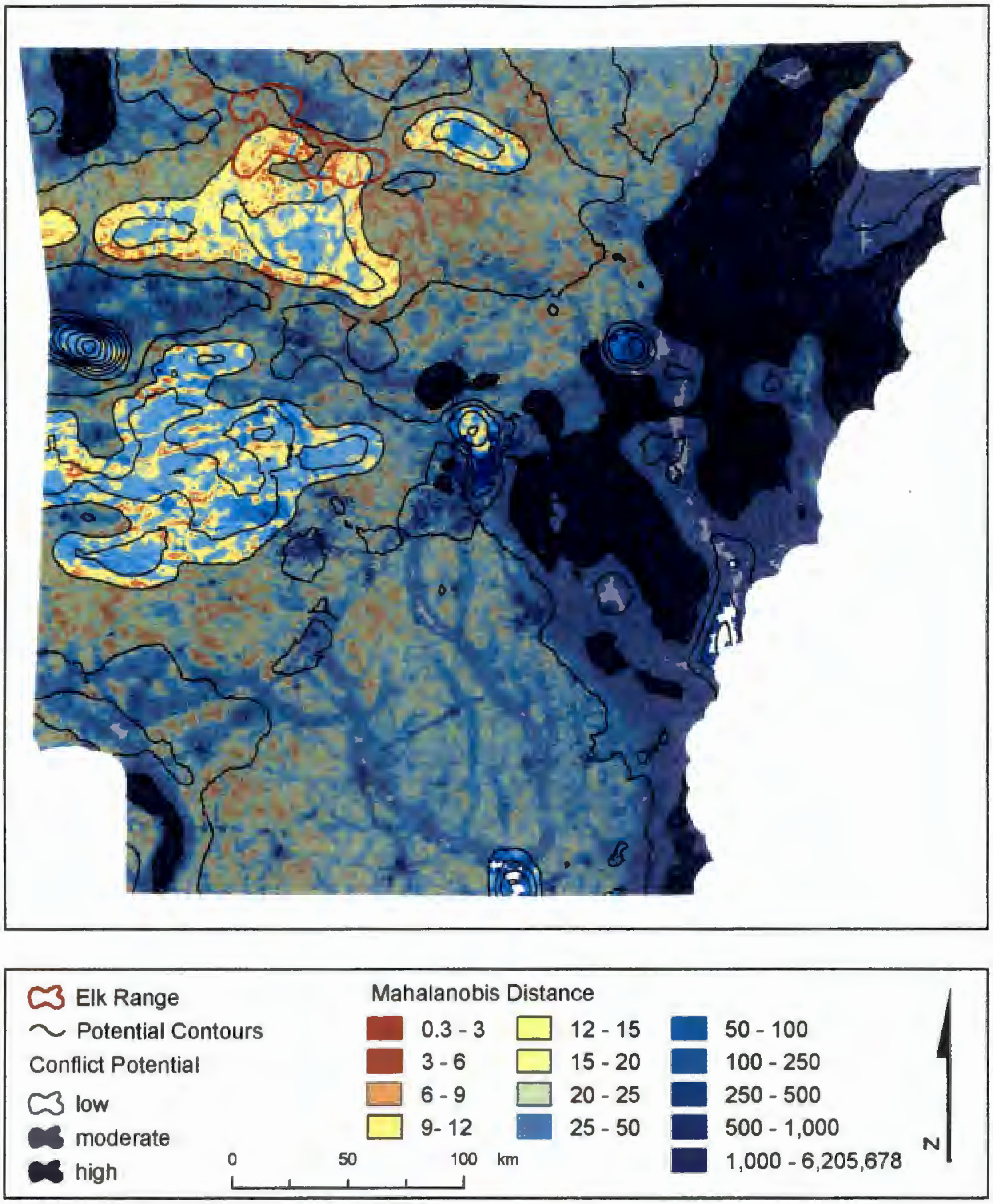

Fig. 29. Integrated map of winter habitat suitability and elk-human conflict potential to identify potential elk restoration sites in Arkansas. Mahalanobis distance values below 15 indicate suitable elk habitat. Contours are intervals of 6 standard deviations (SD) from the mean elk-human conflict potential for 4 radio-tracked nuisance cow elk in the Buffalo National River area, Arkansas. Low, moderate, and high conflict potential are indicated by shaded areas for values below, within, and above 6 SD from the mean conflict potential, respectively.

CHAPTER VI

DISCUSSION

HABITAT MODEL

Quantitative assessments of potential elk restoration sites in the eastern United States (e.g., Van Deelen et al. 1997, Didier and Porter 1999, Missouri Department of Conservation 2000) have been difficult to conduct because of the lack of appropriate empirical data. The elk population in the Buffalo National River area provided a good source of data for a habitat assessment because elk were common within their range, providing a relatively large (239 locations) dataset over a 10-year period from which to create the model. Corsi et al. (2000) stated that data availability and quality are the primary limiting factors of GIS-based models. However, coarse-scale GIS datasets were readily available for large extents and were appropriate for a statewide assessment of elk habitat. By creating landscape-scale variables with moving window analyses, I reduced the effect of spatial error on the habitat analysis because those variables characterized the landscape around locations rather than site-specific habitat conditions. In addition, the effect of misclassification errors in the spatial data were reduced because landscape measures were mainly calculated based on proportions rather than actual pixel values (Didier and Porter 1999). Reclassification of land-cover data into more general categories further reduced effects of misclassification error. Thus, the habitat suitability model likely was not sensitive to error associated with the elk locations or the GIS source data. The 90- x 90-m pixel resolution was appropriate to assess elk habitat given that elk tend to use habitat at relatively coarse scales and because the model was applied to the entire state.

Overall, the CART analysis was an effective data exploration procedure; 6 of 7 variables selected by the CART analysis were included in the habitat model. I included 3 additional habitat variables because of their biological relevance to elk, for a total of 9 variables used in the habitat model. Contagion of all natural cover types was the only variable selected by the CART model at the largest scale (80 km^2) and the variable was excluded from further analysis. In general, habitat variables calculated at that scale were highly correlated with each other and with variables calculated at other scales. Furthermore, the averaging effect of calculating habitat variables based on the large window area reduced overall heterogeneity among pixel values, thereby rendering the scale ineffective to characterize elk habitat use.

The presence of 3 scales in the model, representing local movements (0.2 km^2), winter home ranges (8 km^2), and largest seasonal home ranges (30 km^2), suggested that elk habitat selection was influenced by environmental conditions at different scales. Didier et al. (1999) also used 4 analysis scales (representing different home range sizes) in their assessment of potential elk restoration sites in New York. They generated a model at each window size; areas that were suitable at all 4 scales were considered as potential restoration sites (Didier et al. 1999). In contrast, I evaluated the most appropriate scale to evaluate each variable, resulting in a single model representing multiple scales of elk habitat selection.

Elk make broad use of all available habitats (Irwin and Peek 1983, Skovlin et al. 2002). Species with generalized habitat requirements can be more difficult to model than species with specific habitat requirements, because they occur in heterogeneous conditions (Boetsch et al. 2003). Indeed, Edge et al. (1987) found that elk habitat selection occurred at broad scales and that measures of surrounding habitat configuration and sources of human disturbance best characterized elk habitat use. Therefore, I attempted to incorporate variables in the model to capture such landscape pattern.

Elk in the Buffalo National River area seemed to be associated with measures of land-cover availability and spatial configuration, represented in the habitat model by 6 landscape pattern variables at 3 different scales. All landscape pattern variables in the model showed only low to moderate correlations ($|r| = 0.251–0.5933$). In the principal components analysis, those variables explained the most variation among elk-group locations, suggesting that elk habitat use was associated with landscape heterogeneity (Table 6).

The landscape pattern variables used in the habitat assessment measure similar aspects of the landscape, but have different biological interpretations based on the scale and land-cover classes involved. The perimeter-area ratio was calculated for all natural land types at the 8-km^2 scale (Appendix C). That habitat variable indicated the importance of borders among patches, regardless of land-cover type. I speculate that the finding reflects the importance of access to several important habitat types within home ranges. The border between forest and field may be particularly important at that scale, because those transition areas provide increased access to forage and security throughout the home range (Appendix C). Contagion of forests and fields was important at the local movement scale (0.2 km^2); during daily activities, elk were associated with smaller, interspersed patches of forest and field, providing direct access to forage and security cover (Wisdom et al. 1986) and greater diversity and quantity of food items (Skovlin et al. 2002). My study also showed that, at a coarse scale (30 km^2), elk used areas within an increasingly fragmented forest matrix (fractal dimension of forest; Appendix C).

The final 2 landscape pattern variables, fractal dimension of forest and field at the 8-km^2 scale, and forest density at the 30-km^2 scale, were included in the habitat model because of their probable biological relevance. Both variables were important to explain variation among the elk-group locations (Table 6). Krummel et al. (1987) found that the shape of smaller forest patches were simpler (lower fractal dimension) than larger ones because smaller patches likely are more influenced by human development. Similarly, Turner et al. (2001) suggested that fractal dimension is lower in human-dominated land-cover types, because areas of human influence tend to have simpler, more linear shapes. The mean fractal dimension of forest and field at the 8-km^2 scale was simpler than fractal dimension of forest at the coarser scale (30 km^2; Table 5), suggesting elk use of habitats improved by humans.

Finally, I chose to include forest density at the largest home range scale (30 km^2) because of the importance of forest for security cover. Measures of overall availability of a land-cover type, such as forest density, differ from measures of configuration. Because forest density was inversely related to field density ($r = -0.98$), it essentially represented the proportion of cover and forage within that analysis window. Forest density ranged from 51.8 to 95.6 ($\bar{x} = 84.1 \pm 8.8$), suggesting that elk were associated with fields within a forest background. Overall, the interspersion of land-cover types was important to elk, likely because it reduced the time and energy required to access various resources (Wisdom et al. 1986, Skovlin et al. 2002). Elk seemed to select for high forest density at broad scales, and a high interspersion of cover types, particularly forest and field, at more local scales.

Elk in the Buffalo National River area were associated with smaller densities of human populations and heavily traveled roads. Human population density was important at the local movement scale (Appendix C). Depending on the degree of disturbance, elk typically respond in the form of temporary, local shifts in movement (see Lyon and Christensen 2002 for review). Edge et al. (1985) found that cow elk did not shift or change size of home ranges during logging activities in Montana, but that localized change in habitat selection did occur. Although elk seemed to respond locally to human activity, I speculate that increasingly populated areas, such as the town of Harrison, limit elk movements and range expansion on a broader scale (Fig. 23).

Elk habitat assessments in New York and Missouri discounted areas 4–8 km from 4-lane highways (Didier and Porter 1999, Missouri Department of Conservation 2000). Didier and Porter (1999) suggested that 4-lane highways determined home range boundaries, and found that elk habitat suitability greatly increased in value and area when roads were excluded from their model. Consequently, although the variable was not identified in the CART analysis, I included density of heavily traveled roads (8-km^2 scale) in the elk habitat model (Appendix C). In general, elk groups were not found within 1,600 m of heavily traveled highways in the Buffalo River area.

Human disturbance variables exhibited more variation among the elk-group locations than landscape pattern variables (Table 6). High-quality forage and security cover adjacent to heavily traveled roads may outweigh the effects of human disturbance. For example, several elk groups were located <1,600 m from Route 7, within the Buffalo

National River boundaries (Fig. 23). However, both sides of the highway were bordered by highly suitable habitat, including several improved fields that provide high-quality forage. Cooper and Millspaugh (1999) found that elk were attracted to roadsides along lightly traveled roads where thinning had improved forage quality. Elk habituation to human activity may also have contributed to the larger variation in human disturbance variables. Thompson and Henderson (1999) suggested that habituation can be an advantage to elk in winter in habitats fragmented by human development. Although the elk herd in the Buffalo National River area is hunted, relatively few permits are issued annually. Furthermore, elk interactions with the large number of annual visitors to the Buffalo National River (an average of 811,629 visitors annually since 1991; Public Use Statistics Office 2002) generally are non-threatening. Therefore, the effects of human disturbance on elk habitat use may be mitigated in areas providing high-quality resources and limited negative interactions with humans. However, elk habituation to human activity may increase the potential for elk-human conflict.

Mean percent slope was important to elk habitat use at the local scale (0.2 km^2). Elevational gradients likely provide a wide range of habitats and forage opportunities for elk; at broader spatial scales, such patterns would become less evident. Elk in the Buffalo National River area were associated with the gentler slopes of ridge tops and valleys (Appendix C). Johnson et al. (2000) found that elk habitat use in northeastern Oregon was negatively associated with percent slope. Additionally, slope was the most important variable in a summer habitat model in Montana (Edge et al. 1987), with elk selecting gentle slopes.

The comparison of cumulative frequency distributions of elk-group and random locations indicated that the model successfully identified site characteristics associated with elk presence. Because the random locations were selected within the average home range of elk groups (i.e., already suitable habitat), that comparison provided a conservative measure of the model's ability to identify elk habitat within the Buffalo National River. Thus, elk in the Buffalo National River area selected a narrow range of habitat characteristics from habitat available in the landscape.

Relatively few elk habitat models have been tested with independent field data (Roloff et al. 2001, Skovlin 2002). Model testing with independent data is essential to identify biases in the original data and to test the ability of the model to correctly predict suitable and unsuitable sites (Boetsch et al. 2003). Despite several potential biases associated with the design of the helicopter surveys, the original dataset of elk-group locations was relatively unbiased. Results of the transect surveys consistently showed low elk use in areas with low habitat suitability, but substantial variation in elk use along transects in suitable sites. Such a pattern is typical for highly mobile and gregarious species, because not all good habitat areas can be used at once. Thus, variation of elk use in areas of high suitability does not necessarily reflect an inability of the model to predict suitable elk habitat. Although independent data were collected to test the model within the current elk range, the test results cannot be used to assess whether the model is appropriate for the remainder of the state. However, the model was based on landscape measures that were created so that the range of values within the current elk distribution reflected the range of values throughout the state.

Pixels in which pellet groups were present had a slightly smaller mean Mahalanobis distance (7.8 ± 5.4) and cumulative distribution than pixels in which original elk groups were present (13.7 ± 9.8). The regression analysis demonstrated that elk presence was more likely in areas with lower values of D^2 (Fig. 24). That test of model performance likely was conservative because all transects were located within the range of D^2 values associated with elk-group locations. Considering that elk habitat selection likely is influenced by factors other than habitat characteristics (e.g., behavior, herd demographics) the regression equation explained a sufficient amount of variation (Morrison et al. 1992).

Because different combinations of habitat conditions can produce equivalent D^2 values, it is difficult to interpret which variables are contributing to habitat suitability. In addition, although D^2 values ≤ 15 may indicate more suitable winter elk habitat, the model has a continuous range of values so that no clear delineation exists between suitable and unsuitable habitat. However, the results of my study generally indicate that more suitable elk habitat was associated with areas of high landscape heterogeneity, heavy forest cover, and gentle sloping ridge tops and valleys. Less suitable habitat was associated with middle elevations with steeper slopes, large tracts of agricultural land, and human development. Areas of intensive agriculture in the Mississipppi River Delta generally were least suitable. The largest contiguous regions of more suitable habitat were associated with public land borders (forest-field edge with private land) in western and northwestern Arkansas, where human population and road densities also were relatively low (Fig. 22).

ELK-HUMAN CONFLICT MODEL

In a comparison of an expert-opinion model, an expert-literature model, and an empirically-based model using discriminant function analysis, Clevenger et al. (2002) found that the expert-opinion model did not approximate the empirical model as well as the expert-literature model. However, little expert literature is available on eastern elk because few eastern populations have been re-established. Furthermore, managers in Arkansas likely would provide a better assessment of elk-human conflict criteria related to land management priorities in Arkansas. Consistency ratios were <0.10 except for the land ownership sub-criteria (consistency ratio = 0.17). However, that is an acceptable level of inconsistency considering the difficulty in conceptualizing the spatial criteria being compared.

Regions with a greater potential for elk-human conflict included cities, road corridors with a high rate of population growth, and areas of intensive agriculture. Most areas with lower elk-human conflict potential (0.14–0.49) were within public land boundaries. However, when Fort Chaffee was excluded, elk-human conflict potential on public land only ranged from 0.33 to 0.49 (Figs. 29 and 30). The lack of other areas with low elk-human conflict values may be due to the measure of forage availability on public land, which had the strongest influence in the model (32.7%). That variable was represented based on a simple measure of field density within the analysis window (300 km^2). Fort Chaffee had far greater amounts of open fields (54%) compared with, for example, the Ouachita National Forest (2%). However, many other land cover types also provide forage on public land. Factors such as forest type, canopy cover, basal area, and silivicultural treatments of forest stands also affect the amount of forage available, but

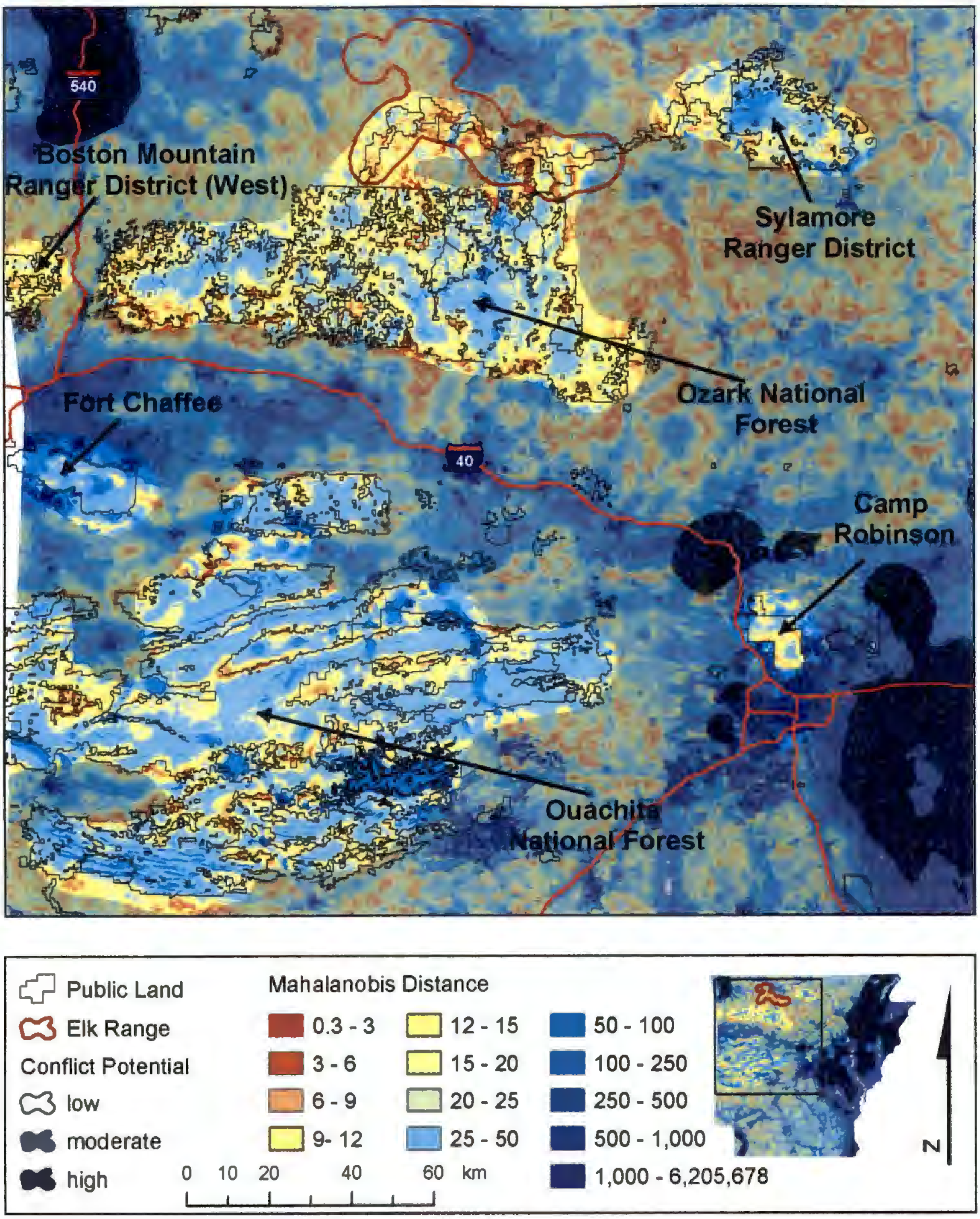

Fig. 30. Potential elk restoration regions in Arkansas, based on winter elk habitat suitability and elk-human conflict potential. Mahalanobis distance values below 15 indicate suitable elk habitat. Low, moderate, and high conflict potential are indicated by shaded areas for values below, within, and above 6 SD from the mean conflict potential, respectively.

could not be measured with available spatial data. Moreover, forage quality may be more important than forage quantity. Food availability generally is not limiting except during severe winter conditions (Wisdom et al. 1986). Despite sufficient forage availability, public lands in Arkansas may not be able to retain elk in winter because they lack the fertilized, cool-season grasses planted in private pastures that are attractive to elk (M. Cartwright, AGFC, personal communication).

I evaluated the influence of forage availability on public lands by comparing model outcomes with and without the public land forage variable. The contours produced were nearly identical, but the range of values was lower for the model that excluded forage availability on public lands (0.09–0.58 vs. 13.9–71.9). Because open forage areas on most public lands are limited, the public land forage variable essentially increased elk-human conflict potential only on public lands. A forage measure that would better assess the availability of forage on public lands would be helpful to better determine the influence of that variable on elk-human conflict potential.

The expert group suggested that private industrial forest land be considered separately from private and public lands in the elk-human conflict model. Arkansas contains large tracts of private industrial timberland, particularly in western and southern portions of the state. Experts decided that private industrial timberland is similar to public land when evaluating for elk-human conflict, but may provide more forage because of silvicultural treatments. However, I could not add that component to any assessment of elk-human conflict potential because no dataset existed to delineate private timberland in the state.

IDENTIFYING ELK RESTORATION SITES

Several elk habitat assessment studies have used a similar 2-step method of quantifying suitable elk habitat and then discounting areas with high potential for elk-human conflict (Roloff 1997, Van Deelen et al. 1997, Didier and Porter 1999, Missouri Department of Conservation 2000). The models in my study were constructed based on continuous variables, without attempting to delineate distinct patches of suitable habitat or low potential conflict with humans. Defining such patches often is a subjective process and implies the existence of suitable areas within a non-suitable landscape, rather than suitability gradients. The combined results of the models in my study provide managers with a continuous range of options to identify elk restoration sites (Fig. 29). Therefore, it is important to note that indicator values, such as D^2 values <15 or contours representing levels of elk-human conflict potential, are merely guidelines to identify areas with the most suitable habitat and lowest elk-human conflict potential. As such, managers have the flexibility to consider factors other than trade-offs between habitat suitability and conflict potential to find the most appropriate areas for elk restoration.

CHAPTER VII

MANAGEMENT IMPLICATIONS

I identified 4 general regions for potential elk restoration in Arkansas that have both a lower potential for elk-human conflict and higher winter habitat suitability; these regions primarily coincide with public land areas (Fig. 30). I excluded Fort Chaffee from consideration because despite having the lowest potential for elk-human conflict, the region has little suitable elk habitat. In addition, the military installation is gradually being phased out and sold to private developers. I also excluded Camp Robinson because the region is close to the metropolitan area of Little Rock, contains relatively few areas of suitable elk habitat, and is isolated within areas of highly unsuitable habitat. Therefore, 4 regions containing the following public lands could be considered for potential elk restoration: the Boston Mountain Ranger District (West) of the Ozark-St. Francis National Forest, the Sylamore Ranger District of the Ozark-St. Francis National Forest, the main body of the Ozark-St. Francis National Forest (i.e., Bayou, Buffalo, Pleasant Hill, and Boston Mountain [East] ranger districts), and the entire Ouachita National Forest (Fig. 30). Most of the public land in those 4 regions is managed by the U.S. Forest Service.

In general, regions identified for potential elk restoration in the Ozark-St. Francis National Forest consist of larger, more contiguous areas with higher habitat suitability than that found in the Ouachita National Forest. However, the Ouachita National Forest region may have a lower potential for elk-human conflict because large private inholdings and large areas adjacent to the national forest belong to private timber companies. In all regions, habitats identified for potential elk restoration generally exist on the borders of private and public land; relatively little habitat exists within the public land interiors, where elk-human conflict potential is lowest (Fig. 30). If elk initially are released in an area of relatively suitable habitat and low conflict potential, they may readily move into more optimal habitats. Management practices within restoration areas should focus on providing abundant high-quality winter forage to limit such expansion.

Many factors must be considered when identifying potential restoration sites for elk based on the habitat assessment. I delineated 6 focal areas within the 4 previously identified regions of high habitat suitability and low elk-human conflict potential to identify and compare several of those factors, and to provide suggestions for interpretation of the habitat assessment maps (Figs. 31 and 32). Three of those focal areas are located in northwestern Arkansas and associated with the following Ozark-St. Francis National Forest ranger districts: Boston Mountain (West), Bayou, and Sylamore.

The Boston Mountain area consists of a contiguous core area of more suitable elk habitat (Fig. 31). However, the public land area is relatively small (approximately 400 km^2), and is bounded to the East and South by Interstate highways. In addition, the Fayetteville metropolitan area, just north of the Boston Mountain area, is one of the fastest growing human population areas in Arkansas (Fig. 18). Future development to accommodate human population growth south of that metropolitan area likely would further isolate the Boston Mountain area. Although the 400-km^2 area may be large enough to establish an elk population, the potential for ultimate isolation because of human development may severely limit elk range expansion and population growth.

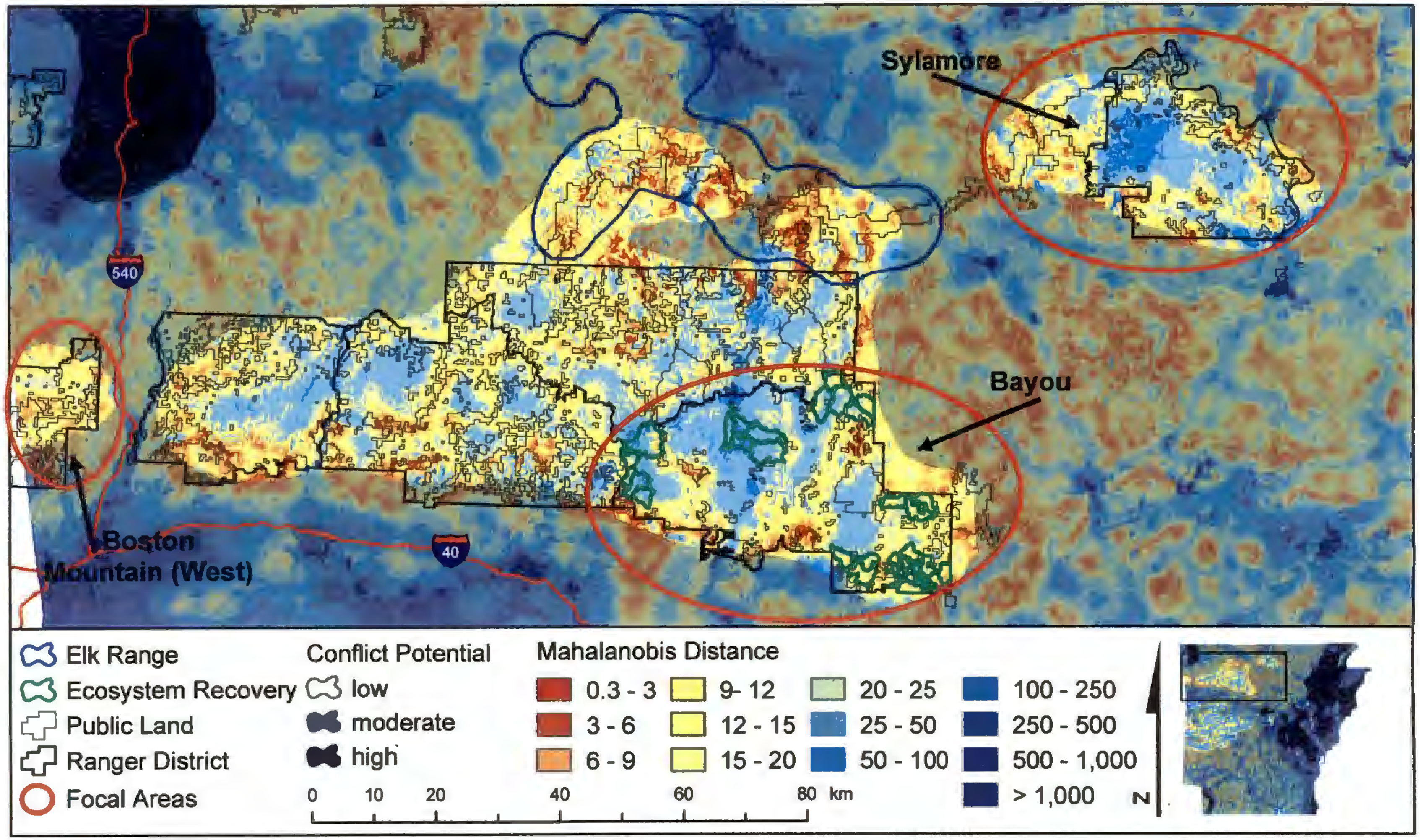

Fig. 31. Integrated map of winter elk habitat suitability and elk-human conflict potential to identify potential elk restoration sites in the Ozark-St. Francis National Forest, Arkansas. Mahalanobis distance values below 15 indicate suitable elk habitat. Low, moderate, and high conflict potential are indicated by shaded areas for values below, within, and above 6 SD from the mean conflict potential, respectively.

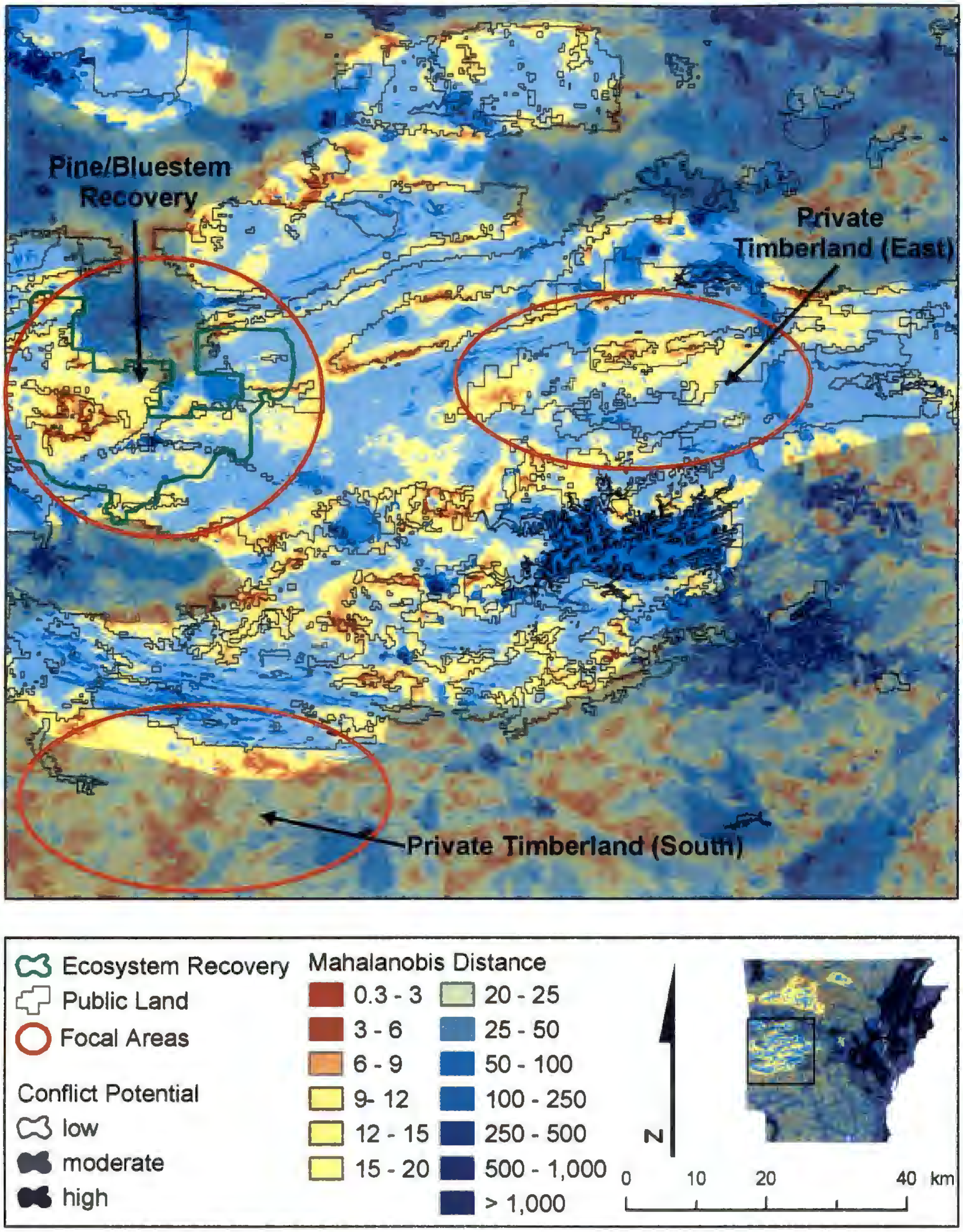

Fig. 32. Integrated map of winter elk habitat suitability and elk-human conflict potential to identify potential elk restoration sites in the Ouachita National Forest, Arkansas. Mahalanobis distance values below 15 indicate suitable elk habitat. Low, moderate, and high conflict potential are indicated by shaded areas for values below, within, and above 6 SD from the mean conflict potential, respectively.

The Sylamore focal area includes the Sylamore Ranger District and the Lower Buffalo Wilderness Area of the Buffalo National River, encompassing approximately 780 km^2 of public land (Fig. 31). Although the area is larger than the Boston Mountain area and has no obvious barriers to range expansion, higher elk habitat suitability is more associated with the public/private land border. Large, contiguous blocks of suitable habitat extend from that border into surrounding private lands of increasing elk-human conflict potential. Because less suitable habitat exists in the core public land area, elk may expand their range onto those private lands. The Sylamore area is relatively close to the current elk range; elk restoration to this area could ultimately result in exchange among the two populations.

The Bayou focal area includes the Bayou Ranger District, with an area of approximately 1,204 km^2 (Fig. 31). The ranger district contains relatively small areas of more suitable elk habitat associated with private inholdings and a larger area of more suitable habitat in the southeastern portion. However, that area is part of a larger region of highly suitable habitat in Arkansas, extending northeast onto private land with increased potential for elk-human conflict. The U.S. Forest Service recently began a long-term project using controlled burns to restore 218 km^2 of the Bayou Ranger District to the fire-dependent ecosystems that existed prior to European settlement (U.S. Forest Service, Hector, Arkansas, unpublished report). Six ecosystem restoration areas were established throughout the Ranger District, ranging in size from 20 to 46 km^2. Those burns will increase the interspersion and diversity of land-cover types and provide more early successional forage within the ranger district, possibly increasing elk habitat suitability and reducing elk movements onto private land.

The Shortleaf Pine/Bluestem Recovery area includes an ecosystem restoration site of approximately 625 km^2 in the Ouachita National Forest (Fig. 32; Bukenhofer et al. 1994). Similar to the Bayou Ranger District, forest managers are using fire disturbance and an extended forest rotation to restore and maintain the ecosystem, creating a mature shortleaf pine dominated forest with an open understory comprised of bluestem grasses and a variety of forbs. Unlike the Bayou Ranger District, this is a single large area of ecosystem recovery, creating a larger area of potential forage, but with less interspersion of dense forest patches for security cover. Because private land north and south of the recovery area has relatively low habitat suitability, movements beyond public land borders are less likely.

Finally, I examined 2 focal areas mainly comprised of private industrial forest (Fig. 31). The private forest in the eastern portion of the Ozark-St. Francis National Forest consists of relatively moderate-sized patches of more suitable elk habitat. The area is completely encompassed by the Ouachita National Forest so range expansion would not substantially increase elk-human conflict. However, the area is relatively isolated by heavily traveled highways and regions of less suitable elk habitat. In contrast, the private timberland area just south of the Ouachita National Forest consists almost entirely of a single patch of suitable elk habitat that continues to the East and South. The area borders public land to the North but habitat suitability is relatively poor. Both industrial forest areas have a dense system of undeveloped roads resulting from intensive logging (Fig. 19). Although logging practices create a mosaic of land-cover types at various successional stages, they may also limit use of highly suitable elk habitat due to human disturbance (see review by Lyon and Christensen 2002)

Although my habitat assessment provides a tool for natural resource managers to identify potential sites for elk restoration, many other aspects must be considered prior to elk restoration such as initial and long-term management costs, long-term management goals, public attitude, and disease transmission (Witmer 1990). Positive public support may allow regions of highly suitable habitat but increased elk-human conflict potential to be considered for elk restoration or range expansion, such as the large region northeast of the Bayou Ranger District (Fig. 31). Regions with relatively high deer densities should also be evaluated for the potential effects of meningeal worm (*Parelaphostrongylus tenuis*) infection on elk restoration. In addition, patterns of human development should be further examined to indicate future range restriction and subsequent increases in elk-human conflict.

The spatial configuration of highly suitable elk habitat with private agricultural lands suggests that crop and pasture damage may be a considerable challenge to elk restoration (Van Deelen et al. 1997). Openings and early-successional understories created in ecosystem restorations may provide an abundance of high-quality warm-season forage but not enough high-quality winter forage. Managers may consider maintaining openings of cool-season grasses and forbs on public lands to reduce the potential for crop and pasture depredation. Overall, the successful establishment of additional elk populations will require cooperation among multiple agencies and landowners to coordinate protection, management, and control of reintroduced elk herds.

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APPENDICES

Appendix A. Landscape measures used to characterize elk habitat in Arkansas.

Table A.1. Landscape measures used to characterize elk habitat in Arkansas.

Measure[a]	Calculation	Units	Range
Percent land-cover class Percentage of landscape in a given cover class	$P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$ P_i = proportion of the analysis window comprised of class i a_{ij} = area of patch ij A = total window area	%	$0 \le P_i \le 100$
Simpson's diversity Probability that any 2 pixels selected at random would be different patch types	$SIDI = 1 - \sum_{i=1}^{m} P_i^2$ P_i = proportion of the analysis window comprised of class i m = number of classes present in the window	none	$0 \le SIDI < 1$
Simpson's evenness Evenness of distribution of area among patch types	$SIEI = \frac{1 - \sum_{i=1}^{m} P_i^2}{1 - \left(\frac{1}{m}\right)}$ P_i = proportion of the analysis window comprised of class i m = number of classes present in the window	none	$0 \le \text{SIEI} \le 1$

Table A.1. Continued.

Measure[a]	Calculation	Units	Range
Patch density Patch density of a given cover class	$PD = \frac{n_i}{A}(1{,}000{,}000)$ n_i = number of patches in the analysis window of class i A = total window area	patches /km^2	PD > 0, constrained by cell size
Edge density Edge density of a given cover class	$ED = \frac{\sum_{k=1}^{m} e_{ik}}{A}(10{,}000)$ e_{ik} = total length of edge in the analysis window involving class i A = total window area	m/ha	$ED \geq 0$, without limit
Perimeter-area ratio, area-weighted mean A measure of shape complexity equal to the ratio of the patch perimeter to patch area	$PARA = \sum_{j=1}^{n}\left[\frac{P_{ij}}{\sum_{j=1}^{n} a_{ij}}\right]$ P_{ij} = perimeter of patch ij a_{ij} = area of patch ij	none	$PARA > 0$

Table A.1. Continued.

Measure[a]	Calculation	Units	Range
Fractal dimension index, area-weighted mean A scale-independent measure of shape complexity	$FRAC = \sum_{j=1}^{n}\left[\frac{2\ln(0.25p_{ij})}{\ln a_{ij}}\left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}\right)\right]$ p_{ij} = perimeter of patch ij a_{ij} = area of patch ij	none	$1 \le FRAC \le 2$,
Percentage of like adjacencies Percentage of cell adjacencies between pixels for class i that are like adjacencies	$PLADJ = \frac{g_{ii}}{\sum_{k=1}^{m} g_{ik}}(100)$ g_{ii} = number of like adjacencies between pixels of class i g_{ik} = number of adjacencies between pixels of classes i and k	%	$0 \le PLADJ \le 100$

Table A.1. Continued.

Measure[a]	Calculation	Units	Range
Contagion The observed contagion over the maximum possible contagion for a given number of patch types	$$CONTAG = \left[1 + \frac{\sum_{i=1}^{m}\sum_{k=1}^{m}\left[P_i \left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}} \right) \right] \left[\ln P_i \left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}} \right) \right]}{2\ln(m)} \right](100)$$ P_i = proportion of the analysis window comprised of class i g_{ik} = number of adjacencies between pixels of classes i and k m = number of classes present in the window	%	$0 < CONTAG \leq 100$,

Table A.1. Continued.

Measure[a]	Calculation	Units	Range
Interspersion and juxtaposition index The observed interspersion divided by the maximum possible interspersion for a given number of patch types	$$IJI = \frac{-\sum_{k=1}^{m}\left[\left(\frac{e_{ik}}{\sum_{k=1}^{m} e_{ik}}\right)\ln\left(\frac{e_{ik}}{\sum_{k=1}^{m} e_{ik}}\right)\right]}{\ln(m-1)}(100)$$ e_{ik} = total length of edge in the analysis window between classes i and k m = number of classes present in the window	%	$0 < IJI \leq 100$,
Mean percent slope Mean percent slope within the analysis window	$$SLOPE = \frac{\sum_{i=1}^{n} x_i}{n}$$ x_{ij} = percent slope for pixel i n_i = number of pixels	%	$SLOPE \geq 0$

Table A.1. Continued.

Measure[a]	Calculation	Units	Range
Mean human density Mean human density within the analysis window	$$HUMAN = \frac{\sum_{i=1}^{n} x_i}{n}$$ x_{ij} = human population density for pixel i n_i = number of pixels	people /ha	$HUMAN \geq 0$
Road density Road density within the analysis window	$$ROAD = \frac{\sum_{k=1}^{m} r_{ik}}{A}(1{,}000{,}000)$$ r_{ik} = total length of road in analysis window involving class i A = total window area	m/km^2	$ROAD \geq 0$

[a]All measures, except mean slope, mean human density, and road density, are from McGarigal et al. (2002). McGarigal et al. (2002) provide more detailed explanations of the calculations, uses, and limitations of these measures.

Appendix B. Expert survey to rank the importance of factors influencing the potential for elk-human conflict in Arkansas.

EXPERT OPINION SURVEY

Background

An elk-human conflict model will be developed using the Analytic Hierarchy Process, a decision-making tool that is used commonly in the business world and increasingly in natural resources. This process helps make decisions when the criteria for the decision are difficult to quantify. In this case, the overall goal is to decide which areas in Arkansas would have the least potential for elk-human conflict.

A group of experts meet to fill out a survey to rank the importance of criteria affecting the potential for elk-human conflict, such as human population growth or public land area. Although many factors are important to elk-human conflict, this model will be limited to those that can be derived from already existing map data. Thus, some criteria, such as public attitude, currently cannot be assessed.

In the survey, each factor will be compared against every other factor to determine which factor is more important, and the degree of importance. Because the process is hierarchical, these comparisons will be made in sections, first comparing main criteria, and then subsequent criteria. After the survey is completed, these ranks are turned into weights that are multiplied by GIS layers representing the criteria, resulting in a map ranking elk-human conflict potential throughout the state -- this final step is similar to the final step in an HSI model.

Objective

To rank factors that evaluate the potential for elk-human conflict based on their importance.

Criteria

Criteria are described in detail under each section of the survey. All criteria were generated using a moving-window analysis, with a circular window size of 30,000 ha (equivalent to 74,132 ac or 116 mi^2). This area has been considered in the literature to be the minimum area needed to support a viable population of reintroduced elk. This means that on the map layers that represent each criteria, the value of each pixel represents an evaluation of a 30,000-ha area around that pixel. For example, on a map layer representing private land, a grid cell value of 2000 means that 2000 ha of private land are present within a 30,000 ha circle around that cell.

Instructions

For each section, read the definitions of the criteria and the perspective statement. This perspective statement is particularly important because comparisons can be heavily affected by your point of view. Then, for each criteria comparison, mark the box below the variable which you decide is more important. Finally, circle the number for each comparison that represents the degree of importance of that variable.

Importance ratings are on a 9-point continuous scale:

1 **Equal importance** = both factors contribute equally to the objective

2

3 **Moderately more important** = experience or judgment favors the selected factor

4

5 **Strongly more important** = experience or judgment strongly favors the selected factor

6

7 **Very strongly more important** = dominance of the selected factor is strongly demonstrated in practice

8

9 **Extremely more important** = dominance of the selected factor is of the highest possible order

MAIN CRITERIA

Description of Main Criteria

- **Land Ownership**

  Definition: This main criterion includes measurements based on public and private land ownership, including size and shape of public land, private land-use type, and forage availability on public land.

  Issue: Do factors related to public and private landownership influence the potential for elk-human conflict?

- **Human Development**

  Definition: This main criterion includes measurements of human activity, including human growth rate and road density.

  Issue: Do factors related to human development influence the potential for elk-human conflict?

Perspective

Overall, which main criteria do you think is more likely to influence the potential for elk-human conflict in elk restoration areas in Arkansas?

Which criteria is more important?	**To what degree?**
Land ownership *OR* human development? ☐ ☐	1 2 3 4 5 6 7 8 9

SUB CRITERIA 1: LAND OWNERSHIP

Land Ownership

Measurements based on private and public land ownership.

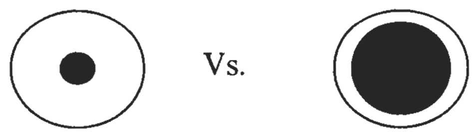
Description of Site Characteristics

- **Private Land Area**

  Definition: Amount of private land (ha) within a 30,000-ha window.

  Issue: Does increased area of private land in elk reintroduction areas influence the potential for elk-human conflict?

  Example:

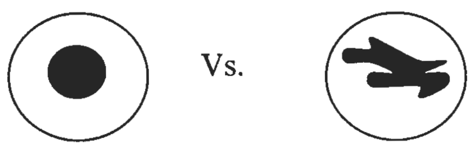


- **Private Land Shape Complexity**

  Definition: Measure of shape irregularity and edge complexity of the public land within a 30,000-ha window.

  Issue: Does increasing the length of border between public and private land influence the potential for elk-human conflict?

  Example:



- **Forage on Public Land**

  Definition: Amount of forage (ha) available on public land within a 30,000-ha window. Forage areas may include improved and unimproved pastures, grasslands, hay fields, and clearcuts.

  Issue: Does increasing forage available on public land influence elk movement onto private land, thereby influencing the potential for elk-human conflict?

SUB CRITERIA 1: LAND OWNERSHIP (CONTINUED)

- **Private Land Use**

  Definition: Percent of private land use by type within a 30,000-ha window, including forest, hay crops/pasture land, and row crops (palatable to elk).

  Issue: Does the type of private land use influence the potential for elk-human conflict?

Perspective

Which criteria of land ownership do you think is more likely to influence the potential for elk-human conflict on elk restoration areas in Arkansas?

Which criteria is more important?	**To what degree?**
Private land area *OR* private land shape? ☐ ☐	1 2 3 4 5 6 7 8 9
Private land area *OR* public land forage? ☐ ☐	1 2 3 4 5 6 7 8 9
Private land area *OR* private land use? ☐ ☐	1 2 3 4 5 6 7 8 9
Private land shape *OR* public land forage? ☐ ☐	1 2 3 4 5 6 7 8 9
Private land shape *OR* private land use? ☐ ☐	1 2 3 4 5 6 7 8 9
Public land forage *OR* private land use? ☐ ☐	1 2 3 4 5 6 7 8 9

SUB CRITERIA 2: LAND-USE TYPES

Land-use Type

Percent of private land use by type within a 30,000-ha window.

Description of Site Characteristics

- **Forest**

  Definition: Amount of private land in timberland and woodland within a 30,000-ha window

  Issue: Does the amount of forest on private land influence the potential for elk-human conflict?

- **Hay Crop/Pasture**

  Definition: Amount of private land used for grazing or planted in hay within a 30,000-ha window.

  Issue: Does the amount of hay crop or pasture on private land influence the potential for elk-human conflict?

- **Row Crop**

  Definition: Amount of private land planted row crops palatable to elk (e.g. soy beans, corn) within a 30,000-ha window.

  Issue: Does the amount of palatable row crops on private land influence the potential for elk-human conflict?

SUB CRITERIA 2: LAND-USE TYPES (CONTINUED)

Perspective

Which private land-use type do you think is more likely to cause elk-human conflict in elk restoration areas in Arkansas?

Which criteria is more important?	**To what degree?**
Forestry *OR* hay crop/pasture? ☐ ☐	1 2 3 4 5 6 7 8 9
Forestry *OR* row crops? ☐ ☐	1 2 3 4 5 6 7 8 9
Row crops *OR* hay crop/pasture? ☐ ☐	1 2 3 4 5 6 7 8 9

SUB CRITERIA 1: HUMAN DEVELOPMENT

Human Development

Measurements of human activity.

Description of Site Characteristics

- **Population Growth**

  Definition: Average rate of human population growth (%) over the past ten years within a 30,000-ha window.

  Issue: Will increased population growth over the next ten years influence the potential for elk-human conflict?

- **Road Density**

  Definition: Density of all road types (km/km^2) within a 30,000-ha window.

  Issue: Does increased road access in elk restoration areas influence the potential for elk-human conflict?

Perspective

Which land-use characteristic do you think is more likely to cause elk-human conflict in elk restoration areas in Arkansas?

Which criteria is more important?	**To what degree?**
Population growth *OR* road density? ☐ ☐	1 2 3 4 5 6 7 8 9

Appendix C. Habitat variables characterizing elk-group locations in the Buffalo National River area, Arkansas, collected by the Arkansas Game and Fish Commission, February–March, 1992–2002.

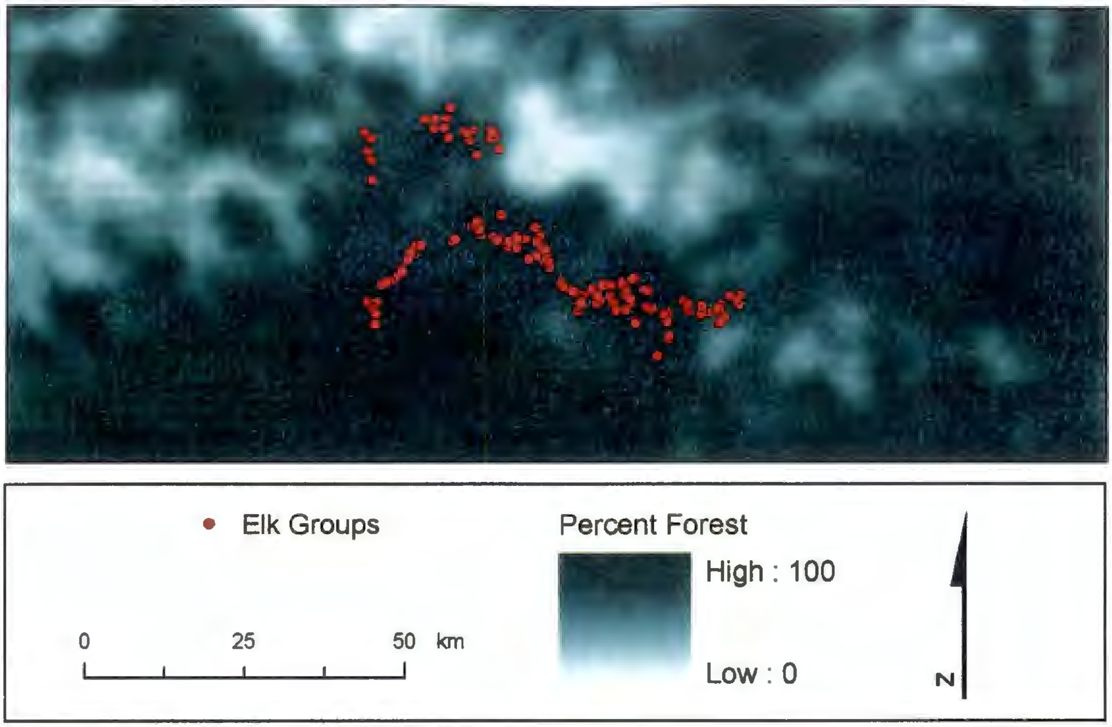


Fig. C.1. Percent forest in the Buffalo National River area, Arkansas (30-km^2 scale).

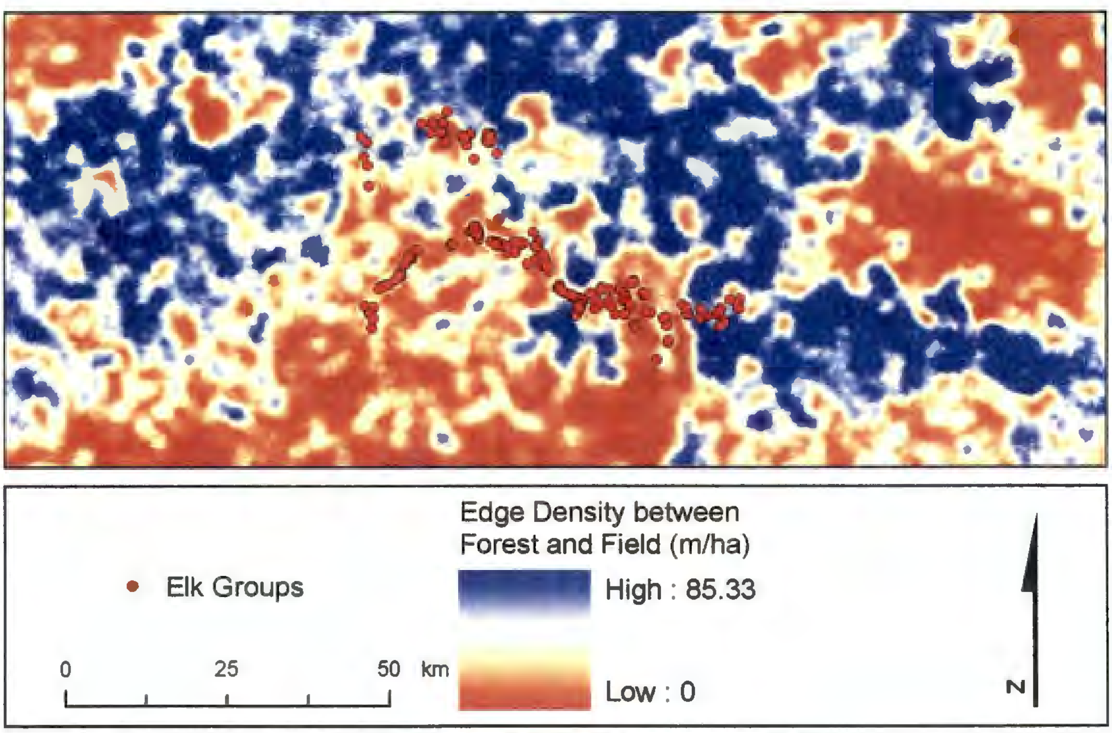


Fig. C.2. Edge density between forest and field in the Buffalo National River area, Arkansas (8-km^2 scale).

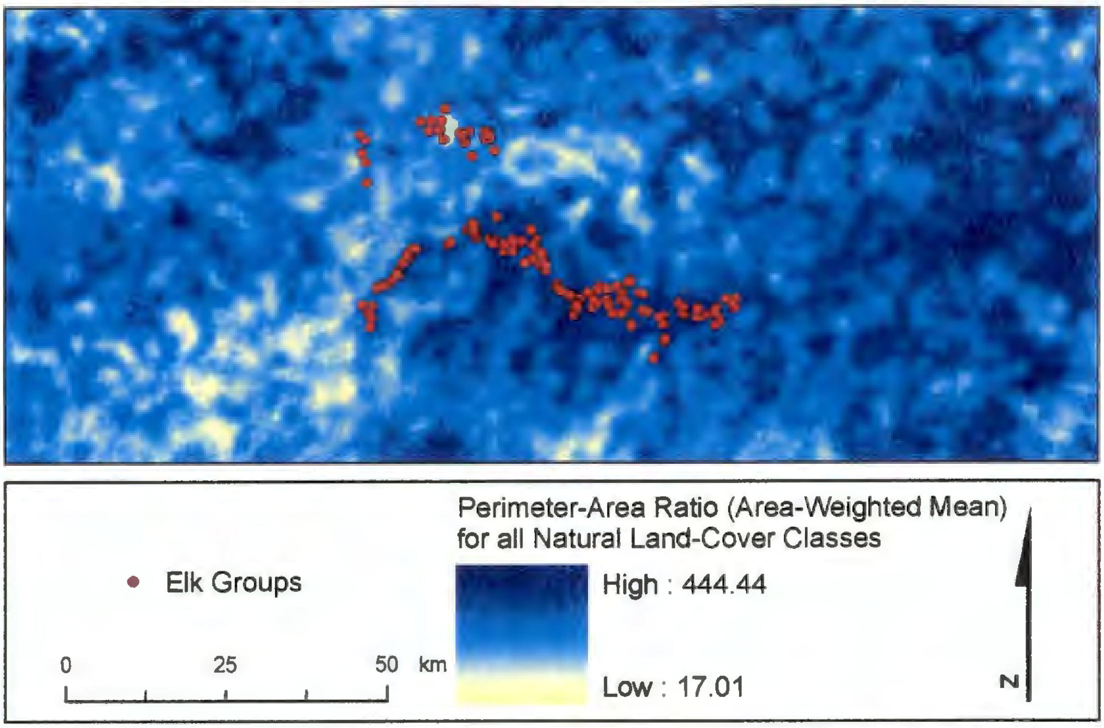


Fig. C.3. Perimeter-area ratio for all natural land-cover classes in the Buffalo National River area, Arkansas (8-km^2 scale).

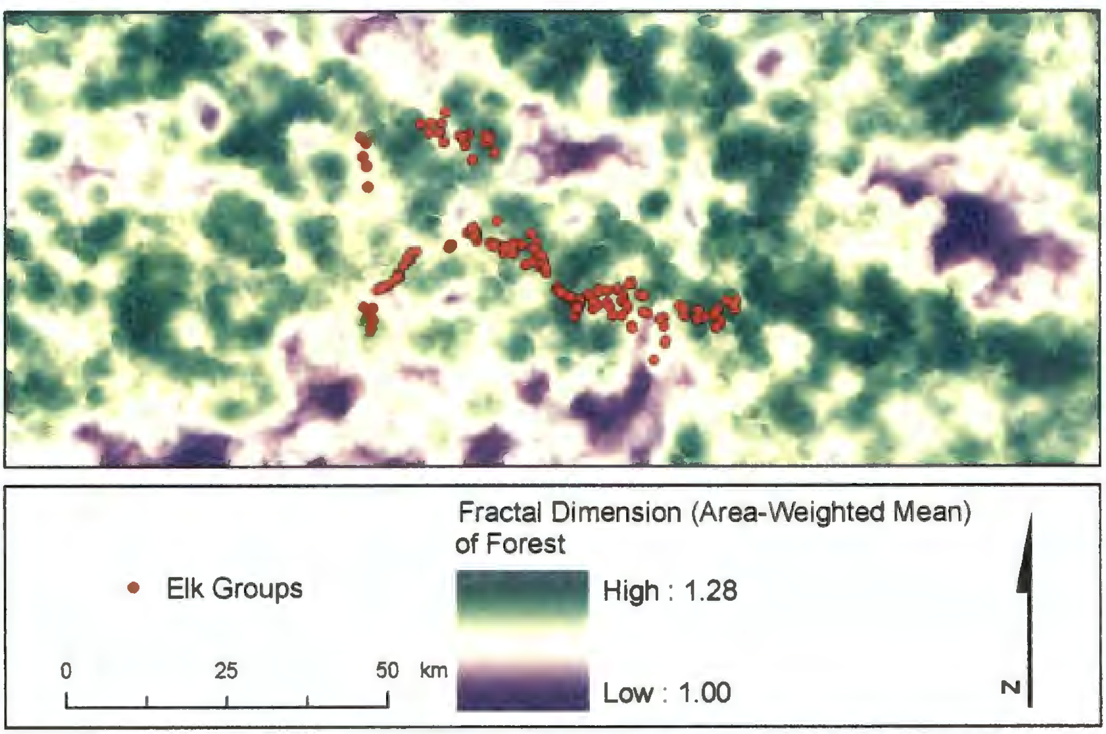


Fig. C.4. Fractal dimension of forest in the Buffalo National River area, Arkansas (30-km^2 scale).

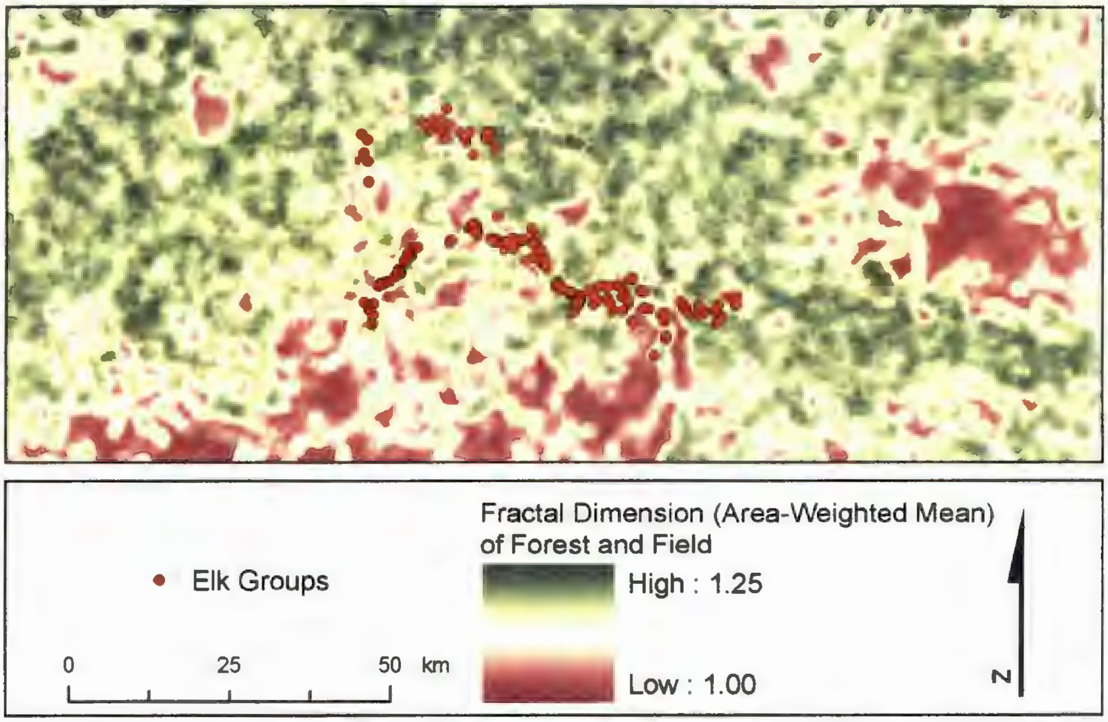


Fig. C.5. Fractal dimension of forest and field in the Buffalo National River area, Arkansas (8-km^2 scale).

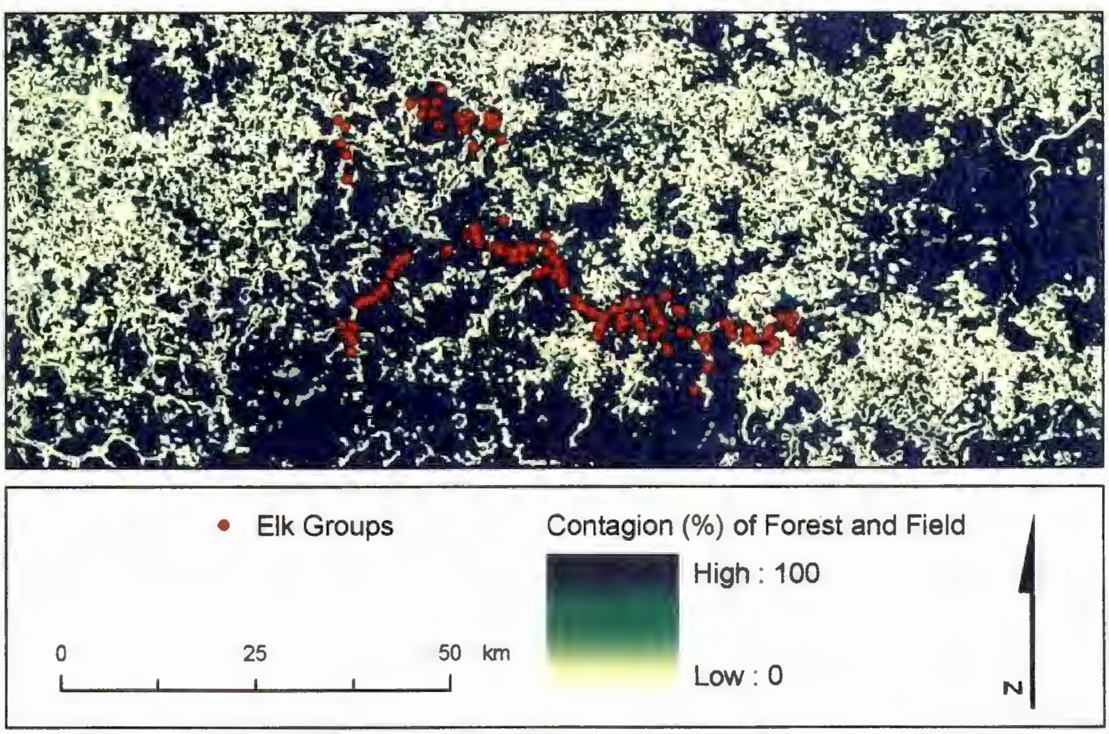


Fig. C.6. Contagion of forest and field in the Buffalo National River area, Arkansas (0.2-km^2 scale).

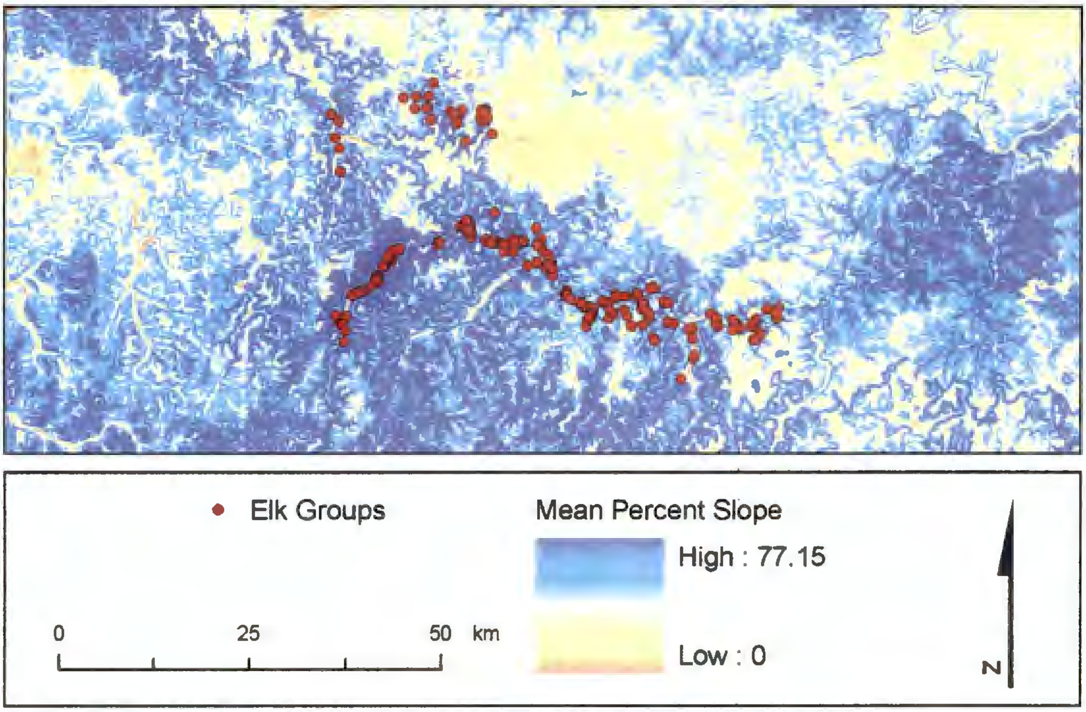


Fig. C.7. Mean percent slope in the Buffalo National River area, Arkansas (0.2-km^2 scale).

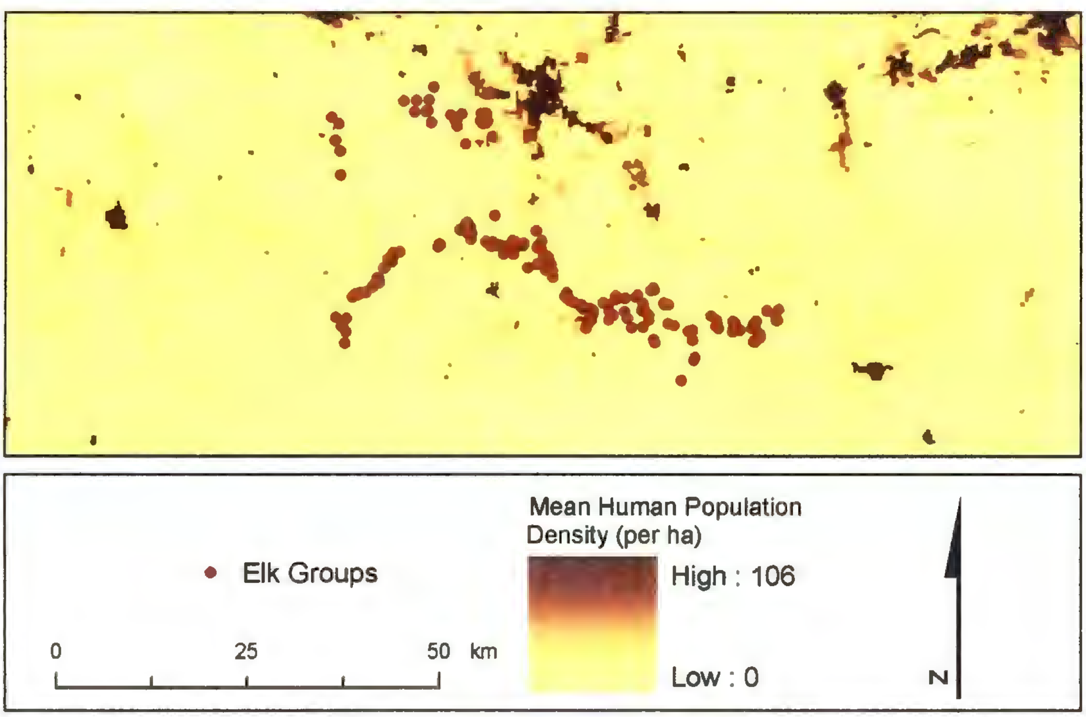


Fig. C.8. Mean human population density in the Buffalo National River area, Arkansas (0.2-km^2 scale).

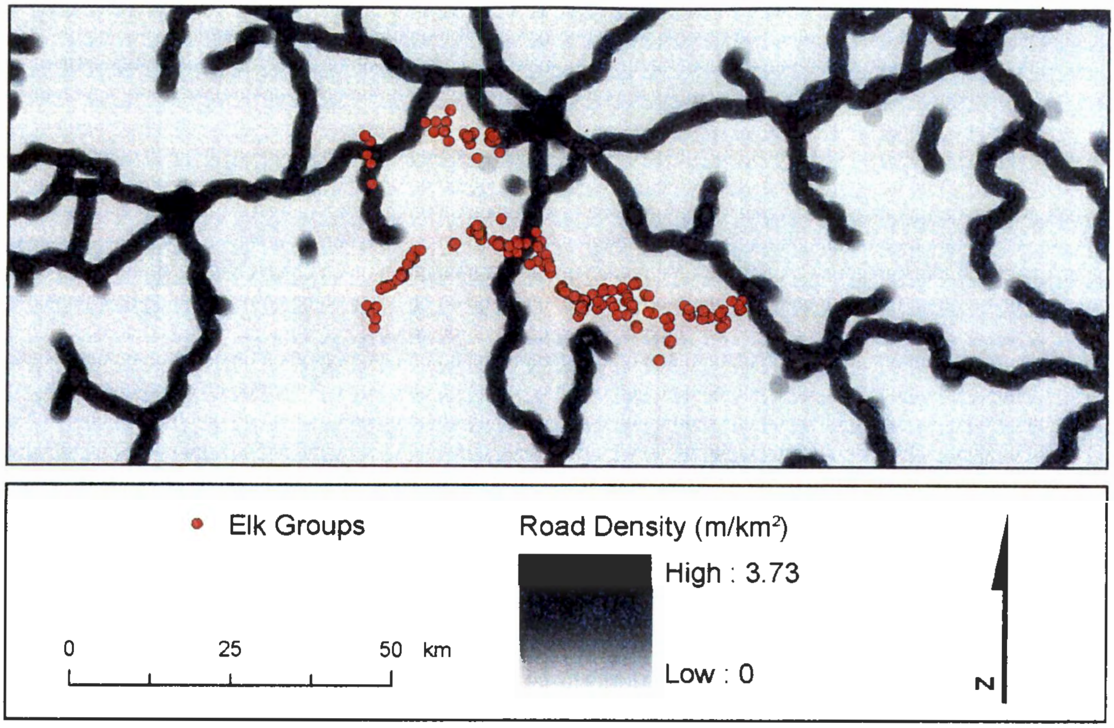


Fig. C.9. Road density of heavily traveled roads in the Buffalo National River area, Arkansas (8-km^2 scale).

VITA

Rebecca Lyn Telesco was born in State College, Pennsylvania, on 2 October 1975. The daughter of Robert and Bonnie Mikkelsen, she was raised in Columbia, Maryland, where she graduated from Wilde Lake High School in 1993. She received her Bachelor of Science Degree in May 1997 from Virginia Tech University, with a major in Forestry and Wildlife Resources. She worked for several years as a biological technician, before attending graduate school at the University of Tennessee, Knoxville in December 2000. She received a Master of Science Degree in Wildlife and Fisheries Science in August 2003. Her research interests are mammalian ecology, spatial ecology, and geographical information systems.