HABITAT ASSESSMENT TO IDENTIFY POTENTIAL SITES FOR FLORIDA PANTHER REINTRODUCTION IN THE SOUTHEAST

Final Report

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Cindy Thatcher[1]

Frank T. van Manen[2]

Joseph D. Clark[2]

[1] *University of Tennessee*
Department of Forestry, Wildlife and Fisheries

[2] *U.S. Geological Survey*
Southern Appalachian Field Branch
University of Tennessee
Department of Forestry, Wildlife and Fisheries
274 Ellington Plant Sciences Building
Knoxville, TN 37996

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Executive Summary

The second revision of the Florida Panther (*Puma concolor coryi*) Recovery Plan (1995) lists the establishment of 3 viable Florida panther populations within the animal's historic range as a major objective. The purpose of our study was to identify prospective Florida panther reintroduction sites by analyzing panther biology and landscape conditions in the southeastern United States. Our analyses were based on: (1) a multi-scale, quantitative landscape assessment to identify habitat patches that could support a panther population, (2) estimates of the colonization potential among habitat patches at prospective panther reintroduction sites, (3) a ranking of landscape characteristics based on an expert-assisted survey, and (4) an examination of factors associated with the release success of translocated western mountain lions in northern Florida.

To identify potential reintroduction sites, we used a geographic information system (GIS) to develop a multivariate landscape-scale habitat model based on the Mahalanobis distance statistic (D^2). The Mahalanobis metric has the advantage of being dependent only on animal use of various habitat characteristics, rather than requiring both use and non-use of habitat, as is the case with most other methods. We used 86 panther home ranges from telemetry data collected from 1981–2001 to develop a multivariate signature of habitat use, based on 3 anthropogenic variables and 3 landscape variables. Results of that analysis were used to delineate 11 potential reintroduction sites within the historic range where habitat conditions were favorable and where a recommended minimum size requirement was met. We then developed a local-scale statistical model to examine fine-scale habitat features within the prospective reintroduction sites that could potentially affect the success of panther restoration. Results from that analysis indicated that some sites had less favorable habitat at the local scale than other sites and, consequently, might not be ideal for panther reintroduction.

We used a metapopulation model to estimate the area of potential habitat that might eventually be colonized by panthers that disperse from the reintroduction site. Because there are few patches currently occupied by Florida panthers, we used data on black bear (*Ursus americanus*) distribution and habitat patch size and connectivity in the

southern Appalachians to estimate the colonization and extinction parameters needed for the panther metapopulation model. We performed that analysis by calculating the incidence probability (occurrence probability) for each patch within historic panther range, given that panthers were hypothetically established at a particular reintroduction site. That procedure was followed for all 11 sites, and the relative recolonization potential of each was estimated.

To coalesce the landscape analyses into a more interpretable form, we used the landscape-scale D^2 model to identify the 11 potential reintroduction sites, used the fine-scale D^2 model to quantify the area of favorable habitat available to panthers at each of those sites, and then quantified the potential habitat area that might be recolonized by dispersing panthers by multiplying the size of each patch by its incidence probability. That resulted in an area calculation of favorable panther habitat at each site, including areas that potentially could be colonized by dispersing panthers (effective habitat area). Our base assumption was that larger areas corresponded to more viable panther reintroductions.

The habitat characteristics of south Florida are unique and, consequently, the region was not an ideal reference for the entire historic range of the Florida panther. As such, some potentially important habitat variables were not appropriate for our empirical analysis (e.g., area of public lands, livestock density, prey density). Therefore, we developed an expert-assisted model to rank and incorporate those variables. Additionally, we included major and minor road density and human density to capture the importance of anthropogenic variables on the quality of Florida panther habitat. We used a quantitative technique called the Analytic Hierarchy Process to weigh the importance of each variable to successful panther reintroduction, according to expert opinion. Based on this method, Florida panther experts ranked human impact on the landscape as the most important variable in the model, followed by area of public land. Those ratings seemed to reflect concerns that human-caused mortality may be an important limiting factor for the success of panther reintroduction efforts.

Anthropogenic factors heavily influenced both the landscape and the expert-assisted models. Generally, favorable panther habitat conditions existed where human populations and road densities were low and where natural land-cover types and mean patch densities were high. Consequently, our evaluations were heavily influenced by those factors.

The potential reintroduction site at Ozark National Forest contains the greatest amount of public land with the exception of the current panther range. The Ozark National Forest region also has low human densities and low habitat fragmentation. Another advantage of this site is that its large size (8,524 km^2) and rugged topography limit human access. Ozark National Forest has relatively low white-tailed deer (*Odocoileus virginianus*) densities, however, and the site's proximity to the rapidly growing population centers in northwest Arkansas could result in future human encroachment. Lastly, this site has low potential for panther recolonization of adjacent habitat patches; it is isolated from the nearest large habitat patch (Ouachita National Forest) by an interstate highway and numerous small cities and agricultural lands in the Arkansas River valley, thereby reducing the value of this site as a metapopulation source. Overall, however, its reintroduction potential should be considered high.

The site centered on the Ouachita National Forest is similar to that on the Ozark National Forest in the large amount of public land, low human densities, inaccessibility, and relatively unfragmented habitat. This site is in close proximity to several smaller habitat patches near the south-central Arkansas site and thus has more potential as a recolonization source. However, an interstate highway separates Ouachita National Forest from the south-central Arkansas site and the site has a relatively low prey density. Nevertheless, this site received high scores for both the empirical and the expert-assisted analyses.

The potential reintroduction sites in south-central Arkansas and south Arkansas are located close together and have few barriers separating them. The 2 sites have a combined area of >10,000 km^2, with low habitat fragmentation, a high percentage of natural land cover, and high prey densities. There are no large urban centers nearby and the human population is declining within portions of this region. The 2 sites are well connected to smaller habitat patches in southern Arkansas and northern Louisiana, which may facilitate colonization beyond the reintroduction site. The drawbacks of this area are its higher road and human densities and its lack of significant public lands other than

Felsenthal National Wildlife Refuge (263 km^2). We consider these sites to be of moderate potential for panther reintroduction.

The Kisatchie National Forest site is 900 km^2 in size and is located in Louisiana on the western side of the Red River. The Red River and associated agricultural lands could inhibit panther movement across this area, isolating the site from nearby smaller patches of favorable habitat in Louisiana, such as the Atchafalaya National Wildlife Refuge to the south and the eastern ranger districts of Kisatchie National Forest. Although this site has high deer and feral hog (*Sus scrofa*) densities, it also has high road and human densities. The overall potential of this site should probably be considered moderate.

The Homochitto National Forest site on the Mississippi/Louisiana border is >7,000 km^2 in size, of which >1,000 km^2 consists of public land. This site has high deer densities and contains large tracts of bottomland hardwood forest along the Mississippi and Homochitto rivers. Densities of humans and roads are intermediate compared with the other sites, but the level of habitat fragmentation is greater and percentage of natural land cover is lower than most of the others. At the local scale, this site has relatively little favorable habitat. The site also is surrounded on 2 sides by interstate highways and on a third side by agriculture in the Mississippi River Delta of Louisiana, which could be an impediment to dispersal to other portions of historic panther range. We consider this site to be of low priority.

Southwest Alabama is the largest of the sites we identified (21,687 km^2) and is almost contiguous with the southeast Alabama site (4,049 km^2). The southwest Alabama site has variable deer and feral hog densities. Human density is low and declining. The site contains relatively small, disjointed public lands, but it also contains large tracts of private bottomland hardwood forests within the floodplains of the Alabama, Tombigbee, and Mobile rivers. Another advantage of this site is its central location and close proximity to several smaller habitat patches. A disadvantage of the southwest Alabama site is that it is bisected by agriculture, resulting in lower habitat quality at the local scale. Additionally, the shape of the site is long and sinuous, which may be less desirable than more compact sites. Finally, seasonal inundation of the bottomland hardwood forests in the southern portion of the site could inhibit the movement of panthers through this area.

The nearby southeast Alabama site has almost no public land and contains lesser-quality habitat with a greater human density and less natural land cover. However, it is in close proximity to several other habitat patches. Overall, southwest Alabama ranks high because of its large size, but public access and the dispersion of favorable local-scale habitat reduces that potential somewhat. Conversely, the ranking of the southeast Alabama site is considered low.

According to the expert model results, the south Tennessee/northern Alabama site contained almost no favorable habitat; this is primarily a function of high road and human densities and the lack of public land. This site also is the smallest of the 11 potential reintroduction sites. Overall, we consider the ranking of this site to be low.

The Apalachicola National Forest site contains a high proportion of public land (2,300 km^2) and natural land cover, and has high local-scale habitat quality. Because the site mainly consists of public land, human density also is low. Another advantage is the relatively high deer and feral hog densities. The site is relatively small (3,081 km^2) and is located just south of the Tallahassee metropolitan area. Our metapopulation analysis indicated limited colonization potential for reintroduced panthers although the Big Bend area to the southeast may be comprised of some potential habitat. Nevertheless, the overall quality of this site for panther reintroduction should be considered as moderate.

The Okefenokee National Wildlife Refuge site was used as a test site for the 2 pilot reintroduction studies. It contains a large amount of public land and is located in an area with low human density. The site is relatively large (5,469 km^2), with little fragmentation, and a high percentage of natural land cover. However, introduced Texas mountain lions made only limited use of the inundated habitats of the refuge interior. Despite the high rankings from the empirical and expert models, we consider this site to be of moderate potential.

Finally, we analyzed data from two experimental reintroductions of Texas mountain lions (*P. c. stanleyana*) to identify release procedures or landscape characteristics that affected various measures of release success. Our results suggest that mountain lion mortality and landowner complaints were best explained by road density. Additionally, we found that sex, age class, wild or captive origin of the release animal, release season, and overall habitat quality were also significant variables in explaining our measures of release success.

Anthropogenic variables, including road and human population densities, were most important to identify potential reintroduction sites for Florida panthers. We emphasize that the 11 areas we identified should be considered starting points for their evaluation as potential reintroduction sites. No one site was found to be optimal for all the criteria we evaluated. Trade-offs will have to be accepted by managers and the final decisions likely will be influenced by less quantitative criteria than those we have presented. In our study, we considered only biological and physical characteristics of panthers and the study area; the sociological obstacles to panther reintroduction likely will be more daunting. Public attitudes towards carnivore reintroduction will need to be evaluated at the top-ranked reintroduction sites. Also, because of the inherent limitations of a broad-scale habitat analysis, field surveys of the chosen reintroduction sites should be undertaken.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

CHAPTER **PAGE**

LIST OF FIGURES

FIGURE **PAGE**

LIST OF TABLES

INTRODUCTION

The Florida panther (*Puma concolor coryi*) is one of the most imperiled mammals in the United States, having been federally listed as "Endangered" since 1967 (Endangered Species Preservation Act of 1967 and the subsequent Endangered Species Act of 1973). The panthers in south Florida represent the only confirmed breeding population of *P. concolor* in the eastern United States. A 1990 survey suggested that $\leq$50 panthers may exist on 8,900 km^2 of habitat in southern Florida (Maehr 1990). Although no formal population estimate has been made, the Florida panther population is now believed to be comprised of <100 individuals (Maehr et al. 2002). Despite the apparent increase in numbers during the past decade, the threat of extinction remains high because of the small population size, limited genetic variability, and habitat loss (Clark 2001).

Habitat loss and fragmentation are arguably the greatest threats to the panther in Florida; these threats are primarily due to continuing urbanization and conversion of natural areas to agriculture (Kautz 1994). Additionally, available panther habitat in south Florida may be nearing carrying capacity. Unfortunately, obstacles, such as the Caloosahatchee River and an increasingly urbanized landscape, impede dispersal north to other portions of the historic range, particularly for females (Maehr et al. 2002). The second revision of the Florida Panther Recovery Plan lists the reestablishment of 2 viable panther populations within other portions of the historic range as a major objective (U.S. Fish and Wildlife Service 1995). That recovery goal can only be accomplished by reintroducing panthers to currently unoccupied areas. In 2001, the U.S. Fish and Wildlife Service formed a new Florida Panther Recovery Team with the primary purpose of revising and updating the existing recovery plan. Habitat assessment to identify potential reintroduction sites was recognized as an important issue for moving forward with panther recovery.

Persecution by humans and, to a lesser extent, habitat loss and severe declines in white-tailed deer (*Odocoileus virginianus*) densities all contributed to the historic disappearance of Florida panthers from most of the Southeast. However, habitat conditions have dramatically changed since the Florida panther was extirpated from most of its historic range. The purchase and protection of large tracts of public land, the recovery of thousands of hectares of forested land within the historic range, the increase in populations of game species, and the legal protection for the Florida panther afforded by the Endangered Species Act have dramatically improved the prospects for reintroduction.

Reintroduction of large carnivores has been the subject of much renewed interest. Reintroduction, however, is a costly and time-consuming endeavor, with only about 11% of all species reintroductions resulting in viable populations (Earnhardt 1999). In general, reintroduction success is enhanced in instances when there are large numbers of founders, low environmental variation, and access to refugia, and for species with high genetic variability, a high rate of population increase with low variance, and low intraspecific competition (Griffith et al. 1989). Panthers rate low in almost all these aspects. Additionally, the sociopolitical issues regarding the reestablishment of a large carnivore into areas where they have been extinct for >100 years are perhaps even more daunting than the biological issues. Consequently, panther reintroduction will present many challenges.

Because of the biological and sociological complexities of panther reintroduction, it is of critical importance that the best possible sites and release methods are utilized. Beginning in 1988, the feasibility of panther reintroduction was evaluated by Belden and Hagedorn (1993) with releases of 7 mountain lions (*P. c. stanleyana*) from western Texas into northern Florida. Although these first releases were largely unsuccessful, a second release of 19 mountain lions in 1993 produced more encouraging results (Belden and McCown 1996). Those studies provided important information on characteristics of the release animals that may have influenced reintroduction success (e.g., sex, age, captive or wild origin). Furthermore, those experiments yielded valuable information on release procedures, expected home-range sizes, habitat use, and potentially limiting factors within the release area (e.g., area size, distribution of highways, prey density, human density, and extent of livestock operations).

In addition to reintroduction methodology, the successful restoration of Florida panther populations will largely depend on the selection of appropriate reintroduction sites. Jordan (1993, 1994) evaluated 24 sites in the southeastern U.S. based on biological and anthropogenic criteria and concluded that 14 sites should be further considered for panther reintroductions. Those 14 sites were then evaluated and ranked based on 4 evaluation criteria (i.e., area size, forest area, human population density, and road density). Jordan (1994) indicated that additional analyses would be needed once more definitive data became available on factors influencing successful reintroductions. In recent years, the availability of high-quality geographic information system (GIS) data has dramatically increased as have advances in landscape characterizations, habitat use analyses, metapopulation modeling techniques, and expert-assisted analyses. These advances, in combination with a large database of panther locations from south Florida, provide an ideal setting within which to conduct a quantitative analysis of the landscape and habitat characteristics needed to support viable panther populations in the southeastern U.S.

Study Objectives

The objective of our study was to identify prospective Florida panther reintroduction sites within the historic range based on:

(1) multi-scale, quantitative and qualitative comparisons of the landscape characteristics of home ranges of radiocollared panthers in southern Florida,
(2) the colonization potential of areas adjacent to potential panther reintroduction sites, and
(3) an examination of factors associated with the release success of translocated western mountain lions in north Florida.

Combining the above information, our ultimate goal was to develop a tool for objectively comparing prospective reintroduction sites.

STUDY AREA

Our study area was the entire historic range of the Florida panther, including most of the southeastern U.S., from Arkansas and Louisiana east to portions of Tennessee and South Carolina and south to the tip of the Florida peninsula (Hall 1981; Fig. 1). The historic range was within the humid temperate and humid tropical domains, and included the following physiographic provinces: Central Appalachian Forest, Eastern Broadleaf Forest, Everglades, Lower Mississippi Riverine Forest, the Ouachita Mountains, the Ozark Mountains, the Outer Coastal Plain Mixed Forest, and the Southeastern Mixed Forest provinces (Bailey 1980).

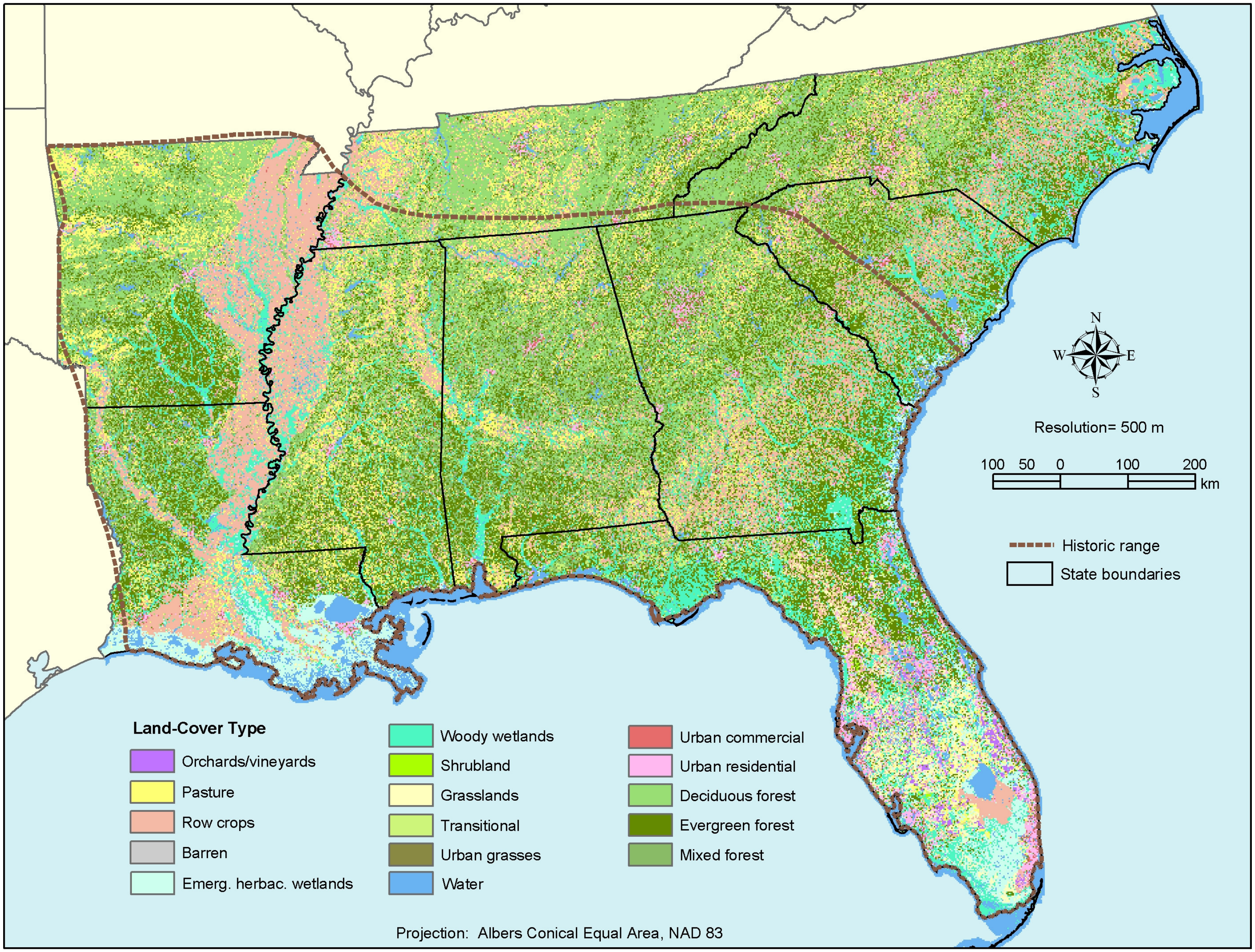

Fig. 1. Historic range of the Florida panther and southeastern U.S. land cover.

The current distribution of panthers in south Florida served as the point of reference for our habitat analyses. South Florida is comprised of a variety of natural, agricultural, and urban land-cover types and is characterized by flat topography and poorly drained soils, resulting in extensive wetlands (Davis 1943). The climate of southern Florida is tropical, with a summer wet season and a winter dry season (Davis 1943). Large tracts of publicly owned land are located within the Florida panther's current distribution, including Big Cypress National Preserve, Everglades National Park, Florida Panther National Wildlife Refuge, and Fakahatchee Strand State Park (Fig. 2).

METHODS

APPROACH

Our approach to delineate potential reintroduction sites was based on a comprehensive assessment of biological and anthropogenic factors that could have an effect on restoration success. Our primary emphasis was on performing spatial analyses to map and assess potential reintroduction sites. Secondly, we examined factors related to release procedures that could influence reintroduction efforts.

Our first objective for the spatial analysis was to identify landscape conditions in the Southeast that were similar to those associated with the extant population of panthers in south Florida. We accomplished that by using GIS to calculate the Mahalanobis distance (D^2) statistic, which is a multivariate measure of dissimilarity (Clark et al. 1993). We chose that statistical technique because it enabled us to use empirical data from south Florida and, thus, was an objective approach to quantifying broad-scale landscape conditions within the historic range that could support a panther population. Other statistical techniques for habitat analysis, such as logistic regression, discriminant function analysis, and resource selection functions (Alldredge et al. 1998) require observations where the species is known to be present or absent or, alternatively, where the species is present and the proportion of available habitat in an area is known. False negatives are produced, however, if a species is present and not observed or if a species occupies a habitat at a later time. If the proportion of a particular habitat available to a species must be known, an assumption must be made on what constitutes "availability", which can be complicated for wide-ranging species such as Florida panthers. The

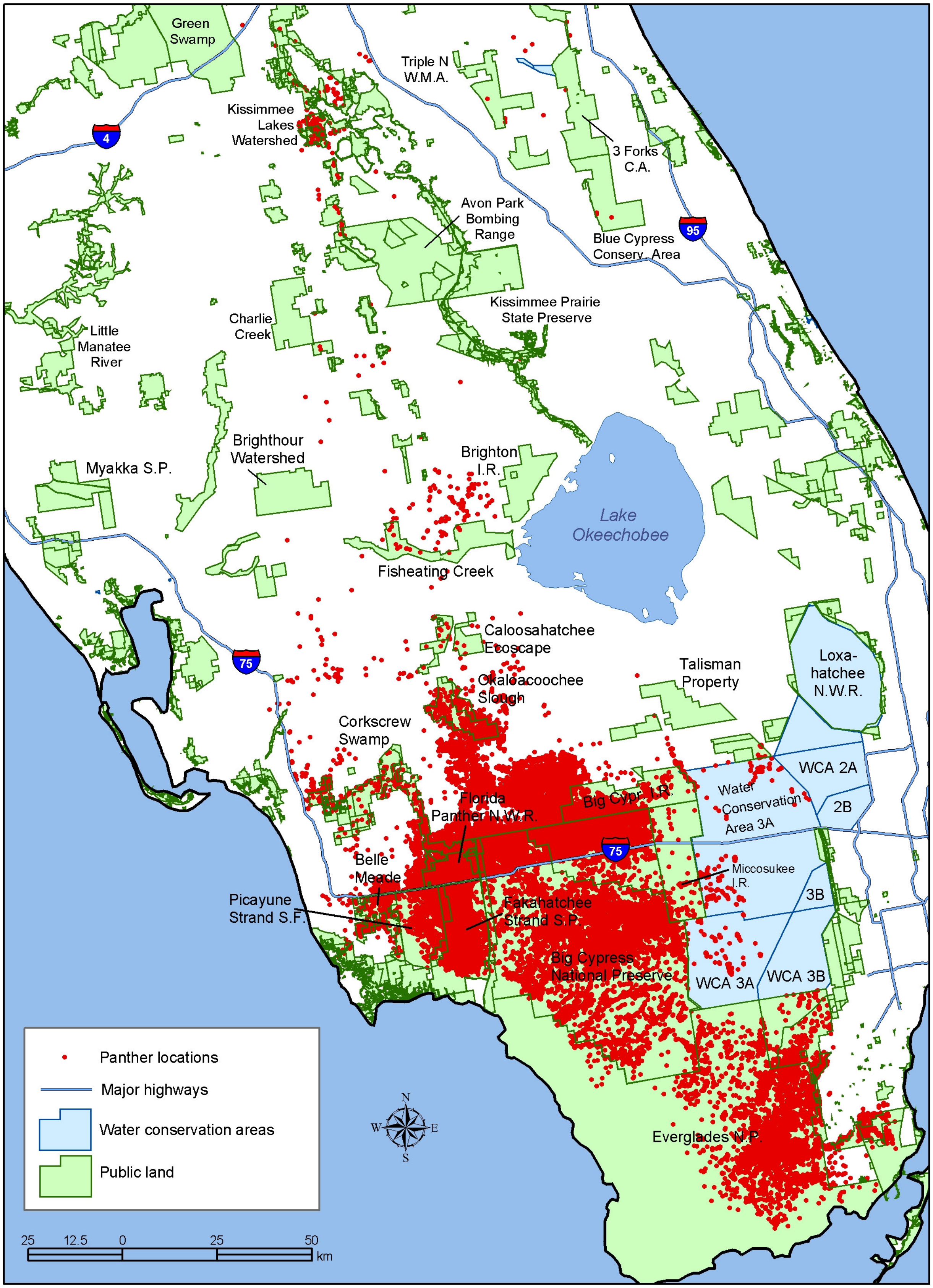

Fig. 2. Distribution of Florida panther telemetry locations, 1981–2000.

Mahalanobis distance statistic has the advantage over other methods because only presence data are used, and no assumptions must be made on what is available (Alldredge et al. 1998, Farber and Kadmon 2003). Additionally, Mahalanobis distance is determined from the variance-covariance matrix, thus correcting for correlation among variables, and the assumption of multivariate normality does not have to be met (Knick and Rotenberry 1998). Finally, the Mahalanobis distance statistic allows the consideration of habitat quality as a continuum, rather than a simple binary classification of suitable or unsuitable habitat.

Because several potentially important landscape variables could not easily be quantified and because panther demographic parameters are ignored in the D^2 model (e.g., metapopulation processes), we used additional techniques to refine those predictions: (1) a local-scale statistical model of habitat features within potential reintroduction regions, (2) a metapopulation model to examine configurations of habitat patches that would hold the most potential for natural colonization, (3) and an expert-assisted model that considered landscape conditions for which south Florida did not provide a good reference (e.g., area of public land, human population growth, prey density). Thus, the landscape assessment based on the statistical model provided the basis for delineation of potential reintroduction sites, with the 3 additional models serving to refine model outcomes (Fig. 3).

Finally, we performed a statistical analysis of landscape factors and animal characteristics that were associated with the release success of western mountain lions in north Florida. The purpose of that analysis was to identify factors that may further increase the success of a reintroduction effort (Fig. 3).

SPATIAL ANALYSES

Landscape-Scale Statistical Model

***Telemetry Data*.--**We obtained panther radiotelemetry locations collected by the Florida Fish and Wildlife Conservation Commission, the National Park Service, and the University of Tennessee. That database contained >60,000 locations of 113 panthers that were monitored year-round, approximately 3 times per week, from 1981 to June 2001.

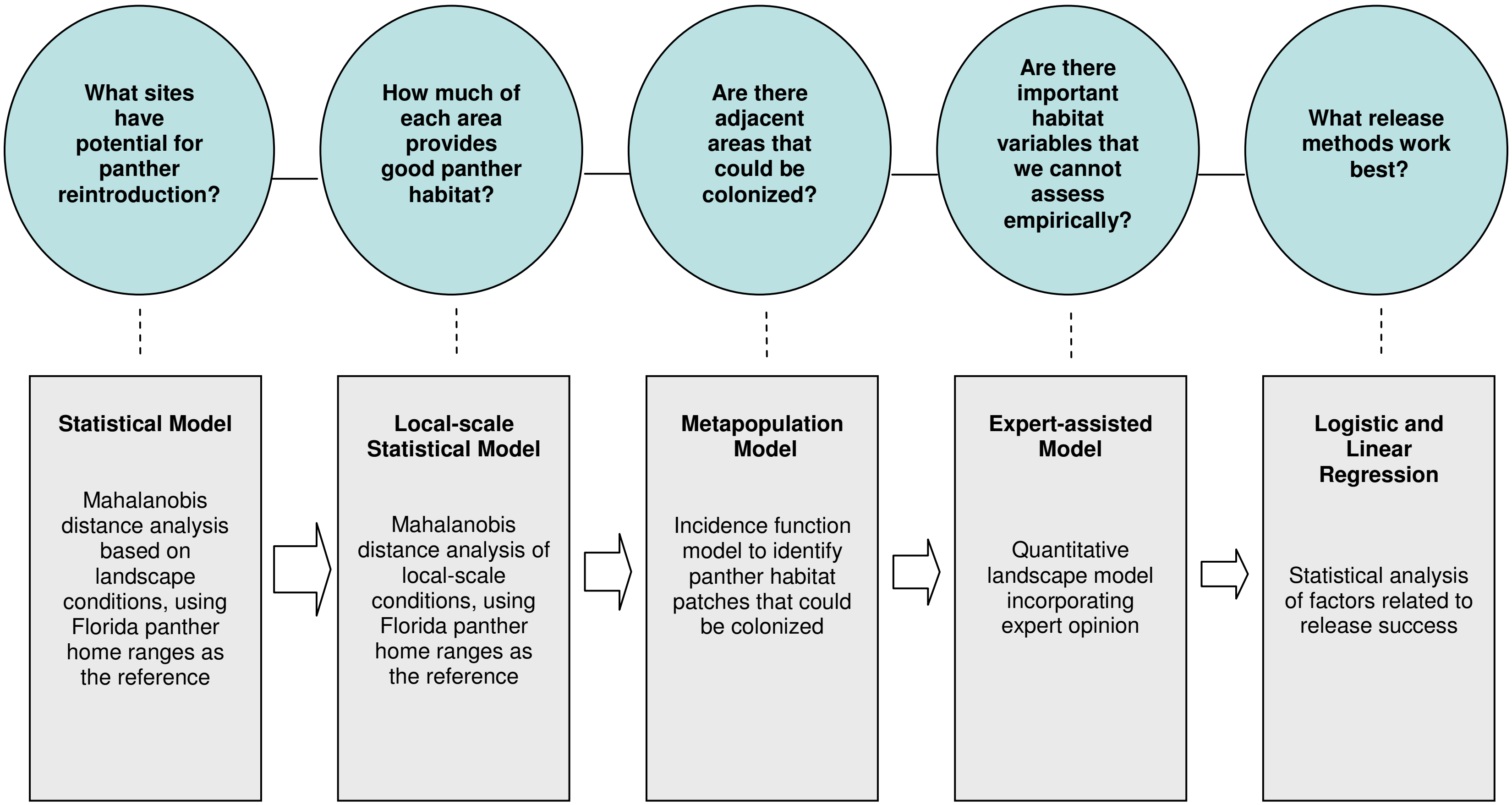

Fig. 3. Analysis approach to identify sites for the potential reintroduction of Florida panthers in the southeastern U.S.

The database included 8 female Texas mountain lions introduced to south Florida in 1995. Information on panther age, sex, and capture date was added to the telemetry database (Shindle et al. 2001). We excluded panthers that were <1.5 years of age because of probable movement and activity biases (Janis and Clark 2002). No more than 1 location per panther per day was included in the dataset to reduce autocorrelation (Janis and Clark 2002). Mean telemetry error for locations collected by all agencies was estimated to be 176 m, with 95% of locations within 489 m (Janis and Clark 2002).

Radiolocations were primarily obtained in the morning and likely reflected bedding activity rather than foraging activity, the latter being more ecologically important. Those daytime telemetry locations were adequate for delineating home ranges, but not for examining habitat selection at individual panther locations. For that reason, we used panther home ranges as the sampling unit in the D^2 analysis.

***Home-Range Analysis*.--**We eliminated panthers with <100 locations from the home-range analysis to ensure sufficient sample sizes for home-range calculation. Eighty-six individual panthers (47 F, 39 M) met the age and sample size requirements. We used all available telemetry locations for the 86 panthers to delineate home ranges. The fixed kernel method was used to calculate a 95% probability contour for each panther (Worton 1989) using the Animal Movement extension (Hooge and Eichenlaub 1997) in ArcView® GIS (ESRI, Redlands, California, USA). We calculated home-range sizes based on locations from multiple years for some animals, regardless of any shifts in home-range location, to ensure that we incorporated temporal variation in resource use.

***GIS Data Layers*.--**We generated GIS map layers to examine habitat conditions throughout the historic range of the Florida panther (Table 1). We chose a pixel size (resolution) of 500 x 500 m for all habitat variables. That coarse resolution was appropriate given the extent of the study area and the large-scale movements of panthers. We chose landscape variables for the habitat model that were applicable to areas throughout the historic range, despite habitat and landscape conditions that differed markedly from those in south Florida. For example, south Florida contains large tracts of emergent herbaceous vegetation and woody wetlands that are not common in other portions of the southeastern U.S. Had we developed a habitat model with that cover-type classification as the "target", we likely would have classified almost all of the remainder of the historic panther range as poor panther habitat, because of the relative scarcity of wetlands there. We avoided that effect by aggregating the land-cover classes from the 1992 National Land Cover Data (Vogelmann et al. 2001) into a binary map of "natural land cover" versus all remaining land-cover types to allow habitat comparisons between south Florida and the southeastern U.S. For that binary classification, natural land cover included deciduous forest, mixed forest, evergreen forest, woody wetlands, emergent herbaceous wetlands, shrublands, and grasslands; urban and agricultural areas and water constituted the other binary class.

We used 2 groups of variables to measure landscape and habitat features that we deemed to be important to Florida panthers: (1) landscape indices and (2) measures of anthropogenic influence. Landscape indices were used to measure cover type by percent and to quantify spatial patterns of landscape fragmentation, heterogeneity, and juxtaposition of land-cover types (Mladenoff et al. 1995). Those indices provided information on the general structure of the landscape, such as the density of edges between natural and agricultural land cover, the size and contiguity of natural land-cover patches, and the level of habitat fragmentation. We calculated 8 landscape indices with Program FRAGSTATS 3.1 (McGarigal and Marks 1995) based on our definition of natural land cover (Table 1): (1) percent natural land cover, calculated as the proportion of natural land-cover patches within an area; (2) proximity, a measure of the size and proximity of patches to each other; (3) contagion, which quantified the spatial aggregation of natural land-cover patches; (4) fractal dimension, an index of the shape complexity of patches; (5) cohesion, which measured the physical connectedness of patches; (6) edge density, the amount of juxtaposition between different patch types; (7) patch density, whereby higher patch density indicated an increase in fragmentation of natural land cover; and (8) the ratio of patch perimeter to its area (McGarigal and Marks 1995, Riitters et al. 2000). A final landscape variable, Simpson's diversity index, was calculated based on all original land-cover classes. Simpson's diversity index measured the proportional abundance of each land-cover type (McGarigal and Marks 1995).

The Florida panther persists today only in the most inaccessible, undeveloped portion of the historic range, thus, a second set of variables was developed to measure anthropogenic influence on the landscape. Human disturbance may reduce habitat

Table 1. Mean and range of values of landscape variables within Florida panther home ranges (n = 86) in the southeastern U.S.

Variable[a]	Potential range of values	Range for home ranges	Range for study area	Mean for home ranges	Mean for study area	Variable definition
Natural vs. other land cover						
Percent natural land cover[b]	0 to 100	0 to 100	0 to 100	85.22	62.07	Proportional abundance of natural land cover
Aggregation index[b]	0 to 100	0 to 100	0 to 100	93.13	74.91	Amount of aggregation, from an adjacency matrix
Edge density[b]	0 to ∞	0 to 16.06	0 to 18.91	4.37	9.83	Amount of juxtaposition between patch types
Perimeter-area ratio[b]	0 to ∞	3.07 to 80	3.07 to 80	8.20	22.65	Ratio of patch perimeter to patch area
Contagion[c]	-1 to 1	-1 to 0.97	-1 to 1	0.46	0.33	Frequency with which different patch types appear side-by-side, from an adjacency matrix
Cohesion[b]	0 to 100	0 to 100	0 to 100	97.45	92.01	Physical connectedness of patches
Patch density[b]	0 to ∞	0 to 0.38	0 to 0.525	0.04	0.10	Number of patches divided by window area
Proximity[b]	0 to ∞	0 to 173.68	0 to 208.40	9.31	27.98	Size and proximity of patches
Fractal dimension[c]	1 to 2	1.02 to 1.22	1 to 1.25	1.10	1.16	Index of shape complexity of patches
Diversity of natural land cover						
Simpson's diversity index[b]	0 to 1	0.21 to 0.86	0 to 0.87	0.67	0.67	Proportional abundance of land-cover types defined as “natural” (e.g., deciduous forest, evergreen)
Human impact on landscape						
Road density[c]	0 to ∞	0 to 0.004	0 to 0.01	0.0007	0.0015	Total length of roads divided by window area
Human population density[c]	0 to ∞	0 to 719.63	0 to 23140	17.36	51.89	Human density per km^2 averaged within window
Percent urban land cover[c]	0 to 100	0.11 – 16.27	0 - 98.01	2.36	4.42	Proportional abundance of urban land cover
Prey availability						
Deer and feral hog density	0 to 3	0.08 to 3	0 to 3	2.77	1.96	Average prey ranking within window

[a]Data sources: 1992 land-cover data: U.S. Geological Survey National Land Cover data (Vogelmann et al. 2001); 2000 human population density data: U.S. Census Bureau (2002); 2000 road density data: U.S. Census Bureau TIGER/Line files (U.S. Census Bureau 2002); 1988 prey density data: Southeastern Wildlife Disease Cooperative Study (SWDCS) data (SWDCS 2002) and 1999 Quality Deer Management Association (QDMA) data (QDMA 2003).

[b]Measured based on circular window with 8,800-m radius.

[c]Measured based on circular window with 15,600-m radius.

connectivity, restrict movements to portions of the range, and increase risks to panthers from vehicular mortality and poaching (Comiskey et al. 2002). Human population density was calculated from block group-level census data (U.S. Census Bureau 2002). A block group is a polygon representing an area of varying size generally containing between 600 and 3,000 people, with a typical population of 1,500 (U.S. Census Bureau 2002). Human density was calculated by dividing the population within each block group by its area (Table 1). Road density was included because roads sometimes serve as barriers to panther movements, result in panther mortalities from vehicular collisions (Maehr and Cox 1995), and can be an index to human influence on the landscape. Road density was calculated as the total length of roads within a specified window size, based on a vector map layer of roads developed by the U.S. Census Bureau (Table 1). The road data included all roads ranging from interstate highways to gravel roads; we did not separate major and minor roads for this analysis because of inconsistencies in Census Feature Class Code (CFCC) road classifications. Based on a review of initial model results, we added a third anthropogenic variable (percent urban land cover; Table 1) to underscore the importance of minimizing panther-human interactions for panther survival (Belden and Hagedorn 1993). Urban land-cover pixels consisted of areas containing ≥30% residential, commercial, industrial, transportation, and similar land-use types (Vogelmann et al. 2001).

We calculated each variable at 2 scales to examine multi-scale habitat selection (Kerkhoff et al. 2000). We used circular moving windows of 2 sizes based on the life history of the Florida panther. Because habitat selection of large carnivores likely is influenced by landscape features at the home-range scale or greater (Carroll et al. 1999), we used mean home-range areas to determine appropriate sizes of moving windows to calculate habitat variables. The first window radius was based on our calculations of mean female home-range size, whereas the second window radius was based on the mean size of male home ranges. Thus, each pixel in the resulting GIS grid represented the average of surrounding habitat characteristics within an area equal to that encompassed by a female or male panther home range. For each panther home range, we calculated the mean value of each landscape variable for both window sizes. Based on those values, we used coefficients of variation and cumulative frequency distributions to determine which window size produced the most precise response for each variable. That window size was then chosen as the initial measurement scale for each variable. We also used the mean values to calculate a correlation matrix to identify redundancy among variables.

***Mahalanobis Distance (D^2) Analysis*.--**Our empirical model was based on the Mahalanobis distance statistic,

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

where $\underline{x}$ is a vector of habitat characteristics associated with each pixel; $\underline{\hat{u}}$ is a mean vector of landscape characteristics estimated from the set of home ranges; and Σ^{-1} is the inverse of the variance-covariance matrix calculated from the home ranges (Rao 1952). The D^2 statistic is based on a vector of mean values of landscape variables and their variances and covariances (Rao 1952), as measured using panther home ranges in south Florida as the reference. We used the Mahalanobis distance statistic to determine where similar landscape conditions occurred in the southeastern U.S. As such, the Mahalanobis distance statistic provided a dimensionless index of similarity to the multivariate landscape conditions associated with panther home ranges in south Florida (Knick and Rotenberry 1998).

The D^2 statistic was calculated in ArcGIS™ (ESRI, Redlands, California, USA) on a pixel-by-pixel basis for the entire historic range of the species (Clark et al. 1993). The calculated values represent a quantitative index of panther habitat use for the southeastern U.S., using panther home ranges in south Florida as the point of reference or "target". Home ranges rather than individual telemetry locations were used as the sampling unit because we wanted to identify habitat conditions that could support all the life requirements of Florida panthers, and to avoid biases associated with radiotelemetry error, exclusive use of daytime locations, and pseudoreplication. Finally, we calculated the sizes of large contiguous areas with favorable panther habitat with the assumption that larger areas of high-quality habitat would potentially result in greater panther populations and contribute more to eventual Florida panther recovery.

We tested model predictions by sampling D^2 values within each panther home range. The D^2 score that captured the greatest percentage of panther home ranges within the smallest percentage of the study area was chosen as a threshold value. In the resulting D^2 map, any pixels with D^2 values below that value may be considered more favorable habitat, whereas all pixels above that value are more unfavorable (Pereira and Itami 1991). This method can be used to determine if a model provides a relatively precise definition of favorable habitat in terms of geographical area, while still capturing a large percentage of panther home ranges.

Additionally, we used 10-fold crossvalidation to quantitatively test model performance and to determine which panther home ranges did not fit the model. In this resampling procedure, the panther home-range dataset was partitioned into 10 subsamples. The D^2 model was calculated with n - 1 subsamples and tested with the excluded subsample. Once all subsamples were excluded, overall model accuracy was determined by calculating the mean accuracy of all 10 D^2 models (Verbyla and Litvaitis 1989).

Local-Scale Statistical Model

Because we used low-resolution map layers (500 x 500-m pixels) and large moving windows (corresponding to a female or male home-range size), the D^2 model emphasized broad-scale patterns in the landscape. That model was used to identify large, contiguous areas of favorable habitat. However, there may be habitat of varying quality within those sites that we could not detect with the coarse-scale model. Therefore, within sites with good overall habitat quality as identified by the landscape-scale D^2 model, we also examined local-scale habitat features that could potentially affect the success of panther reintroduction. We recalculated the D^2 model using 90-m pixels, rather than the 500-m pixels used in the original model, and we reduced the size of the moving windows to 3,000 m, which approximately corresponded to the mean daily movement rate of male and female Florida panthers (Janis and Clark 2002). Panther home ranges were again used as the sampling unit. We calculated the percent favorable habitat within each potential reintroduction site based on the 90-m pixels to assess availability of favorable habitats at the local scale. The resultant area of each site comprised of favorable habitat was then recalculated based on that analysis.

Metapopulation Model

***Incidence Function Model*.--**Habitat loss frequently leads to fragmentation of once contiguous habitat, resulting in isolation of remaining habitat patches. Within highly fragmented landscapes, animals that typically inhabit large, contiguous areas of habitat may exhibit a metapopulation structure. A metapopulation is a group of relatively isolated, localized populations connected by occasional migration of individuals between populations (Hanski 1999). These dispersal events provide for the recolonization of local populations that periodically become extinct. It may be possible to estimate extinction risks and colonization probabilities that are unique to each habitat patch, given information on the size and degree of isolation of patches along with information on species presence or absence (Hanski 1999). Toward that end, we applied an incidence function metapopulation model to Florida panther habitat patches in the Southeast. Our goal was to evaluate potential panther reintroduction sites as sources for colonization of adjacent habitat patches within the patch matrix. Thus, we used a metapopulation model to identify habitat patches that might be colonized by panthers from source areas.

Patches that are currently occupied by Florida panthers are few and at the extreme of the historic range, so the incidence of patch occupancy there is not an appropriate model. Moreover, patch occupancy data on western mountain lions were not optimal for our study because the size and distribution of habitat patches and the characteristics of the landscape matrix between those patches differ markedly in the West from those in the Southeast. However, parameter estimates for an ecologically similar species can be used as surrogates when little information is available for a rare species (Wahlberg et al. 1996). Metapopulation data on black bears (*Ursus americanus*) in the southern Appalachians were available (Murrow 2001) and we used that dataset to develop a metapopulation model as a substitute for Florida panthers. Although there are substantial differences between the 2 species (e.g., black bears have smaller home ranges, are dormant in winter, and exhibit seasonal movement patterns), the black bear and the Florida panther are both large carnivores with similar dispersal capabilities and similar landscape requirements. Like bears (Schwartz and Franzmann 1992), female panthers often establish home ranges that overlap with those of their mothers (Maehr et al. 2002) with occasional dispersals of many kilometers coupled with increased mortality risk (Maehr et al. 2002, Clark 1991).

The incidence function model was parameterized for panthers by using a snapshot of patch occupancy data for black bears in the southern Appalachians (Murrow 2001). In the incidence function model, the probability of extinction is determined by the size of the habitat patch, under the assumption that population size is positively correlated with patch size. The probability of colonization is determined by the distance from the habitat patch to occupied patches (isolation), and by the area of these patches (Wahlberg et al. 1996). The model is based on the assumption that all patches, or populations, have some risk of extinction. The probability of species occurrence within patch *i*, called the incidence J_i, is given by:

$$J_i = \frac{C_i}{C_i + E_i},$$

where C_i and E_i are the colonization and extinction probabilities of patch *i*, respectively (Hanski 1993). The extinction parameter E_i is a constant and is directly related to patch area, $E_i = e / A_i^x$, where A_i is the area of patch *i*; *x* and *e* pertain to the risk of extinction, given the patch size. The colonization parameter C_i is a function of patch connectivity (S_i), as $C_i(t) = S_i^2(t) / (S_i^2(t) + y^2)$, where *y* is a parameter that expresses the colonization ability of the species (Moilanen 1999). S_i is based on the sizes and locations of occupied patches *j* as

$$S_i(t) = \sum p_j(t) \exp(-\alpha d_{ij}) A_j^b, \quad j \neq i,$$

where $p_i(t)$ is the state of occupancy at time *t*, α is a constant that determines the survival rate of migrants dispersing over the distance between patches, d_{ij}. The exponent *b* scales population size to patch area; α and *b* are sometimes independently estimated based on species biology (Moilanen 1999). We used the program Stochastic Patch Occupancy Model Simulator (SPOMSIM version 1.0b; Moilanen 2003) to fit the incidence function model to the black bear occupancy data, estimating the unknown parameters *x*, *y*, and *e* with non-linear regression. Our initial parameter settings were $\alpha = 0.1$, $b = 0.95$, $x = 1.5$, $y = 10$, and $e = 1$, based on literature on black bear ecology (Appendix C; Murrow 2001). In program SPOMSIM, we used >2,400 iterations of the non-linear regression procedure to estimate the parameter estimates, holding parameter *b* fixed at 0.95 and specifying a turnover rate of 6 events per year (Appendix C).

***Evaluating Panther Reintroduction Sites*.--** We identified habitat patches for consideration for panther reintroduction based on the statistical landscape analysis. That was done by creating a binary map layer of favorable and unfavorable habitat. Patches were delineated by overlaying 20-km^2 grid cells on that binary habitat map. If ≥75% of the pixels within the 20-km^2 grid cell were favorable habitat, we assigned a value of 1 to that cell. A value of 0 was assigned to grid cells containing <75% favorable habitat. Following that, we used the non-linear regression equation with the final parameter estimates to predict the occupancy status of potential panther habitat patches, using information on the area and isolation of these patches. Our purpose was to identify those patches within the historic range that, if occupied, would hold potential for the colonization of surrounding patches. For example, one potential reintroduction site might be small in size but adjacent to other patches. If the colonization potential for those other patches was high, the overall potential for population reestablishment would be greater than a similarly sized area with no colonization potential. Thus, given that panthers were hypothetically restored to a particular site, we calculated the relative colonization probability of all adjacent patches identified as panther habitat based on the Mahalanobis distance analysis. That simulation was repeated for each of the potential reintroduction sites so that the relative incidence probabilities could be estimated. This was simulated for a period of 100 years. We then multiplied the area of each site and surrounding patches (A_i) by their respective incidence probabilities (J_i) and summed those products to estimate the total area of potential panther habitat.

Expert-Assisted Landscape Model

***Analytic Hierarchy Process*.--**Some potentially important landscape variables could not be analyzed with the empirical D^2 model. Therefore, we developed an expert-assisted model to incorporate those variables into our assessment. A pairwise comparison technique called the Analytic Hierarchy Process, developed by Saaty (1977), provides a quantitative method for comparing alternatives (Eastman et al. 1995). This pairwise comparison procedure has been successfully used in other wildlife studies (e.g., Clevenger et al. 2002) and is commonly used to solve multi-variable problems where both quantitative and qualitative information are relevant. With this modeling technique, experts rank the relative importance of each variable in a pair using a continuous scale. The ranking of pairwise comparisons can be conducted by group consensus or individually; in the latter case all comparisons are averaged (Schmoldt and Peterson 2000). Although there are advantages to either method, we chose to average survey responses from individuals because it was logistically more feasible, it weighted the opinion of each expert equally, and it tended to reduce the influence of extreme values, thus improving the consistency of the pairwise comparisons (Schmoldt and Peterson 2000).

***Model Structure and Variables*.--**We selected landscape variables and determined the proper model structure (Appendix A) upon development of a pilot survey and subsequent consultation with a small group of Florida panther experts. We obtained or developed quantitative data for each variable within the historic range of the Florida panther and represented each as a spatial map layer in a GIS, using the same resolution as the statistical landscape-scale model (500 m). Variables were based on county-level data, or were averaged over an area of 2,590 km^2, the minimum estimated size of a potential panther reintroduction site (Belden and Hagedorn 1993).

We used 4 primary variables for the expert-assisted model: (1) prey density, (2) area of public lands, (3) livestock density, and (4) human impact (Table 2). The prey density variable was intended to evaluate the extent that prey density (food availability) may influence the success of panther restoration. The 2 primary prey species of the Florida panther are the white-tailed deer and the feral hog (*Sus scrofa*; Maehr 1997). That variable was not appropriate for the statistical model because of atypical prey densities in south Florida, where feral hogs were abundant across a large area and white-tailed deer were relatively scarce compared with the remainder of the Southeast. Densities of feral hogs were digitized from 1988 feral hog density maps (Southeastern Cooperative Wildlife Disease Study 2002; Table 2), whereas deer densities were digitized from a 1999 white-tailed deer density map (Quality Deer Management Association 2003; Table 2). The prey densities for the 2 map layers were combined to produce a single index of overall prey density.

The availability of public lands may limit the number of human-panther conflicts. Therefore, we intended to determine the extent that the availability of public lands may influence the success of panther reintroduction. That variable was not appropriate for our statistical analysis because large tracts of public lands are more prevalent in the area where panthers occur compared with other portions of the Southeast. The inclusion of that variable in the statistical model likely would have caused a bias towards finding reintroduction sites only where public land occurred. The basis for this variable was a

Table 2. Variables used in the expert-assisted model to identify potential reintroduction sites for Florida panthers in the southeastern U.S.

Variable	Variable definition
Human impact on the landscape	A combination of minor road density, major road density, and human density (U.S. Census Bureau 2002).
Minor road density	Density of paved and unpaved roads, excluding U.S., state, and interstate highways (U.S. Census Bureau 2002).
Major road density	Density of major highways (U.S., state, and interstate highways; U.S. Census Bureau 2002).
Human density/population growth	A combination of both human density in 2000 and human population growth from 1990 to 2000 (U.S. Census Bureau 2002).
Area of public lands	Area of public lands, including federal, state, and military land, from the Conservation Biology Institute/World Wildlife Fund Protected Areas Database (2001 data; Conservation Biology Institute 2001).
Prey density	Density of feral hogs (1988 data; Southeastern Cooperative Wildlife Disease Study 2002) and deer (1998 data; Quality Deer Management Association 2003).
Livestock density	Density of cattle by county from the National Agricultural Statistics Service (1997 data; U.S. Department of Agriculture 2003)

map of public lands (including national forests, national parks, national wildlife refuges, state parks, wildlife management areas, military bases, and other public lands; Table 2).

The livestock depredation variable addressed the extent that livestock depredation may influence the success of panther reintroduction. This variable was not appropriate for the statistical analysis because current panther distribution likely is little influenced by livestock depredation conflicts. Livestock losses, however, could be an important factor for panther reestablishment elsewhere in the Southeast. We obtained information on the density of cattle by county in 1997 from the National Agricultural Statistics Service (U.S. Department of Agriculture 2003) to represent livestock density (Table 2). No information was available on goat or sheep densities in the southeastern U.S.

The human impact variable was a combination of several map layers related to anthropogenic disturbance, and addressed how the extent and level of human impact on the landscape may influence the success of panther reintroduction. We used expert assistance for this variable for reasons similar to those for livestock density. Human population density and road density were weighted according to the results of the survey and were then combined into a single measure of human impact (Appendix A). Road density was measured based on 2 variables (Table 2): (1) density of paved and unpaved roads, except U.S., state, and interstate highways, and (2) density of major highways (U.S., state, and interstate highways). Although there were inconsistencies in the CFCC codes we used to define major and minor roads, we assumed that spatially averaging over a very large area (using a 2,590-km^2 moving window) would reduce the impact of these inconsistencies. Although road density was used in the statistical model, we also included this variable in the expert-assisted model because we wanted to separate the potentially different influences of the 2 classes of roads on panther restoration. The presence of less-developed roads can provide human access for poaching, whereas the presence of major highways can result in vehicular mortality of panthers and can impede panther movements. These 2 road density variables were weighted according to the results of the expert survey and combined into a single index of road density (Appendix A). Human population density was a combination of human density and human population growth from 1990 to 2000 (U.S. Census Bureau 2002). Human population density is an indicator of urban and suburban development, and a measure of the potential for human-panther conflicts. Human population growth from 1990–2000 was incorporated as an indicator of where future population growth (or loss) may impact panther restoration efforts. As such, this measure was different from the human population density variable used in the statistical model.

Because human impact and livestock density may have a negative association with the suitability of panther reintroduction sites, we calculated the inverse of these variables so that greater values indicate more favorable areas (Eastman et al. 1995). We standardized all variables using linear scaling (Eastman et al. 1995).

***Expert Survey*.--**In May 2003, we sent a survey to 50 selected panther experts, including the Florida Panther Recovery Team and additional *P. concolor* experts from the western U.S. We requested that each participant select the variable (as defined previously) deemed to be more important in each of 8 pairwise comparisons and to rank how important the selected variable was, compared with the other (Appendix A). We used a web-based program (Web-HIPRE; Mustajoki and Hämäläinen 1999) to transform the pairwise comparisons into weights based on the Analytic Hierarchy Process model. We calculated a consistency ratio to determine the degree of consistency among the experts in rating the pairwise comparisons (Eastman et al. 1995). A consistency ratio of ≤ 0.1 is preferred; when relatively high consistency ratios are obtained, the pairwise comparisons should be re-evaluated. From the matrix of pairwise comparisons, we calculated a weight (0–1 scale) for each variable, representing its importance to panther ecology. Next, we used GIS to multiply each habitat variable by its weight as calculated from the pairwise comparisons. Finally, we summed the weighted map layers, providing a single score for each pixel in the study area. Areas with greater values indicated greater potential to support a panther population.

RELEASE SUCCESS OF PANTHERS IN NORTH FLORIDA

Data Collection

Two experimental reintroductions were conducted in the late 1980s and early 1990s to assess the feasibility of establishing a population of Florida panthers in unoccupied areas of the historic range. The release site was located in Pinhook Swamp, between Okefenokee National Wildlife Refuge and Osceola National Forest in northern

Florida (Belden and Hagedorn 1993). The first releases occurred in 1988 with the translocation of 7 mountain lions from western Texas as experimental surrogates for Florida panthers (Belden and Hagedorn 1993). Additional releases of 19 mountain lions took place in 1993 and 1994 (Belden and McCown 1996). Those studies provided important information about the characteristics of the animals that may have influenced release success (e.g., sex, age, captive or wild origin).

We obtained the database of telemetry locations and information on the characteristics of released mountain lions (Belden and Hagedorn 1993, Belden and McCown 1996) to provide further guidelines for effective release procedures and selection of proper release candidates (van Manen et al. 2000). Mountain lions were located daily, except on Sundays, during the first study and on Mondays, Wednesday, and Fridays during the second study (Belden and Hagedorn 1993, Belden and McCown 1996). We pooled all mountain lion releases from both studies for a total of 35 releases of 26 mountain lions. Like Belden and Hagedorn (1993) and Belden and McCown (1996), we also used those data to identify landscape characteristics that were associated with the success or failure of the Texas mountain lions. Our analysis, however, was performed using improved spatial data and statistical techniques that were not available when those earlier studies were completed.

Logistic Regression

We developed several binomial dependent variables for the logistic regression analysis. Four dependent variables were used to define release success based on (1) survival >6 months without management intervention, (2) occurrence of livestock depredation, (3) mortality of the study animal, and (4) landowner complaints (i.e., mountain lion sightings near human habitation or landowner complaints about mountain lion presence; van Manen et al. 2000). We evaluated independent variables that were potentially associated with release success, including characteristics of the study animals, release procedures, and habitat characteristics of the release site. Variables associated with mountain lion characteristics included sex, origin (wild or captive), release season, release group size, age class (adult or subadult/kitten), and number of months held in captivity prior to release.

Animals that were censored (recaptured after <6 months in the wild because the study ended) were excluded from further analysis. We classified mountain lions of wild origin as captive because they were held captive for a long period (2–8 years) prior to release (Belden and Hagedorn 1993). Habitat variables included road density, human density, natural land-cover density, urban land-cover density, and patch density of natural land cover. All habitat variables were calculated in ArcGIS™ or FRAGSTATS (McGarigal and Marks 1995) at a resolution of 500 m. Those landscape metrics were calculated at 2 different moving window sizes, based on the mean fixed kernel home ranges of females and males. Road density, human density, and urban land-cover density measured the human imprint on the landscape, whereas natural land-cover density and patch density characterized the size and fragmentation of potential habitat patches. Release area characteristics were determined by querying the values of habitat variables at each telemetry location in ArcGIS™. We used the mean value of habitat variables at all telemetry locations for each animal to represent the general habitat characteristics of each animal's use area.

We performed univariate logistic regression (PROC LOGISTIC; SAS Institute 2000) with all combinations of independent and dependent variables. We created dummy variables for categorical variables (i.e., release season, mountain lion origin, sex, age class). Independent variables with a $P < 0.25$ for the Wald χ^2 statistic were selected for initial inclusion in the multi-variable model (Hosmer and Lemeshow 1989). When variables were measured at multiple spatial scales, we selected the scale that was statistically most significant. We used a correlation matrix to identify and remove redundant variables before fitting multi-variable models. Stepwise logistic regression was conducted with the independent variables that met the initial selection criteria. We determined the fit of the resulting models with the Hosmer-Lemeshow goodness-of-fit statistic (Hosmer and Lemeshow 1989).

Model performance was assessed by calculating the correct classification rates for each model. Probability cut-off levels were selected for each model that maximized correct classification rates, while minimizing the false positive rate (van Manen et al. 2000).

Linear Regression

Success or failure of the released animals also can be assessed in terms of their home-range sizes, movement patterns, and dispersal distances. Animals that move long distances, disperse far from the release site, or have large home ranges exhibit behavior that is less desirable compared with animals that quickly establish small home ranges near the release site (Ruth et al. 1998). For example, transient or dispersing mountain lions are more likely to be involved in nuisance behavior or other human-mountain lion interactions (Belden and McCown 1996). Therefore, we considered home-range size and 3 variables related to mountain lion movement patterns: mean daily movement distance, dispersion (mean squared distance from the center of activity; Hooge and Eichenlaub 1997), and linearity of movement patterns (measured as the fractal dimension of the animal's movement path; Nams 1996). Fractal dimension (*FD*) is a measure of movement path "crookedness", where *FD* = 1 when the path is perfectly linear, and *FD* = 2 when the path is extremely sinuous (Nams 1996). Minimum convex polygon (MCP) home ranges were calculated with the Animal Movement extension to ArcView® GIS (Hooge and Eichenlaub 1997) using all locations for each release, regardless of initial exploratory movements or date of home-range establishment. Although the MCP home range is only an approximate measure in this case, it provides a general estimate of the size of the animal's use area.

Analysis of the 4 dependent variables was performed with multiple linear regression (PROC REG; SAS Institute 2000). We used 8 independent variables, including an index of habitat quality, sex, origin (wild or captive), release group size, number of previous releases, release season (winter or spring, with summer as the reference), number of months held captive prior to release, and age class. The index of habitat quality consisted of a map layer of Mahalanobis distance values from our landscape analysis of Florida panther habitat in the Southeast. We chose to use this index rather than individual landscape variables (e.g., road density, percent natural land cover) to reduce the number of variables in the linear regression. For all independent variables, we calculated a correlation matrix to determine multicollinearity. We assessed the explanatory power and significance of all possible combinations of independent variables; we used the lowest Akaike's Information Criterion (AIC) to choose the most parsimonious model for each dependent variable (Bozdogan 1987). We tested residuals for normality and homogeneity of variances with the Shapiro-Wilk and Levene's tests, respectively (SAS Institute 2000).

RESULTS

SPATIAL ANALYSES

Landscape-Scale Statistical Model

Home Ranges.--The mean home-range area was 244.1 km^2 (SD = 186.2, range = 59.9 to 1,074.4) for female panthers and 768.6 km^2 (SD = 828.2 , range = 28.4 to 4,682.3) for males. Based on those home-range sizes, we calculated habitat variables for the Mahalanobis distance (D^2) model using circular moving windows with radii of 8,800 m (mean female home-range size) and 15,600 m (mean male home-range size).

Model Application.--We selected 6 variables for the initial D^2 model based on their biological significance, relatively low correlation among variables, and low coefficients of variation at sampled panther home ranges: landscape diversity, contagion, patch density, percent natural land cover, human density, and road density. Habitat variables quantifying area and connectedness of patches were strongly correlated, so we removed several of those variables and only used percent of natural land cover because of its interpretability.

The final model included the variables road density, human density, percent urban land cover, percent natural land cover, patch density, and contagion. The resulting map consisted of D^2 values ranging from 0.457 to 36,967.3 (Fig. 4).

Model Assessment.-- Based on the cumulative frequency graph for the selected model, values of $D^2 \leq 20$ correctly classified an average of 80.6% pixels within panther home ranges, while restricting predictions of suitable habitat in the southeastern U.S. to 15.8% (Fig. 5). Sixty-eight of the 86 home ranges (79%) had a mean D^2 value $\leq$20. We also evaluated model accuracy with 2002 telemetry data that were not available at the time of model development. Within the 4 home ranges from the 2002 telemetry data, 64.2% of the pixels had D^2 values $\leq$20. Based on a minimum size of 2,590 km^2 for a panther reintroduction site as recommended by Belden and Hagedorn (1993), we identified 16 contiguous areas of suitable habitat with D^2 values $\leq$20. Those 16 areas

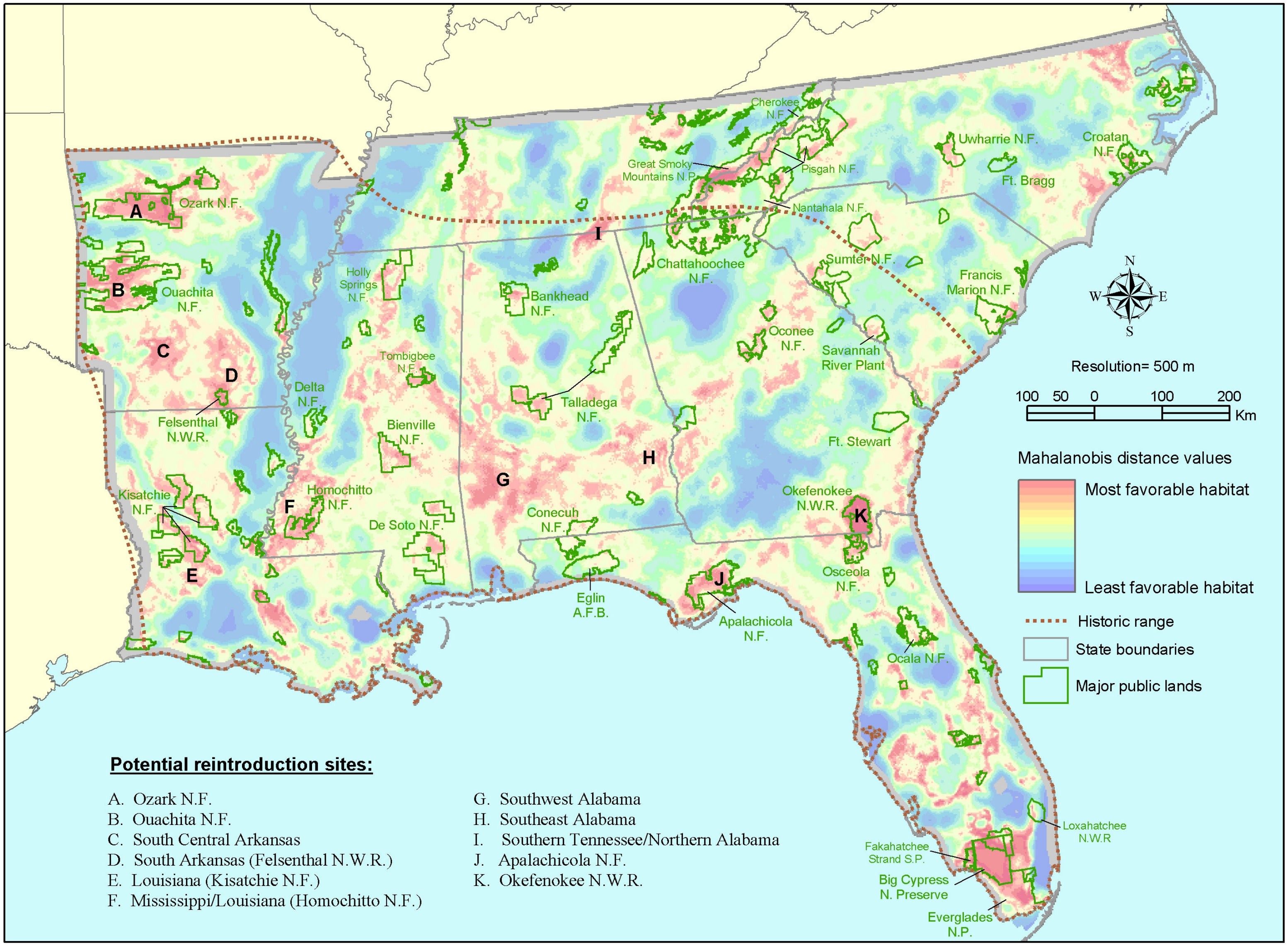

Fig. 4. Mahalanobis distance values used to identify sites for the potential reintroduction of Florida panthers in the southeastern U.S.

27

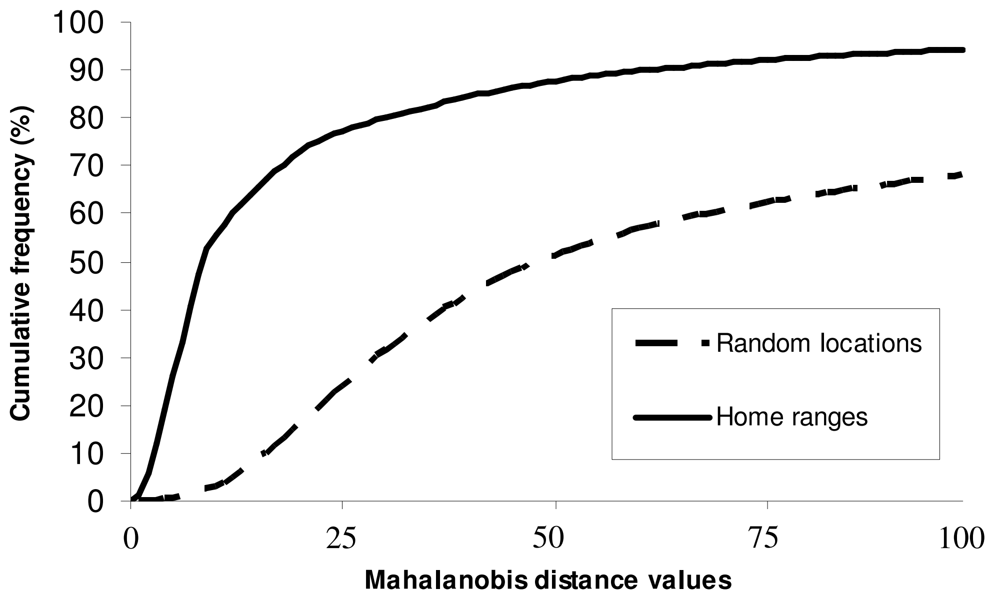

Fig. 5. Cumulative frequency distribution of D^2 values within panther home ranges compared with D^2 values at random locations in the southeastern U.S.

included 3 areas outside the historic range, the current range in south Florida, and a potential expansion/augmentation site in south-central Florida (Table 3). Therefore, we only included the remaining 11 potential reintroduction sites for further consideration.

The mean error based on the 10-fold crossvalidation was 3.7% (range = 0.0005–99.8). The largest error occurred for panther #85, a male whose home range extended near urban areas in southeastern Florida. Overall, 78–79% of panther home ranges were correctly classified in the 10 iterations of the crossvalidation, indicating strong model stability and little influence of outliers.

To further test model accuracy, we used telemetry data from the 1988 and 1993 experimental releases of Texas mountain lions in the Okefenokee National Wildlife Refuge/Osceola National Forest region of northern Florida (Belden and Hagedorn 1993, Belden and McCown 1996). We sampled Mahalanobis distance scores within MCP home ranges calculated from mountain lion telemetry locations from those studies. Within the 35 home ranges, an average of 49.0% of all pixels had D^2 values ≤ 20, compared with 15.8% if home ranges had been randomly located.

Local-Scale Statistical Model

We limited our local-scale analysis to the 11 potential panther reintroduction sites, defined as large (>2,590 km^2), contiguous areas of favorable habitat according to the original D^2 model. Among those potential reintroduction sites, substantial variance of D^2 values was apparent (Fig. 6). Areas with a higher variance had a mix of high and low D^2 values, indicating the presence of both favorable and unfavorable habitat at the local scale (Fig 6; Table 3). Conversely, some areas, such as south-central Arkansas, had much lower variance at the local scale (Table 3).

Metapopulation Model

The 20-km^2 pixels with D^2 values ≤ 20 encompassed 9.9% of the study area. Because of the methods we used to define patches, some of the potential reintroduction sites were divided into several smaller patches. In those cases, we simulated panther occupancy in the largest remaining patch.

Non-linear regression based on the black bear patch network and occupancy data for the southern Appalachians resulted in stable parameter estimates ($\alpha = 0.065$, $x = 0.96$,

Table 3. Summary statistics to evaluate potential sites for Florida panther reintroduction in the southeastern U.S.

Site name (site label)	Size of site (km^2)[a]	Mean expert model score[b]	% local-scale habitat[c]	No. of potentially occupied patches[d]	Area of potentially occupied patches (km^2)[d]	Range of patch incidence probabilities[d]	Average patch incidence probability[d]
Ozark National Forest region (A)	8,524	27.70	0.80	0	0	0.00	0.00
Ouachita National Forest region (B)	5,107	37.55	0.79	3	162	0.02–0.13	0.06
South-central Arkansas (C)	3,731	20.79	0.82	15	6,926	0.01–0.87	0.35
South Arkansas (Felsenthal National Wildlife Refuge region) (D)	6,627	22.80	0.78	13	3,605	0.01–0.92	0.45
Kisatchie National Forest region (E)	3,502	24.56	0.72	10	2,369	0.03–0.91	0.29
Mississippi/Louisiana (Homochitto National Forest region) (F)	7,018	24.93	0.48	19	2,653	0.01–0.97	0.39
Southwest Alabama (G)	21,687	22.30	0.62	16	2,471	0.01–0.99	0.17
Southeast Alabama (H)	4,049	18.59	0.42	14	3,159	0.01–0.83	0.30
South Tennessee/Northern Alabama (I)	2,613	14.20	0.70	1	567	0.03	0.03
Apalachicola National Forest region (J)	3,081	42.31	0.79	2	182	0.16–0.94	0.55
Okefenokee National Wildlife Refuge region (K)	5,469	36.02	0.73	8	709	0.11–0.75	0.44
Central Tennessee (outside historic range)	2,655	14.16	0.50	7	506	0.03–0.81	0.36
Eastern North Carolina (outside historic range)	2,682	20.67	0.19	5	891	0.03–0.88	0.55
Great Smoky Mountains National Park region (outside historic range)	3,884	29.61	0.86	5	952	0.01–0.19	0.11
South-central Florida (potential augmentation/expansion site)	4,030	30.16	0.28	13	2,207	0.01–0.85	0.26
South Florida (current range)	8,797	63.32	0.75	7	344	0.04–0.94	0.42

[a] Area of contiguous pixels with $D^2 \leq 20$.
[b] Mean expert model score for all pixels within potential reintroduction site, based on expert-assisted model results.
[c] Percent of pixels, based on 90-m resolution, within potential reintroduction sites with $D^2 \leq 20$ (relatively favorable habitat).
[d] Potentially occupied patches defined as those with a $J_i > 0.01$.

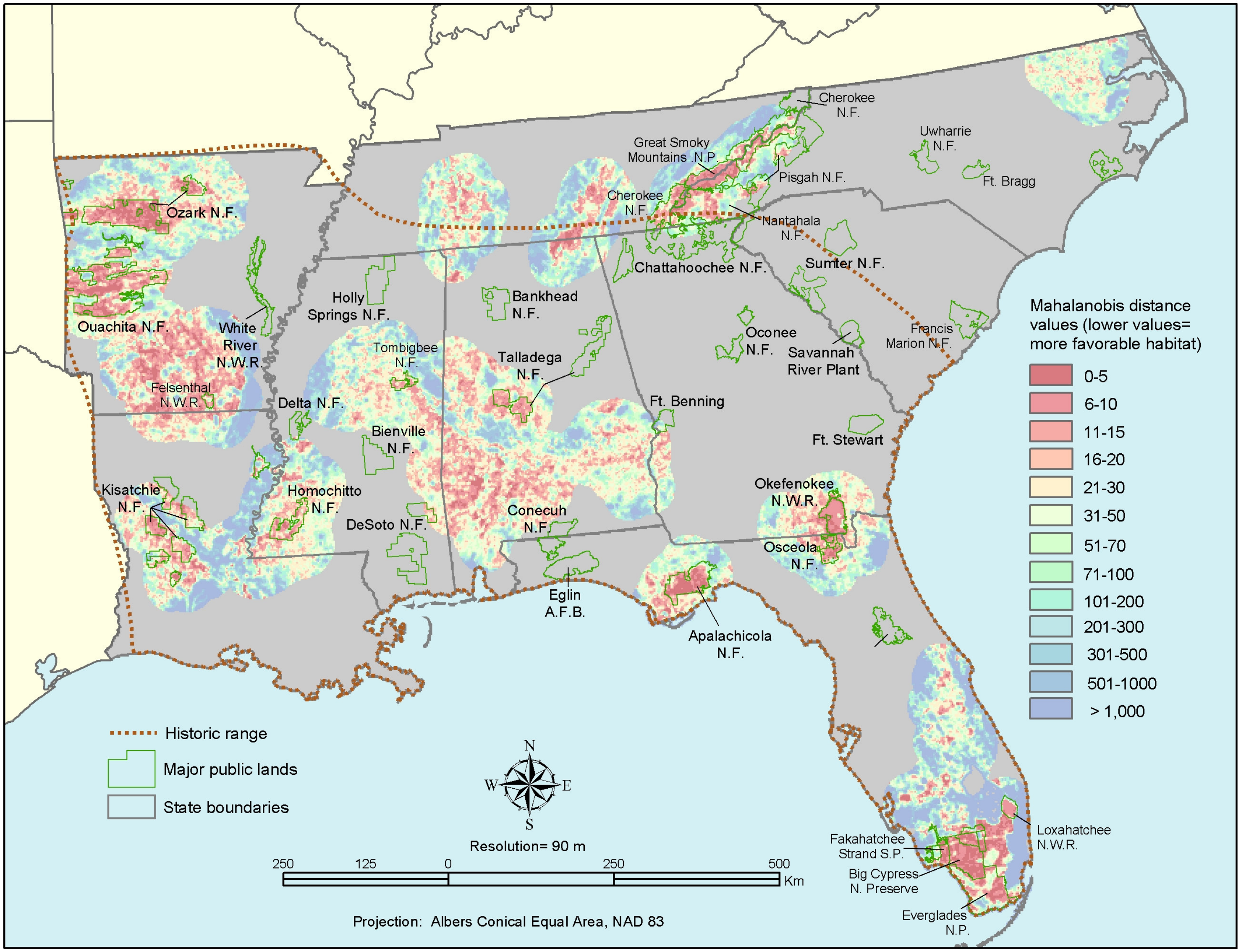

Fig. 6. Mahalanobis distance values calculated at the local scale to characterize habitat quality within potential reintroduction sites for the Florida panther in the southeastern U.S.

$y = 411.95$, and $e = 0.381$). We applied those estimates to the Florida panther patch network in the Southeast by simulating the occupation of each potential reintroduction site. Those simulations resulted in incidence estimates (i.e., probability of occurrence, J_i) for habitat patches surrounding each potential reintroduction site. Incidence values for nearby habitat patches ranged from 0 to 99% at the end of a 100-year simulation (Table 3), and decreased markedly as patches became more isolated (Fig. 7). Colonization of empty patches seemed more affected by patch isolation than patch area.

The simulation results indicated that panthers reintroduced to the Ozark National Forest site had the lowest probability of occupancy of surrounding patches, whereas the south-central Arkansas, Mississippi/Louisiana (Homochitto National Forest region), southwest Alabama, and southeast Alabama sites had a relatively high overall probability of occupancy of nearby patches (Fig. 7; Table 3).

Expert-Assisted Landscape Model

Sixteen *P. concolor* experts and members of the Florida Panther Recovery Team evaluated the relative importance of the 6 variables to characterize potential suitability of reintroduction sites in the southeastern U.S. (overall survey response rate = 32%). Aggregating the 16 individual pairwise comparisons based on the geometric mean (Table 4), the consistency ratio for the comparison matrix was 0.127, which is only slightly greater than the ideal of $\leq$0.1. Therefore, we performed no additional sensitivity analyses to determine how varying opinions could have influenced the results. Human impact was considered by our experts to be the most important variable, followed by the amount of public land, prey density, and livestock density (Table 5). The 6 GIS map layers were multiplied by their respective weights and then summed to produce an index of potential suitability of reintroduction sites (Fig. 8).

RELEASE SUCCESS OF PANTHERS IN NORTH FLORIDA

Univariate logistic regression exposed few relationships with habitat variables or characteristics of release animals that met initial selection criteria. Additionally, because of the low sample size ($n = 30$), we could not fit multi-variable models to any of the 4 dependent variables. The criterion based on landowner complaints showed the greatest R^2 (0.527) and seemed to have the best performance (Table 6); this criterion indicated a

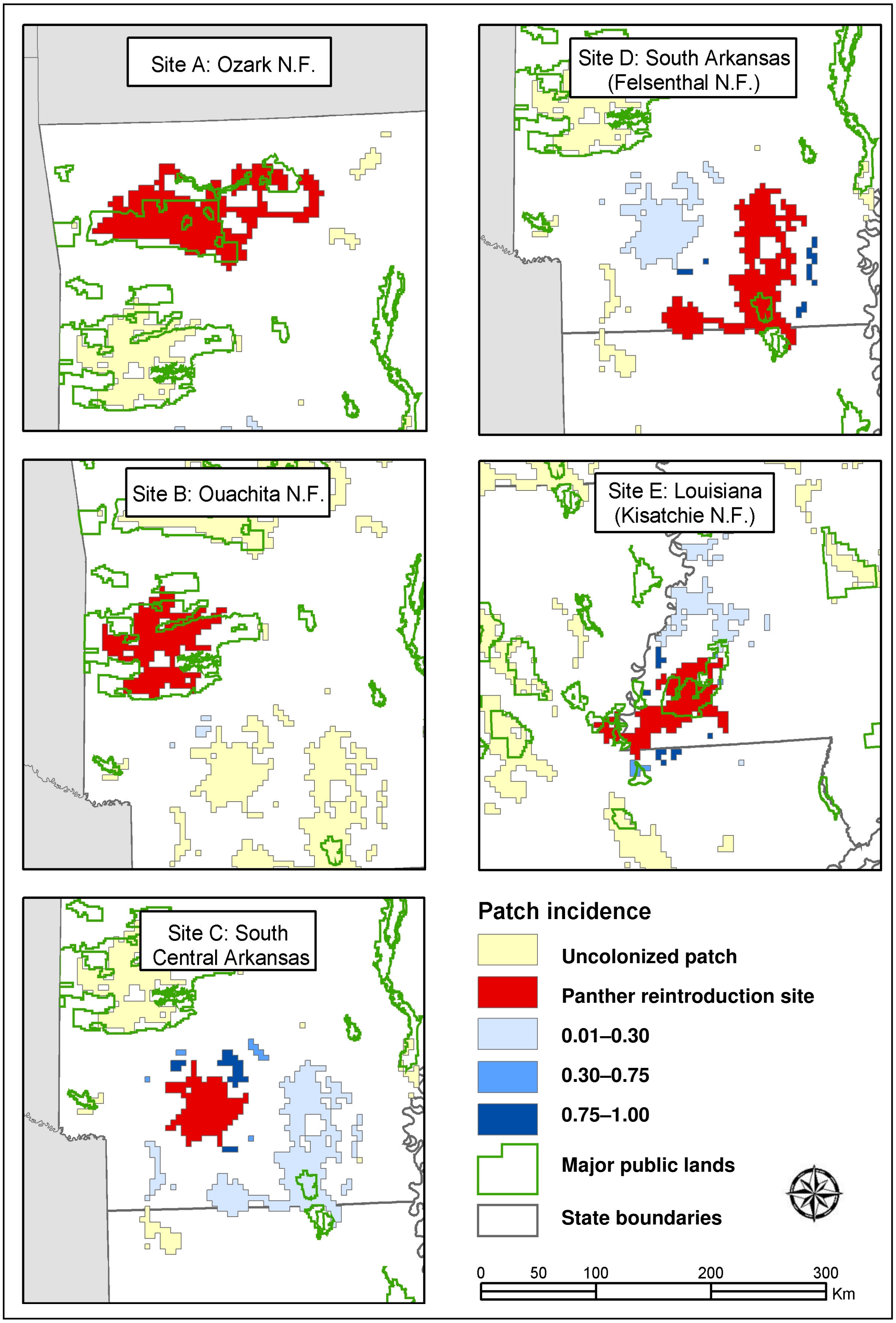

Fig. 7. Patch incidence probability for potential reintroduction sites for the Florida panther in the southeastern U.S. Patch incidence is the probability that a patch will be occupied by panthers during a 100-year period.

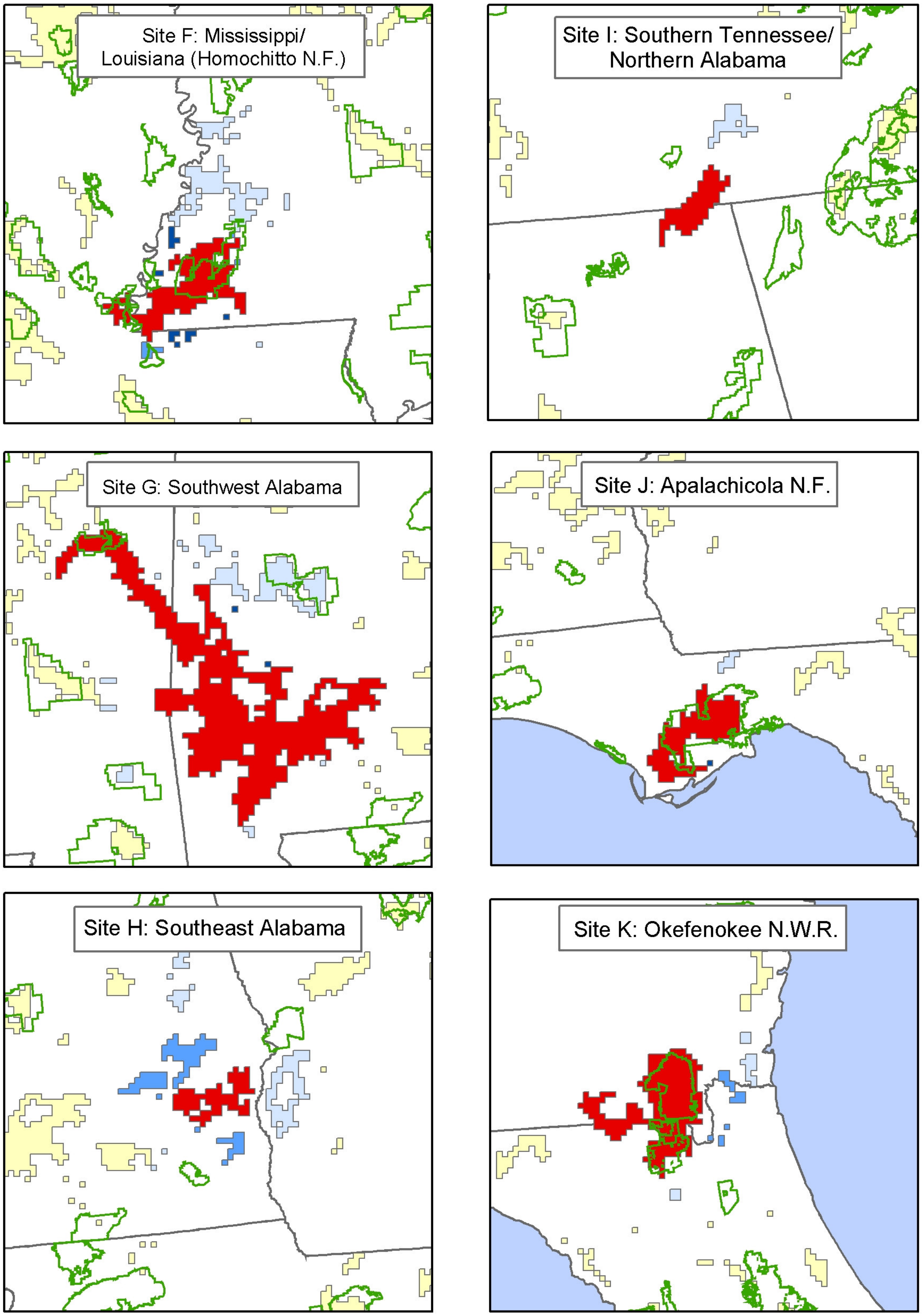

Fig. 7 (continued).

Table 4. Pairwise comparison matrix for the main variables in the expert-assisted model to identify potential reintroduction sites for Florida panthers in the southeastern U.S.[a]

	Area of public lands	**Livestock density**	**Prey density**	**Human impact**
Area of public lands	1.00	4.30	2.40	0.83
Livestock density	0.23	1.00	0.24	0.17
Prey density	0.42	4.20	1.00	0.33
Human impact	1.20	5.90	3.00	1.00

[a] The pairwise comparison results indicate the relative importance of the variable in the left column relative to the variable in the top row. Ratings are on a 9-point scale, in which 9 is extremely more important, 1 is equally important, and 1/9 is extremely less important in terms of identifying potential reintroduction sites. For example, experts ranked the area of public lands as 4.3 times more important than livestock density.

Table 5. Relative weights of habitat variables based on an expert-assisted model to identify potential reintroduction sites for Florida panthers in the southeastern U.S.

Variable	**Weight**
Human impact on the landscape	
Minor roads	0.114
Major roads	0.088
Human density/population growth	0.222
Total weight	0.423
Area of public lands	0.339
Prey density	0.176
Livestock density	0.062

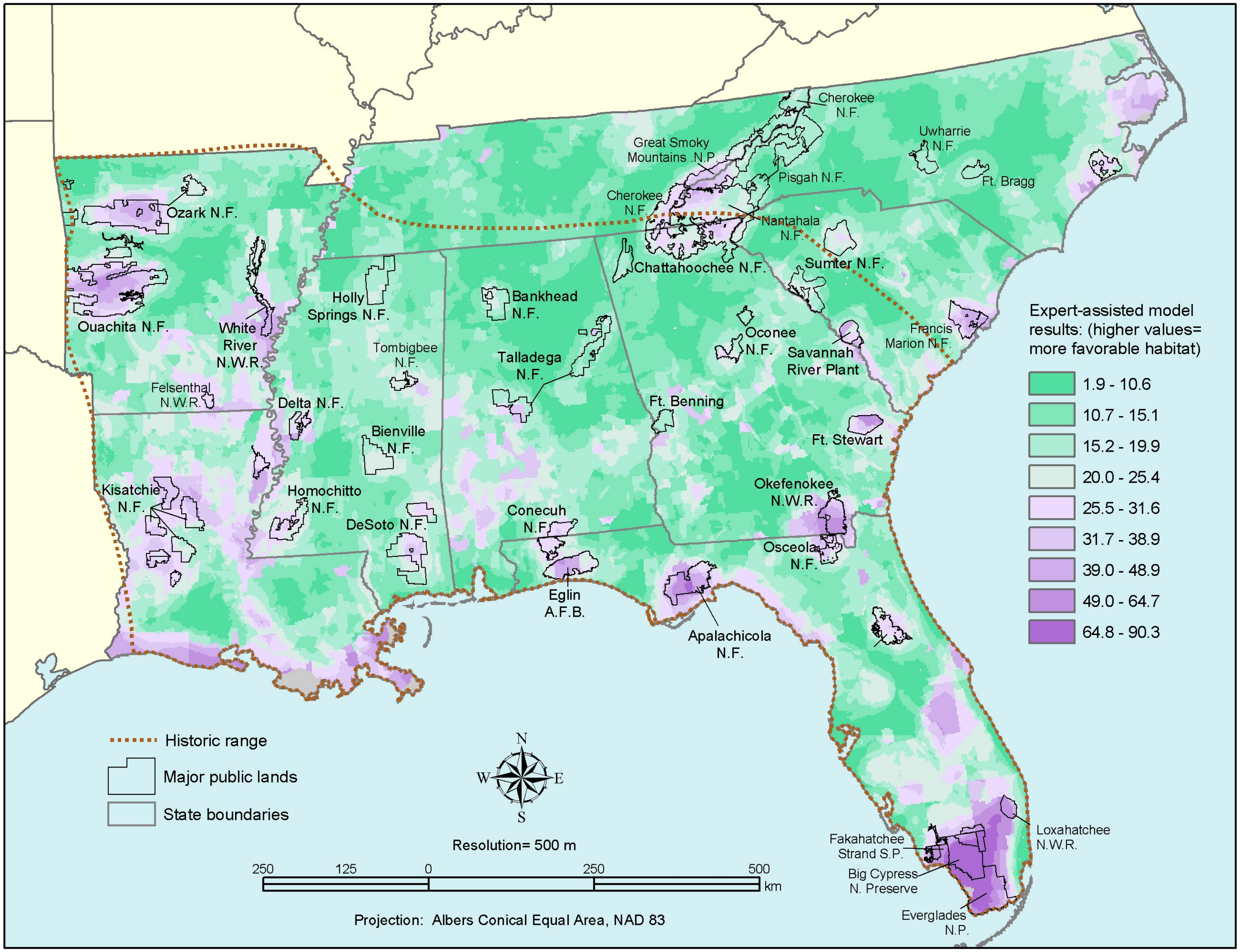

Fig. 8. Expert-assisted model scores to identify sites for the potential reintroduction of Florida panthers in the southeastern U.S.

negative relationship with road density (Table 6). The remaining 3 criteria showed relatively poor model fit and performance (Tables 6 and 7). The false positive rates for the livestock depredation and mortality criteria were particularly high (50.0% and 66.7%, respectively). Presence or absence of kittens with adult females was believed to be an important variable (Belden and McCown 1996), but could not be evaluated because few females were released with kittens.

With the linear regression analysis, the best predictors of home-range size were habitat quality and mountain lion origin (Table 8). Linearity (fractal dimension) of movements after release was best predicted by a single variable, spring release season (Table 8). Although the AIC value was lower for the model that included sex, group size (range = 1–10), and spring release season, the difference in AIC values was small (0.06), and the additional variables did not provide enough improvement in explanatory power (R^2 increase of 0.09) to warrant inclusion in the model. Also, stepwise model selection chose the spring-only model, which was the only instance where AIC and stepwise model selection techniques did not agree. That relationship captured 31.8% of the variation in the linearity of movement patterns.

The model based on the mean daily movement distance explained most of the variation (58.7%) and was best predicted by the sex and age class of the release animal, the number of months in captivity prior to release (range = 0–96), and habitat quality (Table 8). Daily movements of males and adults were greater than those of females or subadults/kittens. Furthermore, longer captivity periods and higher quality of habitat in the release area were associated with smaller distances traveled per day. Finally, dispersion was associated with sex and origin of the release animals, with males and wild panthers exhibiting the greatest dispersion (R^2 = 0.254; Table 8).

Table 6. Parameter estimates of logistic regression models to determine release success of Texas mountain lions in north Florida, 1988–1995.

Criterion	**Independent variable**	**Parameter estimate**	**SE**	***P***	***R*^{2}**
Persistence					0.125
>6 months	Intercept	-0.833	0.64	0.195	
	Patch density (15,600-m window)	30.422	20.20	0.132	
Livestock					0.180
depredation	Intercept	0.462	0.73	0.527	
	Patch density (15,600-m window)	-48.321	29.75	0.104	
Mortality					0.115
	Intercept	-6.307	3.7	0.084	
	Road density (15,600-m window)	3,903.2	2,629.7	0.138	
Landowner complaints					0.527
	Intercept	16.799	9.5	0.076	
	Road density (15,600-m window)	-14,598.2	7,747.7	0.060	

Table 7. Accuracy assessment of logistic regression models to determine release success of Texas mountain lions in north Florida, 1988–1995.

Model	*P* cut-off	Correct rate (%)[a]	Sensitivity rate (%)[b]	Specificity rate (%)[c]	False positive rate (%)[d]	False negative rate (%)[e]	Reliability[f]
Persistence >6 months	0.65	56.7	26.7	86.7	33.3	45.8	0.59
Livestock depredation	0.40	66.7	60.0	70.0	50.0	22.2	0.64
Mortality	0.45	70.0	12.2	90.9	66.7	25.9	0.53
Complaints	0.45	88.0	40.0	100.0	0.0	13.0	0.92

[a] % of correctly classified releases.
[b] Correct prediction of release success (A).
[c] Correct prediction of release failure (B).
[d] Release success predicted for actual release failure (C).
[e] Release failure predicted for actual release success (D).
[f] (A+B)/(A+B+C+D).

Table 8. Parameter estimates of linear regression models to determine release success of Texas mountain lions in north Florida, 1988–1995.

Variable	**Parameter estimate**	**SE**	***P***	***R^2***
Home-range area (km^2)				0.254
Intercept	-1,077.0	6,820.4	0.126	
Origin (wild=1, captive=0)	8,024.7	3,368.1	0.025	
Habitat quality	698.3	389.0	0.084	
Linearity of movement (fractal dimension)				0.318
Intercept	1.20	0.0	<0.001	
Spring release season	0.17	0.1	0.002	
Mean daily movement distance (m/day)				0.587
Intercept	-1,377.2	1,154.2	0.244	
Habitat quality	201.7	64.7	0.005	
Age class (adult=1, kitten=0)	1,884.6	726.5	0.016	
Months captive prior to release	-27.1	10.0	0.012	
Sex (male=1, female=0)	915.7	573.6	0.123	
Dispersion (squared distance in km)				0.254
Intercept	-274,355	752,723	0.718	
Sex (male=1, female=0)	1,529,235	903,700	0.102	
Origin (wild=1, captive=0)	1,781,479	935,568	0.068	

DISCUSSION

LANDSCAPE ANALYSIS

General

Mountain lions once were the most widely distributed wild mammal in the western hemisphere and, as such, do not require a specific habitat structure or ecosystem type to survive. Because of their large home ranges, low densities, and persecution by humans, large carnivores are especially vulnerable to localized extinction due to habitat loss and fragmentation (Crooks 2002). Additionally, panthers are susceptible to human disturbance. The best evidence for this is that Florida panthers persist today only in that portion of the Southeast where human densities are lowest, vehicular access is most restricted, and habitat is most contiguous, despite prey densities that are less than optimal (Clark 2001). Those factors heavily influenced our landscape model. The D^2 model predicted favorable panther habitat conditions where human populations and road densities were low and where natural land-cover types and mean patch densities were high.

We attempted to represent a variety of aspects of panther ecology in our assessment by using generalized land-cover data, and by including anthropogenic and landscape variables that quantify landscape structure and fragmentation. However, there are limitations inherent in a range-wide evaluation of habitat. Our study was extensive in scope but lacking in local-scale detail; GIS-based habitat models often cannot incorporate fine-scale habitat characteristics, such as vegetation structure and detailed information on prey availability (e.g., small mammal density, stalking cover). Given the large scale at which panther habitat use occurs and the broad extent of our study area, we chose GIS data sources and resolutions that were most appropriate to accomplish our objectives.

The statistical assessment of landscape conditions based on the Mahalanobis distance model provided the basis for identifying potential Florida panther reintroduction sites in the Southeast. The Mahalanobis distance model may perform poorly when unfavorable conditions are present that cannot be readily identified from digital map sources, such as seasonal inundation or lack of understory vegetation for stalking cover. For example, our model identified several Water Conservation Areas in south Florida as favorable habitat although panthers rarely used these areas. The land-cover data could not be used to distinguish this disturbed and flooded grassland landscape from the drier, less disturbed grasslands found to the west, which are used by panthers. These possibilities must be kept in mind when perusing the habitat maps. Additionally, the model may be inaccurate should the habitat matrix change over time (Knick and Rotenberry 1998); however, we assumed a relatively stable landscape over the reintroduction period.

We used the National Land Cover Data (Vogelmann et al. 2001) for our analysis because of its consistency throughout the study area and because it was developed from 1992 satellite data, the relative temporal midpoint for telemetry data collection. Effects of localized land-use changes that may have occurred before or after that period were reduced by our use of large moving windows in GIS to calculate the landscape indices. The D^2 model provided an objective and quantitative evaluation of the overall landscape conditions that enabled us to identify prospective sites for further analysis.

Eleven contiguous areas of favorable habitat ($D^2 \leq 20$) met the minimum size requirement for a panther reintroduction site (Fig. 4; Table 3). The area of favorable habitat, however, varied widely among the 11 potential reintroduction sites. For example, the southwest Alabama site, with 21,687 km^2 of contiguous habitat, was more than twice the size of the next largest site (Table 3).

Given the lack of telemetry data for the vast majority of the study area, we used the results of previous studies (Jordan 1993, 1994) to qualitatively assess the D^2 models. Jordan (1993, 1994) identified and ranked potential reintroduction sites for the Florida panther based on expert opinion. Although our empirical model identified large tracts of favorable habitat at 11 of 14 sites identified by Jordan (1993, 1994), there were some differences between the 2 models, which were likely due to differences in methods and data. For example, Jordan (1993, 1994) identified coastal South Carolina, the Georgia/South Carolina Piedmont region, and the Big Bend region of Florida as potential reintroduction sites, whereas our statistical landscape model did not. Although favorable habitat was found in these regions, the areas of contiguous habitat did not meet our size criterion to qualify as potential reintroduction sites.

The local-scale assessment of panther habitat was performed only for regions identified in the statistical landscape model. The objective of the local-scale analysis was to determine whether regions with substantial panther habitat, as measured at a broad scale and mapped at a 500-m resolution, also provided sufficient habitat at a more local scale and greater resolution of 90 m. The results from that analysis indicated that some sites had much less favorable habitat at the local scale and might not be suitable for panther reintroduction (Table 3). The Mississippi/Louisiana, southwest Alabama, and southeast Alabama regions had the lowest percentages of favorable habitat at the local scale (Table 3). The proportion of favorable local habitat also was relatively low for the potential population expansion site in south-central Florida.

The metapopulation model provided information on the potential for panther colonization and dispersal between habitat patches. Low levels of fragmentation between patches improve the long-term potential for expansion into other unoccupied areas of the historic range. Although we used the black bear as a surrogate species, our results seem reasonable given current knowledge of Florida panther dispersal. For example, the model predicted a low probability of colonization from the currently occupied south Florida area to the south-central Florida area. That appears to be the case; we know of no instances whereby Florida panthers have successfully colonized (i.e., dispersal coupled with subsequent reproduction) habitats in south-central Florida. Nevertheless, our incidence probabilities (J_i) should be interpreted with caution because we used a surrogate species and some assumptions of the model (e.g., quasi-stationary equilibrium) may have been violated. Additionally, the incidence function model that we used does not include elements of habitat quality. Although habitat quality of the surrounding landscape has only minor effects on metapopulation models (Wahlberg et al. 1996), colonization probabilities may be different if movement barriers are present. For example, colonization probability may be less than predicted by the metapopulation model for patches that are separated from an occupied patch by highways and urban areas, and greater for those patches that are not.

Our intention for using the expert-assisted landscape model was to give weight to issues for which south Florida was not a good reference site. The variables we chose for this non-empirical model reflected the practical concerns of identifying reintroduction sites that reduce the likelihood of panther-human conflicts, provide protection from human disturbance, and provide prey for panthers. Based on our survey, Florida panther experts ranked human impact on the landscape as the most important variable in the model, followed by area of public land. Those ratings seemed to reflect concerns that human-caused mortality may be an important limiting factor for the success of panther reintroduction efforts. Based on the expert model results, the current panther range in south Florida provides the best landscape conditions, primarily because of the low human and road densities and large tracts of public land (Fig. 8; Table 3).

It is difficult to objectively interpret the results of our 4 spatial analyses singly because the weightings to give each are unknown. Additionally, when taken individually, some of the measures we calculated may be misleading. For example, the Ozark National Forest site had the lowest potential for panther occupancy of adjacent patches. However, that site was among the largest that we evaluated and, as such, eventual occupation of adjacent patches would not be essential (Table 3). To coalesce some of the landscape metrics into a more interpretable form, we used the landscape-scale D^2 model only to identify potential reintroduction sites, quantified potential habitat that might be recolonized by dispersing panthers by multiplying the size of each patch by its incidence probability, and then used the fine-scale D^2 model to quantify the total area of favorable habitat available to panthers at each of those sites. That resulted in an area calculation of favorable panther habitat at each site, including areas that potentially could be colonized by dispersing cats (effective habitat area). Our base assumption was that larger areas would correspond to more viable and stable panther reintroductions. That measure can then be compared with our non-empirical model results (i.e., expert-assisted model) to assess each site (Fig. 9; Table 9).

We emphasize that the maps that we produced should be considered as starting points for evaluation of potential reintroduction sites. We employed cutoff values to help delineate sites as favorable or unfavorable, but we emphasize that the site maps represent a continuum of site conditions. The cutoff values we chose were, at least partially, subjective as were the relative contributions of the 4 map layers produced with our 4 analytical approaches. Nevertheless, decisions ultimately must be made by managers,

Table 9. Effective habitat area and expert-assisted model scores at 11 potential reintroduction sites for Florida panthers in the southeastern U.S. South-central Florida and south Florida data are provided for reference purposes.

Site label	**Site name**	**Effective habitat area of site (km^2)[a]**	**Mean expert model score**
G	Southwest Alabama	9,629	22.3
A	Ozark National Forest	6,168	27.7
D	South Arkansas (Felsenthal National Wildlife Refuge)	4,794	22.8
K	Okefenokee National Wildlife Refuge	3,713	36.0
B	Ouachita National Forest	3,535	37.6
E	Louisiana (Kisatchie National Forest)	2,449	24.6
C	South Central Arkansas	2,228	20.8
J	Apalachicola National Forest	2,227	42.3
F	Miss./Louisiana (Homochitto National Forest)	2,159	24.9
H	Southeast Alabama	1,261	18.6
I	South Tennessee/Northern Alabama	1,004	14.2
	South-central Florida (potential augmentation/expansion site)	208	30.2
	South Florida (current range)	5,761	63.3

[a]Area of the potential reintroduction site plus areas (A_i) of surrounding colonized patches multiplied by their respective patch incidence probability (J_i); that total area was then multiplied by the percent of pixels defined as favorable habitat ($D^2 < 20$) in the local-scale statistical habitat model.

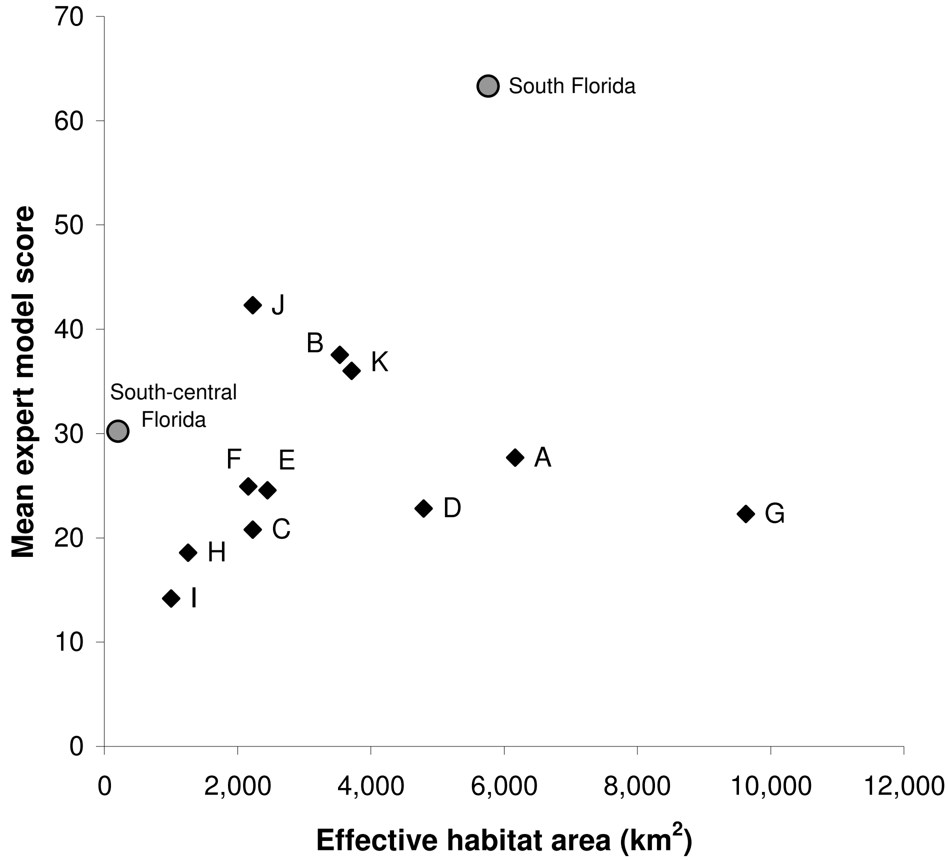

Fig. 9. Scatterplot of effective habitat area and mean expert-assisted model score to identify potential reintroduction sites for Florida panthers in the southeastern U.S. Larger values on both axes indicate more favorable habitat. Effective habitat area is the area of the potential reintroduction site plus areas (A_i) of surrounding colonized patches multiplied by their respective patch incidence probability (J_i); that total area was then multiplied by the percent of pixels defined as favorable habitat ($D^2 < 20$) in the local-scale statistical habitat model. The letters labeling each observation refer to the reintroduction sites listed in Table 9. South-central Florida and south Florida data are provided for reference purposes.

and our list of prospective sites is an attempt to initiate that selection process, keeping the above caveats in mind.

We evaluate and discuss the 11 sites in order, moving approximately west to east across the historic range, based on the results of the 4 spatial analyses. Several potential reintroduction sites were located close together; given the wide-ranging movements of Texas mountain lions released in northern Florida and the dispersal capabilities of panthers, we discuss those together (Table 3, Figs. 4–7).

Individual Site Evaluations

The potential reintroduction site at Ozark National Forest contains the greatest amount of public land with the exception of the current panther range. The Ozark National Forest region also has low human densities and low habitat fragmentation. Another advantage of this site is that its large size (8,524 km^2) and rugged topography limit human access. Conversely, Ozark National Forest has a relatively low prey density, which contributed to an intermediate expert-assisted model score (Table 3). In addition, the site's proximity to the rapidly growing population centers in northwest Arkansas could result in future human encroachment toward the Ozark National Forest boundary. Lastly, this site has low potential for panther recolonization of adjacent habitat patches; it is isolated from the nearest large habitat patch (Ouachita National Forest) by an interstate highway and numerous small cities and agricultural lands in the Arkansas River Valley, thereby reducing the value of this site as a metapopulation source (Table 3). Overall, however, its reintroduction potential should be considered high.

The site centered on the Ouachita National Forest is similar to that on the Ozark National Forest in the large amount of public land, low human densities, inaccessibility, and relatively unfragmented habitat (Table 3). This site is in close proximity to several smaller habitat patches near the south-central Arkansas site and thus has more potential as a recolonization source (Fig. 7; Table 3). However, an interstate highway separates Ouachita National Forest from the south-central Arkansas site and the site has a relatively low prey density (Tables 5 and B-2). Nevertheless, this site received high scores for both the empirical and the expert-assisted analyses.

The potential reintroduction sites in south-central Arkansas and south Arkansas are located close together and have few barriers separating them. The 2 sites have a combined area of >10,000 km^2, with low habitat fragmentation, a high percentage of natural land cover, and high prey densities (Tables B-1 and B-2). There are no large urban centers nearby and the human population is declining within portions of this region (U.S. Census Bureau 2002). The 2 sites are well connected to smaller habitat patches in southern Arkansas and northern Louisiana, which may facilitate colonization beyond the reintroduction site (Fig. 7; Table 3). The drawbacks of this area are its higher road and human densities and its lack of substantial public lands other than Felsenthal National Wildlife Refuge (263 km^2). A reintroduced black bear population in the area has suffered a number of poaching-related mortalities, mostly on private land (Wear 2002). We consider the potential of these sites to be moderate.

The Kisatchie National Forest site is located in Louisiana on the western side of the Red River. This site contains almost 900 km^2 of U.S. Forest Service land, which consists mainly of the Calcasieu and Kisatchie ranger districts. The Red River and associated agricultural lands could inhibit panther movement across this area, isolating the site from nearby smaller patches of favorable habitat in Louisiana, such as the Atchafalaya National Wildlife Refuge to the south and the eastern ranger districts of Kisatchie National Forest. Although this site has high deer and feral hog densities, it also has high road and human densities (Tables B-1 and B-2). The overall potential of this site should probably be considered moderate.

The Homochitto National Forest site on the Mississippi/Louisiana border is >7,000 km^2 in size, of which >1,000 km^2 consists of public land (Tables 5, B-2). This site has high deer densities and contains large tracts of bottomland hardwood forest along the Mississippi and Homochitto rivers. Densities of humans and roads are intermediate compared with the other sites, but the level of habitat fragmentation is greater and percentage of natural land cover is lower than most of the others. Furthermore, at a local scale, this site has relatively little favorable habitat (Table 3). The site also is surrounded on 2 sides by interstate highways and on a third side by agriculture in the Mississippi River Delta of Louisiana, which could be an impediment to dispersal to other parts of the historic panther range (Table 3). We consider this site to be of low priority.

Southwest Alabama is the largest of the sites we identified (21,687 km^2; Table 3) and is almost contiguous with the southeast Alabama site, which is 4,049 km^2 in size.

The southwest Alabama site has variable deer and feral hog densities. Human density is low and declining (Table B-2). The site contains relatively small, disjointed public lands, but it also contains large tracts of private bottomland hardwood forests within the floodplains of the Alabama, Tombigbee, and Mobile rivers. Another advantage of this site is its central location and close proximity to several smaller habitat patches, which may facilitate colonization of additional portions of the historic range (Table 3). The nearby southeast Alabama site has almost no public land and contains lesser-quality habitat with greater human density and less natural land cover (Tables B-1 and B-2). However, it could be a strategic area from a metapopulation perspective, due to its proximity to several other habitat patches (Fig. 7), as indicated by our metapopulation analysis (Table 3). A disadvantage of the southwest Alabama site is that it is bisected by the agricultural "black belt" of Alabama and Mississippi, resulting in lower habitat quality at the local scale (Table 3). Additionally, the shape of the site is long and sinuous, which may be less desirable than more compact sites. Finally, seasonal inundation of the bottomland hardwood forests in the southern portion of the site could inhibit the movement of panthers through this area. Overall, southwest Alabama ranks high because of its large size, but public access and the dispersion of favorable local-scale habitat reduces that potential somewhat. Conversely, the ranking of the southeast Alabama site is considered low.

According to the expert model results, the south Tennessee/northern Alabama site contained almost no favorable habitat, which was primarily a function of high road and human densities and the lack of public land (Table 3). This site also is the smallest of the 11 potential reintroduction sites. Overall, we consider the ranking of this site to be low.

The Apalachicola National Forest site contains a high proportion of public land (2,300 km^2) and natural land cover, and has high local-scale habitat quality (Tables 3, B-1, and B-2). Because the site mainly consists of public land, human density also is low (Tables B-1 and B-2). Another advantage is the relatively high deer and feral hog densities (Table B-2). Our metapopulation analysis indicated limited colonization potential for reintroduced panthers (Table 3). The site is relatively small (3,081 km^2) but marginal panther habitat may be present in the nearby Big Bend area. Furthermore, this site is located just south of the Tallahassee metropolitan area, where human densities are high. Nevertheless, the overall quality of this site for panther reintroduction should be considered moderate.

The Okefenokee National Wildlife Refuge site was used as a test reintroduction site for the 2 pilot reintroduction studies. It contains a large amount of public land and is located in an area with low human density. The site is relatively large (5,469 km^2), with little fragmentation, and a high percentage of natural land cover (Tables B-1 and B-2). However, the extensive freshwater wetlands within the Okefenokee National Wildlife Refuge (Loftin et al. 2000) was the probable reason the introduced Texas mountain lions made only limited use of the refuge interior. This site may represent an instance where our natural land-cover classification may have resulted in a better characterization of panther habitat than was actually there. Despite the high rankings from the empirical and expert models, we consider this site to be of moderate priority.

Finally, we evaluated the south-central Florida site not because it would be considered for potential reintroduction, but because of the potential for range expansion of the current panther population in south Florida. Although this site has favorable habitat according to the D^2 and expert-assisted models, habitats are highly interspersed with agricultural and urban development, thus reducing the availability of favorable habitats at the local scale (Fig. 6, Table 3). This area also is experiencing rapid human population growth (U.S. Census Bureau 2002). After considering the interspersion of less favorable habitats at the local scale (Table 9), this site is smaller than the 11 prospective reintroduction sites we evaluated (Table 9). Thus, we consider the habitat quality of the south-central Florida site to be low.

RELEASE PROCEDURES

Our results corroborate the results of previous studies (Belden and Hagedorn 1993, Belden and McCown 1996) indicating that the use of certain types of release animals and release procedures can help optimize the success of reintroduction efforts. Wild-caught or male mountain lions had larger home ranges, greater mean daily movements, and a greater dispersion rate than captive-raised animals or females. However, an advantage of wild-caught mountain lions is that they were less likely to engage in nuisance activities or livestock depredation than captive-raised animals (Belden and McCown 1996). Similarly, van Manen et al. (2000) found that red wolf (*Canis rufus*) translocations were more successful if release animals were raised in the wild.

Releasing mountain lions in spring may be preferable to a winter or summer release. Animals released in spring displayed more circuitous movement patterns, suggesting that spring-released mountain lions more quickly established home ranges than animals released during summer or winter. Differences in movement patterns may be related to a greater availability of prey in spring. Home-range size and habitat use patterns of panthers are related to prey availability (Comiskey et al. 2002), which fluctuates seasonally. During the 1988 reintroduction feasibility study, wild hogs made up a greater percentage of the lion diet in early spring, which corresponded with the wild hog farrowing season (Belden and Hagedorn 1993), when hogs are more abundant. Deer births occur later in spring (Belden and Hagedorn 1993) and also provide a source of abundant prey. Another consideration for release timing is hunting seasons. The onset of fall hunting seasons had a negative impact on translocated mountain lions during the feasibility study, apparently causing some animals to abandon their home ranges (Belden and Hagedorn 1993). It should be noted, however, that most of the animals released during spring were of captive origin. Therefore, it is possible that there may have been a confounding effect between those 2 variables.

Kittens and subadults tended to have smaller daily movements and home-range sizes than adults (mean adult home range = 6,087 km^2, SD = 2,136 km^2; mean subadult/kitten home range = 2,188 km^2, SD =1,175 km^2). Ruth et al. (1998) found that translocation success of younger mountain lions (12–27 months old) in New Mexico was greater because they traveled shorter distances, established home ranges more quickly, and had a greater survival rate than older animals.

We could not evaluate the effect of kittens accompanying females at the time of release because of small sample sizes. However, the presence of kittens generally is believed to restrict the movements of the mother and, therefore, would prevent post-parturient animals from ranging far from the release site. Belden and McCown (1996) noted that wild-caught females released with kittens did not travel far from the release site, thus decreasing the probability of mortality or human-lion interactions. Other researchers have also reported that adult carnivores released with young were less likely to extensively move after release (e.g., van Manen et al. 2000, Eastridge and Clark 2001).

We found a positive relationship between patch density and persistence >6 months, and a negative relationship between patch density and livestock density. These results were unexpected, because greater values for patch density indicate increasingly fragmented habitat. One would expect lower persistence rates and more frequent livestock depredation incidents for panthers that used more fragmented habitat. The unexpected results may be due to the low sample size and the wide-ranging movements of some animals through a variety of habitats.

Road density in and near a release area is an important consideration for the success of panther releases. Because of the large home ranges and daily movements, mountain lions frequently cross roads within their home ranges (Land et al. 2001). Mountain lions that use habitats with greater road densities tend to be sighted more often and are more likely to engage in nuisance behavior because of increased exposure to areas with intense human use. Indeed, the logistic regression model for mountain lion mortality was most closely associated with road density. Vehicular collisions were the second largest source of mortality for Florida panthers in south Florida (Land et al. 2001), and were also the cause of mortality for 2 of the released mountain lions in north Florida. In addition to vehicular mortality, roads provide access for humans, increasing the chance that released mountain lions could be illegally killed. The most striking characteristic of the current range of the Florida panther is that it is comprised of the largest contiguous area of low road density in the Southeast (U.S. Census Bureau 2002). Belden and Hagedorn (1993) noted the influence of road density on mountain lion habitat selection in northern Florida. The road density within mountain lion home ranges was approximately half that of the entire study area (Belden and Hagedorn 1993). Interactions with humans were responsible for the failures of 13 of 30 released cats (43%) because of vehicular collisions, human-mountain lion conflicts, and poaching. A western mountain lion study also found a correlation between human densities and increases in human-mountain lion conflicts, particularly in the form of pet depredation incidents (Torres et al. 1996). Our results similarly indicate that choosing a release site with low road density is an important factor in terms of reducing both mountain lion mortality and nuisance behavior (see Appendix B, Table B-1 .

Overall habitat quality of the release area also is an important consideration. Higher quality habitat, as indicated by the results of D^2 statistical model, was associated with smaller home ranges and smaller mean daily movements. The inclusion of habitat quality as a variable in 2 of the 4 linear regression models seems to emphasize the importance of both security from humans and the presence of natural land-cover types for daytime bedding sites, den sites, and cover for stalking prey (Kerkhoff et al. 2000). Animals that use areas of relatively poor habitat must travel further and establish larger home ranges to meet those basic life requisites.

MANAGEMENT RECOMMENDATIONS

Our spatial analyses identified regions within the historic range that provide favorable conditions for reintroduction of panther populations. Using a conservative density estimate for panthers in south Florida as a reference (Maehr et al. 1991; 0.91 panthers/100 km^2) in combination with contiguous habitat areas based on our landscape-scale model (Table 3), we estimate that the largest potential reintroduction site may support 197 panthers, whereas the smallest site might support 24 animals. However, densities in the potential reintroduction areas may be greater than those in south Florida, as was observed for the released mountain lions in north Florida (2.14 lions/100 km^2; Belden and McCown 1996). Using the latter density as a reference, the largest of the 11 sites may support over 450 animals whereas the smallest might still support at least 50 panthers. We only considered the most favorable habitat to calculate potential population abundance but we point out that many of the 11 potential reintroduction sites have adjacent areas that would likely support panthers, albeit at lower densities (Fig. 4).

No one site was found to be optimal for all the criteria we evaluated. Obviously, trade-offs will have to be accepted by managers and the final decisions likely will be made using less quantitative criteria than those we have presented. Once reintroduction sites have been selected, the results of the release success analysis can be used to determine which panthers are the best candidates for release and which site characteristics may have a stronger influence on release success. Belden and McCown

(1996) provide excellent recommendations regarding the sex and origin of animals selected for release.

Anthropogenic variables, including road and human population densities, were the most important factors in selecting Florida panther reintroduction sites. The scarcity of humans and roads are major reasons that vestigial panther populations are located in south Florida and nowhere else within the historic range (Belden and McCown 1996). Other carnivore reintroduction assessments have reached similar conclusions. Mladenoff et al. (1995) found that road density was the strongest predictor variable of habitat use for gray wolves (*Canis lupus*) recolonizing parts of Minnesota and Wisconsin. In a red wolf reintroduction study, van Manen et al. (2000) also found that wolf release success was more closely associated with anthropogenic variables than other habitat variables.

In our study, we considered only biological and physical characteristics of panthers and the study area. Clark et al. (2002) stressed that the sociopolitical obstacles to large carnivore reintroduction are more daunting than the biological ones. Sociological information, such as public attitudes towards carnivore reintroduction, will need to be evaluated at the top-ranked reintroduction sites. Also, because of the inherent limitations of a broad-scale habitat analysis, field surveys of the chosen reintroduction sites should be undertaken. Such surveys to examine local habitat conditions should involve an assessment of localized prey densities and the availability of understory vegetation or varied topography for stalking and denning cover. Other potential concerns include the extent of seasonal inundation in certain areas, the presence of highly disturbed landscapes that appear to be natural land cover in the GIS data, local hunting regulations and traditions, and accessibility of the site to humans.

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APPENDIX A: EXPERT OPINION SURVEY – FLORIDA PANTHER RESTORATION

Background Information

To identify potential restoration sites for Florida panthers within their former range, we examined habitat conditions using a geographic information system (GIS) analysis. The model was based on the Mahalanobis distance (*D^2*) statistic, a multivariate measure of dissimilarity (Clark et al. 1993). We chose 6 variables for the habitat model, including road density, human density, % urban land cover, % natural land cover, patch density, and aggregation of natural land cover. The D^2 values represent a quantitative index of predicted panther habitat use for the southeastern U.S., using panther home ranges in south Florida as the reference dataset. From the resulting D^2 map, we identified landscape conditions that were similar to those that support panthers in south Florida, and thus most likely to support a panther population.

The Mahalanobis distance model was strictly based on landscape measures. However, some important variables could not be considered because south Florida may not provide an appropriate reference for other portions of the Southeast (e.g., area of public land, human population growth). Therefore, we designed an expert opinion-based model to complement the results of the empirical landscape model, thereby providing a better delineation of potential restoration regions. A pairwise comparison technique called Analytic Hierarchy Process, developed by Saaty (1977), provides a quantitative method for comparing alternatives (Eastman et al. 1995). This pairwise comparison procedure has been successfully used in other wildlife studies (e.g., Clevenger et al. 2002) and is commonly used to solve multivariate problems where both quantitative and qualitative information are relevant.

With this modeling technique, experts rank the relative importance of each variable in a pair based on a continuous scale. We plan to use such pairwise comparisons to develop a quantitative system of weights to rank the relative importance of variables for successful restoration of panthers. Each variable is represented by a map layer. The map layers are multiplied by their respective weights, which represent their importance to panther biology based on expert knowledge. Finally, the weighted map layers are summed, providing a single score for each GIS pixel in the study area. Areas with higher values would indicate greater potential to support a panther population.

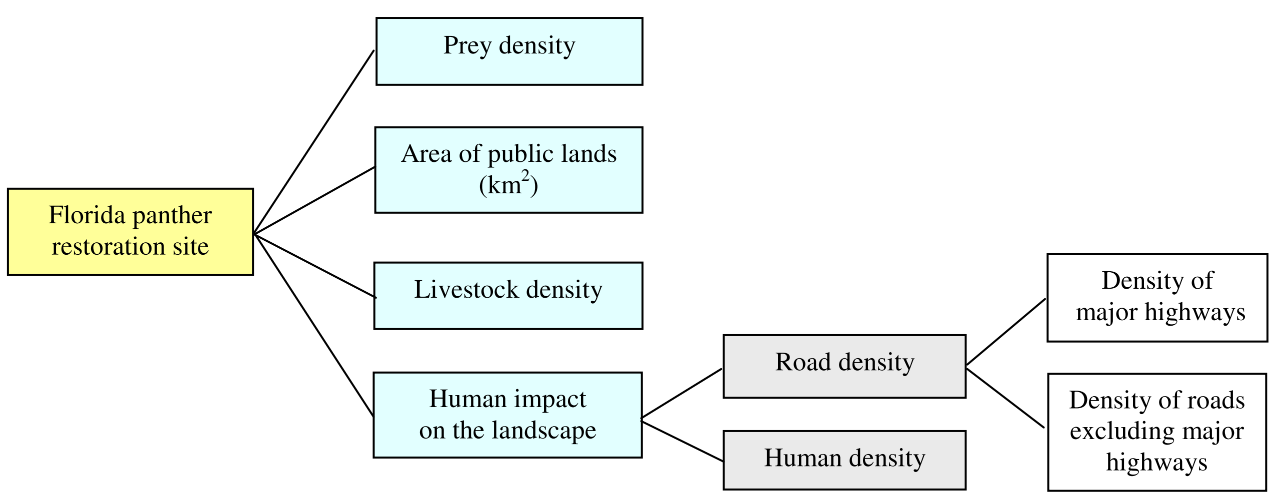
Objective

To rank factors important to restoration of Florida panthers to a particular site.

Model Structure and Variables

The model structure and variables are shown in Figure 1. All variables are represented as spatial map layers in a GIS, as described in the next section. Variables are represented by county-level data, or were averaged over an area of 2,590 km^2 (640,000 acres), the minimum size of a potential panther restoration site recommended by Belden and Hagedorn (1993).

Figure 1. Variables to refine delineation of potential Florida panther restoration sites. Weights resulting from the pairwise comparison procedure represent the relative importance of each variable to successfully restore Florida panthers. Note that the human impact variable is derived from four map layers that are combined using a hierarchical set of pairwise comparisons.



Descriptions of map layers used as variables in the Expert Opinion Model

Prey density.-- This variable is intended to address to what extent prey density (food availability) influences the success of panther restoration. The two primary prey species of the Florida panther are white-tailed deer (*Odocoileus virginianus*) and the feral hog (*Sus scrofa*) (Maehr 1997). Density of feral hogs was obtained from Southeastern Cooperative Wildlife Disease Study maps (1988 data), whereas deer density was obtained from a Quality Deer Management Association map (1999 data). The two map layers were combined into a single index of overall prey density.

Area of public lands (km^2). -- The availability of public lands may influence the number of human-panther conflicts. This variable is intended to address to what extent the availability of public lands influences the success of panther restoration. The basis for this variable is a map of public lands (including national forests, national parks, national wildlife refuges, state parks, wildlife management areas, military bases, and other public lands).

Livestock density.-- Livestock depredation often results in human-panther conflicts. This variable addresses to what extent the potential for human-panther conflicts resulting from livestock depredation may influence the success of panther restoration. We obtained information on the density of cattle by county from the National Agricultural Statistics Service to represent livestock density. No information was available on goat and sheep densities in the southeastern U.S.

Human Impact on the Landscape.-- The human impact variable is a combination of 3 map layers related to anthropogenic disturbance, and addresses to what extent the level of human impact on the landscape influences the success of panther restoration. The human population density and road density variables are weighted according to the results of this survey and are then combined into a single measure of human impact on the landscape.

Three map layers included within the human impact variable:

1) Density of paved and unpaved roads, except U.S., state and interstate highways, from U.S. Census Bureau roads data.

2) Density of major highways (U.S., state and interstate highways, defined as CFCC codes A10-A28) from U.S. Census Bureau roads data.

   --Density of major highways and density of roads excluding major highways are weighted according to the results of the expert survey and combined into a single index of road density. The presence of smaller roads can provide human access for poaching, whereas the presence of major highways can result in vehicular mortality of panthers and can impede panther movement.

3) Human population density is a combination of both human density and human population growth from 1990 to 2000 (U.S. Census Bureau 2000). Human population density is an indicator of urban and suburban development, and a measure of the potential for human-panther conflicts. Human population growth from 1990-2000 is also incorporated within this variable as an indicator of areas of future population growth (or loss) that could impact panther restoration efforts.

<u>Survey Instructions</u>

On the following 8 question survey, please indicate (1) which variable you believe is more important to successfully restore Florida panthers to a particular site, and (2) to what degree. (See previous section for more information about each variable.)

The degree of importance is rated on a 9-point continuous scale:

1 = Equal importance (both variables contribute equally to the objective)

2

3 = Moderate importance of selected variable over other (experience or judgment favors one over the other)

4

5 = Essential or strong importance of selected variable over other (experience or judgment strongly favors one over the other)

6

7 = Very strong importance of selected variable over other (the dominance of selected variable is strongly demonstrated in practice)

8

9 = Extreme importance of selected variable over other (the evidence favoring the selected variable is of the highest possible order of affirmation)

Please mark your answer by clicking within the appropriate box and typing an "X" in the box. For example:

Which variable is more important for restoration of Florida panthers to a particular site?	**To what degree?**								
	1	2	3	4	5	6	7	8	9
[ ] Variable one *or*	[ ]	[ ]	[ ]	[x]	[ ]	[ ]	[ ]	[ ]	[ ]
[x] variable two?									

Once you have completed the survey on the next page, please save this file and return it by May 23 as an attachment to Cindy Thatcher: cthatch1@utk.edu.

Alternatively, if you prefer you can print the Word or .PDF document and mark you answers in pen. Please FAX the completed survey to Cindy Thatcher: 865-974-3555.

Expert Opinion Survey – Florida Panther Reintroduction Site Assessment

Which variable is more important for successful restoration of Florida panthers to a particular site? — **To what degree?**

Primary variables: prey density, public lands, livestock density, and human impact

☐ Prey density *or*
☐ area of public lands?
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐

☐ Prey density *or*
☐ livestock density?
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐

☐ Prey density *or*
☐ human impact on the landscape?
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐

☐ Area of public lands *or*
☐ human impact on the landscape?
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐

☐ Area of public lands *or*
☐ livestock density?
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐

☐ Livestock density *or*
☐ human impact on the landscape?
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐

Human impact

☐ Human population density *or*
☐ density of all roads?
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐

Road density

☐ Density of roads, excluding major highways *or*
☐ density of major highways?
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐

APPENDIX B: QUANTITATIVE DESCRIPTION OF POTENTIAL FLORIDA PANTHER REINTRODUCTION SITES.

Table B-1: Mean values of the variables used in the D^2 model to evaluate potential Florida panther reintroduction sites in the southeastern U.S.

Site name (site label)	% Natural land cover	Human density	Road density	Patch density	% Urban land cover	Contagion
Ozark National Forest region (A)	87.8	4.8	0.914	0.023	3.0	46.6
Ouachita National Forest region (B)	87.3	4.9	0.979	0.030	7.0	46.4
South-central Arkansas (C)	87.8	7.4	1.044	0.023	19.4	47.9
South Arkansas (Felsenthal National Wildlife Refuge region) D)	90.8	8.9	1.036	0.012	18.9	56.0
Kisatchie National Forest region (E)	84.7	12.0	1.000	0.030	36.4	38.3
Mississippi/Louisiana (Homochitto National Forest region) (F)	78.5	9.1	0.928	0.043	16.0	28.1
Southwest Alabama (G)	84.2	7.6	0.987	0.027	10.6	38.7
Southeast Alabama (H)	77.7	9.9	0.895	0.045	11.2	24.7
South Tennessee/Northern Alabama (I)	87.9	12.7	0.944	0.029	20.6	46.6
Apalachicola National Forest region (J)	92.5	5.7	0.989	0.012	15.7	60.1
Okefenokee National Wildlife Refuge region (K)	91.2	6.4	0.883	0.015	20.3	57.6
Central Tennessee (outside historic range)	84.4	9.1	1.144	0.029	14.0	36.5
Eastern North Carolina (outside historic range)	70.4	17.7	1.164	0.069	58.5	13.6
Great Smoky Mountains National Park region (outside historic range)	96.7	9.2	0.666	0.007	13.5	76.1
South-central Florida (potential augmentation/expansion site)	74.0	8.2	0.681	0.059	54.5	21.3
South Florida (current range)	91.1	3.5	0.310	0.020	18.3	63.2

Table B-2: Mean values of the variables used in the expert-assisted model to evaluate potential Florida panther reintroduction sites in the southeastern U.S.

Site name (site label)	Area of public land (km^2)	Deer density per mi^2	Feral Hog density per mi^2	Livestock density per km^2	Human density	Minor road density	Major road density
Ozark National Forest region (A)	4,522	15–30	0	19.8	4.8	1.081	0.0002
Ouachita National Forest region (B)	4,039	15–30	0	13.4	4.8	1.082	0.0001
South-central Arkansas (C)	83	30–45	≤ 10	8.3	7.4	1.150	0.0002
South Arkansas (Felsenthal National Wildlife Refuge region) (D)	337	30–45	≤ 10	5.0	8.9	1.151	0.0001
Kisatchie National Forest region (E)	882	30–45	≤ 10	9.6	12.0	0.997	0.0002
Mississippi/Louisiana (Homochitto National Forest region) (F)	1,024	> 45	0	9.4	9.1	0.944	0.0001
Southwest Alabama (G)	943	30–45	0	9.0	7.6	0.978	0.0001
Southeast Alabama (H)	69	> 45	0	11.7	9.9	0.777	0.0003
South Tennessee/Northern Alabama (I)	211	15–30	0	13.9	12.7	0.998	0.0002
Apalachicola National Forest region (J)	2,303	< 15	≤ 10	1.2	5.7	1.001	0.0001
Okefenokee National Wildlife Refuge region (K)	2,355	15–30	≤ 10	3.2	6.4	1.009	0.0001
Central Tennessee (outside historic range)	100	15–30	0	10.9	9.1	1.076	0.0002
Eastern North Carolina (outside historic range)	123	> 45	0	1.9	17.7	1.039	0.0002
Great Smoky Mountains National Park region (outside historic range)	2,959	< 15	≤ 10	12.1	9.2	1.035	0.0002
South-central Florida (potential augmentation/expansion site)	777	15–30	≤ 10	35.0	8.2	0.833	0.0001
South Florida (current range)	7,373	< 15	> 10	8.3	3.5	0.423	0.0001

APPENDIX C: METAPOPULATION ANALYSIS METHODS

Our metapopulation analysis was based on the incidence-function model (IFM) developed by Hanski (1994). The IFM uses spatial information on patch occupancy to estimate metapopulation parameters such as colonization and extinction probabilities and, consequently, patch occupancy or incidence probabilities. Those parameters can be estimated for a given metapopulation from a single snapshot of presence-absence data within habitat patches, if patch size and distance between patches are known. Since the initial development of this model, there have been numerous refinements in estimation methods, including the development of user-friendly computer simulation models. One such model is the stochastic patch occupancy model SPOMSIM (Moilanen 2003). We used SPOMSIM to estimate individual patch occupancy (J_i) for Florida panthers, using data collected on black bear patch occupancy in the southern Appalachians (Murrow 2001).

We conducted this analysis with data from 424 habitat patches in the southern Appalachians, ranging from West Virginia south to northern Alabama, as described by Murrow (2001). Presence-absence data were available for each patch, as were the size and UTM coordinates (Murrow 2001); these data were then downloaded into SPOMSIM. We estimated the necessary metapopulation parameters using the non-linear regression option within SPOMSIM. With the non-linear regression estimator, we supplied the program with initial starting values that the algorithm would use to simulate trial values.

We derived reasonable starting values for our simulations by using a variety of approaches. The effect of distance on colonization (α, Wahlberg et al. 1996) is defined as $\exp^{(-\alpha d)}$, where d is the distance dispersed, α is a constant, and the entire quantity is the dispersal probability. In a metapopulation sense, dispersal implies subsequent colonization and establishment of a viable population. Because dispersal distances of female black bears are much shorter than for males, we used female dispersal for estimating α. Young female black bears usually establish home ranges within the home ranges of their mothers (Schwartz and Franzman 1992), although female dispersals occasionally occur, with distances of up to 60 km being reported (Clark 1991). Through substitution, we found that $\alpha = 0.1$ created a reasonable distribution of dispersal probabilities for female bears.

Another parameter, b, scales population density with patch area (i.e., A^b). If $b = 1$, the population increases at a 1:1 ratio with area. Because bears typically depend on social mechanisms to regulate density (i.e., home ranges are resistant to change with increasing numbers), we chose a value for b near 1 (0.95). We chose a value slightly <1 because it is conceivable that those densities might slightly increase with more bear numbers and because some of the highest reported bear densities have been in relatively small habitat fragments, again suggesting that territories might become more compact in some circumstances (Beausoleil 1999). For our simulations, b was fixed.

The parameter y relates to how rapidly a colonization approaches unity. For poor colonizers, y is large (i.e., >1, Hanski 1994). Because bears are considered poor colonizers (Clark et al. 2002) we gave y a starting value of 10. Parameter x is the rate of decline in extinction risk with increasing patch area. We gave x a starting value of 1.5 (Hanski 1994). Finally, e is a function of critical patch area and x; we gave e a value of 1, the default. Again, the model has been shown to be relatively insensitive to initial parameter values (Hanski 1994, Moilanen 1999). We set the annual turnover rate at 6 (i.e., 6 patches can be expected to change occupancy status in a year).

With those initial parameter estimates, we performed non-linear regression using >2,400 substitutions. Additional runs were conducted to try to improve model fit and to determine whether the model converged on the same general set of values. Our best model fit resulted in the following parameter estimates: $\alpha = 0.065$, $x = 0.96$, $y = 411.95$, and $e = 0.381$ with an AIC value of 270.2. With those parameter estimates and using data on sizes and connectivity of patches considered for Florida panther reintroduction, we performed 100 simulation runs to estimate patch incidence (J_i) for each patch in the study area. Patch incidence is the probability of species occurrence for each patch during a 100-year period. In so doing, we could evaluate the impact that panther reintroduction might have on the adjacent patches.