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How much is enough? Landscape-scale conservation for the Florida panther

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ABSTRACT

The Florida panther (*Puma concolor coryi*) is an endangered, wide-ranging predator whose habitat needs conflict with a rapidly growing human population. Our goal was to identify specific regions of the south Florida landscape that are of high conservation value to support a self-sustaining panther population. We used compositional and Euclidean distance analyses to determine relative importance of various land cover types as panther habitat and to investigate the role of forest patch size in habitat selection. A model of landscape components important to Florida panther habitat conservation was created. The model was used in combination with radio telemetry records, home range overlaps, land use/land cover data, and satellite imagery to delineate Primary and Secondary zones that would comprise a landscape mosaic of cover types sufficient to support a self-sustaining population. The Primary Zone generally supports the present population and is of highest conservation value, while the Secondary Zone is of lesser value but could accommodate expansion of the population given sufficient habitat restoration. Least-cost path models identified important landscape linkages, and model results were used to delineate a Dispersal Zone to accommodate future panther dispersal outside of south Florida. We determined that the three habitat zones could support 80–94 panthers, a population likely to persist and remain stable for 100 years, but that would be subject to continued genetic problems. The Primary, Dispersal and Secondary zones comprise essential components of a landscape-scale conservation plan for the protection of a viable Florida panther population in south Florida. Assessments of potential impacts of developments should strive to

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achieve no net loss of landscape function or carrying capacity for panthers within the Primary Zone or throughout the present range of the Florida panther.

1. Introduction

The Florida panther (*Puma concolor coryi*) is a wide-ranging predator whose current breeding population is restricted to an area of approximately 10,000 km^2 in southern Florida, USA, south of Lake Okeechobee. The habitat of the Florida panther is an extensive landscape comprised of a mix of natural, semi-natural, and agricultural land uses (Maehr and Cox, 1995; Comiskey et al., 2002). Due to past persecution and ongoing habitat loss, the Florida panther is listed as an endangered species by the State of Florida and the US Fish and Wildlife Service (Sullivan, 2004). The Florida panther population was previously estimated at 30–50 individuals (Maehr, 1992), but recent counts place the population at 80–100 adults and sub-adults (Land and Lacy, 2000; McBride, 2001, 2002, 2003).

Habitat loss remains the greatest threat to the Florida panther. Large areas of natural habitat have been converted to agricultural and urban uses to support the rapidly growing human population in south Florida (Kautz, 1994) and statewide (Kautz, 1998). Further loss of natural areas may be expected as the population of the 5-county south Florida region supporting most of the current panther population (i.e., Lee, Hendry, Collier, Miami-Dade, Broward) is projected to increase 55% between 2000 and 2030 (BEBR, 2001). Agencies involved in reviewing proposed development projects in areas inhabited by Florida panthers are keenly aware that continued development will result in the loss of additional habitat, and they recognize that the consequences of permitting decisions may further compromise panther population viability. However, attempts to protect panther habitats through regulatory programs often are confounded by the wide-ranging nature of the species, low population density that makes it difficult to target specific locations for protection, the large landscapes needed to support a viable population, private landowner concerns, and limitations inherent in laws and rules that regulate the incidental take of endangered species. Although land acquisition programs have brought almost 200,000 ha of panther habitat into public ownership over the past decade, previous spatially-explicit conservation plans (Logan et al., 1993; Cox et al., 1994) indicate that much more habitat needs to be protected to ensure panther survival.

The range-wide recovery objective for the Florida panther is to achieve 3 viable, self-sustaining populations within the historic range of the animal. The first priority of the recovery plan is to secure the population in south Florida (USFWS, 1995), which is the only existing Florida panther population. Our goal was to identify those portions of the south Florida landscape needed to ensure the long-term persistence of the Florida panther in south Florida. To accomplish this, we conducted a series of geographic information system (GIS) analyses. First, we completed several analyses of land cover types and forest patch sizes associated with telemetry locations and panther home ranges, and we used the results to develop a new spatially explicit model of habitat components important to Florida panther habitat conservation needs. Next, using the spatial model, Florida panther telemetry and home ranges, land use/land cover data, and satellite imagery as guides, we identified areas of suitable habitat that have been consistently occupied by panthers in the past 20 years (Primary Zone), adjacent areas that would be most likely to be occupied by an expanding panther population (Secondary Zone), and areas that would best facilitate dispersal and population expansion north of the Caloosahatchee River (Dispersal Zone). Finally, we used the results of previous population viability analyses to evaluate the potential for the landscape we delineated to support a population large enough to remain viable.

1.1. Study area

The entirety of our study area covered 60,256 km^2 of central and south Florida, and comprised all or portions of 25 counties (Fig. 1). This large region was selected as the study area because it contained all telemetry location records for radio-collared panthers through 30 March 2001 (Fig. 2), and because habitats north of Lake Okeechobee were likely destinations for dispersing panthers. However, most of our analyses focused on the landscape south of Lake Okeechobee and the Caloosahatchee River, the region where reproducing panthers were found and where 99% of telemetry records have been collected (Fig. 2).

Rapidly growing urban areas characterized both coasts of the study area. Dominant land uses of interior regions included pastureland, citrus production, croplands, and scattered smaller urban and residential lands. Throughout much of the study area, natural areas consisting of slash pine (*Pinus elliottii*) flatwoods, hardwood hammocks, dry prairies, and forested and herbaceous wetlands were interspersed among lands that have been converted to more intensive human uses. Public land south of Lake Okeechobee contained approximately 73% of the area known to support the Florida panther. Big Cypress National Preserve (2950 km^2) in the southwestern portion of the region south of Lake Okeechobee consisted of a vast system of forested and herbaceous wetlands interspersed with smaller upland islands dominated by slash pine and hardwood forests. The Everglades of southeastern Florida consisted predominantly of herbaceous freshwater wetlands interspersed with numerous small tree islands.

2. Methods

2.1. Land use and land cover data

We created a statewide land cover data set by merging land use/land cover data available from Florida's 5 water

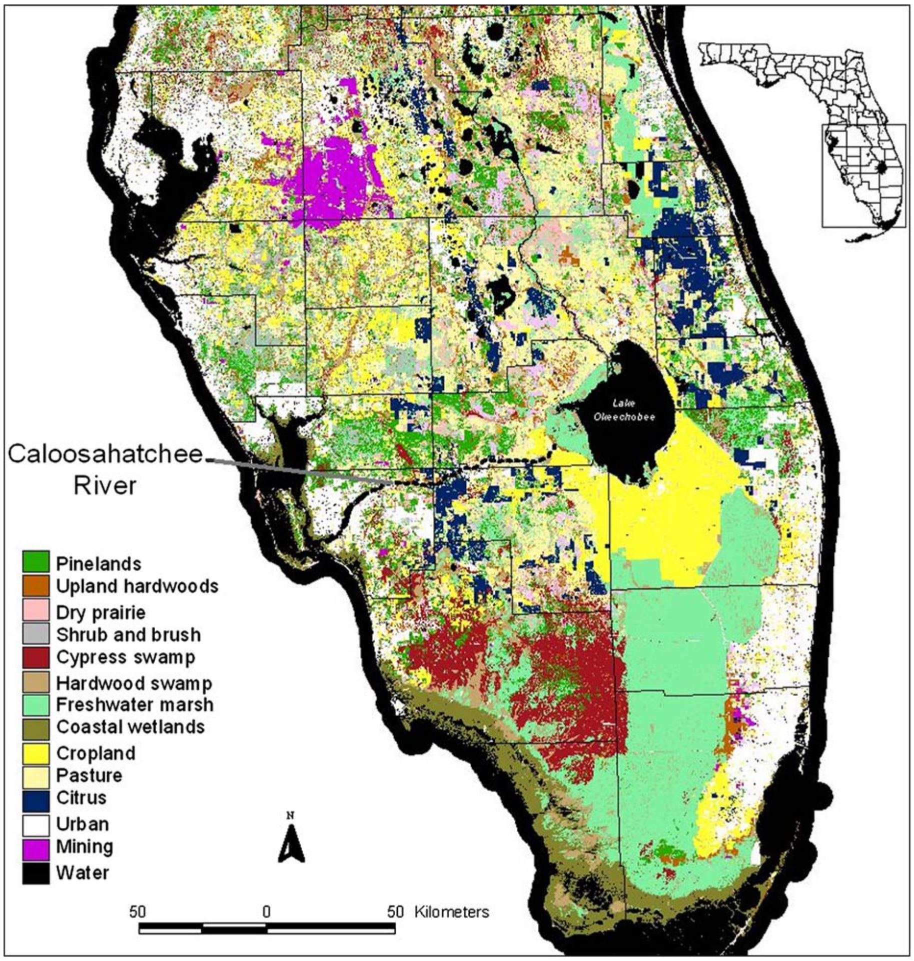

Fig. 1 – South Florida study area for modeling and mapping habitats important to the conservation of the Florida panther. While the current reproducing population is found south of the Caloosahatchee River, the entire study area extends through south central Florida to include all records of radio-collared panthers.

management districts (WMD). Each WMD data set was in vector format and derived from 1995 aerial photography, and each had been subjected to ground-truthing and accuracy assessment prior to release to the public. The land use/land cover data had minimum mapping units (MMU) of 2 ha for all classes except wetlands. Wetlands were mapped with a 0.2 ha MMU in all areas except south Florida where the wetlands MMU was 0.8 ha. We converted the vector data sets to 30 m pixel grids, and then we merged the 5 grids into a single statewide grid. The combined statewide data set contained 298 Level III/IV land use/land cover classes (Anderson et al., 1976; as modified for Florida by Kuyper et al., 1981), but similar cover types were grouped to produce a data set with 44 classes. We accomplished this by grouping 101 classes representing residential, commercial, industrial, institutional, and recreational areas into five urban lands classes; 15 types of extractive land uses into a single mined lands class; 35 types of cropland, feeding operations, groves, nurseries, vineyards, specialty farms, and rural open lands into four agricultural lands classes; nine types of pasture and rangeland into five pasture and rangeland classes; 18 water classes into a single open water class; 10 types of barren land into two barren land classes; 21 types of transportation facilities into a single transportation class; four types of communications facilities into a single communications facilities class; 10 types of utilities into a single utilities class; four types of tree plantations into a single plantation class; four non-native plants classes into a single exotics class; and 61 natural community types into 21 natural community classes.

We acknowledge that the results of our analyses might be different if we used land cover data that were contemporaneous with Florida panther telemetry records. However, earlier land cover data sets (Kautz et al., 1993; WMD 1988 land use/land cover) used different classification schemes that were not always consistent over time. In addition, most telemetry records were collected from radio-collared panthers inhabiting remote areas of public lands where land use changes have been minimal, and we suspect that use of land cover data sets closer to the dates of telemetry would yield only minor or even insignificant differences in the results we obtained.

2.2. Analysis of habitat use

We used 2 methods to assess Florida panther habitat use within the landscape (Fig. 1), compositional analysis (Aebischer et al., 1993) and Euclidean distance analysis (Conner

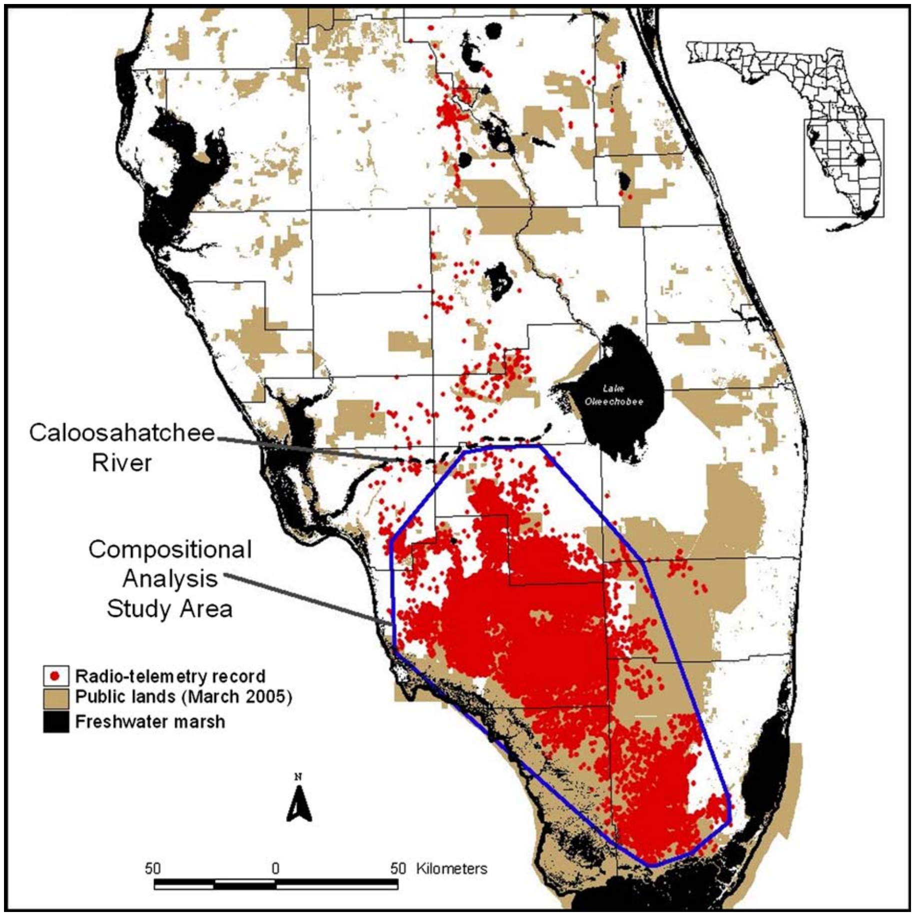

Fig. 2 – Florida panther radio-telemetry locations (*n* = 55,542) collected between February 22, 1981, and March 30, 2001, and the compositional analysis study area boundary. The study area used to determine characteristics of the landscape used by panthers was defined by a minimum convex polygon containing 46,350 telemetry records for 79 panthers >2 years of age for which >50 telemetry records were available.

and Plowman, 2001). Although both methods use a similar statistical technique (i.e., MANOVA) to test for differences in habitat use, each method uses a different technique for determining used habitats relative to telemetry locations. We used compositional analysis to determine the composition of land cover types within home ranges relative to the study area. We used Euclidean distance analysis to determine habitat use by comparing distances from each radio-telemetry location of individual Florida panthers to each land cover class and distances from random locations to each land cover class.

Our master set of Florida panther radio-telemetry records consisted of data collected between February 1981 and March 2001 (*n* = 55,542) (Fig. 2). However, our determinations of Florida panther home ranges and our analyses of relative importance of various land cover types as panther habitat were limited to telemetry records for 79 Florida panthers that occurred south of the Caloosahatchee River (*n* = 46,350) to coincide with the region occupied by the reproducing population. Methodology for collection of telemetry locations was described by Belden et al. (1988). Spatial accuracy of telemetry data (i.e., 95th percentile) has been estimated to be within 230 m (Belden et al., 1988; Dees et al., 2001). Telemetry records were acquired between 0600 and 1000 hours when panthers usually were not active, and thus the majority of locations were recorded when individuals were at or near daytime resting sites (Comiskey et al., 2002; Beier et al., 2006).

The compositional analysis study area was delimited as a minimum convex polygon containing 46,350 telemetry records south of the Caloosahatchee River (Fig. 2). We calculated fixed kernel home ranges (Worton, 1989) with the software program KERNELHR (Seaman et al., 1998) using the least squares cross-validation (LSCV) method for choosing the kernel smoothing parameter. Home ranges (*n* = 79) were calculated for radio-collared panthers >2 years old and for which >50 radio locations were determined. The age limitation was applied to ensure individuals were independent of their mothers and to reduce the effect of dispersing juveniles on home ranges. The criterion for minimum number of locations follows the recommendation of Seaman et al. (1999) to reduce effects of small sample sizes on the kernel estimator.

We used compositional analysis (Aebischer et al., 1993) to identify proportions of land cover types within the fixed kernel home ranges that differed from proportions of land cover types within the study area. All land cover types were not represented in each home range, thus land cover types were further combined into 16 habitat classes to reduce effects of inflated Type I error rates on our results (Bingham and Brennan, 2004). If proportions of land cover types differed ($p \leqslant 0.05$; PROC GLM, SAS Institute, 1999), land cover types were ranked according to the number of positive differences between pairs. Paired *t*-tests were then used to determine differences ($p \leqslant 0.05$) between ranked land cover types. Results from these analyses were then incorporated in our GIS models below.

We used Euclidean distance analysis to identify differences in mean distances from each of the 16 land cover types to radio-telemetry locations of individual Florida panthers and to random locations ($n = 5000$) within the study area. The methodology used to determine statistical differences in habitat use was identical to that described for compositional analysis above.

2.3. Forest patch size metrics

We also used compositional analysis to assess the effect of forest patch size on panther habitat use within the study area south of the Caloosahatchee River (Fig. 2). We accomplished this by reclassifying upland and wetland forest types into one forest class, determining patch size, and assigning individual forest patches to size classes according to an equal area increment function. Similar to constraints put on the number of different habitat classes above, the number of forest patch size classes was limited by availability of each class within each fixed kernel home range. Consequently, to reduce effects of absence of specific patch size classes in individual home ranges and the resultant effect of inflated Type I error rates (Bingham and Brennan, 2004), 13 forest patch size classes were used. Differences in proportions of forest patches within each home range relative to the entire study area were tested using the same methodology described above for the compositional analysis of land cover types.

2.4. Spatially explicit model of important habitat components

Based on results from our compositional analyses of land cover types and forest patch sizes, and based on reviews of Belden et al. (1988) and Maehr et al. (1991), we created a spatially explicit raster model of habitat patches potentially suitable for use by panthers for cover. The model was based on the following criteria: (1) all forest patches >2 ha regardless of forest type were included in the model, and (2) all non-urban cover types within 200 m of forest patches >2 ha were included. This model reflected panther use of all types of upland and wetland forest patches, regardless of size, and it also reflected the minimum mapping unit of 2 ha for upland forests in the land cover database. The model accounts for spatial error in the telemetry data by allowing for inclusion of other natural or disturbed cover types in close proximity to forest patches. This model was needed as a basis for delineating boundaries around a landscape that links together the most important components of panther habitat with intervening cover types (e.g., agricultural and pasture lands) present in the landscape.

2.5. Primary zone

Our principal goal was to identify south Florida lands essential to the long-term viability and survival of the Florida panther. Survival is defined as “the condition in which a species continues to exist into the future while retaining the potential for recovery. This condition is characterized by a species with a sufficient population, represented by all necessary age classes, genetic heterogeneity, and number of sexually mature individuals producing viable offspring, which exists in an environment providing all requirements for completion of the species’ entire life cycle, including reproduction, sustenance, and shelter” (USFWS and NMFS, 1998; page xix). We called lands that met this goal the Primary Zone.

To delineate Primary Zone boundaries, we overlaid panther telemetry data on the model of important landscape components, overlapping minimum convex polygons of panther home ranges that identified areas with heaviest use by panthers from 1981 to 2001 as described by Comisky et al. (2002), and WMD land use/land cover data. We then screen-digitized a line around the outer edges of habitat patches in the landscape components model in a manner that (1) encompassed most telemetry locations of currently monitored panthers in areas of highest home range overlap and (2) incorporated a mix of non-urban land cover types (e.g., citrus groves, croplands, pastureland, freshwater marsh) in areas between patches of forest in which the preponderance of telemetry data occurred. The landscape delineated in this manner consisted of forest patches panthers would most likely select as daytime resting sites and den sites, and would use as cover for stalking prey. Moreover, other natural and non-urban disturbed land cover types between forest patches served as landscape connections that accommodate panther home range and dispersal movements (Maehr et al., 2002b), and they contributed to the support of prey species. After the first draft of the Primary Zone boundary had been completed, we adjusted the boundary slightly to account for changes to intensive land uses (e.g., suburban or urban development) found through visual interpretation of the draft boundary in relation to recent satellite imagery (i.e., Landsat 5 Thematic Mapper satellite imagery dated December 26, 1999 [US Geological Survey, EROS Data Center, Sioux Falls, South Dakota, USA]).

2.6. Landscape linkage model and dispersal zone

Since 1998, three radio-collared male panthers have dispersed into south central Florida, and telemetry records indicate that all crossed the Caloosahatchee River (Fig. 1) near the same location (Maehr et al., 2002b). At the same time, the growing human population of southwest Florida is expanding east from Ft. Myers along the State Road 80 corridor immediately south of the Caloosahatchee River, and development is expected to reach the area where the panthers crossed the river. To maintain future opportunities for an expanding Florida panther population to disperse out of south Florida, our second goal was to identify lands that should be protected from urban development to serve as a dispersal corridor. We called lands that met this goal the Dispersal Zone.

We used ArcView GIS© version 3.3 and ArcView Spatial Analyst© version 2 (Environmental Systems Research, Inc., Redlands, CA, USA) to construct a set of least-cost path models to identify optimum panther dispersal corridor(s). The least-cost path models operated on 2 cost surfaces that ranked suitability of the landscape for use by dispersing panthers under the assumption that habitat suitability influences the routes likely to be taken by dispersing panthers. The 2 cost surfaces were 30 m pixel grids produced from the results of our compositional and Euclidean distance analyses of habitat types. We scored the 16 land cover types from 1 to 11 and 1 to 10 based on results of pair-wise comparisons of habitat types in the compositional and Euclidean distance analyses, respectively, with lower scores indicating higher likelihood of use by dispersing panthers (Table 1). It is worth noting that the urban lands class, which included residential and commercial areas as well as roads and power lines, appeared in the habitat suitability ranking because this class occurred within some panther home ranges and within the study area used for the compositional analysis.

We also performed sensitivity analyses to determine whether higher cost scores for roads and water, which may provide greater impedance to panther movements, would affect the outputs of the model. We assigned water a score of 15 in each of the 2 cost surfaces to indicate that water is less likely to be used by dispersing panthers than vegetated uplands or wetlands. We assigned major roads a score of 20 in each cost surface as an indication that, even though dispersing panthers can and do cross highways, the cost of dispersing along a highway would accumulate rapidly relative to the cost of crossing perpendicular to a road.

To run least-cost path models, it is necessary to designate specific habitat sources and destinations for dispersing panthers. Based on radio-telemetry locations and overlap of fixed kernel home ranges, we selected all of Florida Panther National Wildlife Refuge (FPNWR) and patches of potential habitat within Big Cypress National Preserve (BCNP) north of I-75 as source areas for dispersing panthers (Fig. 3). We then selected patches of potential panther habitat within various large parcels of public land in central Florida as destinations. We made no attempt to model dispersal paths between occupied habitats in BCNP and Everglades National Park because these areas were protected by public ownership, and the goal of this effort was to find one or more dispersal pathways into central Florida. The 4 cost surfaces (i.e., 1 from each of habitat rankings analyses; 1 from each analysis modified to test effects of roads and water) were used to find a set of one-pixel-wide least-cost paths from source patches to destination patches. We reviewed the resulting set of least-cost paths (Fig. 3) in relation to recent Landsat satellite imagery (26 December 1999; 3 April 2001), 1995 land use/land cover data, the spatially explicit model of important landscape components, apparent paths followed by three radio-collared males known to have dispersed out of south Florida since 1998, and literature recommendations for possible corridor widths (Harrison, 1992; Noss, 1992; Beier, 1995). We screen-digitized a 3.0–7.8 km wide boundary of a Dispersal Zone to encompass a mosaic of suitable land cover types in an area east of the town of LaBelle, Hendry County, FL.

2.7. Secondary zone

Our final goal was to identify additional natural and disturbed lands in south Florida that may be important to transient subadult male panthers and have potential to support an expanding panther population, especially if habitat restoration were

Table 1 – Florida panther habitat use as determined by compositional analyses (CA) between fixed kernel home ranges and the CA study area (Fig. 2) and Euclidean distance analysis (EDA) of panther telemetry records by individual animal

Habitat rank	Compositional analysis			Euclidean distance		
	Habitat type	Rank differences[a]	Cost surface score	Habitat type	Rank differences[a]	Cost surface score
15	Upland forest	A	1	Cypress swamp	A	1
14	Hardwood swamp	A	1	Pineland	AB	2
13	Pineland	AB	2	Hardwood swamp	BC	3
12	Scrub	B	3	Upland forest	CD	4
11	Cypress swamp	B	3	Dry prairie	DE	5
10	Shrub and brush	C	4	Pasture/grassland	EF	6
9	Freshwater marsh	CD	5	Unimproved pasture	F	7
8	Dry prairie	CD	5	Shrub and brush	F	7
7	Barren land	DE	6	Urban	G	8
6	Unimproved pasture	E	7	Cropland	G	8
5	Urban	EF	8	Coastal wetlands	G	8
4	Pasture/grassland	F	9	Orchard/citrus grove	G	8
3	Cropland	F	9	Freshwater marsh	H	9
2	Open water	G	10	Barren land	H	9
1	Orchard/citrus grove	G	10	Scrub	H	9
0	Coastal wetlands	H	11	Open water	I	10

Fixed kernel polygon home ranges were determined using 46,350 telemetry locations for 79 panthers that were >2 years old and for which >50 telemetry records were available. Land cover source data was derived from a composite of 1995 water management district land use/land cover data. Results from the CA and EDA were used to assign values to cost surface grids used in determining a landscape linkage across the Caloosahatchee River, FL, USA.

a Pairwise *t*-tests indicated habitat types with the same letter code were not different ($p > 0.05$) from each other.

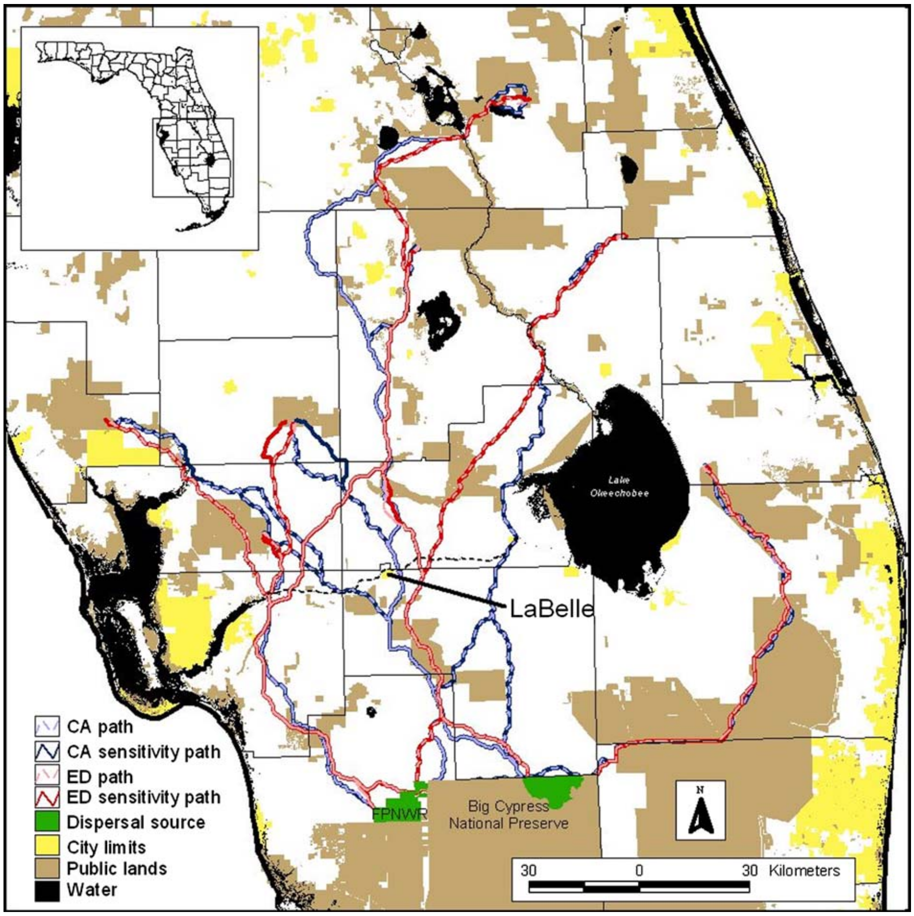

Fig. 3 – Least-cost paths most likely to be taken by Florida panthers dispersing out of south Florida. The Florida Panther National Wildlife Refuge (FPNWR) and occupied habitat patches in the northeastern corner of Big Cypress National Preserve were used as source areas for dispersal. Destinations for dispersing panthers were patches of apparently suitable habitat on parcels of public land in peninsular Florida north of the Caloosahatchee River. Scores for cost surfaces derived from the results of compositional analysis (CA) and Euclidean distance (ED) analysis.

possible. We called lands that met this goal the Secondary Zone. We sketched a preliminary boundary of a Secondary Zone on a hard copy map, and the boundary was screen-digitized utilizing the panther potential habitat map, recent satellite imagery, and telemetry locations as guides. We then conducted a GIS-based assessment of landscape context inside the draft Secondary Zone to provide direction to the process of creating a final boundary. We used a ranking method that involved subjective quantitative estimates of various landscape variables to score lands within the draft Secondary Zone based on presumed indicators of potential suitability to panthers.

We evaluated the landscape context of the draft Secondary Zone by combining a set of 30-m pixel grids created to measure three habitat-related variables (i.e., proximity to Primary Zone, proximity to a forest plus buffer patch, forest plus buffer patch size) and three land-use variables (i.e., proximity to urban lands, intensity of land use, and road type and density). We used WMD data as the source of land cover classes input to each layer except roads, which derived from 1:24,000-scale digital line graph (DLG) coverages for the region. We assigned each pixel in the six data layers with scores of 1–10, with 10 representing the best case for panthers, and then we added the grids together to rank the landscape within the draft Secondary Zone.

We developed scores for proximity to the Primary Zone by first determining the maximum perpendicular distance of the draft Secondary Zone boundary from the Primary Zone boundary, which was found to be 17.53 km. Scores were assigned in increasing increments of distance from the Primary Zone based on this maximum distance. To develop scores for proximity to a forest plus buffer patch, Florida panther telemetry locations were overlaid on the model of important landscape components, and numbers of locations were tallied in increments of 100 m from patches of potential habitat. Scores were assigned as an increasing function of distance from forest plus buffer patches. Scores for forest plus buffer patch size were assigned as an increasing function of size under the assumption that larger patches would likely be more important to panthers in the more disturbed landscape of the Secondary Zone.

We assigned scores for proximity to urban lands based on a review of Beier (1995), who provided some information about cougar behavior in the vicinity of urban areas, and by evaluating the distribution of telemetry locations in 100 m increments from urban lands. We buffered urban lands by 300 m (98.5% of telemetry locations were >300 m from urban lands), and we assigned lands within this buffer a1. We then assigned lands between 300 and 1000 m from urban areas scores of 2–9 in 100 m increments, and we assigned lands >1000 m from urban areas a score of 10. To develop a ranked data layer for land use intensity, we grouped land use/land cover classes into natural, low, moderate, and high land use intensity categories, and we assigned scores to pixels as follows: natural = 0, low = 1, moderate = 2, and high = 3. We then computed the mean value of each pixel in the grid by averaging all scores within a 1.0 km × 1.0 km window of each pixel. The range of mean land use intensity values (i.e., 0.0–3.0) was divided by 10, and scores were assigned in increments of 0.3.

To develop scores for road type and density, we first assigned scores to road segments in the 1:24,000-scale DLG coverage for Florida as follows: major highways = 10, major arterial roads = 7, other paved roads = 4, and minor rural roads = 1. Next, an empty 90 m pixel grid was created, and the DLG road coverage that had been scored by road types was overlaid on the grid. Then, a value for each pixel in the grid was calculated by multiplying the total length of road segments within a 1610 m radius of a pixel by the type score of each road segment. Pixel values in the resulting grid ranged 0–167 and represented a measure of road type-length within 1610 m of a pixel. Regions of the grid with low values contained few or no roads, whereas higher values indicated regions with a high density of busy multi-lane highways. Panther radio telemetry locations were overlaid on the road type-length grid to produce a histogram of number of locations associated with each pixel value. A score of 10 was assigned to road type-length units of 0 (i.e., cells with no roads within 1610 m), and a score of 1 was assigned to road type-length units >23.

Lacking empirical evidence for relative contribution of each data layer to landscape context, we tested 2 approaches to assigning weights to the data layers. First, we assumed each data layer had equal weight. Second, authors were polled for their recommendations for assigning weights between 0 and 1 to each of the six variables, and mean weights suggested by the authors were assigned to each layer. We added the six weighted data layers using both equal weights and mean weights suggested to by authors to create final landscape context layers that were rescaled to 1–10. Differences between equal weights and author assigned weights were negligible. We then intersected panther telemetry locations with the landscape context grids to generate frequency distributions of number of telemetry points by values in the grid. Finding that 99% of telemetry locations were associated with pixels having scores $\geqslant 6$, we created a final Secondary Zone boundary by adjusting the draft boundary to eliminate most areas with scores <6.

2.8. *Florida panther population density*

We generated minimum convex polygons of panther home ranges for all Florida panthers by year ($n = 49{,}889$ telemetry locations, 1981–2000). Each polygon was converted to a 100 m pixel grid, and resulting grids were summed to produce a grid in which the value of each pixel represented the number of overlapping home range polygons that had occurred at that place over the period of record. Assuming that minimum convex polygons derived from transient males that may have used an area only once or twice overestimated the region of south Florida most consistently occupied by Florida panthers over time, we subtracted pixels with values of 1 or 2 from the grid to generate a grid that we defined as the region of most consistent panther occupancy for the period of record. To estimate population density, the total land area within the resulting region of panther occupancy was divided by 62, the panther population count in 2000 (McBride, 2000), which was the year of the most recent telemetry data used to define minimum convex polygon home ranges.

To evaluate the extent to which the Primary, Secondary, and Dispersal zones contribute to survival of the Florida panther, the number of panthers that each could potentially support was estimated. Density estimates of one panther per 11,000 ha (Maehr et al., 1991) and one panther per 12,919 ha (this paper) were used to calculate a range of estimated population sizes as a function of the total land area of each zone. These population estimates assume that habitat quality was homogeneous throughout the landscape, which it was not. Habitat quality in the Secondary Zone was estimated to be 34.53% of that in the Primary Zone based on relative proportions of potentially suitable habitat patches in each zone. To account for this difference, the estimated carrying capacity of the Secondary Zone was adjusted downward accordingly. Population size estimates were reviewed in relation to a suggested set of population viability guidelines assembled from a review of the Florida panther population viability analyses (PVA) that have been conducted to date (Ballou et al., 1989; Seal and Lacy, 1992; Ellis et al., 1999; Kautz and Cox, 2001; Maehr et al., 2002b; Root, 2004).

3. Results

3.1. *Compositional and Euclidean distance analyses*

Comparison of the composition of land cover types found in fixed kernel home ranges relative to the composition of land cover types within the compositional analysis study area indicated that habitat use was disproportionate to availability (Wilk's $\lambda = 0.0297$, df = 15, $P < 0.001$). The 3 highest ranked habitat types found within home ranges included upland hardwood forest, hardwood swamp, and pinelands, respectively (Table 1). Habitats that were found to be disproportionately lower in home ranges than available within the study area included coastal wetlands, orchards/citrus groves, open water, cropland, and pasture/grassland.

Comparison of mean distances between telemetry locations and random locations indicated that habitat use was non-random (Wilk's $\lambda = 0.0016$, df = 16, $P < 0.001$). Florida panther locations during morning hours were within or closer to forested cover types, particularly cypress swamp, pinelands, hardwood swamp, and upland hardwood forests than would be expected based on random locations (Table 1). Conversely, daytime sites were farther from freshwater marsh, barren land, scrub, and open water than would be expected from random locations.

Use of forest patches within fixed kernel home ranges also differed significantly from random (Wilk's $\lambda = 0.0475$, df = 12, $P < 0.001$). Generally, patches in the smallest forest patch size classes occurred within home ranges in higher proportions relative to their availability than larger forest patches (Table 2). With the exception of the largest forest patch, which had an intermediate rank, pairwise comparisons of patch size differences indicate that forest patch sizes 3.2–8.5 ha were found in highest proportions relative to their availability, and forest patches 4886.9–5647.7 ha were used less than their availability within the compositional analysis study area.

3.2. Model of important components of the landscape

The map of landscape components important to the Florida panther (Fig. 4), the criteria for which were based on the findings from compositional and Euclidean distance analyses, indicated that the greatest extent of forest plus buffer patches occurs in southwest Florida, the principal area supporting the current panther population. Large areas of habitat are in public ownership (i.e., Big Cypress National Preserve, Fakahatchee Strand Preserve State Park, Florida Panther National Wildlife Refuge, and Picayune Strand State Forest). These landscape components tend to become progressively more fragmented and isolated north of these parcels of public land as well as in the southeastern portions of the Everglades.

3.3. Primary, Dispersal, and Secondary zones

The Primary, Dispersal, and Secondary zones (Fig. 5) included a total area of 1,258,823 ha (Table 3). The Primary Zone covered 918,895 ha, of which 671,654 ha (73%) were in public ownership and 247,241 ha (27%) were in private ownership (Table 4). Forests accounted for 45% of Primary Zone cover types; freshwater marshes for 41%; prairie and shrub lands for 2.6%; and agricultural lands for 7.6%. Urban lands comprised only 0.52%. Privately owned lands within the Primary Zone included more areas in agricultural use but less area of freshwater marsh. Land cover types modeled as potentially suitable habitat patches accounted for 64.3% of the Primary Zone.

The least-cost paths output from the 2 cost surfaces based on the original scores from the compositional and Euclidean distance analyses resulted in multiple routes that Florida panthers might follow when dispersing out of south Florida across the Caloosahatchee River (Fig. 3). There were no discernable differences in the sensitivity analysis least-cost paths that were produced from versions of the cost surfaces that incorporated higher impedance scores for roads and water. Paths west of LaBelle, FL, were rejected as candidate sites for the location of the Dispersal Zone because they passed through dense urban or intensive agricultural areas by following one-pixel-wide paths unlikely to be used by panthers on a regular basis. The path just west of Lake Okeechobee was not a feasible location for the Dispersal Zone because it passed through large expanses of open agricultural lands. The site we selected for the Dispersal Zone incorporated the paths that passed just east of of LaBelle, FL. The Dispersal Zone covered 11,284 ha; ranged 3.0–7.8 km wide; had a mean width of 5.3 km; extended about 20 km north from the Primary Zone; and included a 6 km segment of the Caloosahatchee River that averaged about 100 m across. Immediately north of the Dispersal Zone was a large area mapped as having habitat conditions potentially important for Florida panthers (Logan et al., 1993; Cox et al., 1994), and the entire area was in a single private ownership. Just within the eastern boundary of the Dispersal Zone was an abandoned railroad grade that may facilitate dispersal (Maehr et al., 2002b). Forests accounted for 29% of the Dispersal Zone; freshwater marshes for 7.5%; prairie and shrub lands for 8.8%; agriculture (primarily improved pasture and citrus groves) for 49%; and barren and urban land for 5.1%. Land cover types modeled as potentially suitable habitat patches accounted for 59.9% of the Dispersal Zone.

The Secondary Zone covered 328,654 ha, of which 124,898 ha (38%) were in public ownership and 196,151 ha (60%) were in private ownership. Only 11% of the Secondary Zone was forest, the highest ranking cover types in the compositional analysis. A large percentage (43%) consisted of freshwater marsh, the dominant plant community of the Florida Everglades, most of which is in public ownership. Prairie and shrub lands and agricultural lands accounted for 42% of the Secondary Zone, and a small percentage (2.3%) consisted of low-density residential areas and open urban lands. Land cover types modeled as potentially suitable habitat patches accounted for 22.2% of the Secondary Zone.

3.4. Florida panther population density

The region of most consistent panther occupancy from 1981 through early 2000 covered 800,951 ha. Based on the

Table 2 – Florida panther forest patch use as determined by compositional analyses (CA) between fixed kernel home ranges and the CA study area (Fig. 2)

Forest patch size class (ha)	Habitat rank	Differences in ranks[a]
3.2–8.5	12	A
2.0–3.1	11	A B
21.3–47.7	10	A B
117.3–253.0	9	A B
8.6–21.1	8	B
23,973.7+	7	B C
47.8–115.0	6	B C
254.9–439.1	5	B C
3520.4–4706.6	4	C
505.1–847.8	3	C
848.1–1515.7	2	C
1538.4–3235.2	1	D
4886.9–5647.7	0	D

Fixed kernel polygon home ranges were determined using 46,350 telemetry locations for 79 panthers that were >2 years old and for which >50 telemetry records were available. Land cover source data was derived from a composite of water management district land use/land cover data.

a Pairwise *t*-tests indicated forest patches size classes with the same letter code were not different ($p > 0.05$) from each other.

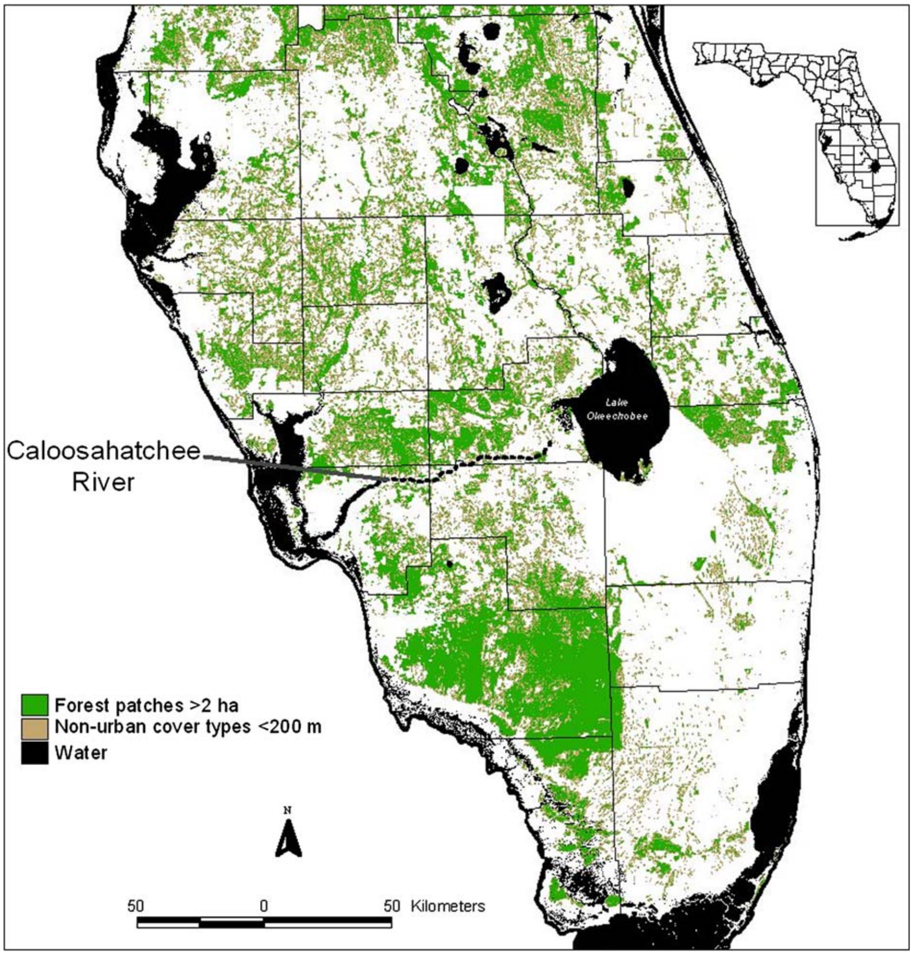

Fig. 4 – A model of landscape components (i.e., forest patches >2 ha surrounded by 200 m non-urban buffers) significant to Florida panther conservation throughout the southern portion of the Florida peninsula.

estimated panther population of 62 individuals (McBride, 2000), population density was one panther per 12,919 ha in 2000.

4. Discussion

4.1. *Habitat analyses*

Previous investigators have reported that Florida panthers are strongly associated with forested habitats, especially in the morning hours of 0600–1000 when telemetry data are typically collected (Belden et al., 1988; Maehr et al., 1991; Land, 1994; Maehr and Cox, 1995; Kerkhoff et al., 2000). Compositional analyses of Florida panther habitat in this study confirmed previous findings that forest patches comprise an important component of Florida panther habitat in south Florida. Our compositional analysis also confirms previous findings that other natural (e.g., freshwater marsh) and disturbed (e.g., agricultural and pasture lands) cover types are also present in the large landscapes that support panthers, but these cover types rank lower in importance as panther habitats (Belden et al., 1988; Maehr et al., 1991; Comiskey et al., 2002). Similarly, Euclidean distance analysis, which ranks the mean distances of telemetry records to the nearest instance of each land cover type, also confirms that forest cover types are either selected by Florida panthers as daytime sites, or they are very close to the sites selected. On the other hand, daytime sites typically are farthest away from freshwater marsh, barren land, scrub, and open water.

The differences in the results in Table 1 are because compositional analysis and Euclidean distance analysis measure two different but related aspects of Florida panther use of the landscape. Compositional analysis measures the relative importance of various land cover types within home ranges. Euclidean distance, on the other hand, ranks land cover types according to whether or not they are selected or are near to sites selected by panthers as daytime rest sites. Thus, not only are panther home ranges composed to a large extent of forest cover types, but forest cover types also are typically selected as daytime sites, or they are at least near to the sites selected. However, freshwater marsh is an example of a land cover type that is fairly abundant within panther home ranges, but sites selected during the daytime tend to be more distant from freshwater marsh.

Contrary to information reported by Maehr and Cox (1995) and Maehr and Deason (2002) that Florida panthers tend to avoid forest patches <500 ha in size, our analyses showed that the smallest classes of forest patches were the highest ranked forest patch sizes within panther home ranges. This

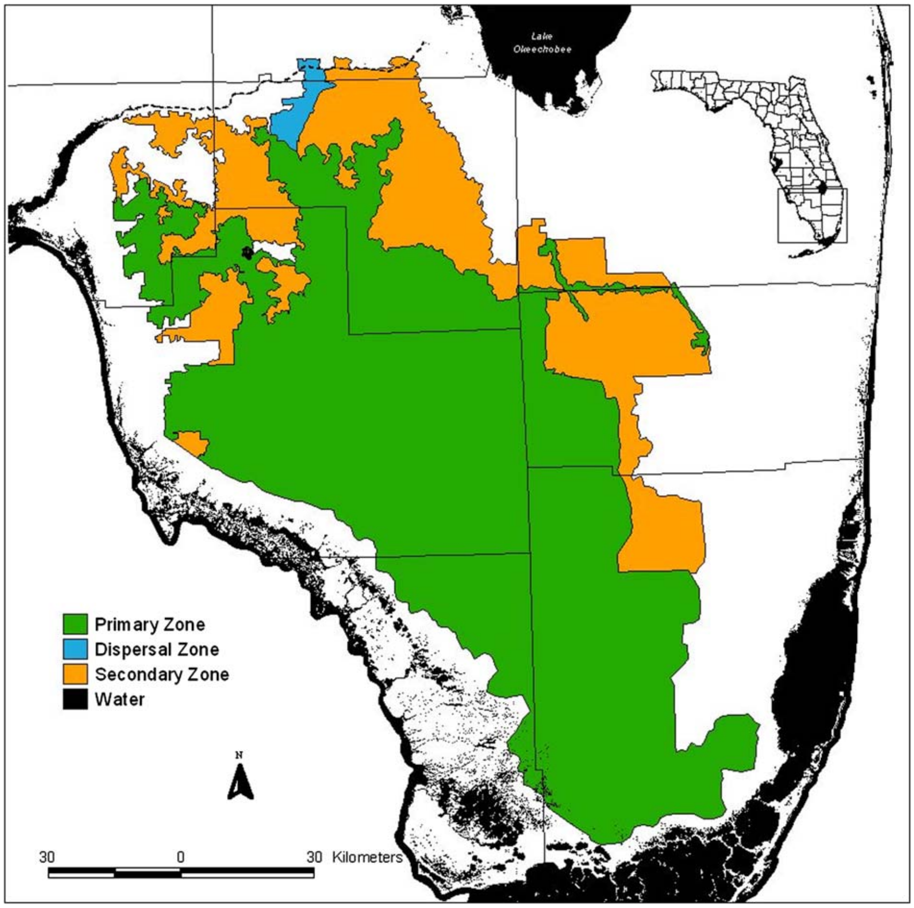

Fig. 5 – Locations of Primary, Dispersal, and Secondary zones identified as important lands for conservation of Florida panther habitat. Whereas the model in Fig. 4 indicates habitat patches providing important cover for panthers, the zones integrate the patches into a connected landscape mosaic of land cover types needed to support the population.

Table 3 – Area of 1995 water management district land use/land cover types within Florida panther Primary, Dispersal, and Secondary zones

Land cover type	Primary zone (ha)	Dispersal zone (ha)	Secondary zone (ha)	Total (ha)
Wetland forest	350,306	1872	18,639	370,817
Upland forest	65,173	1440	16,984	83,597
Freshwater marsh	374,356	844	140,654	515,854
Prairie and shrub lands	23,553	992	20,163	44,707
Agriculture	70,155	5527	119,271	194,953
Barren, urban, exotics	15,236	576	10,864	26,675
Coastal wetlands	17,470	–	18	17,488
Aquatic	2646	34	2062	4742
Total area	918,895	11,284	328,654	1,258,834

finding demonstrates that, not only are forests cover types important to panthers, but forest patches of all sizes appear to be important components of the landscapes inhabited by Florida panthers, not just the larger forest patches. There are several reasons why small forest patches could be important to Florida panther conservation. First, this finding may simply be indicative of the presence of numerous small tree islands in a matrix of freshwater herbaceous wetlands characteristic of the Florida Everglades as well as small forest patches interspersed within agricultural landscapes occupied by some panthers. Second, small forest patches may be important for sub-adult Florida panthers that have not yet established their own breeding territories, but need a place to hunt and disperse in the interim. Additionally, a more heterogeneous landscape characterized by an interspersion of forest and non-forest patches may be more favorable to the production of prey species, including white-tailed deer (*Odocoileus viriginianus*) and wild hogs (*Sus scrofa*), or perhaps prey ambush success is greater under such conditions.

Table 4 – Estimated number of panthers that could be supported by the Primary, Secondary, and Dispersal zones in south Florida by ownership

Zone	Ownership	Area (ha)	Potential number of panthers (1/11,000 ha)[a]	Potential number of panthers (1/12,919 ha)[b]
Primary	Public land (April 2001)	671,654	61	52
	Private land	200,356	18	15
	Tribal land	46,886	4	4
	Total area	918,895	84	71
Secondary	Public land (April 2001)	124,898	11	10
	Private land	196,151	18	15
	Tribal land	7605	1	1
	Total area	328,654	30	25
	Effective area (34.5%)	113,480	10	9
Dispersal	Public land (April 2001)	0	0	0
	Private land	11,284	1	0
	Tribal land	0	0	0
	Total area	11,284	1	0

a Density estimate from Maehr et al. (1991).
b Density estimate derived in this study.

4.2. *Primary zone*

The Primary Zone is the most important of the three zones identified in this project because preservation of these lands will contribute most to the long-term persistence of the Florida panther in the wild. The Primary Zone, which consisted of 86% natural cover types, could support an estimated 71–84 panthers based on estimates of population density (Table 4). The Florida panther population was estimated at 30–50 individuals throughout the 1980s and early 1990s (Maehr, 1992). However, the population has been growing since the mid-1990s when 8 Texas females (*P. c. stanleyana*) were introduced into south Florida, and major sources of roadkill mortality were eliminated with the installation of underpasses along Interstate 75 and State Road 29. If the population continues to grow, it seems likely that additional sub-adult males may eventually disperse outside of currently occupied lands. However, the chances of female dispersal, especially across the Caloosahatchee River, without human intervention remain in doubt. The most likely areas of dispersal are into the Secondary Zone and through the Dispersal Zone to privately owned lands to the north.

A population of 71–84 panthers has a high probability of persistence for 100 years (Table 5) assuming no further loss of habitat. Available PVA models indicate that a population of this size may either remain stable or decline gradually, perhaps by as much as 25%, over the next 100 years; and genetic problems associated with inbreeding depression and loss of heterozygosity are likely to continue without management intervention. Translocation of 2 females into the population every 10 years would minimize the effects of inbreeding depression and loss of heterozygosity in a population of this size (Ellis et al., 1999; Maehr et al., 2002a), but genetic stability would still fall short of the level provided by a population of 300 individuals (Maehr et al., 2002a). Thus, it appears that the Primary Zone, a large landscape consisting of a matrix of natural and disturbed cover types, provides just enough space to support a population that is barely viable demographically as long as the habitat base remains stable. A population of 71–84 panthers would just meet the criteria for survival (USFWS and NMFS, 1998) with the exception of genetic heterogeneity. The Primary Zone takes on additional significance in that it supports the only known breeding

Table 5 – Population guidelines for the Florida panther based on the results of previous population viability analyses (Ballou et al., 1989; Seal and Lacy, 1992; Ellis et al., 1999; Kautz and Cox, 2001; Maehr et al., 2002b; Root, 2004)

Population size	Viability
<50	Extinction highly probable in less than 100 years – demographic instability – $N_e \ll 50$ – high levels of inbreeding
60–70	Barely viable – low probability of extinction in 100 years – expect 25% population decline in 100 years – $N_e < 50$ – declining heterozygosity – no habitat loss or catastrophes can be tolerated
80–100	Stable population likely for 100 years – low probability of extinction in 100 years – expect population to remain stable over 100 years – $N_e > 50$ – slowly declining heterozygosity – no habitat loss or catastrophes can be tolerated
>240	High probability of persistence – low probability of extinction in 100 years – expect population to remain stable over 100 years – $N_e > 50$ – able to retain 90% of heterozygosity – some habitat loss or mild catastrophes can be tolerated

panther population, a population that should be viewed as the essential foundation for one of three self-sustaining populations needed for the recovery of the species (USFWS, 1995).

4.3. Dispersal zone

Our second priority for conservation of panther habitats was the Dispersal Zone, an area intended to function as a landscape linkage maintaining connectivity to potentially suitable habitat north of the Caloosahatchee River. Due to the rapid rate of urban development in the region, the opportunity for panthers to disperse out of south Florida eventually will be precluded if a landscape connection cannot be maintained. Moreover, should a breeding population become established north of the Caloosahatchee River, effectively forming a metapopulation (Wiens, 1996), a landscape connection would facilitate exchange of dispersing individuals between the two sub-populations, thereby increasing genetic and demographic viability of the entire south Florida population (Ellis et al., 1999). Logan et al. (1993) and Cox et al. (1994) identified about 150,000 ha immediately north of the Caloosahatchee River as being potentially important for the long-term conservation of Florida panther habitats. However, there is no certainty that potential habitats north of the Caloosahatchee River actually can support a sub-population of panthers.

The Dispersal Zone includes 113 km^2, an area considerably smaller than the average home ranges of adult male and female panthers (i.e., 416.5 km^2 and 156.1 km^2, respectively [Land et al., 2004]). Therefore, it seems highly unlikely that the Dispersal Zone could support permanent occupancy by adult Florida panthers. However, Beier (1995) reported that dispersing sub-adult males occupied transient home ranges 2–30% the size of adult home ranges for short periods of time. Assuming transient home ranges of sub-adult male Florida panthers were 30% the size of the average adult male, transient home ranges would be 125 km^2, a number only slightly larger than the size of the Dispersal Zone. Thus, the Dispersal Zone may be large enough accommodate infrequent temporary use by dispersing males even though it is not large enough to support permanent occupancy.

Regardless of its small area, the Dispersal Zone may be expected to function as a landscape linkage (Harris and Scheck, 1991; Hoctor, 2003). Mean maximum dispersal distance was 68.4 km for males and 20.3 km for females (Maehr et al., 2002b), suggesting that both males and females could easily traverse the 20 km length of the Dispersal Zone. Although sub-adult females tend to set up home ranges immediately adjacent to their mother's home range (Maehr et al., 2002a), Logan and Sweanor (2001) reported that a sizable minority of female pumas in New Mexico did not settle near their mother, suggesting that use of the Dispersal Zone will not be limited to males. The potential appears to exist for female Florida panthers to eventually disperse over the Caloosahatchee River in an attempt to establish new territories to the north.

As to the widths needed to accommodate dispersal, Beier (1995) reported that mountain lions dispersed through corridors of suitable habitat that were 0.5–1.0 km wide over a distance of 6.0 km. In a California setting of wild lands surrounded by urban areas, Beier (1995) recommended that corridors with a length <0.8 km should be >100 m wide; corridors extending 1–7 km should be >400 m wide; and corridor width should increase as length increases. Noss (1992) suggested that, as a rule-of-thumb, a regional corridor connecting larger hubs of habitat should be at least 1.6 km wide with no bottlenecks <400 m wide. With widths ranging 3.0–7.8 km, the Dispersal Zone appears to be wide enough to facilitate panther dispersal out of south Florida.

The Dispersal Zone appears to be strategically located. Three radio-collared sub-adult males have been documented to have crossed the Caloosahatchee River in the approximate vicinity of the Dispersal Zone (Maehr et al., 2002b). In addition, the southern boundary is contiguous with Okaloacoochee Slough State Forest, a parcel of public land that supported a denning female in 2001 (Comiskey et al., 2002) and again in 2005 (Land, D., personal communication). Thus, a portion of the breeding population was proximal to the southern terminus of the Dispersal Zone in recent years, suggesting that it is likely that dispersing panthers can find this landscape linkage in the future. Perhaps it is only a matter of time before pressure from an increasing population forces a young female to disperse to the north across the Caloosahatchee River.

Immediately north of the Dispersal Zone is a very large parcel of privately owned ranch land containing large areas of habitat potentially suitable for Florida panthers. Our analysis of potential habitats and past evaluations (Logan et al., 1993; Cox et al., 1994; Kautz and Cox, 2001) indicate that these lands possess qualities that may be suitable for panthers. Just within the eastern boundary of the Dispersal Zone is an abandoned railroad grade, a landscape feature likely to accommodate panther dispersal (Maehr et al., 2002b) The Dispersal Zone includes a 6.0 km segment of the Caloosahatchee River that averages 100 m across, thus making this area accessible for panthers to cross. In addition, development intensity in this segment of the river is relatively low.

4.4. Secondary zone

Our third priority for Florida panther habitat conservation was the Secondary Zone, a set of lands immediately adjacent to the Primary Zone but containing lower quality habitat and few records of panther use. Due to its position in the landscape, the Secondary Zone is the area most likely to be encountered by panthers ranging out of the Primary Zone. Areas within the Secondary Zone also may provide temporary habitat or refuge for sub-adult male panthers prior to their recruitment into the population as breeders on established territories. Even though radio-collared panthers previously have been tracked in portions of the Secondary Zone, no panthers are known to inhabit the area on a regular basis. Many areas within the Secondary Zone do not now contain suitable panther habitat (e.g., intensive agricultural lands, low density residential areas), but many areas could feasibly support panthers on a permanent basis if habitat restoration were to occur.

Based on area alone, the Secondary Zone has the capacity to support 25–30 Florida panthers (Table 4). However, under current conditions, habitat quality within the Secondary Zone probably is not sufficient to support that many panthers. Cover types modeled as being important landscape components for panthers (Fig. 4) comprised only 22.2% of the Secondary Zone compared to 64.3% in the Primary Zone. If the proportion of potentially suitable habitat patches in each zone is an indicator of quality, the effective area of the Secondary Zone is about 34.5% of that in the Primary Zone. Applying this ratio to adjust for differences in habitat quality, the Secondary Zone probably can support no more than 9–10 panthers in its current condition (Table 4). However, this estimate is clearly speculative because there is no evidence that panthers consistently occupy the Secondary Zone at the present time.

5. Conservation implications

The Primary, Dispersal, and Secondary zones comprise essential components of a landscape-scale conservation plan for the protection of a viable Florida panther population in south Florida. Taken together, the three zones in their current condition apparently have the capacity to support approximately 80–94 Florida panthers. A population of this approximate size has a high probability of persistence for 100 years and has a good chance of remaining stable or perhaps declining only slightly over the planning period. However, this conclusion assumes that (1) further loss of habitat in all 3 zones, but especially in the Primary Zone, is minimized, (2) the existing population will expand into areas of the Secondary Zone where habitat conditions are presently suboptimal and panthers are only occasionally known to occur, and (3) unforeseen catastrophes do not affect the population. These conditions may not be met as new developments occur within all zones. Moreover, the panther population is currently experiencing an outbreak of feline leukemia, the ultimate consequences of which remain to be seen. Despite the high chance of persistence, a population of 80–94 panthers is nevertheless likely to experience genetic problems associated with inbreeding depression and decreasing heterozygosity, and future management intervention will likely be needed to resolve these problems.

The Primary Zone, which supports the existing panther population and comprises predominantly natural cover types, is the most important of the lands mapped in this project to panther habitat conservation. The maintenance of existing home ranges and habitat function within the Primary Zone is essential to maintaining a viable Florida panther population. Assessments of potential impacts of proposed developments within the Primary Zone should strive to achieve no net loss of landscape function or carrying capacity for panthers within the Primary Zone. Loss of function or carrying capacity within the Primary Zone may be affected by: (1) reduction or degradation of the habitat base, (2) reduction in the areal extent of the Primary Zone, (3) increasing landscape fragmentation, and (4) land use intensification (e.g., moving along a gradient from natural conditions to pasture, to cropland, to urban). Critical aspects of a functioning landscape for panthers include use by panthers for home ranges, breeding access, resting and denning sites, stalking cover, dispersal routes, transient ranges of non-resident males, support for prey, and natural areas that buffer against indirect impacts associated with adjacent urban and industrial uses. Habitat quality, functionality, and availability for panthers must be maintained to ensure that no net loss of function or carrying capacity occurs. When adverse land uses within the Primary Zone are unavoidable, affected lands should be compensated by the restoration or enhancement of habitat that maintains or increases the potential carrying capacity for panthers elsewhere within the Primary Zone. In addition, maintaining the total areal extent of the Primary Zone may require expanding the boundaries of the zone in appropriate locations (e.g., into the Secondary Zone adjacent to protected habitat within the Primary Zone) to compensate for loss of area. In such cases, lower quality areas should be restored to land cover types and landscape configurations that promote healthy prey densities, connectivity, and habitat context to compliment conservation efforts within the Primary Zone.

If the Florida panther population continues to expand, dispersal outside of the Primary Zone is likely. The Dispersal Zone is the second most important area mapped because it will play a key role in maintaining a landscape connection between south Florida and potential habitats to the north should a second breeding sub-population become established. The most important conservation action that could be taken for the Dispersal Zone is to secure it as a public conservation area using fee-simple acquisition or the purchase of conservation easements. Most of the Dispersal Zone is privately owned; however, 11% has been placed under publicly funded conservation easements, and most of the remainder is proposed for public acquisition under the State's Florida Forever land protection program. In addition, habitats within the Dispersal Zone need to be restored to conditions more suitable for panthers to increase the chances that this corridor will be used for dispersal. Although pumas and panthers have been observed to disperse through areas that are not developed to intensive urban uses (Beier, 1995; Maehr et al., 2002b), habitat restoration within the Dispersal Zone would improve chances for dispersal. Another management action that can be taken is for public land managers to maintain high quality habitat conditions within Okaloacoochee Slough State Forest immediately south of the Dispersal Zone. Continued successful reproduction and growth of the panther population in this portion of the range may be the pressure needed to push a female panther through the Dispersal Zone to habitats north of the Caloosahatchee River.

The Secondary Zone is the lowest priority for panther conservation. Even though the Secondary Zone is immediately adjacent to occupied areas of the Primary Zone, much of the Secondary Zone is in intensive agricultural use, and some areas are interspersed with low-density residential subdivisions and golf course communities. Restoration of natural cover types would have to occur in many areas of the Secondary Zone before the area could contribute meaningfully to the recovery of the Florida panther. Therefore, although habitat restoration and protection opportunities should be pursued within the Secondary Zone whenever possible, these efforts should not detract from the goal of protecting and enhancing habitats within the Primary Zone.

Presently, state and federal government programs are actively engaged in obtaining new areas for protection of Florida panther habitat. The State's Florida Forever land acquisition program and the South Florida Water Management District's Save Our Rivers program have purchased almost 200,000 ha of panther habitat over the last decade, and another 118,000 ha are on proposed acquisition lists. The US Fish and Wildlife Service (USFWS) reviews proposed development projects in South Florida for potential impacts to Florida panther habitat under Sections 7 and 10 of the US Endangered

Species Act (ESA). As a result of USFWS project reviews conducted under the ESA between 1 September 2003, and 5 May 2005, over 4850 ha have been conserved in the Primary and Dispersal zones (Slack, J., USFWS, personal communication). The results of this study could aid in increasing the efficiency and effectiveness of these programs by providing information needed to determine which lands should be subject to regulatory programs and to target specific areas for protection, either through fee-simple acquisition or purchase of less-than-fee conservation easements.

Integration of all conservation efforts will be required to support a self-sustaining population of the Florida panther in South Florida. An ambitious, comprehensive strategy for working with private landowners to protect, enhance, and restore panther habitat within the Primary, Dispersal, and Secondary Zones is essential. Public agencies responsible for land use planning, transportation planning, and land management on public lands must also make decisions that maintain or enhance the ability of South Florida to support a viable population of the Florida panther. Trends in human population growth, habitat loss and fragmentation, agricultural conversions, and transportation planning all indicate that these recommended conservation actions need to begin immediately. The future of the Florida panther will likely be determined in the next 2 decades, and without concerted conservation efforts that future is uncertain.

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REFERENCES

Aebischer, N.J., Robertson, P.A., Kenward, R.E., 1993. Compositional analysis of habitat use from animal radio-tracking data. Ecology 74 (5), 1313–1325.

Anderson, J.R., Hardy, E.E., Roach, J.T., Witmer, R.E., 1976. A land use and land cover classification system for use with remote sensor data. Geological Survey Professional Paper 964. US Geological Survey, Washington, DC, USA.

Ballou, J.D., Foose, T.J., Lacy, R.C., Seal, U.S., 1989. Florida Panther (*Felis concolor coryi*). Population Viability Analysis and Recommendations. Species Survival Commission, Captive Breeding Specialist Group, IUCN, Gland, Switzerland.

Beier, P., 1995. Dispersal of juvenile cougars in fragmented habitat. Journal of Wildlife Management 59 (2), 228–237.

Beier, P., Conroy, M.J., Vaughn, M.R., Quigley. H., 2006. Evaluating scientific inferences about the Florida panther. Journal of Wildlife Management 71 (1), in press.

Belden, R.C., Frankenberger, W.B., McBride, R.T., Schwikert, S.T., 1988. Panther habitat use in southern Florida. Journal of Wildlife Management 52 (4), 660–663.

Bingham, R.L., Brennan, L.A., 2004. Type I error rates and resource selection. Journal of Wildlife Management 68, 206–212.

Bureau of Economic and Business Research (BEBR). 2001. Projections of Florida population by county, 2000–2030. Florida Population Studies, vol. 34, No. 1, Bulletin 128. University of Florida, Gainesville, FL, USA.

Comiskey, E.J., Bass, Jr., O.L., L.J. Gross, McBride, R.T., Salinas. R., 2002. Panthers and forests in South Florida: an ecological perspective. Conservation Ecology 6(1):18. [online] URL: http://www.consecol.org/vol6/iss1/art18.

Conner, L.M., Plowman, B.W., 2001. Using Euclidean distances to assess nonrandom habitat use. In: Millspaugh, J.J., Marzluff, J.M. (Eds.), Radio Tracking and Animal Populations. Academic Press, San Diego, CA, USA, pp. 275–290.

Cox, J., Kautz, R., MacLaughlin, M., Gilbert, T., 1994. Closing the Gaps in Florida's Wildlife Habitat Conservation System. Florida Game and Fresh Water Fish Commission, Tallahassee, FL, USA.

Dees, C.S., Clark, J.D., Van Manen, F.T., 2001. Florida panther habitat use in response to prescribed fire. Journal of Wildlife Management 65 (1), 141–147.

Ellis, S., Lacy, R.C., Kennedy-Stoskopf, S., Wildt, D.E., Shillcox, J., Byers, O., Seal, U.S., editors. 1999. Florida panther population and habitat viability assessment and genetics workshop report. IUCN/SSC Conservation Breeding Specialist Group, Apple Valley, Minnesota, USA.

Harris, L.D., Scheck, J., 1991. From implications to applications: the dispersal corridor approach to the conservation of biological diversity. In: Saunders, D.A., Hobbs, R.J. (Eds.), Nature Conservation 2: the Role of Corridors. Surrey Beatty and Sons, Chipping Norton, New South Wales, Australia, pp. 189–220.

Harrison, R.L., 1992. Toward a theory of inter-refuge corridor design. Conservation Biology 6 (2), 293–295.

Hoctor, T.S. 2003. Regional landscape analysis and reserve design to conserve Florida's biodiversity. Ph.D. dissertation, Univesity of Florida, Gainesville, FL, USA.

Kautz, R. 1994. Historical trends within the range of the Florida panther. In: Jordan, D.B., (Ed.), Proceedings of the Florida Panther Conference US Fish and Wildlife Service, Atlanta, GA, USA, pp. 285–296.

Kautz, R.S., 1998. Land use and land cover trends in Florida 1936–1995. Florida Scientist 61 (3–4), 171–187.

Kautz, R.S., Cox, J.A., 2001. Strategic habitats for biodiversity conservation in Florida. Conservation Biology 15 (1), 55–77.

Kautz, R.S., Gilbert, D.T., Mauldin, G.M., 1993. Vegetative cover in Florida based on 1985–1989. Landsat Thematic Mapper imagery. Florida Scientist 56, 135–154.

Kerkhoff, A.J., Milne, B.T., Maehr. D.S., 2000. Toward a panther-centered view of the forests of south Florida. Conservation Ecology 4(1):1. [online] URL: http://www.consecol.org/vol4/iss1/art1.

Kuyper, W.H., Becker, J.E., Shopmyer, A., 1981. Land Use, Cover and Forms Classification System: A Technical manual. Florida

Department of Transportation, State Topographic Office, Remote Sensing Center, Tallahassee, FL, USA.
Land, E.D., 1994. Panther use of the southern Florida landscape. In: Jordan, D.B. (Ed.), Proceedings of the Florida Panther Conference. US Fish and Wildlife Service, Atlanta, GA, USA, pp. 278–284.
Land, E.D., Lacy, R.C., 2000. Introgression level achieved through Florida panther genetic restoration. Endangered Species UPDATE 17 (5), 99–103.
Land, D., Cunningham, M., Lotz, M., Shindle, D., 2004. Florida panther genetic restoration and management Annual report 2003–2004. Florida Fish and Wildlife Conservation Commission, Tallahassee, FL, USA.
Logan, K.A., Sweanor, L.L., 2001. Desert Puma. Island Press, Washington, DC.
Logan, T., Eller Jr., A.C., Morrell, R., Ruffner, D., Sewell, J., 1993. Florida Panther Habitat Preservation Plan: south Florida Population. Florida Panther Interagency Committee, US Fish and Wildlife Service, Gainesville, FL, USA.
Maehr, D.S., 1992. Florida panther (*Felis concolor coryi*). In: Rare and Endangered Biota of Florida. In: Humphrey, S.R. (Ed.), Mammals, vol. I. University Press of Florida, Gainesville, FL, USA, pp. 176–189.
Maehr, D.S., Cox, J.A., 1995. Landscape features and panthers in Florida. Conservation Biology 9 (5), 1008–1019.
Maehr, D.S., Deason, J.P., 2002. Wide-ranging carnivores and development permits: constructing a multi-scale model to evaluate impacts on the Florida panther. Clean Technology and Environmental Policy 3, 398–406.
Maehr, D.S., Land, E.D., Roof, J.C., 1991. Social ecology of Florida panthers. National Geographic Research and Exploration 7 (4), 414–431.
Maehr, D.S., Lacy, R.C., Land, E.D., Bass Jr., O.L., Hoctor, T.S., 2002a. Evolution of population viability assessments for the Florida panther: a multi-perspective approach. In: Beissinger, S.R., McCullough, D.R. (Eds.), Population Viability Analysis. University of Chicago Press, Chicago, IL, USA, pp. 284–311.
Maehr, D.S., Land, E.D., Shindle, D.B., Bass, O.L., Hoctor, T.S., 2002b. Florida panther dispersal and conservation. Biological Conservation 106, 187–197.
McBride, R.T. 2000. Current panther distribution and habitat use: A review of field notes, fall 1999–winter 2000. Report to Florida Panther Subteam of MERIT, United States Fish and Wildlife Service, South Florida Ecosystem Office, Vero Beach, FL, USA. [online] URL: http://www.panther.state.fl.us/news/pdf/report.pdf.
McBride, R.T. 2001. Current panther distribution, population trends, and habitat use: Report of field work, fall 2000–winter 2001. Report to Florida Panther Subteam of MERIT, United States Fish and Wildlife Service, South Florida Ecosystem Office, Vero Beach, FL, USA. [online] URL: http://www.panther.state.fl.us/news/pdf/rtm2001.pdf.
McBride, R.T. 2002. Current panther distribution and conservation implications: Highlights of field work, fall 2001–winter 2002. Report to Florida Panther Subteam of MERIT, United States Fish and Wildlife Service, South Florida Ecosystem Office, Vero Beach, FL. [online] URL: http://www.panther.state.fl.us/news/pdf/rtm2002.pdf.
McBride, R.T. 2003. Documented panther population and its current distribution. In: Shindle, D., Cunningham, M., Land, D., McBride, R., Lotz, M., Ferree, B. (Eds.), Florida Panther Genetic Restoration Annual Report 2002–2003. Florida Fish and Wildlife Conservation Commission, Tallahassee, FL, USA. [online] URL: http://www.panther.state.fl. us/news/pdf/FWC2002-2003PantherGeneticRestorationAnnualReport.pdf.
Noss, R.F. 1992. The wildlands project land conservation strategy. Wild Earth (special issue): pp. 10–25.
Root, K.V., 2004. Using models to guide recovery efforts for the Florida panther. In: Akçakaya, H.R., Burgman, M., Kindvall, O., Wood, C.C., Sjogren-Gulve, P., Hatfield, J., McCarthy, M. (Eds.), Species Conservation and Management: Case Studies. Oxford University Press, New York, NY, USA, pp. 491–504.
SAS Institute. 1999. SAS/STAT users's guide. SAS Institute, Cary, NC, USA.
Seal, U.S., Lacy, R., 1992. Genetic Management Strategies and Population Viability of the Florida Panther (*Felis concolor coryi*). Report of a Workshop to the US Fish and Wildlife Service. Captive Breeding Specialist Group, IUCN, Apple Valley, MN, USA.
Seaman, D.E., Griffith, B., Powell, R.A., 1998. KERNELHR: a program for estimating animal home ranges. Wildlife Society Bulletin 26, 95–100.
Seaman, D.E., Millspaugh, J.J., Kernohan, B.J., Brundige, G.C., Raedeke, K.J., Gitzen, R.A., 1999. Effects of sample size on kernel home range estimates. Journal of Wildlife Management 63 (2), 739–747.
Sullivan, J.D., Jr. 2004. Florida's endangered species, threatened species and species of special concern. Florida Fish and Wildlife Conservation Commission, Tallahassee, FL, USA.
US Fish and Wildlife Service (USFWS). 1995. Second revision Florida panther recovery plan, Atlanta, GA, USA.
US Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS). 1998. Endangered Species Act consultation handbook: procedures for conducting section 7 consultations and conferences, Washington, DC, USA.
Wiens, J.A., 1996. Wildlife in patchy environments metapopulations, mosaics, and management. In: McCullough, D.R. (Ed.), Metapopulations and Wildlife Conservation. Island Press, Washington, DC, USA, pp. 53–84.
Worton, B.J., 1989. Kernel methods for estimating the utilization distribution in home-range studies. Ecology 70, 164–168.