ABSTRACT – The need for regional planning is increasingly important for effective Florida panther (*Puma concolor coryi*) (Bangs 1898) conservation and is essential for protecting enough habitat in South Florida to ensure a viable population. We used two decades of radio telemetry data and geographic information system (GIS) software to develop a regional blueprint for landscape restoration that enhances dispersal, facilitates population colonization, and could be the basis for future land use decisions in the range of the endangered Florida panther. We identified 923,576 ha of forests in an 18-county study area that is a barrier-rich patchwork of land uses. A least cost path analysis simulated natural colonization events and can be used to identify landscape linkages and conservation networks for the panther. Our analysis of planned development permits suggests that large-scale land protection must happen quickly. The alternatives are managing an isolated, heavily managed population or large-scale landscape restoration that is probably economically unfeasible.

INTRODUCTION

Rapid human population growth (Winsberg 1996) and associated development in southwest Florida inhibits dispersal and population growth of the Florida panther by eliminating and fragmenting forest cover (Harris 1988, Maehr and Cox 1995, Mazzotti et al. 1993). According to the U.S. Forest Service (1988), Florida loses 61,000 ha of forest annually. Hendry County, a mostly rural area in the panther’s range, lost about 50% of its natural cover, primarily forest, between 1900 and 1973 (DeBellvue 1976). The entire region became effectively isolated from the rest of peninsular Florida following extensive draining including the dredging of the Caloosahatchee River and the clearing of Lake Okeechobee’s custard apple (*Annona glabra*) forest that served as a linkage to the east coast (Harris and Scheck 1991, Maehr 2000). As forests become more patchy and isolated, their value to the panther declines (Maehr and Cox 1995). Today, the Florida panther inhabits about 5% of its historic range (Maehr 1997a) (Fig. 1), numbers fewer than 100 (Maehr 1997a), and represents the only known population of *Puma concolor* east of the Mississippi River. Continued development threatens to further reduce this remnant distribution.
The sporadic documentation of panthers in peripheral areas of occupied range (Roof and Maehr 1988) has created a set of ambiguous circumstances that has made it difficult and often contentious for private property owners, local governments, and regulatory agencies to reach consensus on the trajectory and impact of local development. This situation is particularly evident in Lee County, Florida where development has eliminated most native habitat. A growing human population, a decline in natural areas, and the recognition by Lee County government officials that regional planning will be needed for effective panther conservation, were the impetus for this study.

Maintaining current panther numbers, let alone expanding them, is a daunting conservation task in the light of current land use patterns. Panther population growth, however, is needed to ensure a viable population, a necessary part of recovery (U.S. Fish and Wildlife Service 1987). To achieve this goal, landscape planning based on the distribution of potential panther habitat and landscape linkages that connect fragmented forest patches must occur. This approach has been suggested as an important component of planning for endangered species (Noss et al. 1997).

This paper builds on past landscape analyses by focusing on recent trends in development permitting and in forest distribution. In addition, it examines a vital component of population demographics, juvenile dispersal, and the potential for southwest Florida and Lee County to facilitate panther population growth through habitat colonization. Our intent is for this information and subsequent recommendations to be used by any and all parties who are interested in or affected by Florida panther habitat conservation.

**STUDY AREA**

The South Florida landscape is a patchwork of agricultural, urban, and natural areas that includes some of the largest tracts of public conservation land in the eastern United States (Maehr 1990). Almost 36% of this 5.3 million-ha region is in public ownership or part of Native American reservations. Most public lands are in extreme southern Florida (Fig. 1) where hydrology and soil fertility limitations preclude extensive human development and limit panther numbers (Maehr 1997a). The northern portions of the study area are predominantly in private ownership where citrus and cattle production are significant land uses and where higher-quality panther habitat occurs (Maehr 1997b). Although there are no recent records of Florida panther reproduction north of the Caloosahatchee River, at least four radio-collared males, an uncollared male, and one uncollared female have been documented in this area since 1972 (Layne and Wassmer 1988, Maehr et al. 1992,
Maehr et al. 2001, Roof and Maehr 1988). As many as four of these males dispersed across the river, formerly believed to be a barrier to panther movement, between 1998 and 2000.

METHODS

We used land cover data based on Landsat Thematic Mapper imagery for an 18-county region of South Florida (Fig. 1) and telemetry data, recorded as Universal Transverse Mercator (UTM) coordinates, collected from 1981-2000, to examine panther-habitat relations in south-
Figure 2. (a.) Forests and (b.) urban areas were buffered by 90m and (c.) major roads were buffered by 500m for the habitat model. Forest buffers expand the potential area available to panthers by including adjacent non-forest, non-urban habitat that might support some important behaviors such as traveling or foraging. Urban and road buffers expand the avoided area as a result of human activities and associated disturbances that limit use by *Puma concolor.*
west Florida. We excluded the area west of Interstate 75 in southwest Florida from our analyses because it is too developed to be occupied by panthers (Maehr and Cox 1995). We included counties to the north of known occupied range because they are increasingly used by dispersing panthers (Maehr et al. 2001) and these areas may be important for future reintroductions or natural expansion of the existing population. Details of panther capture and radio-tracking can be found in Maehr (1997a), Maehr et al. (1989), and McCown et al. (1990).

Telemetry locations (n = 51,861) collected during daytime fixed-wing aircraft flights (Florida Fish and Wildlife Conservation Commission and National Park Service) from 22 February 1981 through 30 June 2000 were used to characterize panther habitat use patterns and to examine dispersal behavior. We developed spatial models using ArcView® (ESRI, Redlands, CA) and associated spatial data management extensions. Land use/land cover classifications based on 1995-1996 data from the St. Johns River Water Management District, the Southwest Florida Water Management District, and the South Florida Water Management District were combined to form a single land cover layer.

Three variables determined important in previous analyses (Beier 1995, Maehr 1997a, Maehr and Cox 1995) characterize Puma concolor habitat and influence movements in areas near human development (Fig. 2). Forest cover (excluding mangroves) reflects the Florida panther’s tendency as a terrestrial forest obligate (Maehr 1997b); urban land areas are generally avoided (Beier 1995); and roads cause forest fragmentation (Noss and Cooperrider 1994). Each variable was buffered to incorporate other land uses that may negatively or positively influence panther use. This concept, which incorporates edge effects, is an increasingly important aspect of reserve design (Forman 1995). Forest buffers (90 m) expand the potential area available to panthers by including non-forest, non-urban habitat that might support important behaviors such as traveling or foraging (Maehr 1997a). Maehr and Cox (1995) found 96% of all panther telemetry locations were within 90 m of preferred land cover (hardwood hammock, mixed hardwood swamp, and cypress swamp). Conversely, urban and road buffers of 90 m and 500 m, respectively, expand the avoided area as a result of human activities and associated disturbances that limit use by Puma concolor (Beier 1995, 1996) and other large mammals (pers. comm., M. Orlando, University of Kentucky). Thus, forest buffers include vegetative cover that may be only tolerated, whereas urban and road buffers exclude areas that might otherwise be preferred habitat in a different landscape context.

We used a forest patch size of 500 ha as a minimum threshold for inclusion as potential habitat because forests greater than 500 ha
tended to be used more often by panthers than forests less than 500 ha (Maehr and Cox 1995). However, smaller forest patches within 2 km of a larger forest patch were included because they may facilitate dispersal movements.

We conducted a least cost path analysis using a computer-generated cost surface (ESRI, Redlands, CA) to calculate the least resistant (least costly) pathway that a dispersing panther could use to navigate between a predetermined source and destination. The cost surface is a 30m x 30m grid superimposed on the land use classification. Each cell within the grid was assigned a value (cost) based on its associated land use/land cover classification and its ability to support panther movement. Grid cells were rated 1, 2, or 3 with 1 = least resistant and 3 = most resistant. The “cost” of each cell was summed for all possible routes between a source and a destination. The least costly path became the most likely dispersal trajectory to facilitate movement through forested areas and avoid movement through urban areas as has been demonstrated by dispersing panthers (Maehr 1997b). A 133,000-ha forest considered to be the panther population core (Maehr 1997b) was the dispersal source and Fisheating Creek, Glades County was the dispersal destination. Fisheating Creek was chosen because the three male panthers mentioned above dispersed through this area after crossing the Caloosahatchee River and because this area has supported other panthers in the recent past (Layne and Wassmer 1988, Maehr et al. 1992, Roof and Maehr 1988). Fisheating Creek also represents the core of a large area of recently protected lands in Glades County that might serve as a primary node for panther recovery in south-central Florida.

As in the habitat model, forests were buffered by 90 m to incorporate adjacent land that may be important to panthers, panther prey, or panther travel. Non-urban cells within the 90m forest buffer were given a cost value of 1, meaning that land uses in this category were least resistant to panther movement. Cells outside the buffered forest that were classified as agricultural, rangeland, or herbaceous wetland were given a value of 2 because dispersing males may wander through unforested areas at night (Beier 1995, Maehr et al. 1992). Non-urban cells that were outside the buffered forest and classified with other uses were given a cost value of 3. These areas are rarely used by dispersing panthers and were assigned the highest cost.

Urban areas were expanded with 90 m buffers, as in the habitat model. Urban cells and urban buffers were classified as “No Data.” These cells prevent the least cost path from traveling through and reflect the observation that South Florida panthers avoid dispersal through urban areas (see Maehr 1997b: 140).

Least cost pathways were created using the ArcView cost distance grid tool extension and the dispersal habitat cost surface. The resulting
pathway was visually compared to actual panther dispersal pathways to evaluate this method for predicting future dispersal trajectories in South Florida and elsewhere.

As a regional planning device, habitat and dispersal models were used to identify panther habitat at a broad scale. Lee County was examined at a finer scale to verify the existence of identified habitat, or to gauge the need for restoration. We used Digital Ortho Quarter-Quad (DOQ) satellite images, proposed conservation lands, and development permits to detect land use changes that would not otherwise be apparent with older satellite imagery. DOQs from 1998 were acquired for Lee County from the Lee County Department of Transportation. Changes in land use were digitized as revealed by the DOQs to update the 1995/1996 land use/land cover data from the WMDs. Changes in future land use for Lee County were digitized using planned development permits (PDP) obtained from Lee County, Department of Community Development. These data were last updated in August 2000 as part of a comprehensive plan to project land uses through the year 2020. New residential, community facilities, planned unit, mixed use, and commercial PDPs were classified as urban. New permit boundaries were superimposed on current land uses. Areas of overlap between this new data layer and existing forest were subtracted from potential panther habitat.

Existing and proposed conservation lands also were digitized using the Lee County Conservation 2020 Program Nominations map. Combining future land uses with potential expansions of public conservation lands may provide the most accurate prediction for Lee County panther habitat for the next 20 years. Areas identified in the habitat and dispersal models were used to identify unprotected, potential panther habitat.

**RESULTS**

**Habitat Model**

The habitat model identified approximately 1.0 million ha as potential panther habitat in the study area (Fig. 3). We found 186 forest patches larger than 500 ha (including their associated 90 m forest buffers) that were at least 90 m from urban areas and at least 500 m from major highways. Eighty-one percent of all panther locations were within a forest larger than 500 ha. Large forest patches ranged from 501 to 141,430 ha and comprised 923,576 ha. Most forests were less than 5,000 ha and only 6% of forests were greater than 10,000 ha. The habitat model removed 241,093 ha of forest that were within highway buffers.

Development permits and satellite imagery revealed regions in Lee County (Fig. 3) where land use changes may degrade and sever panther habitat. According to the latest available database for planned developments in Lee County, over 4,300 ha of forest may be lost and over 3,500
ha of potential habitat identified by our habitat model will be converted to urban or industrial land uses by 2020. Five of the 6 forest patches in Lee County larger than 500 ha will lose area due to local conversion to urban and industrial uses. These calculations are based on permit data that are already one year old and may not accurately reflect the extent of present activities. Thus, these figures are conservative. Removal of forest and other compatible matrix habitats (e.g., prairie, low intensity agriculture, pasture) in areas that are potential habitat could reduce the use of forests in Lee County (and elsewhere) by panthers due to the encroachment of incompatible land uses.

Figure 3. The habitat model identified approximately 1 million ha of potential panther habitat. The inclusion of forests smaller than 500 ha was based on the contribution of these patches to landscape connectivity.
Dispersal Model

The least cost dispersal model created a trajectory that bypassed small areas of development (12 ha - 81 ha) and crossed 14 forest patches ranging from 2 to 20,218 ha before crossing the Caloosahatchee River east of Labelle in Glades County (Fig. 4). The modeled crossing point falls within a 4 km section of the river where three radio-collared male panthers crossed between 1998 and 2000 (Maehr et al. 2002). Further, the dispersal path bisects the Caloosahatchee Ecoscape Project, a proposed conservation area that is currently on the state Conservation and Recreation Lands (CARL) acquisition list. Although the river in this span is about 100 m wide, the banks are gently sloping and are heavily vegetated in some areas.

Figure 4. The dispersal model based on least cost path analysis between the panther core to Fisheating Creek passes through the Okaloacoochee Slough State Forest and the proposed conservation area, Caloosahatchee Ecoscape Project. This path closely parallels actual dispersing panther movement and crosses the Caloosahatchee River within a 4 km zone that was used by the 3 collared panthers from 1998-2000.
In addition, there is little human settlement and concomitant lighting that might create an aversion to crossing (Beier 1995).

**DISCUSSION**

A landscape with few, widely separated large forests provides a marginal context for Florida panther movements. The arrangement and connectivity of forest patches are important in maintaining panther social structure and reproduction (Maehr et al. 1991). Most large forests in the study area are separated by more than 500 m from other forest patches. Such distances between habitat patches create fragmentation that may hinder panther use. Some patches already may be too isolated to function as panther habitat. Although isolated forests may be beyond the potential for future panther occupancy, others could be considered as targets for landscape reconnection and restoration as panther habitat. Additionally, smaller forests may be important in facilitating movement between large forest patches. While large blocks of forest should be the first priority for panther habitat conservation, smaller forests may facilitate panther movement through the landscape and they may become stepping stones in landscape restoration.

Regardless of their proximity to roads, forested lands are important buffers to noise and other edge effects (U.S. Department of Transportation 1980), and they may facilitate movement across roads if suitable habitat exists on both sides e.g., the Fakahatchee Strand in Collier County (Foster 1992). A Lee County forest, bisected by a 2-lane highway (Alico Road) provides an example of this situation. Forests on the south side of this road may be connected to forests to the northeast through two forested corridors that provide cover up to the road shoulder (Fig. 5). Potential crossing zones can be enhanced with highway underpasses, a technique that appears to reduce local panther mortality (Foster 1992, Shindle et al. 2000). Preservation of landscape features such as forested corridors can facilitate panther movement through the landscape (Maehr 1990), and may help maintain populations in areas that are otherwise fragmented.

Our dispersal model and its close match to the behavior of 3 dispersing panthers identify what appears to be an important crossing zone across an artificial waterway. This relatively narrow pathway and adjoining habitat on both sides of the river form a critical landscape linkage that could become a strategic part of panther population expansion and recovery. Dispersing male panthers appear to be tolerant of sparse forest cover and can be found far from the population core (Maehr 1997b). Their travels can cover long distances, appear to avoid urban areas, utilize forest cover whenever possible, and
are often circular in shape. Unlike resident adults, dispersing panthers are less likely to view highways, rivers, and open habitat as movement barriers.

A consideration in the use of our dispersal model as a behavioral simulation is that we determined the dispersal destination for animals that are unfamiliar with the landscape outside of their natal ranges. Nonetheless, in the sense that long-distance dispersal is likely a product of population density and conflict with older, more assertive residents (Christian 1970, Maehr et al. 2002), this aspect of the model may be very realistic. For example, dispersal distances and the likelihood of crossing the Caloosahatchee River have increased with increasing population size (Maehr et al. 2002). Our model simulated a pathway constrained only by endpoints by using landscape and behavioral rules that have emerged out of 2 decades of research. Although it may not exactly duplicate dispersal behavior (i.e., it eliminates tangential, exploratory forays), it is the most practical method that we are aware of for identify-

Figure 5. Forested corridors, such as this one in Lee County (see arrow), connect larger tracts of forest and may facilitate panther movement through a fragmented landscape. Locations such as these are prime candidates for wildlife underpasses, which help reduce panther mortality.
ing realistic landscape linkages that exclude “dead ends.” Thus, we believe that combining the habitat cost surface with the least cost path surface is effective in identifying strategic movement corridors and restoration zones for linking potential panther habitat.

**Regional Planning**

On a regional scale, our models identify important habitat for panther occupation and movement that could serve as conduits for expansion of the current population – an event that must occur to achieve recovery of the subspecies. By itself, panther habitat south of the Caloosahatchee River is likely insufficient to support a viable panther population that can survive much beyond 100 years (Maehr et al. 2001). However, when viewed in the context of statewide natural areas, the forests that we identified exhibit > 80% overlap with the Florida Ecological Network - a blueprint for land conservation and connectivity throughout Florida (Hoctor et al. 2000). Lee County panther habitat is the westernmost segment of a system of public preserves and private land that supports the bulk of forest remaining in south Florida. The ability of this peripheral habitat to support the panther will depend on the maintenance of landscape connectivity.

Because the Florida panther is a wide-ranging creature of the landscape, it serves as a conservation flagship that can benefit other species and ecological services (Maehr et al. 2001). If protected, the 500 ha forests identified by the habitat model as potential panther habitat and the linkages suggested by the dispersal model will become important core areas and buffers of other natural systems that are important to the regional human population and quality of life (e.g., ground water, recreation, clean air, green space, etc). Other sensitive species that will be protected through such efforts include the crested caracara (*Caracara plancus*), eastern indigo snake (*Drymarchon corais couperi*), Florida black bear (*Ursus americanus floridanus*), and swallow-tailed kite (*Elanoides forficatus*).

**The Role of Lee County**

Fragmentation of forests due to highway construction and urban expansion has reduced the amount of panther habitat in Lee County by 8% in the last 5 years. Today, panther habitat in the county covers no more than 16% of its pre-1900 extent. These areas are connected to occupied range to the east and south and deserve management that enhances their value to the panther. This could include the construction of wildlife underpasses and the enhancement of prey populations (Schortemeyer et al. 1991).

Lee County does not appear to be suitable as a conduit for panther dispersal. Panthers that have exhibited dispersal movements in the county follow circular trajectories resulting in departures that retrace their arrivals (Maehr 1997b). Under current and projected develop-
ment scenarios, the most likely successful dispersal pathway from the south Florida population core to potential habitat in south-central Florida is the Caloosahatchee River crossing identified in our dispersal model.

The southeastern portion of Lee County should be the top priority for conserving panther habitat in its western peripheral range. This area provides habitat that is adjacent to conservation lands inhabited by panthers such as Corkscrew Swamp Sanctuary, the Corkscrew Regional Ecosystem Watershed, and proposed conservation lands within Camp Keais Strand. Although much of the county is no longer panther habitat, the role of current and future Lee County forests is still an asset to the subspecies’ recovery.

CONCLUSION

South Florida forests are isolated from the rest of peninsular Florida as a result of more than a century of landscape change. Locally, the opportunities for maintaining or restoring connections with occupied panther habitat occur in southeastern Lee County where forest patches are contiguous with those in Collier and Hendry counties. These areas are connected to the panther habitat core in Collier County through forested corridors. Lee County does not appear to have the appropriate arrangement of habitat to facilitate successful dispersal through the county to areas north of the Caloosahatchee River.

A variety of approaches have been suggested for protecting wilderness lands and wilderness processes in and near urban areas. New, creative approaches are needed in order to incorporate the Florida panther into a future southwest Florida that maintains its natural variety and abundance of plants and animals—the very elements that attracted humans to this part of the world in the first place. A variety of land conservation tools such as those suggested by Adams and Dove (1989), Noss et al. (1997), and Rusmore et al. (1982) should be considered as options in maintaining the peripheral panther habitat that remains in Lee County and elsewhere. Some of these options include:

- Donations of property (and subsequent tax benefits when offered to a 501(c)(3) organization)
- Trade agreements (such as that offered by The Nature Conservancy where less desirable environmental lands are purchased and traded for more desirable lands)
- Conservation easements (i.e., the purchase of abstract “rights” such as access, development, etc.)
- Performance zoning (used by planners to direct development using performance standards – could be used to establish buffers to panther habitat)
Real-estate transfer tax (monies would be used to protect environmentally sensitive lands and potential panther habitat)
Transference of development rights
Voluntary establishment of private-owned and publicly recognized sanctuaries
Safe harbor agreements
Habitat Conservation Plans

Regardless of the conservation options chosen, actions must occur quickly or expanding human activities and infrastructure development will relegate the panther to a dysfunctional, isolated remnant of a once widespread subspecies.

ACKNOWLEDGEMENTS

We thank Darrell Land and his colleagues at the Florida Fish and Wildlife Conservation Commission for access to data and helpful discussion regarding panther ecology and conservation. We also thank Tom S. Hoctor for GIS technical assistance and helpful discussion. This is Kentucky Agriculture Experiment Station journal paper number 02-09-81 and is published with approval of the director.

LITERATURE CITED


