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A Multi-Faceted Approach to Corridor Planning for the Florida Black Bear and Florida Panther

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ABSTRACT: When planning conservation strategies for large apex predators that require sizeable intact home ranges, such as the Florida black bear *(Ursus americanus floridanus)* and Florida panther *(Puma concolor coryi)*, it is useful to identify the quantity and quality of suitable habitat and to understand dispersal barriers. This analysis applies algorithms from computer science, information theory, and electrical theory to geographic data to gain new insights into species conservation potential in Florida as part of an effort to update the Florida Ecological Greenways Network (Hoctor et al. 2000; Hoctor et al. 2013). Taking advantage of species' detection data and landscape metrics, a maximum entropy algorithm was employed to assess species' habitat suitability. The resulting suitability surface, including core areas, was then used to estimate habitat connectivity for bear and panther dispersal using three corridor identification methods: least cost path, network shortest path, and current flow. This combination of analyses reveals potentially robust migration corridors for both species.

Keywords: Habitat modeling, corridor modeling, regional conservation planning, landscape ecology, Florida panther, Florida black bear, ecological networks

INTRODUCTION

The success of large apex predators depends largely upon adequate long-term conservation planning, and management and research at the regional scale (Hellgren and Maehr 1992; Noss et al. 1996; Hoctor 2003; Kautz et al. 2006; Hoctor et al. 2008). Habitat fragmentation and impediments or barriers to dispersal are fundamental limitations to population viability (Noss and Harris 1986; Harris and Scheck 1991; Beier 1996; Maehr et al. 2002). These predators require large, intact home ranges to support viable populations, sufficient connectivity, and to ensure genetic variability (Carroll et al. 2001; Carroll 2006; Dixon et al. 2006). Loss of suitable habitat and increasing fragmentation of natural habitat contribute to the predators' decline and are generally a result of land-use planning methods that do not protect large, contiguous blocks of functional habitat (Zwick and Carr 2006; Florida Fish and Wildlife Conservation Commission 2008). Additionally, these species are often umbrella and/or keystone species, playing a critical role in the overall health of an ecological community (Maehr 1997a; Soulé and Terborgh 1997).

The practice of systematically identifying and prioritizing conservation areas promotes holistic land-use planning and effective decision-making (Noss and Cooperrider 1994; Noss et al. 1996; Margules and Pressey 2000; Groves et al. 2002; Groves 2003). Here we present analysis to assess the habitat suitability and dispersal opportunity for the Florida black bear *(Ursus americanus floridanus)* and the Florida panther *(Puma concolor coryi)* throughout the state of Florida. Both species require large, intact areas to support viable populations (Maehr 1997b; Maehr et al. 2001; Kautz et al. 2006).

The Florida black bear estimated population is over 3,000, after an estimated low of 500 in the 1960s (Florida Fish and Wildlife Conservation Commission 2012). Black bears were classified as a state threatened species until 2012; growing populations resulted in delisting despite ongoing threats from habitat loss and fragmentation. Regardless of recent population growth, genetic drift has occurred across all seven extant subpopulations to the degree that hair samples can be genetically distinguished from the source subpopulation, and all subpopulations have compromised genetic integrity (Dixon et al. 2006). The current statewide Florida black bear management requires additional habitat and corridor protection to ensure protection of all seven subpopulations in the state and restore functional gene flow (Florida Fish and Wildlife Conservation Commission 2012).

The Florida panther population is not yet large enough to ensure population viability and genetic diversity long-term (Maehr et al. 2002; Kautz et al. 2006). Currently, fewer than 200 panthers exist in Florida, and the breeding population is relegated the extreme southwest region of the state. This area is increasingly threatened by suburban sprawl spreading east from the coastal cities of Naples and Ft. Myers (Florida Fish and Wildlife Conservation Commission 2014). Panthers now occupy less than 5% of their original home range (McBride 2003), and the long-term viability of the remaining population is endangered due to ongoing habitat loss and fragmentation.

To better understand the habitat needs as well as potential connectivity and barriers to movement, this analysis employed the use of several habitat and connectivity models in a multi-faceted approach for aiding identification of habitat and corridor protection priorities. Habitat suitability analyses identify areas that the two focal species are likely to occupy based on presence records (dependent variable) and relevant landscape metrics (independent variables). We then performed connectivity analyses to assess the potential for the species to move through the current regional landscapes, from one core area to the next.

Methods

Participation by local Florida black bear and Florida panther experts with extensive field experience was instrumental in determining the analysis methods employed. These experts provided the location data and made recommendations regarding its use, recommended parameters used in the habitat suitability modeling process, and suggested core habitat areas as sources and destinations (nodes) in the connectivity modeling.

Habitat Suitability Using Maximum Entropy Modeling (MaxEnt)

To predict the possible extent of a species' distribution (or potential habitat utilization), we used MaxEnt, which minimizes the relative entropy between probability densities (Elith et al. 2010; Phillips et al. 2004; Phillips et al. 2006). MaxEnt only requires species' occurrence data in conjunction with environmental variables. The resulting output is expressed as the log likelihood of the data associated with presence data minus a penalty term. Each environmental layer is weighted by how much complexity it adds to the model. The sum of these weightings determines how much the likelihood should be penalized for over-fitting. This output is used as a definition of habitat suitability, which in turn was used as a cost/suitability surface for connectivity modeling.

Presence Data

Presence data was from either GPS or radio telemetry of tagged individuals. At a minimum, each record provided indicates species, latitude, longitude, date, time, and sex. Black bear data was obtained through the Florida Fish and Wildlife Commission and the University of Kentucky's Department of Forestry South-Central Florida Black Bear Project. The data spans from 1983 – 2010 and contained 422 individuals. Panther presence locations used in the model were obtained from data supplied by the Florida Fish and Wildlife Conservation Commission. Supplied data spans from 1981 – 2012 and included 123 individuals.

To ensure uniformity and reduce bias, presence data was filtered using several criteria. Because landscape variables represent recent conditions, our models used the most recent ten years of data. Records of male and female individuals were used. To be included, individuals needed at least 50 presence records. This number was chosen to include the greatest number of individuals while still maintaining a representative sample of an individual's movements. A random subset of 50 records was selected per individual to eliminate bias of an individual with more than 50 data points.

Environmental Variables

Environmental variables were used in conjunction with presence data to derive habitat suitability. Both black bear and panther models used the "Landscape Context" layers from the Critical Lands and Waters Identification Project (CLIP) 2.0 report (Oetting et al. 2012). A compilation of ecological integrity-focused landscape metrics is described below:

1. Landscape integrity

This layer is comprised of two related landscape indices assessing ecological integrity based on land use intensity and patch size of natural communities and semi-natural land uses. This new layer was developed as part of the CLIP process after discussion with technical advisors about the need for a layer that would identify areas of high ecological integrity, where areas dominated by large patches of natural and semi-natural land use are assigned the highest significance. The base land cover/land use data set used for this and all other land cover dependent variables was the Florida Natural Areas Inventory (FNAI) 2010 Cooperative Land Cover Data version 2.0.

2. Intactness/fragmentation

This is a multi-scale model of landscape intactness (in this sense, the inverse of fragmentation) where all natural and semi-natural land uses are treated as "intact," and all other land uses are treated as "not intact."

3. Distance from intensive land uses

Intensive development was defined as all higher density residential, commercial, and industrial land uses (including active mining operations) in patches 100 acres or larger.

4. Roads Context

Three road-based models (all roadless, major roadless, and road density) were combined into a Roads Context layer using equal weighting.

- All Roadless Patch Size

  This metric assesses area bounded by all roads within the U.S. Geological Survey 1:24,000 digital line graph roads.

- Major Roads Roadless Patch Size

  This used only roads within the Florida Department of Transportations Major Roads data layers including: major highways and arterial roads including interstates, toll roads, U.S. Highways, state roads, and most county roads. This layer does not include residential or other smaller paved roads, improved dirt or gravel roads, or jeep trails.

- Road Density

  We calculated road density using the U.S. Geological Survey 1:24,000 digital line graph roads. This index represents straight road density in miles/mile^2 using a 1-mile search radius.

In addition to the landscape context layers used for both species, several layers were created specifically for use in the black bear model. These layers were provided by the University of Florida; detailed methodology can be found in

Regional Landscape Analysis and Reserve Design (Hoctor 2003). Bear specific independent variables used were:

1. Primary and Secondary Black Bear Habitat

This variable identifies primary habitat as blocks 15.2 ha and larger and secondary habitat as all smaller blocks of preferred cover types as well as less preferred cover types within 1 km of primary blocks. Habitats are reclassified as either 1 (primary and secondary habitat) or 0 (non-habitat).

2. Forest Density

This is a landscape scale variable where the amount of forest was calculated in a 35 x 35 neighborhood using 90 m cells. The values used in the model were the number of cells within the neighborhood that contained forest cover.

3. Land Use Intensity

This is a landscape scale variable using a neighborhood analysis in an 11 x 11 window with 90 m cells. Land uses were lumped into 4 categories: natural, given a value of 0; low intensity and semi-natural, given a value of 1; moderate intensity including most agriculture and some mining, given a value of 2, and high intensity including residential, commercial, and industrial, given a value of 3. These values were then summed for each focal cell of the neighborhood so that the larger the returned value, the more intensive the land use in the surrounding area.

4. Bear Habitat Density

This variable was created by giving primary and secondary habitat the same value: 1, and all other cells a 0, and then a neighborhood analysis was conducted at the scale of an 11 x 11 90 m cell area.

Additionally, panther specific variables were created. Many were based on a United States Fish and Wildlife Service (USFWS) habitat suitability model that used a random forest model (Frakes et al. 2015). Panther specific variables used were:

5. *Florida Natural Areas Inventory (FNAI) Cooperative Land Cover (CLC)*

Generalized land cover data (FNAI Cooperative Land Cover Map 2010).

6. Forest Edge

This layer is used as a surrogate for prey abundance/availability. It was created using a line density function at the intersection of forested and any other natural landcover, and between upland forest and wetland forest.

7. Human Population Density

Rasterized 2010 U.S. Census Block data in Florida, at 300m resolution.

8. Road Density

Calculation of road density based on a 3 x 3 cell focal neighborhood analysis of major roadways.

Model Performance Metrics

The following performance metrics of model performance were examined. Gain, a measure of the likelihood of deviance, maximizes the probability of presences in relation to the background data. The Area Under Curve (AUC) value of 0.50 suggests that the model's prediction is no better than a random guess. The closer the AUC is to 1.0, the better the model predicts species occurrence. We retained 30% of the data for testing purposes (Witten et al. 2011).

Scenarios Modeled

Three different independent variable scenarios were modeled for each species in conjunction with the point dataset. The environmental layer scenarios included: 1) landscape context, 2) species specific variables, and 3) species specific variables and landscape context combined.

The resulting models were evaluated based on performance metrics, visual congruity, and consensus among the technical advisory group. Additionally, the MaxEnt model output used in the connectivity analyses ignores developed lands. Doing this excludes such areas from subsequent connectivity analyses.

Addressing Distinct Florida Black Bear Subpopulations

The Highlands-Glades population habitat model was developed separately from the other state subpopulations because the landscape this population inhabits is a much more variable mosaic of forest, ranch, citrus, pasture, and low density residential. This model was trained using

Highlands-Glades data only. The MaxEnt habitat suitability model results for this subpopulation were then integrated with the statewide habitat suitability model by applying the MaxEnt model results in the estimated range of the Highlands-Glades subpopulation while using the results from the statewide model for the rest of the state.

Hubs Selection/Delineation

Core areas of habitat were created using a combination of modeled output, existing population ranges, and suitable core protected habitat areas. A modeled output of greater than 50% probability or presence threshold with a minimum patch size of 2,000 acres for bears and 5,000 acres for panthers was used to delineate “core hub” areas. Additional areas were added to these estimated core areas based on input from the bear and panther experts.

Connectivity Modeling

Corridors were mapped in three ways: least cost path, shortest path, and current flow methods. Least cost paths were modeled between specified hubs using the cost distance and cost path tools in ArcGIS. This analysis identifies a single path between the selected hubs using an inverse of the MaxEnt habitat suitability model as a cost surface. From the source, this algorithm assesses all eight neighboring cells in the raster and chooses the least costly option. This process is iterated upon until the two sources are connected. The final path is the smallest sum of raster cell values between the two hubs.

The shortest path analysis was performed using the Connectivity Analysis Toolkit (Carroll 2013). This methodology identifies a minimum network of linkages between nodes. The Connectivity Analysis Toolkit employs network theory to assess connectivity throughout the landscape. This is a stand-alone tool, which processes an ASCII file created from habitat suitability raster data. A hexagonal network shapefile is created from the habitat suitability model at a user-specified resolution. Points and lines on the graph represent nodes and pathways, where nodes facilitate movement across a graph. Weights are assigned to each path based on the habitat suitability model. The resulting output shows the network of linkages in raster format.

Current flow analysis considers conductance and resistance though a diffuse landscape and produces a more distributed output. The Connectivity Analysis Toolkit also models current flow, but the model Circuitscape was ultimately chosen due to its added features and faster performance (McRae et al. 2008). Circuitscape analyzes connectivity as if the landscape were an open circuit. Therefore, a habitat suitability model can be used to specify either conductance or resistance throughout the landscape. Each hub area is used as a current source node to assess pairwise connectivity between hubs. The model supplies a current source and results are shown as potential flow across the landscape.

RESULTS

Habitat Suitability

To assess model performance, the Area Under Curve (AUC) and Gain are observed to determine how well specific scenarios predict the presence of species by using test points. AUC expresses how closely the test data performs to the training data, while Gain is a representation of how much more likely a prediction will be compared to a random offering. Table 1 shows the AUC and Gain for each scenario modeled.

Table 1: Florida black bear and Florida panther MaxEnt model performance

Florida Black Bear Model Performance

Scenario	AUC	Gain
Recent Data Points: 2000 - 2010		
Landscape Context	0.842	0.942
Bear Specific Layers	0.879	0.923
Bear Specific Layers plus Landscape Context	0.874	0.914

Florida Panther Model Performance

Scenario	AUC	Gain
Recent Data Points: 2002 - 2012		
Landscape Context	0.895	1.251
Panther Specific Layers	0.862	0.907
Panther Specific Layers plus Landscape Context	0.853	0.860

For example, regularized training Gain for the “Landscape Context” scenario is 0.998. Gain indicates how well the model is concentrated around the presence samples. Thus, exponential function (0.998) ~= 2.71, which indicates the average likelihood of presence is approximately 2.71 times higher than that of a random background sample.

MaxEnt's geographic output (Figures 1 and 2) show a species' predicted habitat utilization, expressed as percentages in a continuous raster surface. A higher percentage represents habitat that is more likely to be occupied. Our

MaxEnt probability values for black bear range from approximately 85% to near zero. Areas of high likelihood generally align with existing suitable habitat. The highest contributing variables to this model were habitat density and landscape integrity.

Figure 1: Florida black bear MaxEnt output

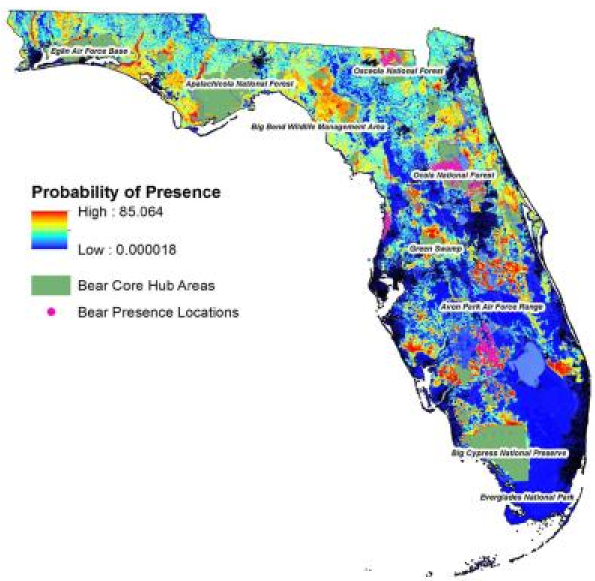
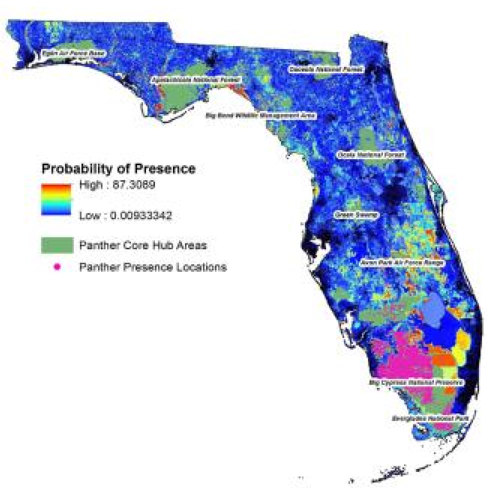


Figure 2: Florida panther MaxEnt output



For the Florida panther, MaxEnt probability values range from approximately 87% to virtually zero. The three highest contributing variables were landscape integrity, human population density, and land cover.

Based upon considerations of model performance, visual congruity, and guidance from our technical advisory committee, the "Species Specific Variables plus Landscape Context" model results for both species were used as the basis for future connectivity analyses. These final habitat suitability models encompass areas experts deemed to be consistent with current black bear and panther dispersal ranges while exhibiting adequate performance metrics.

Final Hubs Delineation

Habitat patch delineation was based upon a 50% probability threshold or greater, and a minimum patch size of 2,000 acres for bears and 5,000 acres for panthers. Additional areas were added with the help of our Florida black bear and Florida panther experts. The map (Figures 3 and 4) shows an aggregate of the habitat patches that meet the quality and size thresholds and added areas.

Core habitat areas identified by MaxEnt tend to occupy portions on or adjacent to existing designated natural areas. These areas include: Big Cypress National Preserve, Avon Park Air Force Range, Kissimmee Prairie State Preserve, Green Swamp Conservation Area, Chassahowitzka National Wildlife Refuge, Ocala National Forest, Osceola National Forest/Okefenokee National Wildlife Refuge, Apalachicola National Forest, and Eglin Air Force Base. These identified hubs were later amended to include additional areas based on expert opinion. These hubs serve as nodes, a critical component for the connectivity analyses.

Connectivity

Current flow, least cost path, and shortest path methodologies identified similar pathways and critical linkages. Results for current flow, least cost path, and shortest path connectivity analyses are shown below in Figures 3 through 6.

Figure 3: Florida black bear least cost path and current flow connectivity results

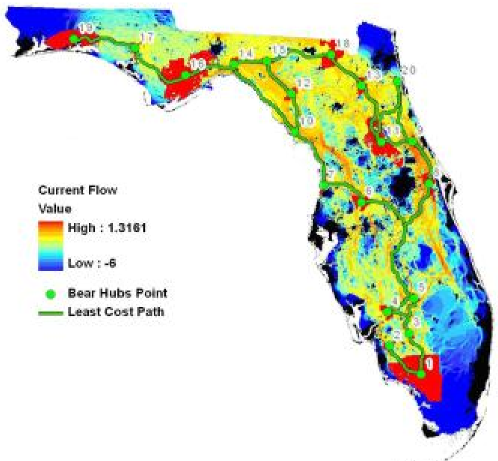


Figure 4: Florida panther least cost path and current flow connectivity results

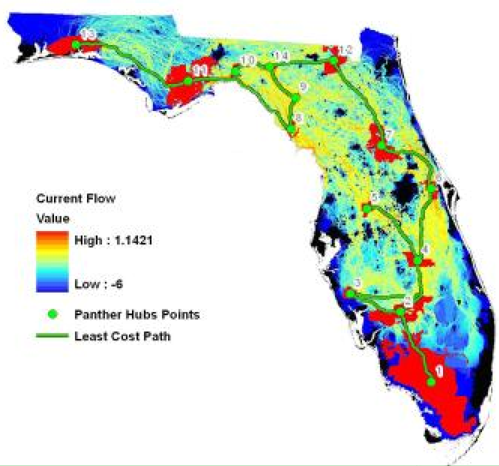


Figure 5: Florida black bear shortest path connectivity results

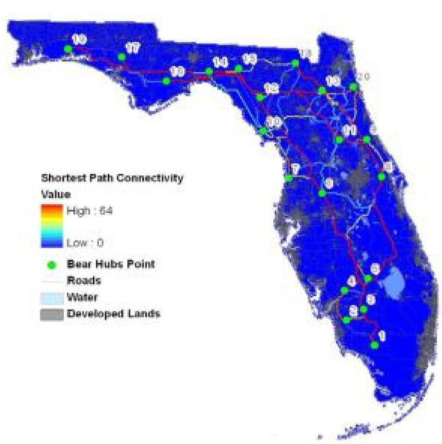
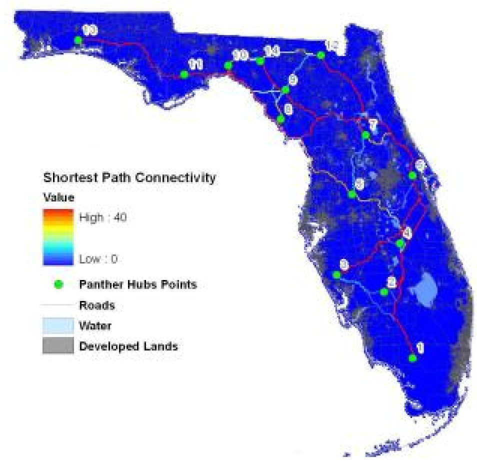


Figure 6: Florida panther shortest path connectivity results



Modeled linkages from south to north include corridors from Big Cypress National Preserve to Avon Park Air Force Range to the Kissimmee Prairie area. From this point, a possible route could either move west through Green Swamp or flank the Orlando area to the east and connect with the Ocala National Forest, though collectively the connectivity model results indicate that the corridor crossing the Kissimmee River watershed north along the ranchlands (including forested upland and wetlands) in eastern Osceola County to Volusia County to reach the Ocala National Forest. North from the Ocala National Forest, corridors head to Osceola National Forest through Camp Blanding Military Site, or veer east and follow the Big Bend area. Connectivity models suggest a wide swath of opportunity exists to protect a functional corridor between Apalachicola National Forest and Eglin Air Force Base.

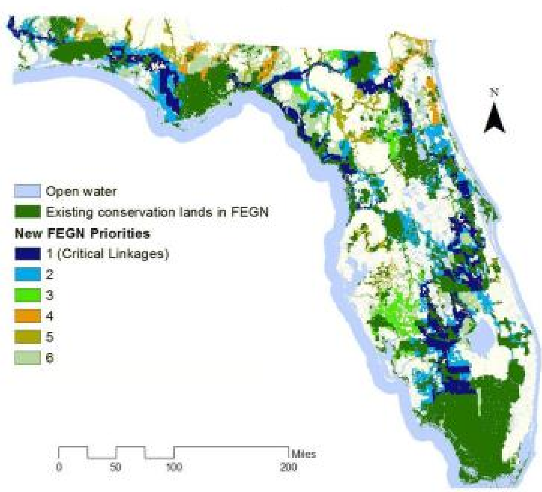
DISCUSSION

In general, Florida's remaining rural landscapes are separated into two primary regions: south and north Florida. Other than the Everglades and the Big Cypress areas of south Florida, much of the remaining rural landscape south of Orlando is a mosaic dominated by open grasslands of either pasture or remnant dry prairie interspersed with upland pine forest, hammocks, scrub, herbaceous wetlands, and forested wetlands. North of Orlando, rural areas are primarily dominated by natural and silvicultural forest cover interspersed with some open agricultural lands, large to small forested wetlands, and herbaceous wetlands.

Several corridors look relatively secure, given they are already protected conservation areas. However, our connectivity analyses also indicate several corridors at risk due to fragmentation from development. Linkages along the I-4 corridor from Tampa to Orlando and from Orlando to Daytona Beach appear to be at the greatest risk, and proposed large-scale development projects in Osceola, Orange, Volusia, and Brevard counties could fragment these corridors in the near future, which could result in isolated populations of bear and panthers separated by nearly continuous development. These analyses identify a critical issue to conserving south to north connectivity that needs to be addressed by strategic land conservation and smart growth policies in the central Florida region.

While the results do identify critical linkages, they do not systematically identify the effects of future projected changes such as development and sea level rise. However, we are continuing to work on such analyses and modifications to the Florida Ecological Greenways Network priorities (Figure 7) to address these issues for these two focal species as well as other fragmentation-sensitive species across the state. Additionally, we did not include the Alabama subpopulation of Florida black bear in the modeling, which would have influenced results in the extreme western Florida panhandle. This should be addressed in future work to identify more specific habitat and corridor priorities for each of the Florida black bear subpopulations in Florida and Alabama.

Figure 7: Florida Ecological Greenways Network new priorities



Based upon the MaxEnt results, certain areas such as Ocala National Forest, Okeefenokee National Wildlife Refuge, and much of the Florida panhandle, are not as suitable for panthers compared to the results for bears. Additionally, current flow for black bear connectivity was much more defined. While the panther results pinpoint many existing core habitat areas also identified in the black bear results, suitable values favor areas of south Florida prominently, which may be reflected by the availability of panther presence values. One concern about the panther MaxEnt results is that they may be biased by occurrence data, which are from the south Florida landscape, and that the potential suitability of the forested landscapes of north Florida may be under or poorly represented in the results. In fact, it is possible that the Florida black bear MaxEnt model results are a better representation of potential panther and other large carnivores habitat suitability in north Florida based on a comparison of the respective MaxEnt model results for the two species and the relatively similar habitat and landscape use of both species. Conversely, the model may be more telling as to the panther population to inhabit broader ranges. Inclusion of Landscape Context data into panther MaxEnt modeling shows a higher probability of presence beyond South Florida, whether combined with the “panther specific” variables or not.

Although each connectivity analysis has unique advantages and was completed using different tools, they generally identify similar pathways that should be of high conservation priority. Least cost path identifies a singular, least costly route to travel. While shortest path does a similar operation, it may consider alternate routes and be able to consider different combinations of routes due to its algorithm. Current flow shows a continuous surface of varying values which can be useful in identifying corridor widths, corridor quality, and narrow linkages in ways a singular path is not capable. Using current flow, if a wide swath of suitable land exists for a wildlife corridor, values will be less than those of a more restricted corridor. These higher values, identifying restricted flows, can help better identify stressed or narrow areas that may be the most important conservation priorities to ensure functional connectivity. Least cost path (singular line) may be more useful for planning wildlife over/under passes while current flow (an area/heat map) may better aid conservation area planning.

Results of this study on the Florida black bear and Florida panther address the need to identify suitable habitat for supporting potentially viable populations as well as opportunities to protect or restore functional connectivity between existing or restored populations. Although further work is needed to assess corridor options for these two wide-ranging focal species, linkages identified in this study can serve as a basic blueprint for guiding conservation efforts to restore connectivity between all Florida black bear subpopulations and to establish potential future breeding populations north of the current breeding range in southwest Florida.

Comparing different connectivity algorithms, including least cost path, network and current flow (using electrical conductance theory) we provide managers a more robust assessment of species distribution and potential connectivity areas or corridors. These results were used as part of a process to update the Florida Ecological Greenways Network, which is an official state plan that identifies opportunities to protect large, intact landscapes important for conserving Florida's biodiversity and ecosystem services. Although this research assessed corridor planning for the Florida panther and black bear, this analysis can be done in any area and for any species where presence data and adequate geospatial information is available.

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