ECOLOGICAL NICHE FACTOR ANALYSIS TO DETERMINE HABITAT SUITABILITY OF A RECOLONIZING CARNIVORE

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Abstract

Identifying available suitable habitat is important for the conservation of large carnivores. Habitat suitability across the Eastern Physiographic Province of Kentucky was investigated for a recolonizing black bear (*Ursus americanus*) population. Due to the expanding nature of this population, presence only techniques were selected over standard presence / absence or use / available methodologies. Ecological Niche Factor Analysis identified 8,522 km^2 of available suitable habitat. This represents enough habitat for Kentucky to support a viable, self sustaining black bear population. Suitable habitat was found to contain high forest frequency, large patches of forest, and occurred away from major roads on moderate slope. Ten-fold cross validation indicated good predictive ability of the habitat model ($p < 0.025$). Ecological Niche Factor Analysis is recommended in circumstances where absence data are unreliable or unavailable.

Keywords. Black bear, habitat suitability index, presence data, umbrella species

Introduction

Understanding and predicting wildlife-habitat relationships is a foundation of wildlife management (Hirzel et al., 2006; Pearce and Boyce 2006). Because of urbanization, and the resulting loss of wildlife habitat, is likely to increase in the future (Crooks 2002; Theobald 2005), identifying and protecting suitable ecological areas and landscape corridors is important to ensure the viability of wildlife populations (Kindall and Van Manen, 2007). Modeling

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In Proceedings of the 6th Southern Forestry and Natural Resources GIS Conference (2008), P. Bettinger, K. Merry, S. Fei, J. Drake, N. Nibbelink, and J. Hepinstall, eds. Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA.

procedures and GIS are commonly used in predicting species occurrence (i.e., habitat suitability analysis) for the management of endangered species (Palma et al., 1999), developing reserve designs (Cabeza et al., 2004), performing population viability analysis (Akcakaya and Atwood, 1997), identifying potential habitat and conducting population projections (Mladenoff and Sickley, 1998), and mapping human-wildlife conflicts (Le Lay et al., 2001).

Monitoring and managing large carnivores is challenging due to their large spatial requirements, low population densities, cryptic nature, and potential conflicts with humans (Schadt et al., 2002). Nonetheless, large carnivores are excellent candidates for habitat suitability (HS) modeling (Kindall and Van Manen, 2007). Large home ranges, extensive movements, and broad habitat requirements have allowed the use of coarse GIS data to develop reliable landscape habitat models for a variety of large carnivores (Mladenoff et al., 1995; Apps et al., 2004; Hoving et al., 2004; Kautz et al., 2006; Alexander et al., 2006; Kindall and Van Manen, 2007).

The Kentucky black bear (*Ursus americanus*) presents a particularly difficult challenge for HS analysis. Extirpated from the Commonwealth by the late 1800s as a result of over-hunting and habitat loss (Unger, 2007), it is currently recolonizing from surrounding states such as West Virginia, Tennessee, and possibly Virginia. However, its current distribution is only partially known. Most habitat suitability or species occurrence models have relied on the use of "presence / absence" or "use versus availability" data in which known locations of study animals are statistically compared to points representing unsuitable or unused habitat (Guisan and Zimmerman, 2000; Hirzel et al., 2002). Modeling methods relying on this technique often utilize Generalized Linear Models (GLMs) or Generalized Additive Models (GAMs) (Mladenoff et al., 1995; Apps et al., 2004; Alexander et al., 2006). When absence data are unavailable, these techniques require that "pseudo-absences" are generated for comparison. The method with which these pseudo-absences are created can influence the quality of the models generated (Engler et al., 2004). For many studies, accurate absence data are not available or difficult to obtain. In addition, with the case of a recolonizing species, it is assumed that more suitable habitat is available but not occupied. GLMs and GAMs commonly used for habitat prediction generally do not perform well in the case of invading or, as in Kentucky, recolonizing species (Hirzel et al., 2001). Brotons et al. (2004) suggested that absence data in the case of invading or spreading species is "ecologically meaningless." Any attempt, to quantify suitable black bear habitat in Kentucky using presence / absence or use versus availability methodology is inherently flawed and will give inaccurate results.

Ecological Niche Factor Analysis (ENFA) predicts habitat suitability using only presence data (Hirzel et al., 2002). ENFA computes suitability functions by comparing the species distribution with that of the entire study area and is regarded as the most reliable of presence only analysis techniques (Brotons et al., 2004, Martinez et al., 2006). ENFA is based on Hutchinson's (1957) concept of the ecological niche, defined as an *n*-dimensional hypervolume of attributes that support a population. An important difference between ENFA and standard presence / absence analysis techniques is that ENFA assesses habitat suitability, not the probability of species occurrence (Zaniewski et al., 2002). In addition, while the models produced by ENFA can be statistically tested, it is a descriptive mapping method based on niche theory and does not "extract causality relations" (Hirzel et al., 2002). While presence / absence methods have proven to more accurately predict species occurrence when reliable absence data are available

(Zaniewski et al., 2002; Brotons et al., 2004), ENFA is robust and often gives similar results (Hirzel et al., 2006).

Methods

Field research was conducted in a 10-county area within the Eastern Physiographic Province of Kentucky (Figure 1). The study area is mountainous and dominated by mixed-mesophytic forest (Unger, 2007). Radio-collared bears were tracked weekly via aerial radio telemetry from a fixed-wing aircraft (Mech, 1983). Locations of radio-collared animals were recorded using a hand held Garmin III GPS unit.

We used the ENFA routine in the Biomapper 3.1 program (Hirzel et al., 2008) to compute a black bear HS map for the entire Eastern Physiographic Province of Kentucky. ENFA computes factors (as in Principal Components Analysis) from ecogeographical variables (EGVs) that describe the ecological niche of a species. The analysis uses two measures of the niche, marginality and specialization. Marginality is defined as the absolute difference between the global mean and species mean for a particular variable. Similarly, specialization factors indicate levels of explained variance and suggest how specialized a species habitat needs are compared to the range of values in the study area (Hirzel et al., 2008).

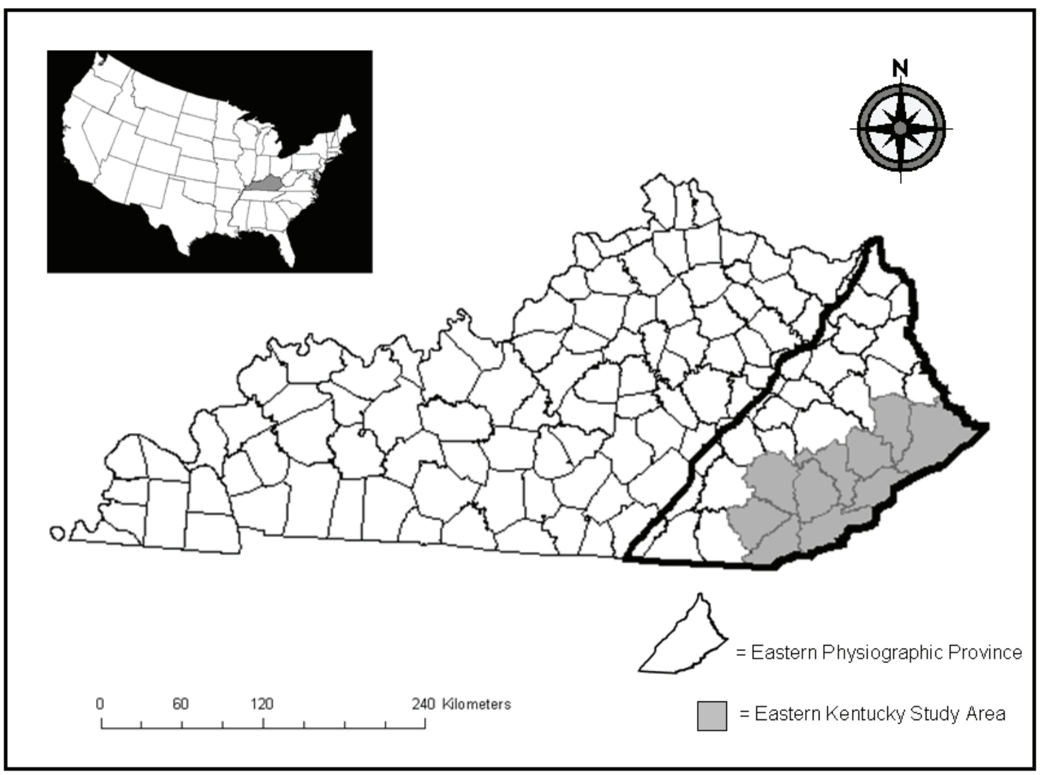

Figure 1. Ten county study area in southeastern Kentucky where black bear field research was conducted.

Four biologically meaningful EGVs were used to produce a black bear HS map: forest frequency, distance to major roads, slope, and forest patch size. These variables were chosen based on previous black bear research in North America (Clark et al., 1993; Rudis and Tansey, 1995; Orlando, 2003; Kindall and Van Manen, 2007; Unger, 2007). All variables were converted to raster maps in ArcGIS with a 30 m pixel resolution.

Biomapper considers the resources required within an area equivalent to the home range size of the focal species (Hirzel et al., 2008). The smallest calculated home range for black bears in Kentucky (6.0 km^2) was used to represent a minimum radius of influence (1,380 m). The Kentucky Snapshot Landcover Dataset, Anderson level 3 (KLCDIII) (Harp et al., 2006) was used to identify and group all forested habitats into a single habitat type (forest). The percent of the home range in forest was calculated using the Biomapper module "circan," option "frequency" (Hirzel et al., 2008) and a 1,380 m radius.

Roads are known to have an impact on black bear behavior and movement (Brody and Pelton, 1989; Wooding and Maddrey, 1994; Tankersley, 1996; Orlando, 2003). A roads coverage was obtained from the Kentucky Division of Geographic Information (2006) and major road types were identified as either interstates, parkways, U.S. highways, or state highways. Orlando (2003) found that bears avoided areas within 500 m of class 1 (> 500 vehicles per hour) and 250 m class 2 (1 to 500 vehicles per hour) highways in a west-central Florida black bear population. In ArcGIS we calculated distance to roads (using the major roads) after converting the vector coverage to a raster using the spatial analyst "raster distance analysis" tool in ArcGIS. These distances were rescaled ordinally into three value ranges, (1) 0-250 m, (2) 251-500 m, and (3) > 500 m, to represent increased suitability with greater distance from roads.

Slope has been identified as an important component of black bear habitat in part because greater slope represents more rugged, and thus, remote, habitat (Clark et al., 1993; Tankersley, 1996). Slope was calculated using DEMs obtained from the U.S. Geological Survey (2008), and using the spatial analyst surface tool in ArcGIS.

Bears require "large" and "remote" blocks of forest to maintain viable populations (Schoen, 1990; Rudis and Tansey, 1995; Maehr et al., 2001; Kindall and Van Manen, 2007). To our knowledge, no study has been published that indicates the minimum patch size used by the species. Mykytka and Pelton (1990) suggested that forest blocks greater than 300 ha be protected for bear populations, while Rudis and Tansey (1995) defined "remote" habitat as any contiguous forest block greater than 1,000 ha. Patches in the Eastern Physiographic Province were rescaled ordinally into three value ranges, (1) 0 to 300 ha, (2) 301 to 1,000 ha, and (3) > 1,000 ha, representing increased suitability with larger patch size.

Weekly aerial telemetry locations obtained from January 2002 through November 2006 were used to develop the Kentucky black bear HS map. Because locations were acquired weekly, spatial and temporal autocorrelation were minimal (Arthur et al., 1996; Otis and White, 1999). Locations were used only from bears that had an established annual home range to prevent bias due to transient bears. A Boolean map was created in which each telemetry location represented an individual bear "presence" and was assigned a value of 1. All other pixels were assigned a value of 0. We randomly selected 2/3 of the telemetry locations for model building and withheld 1/3 for model validation (Browning et al., 2005; Thompson et al., 2006). The suitability threshold for the model was determined as the point of greatest difference in suitability values between random and actual points. Model validation was performed using the k-fold cross-validation procedure (Boyce et al., 2002) in Biomapper 3.1. Ten iterations were performed in which presence locations were randomly partitioned and evaluated for correlation with suitable habitat. Data partitions for model validation were set so that that they did not overlap geographically, minimizing the potential for spatial autocorrelation. The area adjusted frequency (F_i) values of an effective model should correlate closely with HS values (Hirzel et al., 2008).

Results

We used 1,154 aerial telemetry locations from 22 black bears (10 females and 12 males) for the development and validation of a Kentucky black bear HS map of the Eastern Physiographic Province. Each bear had an average number of locations of 52 (standard error = 5.35, range = 28 to 117). We used 770 locations for model development and 384 locations for the cumulative frequency charts.

No EGVs were identified as correlated by Biomapper. ENFA analysis provided an overall marginality of 0.51, indicating that bears occurred in habitats that were not evenly distributed across the Eastern Physiographic Province (marginality value close to 0 if evenly distributed), but habitats that were not considered extreme or specialized (marginality value close to 1). The three factors derived from ENFA explained 90.4% of the total variance (Table 1). Bears were more frequently found in areas with more forest cover, at least 250 m from major roads, and in habitat patches greater than 1,000 ha in size. Bears were found on moderate slopes (average = 20.3 ± 8.6 %, range 0.20 to 48.4 %), but were rarely in areas of very high slope.

Table 1. Score matrix of the first three factors derived from ecological niche factor analysis (ENFA) and the percentage of variance explained by each factor for developing a black bear habitat suitability map of the Eastern Physiographic Province of Kentucky.

	Factors		
Variables	1	2	3
Forest frequency	0.727	-0.576	0.298
Major roads	0.276	-0.070	-0.951
Patch size	0.565	0.811	0.074
Slope	0.276	0.073	0.014
Variance explained (%)	49.7	23.1	17.6

A black bear habitat suitability map was generated for the Eastern Physiographic Province in Kentucky (Figure 2). Two maximum cumulative frequency charts were derived. The first was based on validation points randomly distributed throughout the Eastern Physiographic Province (Figure 3). Because presence locations were recorded only in far southeastern Kentucky, this chart was derived to measure the variability of habitat between actual locations and the entire physiographic province. The second was based on random points distributed only within the boundaries of presence locations (Figure 4). Based on these analyses, the threshold HS value below which suitable black bear habitat occurred was between 25 and 35 percent. Thus, the HSI map was reclassed into three suitability values: unsuitable (0 to 25%), marginal (26 to 35%) and suitable (36 to 100%) (Figure 5). The Continuous Boyce Index ($Boyce_c$) was 0.70 for the cross validation procedure, indicating correlation and, thus, good predictive power of the model ($p < 0.025$).

A total of 8,522.8 km^2 (852,280 ha) of suitable habitat was identified in the Eastern Physiographic Province. Publicly owned land accounted for 1,990 km^2 (23.3%) of suitable habitat. Most of the fragmentation associated with suitable habitat was caused by major roads. Other fragmentation causes included areas of high urbanization and resource extraction such as mining.

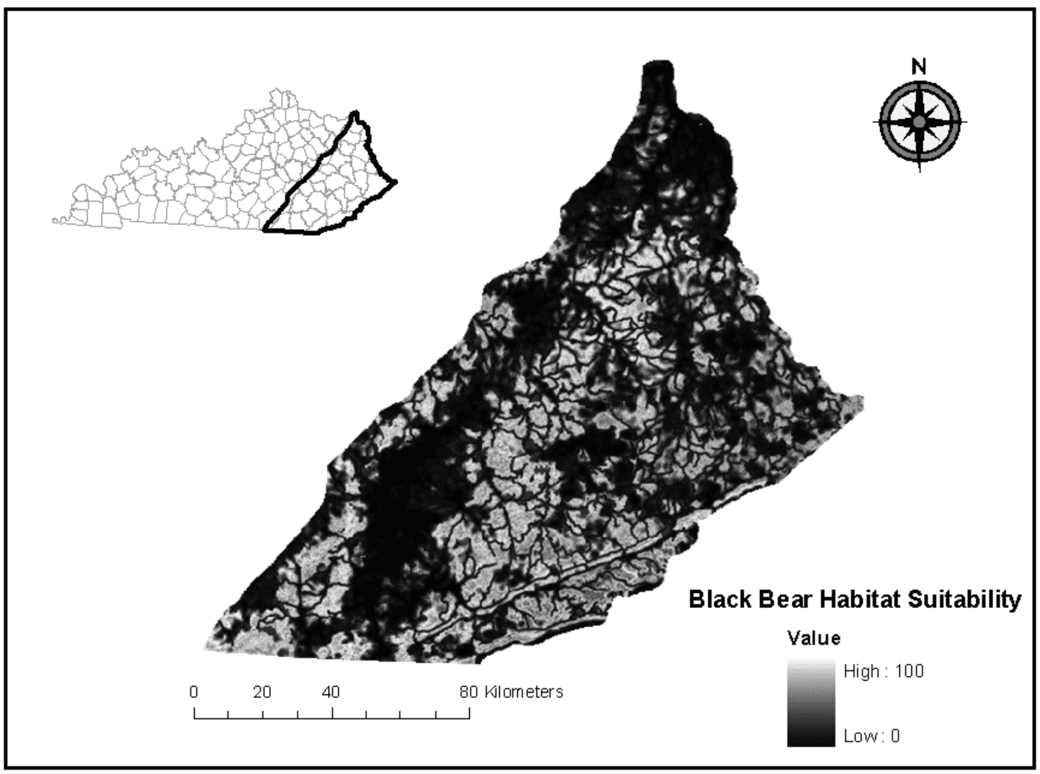

Figure 2. Black bear habitat suitability map for the Eastern Physiographic Province of Kentucky.

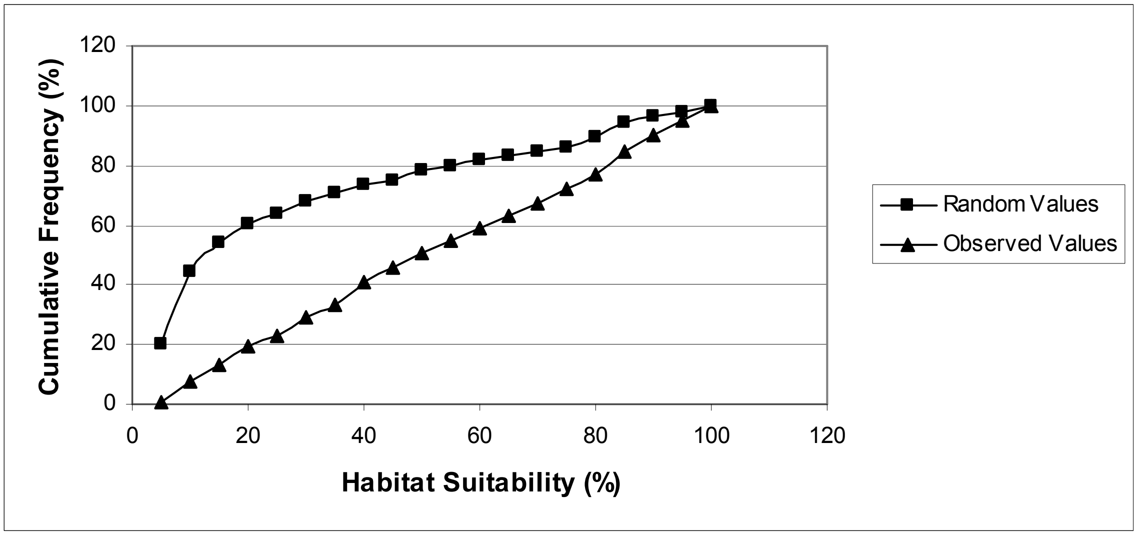

Figure 3. Cumulative frequency distribution of habitat suitability for observed and random pixel values measured across the Eastern Physiographic Province of Kentucky. Differences between the cumulative frequencies was maximized when habitat suitability was 25%.

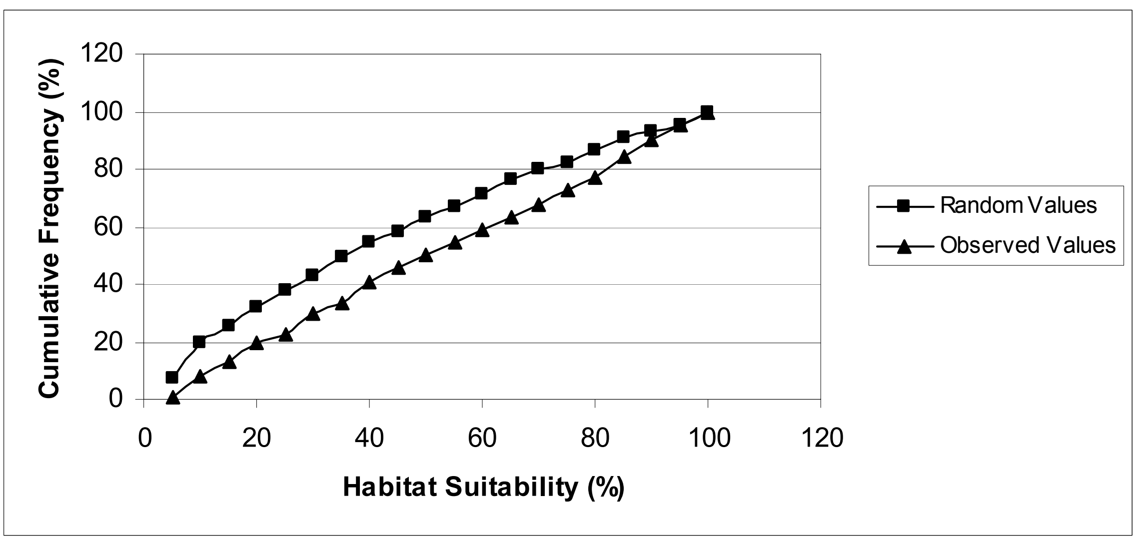

Figure 4. Cumulative frequency distribution of habitat suitability for observed and random pixel values measured within the boundaries of observed locations. Differences between the cumulative frequencies maximized when habitat suitability was 35%.

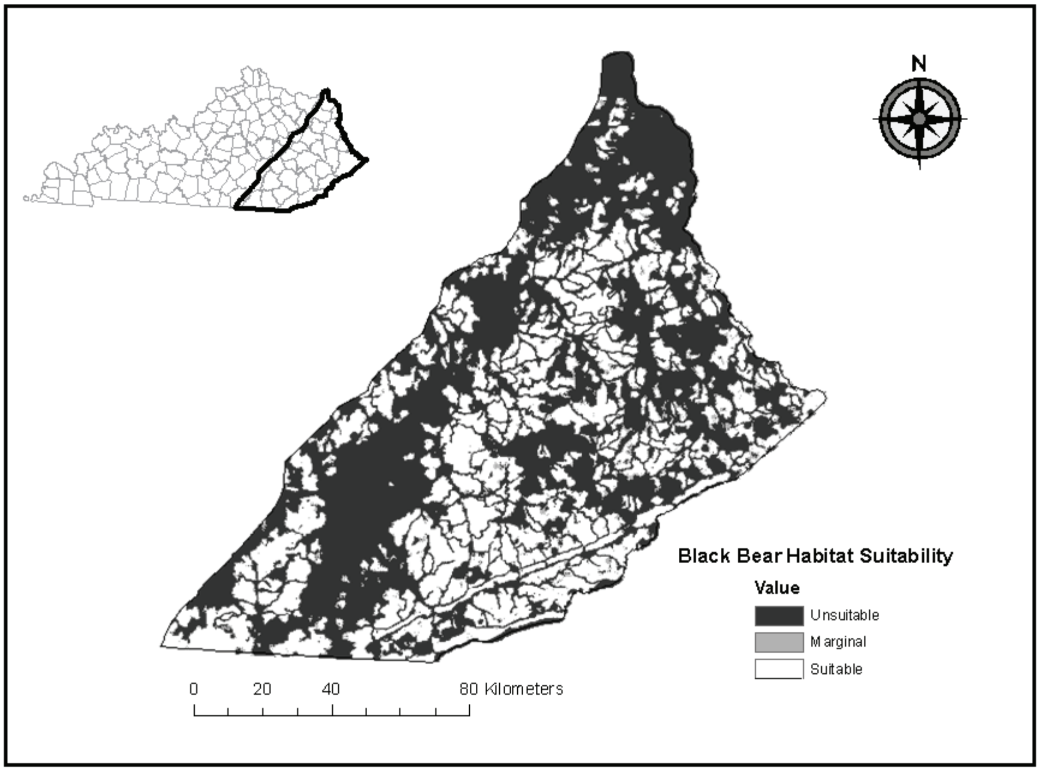

Figure 5. Scaled black bear habitat suitability map for the Eastern Physiographic Province of Kentucky. Unsuitable equaled habitat suitability values ranging from 0 to 25%, marginal habitat included values ranging from 26 to 35%, and suitable habitat included values ranging from 36 to 100%.

Discussion

The accepted minimum area requirements for maintaining a long-term, viable black bear population vary in different studies. Cox et al. (1994) determined the area needed to support a minimum viable black bear population of 200 animals was 2,000 to 4,000 km^2. Rudis and Tansey (1995) suggested 800 km^2 was needed in upland forested areas, while Rogers and Allen (1987) suggested that 288 km^2 of contiguous habitat was sufficient for population viability. Based on this information, the Eastern Physiographic Province appears to contain more than enough suitable habitat (8,500 km^2) for Kentucky to support a long-term, viable black bear population. Black bear density estimates in the southeastern United States range from 0.06 to 0.73 individuals per km^2. Thus, the Eastern Physiographic Province could support between 511 and 6,244 black bears. Given density estimates across the southeastern United States, minimum and maximum average potential population sizes for the Eastern Physiographic Province were 1,833 (standard error = 413) and 2,283 (standard error = 497), respectively (Table 2).

Table 2. Estimates of population densities for black bear populations in the southeastern United States.

Location	Bears per km^2	PPS	Source
North Carolina	0.73	6,244	Martorello, 1998
ONF, FL	0.14	1,197	Dobey et al., 2005
Okefenokee, GA	0.12	1,026	Dobey et al., 2005
OcNF, FL	0.27	2,309	McCown et al., 2004
Oklahoma	0.27	2,309	Bales et al., 2005
Chassahowitzka, FL	0.23	1,967	Cox et al., 1994
CNF, TN	0.18	1,540	McLean and Pelton, 1994
PNF, NC	0.09	684	McLean and Pelton, 1994
GSMNP	0.09-0.59	684-5,046	Carlock et al., 1983
White Rock, AK	0.075	642	Clark and Smith, 1994
Dry Creek, AK	0.09	684	Clark and Smith, 1994
GDSNWR, NC	0.52-0.66	4,448-5,645	Hellgren and Vaughan, 1989
Southeastern NC	0.12	1,026	Hamilton, 1978
Northeastern NC	0.06	513	Hardy, 1974
Southeastern GA	0.26-0.40	2,224-3,421	Abler, 1985
Minimum mean		1,833 $\pm$ 413	
Maximum mean		2,283 $\pm$ 497	

PPS = potential population size for Kentucky
ONF = Osceola National Forest
OcNF = Ocala National Forest
CNF = Cherokee National Forest
PNF = Pisgah National Forest
GSMNP = Great Smoky Mountain National Park
GDSNWR = Great Dismal Swamp National Wildlife Refuge

ENFA may prove to be a valuable for other wide ranging mammals in Kentucky and elsewhere. For example, the actual and potential distributions of a reintroduced elk population in the Eastern Physiographic Province are not currently known. In circumstances where absence data are unavailable or unreliable, our results suggest that ENFA appears to be of value in identifying suitable habitat with only presence data. Delineating the available habitat for both black bear and elk could form the foundation for research on the inevitable future interaction of the largest predator and prey in the Commonwealth (Zager and Beecham, 2006).

ENFA has several advantages over conventional presence / absence procedures. In addition to not requiring absence data, it is robust to deviations from normality (Glass and Hopkins, 1984). In order to perform ENFA analysis using Biomapper 3.1 (Hirzel et al., 2008), all raster maps needed to contain continuous data. We did not feel our roads or patch maps violated this requirement, as the data was ordinally scaled, not categorized. Resources for animals are often distributed continuously across the landscape and not conveniently isolated into distinct pixels or polygons, making this data format both intuitive and ecologically sound (Mitchell et al., 2002). ENFA is somewhat optimistic regarding suitable habitat distributions, which is considered advantageous when a species does not occupy all potential areas of the landscape (Hirzel et al., 2001; Brotons et al., 2004). Finally, highly correlated variables affect the outcome of GLM and GAM analyses, requiring that researchers run multiple models and compare them using some form of information criterion, such as Akaike Information Criteria (AIC) (Burnham and Anderson, 2002). In contrast, ENFA does not reject, but does identify, highly correlated variables (Hirzel et al., 2002).

Conclusions

With adequate suitable habitat to support a viable, self-sustaining black bear population, the recoloniziation of the Eastern Physiographic Province of Kentucky by black bears appears possible. Due to the low growth rate of black bears (Eiler et al., 1989), it is likely to take years if not decades for full recolonization to occur. As an umbrella species (Maehr, 2001; Dugelby et al., 2001), the black bear could be used to promote landscape level forest conservation in Kentucky and provide benefits to a myriad of other species and ecological communities (Simberloff, 1999).

Acknowledgements

Major funding for this project was provided by the Kentucky Department of Fish and Wildlife Resources. Additional funding and support were provided by the University of Kentucky, Cumberland Gap National Historic Park, and Kingdom Come State Park. Special thanks to Jeff Larkin and John Cox for assistance with aerial telemetry and GIS. Thanks also go to volunteers that assisted in trapping efforts.

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