Elk Habitat Suitability Map for North Carolina

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Abstract: Although eastern elk (*Cervus elaphus canadensis*) were extirpated from the eastern United States in the 19th century, they were successfully reintroduced in the North Carolina portion of the Great Smoky Mountains National Park in the early 2000s. The North Carolina Wildlife Resources Commission (NCWRC) is evaluating the prospect of reintroducing the species in other locations in the state to augment recreational opportunities. As a first step in the process, we created a state-wide elk habitat suitability map. We used medium-scale data sets and a two-component approach to identify areas of high biological value for elk and exclude from consideration areas where elk-human conflicts were more likely. Habitats in the state were categorized as 66% unsuitable, 16.7% low, 17% medium, and <1% high suitability for elk. The coastal plain and Piedmont contained the most suitable habitat, but prospective reintroduction sites were largely excluded from consideration due to extensive agricultural activities and pervasiveness of secondary roads. We ranked 31 areas (≥500 km^2) based on their suitability for reintroduction. The central region of the state contained the top five ranked areas. The Blue Ridge Mountains, where the extant population of elk occurs, was ranked 21st. Our work provides a benchmark for decision makers to evaluate potential consequences and trade-offs associated with the selection of prospective elk reintroduction sites.

Key words: elk, habitat suitability, landscape modeling, reintroduction, North Carolina

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Eastern elk (*Cervus elaphus canadensis*) were plentiful in the Carolinas prior to European development in the 1700s (Brickell 1737, Van Doren 1955). Elk were known to inhabit much of the eastern Appalachian Mountains and Piedmont. However, populations began to decline with the advent of large-scale habitat loss, increased agriculture, and unregulated hunting (Christensen 1998, O'Gara and Dundas 2002). Extirpation from North Carolina occurred by the mid-1800s. Early attempts at reintroduction east of the Mississippi were largely unsuccessful with eight to ten efforts prior to 1990 ending in failure (Witmer 1990). The most common reason cited for failed attempts was lack of appropriate habitat. Other reasons were hunting, illegal harvest, removal due to crop damage, and disease/parasites. In the early 2000s, several eastern states attempted to reintroduce the Rocky Mountain elk (*C. e. nelson*; Bryant and Maser 1982, McClafferty and Parkhurst 2001, Larkin et al. 2003a). Reintroduction efforts in the North Carolina portion of the Great Smoky Mountains National Park were deemed successful by the National Park Service, where an estimated population of 140 persists today (J. Yarkovich, Great Smoky National Park, personal communication).

Since the beginning of the 20th century, the areal extent of forest woodlots in North Carolina has increased while acreage of agricultural lands has declined (Billings 1938, Oosting 1942, Christensen and Peet 1984). These trends suggest that suitable elk habitat may occur throughout much of the state, and provide the North Carolina Wildlife Resources Commission (NCWRC) a broader range of options to select sites for reintroduction across the state. Reintroductions are being considered as a means to expand free ranging elk populations in the state to provide viewing opportunities for the public, and perhaps, a population able to sustain annual harvests.

Our objective was to create state-wide elk habitat suitability map as a means to conduct a rapid assessment of potential areas for reintroduction. The map was used to identify where these potential areas occur, but also to provide a basis for decision makers to preliminarily assess trade-offs among areas. Information on elk in North Carolina is scant, consisting mostly of a study and feasibility assessment to reintroduce elk in the Great Smoky Mountains National Park (Long 1996). Thus, we adopted suitability models developed for elk populations in eastern United States (Didier and Porter 1999, Zysik 2010). We treat these as the best available science to date to conduct the state-wide assessment. Suitability was defined as habitats that provide core habitat functions (forage, cover) in contiguous areas large enough to sustain an elk population taking into account sociological factors that might lead to elk-human conflicts. We identified potential candidate areas for reintroduction, highlighted factors that influenced suitability values, and discuss preliminary implications for decision makers.

Methods

The geographic extent considered in this assessment was the entirety of North Carolina. The assessment, therefore, included the coastal plain of the state, where elk was not known to occur prior to European settlement. The NCWRC chose to include the coastal plain because its fundamental objective was not restoring the historic range of the species, but to provide greater opportunities for recreation to a variety of users. The vast change in plant community composition throughout the state in the intervening 250 years since European settlement did not justify constraining the assessment to only the historical range of the species.

We used a two-component modeling approach adopted from Didier and Porter (1999) and Zysik (2010). Didier and Porter's (1999) model was developed for elk populations in New York. Zysik's (2010) model built upon and refined Didier and Porter's model by incorporating telemetry data collected in Kentucky. The approach generated suitability values obtained from applying functions or rules that defined the relationship between habitat and variables pertaining to the two components of the assessment, that is, biological or sociological (see Table 1 for variable definitions).

The biological component was aimed at identifying quality habitat for elk. We used five habitat variables for this process (Zysik 2010). These were: 1) food and cover habitat in close proximity, 2) hardwood forest habitat, 3) early successional/scrub-shrub habitat, 4) open habitat, and 5) secondary road density. We assessed these variables using SE-GAP land cover, which is based on 2001 Landsat Thematic Mapper imagery (USGS SE-GAP 2007). We aggregated 82 land cover classes present in North Carolina into 10 classes to match the thematic grain of Zysik's (2010) model. More recent NLCD data exist (i.e., 2006; Wickham et al. 2013); however, the aggregation of woodland and forest classifications in the latter dataset were deemed incompatible with the thematic classification required to detect suitable elk habitat. Spatial analyses were conducted using ESRI ArcGIS 10.0 and Model Builder 10.0.

Each land cover type was assigned a food and cover suitability value as described by Zysik (2010; Table 2). Land cover was reclassified to a corresponding suitability value (SVcv, SVfd). Distance modifiers (MODdc, MODdf) were applied to both cover and food suitability values to assess the degree of interspersion of habitats. These modifiers, in turn, produced corresponding modified suitability values termed MSVcv and MSVfd.

$$MSV_{cv} = SV_{cv} * MOD_{df}$$
$$MSV_{fd} = SV_{fd} * MOD_{dc}$$

Table 1. Variable acronyms and names used to build an elk habitat suitability map for North Carolina.

Variable acronym	Variable name
SVcv	suitability value—cover
SVfd	suitability value—food
MODdc	distance modifier—cover
MODdf	distance modifier—food
MSVcv	modified suitability value—cover
MSVfd	modified suitability value—food
SVcvfd	suitability value—cover/food matrix
SVforest	suitability value—forest
SVopen	suitability value—open
SVshrub	suitability value—early successional/scrub-shrub
SVroads	suitability value—roads
SVbio	suitability value—biological variables
SVrc	suitability value—row crops
SVhwy	suitability value—4 lane highway
SVurban	suitability value—urban
SVsc	suitability value—sociological constraints
FSV	final suitability value

Table 2. Elk habitat suitability values for food and cover of land cover types in North Carolina

Cover type	HSI food value	HSI cover value
Deciduous forest	0	1
Coniferous forest	0	1
Mixed forest	0	1
Early successional – scrub/shrub	1	1
Open	1	0
Urban	0	0
Barren	0	0
Water	0	0
Wetland	0	0
Other	0	0

The combined cover/food suitability value was based on the greater of the resulting modified suitability values except where both were >0, in which case the suitability value was set at 1.

$$SV_{cvfd} = IF(MSV_{cv} \geq 0 \text{ and } MSV_{fd} \geq 0, \text{ THEN } 1, \text{ ELSE } IF(MSV_{cv} \geq MSV_{fd}, \text{ THEN } MSV_{cv}, \text{ ELSE } MSV_{fd}))$$

Habitat composition was characterized by the percentage of three distinct habitat types: forest, early successional/scrub-shrub, and open habitats. The functional relationships defining suitability in this case were described by Didier and Porter (1999; Figure 1).

Given that elk avoid habitat adjacent to roads (Rost and Bailey 1979, Edge 1982, Lyon 1983, Edge et al. 1987, Rowland et al. 2000), the potential influence of roads on habitat quality was incorporat-

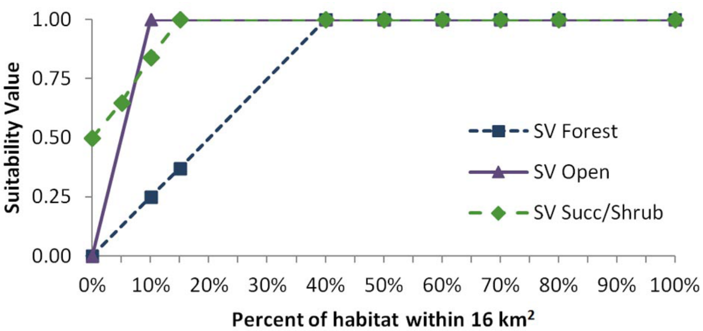

Figure 1. Functional relationships used to calculate habitat suitability values for elk in North Carolina based on percent of forest, early successional/scrub-shrub, and open habitats within 16 km^2.

ed by developing a suitability value based on the density of secondary roads (Zysik 2010). The analysis window to search for these potential areas of lower habitat quality was based on a mean home range area of 55 km^2 (123,553 acres) (Wichrowski 2001).

The five habitat variables were combined into a single biological suitability value (SVbio) defined as the geometric mean of the five variables (Zysik 2010):

$$SV_{bio} = [\ SV_{cvfd} * SV_{forest} * SV_{open} * SV_{shrub} * SV_{roads}\ ]^{1/5}$$

We used three variables to identify areas of potential of elk-human conflicts (i.e., sociological constraints): urban land use, agricultural production, and proximity to 4-lane highways. In contrast to Didier and Porter (1999) and Zysik (2010), who used coarse-scale data based on county or municipal areas, we used medium-scale digital data based on 30-m^2 pixels (USGS SE-GAP 2007) to improve our ability to identify potential areas of elk-human conflicts without removing surrounding habitat that could be of benefit to elk.

Urban land use was defined by the Southeast Gap Analysis Project Urban Avoid dataset (USGS SE-GAP 2007). This data layer consisted of a compilation of secondary road density (U.S. Census Bureau 2007) and urban development from land cover data (USGS SE-GAP 2010). We removed areas from consideration for elk reintroduction by utilizing the medium and high exclusion setting put forth by the SE-GAP Urban Avoid dataset (i.e., portions of the landscape identified as being highly or moderately influenced by human use). Areas of high agricultural activity were removed from consideration due to the inherent potential conflict with crop depredation. We searched for these areas based on the percentage of row crops within a moving window of 81 km^2 (20,000 acres). We ranked suitability of agricultural landscapes (SVrc) using the following functional relationship: 0% – 5% row crops = full suitability (value = 1), 5% – 20% row crop was a linear function from full suitability (1) to no suitability (0), and >20% row crop (no suitability or value = 0). The functional relationship of agricultural landscapes was based on Didier and Porter (1999). The third and last variable of the sociological assessment was proximity to 4-lane highways. We applied a fine scale filter where distances of <1 km provides no suitability (value = 0), 1 – 8 km was an increasing linear function from 0 to 1, and >8 km represented full suitability (value = 1). The functional relationship was based on the 8-km limit used by Didier and Porter (1999).

The suitability value for sociological constraints (SVsc) was the product of the three variables.

$$SV_{sc} = [\ SV_{rc} * SV_{hwy} * SV_{urban}\ ].$$

Before finalizing the suitability assessment based on sociological constraints, we removed contiguous areas <500 km^2 (123,553 acres) as these were not considered to be large enough to sustain a viable elk population (Witmer 1990).

The final suitability value (FSV) for elk habitat was the product of the suitability values from sociological constraints (SVsc) and biological variables (SVbio), or the two components of the modeling process. We used the product, as opposed to a geometric mean, because it better represented the loss of site suitability when combining biological and sociological constraints due to their exclusionary relationship as opposed to compensatory. For example, poor biological habitat is not improved when not impacted by any sociological constraint.

$$FSV = [\ SV_{sc} * SV_{bio}\ ]$$

Final suitability values were summarized following the same categories used by Didier and Porter (1999). These were: unsuitable (0 – 0.25), low (0.25 – 0.5), medium (0.5 – 0.75), and high suitability (0.75 – 1.0). We calculated the mean (± SD) final suitability values for each of the contiguous habitat blocks ≥500 km^2, reported their extent (km^2), and highlighted the five areas with highest suitability values. Means (± SD) were based on the number of 30 m^2 pixels in each block, each having a suitability value. The sample size (N) of each block can be calculated by multiplying the area (km^2) by 1,111 (the number of 30 m^2 pixels in a square kilometer).

Results

On the basis of the biological assessment, 20.1% of the total land area within North Carolina was classified as unsuitable, 18.2% as low suitability, 60.4% as medium suitability, and 1.3% as highly suitable (Figure 2a). A breakdown of the individual biological variables indicate that food and cover attained maximum suitability value (SVcvfd =1) in 80% of the state. Fifty-seven percent (57%) of forest and 27% of open habitats had maximum suitability values. Early successional/scrub-shrub suitability values, on the other hand, had lower suitability values. Eighty-five percent (85%) of the state had suitability values of <0.3 and only 3% were >0.5. When

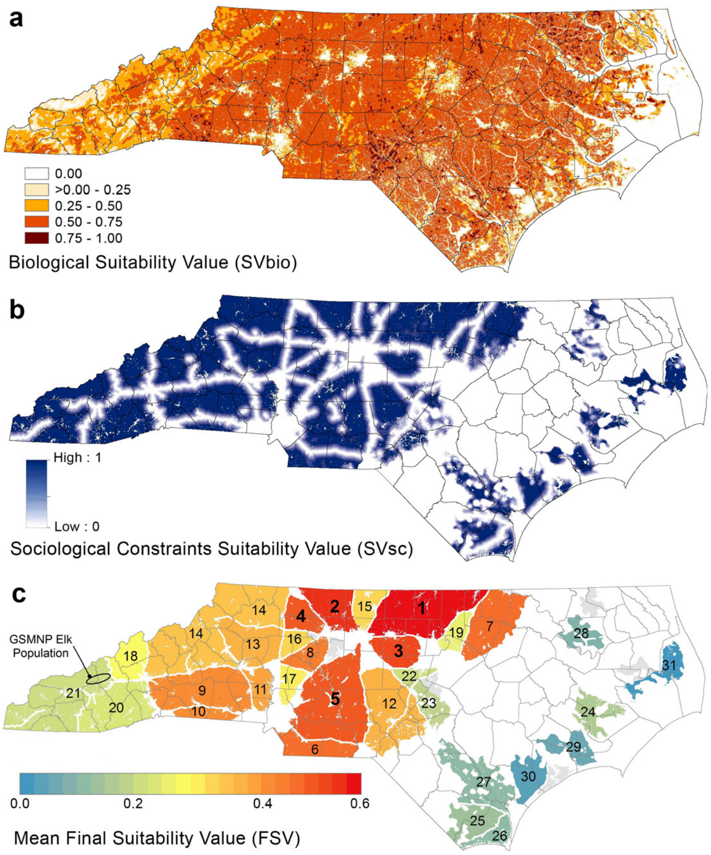

Figure 2. Map of North Carolina depicting areas ranked in an ordinal scale based on mean final suitability value. Panel a) Elk habitat suitability based only on biological requirements (SVbio); Panel b) Elk habitat suitability based only on sociological constraints (SVsc); and Panel c) Mean final suitability value (FSV) of contiguous blocks of habitat >500 km^2. The map highlights the five areas with highest mean habitat suitability (bold numbers), and depicts the location of the extant population of elk at the Great Smoky Mountain National Park.

we considered sociological constraints, and after filtering out contiguous habitat patches <500 km^2, 43.8% of the state was excluded from the pool of potential reintroduction areas with an additional 31.4% having reduced suitability due to the influence of one or all of the factors (Figure 2b).

The final statewide suitability value (FSV), a metric that accounted for biological and sociological considerations simultaneously, indicated that 66% of the land area in the state as unsuitable for elk reintroduction followed by 16.7% regarded as low suitability, 17% medium suitability, and <1% high suitability. Using the mean final suitability value (FSV), we identified and ranked 31 areas of suitable contiguous habitat blocks (≥500 km^2) for elk (Table 3). The areas with highest mean suitability were concentrated in the Piedmont (bold numbers, Figure 2c). The Blue Ridge Mountains, where the extant population of elk occurs, was ranked 21st (mean FSV = 0.223).

Table 3. Summary of habitat blocks >500 km^2, ranked by its mean final suitability value (FSV ± standard deviation) for elk in North Carolina. Means (± SD) were based on the number of 30 m^2 pixels in each block, each having a suitability value. The sample size (*n*) of each block can be estimated as pixels = $km^2 * 1111.11$.

Rank	Mean FSV	SD FSV	Area (km^2)
1	0.524	0.217	4904.16
2	0.46	0.217	1995.43
3	0.427	0.242	1557.67
4	0.422	0.218	6179.01
5	0.422	0.242	1228.26
6	0.42	0.208	1636.89
7	0.418	0.224	3348.3
8	0.406	0.247	1101.61
9	0.403	0.223	4401.89
10	0.4	0.256	748.92
11	0.391	0.24	978.49
12	0.386	0.25	4309.81
13	0.383	0.225	2609.89
14	0.375	0.184	8122.33
15	0.368	0.226	1037.83
16	0.364	0.233	688.21
17	0.351	0.227	823.97
18	0.34	0.178	1622.8
19	0.311	0.212	880.99
20	0.289	0.146	3269.48
21	0.223	0.153	5097.39
22	0.222	0.162	531.63
23	0.201	0.179	925.76
24	0.184	0.178	1276.15
25	0.177	0.205	1599.59
26	0.169	0.183	727.61
27	0.165	0.174	2683.73
28	0.16	0.162	930.64
29	0.11	0.145	1223.28
30	0.106	0.155	1464.57
31	0.041	0.111	1128.8

Discussion

The suitability of habitat for elk throughout North Carolina was evident by the prevalence and extent of land that could provide food, cover, forest and open habitats. The notable exception was early successional/scrub-shrub habitat (SVsh), a land cover type exerting a strong influence on habitat suitability because it serves both as a source of food and cover. This plant community association became the primary biological factor that reduced habitat suitability state-wide as only 3% of the land area had suitability values of >0.5.

Habitat in the coastal plain and Piedmont offered the highest suitability values based on biological variables. Land in the coastal plain, however, was largely excluded due to extensive agricultural activities. Moreover, the coastal plain had relatively few large blocks (>500 km^2) of contiguous habitat types (i.e., forest, open, early successional/scrub-shrub). Extensive contiguous blocks of habitat characterized by low density of roads exist in the Blue Ridge region, all within public lands (i.e., Great Smoky Mountains National Park and Nantahala National Forest). This factor likely contributed to the decision to reintroduce elk in the region (Long 1996). However, habitat in this region is considered of poorer quality because there are few grazing opportunities, a point also noted by Long (1996). Furthermore, opportunities are primarily restricted to open valleys, where the risk of potential conflicts with human activities is high. These factors contributed to the low final suitability value of this region for reintroduction (i.e., 21st). The setting in the Blue Ridge Mountains is in sharp contrast to elk reintroduction in Kentucky, where animals were released in a forested landscape with large open blocks of land with little to no human activity (Larkin 2003a).

Admittedly, there are few areas devoid of potential for human conflict in North Carolina. Therefore, the trade-offs of each alternative action in the strategy, starting with the selection of reintroduction sites, needs to be carefully evaluated (i.e., consequences). This evaluation includes consultation with stakeholders to ensure the utility (i.e., benefits) of alternative actions, given the NCWRC objectives, is well understood. Our assessment underscores that any population expansion or reintroduction, be it in the mountains or Piedmont, will quickly lead to some form of elk-human interactions. As such, a well-coordinated outreach and education effort should be considered an integral part of any implementation program (Long 1996).

We view our results as prior information that could be updated as part of an adaptive process (MaCarthy et al. 2012). Structuring the reintroduction strategy in such a fashion would allow decision makers to identify key uncertainties to better inform decisions in the process. For example, decision makers would be in a better position to determine if resources should be spent improving model parameterization to re-assess habitat suitability in the state (e.g., value of perfect information; Runge et al. 2011), or in other aspects of a release strategy (e.g., site-specific habitat assessment, selecting source population, demographic structure of released elk, risks of contracting meningeal worm; Long 1999, Larkin et al. 2003b, MaCarthy et al. 2012, Sainsbury et al. 2012).

Selecting potential reintroduction sites is a complex process because it involves numerous biological components, many beyond the scope of this work, as well as consultation and involvement of multiple agencies and stakeholders (Long 1996, Larkin 2003a, Osborne and Seddon 2012). Here we focused on two components; that is, quality (presence of selected biological requirements) and elk-human conflicts (sociological). Our work represents a benchmark towards the development of a comprehensive strategy for elk reintroduction and management in North Carolina. It provides decision makers a basis to preliminarily evaluate consequences and trade-offs regarding the relative value of reintroduction sites.

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