ASSESSING RE-COLONIZATION OF MOOSE IN NEW YORK WITH HSI MODELS

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ABSTRACT: After nearly a century of decline and range contraction in the northeastern United States, moose (*Alces alces*) have re-colonized Adirondack Park, New York due to improved habitat and adjacent source populations. In this paper I present the results of 2 Habitat Suitability Index (HSI) models used to examine the pattern of moose recovery in Adirondack Park. Sighting data collected in 1980-1999 by the New York State Department of Environmental Conservation were used to compare moose locations with 3 suitability levels of moose habitat predicted by the HSI models. The 2 models indicated that most of Adirondack Park was a combination of suitable (49-73%) and most suitable habitat (10-35%) for moose; the majority (53-77%) of sightings occurred in suitable habitat. However, the distribution of moose locations derived from sighting data might have been influenced by where human recreational activity occurred because sighting locations were not well correlated with the most suitable habitat. The combined analysis of the sighting locations and the HSI models provided valuable insight into the current and potential occupation and distribution of moose in Adirondack Park.

ALCES VOL. 44: 117-126 (2008)

Key words: Adirondack Park, *Alces alces*, habitat suitability index, habitat model, population.

How species select and use habitat forms one of the central fields of inquiry in ecology (Guisan and Zimmerman 2000). Determining how and when animals use different habitats provides information about their distribution and abundance relative to a given landscape (Fielding and Bell 1997, Pearce and Ferrier 2001, Anderson et al. 2002). Several methods have been used to investigate species-habitat relationships including statistical methods based on empirical data, expert-based knowledge, and a variety of modeling approaches (Heglund 2002, Anderson et al. 2003). Species distribution models can be a useful tool to predict distribution of a species by relating records of species presence and absence to environmental factors (Elith et al. 2006). Predictive geographic modeling uses the species-environment relationship in an attempt to understand potential species distributions, and has been applied to habitat use by moose (*Alces alces)* for nearly 2 decades in the form of Habitat Suitability Index (HSI) models (Allen et al. 1987, Koitzsch 2002, Snaith et al. 2002, Dussault et al. 2006).

It is important to identify factors that influence habitat selection by moose to understand patterns of habitat use and choose appropriate model parameters. Habitat preferences are largely related to forage and cover requirements (Dussault et al. 2006). Habitat requirements and preferences change seasonally, but are comprised of a few basic elements including variable and patchy forests that contain young and old deciduous and coniferous cover, and wetlands and water environments (Snaith et al. 2002). Open or disturbed areas within mature hardwood forests provide early successional vegetation that is a diet staple in the growing season, while conifers provide food and shelter during winter (Peek 1998, Snaith et al. 2002). Wetlands provide important sources of minerals and other nutrients, and also provide shelter from predators, insects, and high ambient temperature (Peek 1998, Snaith et al. 2002, Dussault et al. 2006).

Historically moose were found throughout New York including the Adirondack Park (Park) prior to European colonization (Hicks 1986, Karns 1998). European immigrants cleared and converted much of the forestland to farmland in New England and New York. This dramatic land use change and increasing human settlement led to higher hunting pressure and reduction of forest habitat that caused the decline and extinction of local moose populations (Alexander 1993, Bontaites and Gustafson 1993, Foster et al. 2002). The last record of a moose shot in the Park was in 1861 (Jenkins and Keal 2004). Populations in neighboring states of Vermont and Massachusetts were either extirpated or unable to serve as viable source populations due to habitat fragmentation (Alexander 1993, Foster et al. 2002). Periodic, unsuccessful reintroductions of moose occurred in northern New York in the 1870s-early 1900s (Hicks 1986). Eventually, lack of hunting combined with recovery of forests and wetlands, the latter due to resurgent beaver (*Castor canadensis*) populations, created improved moose habitat in the Park by the late 1900s.

Moose dispersing from northern New Hampshire began to occupy adjacent Vermont in the 1960s (Koitzsch 2002). Subsequently, dispersing moose from Vermont and southern Canada provided the source animals that re-established a moose population in the Park and northern New York around 1980 (Hicks 1986, Hicks and McGowan 1992); this population has expanded steadily (Jenkins and Keal 2004). In the first decade the population exhibited a highly skewed sex ratio of approximately 3 males:1 female, a ratio typical of newly established mammal populations (Garner and Porter 1990). It is estimated that ~400 moose reside in the Park currently (Ed Reed, New York State Department of Environmental Conservation, pers. comm.).

As moose established a resident population in the Park, the New York State Department of Environmental Conservation (DEC) monitored moose numbers and movements (Hicks 1986). DEC used public sightings of moose to monitor population trends in 1980-2004. Sightings were solicited through newspaper articles and were accepted from individuals calling DEC offices. The information included date of sighting, location or general area of sighting, length of sighting, behavior observed, age, sex, type of sign observed (animal, track, scat, carcass), additional comments, and the name and contact information of the observer. Sightings were assigned latitude and longitude coordinates and an approximate elevation (increments of 100 m) based on the reported area of sighting. Other data sources included aerial surveys and locations of radio-collared moose. These efforts slowed considerably after 1999, consequently, my analysis only included data prior to 1999 (Fig. 1).

HSI models were first developed by the United States Fish and Wildlife Service (USFWS) in the late 1970s and early 1980s (Koitzsch 2002); they were derived from expert knowledge or process-based models (Ray and Burgman 2006). The models use habitat variables related to species presence, abundance, and distribution (e.g., habitat used for food and shelter) and represents them as quantifiable measures of suitability with values ranging from 1 (optimal) to 0 (not suitable) (Koitzsch 2002, Dettki et al. 2003, Ray and Burgman 2006). Variables can be combined using different equations and assigned to discrete units of the landscape. They can be used to predict species distribution and effects of habitat change on species presence and distribution (Dettki et al. 2003), and are useful for conservation planning and resource management (Pearce and Ferrier 2001, Koitzsch 2002).

Allen et al. (1987) developed 2 models for moose based on suitable habitat in the Lake Superior area of northern Minnesota. These models were based on expert knowledge and selection of habitat variables based on research of Peek et al. (1976) in northern Minnesota.

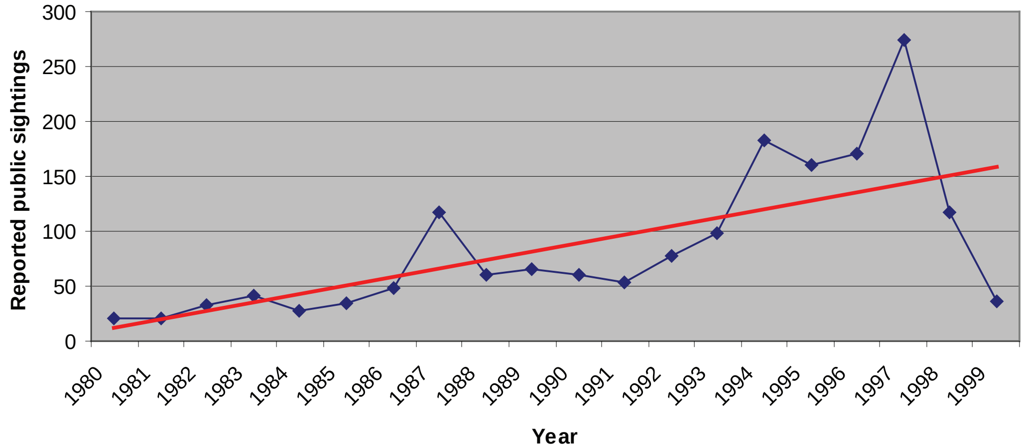

Fig. 1. Moose sightings in the Adirondack Park reported by the public to the New York State Department of Environmental Conservation, 1980-1999.

They have been widely applied and have provided the basis for the development of recent models to inventory moose habitat and document changes therein (Koitzsch 2002, Snaith et al. 2002, Dussault et al. 2006). The HSI Model I was based on a high resolution analysis of a small area (~600 ha) that included the annual habitat requirements of moose. The model was designed to analyze requisite food and cover and requires detailed information about browse availability. The HSI Model II was designed to rapidly assess the potential of larger areas to provide suitable browse and cover for moose; remote sensing data of coarse resolution can be used in this analysis (Allen et al. 1987). It has been used recently to evaluate moose habitat in Vermont (Koitzsch 2002) and Nova Scotia (Snaith et al. 2002).

This study was designed to apply HSI Model II in Adirondack Park to assess the availability and suitability of habitat for moose. This habitat information and the moose sighting data collected by DEC were evaluated to assess the relationship between sightings and relative habitat suitability. These exercises should provide information useful for management of moose in Adirondack Park.

STUDY AREA

The study area was the Park, 23,876 km^2 of state and privately owned land in northern New York (Fig. 2). The Park was created in 1892 and its core zone is the Forest Preserve, an 11,331 km^2 area incorporating old-growth forest that represents a distinct biological area (Jenkins and Keal 2004). It is characterized by mountains and highlands intersected by river valleys. Elevation is consistently high reaching nearly 1600 m, with valley floors about 100-200 m (Jenkins and Keal 2004). The region has a cooler climate than the immediately surrounding area, with average winter snow depth >2.5 m. The Park is dominated by forests and wetlands that exist in an ecological tension zone between New England forests/Appalachian zone and Canadian/boreal forests (Jenkins and Keal 2004).

Past and present logging has played an important role in shaping the composition of the commercial forestland representing 75% of the Park (Jenkins and Keal 2004). It is a predominantly coniferous forest interwoven patchily with hardwood stands, except at higher elevations where conifers dominate. Predominant species in the temperate forests include red spruce (*Picea rubens*), red pine (*Pinus resinosa*), white cedar (*Thuja occidentalis*), black ash (*Fraxinus nigra*), aspen (*Populus tremuloides*), beech (*Fagus grandifolia*), hemlock (*Tsuga canadensis*), sugar maple (*Acer saccharum*), white pine (*P. strobus*), and yellow birch (*Betula lutea*), while

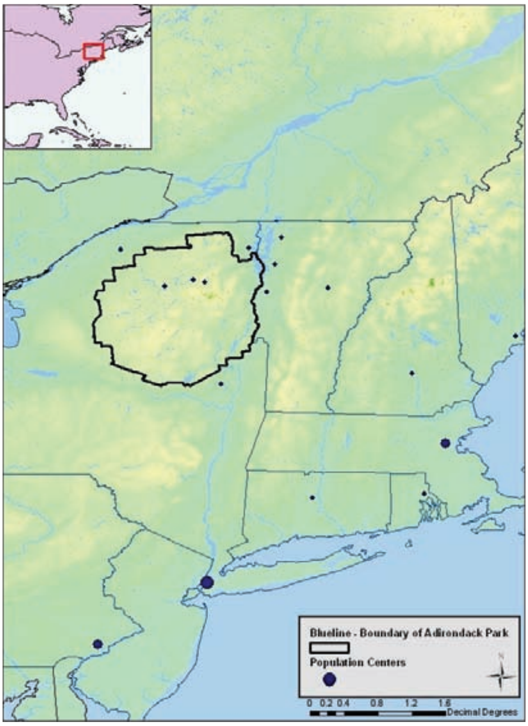

Fig. 2. The location of Adirondack Park in northern New York State. Source populations of moose came from southern Canada and the neighboring state of Vermont.

the core boreal area of the Park is comprised of balsam fir (*Abies balsamea*), black spruce (*P. mariana*), aspen, tamarack (*Larix laricina*), white spruce (*P. glauca*), and white birch (*B. papyrifera*). The other major category of land cover is wetlands that are common and as large as 200 ha. There are 3 major types of wetlands including open river corridors, floating bogs, and large open bogs sometimes dominated by conifers. Open wetlands are diverse and change species composition frequently due to beavers that create and maintain high species richness within wetlands (Wright et al. 2002). Predators are limited to coyotes (*Canis latrans*) and black bears (*Ursus americanus*) both of which prey on moose calves (Ballard and Van Ballenberghe 1998).

METHODS

Habitat Suitability Index Models

The HSI Model II is a GIS based model that uses 4 variables or classes of land cover considered important in habitat use and selection by moose (Table 1) (Allen et al. 1987). This model was applied to the Park and data for each class of land cover were extracted from raster layers provided by the Adirondack Park Agency and Adirondack GIS Users Group, vector and raster layers provided by the Wildlife Conservation Society, and the USGS NLCD 2001 raster for the Adirondack Park. Moose sighting data from 1980-1999 were digitized in Excel, a corresponding shape file was created, and this was projected into NAD 1983 UTM 18N to correspond with the projection of pre-existing layers used in the GIS analysis.

Data were analyzed using ArcGIS 9.1, the Spatial Analyst Extension, and Hawths Tools. Two raster files of land cover were used; the 1982 land cover layer for the area provided by the Adirondack Park Agency and Adirondack GIS Users Group (<http://www.apa.state.ny.us/gis/shared/index.html>), and the 2001 NLCD layer for the area obtained from the USGS. The 1982 land cover map was projected in Albers Conical Area and had a cell size of 63.615 m; the 2001 land cover map was also projected in Albers Conical Area and had a cell size of 30 m. In order to make both maps compatible, the 2001 land cover map was degraded to 63.615 meters using Spatial Analyst tools in ArcGIS 9.1. Both layers were then re-projected into NAD 1983 UTM 18N to render them compatible with other layers used in the analysis. Both layers were clipped to the extent of a vector layer conveying the boundary of the Park known as the Blueline established in 2001 (Fig. 2).

Cells were selected that corresponded to the following 4 habitat variables of HSI Model II: new/regenerating hardwood forest, wetlands, softwood, and old and mixed hardwood forest (Table 1). All other land cover classifications in the selected layers were coded as no data. Two vector layers depicting damage due to wind and ice storms in the late 1990s

Table 1. Description of the 4 habitat variables used in the HSI Model II (Allen et al. 1987) and equivalent layers derived from National Land Cover Datasets (1982, 2001), Adirondack Park.

Habitat Variable	Description (Allen et al. 1987)	Description (NLCD 1982, 2001)	Optimum habitat suitability (% area)
New/regenerating hardwood forest	Hardwood stands <20 yr old	Areas dominated by trees generally >5 m, and >20% of total vegetation cover. More than 75% of the tree pecies shed foliage simultaneously in response to seasonal change and area is <20 yr old.	40-50
Emerging herbaceous wetlands	Emerging herbaceous wetlands	Emerging Herbaceous Wetlands	5-10
Softwood forest	Conifer forest ≥20 years old with canopy cover >50% in evaluation area divided by total area	Areas dominated by trees generally >5 m tall, and >20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage. No age calculated.	5-15
Old and mixed hardwood forests	Upland deciduous or mixed forests ≥20 years old. More than 25% of the canopy is older than ≥20 years old and composed of <50% canopy cover of conifers.	Areas dominated by trees generally >5 m tall, and >20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change and area is ≥20 years old.	35-55

were converted to raster layers with the same cell size, and areas of high and medium level damage to hardwoods were removed from the older hardwood layer and converted to new/regenerating hardwood forest.

Habitat variable 1 – new/regenerating hardwood forest

The data used to classify cells representing new/regenerating hardwood forest were derived from multiple sources. Cells classified as hardwood forest in both the 1982 and 2001 land cover maps were selected and the resulting layers were overlaid; raster calculator was used to identify which areas defined as hardwood forest in 2001 were not defined as such in 1982. After identifying these cells, I applied layers identifying damage from a 1995 wind storm and a 1997 ice storm (K. Didier, Wildlife Conservation Society) to the new hardwood forest layer. I assumed that cells classified as medium and high damage would contain mostly regenerating forest. I selected those cells and overlaid the resulting layers on the 2001 land cover map to determine the area of hardwood in the damaged areas, and subsequently added them to the new/regenerating hardwood forest category. Raster calculator was used to calculate the number and percent of cells in each grid square represented by new/regenerating hardwood forest on the finished land cover map.

Habitat variable 2 – wetlands

Cells classified as wetland areas were extracted from the 2001 land cover map because the area has not yet been completely classified by the USGS National Wetland Inventory or the Adirondack Park Agency and Adirondack GIS Users Group. The 2001 land cover map had 2 categories of wetlands, woody wetlands and emerging herbaceous wetland. Wetlands with woody vegetation were excluded because they don't provide optimal food for moose (Allen et al. 1987) consequently, the wetland layer only utilized cells categorized as emerging herbaceous wetland. The raster calculator was used to determine the number and percent of cells represented by wetlands in each grid square on the finished land cover map.

Habitat variable 3 – softwood

Cells classified as softwood forest were extracted from the 2001 land cover map. The raster calculator was used to determine the number and percent of cells represented by softwood forest in each grid square on the finished land cover map.

Habitat variable 4 – old and mixed hardwood forest

Cells representing hardwood forest >20 years old and mixed hardwood forest were derived from multiple sources and combined to a single variable. Cells classified as hardwood forest in both the 1982 and 2001 land cover maps were identified initially. These layers were overlaid and raster calculator was used to verify that areas defined as hardwood forest in 1982 remained as hardwood forest by definition in 2001. I applied layers indicating damage from the 1995 wind storm and 1997 ice storm to the old and mixed hardwood forest layers. I assumed that cells classified as medium and high damage should be classified as new/regenerating hardwood forest. I then reclassified (removed) the appropriate cells originally identified as hardwood forest on the 2001 land cover layer. Raster calculator was used to determine the number and percent of cells represented by hardwood forest >20 years old and mixed hardwood forest in each grid square on the finished land cover map.

Habitat Suitability

I used the approach of Koitzsch (2002) and calculated habitat suitability for moose in grid squares of 25 km^2 that approximated the home range of moose in New England. The percent availability of each of the 4 variables was calculated for each grid square and results were applied to an equation that ranked the percentage of each variable according to HSI Model II (Allen et al. 1987). Weighted results were inserted into the equation:

$$HSI = (SI_1 \times SI_2 \times SI_3 \times SI_4)^{1/4}$$

Grid squares were ranked for low, medium, and high suitability. Optimal habitat was represented by cells with a value of 1.0 and less optimal habitat was represented by cells with value <1.0.

RESULTS

The HSI Model II indicated that suitable moose habitat occurred throughout the Park (Fig. 3 and 4). The spatial distribution of moose habitat was described in 3 gradations from "most suitable" to "least suitable." Two methods of classification were applied to the HSI data; an equal division of the grid squares into thirds based on HSI ranking (Koitzsch 2002), and a division of the grid squares using a Natural Breaks (Jenks) division. The Natural Breaks division groups data into classes that maximize the differences between classes; divisions are created in places where relatively big changes occur in the data. The percentages and distribution of "most suitable" and "suitable" habitat varied depending on the numerical analysis assigned to each category, but under 2 tested scenarios the area and percentage of "least suitable" habitat remained constant.

When the 1026 HSI grid squares were divided into categories based on 3 equal divisions of the total possible values, there were179 grid squares (17%) of "least suitable" moose habitat (HSI = 0.0-0.31), 749 grid squares (73%) of "suitable" moose habitat (HSI = 0.32-0.66), and 98 grid squares (10%) of "most suitable" moose habitat (HSI = 0.67-1.0) (Fig. 3). When the Natural Breaks division was used to categorize the HSI, there were159 grid squares (16%) of "least suitable" moose habitat, 503 grid squares (49%) of "suitable moose" habitat, and 361 grid squares (35%) of "most suitable" moose habitat (Fig. 4).

The relative proportions of the 3 gradations of habitat suitability (least suitable to most suitable) remained largely similar in area and spatially with both classifications. Areas in the west, southwest, and northwest of the Park were found to be "most suitable" when the grid squares were broken into thirds; these areas remained the same but expanded under the Natural Breaks division. Areas in the northeast and the northwestern border of the Park were found to be "least suitable" in

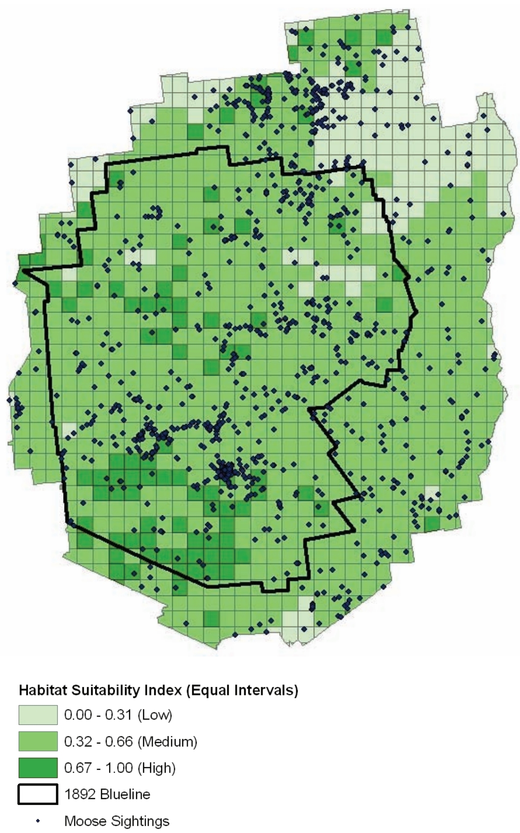

Figure 3. Habitat Suitability Index map of the Adirondack Park with moose sightings overlaid as points. Grid squares are divided equal thirds based on HSI ranking.

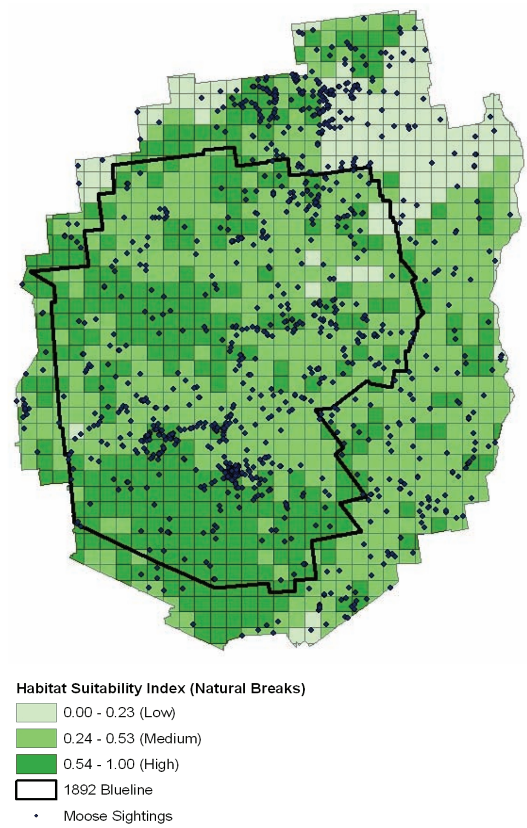

Figure 4. Habitat Suitability Index map of the Adirondack Park with moose sightings overlaid as points. Grid squares are divided into thirds using a Natural Breaks (Jenks) division.

both classifications (Fig. 3 and 4).

Moose sighting data (>1650 locations) were overlaid onto the HSI map and analyzed for presence in grid squares according to suitability under both classifications. More moose were sighted in the "most suitable" habitat under the Natural Breaks division (36.7%) than the other classification (10.7%); under both scenarios most moose were sighted in areas classified as "suitable" habitat (53.5 and 77.3%, respectively; Fig. 3 and 4). Sighting locations in "least suitable" habitat were 9.8 and 12%, or conversely, sighting locations in "suitable" and "most suitable" habitat combined were 90.2 and 88%, respectively.

DISCUSSION

Although this exercise was done primarily to estimate suitable habitat for moose in the Park, importantly, it also identified marginally suitable habitat that is important in management considerations of an expanding population. The "most suitable" habitat defined in HSI Model II is presumed to reasonably support 2 moose/km^2 (Allen et al. 1987). Using this population density estimate, I extrapolated the "most suitable" habitat identified in the 2 classifications and calculated potential populations of approximately 4,900 (98 grid cells with 3 equal divisions) and 18,000 moose (361 grid cells with Natural Breaks). Both of these estimates seem unreasonably high in comparison to well studied moose populations in Vermont, New Hampshire, and Maine (5000-15,000 moose). Nonetheless, the results indicate that there are large areas of suitable habitat for moose in the Park and potential for continued population expansion and growth.

There are no existing guidelines that pertain to choice of divisions for HSI models. Obviously the highly varied results derived in this exercise could lead to different interpretations and management decisions. This variation could be related to a number of factors including differences in habitat relationships between Minnesota and the Park, classification discrepancies of suitable habitat, and flaws in the model and data. Failure of the sighting location data to correlate well with the "most suitable" habitat may be partly explained by the confounding influence of human spatial patterns that biased moose sightings. All observation or presence/absence data were determined by human presence and hence are biased by sampling design. Because the bias of human presence in the landscape dictates sightings, moose locations in certain areas may be grossly over or under sampled.

There are several assumptions inherent in the HSI model that likely influenced the results. Habitat models are often simplified to a limited number of factors that influence habitat selection by a given species leaving room for potential error by omission (Dettki et al. 2003). Several important elements influencing habitat use by moose were not incorporated in this HSI model including mineral licks, diversity of wetland cover types, winter cover, spatial patterns of interspersion of food and cover resources, and human disturbance (Allen et al. 1987, Koitzsch 2002). Further, the model assumes that habitat is uniformly suitable on a year-round basis and that all 4 habitat variables are required throughout the year (Allen et al. 1987, Koitzsch 2002). However, moose are unlikely to use wetlands during winter, and do not necessarily require that 5-10% of their home range contain wetlands as long as suitable wetlands exist within a reasonable distance (Peek 1998). These factors are likely to skew the model towards under-scoring habitat which may be highly suitable for use during all or part of the year, and could explain some of the discrepancy between sighting locations and areas of "most suitable" habitat.

The nature of HSI models is that they are commonly applied to geographic areas where they were not developed and this could affect results and reliability (Guisan and Zimmerman 2000). Further, correlation between sightings and suitable habitat based on the HSI may be based solely on pattern, rather than processes (Dettki et al. 2003) that may be specific to an expanding population of moose, such as exists in the Park. However, application of the HSI model in the Park was unlikely to produce highly skewed results because forest composition, browse and cover species, and climate are reasonably similar in the Park and the Lake Superior region of Minnesota where the model was developed.

Two thirds of the moose sightings occurred within the 1892 Blueline (Fig. 3 and 4), the original boundary of the Park that was also a biological boundary delineating a core ecological zone (Jenkins and Keal 2004). It is possible that the 1892 Blueline is a good ecological delineation of core habitat for moose, and that the high number of sightings indicate that moose are re-colonizing and populating in this area faster. However, the majority of recreational trails in the Park occur within the Blueline, yet the main human population centers in the Park lie outside this zone. Therefore, sightings could have been influenced by the differences in location and habitual travel patterns of Park residents versus those of recreational tourists who may have been more likely to report unique moose sightings.

The sighting data collected by DEC provided a 19 year picture of the increasing moose population in the Park and was useful in developing citizen awareness and concern for its re-colonization. It indicated the trend in moose population and spatial and temporal patterns of moose re-colonization in the Park

(Jenkins and Keal 2004). However, the lack of sampling design or measurable effort required to collect data means that the data should probably not be used to estimate population density and abundance or habitat use relationships (Danielsen et al. 2005, MacKenzie et al. 2006). Although my analysis indicated that the sighting locations were not well correlated with the "most suitable" habitat as predicted by the HSI model, about 90% of sightings did occur in locations described as suitable or better habitat. Further, the HSI model classified the majority of the Park as suitable or better moose habitat (about 84%), and it also identified "least suitable" habitat, valuable information relative to population and habitat management. The results of this HSI model could be combined with a more rigorously designed sampling regime to ascertain more specific information about abundance and distribution of moose in the Park. Nevertheless, the combined analysis of the sighting locations and the HSI model provided valuable insight into the current and potential occupation and distribution of moose in the Park.

ACKNOWLEDGEMENTS

I would like to thank Drs. Joshua Ginsberg, Kate McFadden and Samantha Strindberg, Richard Pearson, and Yuri Gorokhovich for their support in developing the models and designing this study. Drs. Michale Glennon and Heidi Kretser of the Wildlife Conservation Society's Adirondack Program provided extensive guidance and assistance in acquiring data. The New York State Department of Environmental Conservation and particularly Al Hicks graciously provided moose sighting data. Funding for this work was provided by Joshua Ginsberg.

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