PRELIMINARY HABITAT SUITABILITY ANALYSIS FOR MOOSE IN MAINLAND NOVA SCOTIA, CANADA

Tamaini V. Snaith[1], Karen F. Beazley[1], Frances MacKinnon[2], and Peter Duinker[1]

[1]School for Resource and Environmental Studies, Dalhousie University, 1312 Robie St. Halifax, NS, Canada B3H 3E2; [2]Applied Geomatics Research Group, Centre of Geographic Science, 50 Elliot Road, RR1 Lawrencetown, NS, Canada B0S 1M0

ABSTRACT: Ecosystem management for biological conservation should include consideration of landscape-scale processes such as the habitat requirements of focal species. Moose (*Alces alces americana*) have been identified as an appropriate target for focal attention in mainland Nova Scotia. Currently, the population is at risk, and strategies for conservation should include the protection of sufficient habitat to meet the spatial requirements of the population. Delineation of spatial habitat requirements calls for an understanding of species-habitat associations and the distribution of suitable habitat across the landscape. To this end, habitat suitability in Nova Scotia was assessed relative to four criteria: (1) food availability; (2) conifer cover; (3) mixed-wood cover; and, (4) aquatic resources. Model predictions were tested by comparing habitat suitability values to provincial pellet inventory data. Road density was found to be more important than habitat composition in determining moose pellet distribution.

ALCES VOL. 38: 73-88 (2002)

Key words: *Alces alces americana*, conservation, habitat suitability index/analysis, Nova Scotia

Ecosystem management for biological conservation should incorporate coarse-filter considerations, such as adequate protection of all natural landscapes, and fine-filter considerations including the habitat requirements of focal species (Noss 1995, 1996; Miller et al. 1998/99; Noss et al. 1999). In Nova Scotia, American moose (*Alces alces americana*) has been identified as an appropriate target of focal attention (Beazley 1997, Snaith and Beazley 2002).

The spatial requirements of wide-ranging species such as moose are an important consideration in the determination of the area required to maintain biodiversity at a landscape scale (Noss 1995). Determination of spatial requirements must incorporate consideration of ecological processes such as population viability, range use, and habitat requirements. In addition, the supply, composition, and spatial distribution of suitable habitat across the landscape must be understood to identify and delineate the spatial habitat requirements for long-term species persistence.

In this paper we describe the development and application of a habitat suitability model for moose in mainland Nova Scotia. This analysis forms part of a larger project which describes the current status and distribution of moose populations within the context of biodiversity conservation, and develops management recommendations for protected areas system design in Nova Scotia (Beazley et al. 2002).

Moose Populations in Nova Scotia

Prior to European colonization, moose were widely distributed and abundant throughout Nova Scotia. However, there have been fluctuations and general declines in moose numbers since the early seventeenth century (Dodds 1963, Pulsifer and

Nette 1995). Currently, mainland Nova Scotia is thought to contain approximately 1,000 moose, fragmented among a number of isolated smaller populations (A.L. Nette, M. Pulsifer, and R. Hall, Nova Scotia Department of Natural Resources, personal communication). Moose are at risk of extirpation in mainland Nova Scotia, and will require special management attention if they are to persist (Pulsifer and Nette 1995, CESC 2001).

A wide range of factors have been invoked to explain the declining moose populations. Over-harvesting, habitat conversion, brain worm (*Paralephostrongylus tenuis*), winter ticks (*Dermacentor albipictis*), and black bear (*Ursus americanus*) predation are among the factors affecting moose populations in Nova Scotia, and may regulate or limit moose density (Pulsifer and Nette 1995, Snaith and Beazley 2004). Although there is currently no legal moose hunt in mainland Nova Scotia, hunting has been associated with major declines in the past, and may still be a marginal factor as there is evidence to indicate that some poaching occurs (Snaith and Beazley 2004).

Human land-use, including settlement and development, land clearing, cultivation, urbanization, and recreational development, restrict and eliminate moose habitat (Houston 1968, Dodds 1974). Roads may fragment habitat, isolate populations, and affect moose density by constraining movement and habitat use, influencing habitat quality, favouring competitors or predators, causing mortality by vehicle collision, or by allowing increased human access and poaching pressure (Houston 1968, Prescott 1968, Peek et al. 1987, Hogg 1990, Noss 1995, Forman et al. 1997, Rempel et al. 1997, Beazley et al. 2004). Because roads affect habitat suitability for many large mammals, it has been suggested that road density is the best indicator of ecological integrity and the intensity of human land-use (Noss 1995, Forman et al. 1997)

Moose Habitat Requirements in Nova Scotia

Moose need a diverse and heterogeneous habitat. Optimal moose habitat contains a dynamic mosaic of forest patches with a variety of species and successional types (Eastman 1974, Telfer 1984, Allen et al. 1987, Harcombe 1988, Hjeljord et al. 1990, McNicol 1990, Puttock et al. 1996). Food-producing areas, water bodies, and patches of dense mature forest are critical components of moose range. Small-scale patch dynamics, where open areas are scattered within dense mature forest, are most beneficial for selective feeding and will minimize travel between habitat components (Timmermann and McNicol 1988, Jackson et al. 1991, Heikkila et al. 1996).

If present in sufficient quantity, the productive mixed forests of Nova Scotia can provide ideal year-round habitat for moose. Forest cover is a critical habitat element which provides refuge from snow, wind, and cold temperatures, and relieves heat stress during both summer and winter months (e.g., Peterson 1955; Knowlton 1960; Telfer 1967b, 1970; Coady 1974; Renecker and Hudson 1986; Thompson and Euler 1987; Schwab and Pitt 1991; Miquelle et al. 1992). Because Nova Scotia is near the southern limit of moose range, thermal cover, particularly when in close proximity to forage producing areas, may be a limiting factor for moose in this area, especially during the hot summer months (Telfer 1984, Mitra 1999).

Early successional vegetation is the primary source of moose forage and an important habitat element. Open areas following disturbance such as wind-throw, insect damage, wildfire, or timber harvest often contain good moose forage, as does the understory of mature forest with abundant small canopy openings (e.g., Wright 1956; Telfer 1967a, 1967b, 1968, 1970; Prescott 1968; Leptich and Gilbert 1989; Bontaites and Gustafson 1993; Hjeljord and Histol 1999). Studies indicate that moose avoid foraging in large open areas, and generally will not move more than 80-200 m from cover, especially during snowy periods (Eastman 1974, Hamilton et al. 1980, Tomm and Beck 1981, Peek et al. 1987, Jackson et al. 1991, Thompson et al. 1995).

Aquatic resources are an important component of moose habitat in many areas (e.g., Wright 1956, Dunn 1976, Crossley and Gilbert 1983, Leptich and Gilbert 1989, Thompson et al. 1995). However, due to the paucity of wetlands in the Cobequid area, and the acidity and low productivity of aquatic systems in the southwestern region where moose nevertheless persist, the importance of aquatic vegetation for moose in Nova Scotia is ambiguous, and it may not be a critical habitat component (Telfer 1984).

Moose habitat selection and the quality of available habitat are biogeographically variable. There is no clear understanding of moose habitat preferences or the distribution of suitable habitat in Nova Scotia. We present here the results of a preliminary assessment of habitat suitability and spatial distribution based on existing data.

Habitat Suitability Analysis

Quantitative habitat suitability analysis can be used to determine the potential of habitat to support moose populations, to assess the relative suitability of candidate areas for protection or special management practices, and to identify measures which may enhance habitat quality (Allen et al. 1987; Duinker et al. 1991, 1993; Puttock et al. 1996). Habitat suitability is an important consideration when applying species area requirements to the landscape, because the quality and distribution of habitat will influence spatial requirements of individuals and populations (Allen et al. 1987, Jackson et al. 1991). An assessment of habitat suitability must consider all critical habitat components including nutritional, reproductive, and shelter requirements, and may include environmental conditions and land-use practices (Allen et al. 1987, Jackson et al. 1991).

Allen et al. (1987) constructed a Habitat Suitability Index (HSI) model which quantitatively measures the suitability of an area to support moose. The HSI model is based on the assumption that moose require certain habitat components, and that an appropriate relative amount of each component must be present for the habitat to be considered optimal (Allen et al. 1987). However, the model is unable to account for special habitat characteristics, such as mineral licks and calving sites, and non-habitat mortality factors, such as poaching, predation, and human land-use. Thus, for this preliminary study, the HSI distribution will simply be used as a relative ranking of habitat suitability and potential to support moose, rather than an absolute index of potential carrying capacity or population density.

The objectives of the habitat suitability analysis were to: (1) analyze the suitability of moose habitat in Nova Scotia using a HSI model; (2) based on the model, produce a theoretical distribution of habitat suitability across the landscape; (3) test the model by comparing it to pellet group inventory (PGI) data as an index of moose distribution; (4) determine which habitat components may influence moose habitat selection; and (5) examine the effects of human land use on moose habitat selection by using road density as an index of human influence.

METHODS

Habitat Suitability Index Model Construction

Allen et al. (1987) developed two HSI

models for moose habitat evaluation in the Lake Superior Region. Model I involves a complex assessment of seasonal cover and browse quantity, quality, and interspersion. It requires extensive data including height, density, and species composition of forest cover; biomass productivity; browse diversity and quality; and interspersion of food and cover. Model II provides a less detailed examination of habitat based on easily accessible forest cover data and can be used for rapid, low-resolution evaluation of large areas. Although Model II does not consider the fine scale spatial distribution of habitat components, it is useful because it is relatively simple and the necessary data are readily available (Naylor et al. 1992).

The models were designed for use in the Lake Superior Region and have been applied and validated in a number of studies and modified for use in other regions (Allen et al. 1991, Naylor et al. 1992, Puttock et al. 1996, Rempel et al. 1997). For this study, HSI Model II (Allen et al. 1987) was modified based on extensive literature review and local expert opinion, and applied to mainland Nova Scotia for preliminary assessment of moose habitat suitability. The model was used to conduct a GIS-based static inventory of the forest cover, and to estimate the relative potential of the landscape to support moose.

Forest cover inventory. — The 1992 provincial forest cover inventory (Nova Scotia Department of Natural Resources, unpublished data) was used as the input dataset for habitat coverage. These data were provided as an ArcInfo® GIS coverage (UTM NAD83) representing landscape vegetation patterns as polygons. Vegetation was classified by cover type (e.g., forested, non-forested), forest type (e.g., softwood, hardwood), species composition, age, and non-forest attributes such as wetlands and agricultural areas. For this study, the forest cover dataset was analyzed according to the attributes of 4 habitat components used in the HSI model (forage, softwood cover, hard/mixed-wood cover, and wetlands) (Table 1). Any forest cover attributes which did not qualify as critical habitat components had no value in the HSI calculation. Due to the challenges of using polygon data for this type of habitat model, the forest coverage was transformed into point data with points on a 200 m grid (Duinker et al. 1991, 1993; McCallum et al. 1993).

Evaluation units. — Habitat suitability was calculated individually for a series of systematically distributed evaluation units, which together depict the spatial patterns of HSI values across the landscape (Allen et al. 1987, Duinker et al. 1991). Based on considerations of moose home range size, the total size of the study area, and the original design of Model II (recommended evaluation unit of 93 km^2 or larger) (Allen et al. 1987, Duinker et al. 1991), an evaluation unit size of 100 km^2 (10 x 10 km) was selected. The evaluation units were applied to the province using the moving-window technique developed by Duinker et al. (1991, 1993). This technique allows each stand to contribute to the HSI calculation several times, provides a more realistic representation of habitat heterogeneity, and accounts for the possibility that moose ranges overlap the boundaries of evaluation units.

Critical habitat components. — The HSI was calculated based on the relative availability of critical habitat components within each evaluation unit. Following Allen et al.'s (1987) HSI Model II, suitable moose habitat contains 4 habitat components; open forage-producing areas, softwood cover, hardwood or mixed-wood cover, and wetlands. The composition of habitat components was modified slightly from the original model to accommodate the Nova Scotia forest cover classification system and local vegetation characteristics (Table 1). For

Table 1. Habitat component composition and associated forest cover attributes.

Habitat Component	Original Composition (from Allen et al. 1987)	Modified for this Study	Forest Cover Attributes
Forage (SI_1)	Shrub or forested cover types <20 years old	Any forest type <20 years old	**Cover type:** Softwood Mixedwood Hardwood **Age:** <20
Softwood Cover (Winter Cover) (SI_2)	Spruce/fir forest ≥20 years old	Softwood forest ≥20 years old	**Cover type:** Softwood **Age:** ≥20
Hard or Mixedwood Cover (Forage/Cover) (SI_3)	Upland deciduous	Deciduous or mixed forest ≥20 years old	**Cover type:** Hardwood Mixedwood **Age:** ≥20
Wetlands (Aquatic Forage) (SI_4)	Riverine, lacustrine, or palustrine wetlands not dominated by woody vegetation	Wetlands not dominated by woody vegetation, and not including acidic, unproductive wetlands	**Nonforested:** Wetlands Beaver flowage Lake/wetland Marsh/swamp

example, unproductive acidic wetlands were considered unacceptable, and the softwood cover component was broadened to include all softwood species.

The percent availability of habitat components within each evaluation unit was extracted from the converted forest cover point data using ArcInfo®. Suitability index (SI) values were derived for each habitat component using curves which model the predicted suitability of habitat based on percent availability (Fig.1) (Allen et al. 1987). SI values range from 0.0 to 1.0, where 0.0 represents unsuitable habitat and 1.0 represents the optimum proportion of each habitat component. According to the model, optimum moose habitat contains 40 - 50% preferred forage area (SI_1); 5 - 15% softwood forest cover (SI_2); 35 - 55% deciduous or mixed forest cover (SI_3); and 5 - 10% wetlands (SI_4). Evaluation units which did not contain forage or cover received a SI of 0.0. However, evaluation units without wetlands received a SI of 0.2, rather than 0.0, because the resolution of the data may have failed to represent small wetlands, and because areas with no wetlands are not totally unsuitable as moose habitat (Telfer 1984, Allen et al. 1987).

Habitat suitability calculation: — According to the original model, ideal year-round moose habitat contains all 4 habitat components (Allen et al. 1987). The suitability index values were combined to calculate the overall HSI for each evaluation unit. HSI values range from 0.0 to 1.0, where, as with SIs, 0.0 represents highly unsuitable habitat and 1.0 represents optimum moose habitat.

Following Allen et al. (1987), SI values were combined using the geometric mean. Although a variety of mathematical functions may be used to calculate HSI, the geometric mean is a good choice because it

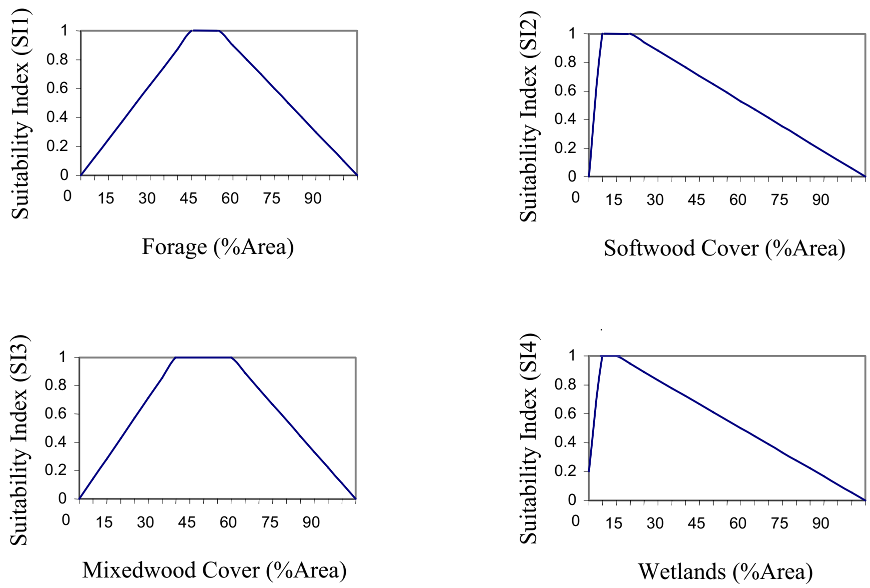

Fig.1. Derivation of Suitability Index (SI) for each habitat component.

assumes that components can partially compensate for one another, but that HSI is affected by the smallest value (Van Horne and Wiens 1991). Any 0.0 SI value will produce an overall HSI of 0.0, which means that in the absence of food or cover, the HSI will always be 0.0 (Van Horne and Wiens 1991).

Six experimental equations were used to calculate HSI values for Nova Scotia (Table 2). Allen et al.'s (1987) original equation (HSI_1) was modified (HSI_2 though HSI_6) to attempt to account for local conditions where it was hypothesized that: (1) mature forest (thermal cover) may be especially critical; (2) wetlands may be less important; and (3) forage beyond 200 m of cover may be of little value.

HSI_1 is the original HSI Model II equation, which calculated the geometric mean of the 4 suitability index values (Allen et al. 1987). HSI_2 and HSI_3 were modified to explore the assumption that aquatic resources may not be a critical habitat component (Telfer 1984). In HSI_2, the wetland component was removed from the equation, and the geometric mean of the 3 remaining habitat components was taken. HSI_3 is similar to HSI_2, but the cover components were weighted more heavily than the forage component due to the possibility that for at least some portion of the winter and/or summer, moose require dense cover and will seek shelter at the expense of food.

To model the known importance of the proximity of food and cover, an additional SI was calculated. SI_{1m} was a modification of SI_1, and was derived using the same forest attributes and suitability curve as SI_1, but only included forage areas located within 200 m of cover. HSI_4, HSI_5, and HSI_6 substitute SI_{1m} for SI_1 into HSI_1, HSI_2, and HSI_3, respectively.

Based on the calculated HSI index values, 6 maps were produced to illustrate the spatial distribution of habitat suitability, and its relative potential to support moose, across the province.

Application of the HSI Model

The validity of the HSI was tested using moose pellet counts collected along PGI transects throughout the province (Nova Scotia Department of Natural Resources, unpublished data). Although PGI data cannot provide reliable estimates of population

Table 2. HSI equations.

$HSI_1 = (SI_1\ SI_2\ SI_3\ SI_4)^{1/4}$	original equation following Allen et al. (1987)
$HSI_2 = (SI_1\ SI_2\ SI_3)^{1/3}$	wetlands removed
$HSI_3 = [SI_1\ (SI_2^2)\ (SI_3^2)]^{1/5}$	wetlands removed and cover weighted more heavily
$HSI_4 = (SI_{1m}\ SI_2\ SI_3\ SI_4)^{1/4}$	same as HSI_1 but using SI_{1m} only includes forage near cover
$HSI_5 = (SI_{1m}\ SI_2\ SI_3)^{1/3}$	same as HSI_2 but using SI_{1m} only includes forage near cover
$HSI_6 = [SI_{1m}\ (SI_2^2)\ (SI_3^2)]^{1/5}$	same as HSI_3 but using SI_{1m} only includes forage near cover

density, they are useful indicators of population trends and habitat selection (Neff 1968, Franzmann et al. 1976, Harkonen and Heikkila 1999). Nova Scotia Department of Natural Resources has conducted a province-wide PGI since 1983 as a tool for estimating the size of the provincial white-tailed deer (*Odocoileus virginianus*) population. As transects were surveyed, moose pellet data were also recorded. Because transects were established randomly, the pellet counts provide a random sample of moose pellet distribution. However, the usefulness of the PGI data is limited because the exact location of pellets within transects and the characteristics of the surrounding habitat were not recorded. Additionally, since only pellets deposited between leaf-fall (November) and pellet count (April/May) were recorded, the PGI data can only be used as an indication of moose habitat selection during the period from late fall to early spring. The modified HSI equations were conducive to an analysis of fall/winter habitat suitability because during winter, aquatic resources are not critical, thermal cover is required, and forage within close proximity to cover is preferred.

The PGI location data were converted into UTM NAD83 and plotted in ArcInfo®. The transects were overlain on the previously generated HSI coverages. Each transect was assigned the habitat characteristics and HSI index of the corresponding HSI evaluation unit. When a transect crossed more than one HSI evaluation unit, it was assigned the value of the unit where the majority of the transect was located. A database table suitable for statistical analysis was produced which included transect identification numbers and their associated habitat values and HSI indices.

Preliminary descriptive statistics were generated for the PGI pellet count data using Microsoft Excel® and SPSS® 9.0 to identify the best summary statistic for the data. Scatter plots were produced for each transect to examine the distribution of moose pellet counts over time. Many transects (67.39%) contained zero moose pellets in all years. Pellet counts were generally low on transects where moose pellets were observed (1983-2000, 524 transects: $n = 7702$, mean = 0.70, median = 0, SD = 3.64, range = 0-79), and there were no observable patterns consistent among transects over time. For these reasons, and because the reliability of using pellet counts as an indication of moose density is tenuous, presence/absence was selected as the best statistic to summarize pellet counts on transects over time (Franzmann et al. 1976, Harkonen and Heikkila 1999).

All PGI data collected after 1992 were excluded from analysis because the forest inventory used to generate the HSI was current only to 1992. After transects were excluded from analysis due to missing data or because they were located outside the study area (on Cape Breton Island), 370 transects remained for analysis.

To test the validity of the models, we examined the ability of HSIs to predict the presence/absence of moose pellets using logistic regression analysis. Additional analyses were run to determine the ability of each of the 4 critical habitat components independently to predict pellet presence/absence, and to examine the influence of individual habitat components on overall habitat suitability. The results of these analyses can be used to construct a more reliable suitability index for Nova Scotia.

Due to their geographical nature, habitat values are inherently auto-correlated, or spatially dependent. However, auto-correlation must be identified because it violates the mathematical assumptions of regression analysis (Goodchild 1986). The residuals of logistic regression analysis were tested for auto-correlation using the Geary and Moran indices of the GRID function in ArcInfo®, and wherever auto-correlation was identified, the results must be interpreted with caution.

Effect of Road Density

Habitat suitability is likely affected by a variety of factors, such as human land-use practices, which were not accounted for in the HSI models. Road density was selected as a surrogate index of human influence. Using GIS, road density (including all major and secondary roads, trails, railways, cart-tracks, and woods roads) was divided into 6 classes (density classes (km/km^2): 0, 0.1-0.06, 0.06-0.6, 0.6-1, 1-3, >3) and mapped on a 1 x 1 km grid (Fig.2) (Beazley et al. 2004). Additional regression analyses were run to determine the ability of road density to predict the presence of moose pellets, and to examine the effects of roads on habitat suitability by running multivariate logistic regression, using roads in combina-

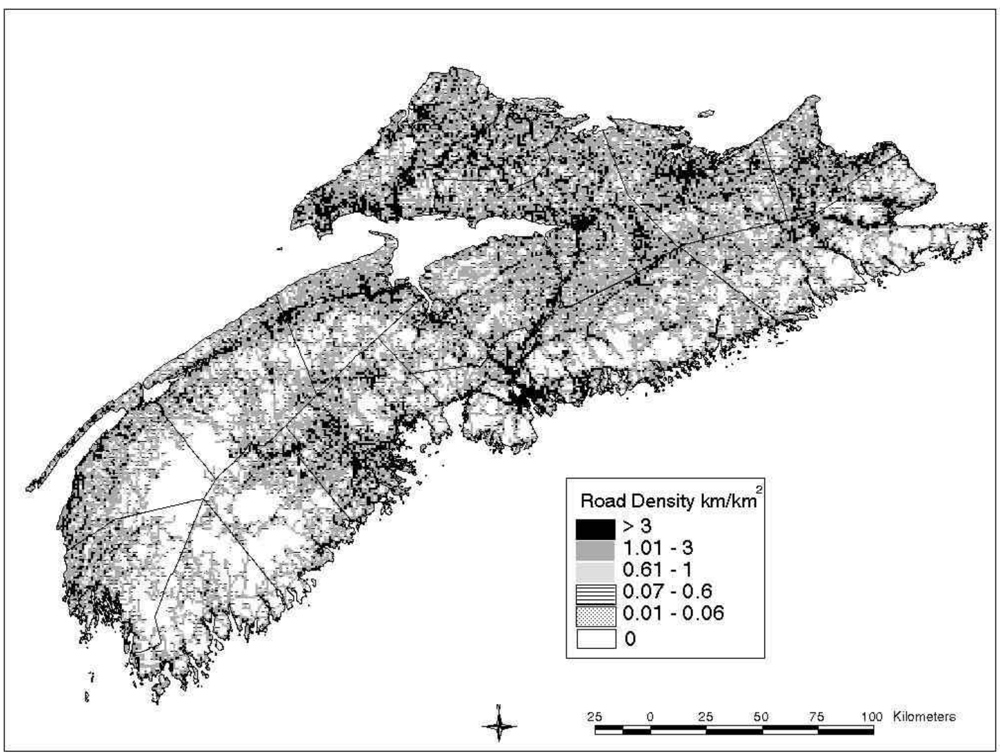

Fig.2. Road density in mainland Nova Scotia.

tion with the habitat suitability values, to predict moose pellet presence.

RESULTS

Habitat Suitability Modeling

Results of the HSI modeling indicate that there is little highly suitable moose habitat in Nova Scotia. HSI values were mapped to show the spatial distribution of habitat suitability across the landscape (Fig.3). For graphic representation, HSI values were divided into 5 suitability categories: very poor (HSI = 0.00-0.19); poor (0.20-0.39); moderate (0.40-0.59); good (0.60-0.79); and very good (0.80-1.00). According to all equations, a large amount of the mainland was of very poor (27.48-29.31%), poor (14.08-31.89%), or moderate (36.29-52.44%) habitat suitability. Only 2.50-12.87% was of good suitability, and 0.0-0.42% was very good (Fig.4). In effect, the models predicted that only 1,114-5,737 km^2 of the Nova Scotia mainland were good, and 0-185 km^2 were very good moose habitat.

The spatial distribution of HSI values across the landscape differed little among HSI equations. In general, the southern coastal areas were of very low suitability, inland areas were slightly more suitable, and the few areas of high suitability were located mostly in the hilly regions of the Cobequid and Pictou-Antigonish Highlands.

Application of the HSI Model

Summary statistics indicated that of the 370 transects, only 126 (34.1%) had at least one moose pellet between 1983 and 1992, while moose pellets were completely absent from 244 (65.9%) transects (Fig.5). The spatial distribution of pellets seemed to correspond roughly to known moose distributions, with concentrations in the Tobeatic and the Cobequid to Antigonish Highland

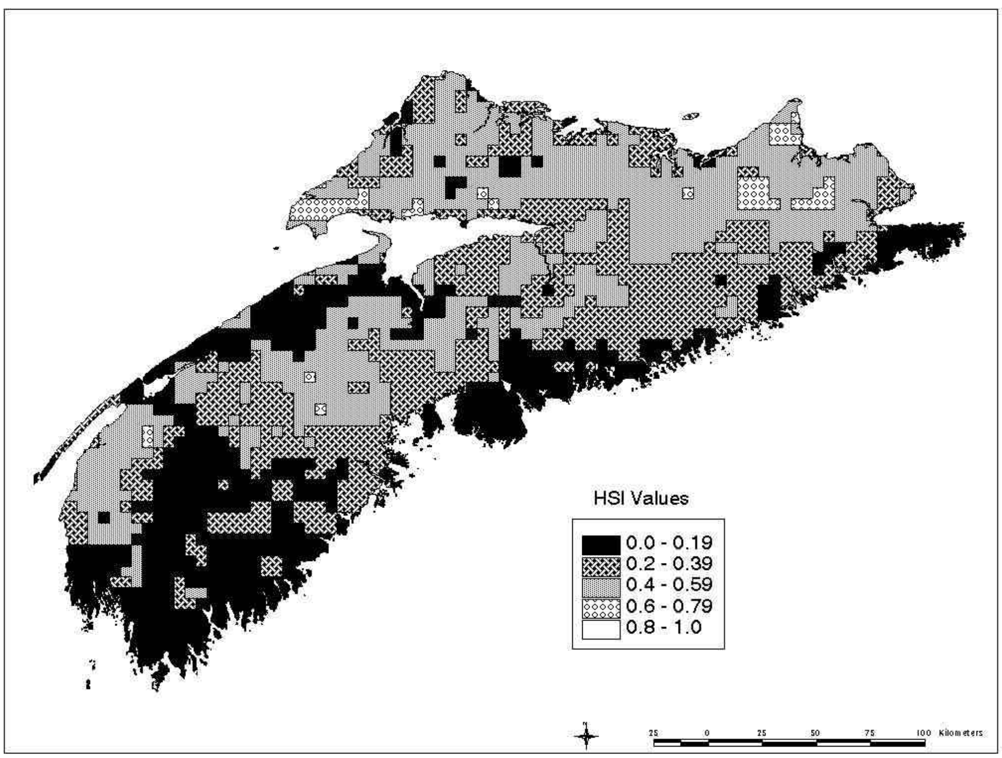

Fig.3. An example of theoretical habitat suitability distribution for mainland Nova Scotia (HSI$_5$).

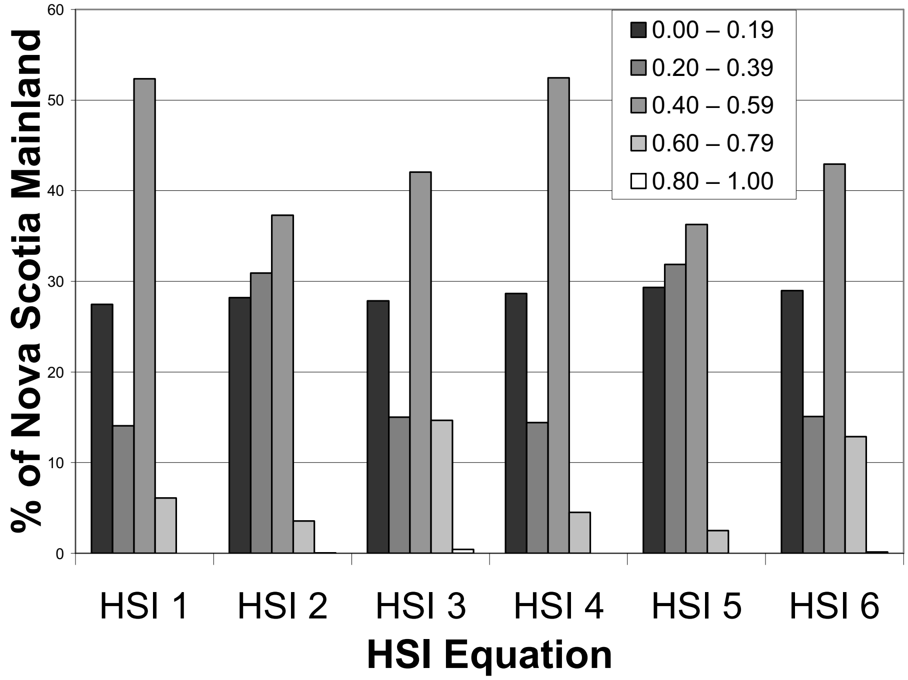

Fig.4. Summary of habitat suitability in mainland Nova Scotia from 6 experimental equations.

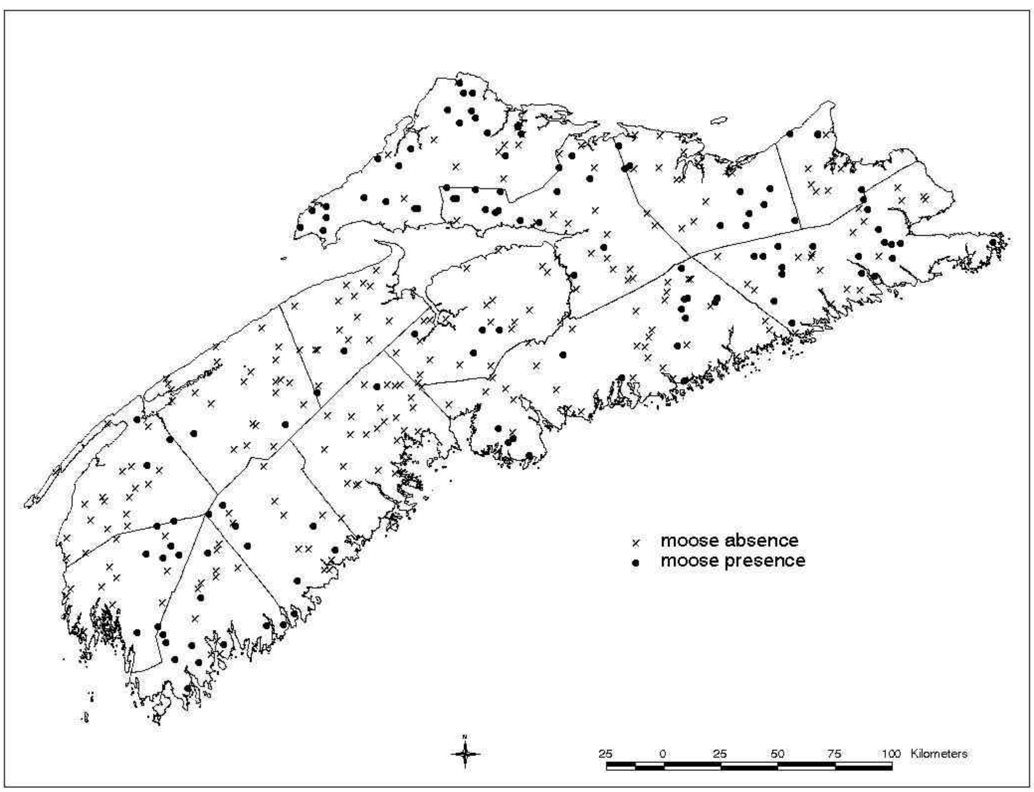

Fig.5. Distribution of moose pellet presence on PGI transects.

areas. However, pellet presence was scattered throughout much of the rest of the province, and may represent occasional or low-density moose occupation, or perhaps pellet presence from the early years of PGI surveys when moose populations were more widely distributed (Kelsall 1987, Timmermann and Buss 1997). Unfortunately, due to the nature of PGI data, and the simplification to presence/absence, it was not possible to identify trends through time or to make any inferences about moose densities across the province.

The results of logistic regression analysis indicated that none of the 6 HSI models could predict the presence of moose pellets. Only 2 individual habitat components (forage and forage in proximity to cover) could significantly predict the presence of moose pellets across the landscape (Table 3). Results of the test for spatial dependence indicate that the habitat suitability data were autocorrelated (forage: Geary 0.006, Moran 0.001; forage in proximity to cover: Geary 0.006, Moran 0.001).

Effect of Road Density

Regression analysis indicated that road density could significantly predict the presence of moose pellets (Table 3). A significant negative correlation suggested that as road density increased, the probability of moose pellet presence decreased. When multivariate logistic regression was used to test the combined effect of road density and HSI results on pellet presence, all HSI values and individual habitat components, when combined with the effect of roads, could

Table 3. The ability of habitat values and road density to predict moose pellet presence on transects (Chi-square values from regression analysis).

	Habitat values or roads alone[1]	Habitat and road combined[2]	Roads after habitat is accounted for[1]	Habitat after roads are accounted for[1]
HSI 1	1.567	*16.412	*15.954	1.459
HSI 2	1.567	*20.297	*18.085	*5.178
HSI 3	0.338	*17.515	*16.702	2.529
HSI 4	0.000	*15.830	*15.483	0.892
HSI 5	1.059	*19.069	*17.453	*4.022
HSI 6	0.254	*17.136	*16.445	2.166
Comp. 1[3]	*16.229	*38.576	*21.519	*21.248
Comp. 1m	*15.312	*37.388	*21.254	*20.605
Comp. 2	0.464	*14.994	*14.291	0.067
Comp. 3	0.209	*14.931	*14.501	0.004
Comp. 4	3.162	*19.375	*15.886	3.903
Roads	*14.927	N/A	N/A	N/A

* significant result $P < 0.05$.

[1] 1 degree of freedom.

[2] 2 degrees of freedom.

[3] Comp. = habitat components as described in Table 1.

significantly predict pellet distribution. After the effect of HSI was statistically accounted for, road density was able to predict moose pellet presence in all cases. Conversely, once roads were accounted for, only HSI_2 and HSI_5, forage, and forage in proximity to cover, were able to predict pellet presence. However, there was spatial dependence among the road density data (Geary 0.006, Moran 0.002) and the results must be interpreted with caution.

DISCUSSION

The results of the HSI modeling suggest that HSI_2 and HSI_5, in combination with road density, may provide a reliable index of moose habitat quality in Nova Scotia. However, these results should not be accepted as conclusive, as the validation using PGI does not account for summer habitat selection, when thermal cover is likely more critical.

According to these models, there is little optimal moose habitat in Nova Scotia. This is not surprising given the current low densities of moose populations in the province (although a host of other factors likely contribute to limit the population). The results of this analysis may help to explain the current distribution of moose in Nova Scotia. High suitability indices occurred in the areas known to contain the largest and most stable moose populations (Cobequid and Pictou-Antigonish Highlands), while the south-western region (also known to contain a remnant population) likely supports moose due to low road density, despite poor habitat suitability.

Statistical analysis using moose pellet data as an index of habitat selection was unable to validate the HSI models alone. HSI alone was unable to predict the presence of moose pellets across the landscape, and forage was the only habitat component that significantly predicted moose pellet presence. The importance of forage within close proximity to cover, and its influence on habitat suitability, remains unclear because forage was significantly related to pellet presence when all forage areas were included and when only forage areas within 200 m of cover were included in the calculation of HSI.

The results suggest that human influence, as indicated by road density, had a greater effect on moose habitat selection, and presumably habitat suitability, than habitat composition alone. This hypothesis is supported by the significant relationship between road density and moose pellet presence on provincial transects, and strengthened by the ability of 2 of the HSI indices (Equations 2 and 5) to predict pellet presence after the effect of road density was accounted for. This result is interesting because it indicates that, roads being equal, these 2 HSI calculations might approximate fall and winter habitat suitability for moose in mainland Nova Scotia. Future models should include road density as an initial habitat variable.

Statistical validation of the HSI models was limited by the nature of the PGI data. The intent of the original HSI model was to predict the potential carrying capacity of moose habitat, and did not suggest that moose cannot survive or will not be present in sub-optimal habitat. When further data, such as aerial surveys or more comprehensive PGI, become available, the HSI model should be compared to moose density, rather than pellet presence/absence, for validation. Furthermore, year-round moose distribution data are required to ensure the inclusion of summer habitat suitability when mature forest for thermal cover is likely critical.

Further research is required to strengthen habitat suitability analysis, to validate its ability to delineate critical habitat, and to determine the effects of human land-use practices such as roads and forest management. A better model for habitat suitability will incorporate human-induced habitat characteristics, such as road density, into index calculation. The results of this type of analysis can be used to identify critical habitat areas as candidates for protection, and to make management recommendations which will improve habitat suitability for moose in Nova Scotia.

ACKNOWLEDGEMENTS

T. Snaith and K. Beazley thank Tony Nette, Vince Power, Dalhousie University Faculty of Graduate Studies, School for Resource and Environmental Studies, EJLB Foundation, Canadian Wildlife Federation, Frederik Doyon, Wade Blanchard, and Tony Schellinck. F. MacKinnon thanks David Colville, Bob Maher, Tony Nette, Nova Scotia Department of Natural Resources, the Sustainable Forest Network, Bowater Mersey Paper Co. Ltd., J.D. Irving, and seventeen member groups of the Nova Scotia Federation of Hunters and Anglers. We thank the editor of Alces and two unknown reviewers for helpful comments and suggestions.

REFERENCES

ALLEN, A. W., P. A. JORDAN, and J. W. TERRELL. 1987. Habitat suitability index models: moose, Lake Superior region. U.S. Department of the Interior Biological Report 82 (10.155).

_______, J. W. TERRELL, W. L. MANGUS, and E. L. LINDQUIST. 1991. Application and partial validation of a habitat model for moose in the Lake Superior region. Alces 27:50-64.

BEAZLEY, K. 1997. Ecological considerations for protected area system design. Proceedings of the Nova Scotia Institute of Science 41:59-76.

_______, P. AUSTIN-SMITH, and M. RADER. 2002. Toward completing a protected areas system for Nova Scotia. Pages 516 - 530 *in* S. Bondrup-Nielsen and N. Munro, editors. Managing Protected Areas in a Changing World. Proceedings of the Fourth International Conference on Science and the Management of Protected Areas. Wolfville, Nova Scotia, Canada. May 14-19, 2000.

_______, T. SNAITH, F. MACKINNON, D. COLVILLE, and S. BROWN. 2004. Road density and impacts on mammals in Nova Scotia. Proceedings of the Nova Scotia Institute of Science 42:152-170.

BONTAITES, K. M., and K. GUSTAFSON. 1993. The history and status of moose and moose management in New Hampshire. Alces 29:163-167.

(CESC) CANADIAN ENDANGERED SPECIES COUNCIL. 2001. Wild species 2000: the general status of species in Canada. Ministry of Public Works and Government Services, Ottawa, Ontario, Canada.

COADY, J. W. 1974. Influence of snow on behavior of moose. Naturaliste Canadien 101:417-436.

CROSSLEY, A., and J. R. GILBERT. 1983. Home range and habitat use of female moose in northern Maine - a preliminary look. Transactions of the Northeast Section of the Wildlife Society 40:67-75.

DODDS, D. G. 1963. The present status of moose (*Alces alces americana*) in Nova Scotia. Proceedings of the Northeast Wildlife Conference 2:1-40.

_______. 1974. Distribution, habitat and status of moose in the Atlantic provinces of Canada and northeastern United States. Naturaliste Canadien 101:51-65.

DUINKER, P. N., P. E. HIGGELKE, and N. A. BOOKEY. 1993. Future habitat for moose on the Aulneau Peninsula, northwest Ontario. Pages 551-556 *in* 7th Annual Symposium on Geographic Information Systems in Forestry, Environment and

Natural Resources Management, Vancouver, British Columbia, 15-18, February 1993.

______, ______, and S. Koppikar. 1991. Pages 271-275 *in* GIS-based habitat supply modelling in Northwestern Ontario: moose and marten. GIS'91 An International Symposium. Geographic Information Systems, Vancouver, British Columbia, February 1991.

Dunn, F. 1976. Behavioural study of moose. Maine Department of Inland Fish and Wildlife Project W-66-R-6 Job 2-1.

Eastman, D. S. 1974. Habitat use by moose of burns, cutovers and forests in north-central British Columbia. Proceedings of the North American Moose Conference and Workshop 10:238-256.

Forman, R. T. T., D. S. Friedman, D. Fitzhenry, J. D. Martin, A. S. Chen, and L. E. Alexander. 1997. Ecological effects of roads: toward three summary indices and an overview for North America. Pages 40-54 *in* K. Canters, editor. Habitat fragmentation and infrastructure. Ministry of Transportation, Public Works and Government Services, Delft, Netherlands.

Franzmann, A. W., J. L. Oldemeyer, P. D. Arneson, and R. K. Seemel. 1976. Pellet-group count evaluation for census and habitat use of Alaskan moose. Proceedings of the North American Moose Conference and Workshop 12:127-142.

Goodchild, M. F. 1986. Spatial autocorrelation. Geo Books, CATMOG 47, Norwich, U.K.

Hamilton, G. D., P. D. Drysdale, and D. L. Euler. 1980. Moose winter browsing patterns on clear-cuttings in northern Ontario. Canadian Journal of Zoology 58:1412-1416.

Harcombe, A. P. 1988. Wildlife habitat handbooks for the southern interior ecoprovince. Volume 5: species-habitat relationship models for mammals. Ministry of the Environment, Victoria, British Columbia, Canada.

Harkonen, S., and R. Heikkila. 1999. Use of pellet group counts in determining density and habitat use of moose *Alces alces* in Finland. Wildlife Biology 5:227-233.

Heikkila, R., K. Nygren, S. Harkonen, and A. Mykkanen. 1996. Characteristics of habitats used by female moose in the managed forest area. Acta Theriologica 41:321-326.

Hjeljord, O., and T. Histol. 1999. Range-body mass interactions of a northern ungulate - a test of hypothesis. Oecologia 119:326-339.

______, N. Hovik, and H. Pedersen. 1990. Choice of feeding sites by moose during summer, the influence of forest structure and plant phenology. Holarctic Ecology 13:281-292.

Hogg, D. 1990 Moose management: the forest habitat. Pages 30-33 *in* M. Buss and R. Truman, editors. The moose in Ontario, Book 1. Ontario Ministry of Natural Resources, Queen's Printer for Ontario, Toronto, Ontario, Canada.

Houston, D. B. 1968. The Shiras moose in Jackson Hole, Wyoming. U.S. Department of the Interior Technical Bulletin 1:1-62.

Jackson, G. L., J. G. Racey, J. G. McNicol, and L. A. Godwin. 1991. Moose habitat interpretation in Ontario. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Technical Report 52.

Kelsall, J. P. 1987. The distribution and status of moose in North America. Swedish Wildlife Research Supplement 1:1-10.

Knowlton, F. F. 1960. Food habits, movements and populations of moose in the Gravelly Mountains, Montana. Journal of Wildlife Management 24:162-170.

LEPTICH, D. J., and J. R. GILBERT. 1989. Summer home range and habitat use by moose in Northern Maine. Journal of Wildlife Management 53:880-885.

MCCALLUM, I., P. HIGGELKE, and P. DUINKER. 1993. GIS-based habitat supply analysis for moose (*Alces alces*) and marten (*Martes americana*) in northern Ontario forests. Pages 370-375 *in* Proceedings of the International Union of Game Biologists XXI Congress: Forests and wildlife - towards the 21st century. Chalk River, Ontario, Canada.

MCNICOL, J. 1990. Moose and their environment. Pages 11-18 *in* M. Buss and R. Truman, editors. The moose in Ontario, Book 1. Ontario Ministry of Natural Resources, Queen's Printer for Ontario, Toronto, Ontario, Canada.

MILLER, B., R. READING, J. STRITTHOLT, C. CARROLL, R. NOSS, M. SOULÉ, O. SANCHEZ, J. TERBORGH, D. BRIGHTSMITH, T. CHEESEMAN, and D. FOREMAN. 1998-1999. Using focal species in the design of nature reserve networks. Wild Earth 9:81-92.

MIQUELLE, D. G., J. M. PEEK, and V. VAN BALLENBERGHE. 1992. Sexual segregation in Alaskan Moose. Wildlife Monographs 122.

MITRA, P. 1999. Predictive modelling of moose habitat in the Tobeatic Wilderness Management Area. College of Geographical Science, Lawrencetown, Nova Scotia, Canada.

NAYLOR, B., S. CHRISTILAW, and P. WIELANDT. 1992. Validation of a habitat suitability index model for moose in the northern portion of the Great Lakes-St. Lawrence forest region of Ontario. Ontario Ministry of Natural Resources, Central Ontario Forest Technology Development Unit, Technical Report 26.

NEFF, D. J. 1968. The pellet-group count technique for big game trend, census, and distribution: a review. Journal of Wildlife Management 32:597-614.

NOSS, R. F. 1995. Maintaining ecological integrity in representative reserve networks. World Wildlife Fund Canada, Toronto, Ontario, Canada.

_______. 1996. Protected areas: how much is enough? Pages 91-120 *in* G. R. Wright, editor. National parks and protected areas: their role in environmental protection. Blackwell Science, Cambridge, Massachusetts, USA.

_______, J. R. STRITTHOLT, K. VANCE-BORLAND, C. CARROLL, and P. FROST. 1999. A conservation plan for the Klamath-Siskiyou ecoregion. Natural Areas Journal 19:392-411.

PEEK, J. M., D. J. PIERCE, D. C. GRAHAM, and D. L. DAVIS. 1987. Moose habitat use and implications for forest management in northcentral Idaho. Swedish Wildlife Research Supplement 1:195-199.

PETERSON, R. L. 1955. North American Moose. University of Toronto Press, Toronto, Ontario, Canada.

PRESCOTT, W. H. 1968. A study of winter concentration areas and food habits of moose in Nova Scotia. M.Sc. Thesis, Acadia University, Wolfville, Nova Scotia, Canada.

PULSIFER, M. D., and T. L. NETTE. 1995. History, status and present distribution of moose in Nova Scotia. Alces 31:209-219.

PUTTOCK, G. D., P. SHAKOTKO, and J. G. RASAPUTRA. 1996. An empirical habitat model for moose, *Alces alces*, in Algonquin Park, Ontario. Forest Ecology and Management 81:169-178.

REMPEL, R. S., P. C. ELKIE, A. R. RODGERS, and M. J. GLUCK. 1997. Timber-management and natural-disturbance effects on moose habitat: landscape evaluation. Journal of Wildlife Management 61:517-524.

RENECKER, L. A., and R. J. HUDSON. 1986.

Seasonal energy expenditures and thermoregulatory responses of moose. Canadian Journal of Zoology 64:322-327.

SCHWAB, F. E., and M.D. PITT. 1991. Moose selection of canopy cover types related to operative temperature, forage, and snow depth. Canadian Journal of Zoology 69:3071-3077.

SNAITH, T., and K. BEAZLEY. 2002. Moose *(Alces alces)* as a focal species for reserve design in Nova Scotia, Canada. Natural Areas Journal 22:235-240.

_______. 2004. The distribution, status, and habitat associations of moose in mainland Nova Scotia. Proceedings of the Nova Scotia Institute of Science 42:76-134.

TELFER, E. S. 1967a. Comparison of a deer yard and a moose yard in Nova Scotia. Canadian Journal of Zoology 45:485-490.

_______. 1967b. Comparison of moose and deer winter range in Nova Scotia. Journal of Wildlife Management 31:418-425.

_______. 1968. Distribution and association of moose and deer in central New Brunswick. Transactions of the Northeast Section of the Wildlife Society 25:41-70.

_______. 1970. Winter habitat selection by moose and white-tailed deer. Journal of Wildlife Management 34:553-558.

_______. 1984. Circumpolar distribution and habitat requirements of moose (*Alces alces*). Pages 145-182 *in* R. Olson, R. Hastings, and F. Geddes, editors. Northern ecology and resource management. University of Alberta Press, Edmonton, Alberta, Canada.

THOMPSON, I. D., and D. L. EULER. 1987. Moose habitat in Ontario: A decade of change in perception. Swedish Wildlife Research Supplement 1:181-193.

THOMPSON, M. E., J. R. GILBERT, G. J. MATULA, and K. I. MORRIS. 1995. Seasonal habitat use by moose on managed forest lands in northern Maine. Alces 31:233-245.

TIMMERMANN, H. R., and M. E. BUSS. 1997. The Status and Management of Moose in Northern America in the Early 1990s. Ontario Ministry of Natural Resources, Thunder Bay, Ontario, Canada.

_______, and J. G. MCNICOL. 1988. Moose habitat needs. Forestry Chronicle 1988:238-245.

TOMM, H. O., and J. A. BECK, JR. 1981. Responses of wild ungulates to logging practices in Alberta. Canadian Journal of Forest Research 11:606-614.

VAN HORNE, B., and J. A. WIENS. 1991. Forest bird habitat suitability models and the development of general habitat models. Fish and Wildlife Research Paper 8:1-31.

WRIGHT, B. S. 1956. The moose of New Brunswick. New Brunswick Department of Lands and Mines, Fredericton, New Brunswick, Canada.