APPLICATION AND PARTIAL VALIDATION OF A HABITAT MODEL FOR MOOSE IN THE LAKE SUPERIOR REGION

Arthur W. Allen[1], James W. Terrell[1], Warren L. Mangus[1] and Edward L. Lindquist[2]
[1]National Ecology Research Center, U.S. Fish and Wildlife Service, 4512 McMurry Ave., Fort Collins, CO 80525-3400; [2]Superior National Forest, 515 West 1st Street, P.O. Box 338, Duluth, MN 55801.

ABSTRACT: A modified version of the dormant-season portion of a Habitat Suitability Index (HSI) model developed for assessing moose (*Alces alces*) habitat in the Lake Superior Region was incorporated in a Geographic Information System (GIS) for 490 km^2 of Minnesota's Superior National Forest. Moose locations ($n = 235$) were plotted during aerial surveys conducted in December 1988 and January 1990-1991. Dormant- season forage and cover quality for 1,000-m, 500-m, and 200-m radii plots around random points and moose locations were compared using U.S. Forest Service stand examination data. Cover quality indices were lower than forage quality indices within all plots. The median value for the average cover quality index was greater ($P = 0.003$) within 200-m plots around cow moose locations than for plots around random points for the most severe winter of the study. The proportion of highest-quality winter cover, such as mixed stands dominated by mid-age class white spruce (*Picea glauca*) and balsam fir (*Abies balsamea*), was greater within 500-m and 200-m plots around cow moose than within similar plots around random points during the two most severe winters. These results indicate that suboptimum ratings of winter habitat quality used in the GIS for dormant-season forage >100 m from cover, as suggested in the original HSI model, are reasonable. Integrating the habitat model with forest stand data using a GIS permitted analysis of moose habitat within a relatively large geographic area. Simulation of habitat quality indicated a potential shortage of late-winter cover in the study area. The effects of forest management actions on moose habitat quality can be simulated without collecting additional data.

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Integrated planning between forest and wildlife managers with well- defined goals offers the most viable approach to maintain or enhance wildlife habitat quality within managed forest ecosystems (Eastman and Ritcey 1987, McNicol and Gilbert 1987). However, effectively accommodating the habitat requirements of forest-dependent species requires spatial evaluation of forest ecosystems. Effective management of forested ecosystems to improve wildlife habitat often is limited by incomplete data or by information that is not organized in ways to justify modification of silvicultural prescriptions (Ellis 1986).

Geographic Information Systems (GIS) are useful for organizing and analyzing large amounts of habitat data. The U.S. Forest Service (FS) is beginning to use GIS technology to evaluate forest management throughout the national forest system, including the Superior National Forest (SNF) in northeastern Minnesota. The SNF plans to use a GIS with habitat quality measures four ways: (1) in implementing the FS Wildlife and Fish Habitat Relationships System; (2) in addressing how forest fragmentation affects wildlife habitat and consequently biodiversity; (3) in implementing forest plans; and (4) in accomplishing the FS mission by more effectively analyzing and exchanging resource information. The moose is one of 34 species identified for monitoring on the SNF. Populations are believed to be influenced by habitat changes resulting from forest management (Henson 1986). The habitat needs and biology of moose in northeastern Minnesota have been intensively investigated (e.g., Peek 1971, Peek *et al.* 1976); and moose habitat models applicable to this region have been developed (Allen *et al.* 1987). The concurrent availability of biological data and habitat models, combined with the spatial complexity of SNF, provides an opportunity to build a realistic, operational, landscape-level GIS to predict moose habitat changes due to forest management practices.

The likelihood that logging alters the amount and distribution of moose habitat provides an additional incentive to develop an operational GIS. Our goal in this study was to develop and evaluate an operational, prototype, habitat based model that would incorporate interspersion between required habitat resources and provide a credible, timely analysis of moose habitat over a large geographic area. We attempted to meet the criteria of Ellis (1986) that a habitat analysis be founded on accepted techniques, be reliable at the current level of management sophistication, and operate on commonly collected, readily available forest inventory data. Our specific objectives were to: (1) evaluate the validity of the suitability rating for mean distance to dormant- season cover presented by Allen *et al.* (1987); (2) develop and incorporate ratings for dormant-season forage and cover into a GIS based on existing FS stand exam data that could be systematically modified to include results of future research; (3) apply a GIS-based moose habitat model to a relatively large area on the SNF to evaluate the validity of the dormant-season forage and cover ratings; and (4) demonstrate how the GIS-based habitat model and resulting habitat analysis could be used to refine forest management prescriptions and set management goals.

STUDY AREA

All analyses were conducted on digitized data themes for a 490-km^2 portion of the SNF in northeast Minnesota. The study area, as used in this paper, refers to the 344 km^2 area of 10 Minnesota Department of Natural Resources (MDNR) moose survey units located within the digitized area. The landscape within the study area is dominated by nearly continuous forest interspersed with palustrine, lacustrine and riverine wetlands. Forest vegetation includes both boreal and temperate components. Common upland coniferous trees include jack pine (*Pinus banksiana*), red pine (*P. resinosa*), black spruce (*P. mariana*), white pine (*P. strobus*), balsam fir, and white spruce. Upland deciduous stands are dominated by quaking aspen (*Populus tremuloides*), bigtooth aspen (*P. grandidentata*), and paper birch (*Betula papyrifera*). Trees dominating the forested wetlands include black spruce, northern white cedar (*Thuja occidentalis*) and black ash (*Fraxinus nigra*). More thorough descriptions of vegetation and the landscape in the vicinity of the study area are provided by Peek et al. (1976) and Rogers (1987).

METHODS

Two HSI models (Model I, Model II; Allen *et al.* 1987) for evaluating moose habitat in the Lake Superior Region provided the starting point for our GIS-based model of moose habitat. Model I is comprised of two separate submodels to evaluate growing-season (mid-May to mid-September) and dormant-season (mid-September to mid-May) forage and cover quality. Application of Model I requires measuring browse biomass (g/m^2), browse diversity, canopy cover and species composition of trees, and estimating the distance between forage and cover resources. Definition of habitat quality in Model I is based largely on the nutritional requirements of lactating cows which have the highest nutritional demands of individual moose, and the habitat needs of cows with calves which are restricted in habitat use during severe weather. Model II is a less intensive approach that incorporates the habitat composition guidelines of Peek *et al.* (1976) and is intended for rapid evaluations of township (93 km^2) or larger sized areas based on analysis of aerial photography or vegetation maps.

Our objectives could not be met expeditiously by either Model I or II because we did not have the resources to develop the detailed browse production data for individual stands.

Model I and Model II does not differentiate habitat management prescriptions at the spatial scale typical of stand inventory data. Therefore, we developed a GIS-based model using the concepts of the dormant-season component of Model I. We used Model I to complete a matrix of late-winter cover and forage suitability indices that matched the level of detail provided in FS stand exam records and as the source of algorithms defining optimum late-winter interspersion and habitat using the area within 100 m of high quality (SI $\geq$0.5) forage and cover. This information was incorporated into the GIS and is referred to as Model III. The definitions of optimum late-winter habitat and interspersion are based on results of investigations (e.g., Peek *et al.* 1976, Hamilton *et al.* 1980, Welsh *et al.* 1980, Thompson and Vukelich 1981, Peek and Eastman 1983, Thompson and Euler 1987) which indicate that mature, dense, conifer-dominated stands adjacent to, or near, suitable and adequate amounts of forage characterize high-quality winter habitat for moose.

Model I of Allen *et al.* (1987) contains a suitability index (SI) curve to rate the mean distance between winter cover and forage and defines optimum late-winter habitat as areas that have both high quality cover and forage within 100 m. The validity of this SI curve and definition of optimum late-winter habitat were evaluated by comparing the area, species composition, relative age, and spatial distribution of forest stands within various size circular plots centered on moose locations and randomly-located points throughout the study area.

GIS data themes consisted of: (1) 79 forest compartments comprised of more than 3,600 forest stands; (2) cover type maps showing vegetation species composition and size class/stocking rates of each stand for the autumn immediately preceding each moose survey; (3) suitability indices (from our matrix) of dormant-season forage and cover quality for all possible combinations of forest type, tree size, and stocking rate; (4) boundaries of 10 MDNR moose survey units within the digitized area; and (5) sex and locations of moose observed during early-winter aerial surveys.

Forest compartments and stand boundaries

Forest compartment and stand boundaries were digitized from FS forest compartment/stand maps [1:15,840 (4" = 1 mi)]. Each stand was assigned a unique 11 digit code representing Ranger District, compartment number, stand number, forest type, tree size, and stocking rate.

Cover types

Stand types were based on 23 forest types and 10 size/stocking rate classes, yielding 230 potential stand types dominated by tree species of various age classes and stocking rates. Upland and lowland shrubs (e.g., *Alnus* and *Salix* spp.) were each classified based on three density classes to define 6 additional shrub types. The forest stand and shrub types combined with open (nonforested), lake, and unknown types represented a total of 239 potential cover types. Data were updated yearly to include changes due to timber harvest.

Dormant-season forage and cover indices

Model I (Allen *et al.* 1987) defines a dormant-season forage suitability index (FSI) from gm/m^2 of browse within individual stand types. These data were unavailable for the study area. To make Model III more compatible with financial and time constraints for large-scale FS applications, we used browse preference information provided in Model I to define a dormant-season FSI for each cover type (Table 1). The FSI is assumed to describe the availability of dormant-season forage within each cover type based on relationships similar to those illustrated in Fig. 1. FSI's were high in young age-class deciduous and mixed stands and decreased with increasing age and density. We assumed, for example, that seedling/sapling aspen stands provide abundant, available forage (Fig. 1,

Table 1. Dormant-season forage suitability indices (FSI) based on forest type and size/density class.

	Size/density classes[a]									
Forest type	0	1	2	3	4	5	6	7	8	9
01 Jack pine	0.5[b]	1.0	1.0	1.0	0.5	0.2	0.1	0.1	0.1	0.0
02 Red pine	0.5	1.0	1.0	1.0	0.5	0.2	0.1	0.1	0.2	0.0
03 White pine	0.0	0.2	0.2	0.2	0.1	0.1	0.1	0.0	0.0	0.0
11 Balsam fir/aspen/paper birch	0.1	1.0	1.0	1.0	0.5	0.5	0.5	0.1	0.1	0.1
12 Lowland black spruce	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13 Red spruce/balsam fir	0.0	0.2	0.2	0.2	0.1	0.1	0.1	0.0	0.0	0.0
14 Northern white cedar	0.0	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
15 Tamarack	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 White spruce/balsam fir/ norway spruce	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
17 Upland black spruce	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
18 Mixed swamp conifer	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
19 Cedar/aspen/paper birch	0.0	0.5	0.5	0.5	0.1	0.1	0.1	0.1	0.1	0.0
33 Virginia pine	0.0	1.0	1.0	1.0	0.5	0.2	0.2	0.1	0.1	0.0
71 Black ash/American elm	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
76 Red maple (wetland)	0.0	0.5	0.5	0.5	0.2	0.2	0.2	0.1	0.1	0.1
79 Mixed lowland hardwoods	0.0	1.0	1.0	1.0	0.5	0.5	0.5	0.1	0.1	0.1
81 Sugar maple/yellow birch	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
84 Red maple (upland)	0.0	0.5	0.5	0.5	0.2	0.2	0.2	0.1	0.1	0.1
91 Quaking aspen	1.0	1.0	1.0	1.0	0.5	0.5	0.5	0.1	0.1	0.1
92 Paper birch	1.0	1.0	1.0	1.0	0.5	0.5	0.5	0.1	0.1	0.1
93 Bigtooth aspen	1.0	1.0	1.0	1.0	0.5	0.5	0.5	0.1	0.1	0.1
94 Balsam poplar	1.0	1.0	1.0	1.0	0.5	0.5	0.5	0.1	0.1	0.1
95 Aspen/white spruce/balsam fir	1.0	1.0	1.0	1.0	0.5	0.5	0.5	0.2	0.2	0.2
97 Lowland brush	1.0	1.0	1.0	-	-	-	-	-	-	-
98 Upland brush	1.0	1.0	1.0	-	-	-	-	-	-	-
99 Open	0.2	-	-	-	-	-	-	-	-	-

[a] See Fig. 1 legend for description of classes.

[b] A suitability index of 0.0 indicates unsuitable conditions while 1.0 = optimum habitat.

Curve 1). As stands become older, density of stems decreases and the leaves and twigs of remaining trees are less accessible to moose so FSI's decrease.

Information in Model I describing the quality of common tree species as winter cover, plus the assumption that the greater canopy cover provided by large conifers increases cover quality was used to define dormant-season cover suitability indices (CSI's) for each cover type (Table 2). We assumed seedling/sapling stands afford no winter cover value, regardless of stem density or species composition, because of height. As stands approach maturity and the proportion of the stand dominated by conifers increases, the potential to provide suitable cover presumably increases. Densely stocked sawtimber stands dominated by balsam fir, white spruce, or northern white cedar are rated as the highest quality cover. Conversely, stands dominated by deciduous species were assigned low cover values regardless of age class and stocking rate (Fig. 1, Curve 2).

The average SI's for dormant-season forage and cover for each plot around moose and random points were calculated as area weighted means. The area of each cover type within the plot was multiplied by the respective forage or cover SI and the sums of the

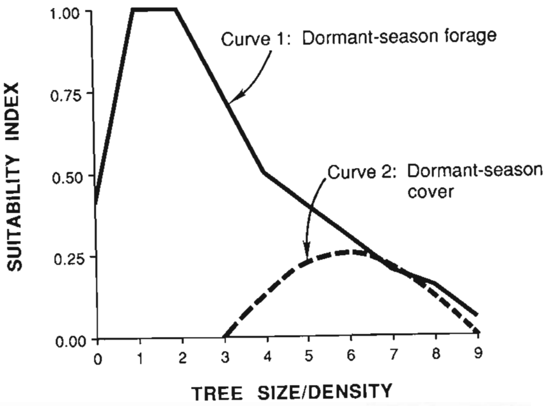


Fig. 1. Assumed relationships between dormant-season forage (Curve 1) and cover suitability indices (Curve 2) for aspen-dominated stands relative to stem size and stocking rates; 0 = nonstocked (<16% stocked); 1 = seedling-sapling (16%-39% stocked); 2 = seedling-sapling (40%-69% stocked); 3 = seedling-sapling (>70% stocked); 4 = poletimber (16%-39% stocked); 5 = poletimber (40%-69% stocked); 6 = poletimber (>70% stocked); 7 = sawtimber (16%-39% stocked); 8 = sawtimber (40%-69% stocked); 9 = sawtimber (>70% stocked).

products divided by the total area of the plot.

Moose survey units

Moose survey units were established previously by the MDNR following Gasaway *et al.* (1986). Boundaries of 20 survey units were plotted on 1:24,000 topographic maps and were digitized and overlaid with the forest compartment data theme to determine which units were predominantly within the original 490-km^2 digitized. Aerial surveys were conducted in 10 contiguous moose survey units. Nine of these units were entirely within the digitized area. The outer boundaries of these survey units (or in the case of the one unit, the boundary of the digitized area) defined the 344-km^2 study area.

Moose locations

Aerial surveys of the 10 moose survey units were completed in December 1988, January 1990, and January 1991 using FS aircraft (DeHavilland Beaver) and MDNR annual moose survey personnel and procedures. In 1988 and 1991, surveys were completed within contiguous 4 day periods; the 1990 survey was completed over 2.5 weeks. Moose were identified as bulls, cows, calves, or unknown; and locations were plotted on 1:24,000 topographic maps. Moose locations within the study area were digitized and coded to sex and year. The GIS was used to establish circular plots with radii of 1,000-m (area = 314 ha), 500-m (79 ha), and 200-m (13 ha) around the location of each adult moose. Tree species composition, size/stocking rate, stand area, area of optimum late-winter interspersion, and area of optimum habitat within each plot were compared to plots of equal size centered on computer- generated random points within the study area. Plots were excluded from analysis if >5% of their area consisted of the "unknown" cover type.

Patterns of habitat use by moose change in response to environmental conditions between early and late-winter (Peek *et al.* 1976, McNicol and Gilbert 1980, Welsh *et al.* 1980, Thompson and Vukelich 1981, Telfer 1984). We conducted aerial surveys from mid-December to mid-January, a period of higher visibility, because moose tend to be present in larger groups and their use of forests with relatively low, open canopies is greater than in late-winter (Lynch 1975, Peek *et al.* 1976). The SI for distance to dormant-season cover (Variable V5, Allen *et al.* 1987) is based on late-winter habitat requirements when weather conditions appear to force moose to utilize conifer-dominated forest stands with tall, dense, multi-layered canopies. Visibility of moose during late-winter aerial surveys is decreased as a result of this shift to dense winter cover (Gasaway *et al.* 1986). Early-winter habitat selection is not the ideal response to evaluate the validity of interspersion between late-winter forage and cover as defined in Model I. We believe it is a conservative response that would possibly under-

Table 2. Dormant-season cover suitability indices (CSI) based on forest type and size/density class.

	Size/density classes[a]									
Forest type	0	1	2	3	4	5	6	7	8	9
01 Jack pine	0.0[b]	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3
02 Red pine	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3
03 White pine	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3
11 Balsam fir/aspen/paper birch	0.0	0.0	0.0	0.1	0.1	0.5	0.5	0.8	0.8	0.8
12 Lowland black spruce	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3
13 Red spruce/balsam fir	0.0	0.0	0.0	0.0	0.5	0.8	0.8	1.0	1.0	1.0
14 Northern white cedar	0.0	0.0	0.1	0.1	0.2	0.5	0.5	0.8	1.0	1.0
15 Tamarack	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.2	0.2
16 White spruce/balsam fir/ norway spruce	0.0	0.0	0.0	0.0	0.2	0.5	0.8	0.8	0.8	0.8
17 Upland black spruce	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.3	0.3
18 Mixed swamp conifer	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.3	0.3	0.3
19 Cedar/aspen/paper birch	0.0	0.0	0.1	0.1	0.5	0.5	1.0	1.0	1.0	1.0
33 Virginia pine	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
71 Black ash/American elm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
76 Red maple (wetland)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
79 Mixed lowland hardwoods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
81 Sugar maple/yellow birch	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
84 Red maple (upland)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
91 Quaking aspen	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
92 Paper birch	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
93 Bigtooth aspen	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
94 Balsam poplar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
95 Aspen/white spruce/balsam fir	0.0	0.0	0.1	0.1	0.5	0.5	0.5	0.8	0.8	0.8
97 Lowland brush	0.0	0.0	0.0	-	-	-	-	-	-	-
98 Upland brush	0.0	0.0	0.0	-	-	-	-	-	-	-
99 Open	0.0	-	-	-	-	-	-	-	-	-

[a] See Fig. 1 legend for description of classes.

[b] A suitability index of 0.0 indicates unsuitable conditions while 1.0 = optimum habitat.

estimate, but not overestimate, late-winter habitat selection. We assumed that periods of severe weather in early-winter would result in patterns of habitat use by moose that would reflect, if only on a short- term basis, preference for vegetation conditions characteristic of late- winter habitat. If this assumption is valid, percentage of stands composed of high-quality forage and cover and a higher degree of interspersion between these resources would increase as weather severity increased and would be greater around moose locations than plots around randomly selected points.

Winter severity index

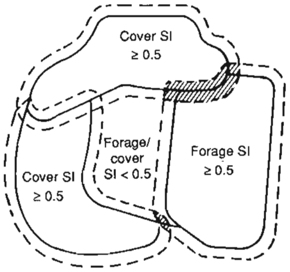
Severity of winter weather was assessed for each day from the initiation to completion of each year's survey plus the 31 days immediately preceding the survey. Daily weather data were obtained from Vermilion Community College in Ely, approximately 22 km northwest of the study area. The daily maximum temperature for each day of the assessment period was subtracted from 32 °F and multiplied by the cumulative snowfall. The sum of these products was divided by the number of days in the assessment period to define an average daily index of winter severity

(Picton and Knight 1971).

Interspersion and area of optimum late-winter habitat

Two spatial characteristics of cover types were compared within plots around moose locations and randomly selected points (Fig. 2). Optimum late-winter habitat was defined as the area of high-quality (SI ≥0.5) forage within 100 m of high-quality (SI ≥0.5) cover plus the area of high-quality cover within 100 m of high-quality forage. The area subtended by the intersection of polygons defined by establishing 100-m buffers around high-quality forage and cover defined optimum late-winter interspersion. Optimum late-winter interspersion is a less stringent habitat description because it includes the area of all cover types within 100 m of high-quality forage and cover regardless of the suitability of the cover type.

a. Optimum late-winter interspersion (shaded area only)



b. Optimum late-winter habitat (shaded area only)

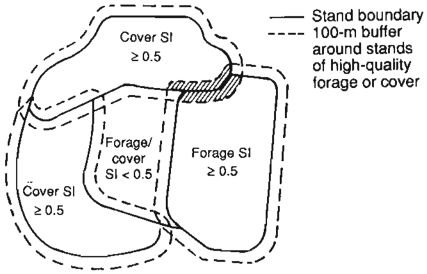


Fig. 2. Spatial relationships used to define optimum late-winter habitat and optimum late-winter interspersion in conjunction with forest stands providing high-quality (SI >0.5) dormant-season forage and cover. Optimum late-winter interspersion is the area of all cover types (except lake) subtended by the intersection of 100-m buffers established around high-quality forage, and high quality cover (Fig. 2a). Optimum late- winter habitat includes only the area providing high-quality forage within 100 m of high quality cover and high quality cover within 100 m of high quality forage (Fig. 3b).

Average suitability indices for cover and forage, proportion of optimum late-winter habitat and interspersion, and area in a specific value range of winter cover quality were compared in circular plots around moose and random points by using a distribution-free multiresponse permutation procedure (MRPP) (Biondini *et al.* 1988). The observed test statistic is based on a Euclidean distance measure of variation. Probabilities of more extreme test statistics are based on an approximation with a Pearson type III distribution fit to the first 3 exact moments of the permutation distribution. The Euclidean distance- based statistic has greater power to detect shifts in median values of skewed distributions, such as found in our data sets, than test statistics based on variances. Because the Euclidean distance statistic in MRPP is sensitive to differences in medians and dispersion, data were plotted to determine whether significant differences were due to shifts in medians, dispersion, or both. Statistical analysis was completed using BLOSSOM software available from the National Ecology Research Center.

RESULTS

Of 239 defined cover types, 191 occurred within the study area. Locations of 85, 79, and 71 moose were plotted during survey flights in December 1988, January 1990, and January 1991, respectively. A total of 174 random points were generated within the study area. In general, the number of plots included in the analysis decreased in response to larger plot size because plots centered near the study area border were more likely to contain >5% of their area in the unknown cover type as plot

Table 3. Number (by year) of plots around random points and early- winter moose locations used to compare habitat use and availability within a 344-km^2 portion of the Superior National Forest.

Year	Plot radius (m)	Total	Number of useable plots			
			Bulls	Cows	Calves	Unknown
1988						
	1,000	59	25	23	10	1
	500	65	31	24	10	-
	200	71	34	26	11	-
1990						
	1,000	46	20	12	6	8
	500	43	19	13	5	6
	200	58	28	17	5	8
1991						
	1,000	44	24	12	8	-
	500	50	22	18	8	2
	200	56	25	20	10	1
Random points	1,000	76	-	-	-	-
	500	81	-	-	-	-
	200	80	-	-	-	-

area increased (Table 3).

Winter weather severity indices showed the 1991 evaluation period was the most severe with an average daily index of 372.8. Winter weather in 1988 (average daily index = 160.3) and 1990 (average daily index = 121.6) was less severe.

The median average dormant-season cover suitability index (CSI) was less than the median average dormant-season food suitability index (FSI) for all plot sites regardless of whether the plot was around a moose location or a random point (Table 4). The remaining description of results pertains only to cows since the assumptions used in formulation of Model I and Model III are based primarily on cow habitat requirements. The median of the average dormant-season CSI was higher for 200-m radii plots around cows in 1988 ($P = 0.002$) and 1991 ($P = 0.003$) and for 500-m radii plots around cows in 1988 ($P = 0.02$) than for similar size plots around random points. Medians of dormant- season CSI for other combinations of equal size plots around cow locations and random points were not different ($P > 0.066$).

The percent of plot area around cows in optimum late-winter interspersion increased in response to severity of winter weather and smaller size of plots (Fig. 3a). In 1991, which had the highest winter severity index, the median percent area of 200-m radii plots in optimum late-winter interspersion was significantly greater around cows ($P = 0.025$) than around random points (27.6% vs 11.0%). The median percent area of optimum late-winter interspersion within 500-m plots around 1991 cow locations and random points was not different ($P = 0.252$). In 1988, the median of the percent area in optimum late- winter interspersion was greater ($P = 0.046$; $P = 0.018$) for 500-m and 200-m radii plots around cows than for the same size plots around random points. In 1990, the least severe of the three winters, the percent area of plots in optimum late-winter interspersion around cows was lower than within random plots of the same size; however, median values were not different (500-m, $P = 0.172$; 200-m, $P = 0.272$). The median percent area in optimum late-

Table 4. Medians of average dormant-season forage suitability index (FSI) and cover suitability index (CSI) values within 1,000-m, 500-m, and 200-m radii plots around random points and cows observed during December 1988, January 1990, and January 1991, Superior National Forest, Minnesota. Suitability indices describe habitat quality where 0.0 = unsuitable and 1.0 = optimum habitat.

	Plot size and medians of weighted average dormant-season forage and cover SI's					
	1,000 m		500 m		200 m	
	FSI	CSI	FSI	CSI	FSI	CSI
Random points	0.31	0.10	0.30	0.09	0.30	0.07
All cows, all years	0.35	0.12	0.33	0.12	0.32	0.12
Cows 1988	0.34	0.15	0.23	0.13	0.33	0.15
Cows 1990	0.35	0.13	0.42	0.08	0.33	0.08
Cows 1991	0.39	0.09	0.35	0.12	0.24	0.13

winter interspersion within 1,000-m buffers around cow locations was not significantly different than within 1,000 m buffers around random points (1988, *P* = 0.073; 1990, *P* = 0.377; 1991, *P* = 0.218).

Although slightly smaller than the area of optimum late-winter interspersion, the percent of plot area around cows in optimum late-winter habitat also increased in response to severity of weather and smaller plot size (Fig. 3b). For all 3 years the median percent area of 1,000-m plots around cows in optimum late-winter habitat was not significantly different (P ≥ 0.364) from that found within random plots. The median percent area of 500-m plots around cow moose in optimum late- winter habitat was greater than within random plots in 1988 (*P* = 0.047) and 1991 (*P* = 0.048). In 200-m plots, the percent of area in optimum late-winter habitat was 14.1% in 1988 and 18.4% in 1991 as compared to 8.8% within equally sized plots around random points. In

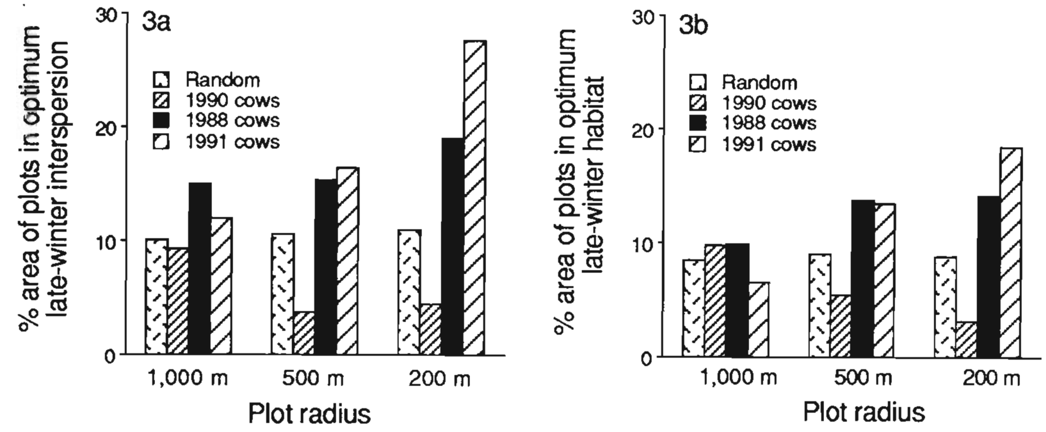


Fig. 3. Percent area of 1,000-m, 500-m, and 200-m radii plots around cow moose locations and random points in optimum late-winter interspersion and optimum late-winter habitat as defined in Fig. 2. Winter severity indices: 1988 = 160.3; 1990 = 121.6; 1991 = 372.8.

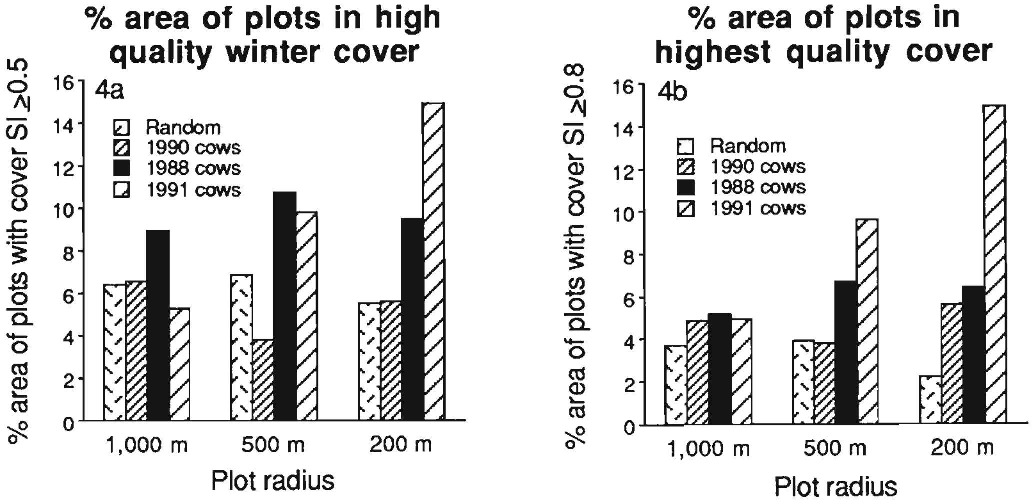


Fig. 4. A - Percent area of 1,000-m, 500-m, and 200-m radii plots around cow moose locations and random points in high quality (SI ≥0.5) cover. B - Percent area of plots in highest quality (SI ≥ 0.8) cover.

neither year, however, were the median values of 200-m plots in optimum late-winter habitat different from the median value of random plots (1988, $P = 0.200$; 1991, $P = 0.090$). Median values of percent area of plots in optimum late-winter habitat around cows in 1990, the mildest winter, were not different than values from plots around random points for all plot sizes (1,000-m, $P = 0.364$; 500-m, $P = 0.342$; 200-m, $P = 0.254$).

Poletimber and sawtimber stands dominated by balsam fir, northern white cedar, white spruce, and aspen/white spruce/balsam fir were given SI ratings of ≥0.5 for winter cover (Table 2). The percent area of high-quality (SI ≥0.5) and highest-quality (SI ≥0.8) winter cover around cow locations generally increased in response to smaller plot size and severity of winter weather when compared to plots of equal size around random points (Figs. 4a, 4b). Less than 4% of the total area of 500-m random plots was in highest-quality winter cover as compared to 2.2% within 200-m random plots. The greatest difference between random plots and plots around cow locations occurred in 1991, the most severe winter, when 9.6% of 500-m and 14.9% of 200-m plots around cows were comprised of cover with a SI ≥0.5. In this year, 98% of the high-quality cover within 500-m plots and 100% of the high-quality cover within 200-m plots consisted of stands with a SI ≥0.8.

The median percent area (6.49) in high-quality (SI ≥0.5) cover for 1,000-m plots around cow locations was not different ($P = 0.222$) than the median (2.78) for 1,000-m plots around random points in 1990, the mildest winter. The median percent area of high-quality cover within 500-m and 200-m plots around random points and cow locations also were not different ($P \geq 0.305$; all medians = 0.0) in 1990. The median percent area of high-quality winter cover around 1988 cow locations (1,000- m = 0.0, 500-m = 2.47, 200-m = 10.71) and random points (1,000-m = 2.78, 500-m = 0.0, 200-m = 0.0) differed for all plot sizes (1,000-m, $P = 0.066$; 500-m, $P = 0.022$; 200-m, $P = 0.001$). The median percent area of individual plots in high-quality cover in 1991, the most severe winter, increased as plot radius decreased (1,000-m = 0.0, 500-m = 0.17, 200-m = 6.65); however, it differed from the random point median only for the 200-m radii plots ($P = 0.033$).

Differences between median percent area of equal size plots around cows and random points in highest-quality (SI $\geq$0.8) winter cover was not significant ($P \geq 0.063$) except for the most severe winter (1991) of the study. In 1991, the median percent area of highest-quality cover within 500-m and 200-m plots (23.29 and 3.05, respectively) around cows was different (P $\leq$0.001) from the medians (0.0) for the same size random plots. Larger medians were associated with greater variation in percent cover of both high-quality and highest-quality cover within individual plots around cow moose locations.

DISCUSSION

We developed a simplistic rating system of moose habitat for a portion of the SNF which combines stand inventory data with indices of moose food and cover quality. We further developed definitions of optimum late-winter habitat and interspersion that encompassed area and distance between high quality forage and cover. Using GIS, we were able to quantify these values, calculate their areas and compare them between moose and random locations. The comparisons indicated moose tended to occur in areas that had a higher proportion of optimum late-winter habitat, higher proportions of optimum late-winter interspersion, and greater amounts of high quality of forage and cover than would be expected in areas around random points. Thus, it appears that our descriptions of optimum habitat, interspersion, and high-quality forage and cover are realistic for rating late-winter moose habitat on the SNF.

Our data, relative to cover type composition within 1,000-m, 500-m, and 200-m radii plots around moose located during aerial surveys in early winter, suggest that cows select specific stand types. High- quality winter habitat can be characterized as poletimber (>40% stocked) and sawtimber stands of mixed species composition that contain a multi- layered canopy of balsam fir or white spruce associated with aspen and paper birch. This relationship was most apparent in the analysis of habitat using 200 or 500-m plots and when winter severity was greatest. Since an increasing use of older age class, conifer-dominated stands with intrinsically low quality and availability of forage appears to occur in response to severity of early-winter weather, it seems reasonable to assume that affiliation with those stand types would be even greater during late winter when weather most severely impacts availability of forage and cover and the mobility of moose.

Although habitat is not believed to limit moose populations in the study area, availability and quality of late-winter cover may limit local populations (Thompson and Euler 1987). Interspersion between mature conifer-dominated stands and cutover stands, with high availability, diversity, and quality of browse species, appeared to be important during the study. Cover type composition around random points and moose locations in the study area showed that high-quality forage was always present regardless of plot size. Slightly less than 36% of the 344-km^2 study area provided high-quality forage for moose. In contrast, only 5.8% of the area consisted of forest types with a dormant-season CSI of $\geq$0.5. Interspersion of dormant-season forage and cover, resulting in higher habitat quality for moose within this study area, could be enhanced through extended rotations within mixed-species stands containing a high proportion of balsam fir and white spruce. Mature balsam fir/aspen/paper birch stands and aspen/white spruce/balsam fir stands should be identified and used as a focal point for situating future harvest units that will provide high-quality forage closely associated with high-quality cover.

Although it is recognized that moose require large areas for their home range, the ideal size, interspersion, and configuration of cover types within large management units have not been defined. Simple guidelines for proportions of management units that should be in specific forest types and age classes, such as those made by Peek *et al.* (1976) and Oldemeyer and Regelin (1987), can be implemented on a variety of spatial scales. Guidelines can be employed as criteria for comparing land classification themes within geographical subdivision themes using GIS. For example, only 5.8% of our study area consisted of cover types ranked as high-quality winter cover. This percentage was consistent for all plot sizes, indicating good interspersion throughout the study area. Guidelines provided by Peek *et al.* (1976) recommend that 5% to 15% of a township, or larger area, be in winter cover. Our study area is currently at the lower range of these guidelines. Selection of high- quality cover by cows was apparent when comparing habitat composition of smaller plot sizes. Managers concerned with moose habitat may want to avoid further elimination of widely-scattered stands providing high- quality winter cover.

When planning timber harvests, habitat management recommendations should be specific to individual management units, have clearly defined objectives, and be incorporated in the planning process when timing and spatial distribution of harvest units are identified (Thomas 1984, Innes 1985). Evaluating habitat conditions and defining a recommended management plan within a single compartment are relatively uncomplicated. However, this task becomes monumental when one considers that: (1) a managed forest may contain dozens of compartments and thousands of stands; (2) habitat composition and quality within one compartment potentially influences habitat quality in adjacent compartments; (3) habitat composition and quality change through time in response to forest management as well as natural processes; and (4) several wildlife species of special concern, with potentially conflicting habitat requirements, may be present within the area of management responsibility.

Escalating demands for forest use and products highlight the importance of integrating wildlife habitat management with that of other forest resources (Flader 1983, Smith and Blyth 1989, Hackett 1990). To accomplish this, habitat data must be quantified and compatible with other forest resource data. Spatial and temporal distribution of habitat within forest landscapes cannot be ignored if long-term goals are to maintain and enhance habitat quality (Flather and Hoekstra 1989, Hunter 1990, Greig *et al.* 1991). While timber harvest often creates suitable habitat, moose populations have fluctuated without appreciable consideration of cause and effect relationships (Peek 1986, Thompson and Euler 1987). To be successful, habitat and silvicultural planning should be based on coordinated, quantifiable management goals (Marquis 1986, McNicol and Gilbert 1987, Wildlife Habitat Canada 1991). Although management actions intended to enhance winter habitat for moose should be directed toward stands of lower commercial value, preservation of, or longer rotations within, financially valuable stands may be justified if those stands represent a potentially critical, limited resource such as late-winter cover.

Our matrix values of forage quality do not directly address the actual amounts of useable high-quality forage, because they are based only on size, stocking rate, and species composition of trees within a forest stand. A more accurate matrix of dormant-season forage quality could be developed by using the biomass and quality of browse from all sources, including understory and midstory species found in the defined cover types and by defining more cover types. This type of detailed forage biomass information and data describing the value of various wetland types currently lumped together as "lakes" in our analysis are being developed (Adair *et al.*, 1991) for portions of the SNF. Specific estimates of forage biomass contributed by each of the 239 cover types (or additional cover types) can be used to revise the SI values by rescaling the biomass estimates to a 0 to 1.0 scale. Values less than 1.0 represent a proportion of maximum, i.e., an SI of 0.5 equals 50% of maximum biomass per unit area. Such refinements in the model can be accomplished without altering the basic structure of the model.

Our cover type rating matrix and distance algorithm do not attempt to explain causal mechanisms of late-winter habitat selection by moose. However, we do believe that they are reasonable guides to management in the study area. Changing the matrix values or adding more complex distance functions to reflect local conditions are simple tasks. We encourage other biologists to make creative changes in the habitat model and to use a GIS to compare predicted habitat quality to habitat use or other more sophisticated responses to habitat, thereby testing different formulations of habitat quality for moose and other species.

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