Application of a Modified Habitat Suitability Index Model for Moose

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Abstract

This paper explores alternative approaches for calculating moose Habitat Suitability Index (HSI) values using a GIS. We modified an existing moose HSI model and implemented it using moving windows and various boundary value estimation methods. The habitat window and boundary analyses indicate that a 50 percent window overlap is sufficient to capture variation in the landscape. A mirror data set for areas outside the study area, used to estimate boundary habitat values from a sample grid within a vector GIS, is proposed as a useful alternative for supporting landscape-scale resource management.

Introduction

A moose (*Alces alces*) Habitat Suitability Index (HSI) model for the Lake Superior region is being used to aid in moose management decisions on the Superior National Forest (Allen *et al.*, 1987; Jordan *et al.*, 1988; Allen *et al.*, 1991). The moose HSI is a two-part model; with growing-season (browse, aquatic forage, and cover) and dormant-season (browse and cover) components evaluated separately. Application of the moose HSI to an area provides managers with a standard procedure for evaluating possible effects of present and future land management activities on moose habitat.

GIS techniques are being used with increasing frequency because they can be used to manipulate spatial data (Donovan *et al.*, 1987; Sample, 1994). For example, many habitat models require proximity analyses such as interspersion and juxtaposition of resources in order to accurately model and asses species habitat requirements (e.g., Lyon, 1983; Allen *et al.*, 1987; Lyon *et al.*, 1987; Ormsby and Lunetta, 1987; Shaw and Atkinson, 1988; Allen *et al.*, 1991; Pereira and Itami, 1991; Homer *et al.*, 1993; Herr and Queen, 1993; Rickers *et al.*, 1995).

Research applying, modifying, and validating the moose HSI model has been conducted on a limited scale (Allen *et al.*, 1991; Adair *et al.*, 1991; Adair, 1996). The moose HSI model was expanded to utilize geographic information system (GIS) techniques for analysis (Allen *et al.*, 1991), as used previously on other GIS-based implementations of habitat models (Mangus, 1990; Webb and Allen, 1990; Koppikar, 1990; Allen *et al.*, 1991; Evans and Gilbert, 1991). Allen *et al.* (1991) determined that interspersion of winter cover and winter browse was important in predicting moose location. Adair *et al.* (1991) and Adair (1996) determined the relationship between several suitability index values and levels of the respective resource(s) in northeastern Minnesota.

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Issues of proximity, adjacency, and topology are often implied in habitat models, but were not readily incorporated into an analysis before the advent of GIS. The spatial resolution of the input data must be evaluated. In the original moose HSI, high-resolution forest stand-based data were evaluated *en masse* instead of being applied individually (Allen *et al.*, 1987). Modifications to the existing moose HSI model to incorporate available stand-based data would standardize the spatial resolution required of input data for all suitability indices.

Most species do not recognize the human-defined boundaries that often demarcate GIS data. Because many habitat models, and HSI models in particular, are designed to be applied on a home-range sized unit, modelers are faced with a problem of what to do when evaluating the habitat quality of boundary areas. These areas often require unavailable data from outside the study area to conduct proximity analyses. The aim of this paper is to discuss the use of GIS to determine the effects of boundary conditions and spatial resolution of GIS on application of a modified moose HSI model, and to calculate prototype results useful to resource managers in northeastern Minnesota.

Habitat Suitability Index Models

The HSI concept was formalized in 1981 by the U.S. Fish and Wildlife Service (USDI Fish and Wildlife Service, 1981) to provide methods for evaluating habitat that are consistent with existing knowledge and the information needs of natural resource planners. HSI models are intended to translate existing knowledge of a species' habitat requirements into standard, quantitative measures of landscape quality. Problems exist with empirical validation of HSI models, however, because standards for defining or measuring habitat quality usually do not exist, and there is generally a lack of quantitative data for model development and testing (Schamberger and O'Neil, 1986).

The Lake Superior Region Moose HSI

The original moose HSI (Allen *et al.*, 1987) estimates the density of moose an area could support based on known spatial requirements of moose for food and cover. Hunting, predation, or pathogens are not considered in the HSI model, nor is the HSI model designed to predict the actual number of moose present in an evaluation area. Habitat suitability is determined from the aquatic forage, browse forage, and cover resources for the growing season, and browse forage and cover for the dormant season. The dormant season model is written using the habitat requirements of moose in late win-

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ter, because late winter tends to be the most stressful period for moose (Peek, 1971; Peterson and Allen, 1974; Renecker and Hudson, 1986).

Each seasonal model incorporates suitability indices (SI), with index values of 1 representing optimum suitability and index values of 0 indicating unsuitable. A seasonal summed index value of 1 corresponds to the maximum potential moose density of two moose/km², a conservative maximum density estimate based on research conducted on Isle Royale (Jordan and Wolfe, 1980; Peterson and Page, 1983). The HSI has suitability index curves relating quantities of browse; species composition of browse; percent, height, and species composition of canopy cover; and acreage of aquatic resources to habitat quality for moose. Once a parameter such as quantity of browse is known for a forest stand (a contiguous area of similar tree age and species composition), the SI curves are used to determine a numerical SI value. These SI values for each stand are then multiplied together and summed over the evaluation area in order to determine a final habitat quality value for each season for the evaluation area as a whole. The HSI is designed to be applied on 6 km² evaluation units, an area assumed to be large enough to provide all of the seasonal habitat requirements of a moose (Phillips *et al.*, 1973; Cedarlund *et al.*, 1987).

The moose HSI is written with some SI values calculated for an evaluation unit (6 km²) as a whole (Allen *et al.*, 1987). We used GIS techniques to modify calculation of the growing season browse, growing season aquatic forage, dormant season browse, and dormant season cover SI values. These changes increase the spatial resolution of the model within evaluation units to the level of available stand-based data by explicitly incorporating the contribution of individual stands to the overall habitat suitability of the unit.

Methods

Model Modifications

The original model uses two steps to estimate growing season browse. The first part consists of a series of stand-based assessments. The browse resource for moose is estimated by multiplying together the browse density, the SI for percent canopy cover, and the area of the stand. This stand-based result is then multiplied by the species composition rating for the entire evaluation unit, thus losing detail concerning the mosaic of species composition in each stand. A modified equation was developed that assigns an SI based on the browse resources in each stand, and these SI values are summed up for the evaluation unit. By calculating the browse variable with this formula, each stand's species composition is accounted for, as well as the species composition differences across the landscape: i.e.,

$$\text{GSB} = \text{C} * \Sigma\,(\text{D}_i * \text{A}_i * \text{SIV1}_i * \text{SIV2}_i)$$

where GSB is the growing season browse, C is a constant to account for cropping rate and total seasonal browse dry weight, D is the stand browse density, A is the area of each stand, SIV1 is the suitability index for canopy cover in the stand, and SIV2 is the suitability index for species composition in the stand, all summed for "*i*" stands in the evaluated area.

Wetlands provide a required food source for moose in the Lake Superior region during the growing season. In the growing season model, aquatic forage is assigned equal weighting with growing season browse in such a way that the limiting resource of the two is used along with the growing season cover index value to determine the final growing season HSI value for an area. An area could have an optimum of one forage resource and still have a minimal habitat value to moose if the other forage resource is in short supply.

The original HSI assumes that evaluation units (6 km²) with no fewer than 13.2 ha/km² of riverine, lacustrine, or non-acidic palustrine wetlands have sufficient aquatic resources to support two moose/km². Our modified model incorporates the results of Adair *et al.* (1991) who added a "wetland type modifier" to the model based on field investigations that adjusts the aquatic forage resource for suitability to moose based on more specific wetland types. This method incorporates higher data resolution than the original HSI model. The modifier allows the resource manager to more easily locate areas of wetland deficiency in an evaluation unit. The modified equation calculates the number of moose that the evaluation unit can support based on the evaluation unit's actual aquatic resources: i.e.,

$$\text{GSAF} = \Sigma\,(\text{SIVw}_i * \text{WAw}_i)$$

where GSAF is the growing season aquatic forage, SIVw is the wetland type suitability index, and WAw is the area encompassed by each wetland type, all summed for "*i*" stands in the evaluated area (Adair *et al.*, 1991).

As with the growing season, the original dormant season browse equation calculates the browse species composition index rating for the entire evaluation unit. This equation was modified so that each stand's browse species composition is reflected in the final evaluation unit's browse rating: i.e.,

$$\text{DSB} = \text{C} * \Sigma\,(\text{D}_i * \text{A}_i * \text{SIV4}_i * \text{SIV5}_i * \text{SIV6}_i)$$

where DSB is the dormant season browse, C is a constant to account for cropping rate and total seasonal browse dry weight, D is the stand browse density, A is the area of each stand, SIV4 is the suitability index for proportion of woody browse composed of coniferous species in the stand, SIV5 is the suitability index for mean distance of browse to dormant season cover stand, and SIV6 is the suitability index for dormant season browse species composition rating in the stand, all summed for "*i*" stands in the evaluated area.

The dormant season cover index value (DSCI) originally was calculated using three index values for the entire evaluation unit. We modified this equation so that three SI values for each stand are used and summed for all stands in the evaluation unit: i.e.,

$$\text{DSCI} = (\Sigma\,([\sqrt{(\text{SIV7}_i * \text{SIV8}_i)}] * \text{SIV9}_i) * \text{A})/\text{Total Area}$$

where DSCI is the dormant season cover index, SIV7 is the suitability index for percent canopy cover, SIV8 is the suitability index for proportion of canopy trees composed of conifers, SIV9 is the suitability index for mean canopy conifer height, A is the stand area, summed for "*i*" stands in the evaluated area, and Total Area is the total area of evaluation unit.

The equation accounts for the compensatory nature of stand percent canopy cover and the proportion of the tree canopy in the stand composed of conifers, using the geometric mean of these two indices for each stand. If one of the two variables has a low value, it can be made up for by a high second variable because fewer trees with more conifers present will create a similar microclimate as more trees with fewer conifers. The mean height of conifers, on the other hand, determines whether the other two variables will be of any use, and therefore can only decrease the value of the other two variables.

Estimating Model Suitability Index Values

The application of our modified algorithm is an example of how natural resource managers can apply HSI models with relative ease using existing landscape data while dealing explicitly with two significant impediments to implementation in a vector-based GIS. Each vegetation parameter required to apply the moose HSI was estimated using combinations of forest survey type (FST), stand size class (SSC), ecological land type (ELT), year of stand origin, stand site index (curves interpreted using Carmean *et al.* (1989)), and U.S. Fish and Wildlife Service National Wetlands Inventory data (Hepinstall, 1992; Adair, 1996; W.A. Adair, pers. commun.).

The 61 km^2 Coffee Creek Opportunity Area is located within the Superior National Forest (SNF), Minnesota (Figure 1). This area is known to support moose and is managed as a single unit by the U.S. Forest Service, making it a suitable area for application of the moose HSI model. Land-cover data for the study area were obtained from U.S. Forest Service stand maps, Ecological Classification System (ECS) maps, and U.S. Fish and Wildlife National Wetlands Inventory maps. All three sources of data at a scale at 1:24,000 were compiled into a vector GIS (ARC/INFO).

The modified moose HSI requires that dormant season browse distance to cover be calculated to determine habitat suitability. We identified suitable cover stands based on age, vegetation type, and ECS class, buffered out selected distances from these stands and assigned suitability values to the distance polygons according to the suitability index curve in the HSI model (Allen *et al.*, 1987; Allen *et al.*, 1991).

The moose HSI evaluates all of the resources available in one rectangular home-range sized evaluation unit (6 km^2) at once. Evaluating resources in an area of the landscape in this way creates a habitat "window" superimposed on the study area (Figure 1). By overlapping habitat windows as evaluation of the habitat progresses across the landscape, a "moving-window" or "habitat kernel" is created. This process is analogous to creating a kernel estimator to determine a point-specific HSI value. Differing degrees of overlap correspond to different spacing of estimation points, between which we are interpolating HSI values (Cressie, 1991). Overlapping the habitat windows allows for resources to be evaluated in a continuous manner while still incorporating individual stand data (Koppikar, 1990). Several differing levels of window overlap were tested to determine at what point computational load was increased with no change in mean HSI value, corresponding to a limit in the output resolution of the model. Although any one of a number of window shapes and configurations might be applied, this application considered only rectangular evaluation units for ease of computation.

An external program written in C implemented our HSI model using a rastorized version of our vector-based data created by a point grid overlaid on our vector coverages. Samples in the grid were spaced 100 m apart so that each point represented one hectare of the original vector coverage (an appropriate spacing given an average polygon size of 5.27 ha). A rectangular window was defined for 600 sample points and the window was passed across the entire sample grid. Attribute data for each point sample were selected from the GIS attribute database at each point by the external program, and then input to the modified HSI model. Output from the program was an attribute file of HSI values that was imported directly into the vector attribute database.

We had no knowledge of what habitat elements existed in the zone adjacent to the study area. Ideally, only those areas with a full 6 km^2 of valid data are included in the analysis. Using a fixed rectangular window eliminates areas where the study area boundary is irregular. Assuming no data outside of the study area would cause a number of undesirable conditions to occur. A blank alley showing no habitat values would occur at the edge of the study area. Given the irregular boundary and size of our study area (61 km^2) compared to the size of each habitat window (6 km^2), only a small central area of the study area (55 percent of the total area) would be able to contain a full rectangular evaluation area .

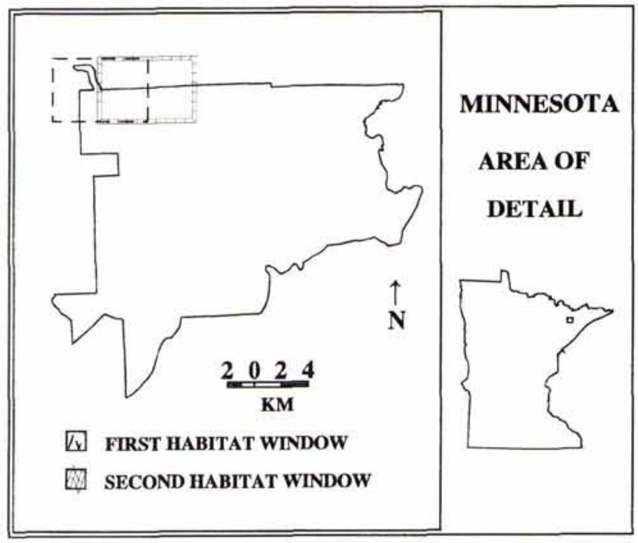

Figure 1. The Coffee Creek study area, showing two superimposed 6-km^2 moving habitat windows with 50 percent horizontal overlap, is located in northeastern Minnesota within the Superior National Forest.

Even with a hypothetical requirement of only 90 percent of the points having valid data, large portions of our study area would have been eliminated from consideration.

Two alternatives for applying the HSI assumed that areas outside of the boundary of the study area contained valid data. In one case the areas outside the boundary were assumed to be a void. Because the moose HSI calculates the habitat values by summing up 6 km^2 of habitat and dividing by six to achieve a moose per km^2 density, this method effectively down-weights the boundary areas of the study area because less than 600 points with valid data were encountered in the boundary evaluation units which had portions outside of the study area. The other case assumed that data outside the study area were the same as data inside the border of the study area (i.e., a mirror data set). The mirroring used the valid points within the boundary evaluation unit to extrapolate values for points outside the study area. A minimum threshold was set which required that 25 percent of the points in the window be within the study area before the extrapolation was completed, leading to an area 56.6 percent of the size of the study area being extrapolated from boundary points. This second alternative was accomplished by using the valid internal points and weighting each intermediate habitat value according to the percentage of valid points that were evaluated.

The second alternative is most useful for resource managers, providing a uniform method of applying the model across an area with irregular boundaries as well as covering the entire study area. Although alleys at the edge of the study area contain estimated data, the conditions and assumptions inherent in the modeling approach are well-known, and output can be thus interpreted accordingly. This is an especially significant issue because different boundary condition assumptions might match different management data requirements. Therefore, the GIS analyst can best serve the decision maker not by developing the "ultimate" boundary condition alternative, but rather by stating openly and clearly the method(s) used and the conditions and assumptions inherent in that approach.

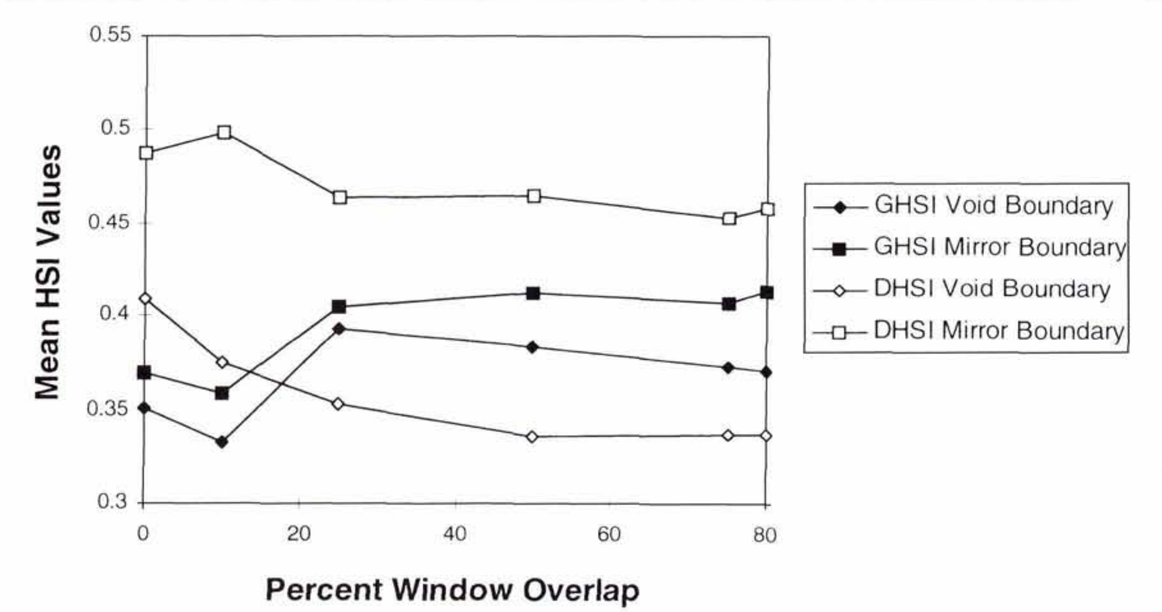

Figure 2. Mean results of HSI determinations based on adjusting the amount of overlap among habitat windows and the type of boundary condition used (GHSI = growing season HSI, DHSI = dormant season HSI).

Results

Modeling Techniques

Six alternative levels of window overlap were analyzed (0 percent, 10 percent, 25 percent, 50 percent, 75 percent, and 80 percent). Each was executed using two different boundary condition treatment alternatives: assuming a void and a mirror data set. Interpretation is based on mean growing and dormant season HSI (Figure 2) and on analysis of the frequency distribution of seasonal HSI scores. Average values for both growing season HIS (GHSI) and dormant season HSI (DHSI) are higher under the mirror data set assumption than under the void data assumption as predicted. Under both boundary conditions, graphs of HSI scores (Figure 2) show asymptotic behavior as the percent window overlap increases. The point at which the curve begins to flatten (> 25 percent) is the point at which sufficient overlap to capture data variability has occurred. By selecting 50 percent as optimal, we are utilizing the full resolution of our data in model output while at the same time minimizing the computational demands of the application.

The frequency distribution of GHSI values for the mirror boundary method with six different percent window overlaps shows a convergence with higher percent overlap. For the intervals of 50 percent to 80 percent overlap, growing season values are similar, but for lower levels of overlap there is more variability in the overall range of scores. This trend occurred for DHSI values as well. Based on these results, we assume that a 50 percent window overlap is appropriate. We also assume that the mirror landscape method is a more useful alternative than the void method, because the mirror method allows for complete approximation of habitat variables over the entire study area. If we did not assume a mirror data set, 45 percent of the study area analysis would be either blank or negatively biased. Given similar landscape conditions in the area surrounding Coffee Creek, this is a viable assumption, being more conservative than liberal.

Implementation

Based on implementation of the modified moose HSI model using the 50 percent overlap and mirror dataset boundary conditions derived above, we were able to evaluate habitat quality for the Coffee Creek study area in an efficient and effective manner. Figure 3 depicts the distribution of seasonal HSI scores for the study area. Summary statistics for simulated HSI values are presented in Table 1. For both growing season and dormant season, the Coffee Creek study area is below optimum habitat for moose. Results indicate that during the growing season the aquatic forage resource was the limiting factor of habitat quality over much of the study area. The growing season portion of the HSI model was written so that the limiting variable of aquatic forage and browse was used to calculate the final HSI value. For the Coffee Creek study area, aquatic forage was limiting in 41 of the 54 evaluation units. Only five of the evaluation units had enough

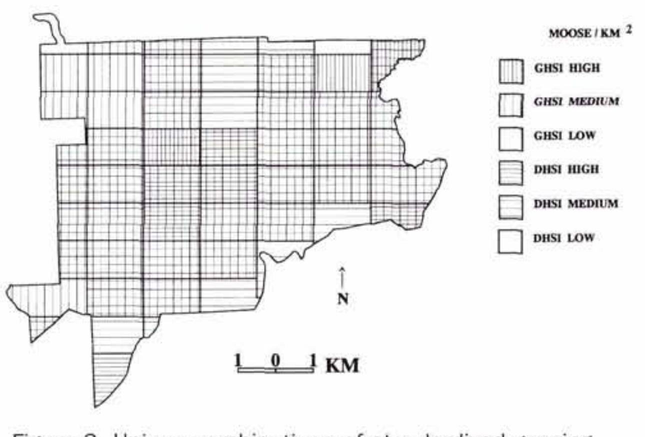

Figure 3. Unique combinations of standardized growing and dormant season HSI scores (GHSI = growing season HSI, DHSI = dormant season HSI, HIGH = 2.0 to 1.0 moose/ km^2, MEDIUM = 1.0 to 0.1 moose/km^2, LOW = less than 0.1 moose/km^2).

Table 1. Moose HSI Results with a Mirror Data Set Boundary and 50 Percent Window Overlap.

Data Distribution (Moose/km² and percent of output areas in each level):

HSI Value	0	0.01 to 0.5	0.51 to 1.0	1.01 to 1.5	1.51 to 2.0	> 2.0
GHSI	0.15	0.50	0.30	0.05	0.00	0.00
DHSI	0.00	0.59	0.30	0.11	0.00	0.00
GSAF	0.15	0.24	0.30	0.13	0.09	0.09
GSB	0.00	0.04	0.20	0.26	0.33	0.17
DSB	0.00	0.20	0.24	0.22	0.24	0.09
GSCI	0.00	0.00	0.00	0.87	0.13	0.00
DSCI	0.00	0.20	0.61	0.17	0.00	0.00

Summary Statistics (Moose/km²):	Min	Max	Mean
Growing-season HSI	0.00	1.27	0.41
Dormant-season HSI	0.01	1.36	0.47
Growing-season Aquatic Forage	0.00	3.78	0.88
Growing-season Browse	0.41	2.52	1.45
Dormant-season Browse	0.07	2.80	1.13
Growing-season Cover Index	1.20	1.68	1.36
Dormant-season Cover Index	0.10	1.14	0.74

aquatics to support the maximum number of moose as defined in the model. Seventy-one percent of the study area would support less than one moose per km², and 15 percent of that area contained no usable wetlands. The browse resource in the study area was less frequently limiting (in 13 of the 54 units) than the aquatic forage. The mean moose density based on the growing season browse resource (1.45/km²) is considerably higher than the mean based on the available aquatic resource (0.88/km²).

Given an average suitability index value of 0.68 (1.36 moose per km²) for the study area, the growing season cover index consistently lowered the final HSI value by approximately one-third. Comparing the cover index value with both aquatics and browse, it appears that cover was less limiting on average than browse or aquatics, with 100 percent of cover values falling in the range of 1 to 2 moose per km². The growing season HSI values for Coffee Creek all fell below 1.5 moose per km², with the majority (80 percent) distributed between 0.1 and 1. Eight of the evaluation units had a GHSI value of 0 due to the lack of aquatic forage in those evaluation units. The low overall HSI values were due to the sub-optimal values for all three variables used to calculate the moose GHSI.

The mean dormant season browse resource (1.13 moose per km²) was slightly lower than the growing season browse resource, with 90 percent of the evaluation units falling almost uniformly between 0.1 and 2 moose per km². Only five of the evaluation units had sufficient browse resources to support more than two moose per km². Results thus indicate that limited seasonal browse resources lowered overall habitat quality in both seasons. Dormant season cover index values were low throughout the study area, with an average value of 0.74 moose per km² and a maximum value of only 1.14 moose per km². This low mean cover value considerably lowers the final dormant season HSI value. The dormant season mean HSI was slightly higher than the GHSI, primarily due to the low aquatic resource mean for the growing season. Eighty-nine percent of the evaluation units had DHSI values between 0 and 1. These low values are caused primarily by the low cover values for each evaluation unit.

Discussion

The assumed maximum potential moose density is two moose per km² and the average results of this analysis for the Coffee Creek study area for both growing season and dormant season habitat potential for moose are lower than 0.5 moose per km². The growing season habitat suitability results indicate that the aquatic resource is most limiting, underscoring the importance of maintaining all existing wetlands in this study area.

The dormant season moose resources are lacking mostly in the area of suitable cover stands. This result agrees with those of Allen *et al.* (1991) who found, in a similar area of northeastern Minnesota, that only 5.8 percent of their study area was in high quality winter cover stands as opposed to the 5 percent to 15 percent recommended by Peek *et al.* (1976). From a management perspective, this means that the existing stands of suitable cover, generally older conifer stands, need to be preserved. The dormant season browse resource is not as limiting as cover but could be improved through harvesting within 100 metres of cover stands.

In attempting to assess moose habitat suitability of a forested landscape, several problems were addressed. First, we hoped to make full use of current technology in order to increase the spatial resolution of model input and results. Second, a strategy that considered the sensitivity of model results to alternative formulations was designed and executed. A method using a mirror data set outside the study area was used to extrapolate the HSI values for the boundary portions. We analyzed the sensitivity of seasonal HSI scores based on these two assumptions and found the model results to be realistic with results within expected ranges, comprehensive with values reported for the entire study area, yet conservative with all assumptions clearly stated. Higher precision could have been achieved by obtaining the necessary data for areas immediately surrounding the study area had they been available. Within the database model of the GIS, we further adapted the HSI model to run on a sample of points in order to increase the efficiency of the model. Results showed that landscape point samples can be combined with different boundary area conditions to estimate both component SI values and composite HSI scores for both seasons. This provides resource managers tools and methods to incorporate the habitat requirements of moose when making management decisions.

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