BIOLOGICAL REPORT 82 (10.155)
SEPTEMBER 1987

HABITAT SUITABILITY INDEX MODELS: MOOSE, LAKE SUPERIOR REGION

Fish and Wildlife Service

S. Department of the Interior

Biological Report 82(10.155)
September 1987

HABITAT SUITABILITY INDEX MODELS: MOOSE, LAKE SUPERIOR REGION

by

Arthur W. Allen
U.S. Fish and Wildlife Service
National Ecology Research Center
Creekside One Building
2627 Redwing Road
Fort Collins, CO 80526-2899

Peter A. Jordan
University of Minnesota
Department of Fisheries and Wildlife
St. Paul, MN 55108

and

James W. Terrell
U.S. Fish and Wildlife Service
National Ecology Research Center
Creekside One Building
2627 Redwing Road
Fort Collins, CO 80526-2899

U.S. Department of the Interior
Fish and Wildlife Service
Research and Development
Washington, DC 20240

Suggested citation:

Allen, A.W., P.A. Jordan, and J.W. Terrell. 1987. Habitat suitability index models: moose, Lake Superior region. U.S. Fish Wildl. Serv. Biol. Rep. 82(10.155). 47 pp.

PREFACE

This document is part of the Habitat Suitability Index (HSI) model series [Biological Report 82(10)], which provides habitat information useful for impact assessment and habitat management. The HSI Model section documents the habitat models and includes information pertinent to their application. The models synthesize habitat use information into a framework appropriate for field application and are scaled to produce an index value between 0.0 (unsuitable habitat) and 1.0 (optimum habitat). The HSI Models include information about the geographic range and seasonal application of the models, their current verification status, and a list of the model variables with recommended measurement techniques for each variable.

The models are a formalized synthesis of biological and habitat information published in the scientific literature and may include unpublished information reflecting the opinions of identified experts. Habitat information about wildlife species frequently is represented by scattered data sets collected during different seasons and years and from different sites throughout the range of a species. The models present this broad data base in a formal, logical, and simplified manner. The assumptions necessary for organizing and synthesizing the species-habitat information into the models are discussed. The models should be regarded as a hypothesis of species-habitat relationships and not as a statement of proven cause and effect relationships. The models may have merit in planning wildlife habitat research studies about a species, as well as in providing an estimate of the relative suitability of habitat for that species. User feedback concerning model improvements and other suggestions that may increase the utility and effectiveness of this habitat-based approach to fish and wildlife planning are encouraged. Please send suggestions to:

Resource Evaluation and Modeling Section
U.S. Fish and Wildlife Service
National Ecology Research Center
2627 Redwing Road
Ft. Collins, CO 80526-2899

CONTENTS

FIGURES

TABLES

ACKNOWLEDGMENTS

These HSI models are based on the results of a modeling workshop held in Duluth, MN in April 1987. Workshop participants included: Robert Aho, Michigan Department of Natural Resources, Baraga, MI; Richard Buech, U.S. Forest Service, Northcentral Forest Experiment Station, St. Paul, MN; Gene DeGaynor, U.S. Forest Service, Tongass N.F., Ketchikan, AK; Peter Jordan, University of Minnesota, St. Paul, MN; Pat Karns, Minnesota Department of Natural Resources (MDNR), St. Paul, MN; Mark Lenarz, MDNR, Grand Rapids, MN; Ed Lindquist, U.S. Forest Service, Superior N.F., Duluth, MN; Mit Parsons, U.S. Forest Service, Wildlife and Fish Ecology Unit, Fort Collins, CO; Don Potter, U.S. Forest Service, Superior, N.F., Cook, MN; Lynn Rogers, U.S. Forest Service, Northcentral Forest Experiment Station, St. Paul, MN; Wayne Russ, U.S. Forest Service, Superior N.F., Tofte, MN; H.R. (Tim) Timmerman, Ontario Ministry of Natural Resources, Thunder Bay, ON; and Tim Webb, MDNR, Grand Marais, MN. The time and willingness of these individuals to contribute to the initial workshop, attend subsequent meetings, and provide reviews of the models are gratefully acknowledged.

Appreciation is extended to Ed Lindquist for coordination of the workshop. The U.S. Forest Service provided funds in support of the modeling workshop.

The following individuals provided valuable critiques on earlier drafts of these HSI models: Vince Crichton, Manitoba Department of Natural Resources, Winnipeg; Adrian Farmer, U.S. Fish and Wildlife Service, Fort Collins, CO; Peter Gogan, National Park Service, International Falls, MN; Larry Irwin, University of Wyoming, Laramie; Michael Link, Northwoods Audubon Center, Sandstone, MN; John Oldemeyer, U.S. Fish and Wildlife Service, Fort Collins, CO; Rolf Peterson, Michigan Technological University, Houghton, MI; Ken Risenhoover, Texas A&M University, College Station, TX; Edmund Telfer, Canadian Wildlife Service, Edmonton, AL; and Ian Thompson, Candian Forestry Service, St. John's N.F. The additional information provided, as well as the time and willingness of these individuals to contribute to the improvement and completion of these models, are gratefully acknowledged.

Word processing was provided by Dora Ibarra. Kay Lindgren assisted with literature searches and information acquisition. The cover of this document was illustrated by Jennifer Shoemaker.

HABITAT SUITABILITY INDEX (HSI) MODELS FOR MOOSE IN THE LAKE SUPERIOR REGION

INTRODUCTION

This document presents models developed for evaluation of moose (*Alces alces*) habitat quality in the Lake Superior region (Figure 1). To the fullest extent possible, the models have been designed to facilitate their application where timber and wildlife management actions are being coordinated in integrated resource planning. The models can be used both to identify impacts to moose habitat or identify measures to enhance habitat quality.

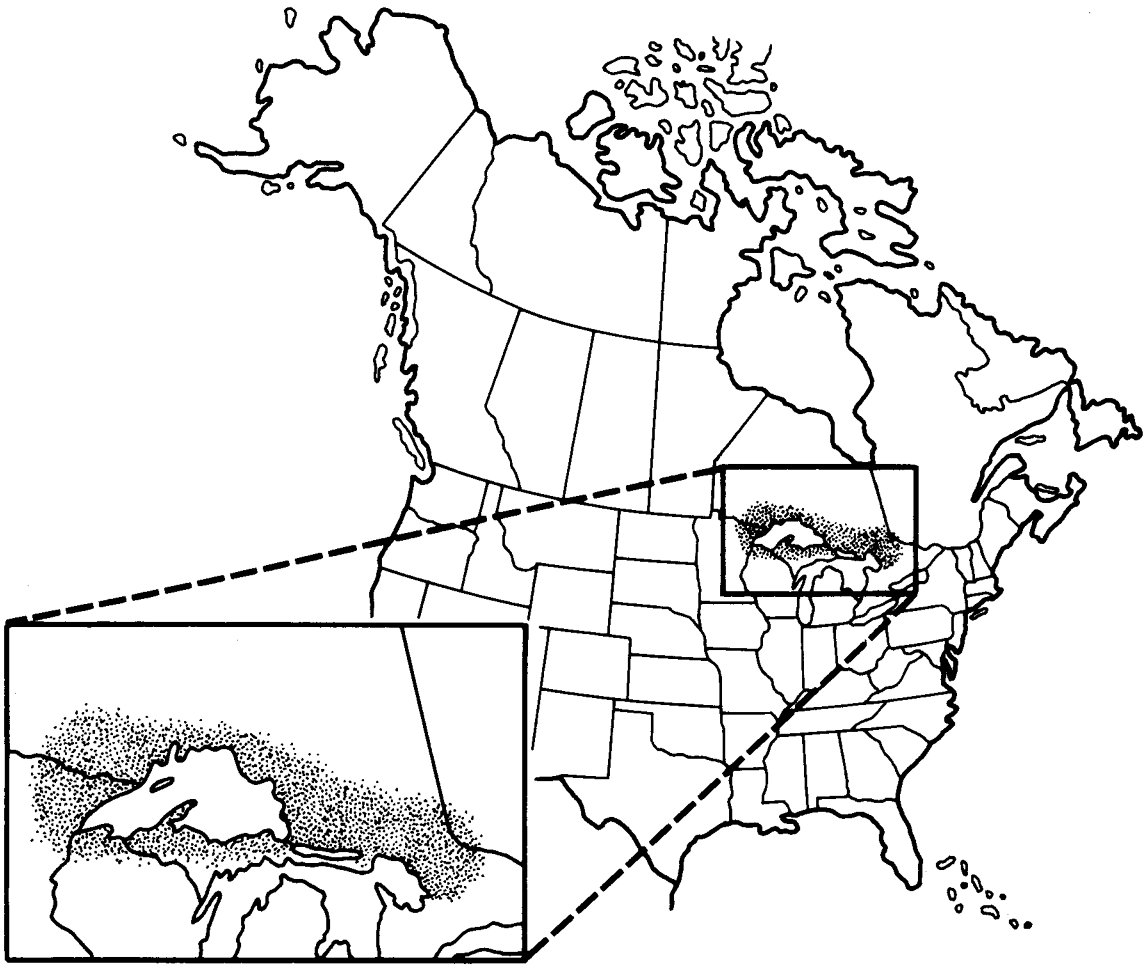


Figure 1. Approximate area of applicability (shaded) of the HSI models for moose in the Lake Superior region.

The models are based on the assumption that populations of moose that have abundant food of sufficient quality interspersed with a suitable amount and quality of cover have the potential to increase or stabilize at relatively high density in the absence of other factors that contribute to mortality. Potentially critical mortality factors for moose in the Lake Superior Region include predation by wolves (*Canis lupus*), black bears (*Ursus americanus*), affliction of parasites for which moose are not the normal host (e.g., *Paraelaphostrongylus tenuis*), and hunting. Although it is recognized that such direct mortality factors may hamper population growth where habitat is otherwise favorable, the following models do not include them in formulations for calculation of habitat suitability. The influence of intraspecific and interspecific competition for browse and their effect on moose density are not addressed in the models. Thus, land managers can use these models to evaluate the potential of an area to support moose without having to account for all factors that operate to determine the actual density present at any given time.

Two habitat models are provided in this document. Model I is structured on evaluations of the abundance and quality of growing and dormant-season food and cover. Although much of the data required for this model can be obtained from existing data sources, portions of the model require on-site data collection. Model I is intended to be applied to individual evaluation units which are assumed to be roughly equal to the minimum area in which the annual habitat requirements of moose can be provided. A 600 ha (1,500 acre) evaluation unit is recommended, but the model is easily adapted to evaluation units of comparable size. A large study area must be subdivided into individual evaluation units to be evaluated with Model I.

Model II is based on an evaluation of cover type composition and its assumed relationship to moose habitat suitability in the region of model applicability. Model II, recommended for rapid evaluations of large areas of habitat, provides a lower resolution approach to evaluation of moose habitat based solely on vegetative cover data that can be obtained from aerial photography or maps. The data required by Model II can often be obtained from timber management data typically collected by management agencies.

Table 1 presents a comparison of data requirements and model outputs, for both Model I and Model II. Although recommended, evaluation units of exactly 600 ha are not required to use Model I. The model is structured so that an HSI can be calculated for different size evaluation units (e.g., stands). Model I requires dividing a large study area into individual evaluation units approximately 600 ha in size and applying the model individually to each evaluation unit. Model II does not require subdivision of the study area, rather it provides a single habitat index for the entire area.

Model Applicability

Geographic area. These models have been developed for application in the Lake Superior region, which includes portions of Ontario, Minnesota, Wisconsin, and Michigan's upper peninsula. Although life requisites and key assumptions identified in the models may be applicable to other regions, these models are not recommended for use outside of the Lake Superior region.

Table 1. Model life requisites, data requirements, and output for HSI Models I and II for moose in the Lake Superior region.

HSI model	Life requisite	Data requirements	Output
I	Growing-season browse	Annual browse production, diversity, and quality	Potential number of moose/km^2 that can be supported by growing-season browse
	Aquatic forage	Area of nonforested wetlands	Potential number of moose/km^2 that can be supported by aquatic forage
	Growing-season cover	Area and species composition of forest cover	Potential number of moose/km^2 that can be supported by growing-season cover
	Dormant-season browse	Annual browse production, diversity, quality, and distance to dormant-season cover	Potential number of moose/km^2 that can be supported by dormant-season browse
	Dormant-season cover	Height, density, and species composition of forest cover	Potential number of moose/km^2 that can be supported by dormant-season cover
II	Cover type composition in relation to overall habitat quality	Percent of area in the following cover types: shrub and forested $<$20 years old, spruce/fir forest $\geq$20 years old, deciduous or mixed forest $\geq$20 years old, and nonforested wetlands	Index of habitat quality ranging from 0.0 to 1.0, where 0.0 = unsuitable 1.0 = optimum

Season. These HSI models are intended for the evaluation of year-round habitat quality; however, habitat conditions are evaluated separately for the growing-season (mid-May to mid-September) and the dormant-season (mid-September to mid-May) in Model I.

Cover types. These models have been developed to evaluate the quality of moose habitat in the following cover types (terminology follows that of U.S. Fish and Wildlife Service 1981): Evergreen Forest (EF); Deciduous Forest (DF); Evergreen Shrubland (ES); Deciduous Shrubland (DS); Riverine (R); Lacustrine (L); Palustrine Forested (PFO); Palustrine Scrub/Shrub (PSS); and Palustrine Emergent (PEM) wetlands. Wetland terminology follows that of Cowardin et al. (1979).

Minimum Habitat Area

Application of habitat suitability criteria requires that certain spatial parameters be specified. Minimum habitat area is defined as the minimum area of contiguous habitat that can support a moose population on a reasonably long-term basis. No specific measurements of this parameter have been made in the Lake Superior region; therefore, the precise minimum area of contiguous habitat required to support a moose population in this region is unknown. Until data become available, it is assumed that a township, 36 mi^2 [9,324 ha (23,040 acres)], is of sufficient size to support a viable moose population, assuming all required life requisites are present and there is frequent genetic interchange.

The potential of an area to support moose varies widely. Where all food and cover requisites are in good quantity, quality, and interspersion, there is potential for supporting, over reasonably long periods, densities of 0.4-4 moose/km^2 (1-10/mi^2). This assumption is based mainly on observations at Isle Royale where, in the presence of wolves, but not bears (*Ursus* spp.), parasites, or hunting, the overall island population has, for several decades, ranged between 1.5 and 3 moose/km^2 (4-8/mi^2). Major sectors of that 544 km^2 (210 mi^2) island have consistently supported 3.8+ moose/km^2 (10+/mi^2) in winter (Jordan and Wolfe 1980; Peterson and Page 1983). While populations inhabiting islands may be judged atypical, the Isle Royale data does provide an upper limit against which other sites within the Lake Superior region can be compared. Thus, to speak of a potential year-round density of 2 moose/km^2 (5/mi^2) in the region is not unreasonable. This density is both conservative and practical and is used in the models as the density that potentially can be carried when habitat is optimum.

Model output is designed to estimate potential moose density in the evaluation area. A maximum HSI value (1.0) suggests that the area has the potential to support 2 moose/km^2. Lower HSI values indicate a capacity to support correspondingly fewer moose. It is not implied that a density of 2 moose/km^2 should be a universal management goal. In some cases, managers may desire a considerably lower density because high moose numbers may cause unacceptable damage to forest reproduction, particularly where hardwood timber is being emphasized. Also, it is clearly recognized that in large sectors of the Lake Superior region, where soils, topography, or climate are less favorable, there is a far lower potential for moose productivity. In these areas, even under the most intensive management, abundance is unlikely to ever reach 2 moose/km^2.

Of more relevance is the minimum size of tract within which the habitat evaluation should be made; this is termed the "evaluation unit." Animals, during a given time period or season, meet their environmental needs by moving among various resources. A critical aspect of habitat quality is the dispersion of such resources. Thus, the more localized the full mix of required resources, the higher the habitat suitability, assuming other variables remain constant.

A reasonable size for the evaluation unit is an estimate of the animal's annual home-range. This recognizes that, whereas animals routinely move about to obtain their various needs, there are distinct limitations to mobility. At the same time, we recognize that when a marked change in seasonal conditions occurs, animals may shift areas, i.e., from a summer to a winter home range. There are no published data on home-range size of moose for the Lake Superior region. In north-central Sweden, Cederlund et al. (1987) found that adult summer home ranges averaged 740 ha (1,829 acres) with a range of 222 to 750 ha (548 to 1,853 acres). Phillips et al. (1973) found that summer-fall home ranges averaged 1,800 ha (4,448 acres) and winter ranges averaged 360 ha (900 acres) in northwestern Minnesota (not in the region considered for this model). Important considerations are that the evaluation unit is not so large as to extend far beyond normal, within-season mobility, and not so small as to become impractical for inventory of vegetation patterns or for forest-management prescriptions. For the purpose of Model I, a 600-ha (roughly 1,500-acre) evaluation unit is assumed to be of sufficient size for analysis of year-round moose habitat quality. Although this figure is somewhat arbitrary, it is assumed that 600 ha can potentially provide the annual habitat requirements of moose and is of sufficient area for prescription of plausible habitat and forest management activities.

Verification level. The two models are the result of a workshop held in Duluth, MN, in April 1987 to define the characteristics that influence moose habitat quality in the Lake Superior region. The models are a hypothesis of species-habitat relationships based on a synthesis of opinions of experienced biologists and managers familiar with moose ecology in the region. The models reflect the prevailing state of knowledge on moose habitat requirements; however, the limits of that knowledge are reflected by the number of weakly supported assumptions used in formulation of the models. This document should challenge biologists to test the assumptions on which the models are based and to improve the models into more accurate tools for habitat management in the Lake Superior region.

The following individuals participated in the workshop:

Robert Aho, Michigan Department of Natural Resources, Baraga

Richard Buech, U.S. Forest Service, Northcentral Forest Experiment Station, St. Paul, MN

Gene DeGaynor, U.S. Forest Service, Ketchikan Ranger District, Tongass N.F., Ketchikan, AK

Peter Jordan, Department of Fisheries and Wildlife, University of Minnesota, St. Paul

Pat Karns, Ecological Services, Minnesota Department of Natural Resources, St. Paul

Mark Lenarz, Forest Wildlife Research Group, Minnesota Department of Natural Resources, Grand Rapids

Ed Lindquist, Superior National Forest, Duluth, MN

Mit Parsons, Wildlife and Fisheries Ecology, U.S. Forest Service, Fort Collins, CO

Don Potter, II, U.S. Forest Service, LaCroix Ranger District, Superior N.F., Cook, MN

Lynn Rogers, U.S. Forest Service, Northcentral Forest Experiment Station, St. Paul, MN

Wayne Russ, U.S. Forest Service, Tofte Ranger District, Superior N.F., Tofte, MN

H.R. Timmermann, Ontario Ministry of Natural Resources, Thunder Bay

Tim Webb, Minnesota Department of Natural Resources, Grand Marais

The following individuals provided additional review of the models: Vince Crichton, Manitoba Department of Natural Resources, Winnipeg; Adrian H. Farmer, U.S. Fish and Wildlife Service, Fort Collins, CO; Peter Gogan, National Park Service, International Falls, MN; Larry L. Irwin, University of Wyoming, Laramie; Michael Link, Northwoods Audubon Center, Sandstone, MN; John L. Oldemeyer, U.S. Fish and Wildlife Service, Fort Collins, CO; Rolf O. Peterson, Michigan Technological University, Houghton; Ken L. Risenhoover, Texas A&M University, College Station; Edmund S. Telfer, Canadian Wildlife Service, Edmonton, AL; and Ian D. Thompson, Canadian Forestry Service, St. John's N.F.

Modifications suggested by these reviewers have been incorporated into the models where possible. Use of reviewers' and workshop participants' names, however, does not imply that they concur with each component of the models, or with the models in their entirety.

MODEL I

Model Description

Overview. The ability of land to support moose in the Lake Superior region is assumed to be primarily a function of the amount and quality of available food, including aquatic forage in summer, and the sufficiency of both winter and summer cover. Browse is the primary food of moose throughout the year (Peek 1974; Telfer 1978). Under most circumstances, maximum browse production is associated with early stages of forest succession (Telfer 1974). The primary role of wetlands in this region is assumed to be the provision of aquatic forage, which is significant because of high concentrations of macro and micro elements, including sodium (Botkin et al. 1973; Belovsky and Jordan 1981; Jordan in press). This essential mineral is otherwise scarce in the region except where mineral springs or "licks" may provide it. Winter cover is chiefly provided by mature conifer or mixed stands; mature upland deciduous forest is of much less value.

This model is based on separate evaluations of the abundance, distribution, and quality of aquatic forage during the growing-season, browse during both the dormant and growing-season, and winter and summer cover. While there is far more information in the literature on use of winter cover, there appears reasonable evidence that cool microhabitats are critical in preventing heat stress during the warmest parts of summer. Summer cover may be particularly important along the southern edge of moose distribution in this region.

Growing Season (mid-May to mid-September)

Food component. The availability of preferred forage is believed to be a major determinant of habitat selection by moose (Krefting 1974). Seasonal and annual changes in food habits are related to differences in forage palatability (i.e., quality) and availability as affected by plant phenology, prior use, snow depth, and weather (Peek 1974; Peek et al. 1976). Seasonal movements are related to changing availabilities of preferred forage according to topography, moisture, and shading. On a regional basis, typically <30 species compose most of the diet (Morrow 1976, cited by Telfer 1978). The feeding strategy of moose has been characterized as a balance between diversification and specialization. Miquelle and Jordan (1979), in summer studies at Isle Royale, found there was not a consistent ranking of species selected by moose, but rather the principal species consumed varied among individuals using the same sites as well as between moose at different sites. Moose tended to concentrate up to 60% to 70% of their seasonal foraging on a single species, but numerous additional species were consistently eaten.

Cowan et al. (1970) concluded that no single food item is capable of sustaining moose and that the nutritive value of each component is dependent on its relationship to all other foods consumed. Analysis of key browse species [paper birch (*Betula paprifera*), aspen (*Populus tremuloides*), willow (*Salix* spp.), alder (*Alnus* spp.), and mountain cranberry (*Vaccinium vitis-idaea*)] in Alaska showed significant variation in fiber, protein, and mineral content among species as well as within species over the year

(Oldemeyer et al. 1977). The authors concluded that quality of browse was as important as quantity for the maintenance of a healthy moose population, and that any single species, regardless of its abundance, was insufficient to support the population. The quality of that Alaskan winter range had become degraded as a result of increased dominance of paper birch with a resultant decrease in the diversity and availability of other browse species.

The food components of this model are based on evaluation of growing-season browse (leaves of deciduous woody vegetation) and dormant-season browse. Dormant-season browse includes the twig growth of only the most recent growing-season for deciduous species as well as green needles and associated twigs of coniferous species. Although older twigs of deciduous species and bark are occasionally consumed they are assumed to be relatively unimportant and should not be included in evaluation of browse abundance.

Nonaquatic herbaceous vegetation was a minor component (<0.1%) of the annual diet of moose in northeastern Minnesota (Peek et al. 1976) and at Isle Royale (Belovsky and Jordan 1981). Although grasses, forbs, and lichens ("herbage") can be important nutritional supplements, particularly when browse quantity and quality are less than ideal (Edwards 1984), we assume they are not a limiting component of forage, and they are not addressed in this model.

The growing-season food component is based on the assumption that lactating cows have the highest nutritional demands. If the nutritional requirements of a given number of lactating cows are provided, the nutritional needs of the same number of moose consisting of both sexes and various ages are assumed to be met. Based upon data provided in Belovsky and Jordan (1981) we have assumed that lactating cows require ≥5 kg/day (11 lbs/day) (dry weight) of food, of which 4 kg (8.8 lbs) is browse, to meet their nutritional demands.

Because moose must ingest 30+ kg wet-weight of browse in the 5 to 8 hr/day spent feeding, sources of forage must be concentrated. Moose cannot meet their daily intake requirements by simply picking off single leaves as do deer. Rather, moose must find sites where leaves are concentrated enough that whole mouthfuls can be stripped off in fairly continuous succession. A key input for this model component is a minimum growing-season browse density below which, no matter how extensive, the stand is essentially of no use to moose. During the growing-season, this minimum browse density is assumed to be 5 g/m^2 (0.02 oz/ft^2) (dry weight). Thus, all areas within an evaluation unit with ≤5 g/m^2 (dry weight) of growing-season browse are assumed to provide no usable browse in the model. An overall average browse density for an evaluation unit is not likely to be a particularly useful figure, unless the evaluation unit is highly productive, with much of its area showing an above-minimum browse density. In most areas, mature forests offer inadequate summer browse, while sufficient browse exists mainly in recently cutover areas or in recent burns (Peek 1974). An average growing-season browse density of ≥36 g/m^2 (0.16 oz/ft^2) dry weight for an entire evaluation unit would be an unusually high level; however, that quantity was found by Jordan and Botkin (1971) for their Yellow-Birch Study Area at Isle Royale, where year-round density of moose may have been as high as 3.8/km^2 (10/mi^2). Vegetation there was a relatively uniform, mixed hardwood-conifer forest with a broken canopy under which shrubs prospered as tree reproduction was suppressed by moose hedging.

Where timber is being cut and moose densities are much lower, significant amounts of browse are restricted to sites, often of only 4 to 20 ha (10 to 50 acres), recently cleared and regenerating with broad-leaf trees and shrubs. Here browse density may be considerably greater than 36 g/m². In adjacent, full-canopy, mature stands, browse density is often below the minimum specified level, and species are of lower palatability. When browse density is averaged for an entire evaluation unit, the overall figure may be well below 36 g/m². Patches of concentrated browse are undoubtedly superior to overall widespread low density.

Based on data provided by Belovsky and Jordan (1981), it is assumed that one lactating cow requires 432 kg (dry weight) of browse during the 108-day growing-season. Assuming a maximum cropping rate of 20% of the current leaves and twigs, to prevent excessive reduction of browse plant vigor, and a minimum growing-season browse density of >5 g/m² (dry weight), 2,160 kg (dry weight) of browse (432 kg ÷ 0.2) would have to be present to support one lactating cow during the growing-season. Given these assumptions, the amount of browse present on each stand in the evaluation unit can be measured, and the number of moose that could be supported by the browse in an evaluation unit estimated with Equation 1. Equation 1 (based solely on browse abundance and requirements of lactating cows) provides a conservative estimate of potential moose numbers supported by browse because lactating cows have higher nutritional demands than other moose.

$$M_1 = \sum_{i=1}^{n} (0.2)[(D_i)(A_i)/1,000]/432 \qquad (1)$$

where M_1 = potential number of moose that could be supported by browse during the growing-season, assuming optimum browse quality in evaluation unit

0.2 = reduction factor accounting for 20% maximum cropping rate

D_i = estimated density of growing-season browse (g/m² dry weight) in stand "i"; enter 0 for all areas where density is ≤5 g/m² dry weight

A_i = area of i<u>th</u> stand

1,000 = conversion constant $\frac{\text{grams}}{\text{kilograms}}$

432 kg = dry weight (kilograms) of browse consumed by a lactating cow, which is assumed to be enough browse to support a moose of any age or sex

Example: 600-ha evaluation unit composed of:

Stand 1, 40.47 ha of browse at 36 g/m^2
Stand 2, 80.94 ha of browse at 20 g/m^2
Stand 3, 478.59 ha of browse at <5 g/m^2

$$\text{Stand } 1 = (0.2)[(36\ g/m^2)(404{,}700\ m^2)/1{,}000] = 2{,}914\ kg$$
$$\text{Stand } 2 = (0.2)[(20\ g/m^2)(809{,}400\ m^2)/1{,}000] = 3{,}237\ kg$$
$$\text{Stand } 3 = (0.2)[(0\ g/m^2)(4{,}856{,}400\ m^2)/1{,}000] = \underline{\quad 0 \quad}$$
$$6{,}151\ kg$$

$$(6{,}151\ kg)\left(\frac{1\ moose}{432\ kg}\right)$$

$$M_1 = 14.2\ moose$$

To simplify browse inventory, we suggest classifying browse into the following density classes and using the values to the right of the density class in Equation 1.

≤5 g/m^2 of browse, use 0 g/m^2

6-15 g/m^2 of browse, use 10 g/m^2

16-25 g/m^2 of browse, use 20 g/m^2

26-35 g/m^2 of browse, use 30 g/m^2

>36 g/m^2 of browse, use 36 g/m^2

Browse densities <5 g/m^2 are assumed to be too sparse for energy efficient foraging by moose and do not contribute to available browse. The capability of a site to support moose is assumed to increase as browse biomass increases. Based on Equation 1, only 12 ha (30 acres) of the highest density class of browse would be needed to support two moose.

Forage diversity is assumed to have a major influence on the potential number of moose that a given quantity of browse can support. Areas dominated by one species are believed to have lower potential for meeting the nutritional demands of moose than do equally sized areas that support a diversity of species. Even though an individual species may have high nutritional quality, studies suggest that moose seek and probably require forage diversity (Miquelle and Jordan 1979), so an abundance of a single species does not contribute to browse quality as well as the same biomass composed of several species. Table 2 lists browse species commonly encountered in the Lake Superior region

Table 2. Preference classes of common browse species used by moose during the growing-season in the Lake Superior region. The growing-season browse species composition rating is the sum of the index values for each species accounting for ≥10% of the biomass in the evaluation unit. The browse species composition rating is converted to a suitability index using Figure 2b.

High preference (index per species = 0.2)	Moderate preference (index per species = 0.1)	Low preference (index per species = 0.0)
Aspen (*Populus grandidentata*, *P. tremuloides*)	Hazel (*Corylus* spp.)	Speckled alder (*A. rugosa*)
Willow (*Salix* spp.)	Green alder (*Alnus crispa*)	Thimbleberry (*Rubus parviflorus*)
Mountain ash (*Sorbus americana*)	Red osier dogwood (*Cornus stolonifera*)	Raspberry (*Rubus* spp.)
Mountain maple (*Acer spicatum*)	Yellow birch (*Betula lutea*)	Blueberry (*Vaccinium* spp.)
Red maple (*A. rubrum*)	High-bush cranberry (*Viburnum* spp.)	Elderberry (*Sambucus* spp.)
Juneberry (*Amelanchier* spp.)	Balsam poplar (*Populus balsamifera*)	Canadian honeysuckle (*Lonicera canadensis*)
Cherry (*Prunus* spp.)		Bog shrubs [woody vegetation associated with saturated, acidic soils; e.g., bog birch (*Betula pumila*), laurel (*Kalmia* spp.), leatherleaf (*Chamaedaphne* spp.)] labrador tea (*Ledum* spp.)
Paper birch (*Betula papyrifera*)		
Bush honeysuckle (*Diervilla lonicera*)		

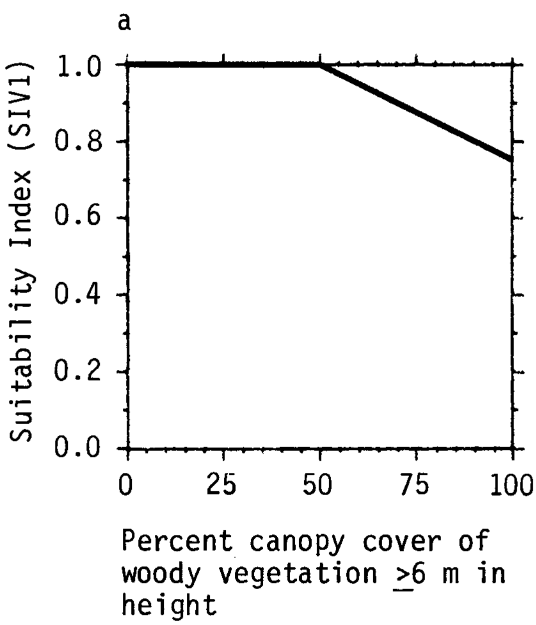
categorized into high, moderate, and low preference classes, that are assigned indices of 0.2, 0.1, and 0.0, respectively. These classes quantify the assumption that relative nutritional quality of browse is reflected by moose preference.

The nutritional quality of growing-season browse is assumed to be influenced by the density (represented by percent canopy cover) of overstory (>6 m in height) vegetation. Production and species diversity of browse decrease as forest stands mature and overstory canopy density increases (Cowan et al. 1950; Blair 1969). Cowan et al. (1950) found that a decrease of up to 19% in protein content and an increase in crude-fiber were associated with lower light penetration, suggesting a resultant decline in digestibility of browse for moose. As forests matured, there was a general decrease in the availability of palatable browse species and an increase in unpalatable browse species.

The nutritional quality of browse is assumed not to be degraded in sites where the overstory density is ≤50% canopy cover, so these sites are assigned an SI of 1.0 (Figure 2a). As overstory density increases above 50% the nutritional quality of understory vegetation is assumed to decrease. It is assumed that totally closed stands will contain understory vegetation with 75% the nutritional quality of vegetation growing in open stands (i.e., those with <50% canopy cover), and these conditions are assigned an SI of 0.75.

Figure 2b is used to rate browse species composition in an evaluation unit, based on the indices in Table 2. Evaluation units with a browse composition rating of 1.0 are assumed to reflect ideal species composition and diversity. In areas where preferred browse accounts for <50% of biomass a 1.0 browse species composition rating can be obtained by five species from the high preference category, or a combination of species from both the high and moderate categories. If available, moose will concentrate up to 70% of their foraging on preferred species (e.g., aspen, willow, paper birch, mountain maple). Evaluation units dominated by preferred species are assumed to reflect greater browse quality than do evaluation units with an equal amount of less preferred species (Figure 2b, curve 1). Low preference species have a 0.0 index and, regardless of their abundance, do not contribute to the browse species composition rating. We recommend that each species account for ≥10% of the biomass in the evaluation unit before it is included in the calculation of the browse species composition rating (Figure 2b). A <10% limit is recommended so that rare species (i.e., those occurring as a single plant or one occurrence in sample plots) will not inflate the diversity value.

The model assumes that suboptimal browse species composition and nutritional quality described above will reduce the number of moose that a given amount of browse could support. The actual effects of reduced browse quality may be a more subtle reduction in moose productivity, but for the purposes of



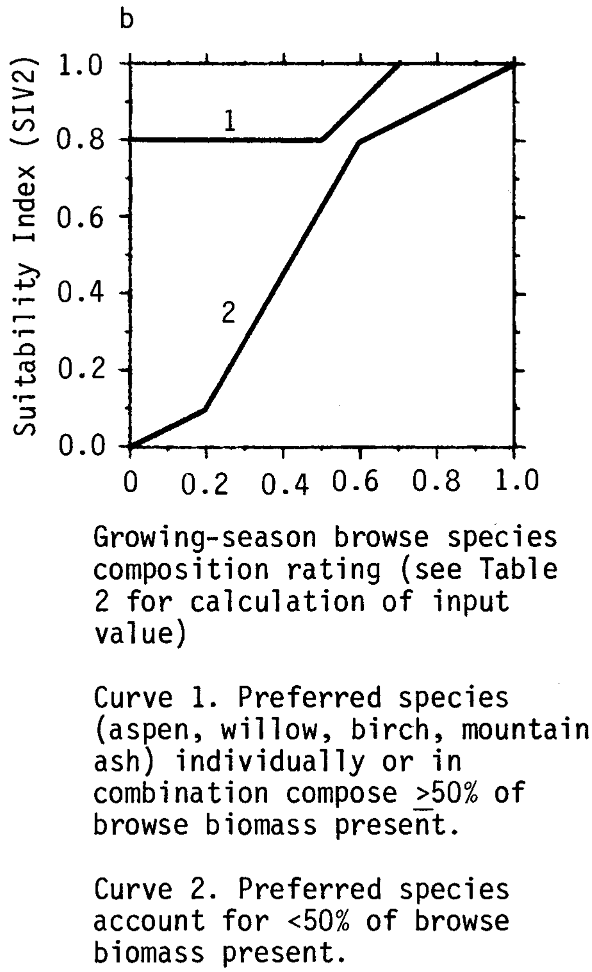


Figure 2. Relationships between variables used to evaluate the abundance and quality of browse during the growing-season (mid-May to mid-September) and suitability index values for moose in the Lake Superior region.

the model, a simple reduction in potential numbers is assumed. Equation 2 is a modification of Equation 1 that quantifies the assumed influences of browse species composition and overstory canopy cover on the potential number of moose the browse could support.

$$M_2 = \left(\frac{SIV2}{432}\right) \times \left[\sum_{i=1}^{n} 0.2[(D_i \times A_i \times SIV1_i)/1,000]\right] \quad (2)$$

where 0.2, D_i, A_i, 432, and 1,000 are defined in Equation 1

M_2 = potential number of moose that could be supported by browse during the growing-season at measured level of overstory canopy cover and species composition in evaluation unit

$SIV1_i$ = suitability index for percent canopy cover of woody vegetation ≥6 m in height in i<u>th</u> stand

SIV2 = suitability index for browse species composition in evaluation unit

<u>Example:</u> 600-ha evaluation unit composed of:

Stand 1, 40.47 ha of browse at 36 g/m², SIV1 = 1.0
Stand 2, 80.94 ha of browse at 20 g/m², SIV1 = 0.8
Stand 3, 478.59 ha of browse at <5 g/m², SIV1 = 0.75
SIV2 = 0.8 for entire evaluation unit

Stand 1 = 0.2[(36 g/m²)(404,700 m²)(1.0)/1,000] = 2,914 kg
Stand 2 = 0.2[(20 g/m²)(809,400 m²)(0.8)/1,000] = 2,590 kg
Stand 3 = 0.2[(0 g/m²)(4,856,400 m²)(0.75)/1,000] = 0
5,504 kg

$$\text{Times the quantity} \left(\frac{SIV2}{432 \text{ kg/moose}}\right) = \left(\frac{0.8}{432 \text{ kg/moose}}\right) \times 5,504 \text{ kg}$$

$$= M_2 = 10.2 \text{ moose}$$

In this example, percent canopy cover of woody vegetation >6 m in height (SIV1) reduces the amount of browse only in stand 2. Stand 3 is assumed to have no foraging value to moose due to low browse density. The browse species index (SIV2), which is applied to the entire evaluation unit further reduces the amount of browse due to less than optimum diversity (0.8). Estimated density in the evaluation unit is 10.2 moose which equates to 1.7 moose/km² (4.4 moose/mi²).

Aquatic forage. Although moose inhabit extensive regions where aquatic cover types and wetland foods play an insignificant role in their ecology (Peek 1979; Telfer 1984), the use and importance of aquatic habitat in the Lake Superior region is well-documented (VanBallenberghe and Peek 1971; Botkin et al. 1973; Kearney and Gilbert 1976; Brusnyk and Gilbert 1983; Fraser et al. 1984). Peek et al. (1976) recorded the greatest use of wetland cover types and aquatic foraging in northeastern Minnesota in early summer. Use decreased during midsummer and increased again in early fall. Extensive use of wetlands and relatively restricted movements during summer suggests that moose may spend considerable time in wetland-associated cover types in this region (VanBallenberghe and Peek 1971). Peek et al. (1976) recorded only 2% of observations of moose in wetlands, but believed wetlands were important and that the low recorded use partially resulted from small wetland cover types being classified into nonwetland categories.

In the Lake Superior region moose may face a special nutritional problem resulting from low sodium concentration in terrestrial forage (Botkin et al. 1973; Jordan 1987). Although mineral licks, if present, are often used, moose may obtain the majority of their mineral requirements from vegetation consumed during the growing-season. Browse composes approximately 85% of the annual diet of moose. However, for Isle Royale, it was estimated that browse provides about 14% of the annual sodium requirements of moose (Botkin et al. 1973; Belovsky and Jordan 1981). Compared with terrestrial vegetation, floating-leaved and submersed aquatic vegetation have much higher levels of sodium and iron, while concentrations of other nutrients are similar (Fraser et al. 1984). Aquatic vegetation contained 50 to 400 times the sodium, 2 to 200 times more iron, and twice as much ash as woody vegetation in Ontario, but only sodium was found to be inadequate in terrestrial browse. Similarly, Botkin et al. (1973) reported that the sodium content in submersed and floating-leaved aquatic vegetation was approximately 500 times greater than in terrestrial vegetation and about 50 times greater than in emergent vegetation.

Riverine, lacustrine, or palustrine wetlands (as defined by Cowardin et al. 1979), not dominated by woody vegetation, are assumed to potentially provide sites of aquatic vegetation production. Although environmental conditions that support production of preferred aquatic vegetation are not clearly defined, it appears that palustrine wetlands with high mineral content in the substrate and higher flushing rates are most suitable for growth of aquatic vegetation preferred by moose in Ontario (Fraser et al. 1984). Wetlands that are poorly drained, acidic, or have a high organic content in the substrate, appear unproductive. If a sufficient wetland area is present within a 600-ha evaluation unit it is assumed that aquatic forage will be available for moose and their sodium requirements will be met. Based on what appeared to be maximum cropping of aquatic forage at Isle Royale, where summer density may have been as high as 3.8 moose/km^2, there were roughly 1.3 to 3.3 ha (3.2 to 8.1 acres) of medium to heavy stands of submersed vegetation/km^2 (Aho and Jordan 1979). This amount of aquatic forage should easily support the 2 moose/km^2 used as the standard of comparison. The aquatic forage component of the model is based on the assumption that only about 10% of riverine, lacustrine, or palustrine wetlands not dominated by woody vegetation will likely be composed of littoral areas supporting suitable, dense stands of accessible aquatic vegetation. Applying this 10% factor to the vegetation area figures (1.3 to 3.3 ha) assumed to be capable of supporting two moose indicates that 13 to 33 ha/km² of the defined wetland classes should provide sufficient aquatic forage for two moose. The mean of this range translates to about 11 ha of the defined wetland classes required to provide aquatic forage for one moose. In equation form:

$$M_3 = \frac{WA}{11} \qquad (3)$$

where M_3 = potential number of moose that can be supported by aquatic forage

WA = the area of riverine, lacustrine, or nonacidic palustrine wetlands not dominated by woody vegetation (ha)

11 = the density of suitable wetland classes required to support 1 moose (ha/moose)

Equation 3 is based on the following assumptions. For habitat evaluation purposes, estimates of aquatic macrophytes, as made in intensive studies (e.g., Aho and Jordan 1979), are not practical. While there are preferences by moose among species of submersed and floating-leaved aquatic plants, just as there are differences in plants' sodium contents (Fraser et al. 1984) essentially all species were consumed in heavily cropped sites at Isle Royale (Aho and Jordan 1979). Therefore, for gross level habitat evaluation, species composition of aquatic forage is assumed to be insignificant in the definition of aquatic forage quality. Evaluation units with ≥22 ha/km² in riverine, lacustrine, or nonacidic palustrine wetlands not dominated by woody vegetation are assumed to have sufficient wetland area to provide aquatic vegetation to support 2 moose/km². The model rates evaluation units with less wetland area as potentially able to support proportionally lower moose densities.

Cover component. Much has been written on the use of cover by moose, but there are few data that permit quantification of importance values. Furthermore, contradictory observations that indicate moose can exist in the absence of certain types of cover add to the confusion in our understanding of their cover requirements.

The complete model evaluates cover requirements during the growing and dormant-seasons separately. Security cover is not incorporated into the model, but it is discussed in the Special Considerations section. Little is known about specific effects of heat on moose, but anecdotal reports from zoos plus some field observations suggest that heat stress may occur when air temperatures exceed 31 °C (87 °F). Moose are adapted to withstand extremely cold temperatures, but are intolerant to heat stress in all seasons (Renecker and Hudson 1986). Recent studies conducted in Alberta on hand-reared moose suggest upper critical temperatures are 14 to 20 °C+ in summer and -5 to 0 °C in winter (Renecker and Hudson 1986). Insufficient cover during critical temperatures promotes increased metabolism, elevated heart and respiratory rates, and causes reduced food intake, resulting in subsequent weight loss. Changes in daily behavioral patterns and habitat utilization (Flook 1955; Knorre 1959, cited by Renecker and Hudson 1986) are also heat induced. Belovsky (pers. comm.) analyzed bedding sites of moose during hot weather and determined that they chose sites with significantly lower soil temperatures than the overall average in the vicinity. Substrates chosen were generally damp and under dense conifer canopy. From this it is conservatively estimated that habitat will be less than optimal without mature, closed-canopy forest.

Growing-season cover quality is based on the assumption that ≥8 individual stands of mature closed canopy forest each ≥2 ha (5 acres) within a 600-ha (1,500-acre) evaluation unit are required to provide optimum cover conditions for a density of 2 moose/km². The growing-season cover component is based on the assumption that numerous, relatively small stands of dense forest cover will provide growing season cover of higher quality than will one large stand. The requirement of eight individual stands is based on the following rationale. The model uses 2 moose/km² (5/mi²) as a reasonable estimate of the number of moose that could be supported by optimum habitat in the Lake Superior region. The model is designed for habitat assessment within a 600-ha (1,500-acre) evaluation unit which equates to 6 km² (2.3 mi²). Therefore, it is assumed that under optimum habitat conditions an evaluation unit could support about 12 moose (2 moose/km² x 6 km²). If it is assumed that the cow/bull ratio of an actual population would be slightly in favor of cows, then under optimum conditions an evaluation unit could be expected to support about seven cows (1.2 cows/km²) and five bulls (0.8 bulls/km²). For optimum growing-season cover it is assumed that at least one 2-ha, or larger, stand of suitable forest cover should be available per cow for cover, so ≥8 stands per 600 ha is selected as a conservative optimum. As the number of individual stands providing growing-season cover decreases below eight, habitat quality is assumed to decrease.

Figure 3 illustrates the assumed relationships between the type of forest present and growing-season cover quality for individual stands. To insure interspersion of cover stands within the evaluation unit each stand evaluated with SIV3 should be >600 m from any other stand evaluated (distance measured between stand centers so that distance measurement is independent of stand site). Lowland conifers (e.g., black spruce, northern white cedar) are assumed to provide optimum cover as a result of the normally dense canopy and moist substrate associated with these species. Lowland hardwoods are assumed to represent slightly less than optimum cover as a result of their more open canopy; however, because they are associated with mesic sites and cooler microclimate they are assumed to be indicative of relatively high quality cover. Mature, dense stands of upland conifers and hardwoods are assumed to provide growing-season cover of moderate value as a result of the more xeric conditions and warmer microclimates associated with these species.

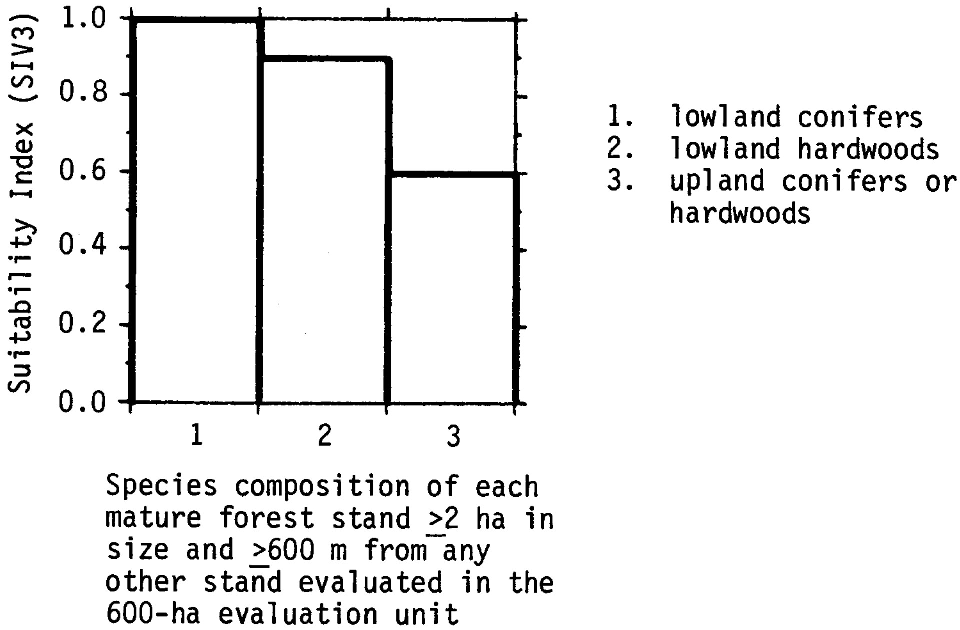


Figure 3. Relationships between the species composition of each mature forest stand ≥2 ha in size and >600 m from any other stand evaluated in the 600-ha evaluation unit and suitability index values for moose.

The above relationships have been combined in Equation 4 to determine a growing-season cover index (GSCI) for an entire evaluation unit.

$$GSCI = \Sigma[SIV3_1 + SIV3_2 + ... + SIV3_8]/8 \quad (4)$$

where $SIV3_{1-8}$ = SI value for each of the eight best forest stands >2 ha in size and ≥600 m from any other stand per 600 ha of evaluation unit

Equation 4 assumes that if eight ≥2-ha stands dominated by lowland conifers in a 600-ha evaluation unit represent optimum growing-season cover, then only the best eight stands should be used in the cover rating because moose will select the stands providing the best growing-season cover. A lower GSCI will be calculated where <8 forest stands ≥2 ha/600 ha are present or where the forest stands are dominated by lowland hardwoods or upland forest types. If evaluation unit size is not equal to 600 ha, the number of stands evaluated should be proportional to 8 stands/600 ha.

Equation 5 is used to combine the growing-season cover index (GSCI) with the estimates of the potential number of moose supported by growing-season browse (M_2) and aquatic forage (M_3) into an estimate of the potential number of moose per unit area that can be supported during the growing-season in a 600-ha evaluation unit. The growing-season cover index is not as directly related to moose numbers as M_2 and M_3. We believe that, in many cases, the browse and aquatic forage resources represented by M_2 and M_3 are likely to be well scattered across an evaluation unit even when present at low levels. If this is the case, optimum use of these resources by even a low density of moose should occur if growing-season cover is well interspersed throughout the evaluation unit. Thus, we have chosen to interpret the GSCI as an index of cover needs for any density of moose to efficiently exploit the food resources represented by M_2 and M_3. In equation form:

$$M_4 = (\text{lowest of } M_2 \text{ or } M_3) \times \text{GSCI} \times \frac{1}{A} \qquad (5)$$

where M_4 = potential number of moose per unit area (A) that can be supported by growing-season browse, aquatic forage, and growing-season cover in an evaluation unit

M_2, M_3, and GSCI are as defined in Equations 2, 3, and 4

A = area of evaluation unit in km² (or mi²) (suggested evaluation unit size is 6 km². If a different evaluation unit size is selected, GSCI must be redefined in terms of the best "n" forest stands in the evaluation unit selected using the same stand density (8 stands/6 km²) as in Equation 4.

Dormant-Season (mid-September to mid-May)

Food component. Dormant-season browse is evaluated based on the assumption that 1,028 kg (dry weight) of dormant-season browse are required by an adult moose during the 257-day dormant-season (4 kg/day x 257 days = 1,028). The allowable cropping rate of dormant-season browse is assumed to be 60%. Therefore, 1,714 kg of browse are required to provide the 1,028 kg of browse assumed to be consumed by an adult (1,714 kg x 0.6 = 1,028 kg). Sites where browse is present at ≤1 g/m² are assumed to provide browse too sparse for efficient foraging by moose in the dormant season and do not contribute to the amount of dormant-season browse in the model. The availability of required nutrients during the dormant-season is assumed to be a function of the amount and quality of available browse. In contrast to the growing season, overstory density is not assumed to influence dormant-season browse quality. Only browse resources near cover are useful when snow is deep. Use of coniferous browse shows a peak in late winter when deep snow and inclement weather reduce availability and accessibility of deciduous species and moose concentrate in conifer-dominated cover; therefore, coniferous browse is included in dormant-season browse biomass estimates.

Following the same rationale used to estimate forage values for the growing-season, forage is restricted to browse, and browse biomass is estimated by summing per-stand density estimates of twig and needle (dry-wt) biomass for all stands in the evaluation unit. Browse must be composed of acceptable species (Table 3) and be within the reach of moose [≤4 m (13 ft) high]. Table 3 provides winter preference indices for common woody plants in the Lake Superior region. In general, conifer forage is higher in nutrients than most dormant hardwood twigs; however, we assume a limit to the proportion of conifer in the diet because of the effect of sècondary compounds. The effects of secondary compounds have not been quantified for moose, so such representations in the model are imprecise at best.

It is assumed that as the proportion of coniferous species increases past 50% that the quality of dormant-season browse will decrease (Figure 4a). Dormant-season browse nutritional quality is assumed to rapidly diminish if the proportion of total browse available composed of coniferous species increases above 50%. Areas totally dominated by coniferous browse are assumed to reflect minimum potential for providing the nutritional requirements of moose during the dormant-season.

It has been suggested that availability of dormant-season browse will be overestimated if burial by snow is not incorporated into the model. Browse burial by snow is influenced by several environmental and biological variables, which results in complex relationships between browse availability and snow depth (Schwab et al. 1987). Obvious variables that influence browse burial by snow include aspect, topography, snow moisture content, snow depth, and browse height. Factors further complicating these relationships include the growth form of browse species, the influence of overstory density on browse growth form, the morphological characteristics of the trees composing the overstory, and the density of overstory trees (Peek 1970; Schwab et al. 1987). It is commonly assumed snow depth and browse burial is less severe under a relatively dense forest canopy than in more open cover types. Schwab et al. (1987), reported, however, that increased burial of browse by snow corresponded with increased forest canopy cover during both the snow accumulation period (16 November to 4 March) and snow melt period (4 March to 28 April) in north-central British Columbia. Due to the variety and complexity of factors that influence snow depth and its effect on browse availability, snow depth has not been incorporated into this model. Users may wish to modify the model and reduce estimated available browse by average snow depth within specific cover types. However, a single reduction factor is not likely to be appropriate for multiple cover types. The dormant-season browse component disregards any

Table 3. Preference classes for common browse species used by moose during the dormant-season in the Lake Superior region. The dormant-season browse species composition rating is the sum of the index values for each species presented below accounting for ≥10% of the dormant-season browse biomass in the evaluation unit. The sum is converted to a suitability index using Figure 4c. Species within each category do not reflect ordered preference by moose.

High preference (Index per species = 0.5)	Moderate preference (Index per species = 0.1)	Low preference (Index per species = 0.05)	Avoided (Index per species = 0.0)
Aspen (Populus spp.)	Yellow birch (B. papyrifera)	N. white cedar (Thuja occidentalis)	Canadian honeysuckle (Lonicera canadensis)
Cherries (Prunus spp.)	Sugar maple (A. saccharum)	Black ash (Fraxinus nigra)	Raspberry and thimbleberry (Rubus spp.)
Mountain ash (Sorbus americana)	Balsam fir (Abies balsamea)	Currant/gooseberry (Ribes spp.)	Spruces (Picea spp.)
Willow (Salix spp.)	White pine (Pinus strobus)	Speckled alder (Alnus rugosa)	Jack pine (P. banksiana)
Dogwood (Cornus spp.)	Red pine (P. resinosa)	Elderberry (Sambucus canadensis)	Larch (Larix laricina)
Red oak (Quercus rubra)	Eastern hemlock (Tsuga canadensis)		Juniper (Juniperus spp.)
Highbush cranberry (Viburnum spp.)	Green alder (Alnus crispa) canadensis)		Bog plants (see Table 2)
Red maple (Alnus crispa)			
Hazel (Corylus spp.)			
White birch (Betula papyrifera)			

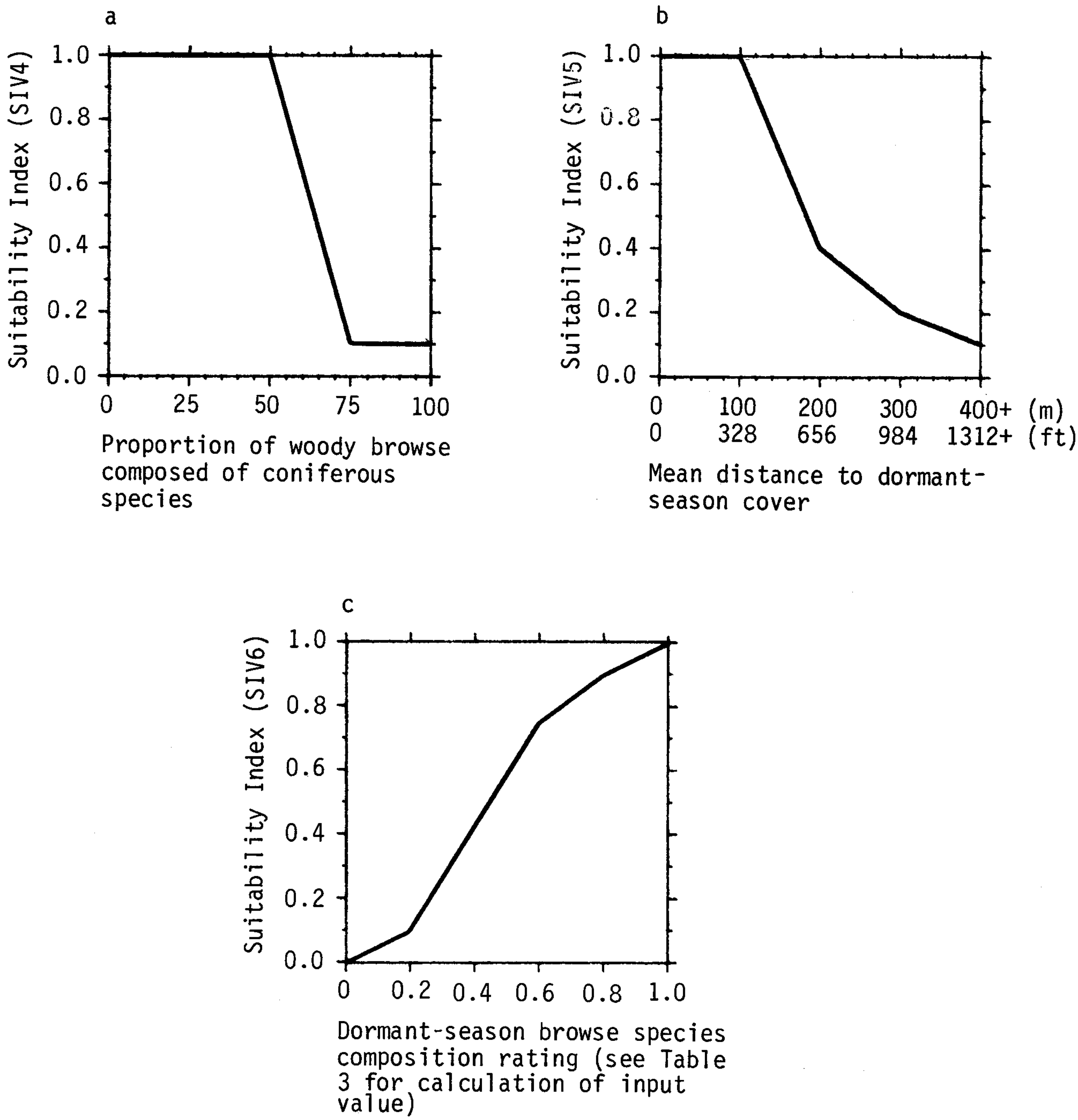


Figure 4. Relationships between variables used to evaluate the abundance and quality of browse during the dormant-season (mid-September to mid-May) and suitability index values for moose.

potential influence of snow, assumes that moose have access to all browse, and rates the ability of an area to meet the forage requirements of moose in direct proportion to browse biomass.

High quality moose winter range is composed of a mosaic of cover types that provide cover and high browse production (Telfer 1978). Interspersion of suitable winter cover and accessible browse of sufficient quality and quantity minimize metabolic demands and energy expenditures, thereby maximizing winter survival (Coady 1974). Declining trends in browse use by moose were evident with increasing distance from cover in Ontario (Hamilton et al. 1980). The authors concluded that there did not appear to be an upper distance limit for moose movement from cover to browse; however, 95% of browse use was recorded within 80 m (262 ft) of cover during 1 year of the study. Cows with calves may be less able to use cutover areas in winter than other moose (Thompson and Vukelich 1982). Although exceptional distances of >400 m (1,312 ft) from cover in early winter were recorded in Ontario, distances from cover averaged 27 m (89 ft). In late winter, movement from cover into cutovers ranged from 0 to 30 m [average = 12 m (39 ft)]. When snow depths were ≥90 cm (35 inches), movement from cover was further reduced to an average distance of 8 m (26 ft). When deep snow was present, cows and calves were generally confined to stands containing semimature or mature conifers. Only the edges of cutovers were used in extremely deep snow conditions, and most foraging shifted to shade tolerant vegetation within stands providing cover. Cows with calves were generally <60 m (197 ft) from cover regardless of snow depth and conditions.

It is assumed that browse within 100 m (328 ft) of dormant-season cover is indicative of optimum interspersion of dormant-season browse and cover (Figure 4b). The accessibility of browse is assumed to decrease with increasing distance from dormant-season cover. Browse >400 m (1,312 ft) from dormant-season cover is assumed to be indicative of very low, but not totally unavailable, browse.

As with growing-season foods, species composition and diversity of browse is assumed to have a major influence on the quality of winter food, although specifics for the Lake Superior region have not been determined. Moose apparently will not forage in areas that offer little other than balsam fir or sugar maple at Isle Royale, even though these species are often consumed otherwise (Jordan, unpubl.). On the other hand, some moose in the Rocky Mountains appear to forage in winter primarily on willow species. It is assumed that forage diversity requirements for dormant-season browse species in the high preference category are less stringent than that required for the growing-season (Table 3). In such instances, any two of these species will result in an optimum value for species composition (Figure 4c). However, in stands devoid of highly ranked species, or when these species are in low abundance, species diversity is assumed to have a major influence on the number of moose that can be supported. Stands composed of moderate to low value browse are assumed to have the potential to support more moose as diversity increases. Stands dominated by species with a 0.0 index value do not contribute to the browse species composition rating.

Equation 6 is used to combine the assumed influences of proportion of browse composed of coniferous species (SIV4), mean distance to dormant-season cover (SIV5), browse species composition (SIV6), and the allowable cropping rate (60%) to estimate the potential number of adult moose that would be supported by dormant-season browse.

$$M_5 = \left(\frac{SIV6}{1{,}028}\right) \times \sum_{i=1}^{n} (0.6)[(D_i \times A_i \times SIV4_i \times SIV5_i)/1{,}000] \qquad (6)$$

where M_5 = potential number of adult moose that could be supported by browse during the dormant-season at measured level of coniferous species composition, distance to dormant-season cover, and species composition in the evaluation unit

0.6 = reduction factor accounting for 60% maximum cropping rate

D_i = estimated density of dormant-season browse (g/m^2 dry weight) for the ith stand except enter 0 for all areas where density is <1 g/m^2 dry weight

A_i = area (ha) of ith stand

$SIV4_i$ = suitability index for proportion of woody browse composed of coniferous species in ith stand

$SIV5_i$ = suitability index for mean distance to dormant-season cover in ith stand

SIV6 = suitability index for dormant-season browse species composition rating in entire evaluation unit

1,000 = conversion constant $\frac{\text{grams}}{\text{kilograms}}$

1,028 = number of kilograms of browse consumed by one adult moose during dormant-season

Equation 6 quantifies the assumption that the proportion of browse composed of coniferous species, mean distance to dormant-season cover and browse diversity may cumulatively reduce the number of moose that can be supported by a fixed amount of browse. If all stands are in close association with dormant-season cover M_5 values calculated from Equation 6 will be equal to values determined for biomass and area alone. Conversely, stands >100 m from dormant-season cover, or where browse is composed of low preference species, will result in estimates of M_5 lower than would be estimated for biomass and area alone. The following example illustrates the influence of $SIV4_i$, $SIV5_i$, and SIV6 on model estimates of the potential number of moose that can be supported by dormant-season browse.

Example: 600-ha evaluation unit composed of:

Stand 1, 40.47 ha of browse at 36 g/m^2; SIV4 = 1.0; SIV5 = 1.0
Stand 2, 80.94 ha of browse at 20 g/m^2; SIV4 = 0.4; SIV5 = 0.1
Stand 3, 478.59 ha of browse at 0 g/m^2; SIV4 = 0.6; SIV5 = 1.0
SIV6 = 0.8 for entire evaluation unit

$$\text{Stand 1} = 0.6[(36\ g/m^2)(404{,}700\ m^2)(1.0)(1.0)/1{,}000] = 8{,}742\ kg$$
$$\text{Stand 2} = 0.6[(20\ g/m^2)(809{,}400\ m^2)(0.4)(0.1)/1{,}000] = 389\ kg$$
$$\text{Stand 3} = 0.6[(0\ g/m^2)(4{,}856{,}400\ m^2)(0.6)(1.0)/1{,}000] = \underline{0\ kg}$$
$$9{,}131\ kg$$

$$\text{Times the quantity } \left(\frac{SIV6}{1{,}028\ kg/moose}\right) = \left(\frac{0.8}{1{,}028\ kg/moose}\right) \times 9{,}131\ kg$$
$$= M_5 = 7.1\ \text{moose}$$

In this example, proportion of browse composed of coniferous species (SIV4), and distance to dormant-season cover (SIV5) are optimum in Stand 1. No reduction in the ability of the browse to support moose occurs in this stand. In Stand 2, SIV4 is 0.4, and SIV5 is 0.1. The ability of browse in the stand to support moose is reduced due to a high coniferous component and excessive distance to dormant-season cover. Stand 3 is assumed to have no value for moose due to the low browse density (e.g., <1 g/m^2). The dormant-season browse species index (SIV6), which is applied to the entire evaluation unit further reduces the amount of equivalent optimum browse due to less than optimum diversity. Estimated potential number of moose in the evaluation unit is 7.1 moose. Converting this to moose/km^2 indicates a potential density of 1.2 moose/km^2 (3.1 moose/mi^2).

Cover component. Moose exhibit a distinct seasonal pattern in winter habitat use that is related to the physical structure and species composition of forest stands (VanBallenberghe and Peek 1971; Peek et al. 1976; Welsh et al. 1980). Moose in northeastern Minnesota occupied densely forested, conifer-dominated cover types when snow accumulation was rapid, but then dispersed during warmer, storm-free periods (VanBallenberghe and Peek 1971). Peek and Eastman (1983) concluded that the protection provided by mature conifer cover is a critical component of midwinter moose habitat in regions subject to severe winters. At Isle Royale, Peterson and Allen (1974) concluded that in years of above-normal snow depth, moose confined themselves to dense coniferous cover, even when there was inadequate forage available at these sites.

There appears to be little selection by moose for specific forest types during early winter. As winter progresses and snow depth increases, use of older, more dense stands with a high conifer component increases. The majority of forest stands used for winter cover in Quebec had canopy coverage of 41% to 80% and a height of 9 to 21 m (30 to 69 ft) (Proulx and Joyal 1981). In northeastern Minnesota, upland spruce-fir stands were used most frequently during severe winter weather, and deciduous stands were used more as severe weather abated (Peek et al. 1976). The tallest and densest stands appeared to be preferred in midwinter. Bed sites during midwinter were most common in the densest conifer cover available, and continued so even after weather improved. Of midwinter bed sites, 71.5% were in stands with trees <3 m (10 ft) apart; 68.5% were adjacent to balsam fir trees; and 56.9% were in stands with a canopy height >15 m (49 ft).

The major effect of snow on habitat use by moose is its influence on the animals' energy balance, either by increasing their metabolic cost for movement or decreasing their energy intake by limiting availability and accessibility of suitable food (Coady 1974). Deep snow forces moose to move to areas where forest cover or topographic features provide relatively shallow snow (Telfer 1978). However, there appears to be little agreement on the critical threshold of snow depth that initiates movement to winter cover. Telfer (1978) and Prescott (1968) concluded that snow depths of >50 cm (20 inches) were required before moose clearly shifted to more dense cover. In contrast, Phillips et al. (1973) and Peek et al. (1976) recorded movement of moose to late-winter cover in Minnesota at snow depths of <50 cm. Use of late-winter cover types in northeastern Minnesota occurred when snow depth in aspen cover types was <45 cm (18 inches), suggesting that snow hardness or density had a more important influence on habitat use than did depth (Peek et al. 1976). On the other hand, moose are extremely tolerant of cold but are easily heat stressed (Renecker and Hudson 1986). Movement to late winter cover, when solar radiation and temperatures are increasing, may reflect intolerance by moose of mid-day temperatures as indicated by their subfreezing upper limit of thermal neutrality (-5 to 0 °C).

Model I is based on the assumption that early-winter cover is less critical than late-winter cover. For the purposes of this model dormant-season cover is defined based on late-winter cover requirements. The suitability of dormant-season cover is a function of percent tree canopy cover, the proportion of the tree canopy composed of conifers, and the mean height of conifers (Figure 5).

Sites devoid of trees [woody vegetation >6 m (20 ft)] are rated as unsuitable dormant-season cover due to the absence of protection and greater potential for snow of excessive depth. Cover quality is assumed to increase as canopy cover increases (Figure 5a). Optimum dormant-season cover is assumed to be present when tree canopy cover is ≥75%. Stands with high canopy cover are assumed to provide maximum protection from low temperatures, wind chill, and to intercept snowfall resulting in snow of lower depth and density than is found in nonforested sites or sparsely stocked stands.

Figure 5b displays the assumed relationships between the abundance of coniferous trees and the potential to provide adequate dormant-season cover. Stands devoid of coniferous species are assumed to have minimum cover value. The quality of winter cover is assumed to increase as the proportion of coniferous species in the stand increases. It is assumed that a stand composed of >60% coniferous species represents optimal dormant-season cover.

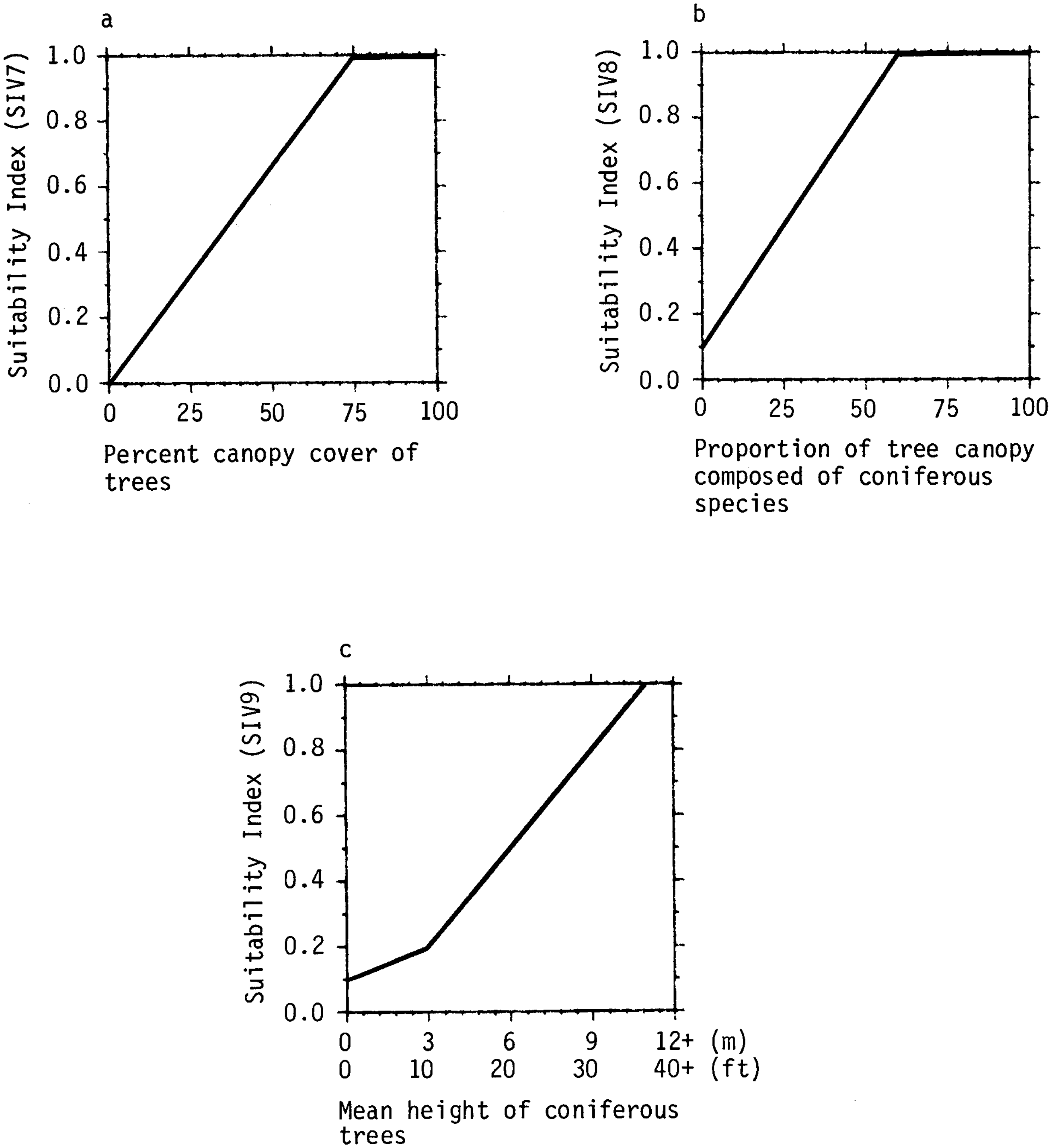


Figure 5. Relationships between variables used to evaluate the quality of dormant-season (late-winter) cover and suitability index values for moose.

Although tree density, as defined by percent canopy cover of trees, and the abundance of coniferous species may be ideal, winter cover is assumed to be unsuitable if the coniferous component of the stand is of insufficient height to provide adequate cover for moose. Figure 5c displays the assumed relationships between mean height of coniferous trees and the quality of winter cover. Stands with a mean confierous tree height of ≤3.0 m (10 ft) are assumed to have minimum potential to provide adequate cover. Cover quality increases as the mean height of coniferous trees increases. Ideal cover is assumed to occur when the mean height of coniferous trees is ≥10.6 m (35 ft).

The relationships presented in Figure 5 have been combined in Equation 7 to determine a dormant-season cover index (DSCI).

$$DSCI = (SIV7 \times SIV8)^{1/2} \times SIV9 \qquad (7)$$

Equation 7 is based on the assumption that percent canopy cover of trees (SIV7) and proportion of the tree canopy composed of coniferous species (SIV8) are compensatory. A high value for one variable will compensate for a low value of the remaining variable. For example, a low tree density will result in a higher DSCI if the trees are predominantly coniferous species. Conversely, an extremely low value will be obtained if the same density of trees is composed wholly of deciduous species. The quality estimated by the geometric means of SIV7 and SIV8 can be reduced, but not increased by mean height of coniferous trees (SIV9). This quantifies the assumption that as a result of decreasing protection and increased snow depth, stands where mean height of coniferous trees is <10.6 m will be less than optimum cover (i.e., DSCI <1.0) even though canopy cover and the proportion of trees composed of coniferous species are ideal.

Equation 8 is used to estimate the number of adult moose per unit area that can be supported in an evaluation unit as influenced by both dormant-season browse and cover.

$$M_6 = M_5 \times DSCI \times \frac{1}{A} \qquad (8)$$

where M_6 = potential number of adult moose per unit area that can be supported by dormant-season browse and dormant-season cover

M_5 = potential number of adult moose that can be supported by dormant-season browse as calculated in Equation 6

DSCI = dormant-season cover index as calculated in Equation 7

A = area of evaluation unit in km^2 (or $mile^2$)

Equation 8 indicates that regardless of dormant-season browse abundance dormant-season cover will limit the potential number of adult moose that can be supported in an evaluation unit unless there is enough cover of sufficient quality to support the number of moose selected as the standard of comparison ($2/km^2$). The reasoning for selecting this approach is similar to that used for growing-season cover, i.e., if there is abundant cover moose should be better able to exploit existing food resources. Evaluation units devoid of coniferous forest cover types, or coniferous cover of low quality as defined by Equation 7, will reflect lower potential moose density.

HSI DETERMINATION

Model I provides separate models for evaluation of growing-season and dormant-season habitat. We recommend that both growing and dormant-season habitat quality be assessed in each evaluation unit and that the resultant indices not be combined to yield a single "year-round" HSI. Figure 6 displays the assumed relationships between habitat variables, life requisites, potential densities, and HSI for both seasonal models.

Model I defines HSI for an evaluation unit as the ratio of the potential density that can be supported in an evaluation unit divided by the potential density of moose assumed to be supported by optimum habitat. The model uses two moose per km^2 ($5/mi^2$) as the potential density in optimum habitat and Equation 5 (growing-season) and Equation 8 (dormant-season) as estimators of the potential density of moose that can be supported in an evaluation unit. The HSI for both seasonal models is equal to the density estimate, or 1.0, whichever is lowest. The default rule to select 1.0 as the HSI if estimated density exceeds 2 moose/km^2 is necessary because in evaluation units of exceptional browse abundance Equation 5 or 8 could show potential density of >2 moose/km^2. Without the default criteria the HSI could exceed 1.0, which is unacceptable for a model in HSI format. In equation form:

$$\text{Growing-season HSI} = \text{lowest of } \left(\frac{M_4}{DM}\right), \text{ or } 1.0$$

$$\text{Dormant-season HSI} = \text{lowest of } \left(\frac{M_6}{DM}\right), \text{ or } 1.0$$

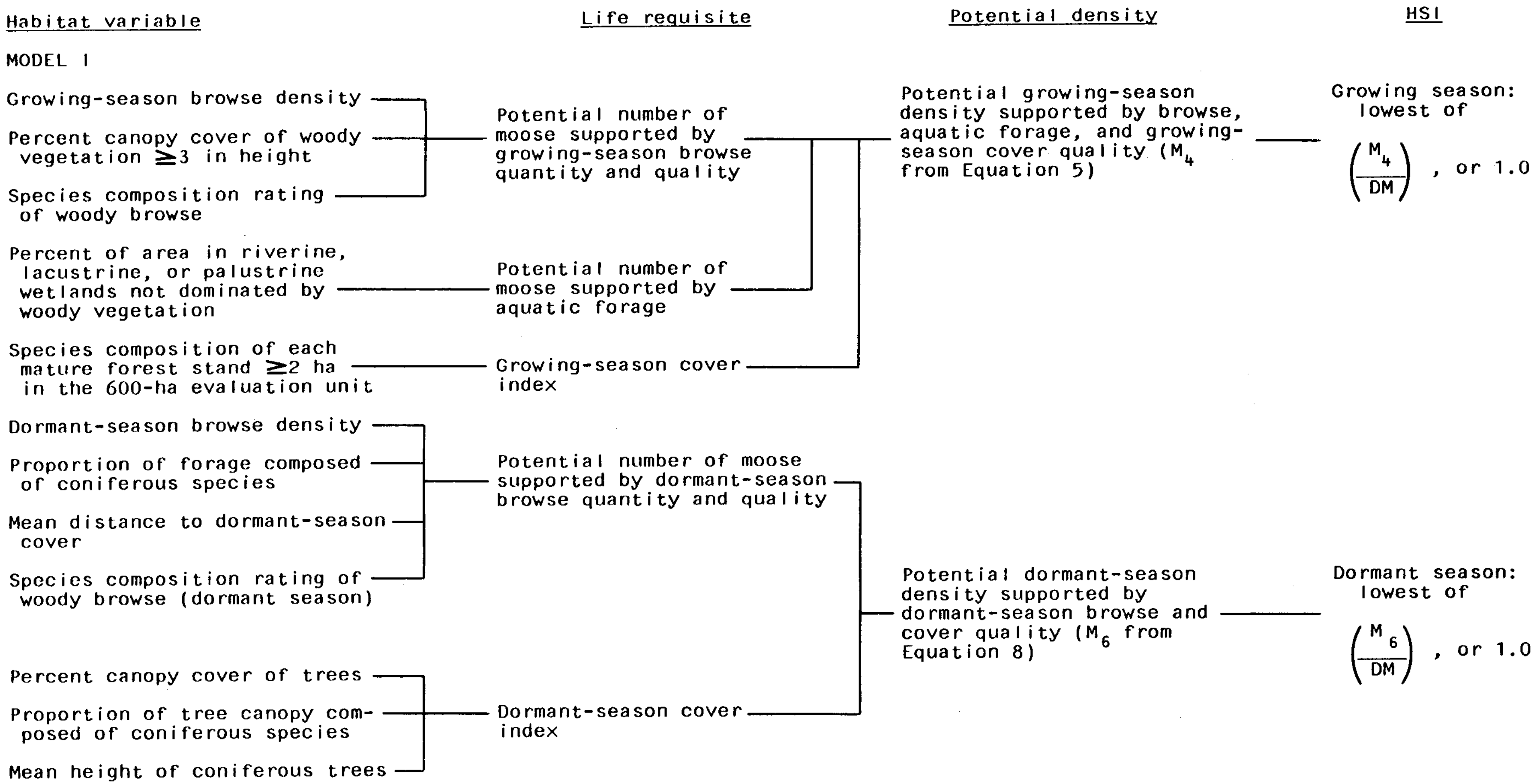


Figure 6. Relationships between habitat variables, life requisites, potential seasonal density, and HSI in Model I. DM equals the standard of comparison for maximum potential moose density (2 moose/km^2 or 5 moose/mi^2) measured in the same units of area used for M_4 and M_6.

where M_4 is as defined in Equation 5

M_6 is as defined in Equation 8

DM = the standard of comparison for potential moose density for this model (2 moose/km² or 5 moose/mi²) measured in the same units of area (km² or mi²) used for M_4 or M_6

To effectively use Model I to estimate the HSI of an area much larger than 600 ha, the area should first be divided into evaluation units of approximately 600 ha. If it is too time consuming to apply the model to all of the evaluation units, the model can be applied to a sample of the evaluation units. The mean HSI of the sampled evaluation units is then used as an estimate of the HSI of the entire area. These models can be used to directly compare seasonal habitat quality between two or more evaluation units or to predict changes in seasonal habitat quality within an individual evaluation unit resulting from forest management.

MODEL II

Model Description

Model I may require more data than available for a particular application, or more than is possible to collect due to time or budget constraints. Model II is based solely on cover type composition and uses data available from cover type maps or aerial photographs. Model II provides a lower resolution alternative that is based on assumed optimum cover type composition. Model II is designed to rapidly evaluate and compare the ability of relatively large areas to provide annual habitat requirements of moose in the Lake Superior region.

Cover Type Composition

Habitat quality for moose is a function of physical structure and spatial relationships of forest vegetation, landform, snow conditions, protection from thermal stress, and forage quality. Optimal habitat has been described as areas dominated by early successional vegetation offering a wide diversity of stand types and age classes that provide both mature conifer cover and open disturbed areas for forage production (Telfer 1978, 1984). Maintenance of adequate winter cover in areas that produce large amounts of preferred browse will enhance habitat conditions for moose (Monthey 1984). Brush fields, interspersed with stands of balsam fir, black spruce, and jack pine were described by Peek et al. (1976) as the highest quality moose habitat in their Minnesota study area.

Although the generalizations above provide a broad description of moose habitat, there has been minimum effort directed toward quantification of optimum moose range in relation to ideal cover type composition and interspersion (Telfer 1974; Oldemeyer and Regelin 1984). The influence of forestry practices, and other forms of habitat management, on the quality of moose habitat is a function of the size and shape of managed stands, the location and interspersion of harvested and unharvested stands, as well as species composition of regenerating and residual stands. Peek et al. (1976) concluded that areas with the highest potential for moose in northeast Minnesota were township-sized [93 km^2 (36 mi^2)] blocks of habitat with the following composition: (1) 40% to 50% in cutover areas <20 years old, (2) 5% to 15% of area dominated by spruce-fir, and (3) 35% to 55% of area dominated by aspen-white birch stands >20 years old and wetlands. Workshop participants assumed that these general guidelines were reasonable but needed further refinement to be of maximum value for moose habitat management in the Lake Superior region.

Figure 7 presents the assumed relationships based on the input of workshop participants between composition of major components of moose habitat and habitat quality in the Lake Superior region. It is assumed that ideal availability of food will be provided when 40% to 50% of the evaluation area (township or larger) is composed of sites with ≥50% of total areal coverage by shrub or forested cover types (regeneration) <20 years old (Figure 7a). Early successional stages are assumed to provide abundant, preferred forage for moose. Cover types in this age class may be the result of direct forest management, wildfire, or defoliation by forest insects [e.g., spruce budworm (*Choristoneura fumiferana*)].

Winter cover is assumed to be a function of coniferous cover. It is assumed that 5% to 15% of an evaluation area (township or larger) dominated by spruce/fir ≥20 years old will provide ideal availability of winter cover for moose (Figure 7b). Evaluation areas devoid of spruce/fir of sufficient age/size are assumed to be unsuitable year-round habitat for moose in the Lake Superior region.

Figure 7c illustrates the assumed relationship between the percentage of the evaluation area in upland deciduous or mixed forest ≥20 years old and habitat quality for moose. It is assumed that ideal composition will exist when 35% to 55% of the evaluation area is dominated by these forest cover types. These forest cover types are assumed to provide food as well as cover.

Wetlands are important for moose in that they provide escape from insect harassment, assist in thermal regulation, and provide escape cover and aquatic forage. The assumed relationships between wetland abundance and moose habitat quality are presented in Figure 7d. Evaluation areas with 5% to 10% of area in wetlands dominated by open water, emergent vegetation, or submersed/floating-leaved hydrophytes are assumed to provide optimum availability of aquatic forage. Wetlands dominated by forested or scrub-shrub vegetation (i.e., woody vegetation) are assumed to have no potential to provide preferred aquatic forage. Evaluation areas devoid of wetlands are assumed to be of very low suitability, but are not totally unsuitable habitat. This assumption may not be entirely true (e.g., Model I indicates no potential moose if there are no wetlands) but large scale, extensive applications of Model II may fail to enumerate very small wetlands so habitat inventoried as having no wetlands is rated as low rather than 0 suitability.

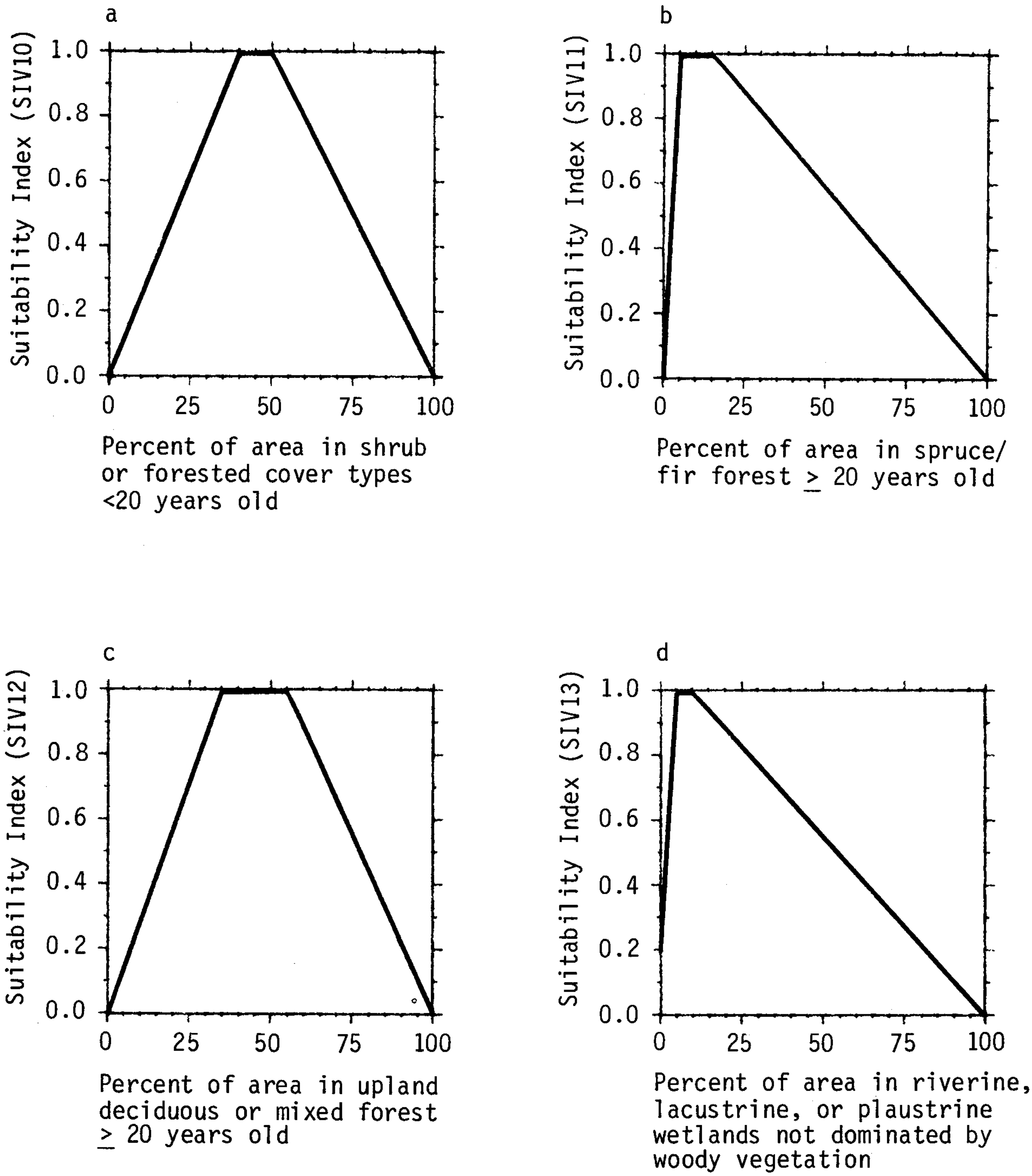


Figure 7. Relationships between variables used to evaluate cover type composition and suitability index values for moose in the Lake Superior region (Model II).

HSI DETERMINATION

Model II is based on the assumption that all four major habitat components must be present for ideal year-round moose habitat. As illustrated in Figure 7, a range of percentages of these major cover type categories is defined. Optimal cover type composition is assumed to be present where the areal coverage of shrub and forested cover types <20 years old is 40%, spruce/fir ≥20 years old is 5%, upland deciduous/mixed forest ≥20 years old is 50%, and suitable wetlands 5%. Ideal conditions also are assumed to exist as well where shrub and forested cover types <20 years old, spruce/fir, upland deciduous/mixed forest ≥20 years old and suitable wetlands account for 45%, 10%, 35%, and 10%, respectively, of the area. Lower HSI values will be calculated when one or more of the four major cover types are present at less than or greater than assumed optimum composition. It is assumed that as the amount of one cover type is increased the abundance of one or more remaining cover types will be decreased. For example, if 90% of an area is managed so that it is composed of shrub and forested cover types <20 years old, then only 10% of the area is available for older age class spruce/fir, upland deciduous/mixed forest, or wetland cover types, reflecting less than optimum cover type composition.

The index values presented in Figure 7 have been combined in Equation 10 to calculate a Habitat Suitability Index (HSI).

$$HSI = (SIV10 \times SIV11 \times SIV12 \times SIV13)^{1/4} \qquad (10)$$

In Equation 10, the variables used to evaluate habitat composition are assumed to have equal value in the definition of habitat quality for moose. All four habitat components must be present within the optimum composition range for a HSI of 1.0. Evaluation areas where any of the habitat composition variables are present at less than or greater than optimum ranges will be rated as having an HSI of <1.0. Variables have been combined with the use of a geometric mean because they are assumed to be compensatory, to have equal weight in the definition of habitat quality, and because a unit increase (e.g., increase an SI by 0.1) in the variable with the lowest suitability is assumed to have the greatest positive impact on overall habitat quality. This equation also quantifies the assumption that if any habitat component, other than wetlands, is missing the HSI will be 0.0, regardless of the extent and quality of the remaining cover types.

Summary of model variables. Ten variables are used in Model I to evaluate food and cover quality and their assumed influence on potential moose density. Four variables are used in Model II to define moose habitat quality based on cover type composition without as direct a linkage to potential moose density. Variable definitions and suggested measurement techniques are provided in Figure 8.

Variable (definition)	Cover types	Suggested techniques
MODEL 1		
Browse density (g/m^2 dry weight) (an estimate of annual production of the leaves, needles, and stems of woody vegetation. Growing-season browse should be measured during the "peak" of biomass, i.e., near the end of the growing-season and includes the leaves of deciduous species. Dormant-season browse is the annual increment of growth of deciduous twigs as well as that of coniferous twigs and needles).	EF,DF,ES,DS	Quadrat, line intercept
Browse species composition rating [a measure of the preference of moose for common browse species in the Lake Superior region combined with an estimate of the value of each species to meet the seasonal nutritional requirements of moose. The rating is derived by summation of species indices presented in Table 2 (growing-season) and Table 3 (dormant-season). The browse species composition rating is intended to be applied to an entire evaluation unit rather than on a per stand basis].	EF,DF,ES,DS	Quadrat, line intercept
Percent canopy cover of woody vegetation >6 m in height [the percent of the ground surface that is shaded by the vertical projection of the canopies of trees and shrubs that are ≥6 m (20 ft)].	EF,DF,ES,DS	Line intercept, circular plot

Figure 8. Definitions of variables and suggested measurement techniques.

Variable (definition)	Cover types	Suggested techniques
Percent of area in riverine, lacustrine, or nonacidic palustrine wetlands not dominated by woody vegetation [the area of wetlands dominated by open water, emergent vegetation, or submersed or floating-leaved hydrophytes in evaluation area divided by total area. Palustrine forested, scrub-shrub, and acidic palustrine wetlands (terminology follows Cowardin et al. 1979) are excluded].	Entire evaluation area	Remote sensing
Species composition in each mature forest stand ≥2 ha in the 600-ha evaluation unit [an estimation or measurement of the dominant tree species composing a forest stand ≥2 ha (5 acre) in a 600-ha (1,500-acre) evaluation unit according to the following categories: 1. lowland conifer; e.g., black spruce, northern white cedar 2. lowland hardwoods; e.g., ash, red maple 3. upland conifer or hardwoods; e.g., white pine, red pine, mixed hardwoods].	EF,DF,PFO	Remote sensing, line intercept
Proportion of dormant-season browse composed of coniferous species [the biomass of coniferous browse (stems, twigs, leaves, needles) sampled divided by total biomass of all dormant-season browse sampled].	EF,DF,ES,DS	Quadrat, line intercept
Mean distance to dormant-season cover [the mean distance (m) from random points in cover types providing dormant-season forage to the nearest edge of a cover type providing dormant-season cover].	ES,DS,PSS	Remote sensing, cover type map

Figure 8. (Continued)

Variable (definition)	Cover types	Suggested techniques
Percent canopy cover of trees [the percent of the ground surface that is shaded by a vertical projection of the canopies of all woody vegetation >6.0 m (20 ft tall)].	EF,DF	Remote sensing, line intercept
Proportion of tree canopy composed of coniferous species (the canopy closure of coniferous tree species divided by the total canopy closure of all trees).	EF,DF	Remote sensing, line intercept
Mean height of coniferous trees (m) (the mean vertical height of all coniferous trees in the stand or sample site).	EF,DF	Remote sensing, line intercept
MODEL II		
Percent of area in shrub or forest cover types <20 years old (the area of shrub or forest cover types in the evaluation area divided by total area).	Total evaluation area	Remote sensing
Percent of area in spruce/fir forest ≥20 years old (the area of evergreen forest ≥20 years old with canopy cover >50% spruce/fir in the evaluation area divided by total area).	Total evaluation area	Remote sensing
Percent of area in upland deciduous or mixed forest ≥20 years old [the area of forest (≥25% canopy cover of trees) cover types ≥20 years old composed of <50% canopy cover of conifers].	Total evaluation area	Remote sensing

Figure 8. (Continued)

Variable (definition)	Cover types	Suggested techniques
Percent of area in riverine, lacustrine, or palustrine wetlands not dominated by woody vegetation [the area of wetlands dominated by open water, emergent vegetation, or submersed or floating-leaved hydrophytes in evaluation area divided by total area. Palustrine forested and scrub-shrub wetlands (terminology follows Cowardin et al. 1979) are excluded].	Total evaluation area	Remote sensing

Figure 8. (Concluded)

SPECIAL CONSIDERATIONS

The following section presents information on factors that may influence habitat quality and use by moose in the Lake Superior region. Although these factors may affect land use or management decisions, they are not incorporated into the present HSI models.

Mineral licks. Use of mineral licks by moose typically occurs in early spring prior to the availability and use of aquatic vegetation (Fraser and Reardon 1980; Fraser et al. 1982). Use of licks varies from a single day to individuals remaining in the vicinity for several weeks (Fraser and Hristienko 1981). Mineral licks are normally widely dispersed, and animals may travel extensive distances to use them. Licks in Ontario were described as areas of mud or bare soil frequently containing standing water (Chamberlin et al. 1977; Fraser et al. 1980). Most were known, or believed, to be associated with springs. A high level of sodium was a common feature of all licks surveyed. Access to and sufficient vegetative cover around mineral licks should be maintained so that use by moose is not excluded.

Wetlands. Wetland cover types appear to influence the selection of parturition sites by cow moose (Peterson 1955). Calving sites in Alaska were often associated with open bay-meadow cover types where there was abundant surface water interspersed with islands, peninsulas, and lake shores (Bailey and Bangs 1980). The affinity for selection of dense vegetative cover associated with wetlands and the isolation provided by islands and peninsulas may be an antipredation strategy (Stringham 1974; Bailey and Bangs 1980). Association with aquatic cover types also may be a function of increased demand for water subsequent to birth and during lactation (Knorre 1961, cited by Stringham 1974; Altman 1963).

These models do not evaluate the diversity or complexity of wetland cover types and their influence on habitat quality for moose. It can be assumed that wetlands with dense vegetative cover in close association with the waters' edge and wetlands that are highly irregular in shape will provide high quality reproductive habitat. Conversely, upland areas are probably parturition sites of lower quality, due to decreased accessibility to drinking water and potentially greater rates of predation on calves. It may be useful in some instances to rank specific areas in terms of their influence on reproductive habitat quality. Table 4 provides index values that represent the workshop participants' perceptions of the importance of hydrotopographic features and the quality of reproductive habitat for moose in the Lake Superior region.

Winter cover. Several additional factors may influence a specific stand's capability to provide adequate winter cover for moose. These factors have not been incorporated into the calculation of the winter cover index; however, they may influence a stand's accessibility to moose and its quality as winter cover.

Table 4. The relative values of hydrotopographic features and upland sites as moose calving sites in the Lake Superior region.

Location	Index
Island	1.0
Peninsula	0.8
Shoreline <100 m from open water	0.5
Upland 100-500 m from open water	0.4
Wetland (no open water)	0.3
Upland >500 m from open water	0.2

Stands with extremely dense understories composed of shrubs and regeneration may limit accessibility and use by moose. Excessive amounts of blowdown may have a similar effect. Coniferous species are superior to deciduous species in relation to snowfall interception and the provision of lower snow depth and density under the canopy. Additionally, greater thermal protection is provided beneath a coniferous canopy. Table 5 provides assumed relative values of coniferous species in relation to the canopy density and structure of individual trees in terms of snowfall interception and provision of thermal cover.

Human disturbance. Human influence may affect moose habitat quality and use. Disturbance and accessibility of an area to humans may eliminate or reduce the amount of useable habitat available even though suitable vegetative and physical features are present (Hancock 1976). Development, such as summer homes, may physically eliminate only a small percentage of habitat. However, concentrated development may restrict movements of moose and utilization of surrounding areas. Greater use of habitat by moose was recorded in zones of low disturbance than in areas subjected to moderate and high levels of disturbance (cottages, road access, snowmobile routes, and communities) in Newfoundland (Hancock 1976). It appeared that the zone of disturbance extended 1 to 2 km (1.6 to 3.2 mi) from the perimeter of high human use areas. Observations of moose in Alberta indicated that moose consistently avoided roads, sites of human inhabitation, and agricultural land (Rolley and Keith 1980). Avoidance of these areas was particularly evident during midwinter. Analysis of the influence of cross-country skiing indicated that moose tended

Table 5. Relative values of coniferous species in relation to their influence on winter cover for moose. Species with a high index value are believed to provide the greatest amount of interception of snowfall and thermal protection.

Species	Index
Cedar	1.0
Hemlock	0.9
Balsam fir	0.8
White spruce	0.7
Jack pine	0.3
Black spruce	0.3

to move away from heavily used routes, possibly reducing the effective size of suitable winter range (Ferguson and Keith 1982). About 60% reduction in use was recorded along high-use ski routes when compared to ski trails with low use. Hunting pressure is believed to be directly related to human access, which may be particularly high in recently logged areas where roads remain open during and subsequent to harvest operations (Eason et al. 1981). Consideration should be given to closing or restricting access to such areas until sufficient cover is regenerated to provide adequate cover for moose. Construction of roads and their use near aquatic feeding sites, mineral licks, calving sites, and winter concentration areas could physically destroy habitat or eliminate its use by moose (Ontario Ministry Natural Resources 1986).

Research Needs

Browse biomass: The forage components of Model I are based on estimates of g/m^2 (dry weight) of browse. While actual clipping, weighing, and drying of vegetation is appropriate for small scale research, it is unreasonable to obtain these data over large areas. To the greatest extent possible, expected browse biomass should be linked to existing data sources or vegetation classification schemes [e.g., soil capability classes or ecological landtypes (U.S. Department of Agriculture 1986)] that are used by resource agencies in the area of model applicability. Definition of relationships between relatively rapid inventory methods (i.e., percent canopy cover) and browse biomass will also assist in more efficient evaluation of habitat quality (Peek 1970).

Forage intake estimates: Model I uses an estimated daily browse consumption rate for lactating cows of 4 kg (8.8 lb)/day (dry weight) to calculate the potential density of moose that can be supported by browse in an evaluation unit. Two simulation models used to predict forage requirements of a 365 kg (805 lb) female moose (*A. a. giga*) in Alaska indicated average daily dry weight forage requirements of 7.7 kg (16.9 lb) and 6.4 kg (14.1 lb) during winter (Regelin et al. 1987). Data that permit more accurate estimates of daily browse consumption rates for moose in the Lake Superior region should improve the ability of Model I to predict potential density of moose.

Interspersion and habitat composition: Minimal data are available that quantify the relationships of interspersion between cover and forage resources to moose. Incorporation of data in relation to cover type interspersion and habitat composition in areas supporting high numbers of moose on a long-term basis will increase the quality of these models.

Minimum habitat area: Definition of the minimum area required to effectively manage a self-sustaining population of moose will enhance the applicability of these models.

SOURCES OF OTHER MODELS

Regelin et al. (1986) present results of a field test of a moose carrying capacity model evaluated at the Moose Research Center in Alaska. Simulation models using nutrient requirements, physiological constraints, and forage quality are used to predict daily forage intake. Results indicate that the models accurately predicted browse utilization levels and provide an estimate of nutritional carrying capacity.

REFERENCES

Aho, R.W., and P.A. Jordan. 1979. Production of aquatic macrophytes and its utilization by moose on Isle Royale National Park. Pages 341-348 in R.M. Linn, ed. Proc. First Conf. Sci. Res. in Natl. Parks. Natl. Park Serv. Trans. Proc. Ser. 5.

Altman, M. 1963. Naturalistic studies of maternal care in moose and elk. Pages 233-253 *in* H.L. Rheingold, ed. Maternal behavior in mammals. J. Wiley, New York. 349 pp.

Bailey, T.N., and E.E. Bangs. 1980. Moose calving areas and use on the Kenai National Moose Range, Alaska. Proc. N. Am. Moose Conf. Workshop 16:289-313.

Belovsky, G.E., and P.A. Jordan. 1981. Sodium dynamics and adaptations of a moose population. J. Mammal. 62(3):613-621.

Blair, R.M. 1969. Timber stand density influences food and cover. Pages 74-75 *in* White-tailed deer in the southern forest habitat. Proc. of Symp., March 25-26, 1969. Southern Forest Ex. Stn. Nacogdoches, TX.

Botkin, D.B., P.A. Jordan, A.S. Dominski, H.S. Lowendorf, and G.E. Hutchinson. 1973. Sodium dynamics in a northern ecosystem. Proc. Nat. Acad. Sci. 70(10):2745-2748.

Brusnyk, L.M., and F.F. Gilbert. 1983. Use of shoreline timber reserves by moose. J. Wildl. Manage. 47(3):673-685.

Cederlund, G., F. Sandegren, and K. Larsson. 1987. Summer movements of moose and dispersal of their offspring. J. Wildl. Manage. 51(2):342-352.

Chamberlin, L.C., H.R. Timmerman, B. Snider, F. Dilken, B. Loescher, and D. Fraser. 1977. Physical and chemical characteristics of some natural licks used by big game animals of northern Ontario. Proc. N. Am. Moose Conf. Workshop. 13:200-214.

Coady, J.W. 1974. Influence of snow on behavior of moose. Nat. Can. (Que.) 101(1/2):417-436.

Cowan, I. McT., W.S. Hoar, and J. Hatter. 1950. The effect of forest succession upon the quantity and nutritive values of woody plants used as food by moose. Can. J. Zool. 28(5):249-271.

Cowan, R.L., J.S. Jordan, J.L. Grimes, and J.D. Gill. 1970. Comparative nutritive values of forage species. USDA Misc. Pub. 1147. Pages 48-56.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish Wildl. Serv. FWS/OBS-79/31. 131 pp.

Eason, G., E.R. Thomas, R. Jerrard, and K. Oswald. 1981. Moose hunting closure in a recently logged area. Alces 17:111-125.

Edwards, J. 1984. Patterns of wolf predation and effects on moose feeding habits. Pages 51-58 in M.M. Harris and A.M. Spearing, eds. Research in forest productivity, use, and pest control. U.S. For. Serv. Gen. Tech. Rept. NE-90.

Ferguson, M.A.D., and L.B. Keith. 1982. Influence of nordic skiing on distribution of moose and elk in Elk Island National Park, Alberta. Can. Field Nat. 96(1):69-78.

Flook, D.R. 1955. Moose using water as a refuge from flies. J. Mammal. 40:455.

Franzmann, A.W. 1980. Alces alces, Mammal Species No. 154. Am. Soc. Mammal. 7 pp.

Franzmann, A.W., J.L. Oldemeyer, and A. Flynn. 1975. Minerals and moose. Proc. N. Am. Moose. Conf. Workshop 11:114-140.

Fraser, D., and E. Reardon. 1980. Attraction of wild ungulates to mineral-rich springs in central Canada. Holarct. Ecol. 3(1):36-40.

Fraser, D., and H. Hristienko. 1981. Activity of moose and white-tailed deer at mineral springs. Can. J. Zool. 59(10):1991-2000.

Fraser, D., D. Arthur, and B.K. Thompson. 1980. Aquatic feeding by moose Alces alces in a Canadian lake. Holarct. Ecol. 3(3):218-223.

Fraser, D., B.K. Thompson, and D. Arthur. 1982. Aquatic feeding by moose: seasonal variation in relation to plant chemical composition and use of mineral licks. Can. J. Zool. 60(12):3121-3126.

Fraser, D., E.R. Chavez, and J.E. Paloheimo. 1984. Aquatic feeding by moose: selection of plant species and feeding areas in relation to plant chemical composition and characteristics of lakes. Can. J. Zool. 62(1):80-87.

Gasaway, W.A., and J.W. Coady. 1974. Review of energy requirements and rumen fermentation in moose and other ruminants. Nat. Can. (Que.) 101:227-262.

Hamilton, G.D., and P.D. Drysdale. 1975. Effects of cutover width on browse utilization by moose. Proc. N. Am. Moose Conf. Workshop 11:5-26.

Hamilton, G.D., P.D. Drysdale, and D.L. Euler. 1980. Moose winter browsing patterns on clearcuttings in northern Ontario. Can. J. Zool. 58(8):1412-1416.

Hancock, J.A. 1976. Human disturbance as a factor in managing moose populations. Proc. N. Am. Moose Conf. 12:155-172.

Hays, R.L., C.S. Summers, and W. Seitz. 1981. Estimating wildlife habitat variables. U.S. Fish Wildl. Serv. FWS/OBS-81/47. 111 pp.

Jordan, P.A. Aquatic foraging and the sodium ecology of moose: a review. Viltrevy (Stockh.) In press.

Jordan, P.A., and D.B. Botkin. 1971. Biomass dynamics in a moose population. Ecol. Soc. Am. Bull. 51(2):28-29.

Jordan, P.A., and M.L. Wolfe. 1980. Aerial and pellet-count inventory of moose at Isle Royale. Proc. Second Conf. Sci. Res. Natl. Parks 12:363-393.

Jordan, P.A., D.B. Botkin, A.S. Dominski, H.S. Lowendorf, and G.E. Belovsky. 1973. Sodium as a critical nutrient for the moose of Isle Royale. Trans. North Am. Moose Conf. Workshop 9:13-42.

Kearney, S.R., and F.F. Gilbert. 1976. Habitat use by white-tailed deer and moose on sympatric range. J. Wildl. Manage. 40(4):645-657.

Kelsall, J.P. 1969. Structural adaptations of moose and deer for snow. J. Mammal. 50:302-310.

Knorre, E.P. 1959. Experimental moose farming. Komi Knizhnoe Izdatil'stro, Skytyvokov, Komi, USSR. [Cited by Renecker and Hudson (1986).]

Knorre, E.P. 1961. The results and perspectives of domestication of moose. Trudy Pechorallych gos. Zapov. 9:1-263. [Cited by Stringham (1974).]

Krefting, L.W. 1974. The ecology of the Isle Royale moose with special reference to habitat. Tech. Bull. Univ. Minnesota Agr. Ex. St. 297. 75 pp.

LeResche, R.E. 1974. Moose migrations in North America. Nat. Can. (Que.) 101(1/2):393-415.

Miquelle, D.G., and P.A. Jordan. 1979. The importance of diversity in the diet of moose. Proc. N. Am. Moose Conf. Workshop 15:54-79.

Monthey, R.W. 1984. Effects of timber harvesting on ungulates in northern Maine. J. Wildl. Manage 48(1):279-285.

Morrow, K. 1976. Food habits of moose from Hugustow Forest. Acta Theriol 21:101-116. [Cited by Telfer (1978).]

Oldemeyer, J.L., A.W. Franzmann, A.L. Brundage, P.D. Arneson, and A. Flynn. 1977. Browse quality and the Kenai moose population. J. Wildl. Manage. 41(3):533-542.

Oldemeyer, J.L., and W.L. Regelin. 1984. Forest succession, habitat management, and moose on the Kenai National Wildlife Refuge. U.S. Dept. Int., Denver Wildl. Res. Center, Final Report. 423 pp.

Ontario Ministry of Natural Resources. 1986. Guidelines for providing moose habitat in timber management.

Peek, J.M. 1970. Relation of canopy area and volume of production of three woody species. Ecology 51(6):1098-1101.

Peek, J.M. 1974. A review of moose food habits studies in North America. Nat. Canadian (Que.). 101:195-215.

Peek, J.M., and D.S. Eastman. 1983. Factors which naturally control moose populations. Pages 175-193 in F.L. Bunnell, D.S. Eastman, and J.M. Peek, eds. Symp. Natural Regulation of Wildlife Populations. University of Idaho, Moscow.

Peek, J.M., D.L. Urich, and R.J. Mackie. 1976. Moose habitat selection and relationships to forest management in northeastern Minnesota. Wildl. Monogr. 49. 65 pp.

Peterson, R.L. 1955. North American moose. University of Toronto Press, Toronto. 380 pp.

Peterson, R.O., and D.L. Allen. 1974. Snow conditions as a parameter in moose-wolf relationships. Nat. Can. 101:481-492.

Peterson, R.O., and R.E. Page. 1983. Wolf-moose fluctuations at Isle Royale National Park, Michigan, USA. Acta Zool. Fenn. 174:251-253.

Phillips, R.L., W.E. Berg, and D.B. Siniff. 1973. Moose movement patterns and range use in northwestern Minnesota. J. Wildl. Manage. 37(3):266-278.

Prescott, W.H. 1968. A study of winter concentration areas and food habits of moose in Nova Scotia. M.S. Thesis. Acadia University. 194 pp. [Cited by Telfer (1978).]

Proulx, G., and R. Joyal. 1981. Forestry maps as an information source for description of moose winter yards. Can. J. Zool. 59(1):75-80.

Regelin, W.L., M.E. Hubbert, C.C. Schwartz, and D.J. Reed. 1987. Field test of a moose carrying capacity model. Alces 23:243-284.

Renecker, L.A., and R.J. Hudson. 1986. Seasonal energy expenditures and thermoregulatory responses of moose. Can. J. Zool. 64(1):322-327.

Rolley, R.E., and L.B. Keith. 1980. Moose population dynamics and winter habitat use at Rochester, Alberta. Can. Field-Nat. 91(1):9-18.

Schwab, F.E., M.D. Pitt, and S.W. Schwab. 1987. Browse burial related to snow depth and canopy cover in northcentral British Columbia. J. Wildl. Manage. 51(2):337-342.

Stringham, S.F. 1974. Mother-infant relations in moose. Nat. Can. (Que.) 101:325-369.

Telfer, E.S. 1970. Winter habitat selection by moose and white-tailed deer. J. Wildl. Manage. 34:553-559.

Telfer, E.S. 1974. Logging as a factor in wildlife ecology in the boreal forest. Forestry Chronicle. 50(5):186-190.

Telfer, E.S. 1978. Habitat requirements of moose - the principal Taiga range animal. Proc. 1st Internat. Range. Congress. Denver, CO.

Telfer, E.S. 1984. Circumpolar distribution and habitat requirements of moose (Alces alces). Pages 145-182 in R. Olsen, R. Hastings, and F. Geddes, eds. Northern ecology and resource management. University of Alberta Press. 438 pp.

Thompson, I.D., and M.F. Vukelich. 1981. Use of logged habitats in winter by moose cows with calves in northeastern Ontario. Can. J. Zool. 59(11):2103-2114.

U.S. Department of Agriculture. 1986. Land and resource management plan, Superior National Forest. U.S. Dept. Agric., For. Serv. Eastern Region. Appendix C.

U.S. Fish and Wildlife Service. 1981. Standards for the development of habitat suitability index models. 103 ESM. U.S. Fish Wildl. Serv., Div. Ecol. Serv. Washington, DC. n.p.

VanBallenberghe, V., and J.M. Peek. 1971. Radiotelemetry studies of moose in northeastern Minnesota. J. Wildl. Manage 35(1):63-71.

Welsh, D.A., K.P. Morrison, K. Oswald, and E.R. Thomas. 1980. Winter utilization of habitat by moose in relation to forest harvesting. Proc. N. Am. Moose Conf. Workshop 16:398-428.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. Biological Report 82(10.155)	2.	3. Recipient's Accession No.
4. Title and Subtitle Habitat Suitability Index Models: Moose, Lake Superior Region			5. Report Date September 1987 6.
7. Author(s) A.W. Allen[1], P.A. Jordan[2], J.W. Terrell[1]			8. Performing Organization Rept. No.
9. Performing Organization Name and Address [1]National Ecology Research Center U.S. Fish and Wildlife Service Drake Creekside One Bldg. 2627 Redwing Rd. Fort Collins, CO 80526-2899 [2]University of Minnesota Department of Fisheries & Wildlife St. Paul, MN 55108			10. Project/Task/Work Unit No. 11. Contract(C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address Department of the Interior Fish and Wildlife Service Research and Development Washington, DC 20240			13. Type of Report & Period Covered 14.
15. Supplementary Notes			

16. Abstract (Limit: 200 words)

A review and synthesis of existing information were used to develop a Habitat Suitability Index (HSI) model for the moose (Alces alces). The model consolidates habitat use information into a framework appropriate for field application, and is scaled to produce an index between 0.0 (unsuitable habitat) and 1.0 (optimum habitat). HSI models are designed to be used with Habitat Evaluation Procedures previously developed by U.S. Fish and Wildlife Service.

17. Document Analysis a. Descriptors

Mammals
Wildlife
Habitability
Mathematical models

b. Identifiers/Open-Ended Terms

Moose
Alces alces
Habitat suitability

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Release unlimited	Unclassified	47
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI–Z39.18) See Instructions on Reverse

OPTIONAL FORM 272 (4–77)
(Formerly NTIS–35)
Department of Commerce

☆ U.S. GOVERNMENT PRINTING OFFICE: 1988—575-728/85,164 REGION NO. 8