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Integrated Modelling of Moose Habitat and Population:

Preliminary Investigations using an Ontario Boreal Forest

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This file report is an unedited, unpublished report submitted as partial fulfilment of NODA/NFP Project #4045, "Integrated modelling of moose habitat and population".

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INTEGRATED MODELLING OF MOOSE HABITAT AND POPULATION: PRELIMINARY INVESTIGATIONS USING AN ONTARIO BOREAL FOREST

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INTRODUCTION

Moose (*Alces alces*) is a wildlife species of major ecological and social importance in Ontario's boreal forest. Habitat management for moose is done by attempting to accommodate habitat needs during forest management operations. To this end, provincial guidelines exist for moose (OMNR 1988) to provide forest managers with information on key habitat characteristics and features.

The intent of the guidelines is not just to protect and develop good habitat, but to foster moose populations. A logical link exists, therefore, between objectives for habitat quality and those for moose populations. However, to our knowledge, nowhere are the processes of timber management and moose population management explicitly linked by considering relationships between habitat characteristics and population dynamics. The integration of habitat and population management is incomplete, therefore, because no objective means exists to translate the effects of forestry operations into measures for moose populations.

Most habitat models predict either a habitat suitability index that is translated in a very simple way into either a population index or a measure of habitat carrying capacity (Greig et al. 1991). Through this project,

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a set of simulation tools was developed that specifically address the missing links between the effects of forest management operations and population numbers of an important vertebrate species. The integrated models will be suitable for use in applied research or in a preliminary exploration of the effects of long-range forest management plans. The approach has been to develop the integrated models with an eye towards normal operational use in the near future. The present version has been oriented toward applied research.

Moose was chosen in this study because: (1) We have experience in building a habitat simulator for moose (Duinker et al. 1991, 1993, Higgelke et al. 1992, Higgelke 1994), (2) Moose is a featured species in the boreal forest of Ontario, and high in social and economic value, so the research could have significant financial implications for the economy of the north, and (3) the costs of planning timber harvests according to moose habitat guidelines can be substantial. Justification for such habitat protection costs needs to be stronger, and can be provided by predicting moose population responses to habitat changes caused by forestry operations.

OBJECTIVES

The main objective was to develop and test an integrated set of simulation models that can predict the effects of combining forest management and moose harvest management on a moose population.

Ancillary objectives for moose in the Lake Abitibi Model Forest (LAMF) were to (1) begin the process of developing computerized tools suitable for use by forest and wildlife managers in an operational context. These will assist in developing and implementing integrated (i.e., habitat and population) management strategies, (2) develop tools to assist in identifying key habitat and population information needs for moose management, and (3) develop tools to assist with the evaluation and testing of hypotheses that relate to moose habitat and population management.

THE CASE STUDY FOREST

The Lake Abitibi Model Forest, some 1.1 million hectares in total area, is situated in northeastern Ontario, east of Cochrane (Fig. 1). The forest is dominated by lowland black spruce stands on surface organic soils and clay subsoils, and is part of the northeastern Ontario claybelt.

METHODS

GIS-based simulation modelling underlies the research framework. A GIS (geographic information system) is needed to account for proximities of food and cover habitat, and for variations of moose habitat quality across the landscape. Simulation is needed to track habitat and population responses through time. Models are linked and used in a modular fashion. Each major set of required calculations are made by a discrete model.

The modelling framework involves three models or sets of models:

• a forest inventory projection tool called HSG (Moore and Lockwood 1990). It requires data on the current forest inventory, management strategies, and successional pathways, and produces simulated future forest inventories.

• a suite of GIS programs that require forest inventories as input data, and interpret those inventories in terms of moose food and cover.

• a moose population model (Fig. 2), which requires data on moose food and cover and on forest age class structure, and calculates cohort-specific moose population data (e.g., number and weight of animals) in response to the habitat data.

Forest Management Strategies

Four forest management strategies were created covering a 100-year period:

• "No Harvest"—No timber management activities take place (i.e., no harvesting or regeneration activities).

• "Basic"—In general terms, all the major assumptions included in the management plan of the Iroquois Falls forest management unit (that comprises most of the model forest territory). This meant acceptance of an annual harvest (clear-cut) of 380 725 m^3 of spruce and incidental volumes of associated species, and silvicultural ground rules for use throughout the 100-year simulation.

• "Lower"— Annual timber harvests were assumed to amount to 75% of those of the Basic strategy (285 544 m^3 of spruce and incidental volumes of associated species). Silvicultural ground rules remained the same, although annual areas treated would be lower, depending on forest types harvested in any time period. The Lower strategy was formulated to explore the general premise that relaxation of timber harvest pressures might benefit some species of forest-dwelling wildlife.

• "Spatial"—Using the harvest volumes and silvicultural ground rules of the Basic strategy, the eligibility of harvestable stands was constrained according to their general location.

This is based on the assumption that by 2054 the whole forest will have a well developed road network. The Spatial strategy was formulated to explore the notion, inherent in the design of the moose habitat guidelines (OMNR 1988), that smaller and well-distributed clear-cuts are better for moose habitat than are larger cuts.

The following specifications were common to all the scenarios in which timber harvesting took place:

- all timber harvests were regulated based on the annual yields of spruce;
- a set of forest-specific yield curves were used that show wood volume trends over stand age for all combinations of stand type, stocking, and site class;
- timber harvest priority rule: minimize primary species volume losses;
- minimum operable volume: 40 m^3/ha;
- prohibition of timber harvesting on site class 4; and
- silviculture programs unrestricted in areal extent, but set in priority according to a treatment priority table.

Forest Inventory Projection

A 10-year time step was used over a 100-year horizon. The simulation outputs from HSG in our study include ten structurally identical future forest inventories for each of the four strategies, one for each 10-year time step. The forest inventory input data for each HSG run was the same 1994 dataset, thus anchoring all simulations to the same present forest.

Moose Habitat Interpretations of Projected Inventories

The main function of the moose habitat models is to interpret future forest inventories in terms of moose food and cover values. Several steps are required to accomplish this in our modelling framework, including:

• reclassification of the forest;

• development of forest type-specific, stocking-dependent, and age-dependent curves for browse availability and cover values;

• calculation of food and cover values for each stand (or part of stand) in the forest;

• calculation of average food and cover values for habitat assessment units.

Reclassification of the Forest

Ontario Forest Resource Inventory working groups are too coarse for calculation of moose food and cover values, and stand composition data are too detailed. The forest was therefore reclassified for the specific purposes of this study, using a procedure similar to that of Higgelke (1994).

Food and Cover Values

Following the protocol of Higgelke (1994), relationships were established depicting stocking-dependent, forest type-dependent food and cover values over stand age.

Food: Food supply curves were generated with consideration of the following key points:

• Forage production peaks 5–20 years after timber harvesting (Crête 1977). After this period browse production begins to diminish (Joyal 1987).

• Food supply curves were set at 450 kg/ha. For early winter, the maximum was set at 167 kg/ha.

Cover: The study deals with early winter cover only. The Higgelke (1994) approach was modified to generate an early winter cover index for each stand for subsequent use in calculating cover-adjusted food values for early winter.

Food and Cover

A 200 m by 200 m point grid was laid over the stand map of the study forest for the purposes of calculating food and cover supplies. The grid was used in calculations of food supplies for all three seasons—spring/summer, autumn, and early winter—but it was actually only necessary for the special calculations of cover-adjusted food in early winter.

Food and Cover Calculations for Habitat Assessment Units (HAU)

It was decided to capture spatial variation in moose carrying capacity across the whole study forest landscape using overlapping HAUs. With stands on the order of tens of hectares, moose home ranges on the order of hundreds of hectares and of unknown location, and a forest of a million hectares, some method must be found to quantify local moose population responses to local habitat change. Given our approach of modelling moose population response to habitat change, and a density of moose known to be roughly 0.1 moose/km^2, a habitat assessment unit of hundreds of square kilometres was needed before a minimally acceptable size of moose population would be amenable to simulation. A square (for simplicity) HAU of approximately 50 000 ha was used.

It is necessary to reduce the raw food data by some appropriate factor that we shall call the cropping rate (actually, a proportion used to reduce the raw food data to available food data). A cropping rate of 0.2 for S/S and 0.6 for autumn and early winter was applied.

Data Transfer to the Population Model

The population model requires the following data from the habitat models:

- season-specific, HAU-specific food supplies for each future snapshot of the forest inventory (in this case, once every 10 years for 100 years); and
- areas of forest in age classes 0–10, 11–20, 21–30, and 31–40.

Moose Population Modelling

Three elements of moose population dynamics represented in the model are mortality, reproduction, and weight change. Feeding occurs in spring/summer, fall, and early winter with changes in weight being a function of the food supply (as predicted by the habitat model). Mortality includes hunting mortality in the fall and other mortality (e.g. predation) in all seasons. Mortality due to starvation can also occur in any season if significant weight loss occurs due to an insufficient food supply. Reproduction is characterized by births that occur in the spring/summer season.

Population Structure

For modelling purposes, the moose population in each HAU is tracked independently over time. The population is divided into cohorts based upon sex and age (11 classes, representing ages 0–10+). For each of these cohorts, the model tracks two state variables over time: the number of animals in the cohort, and the cohort's average weight per animal. The model divides the year into four seasons: spring/summer, fall, early winter, and late winter. It produces "census" data for each between-season enumeration by calculating the change in the number of animals and average weight per animal for each cohort.

Starvation mortality: Mortality due to starvation is calculated by the model in all four seasons. For each cohort, the average weight of the cohort is compared to a threshold weight below which individuals are assumed to die as a result of starvation.

Other mortality: Mortality due to factors other than starvation and hunting is calculated by the model in all four seasons. For each cohort (and season), the proportion of animals that die due to other factors each season is specified as an input to the model.

Hunting mortality: Hunting mortality is calculated in the autumn each year. In calculating the hunting mortality for each of the individual habitat windows, the model first determines a level of harvest for the entire forest. This harvest calculation follows the tag allocation process currently used in Ontario for establishing harvest levels each year (Heyden et al. 1992).

Births: The number of births for the population is calculated by the model each year in the spring season. The number of calves born from each female cohort is calculated as a product of the number of females in the cohort (in spring/summer) and the cohort's average birth rate.

Input Parameters

The moose population model requires the user to specify a number of input parameters for each model run. The following section provides some background on the values assigned to each of these parameters for the model forest model runs.

Initial moose density: The initial density of moose was set to match the estimated 1995 density for the LAMF area. The initial density estimates were:

Calves:	0.039 moose per km^2
Adult females:	0.074 moose per km^2
Adult males:	0.027 moose per km^2
Total density:	0.14 moose per km^2

Ideal weights: The "ideal" weights of each cohort (i.e., weight when food is not limiting) were estimated from information provided by the OMNR:

Calves (5 months):	160–180 kg
Mature bulls:	400–542 kg (average of 483 kg)
Mature cows:	376–533 kg (average of 445 kg)

As the habitat in the LAMF is less productive than in Algonquin Park, these weight estimates were assumed to represent approximate ideal weights for the LAMF. The ideal weights (kg) for each cohort in the model were set as follows:

	Calf	Yearling	Adult[1]	Adult[2]
Male	170	300	450	485
Female	160	250	400	445

1. Young (2–5 years). 2. Mature (6 years+).

Initial weights: To initialize the model, weights for all cohorts were set at their ideal levels, as outlined above.

Weight at death: This variable represents the weight, for each cohort, below which an individual animal will die from starvation. The weight below which an individual will die was set at 66% of the ideal weight for each cohort.

Distribution of weights: The typical distribution of weights is represented in the model through a standard deviation about the mean weight of each cohort, where the standard deviation for each cohort is expressed as a proportion of the cohort's mean weight.

Weight at birth: The average weight of calves at birth was reported as 12–17 kg for Ontario; the value used in the model was set as 15 kg.

Sex ratio at birth: The sex ratio at birth was set to 0.5 for the model.

Energy per unit forage: The energy per unit of forage for the model was estimated as 3 100 kcal per kg (4 200 x 0.74).

Maintenance energy requirement: A value of 170 kcal per kg per day was used for the maintenance energy requirement for all cohorts in the model.

Energy requirement for weight gain: Assuming a 70% efficiency for tissue production, an average of 9 800 kcal is required to produce one kilogram of fat and protein. This value was used for all cohorts in the model to represent the energy required for weight gain.

Energy requirement for weight loss: A value of 8 100 kcal per kg of weight loss was used for all cohorts in the model to represent the energy required for weight loss to occur.

Fecundity: For the purposes of these model runs, fecundity was not made to vary as a function of cow weight.

Target density for harvest: Because the LAMF includes areas from three different WMUs, the target density for the LAMF was calculated using an area-weighted average of the 1995 provincial targets for these WMUs; the resulting target density was calculated as 0.27 moose per km^2.

Cow harvest rate: The relationship between the cow harvest rate and the density of moose each year was defined in the model by the following points:

Actual density / Target density	Cow harvest rate
0	0
0.25	0.02
0.5	0.04
0.75	0.06
≥1.0	0.085

Bull-to-cow harvest ratio: A value of 3.5 was used for all the model runs.

Calf-to-cow harvest ratio: A value of 1.67 was used for all the model runs.

Relative hunting pressure and access: For the model to distribute the moose harvest spatially, the relationship between the amount of forested area and the relative hunting pressure must be specified. In quantifying this relationship, it was assumed that the younger a particular hectare of forest is, the more road access there will be (because of recent timber harvesting) and the greater the relative hunting pressure. The relative contribution of each age class of forest in determining the total proportion of each HAU that was accessed was assumed to decrease exponentially as a function of the time since the last harvest, with access being negligible 40 years after harvesting. This was represented as follows in the model:

Forest age class	Relative contribution to access
0–10	1
11–20	0.5
21–30	0.25
31–40	0.125

Finally, in translating the effect of access into relative hunting pressure in the model, a 1:1 relationship was assumed between the relative hunting pressure and the proportion of access in each habitat window.

RESULTS AND DISCUSSION

Forest Inventory Projection and Wood Supply

Except for one time step in one of the simulations (2004–2014), all timber harvest targets could be met, and therefore can be judged to be sustainable over the 100 year simulation period.

Age Class Structure

Age class structure is important in determining moose food supplies according to our models, because young stands (and, to some degree, very old stands) provide the highest per-unit-area food supplies. Like the other strategies, the No Harvest strategy has substantial area in young age classes in 1994, but as time progresses the strategy has little or no area in these age classes. This will, predictably, have the effect of lowering the moose food supplies of the No Harvest strategy as time passes.

Stocking Levels

In 1994, the average stocking per hectare across the forest was 74.5%. By the end of the 100-year simulation, the average stocking under each strategy increased (a) under the No Harvest strategy, to 86.6%; (b) under the Basic strategy, to 87.9%; (c) under the Lower strategy, to 85.4%; and (d) under the Spatial strategy, to 88.2%.

The shift from variable to moderate stocking will have two main effects upon moose habitat characteristics. On one hand, since the relationships to calculate food supplies are most generous in poorly stocked stands (food is inversely proportional to stocking), the average food supplies will shift downward over time as the average stocking shifts upward. On the other hand, early winter cover is favoured by mid-range stocking, and its value too goes down as stocking moves from mid-range to high range. Thus, moose habitat receives a double downward pressure as the forest stocking increases over time.

Moose Habitat Forecasts

Because of the manner of calculation, spring/summer and autumn food supplies respond in exactly the same manner to changes in forest structure, so the following discussions will focus on spring/summer and early winter food responses. The spring/summer food response in any particular HAU is solely a function of the sum of raw location-specific food supplies, but the early winter food response is conditioned by the proximity of food supplies to good seasonal cover.

Spring/Summer Food Responses

In 1994, the average spring/summer food value for the whole model forest was roughly 24 kg/ha dry weight of browse. This value makes intuitive sense, given that the model forest is not considered prime moose habitat.

Overall, the habitat models as constructed and parameterized in this study are unable to distinguish, for the model forest as a whole, significant differences among the four strategies in terms of the predicted variable of spring/summer food supply response.

Early Winter Food Responses

Early winter food supplies, as an average across the whole model forest, decline steadily in all scenarios, from a 1994 high of almost 3 kg/ha, to a 2094 range of about 1 to 1.5 kg/ha. Again, this is a low value, consistent with the general assumption that the model forest is poor quality moose habitat.

It was concluded that the habitat models as constructed and parameterized are able to distinguish, for the model forest as a whole, significant differences among the four strategies in terms of the predicted variable of early winter food supply response.

Moose Population Forecasts

Five sets of simulations with the moose population model were implemented using the four sets of outputs from the habitat models:

(a) No Harvest strategy with no moose hunting;

(b) Basic strategy with no moose hunting;

(c) Basic strategy with moose hunting;

(d) Lower strategy with moose hunting; and

(e) Spatial strategy with moose hunting.

A run was not made using the No Harvest strategy with hunting because it was expected that roads would become impassible to hunters over time, and that hunting opportunities in new and recent clearcuts would diminish rapidly. Thus, under a No Harvest strategy, the moose hunting opportunities would rapidly erode.

Results of the five runs are shown below in tabular form, with moose populations as forecasted in 100 years:

Strategy	Moose population (number per km^2)
No Harvest, no hunting	0.2
Basic, no hunting	0.1
Basic, hunting	0.05
Lower, hunting	0.06
Spatial, hunting	0.05

Two Strategies Without Hunting

The current (1994) approximate moose population density in the model forest is 0.14 moose/km^2. The moose populations are responding to both their habitat and their predators, which include nonhuman vertebrates such as wolves and bears, as well as humans. When the populations are allowed to come to equilibrium with the simulated habitat alone, without hunting, the model shows that the density of moose as determined by habitat would be just under 0.4 moose/km^2 in 1994. This may indicate that hunting is responsible for holding the current population several times lower than it would be if the population were constrained by habitat alone.

CONCLUSIONS

Hunting seems to play an important role in keeping moose population densities at their current levels in the model forest. If hunting were to cease entirely, the habitat could probably carry significantly higher moose densities.

Forest simulations driven by assumptions that are oriented toward timber production (e.g., successful plantation silviculture) are likely to lead to lower moose population densities. In particular, timber-oriented forest management will result in a more dense forest structure, whereas nature is likely to produce more lower-stocked and older stands in the landscape. Simulation analysts in forest management planning must prepare realistic forest inventory projections for use in interpreting wildlife habitat and other biodiversity-oriented values.

If current hunting pressures on moose in the model forest continue, then the kind of forest management strategy implemented (i.e., how timber is harvested) may have a relatively minor impact on moose densities. The No Harvest strategy failed to incorporate natural disturbances such as fire and insect infestations, and the timber harvest strategies were too similar.

At least three obstacles must be overcome if simulation analysts are to develop and test a useful array of forest management strategies for moose: (a) the uncertainties over what kinds of strategies would elicit sufficiently different responses in habitat and populations; (b) the burden of data and model manipulation to implement the alternative strategies; and (c) the potential for other people to dismiss specific strategies as foolish or unimplementable.

Model Development, Testing, and Research Needs

The need to understand the implications of alternative approaches to forest management on populations of important wildlife species is growing rapidly, as is apparent in many contemporary forest management and policy initiatives. Examples of such initiatives include the criteria and indicators of the Canadian Council of Forest Ministers (1995), the principles and criteria of the Forest Stewardship Council (1995), and the indicators of forest sustainability in the Ontario forest management planning manual (OMNR 1995).

The following tasks would now prove useful:

- development of a wider range of forest management strategies;
- development of mechanisms to incorporate natural disturbances into forest projections;

• implementation of a full sensitivity analysis of the models, particularly our population model;

• development of relationships for food and cover in late winter, a critical time of year for moose;

• development of methods to account for potential immigration and emigration of animals among habitat assessment units, and between the study area and neighbouring forests;

• development of relationships between cow weight and birth rate (i.e., habitat and fecundity);

• collection of field data for moose food and cover relationships, as well as demographic data on moose populations.

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Figure 1. Location of the Lake Abitibi Model Forest.

Figure 2. Calculation sequence in the moose population model.