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Trade-offs between wood supply and caribou habitat in northwestern Ontario

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Abstract: Woodland caribou habitat management in northwestern Ontario is a complex spatial problem. The Strategic Forest Management Model (SFMM), a linear programming PC-based planning tool being developed in Ontario, was used to examine the impacts of alternative management strategies on caribou habitat. The management alternatives investigated included the cessation of timber management and maximising the present value of wood production without any explicit concern (in the model) for caribou. Three major findings are worth noting: 1) trying to maintain prime caribou habitat within active Forest Management Units will come at a cost to wood supply but the cost will depend on the absolute amount of area affected and the spatial configuration of that land in relation to mills. The cost of maintaining caribou habitat in one management unit at a level about 25 000 hectares is roughly $324 000 per year (about 3 cents for each Ontario resident). The imposition of an even-flow constraint on wood production is in fact potentially more costly; 2) Given the region is heavily dominated by spruce aged 90 years and over, forest succession and fire disturbance will likely cause large declines in prime caribou habitat in the near to medium term (20 to 40 years) even if no timber harvesting occurs; 3) The complexities of the trade-offs in this resource management problem highlight the limitations of any single modelling tool to satisfactorily address all issues. Planners need to take advantage of a wide range of analytical techniques to quantify the issues and formulate integrated policies.

Key words: caribou, habitat, wood supply, economic analysis, forest management.

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Introduction

Forest management planning problems tend to be large and complex. For example, wood growth and yield functions are required across many stands. Silvicultural costs and stumpage values may vary spatially and stand management options are usually numerous. When non-wood outputs (values) are considered the complexity increases. A common response to this problem in forest planning has been to use linear programming (LP) to explore the trade-offs implicit in forest planning (e.g. Davis, 1996; Buongiorno & Gilless, 1987; Johnson *et al.*, 1986; McKenney & Common, 1990). Linear programming is a tool which can efficiently search through the large number of possible management combinations and permutations that are typical in forestry to identify a particular scenario that maximises an objective subject to certain types of management constraints.

In this paper, we quantify some of the trade-offs between wood supply and caribou habitat across northwestern Ontario using a linear programming model. The overall area of interest includes 17 Forest Management Units, and over 7 000 000 hectares of land (Fig. 1). A large geographic perspective is required for this forest management problem because of the nomadic nature of woodland caribou and the relatively low densities of caribou remaining in the region (Cumming, 1992). The Ontario Ministry of Natural Resources (OMNR) is committed to maintaining species within their current ranges and have developed a set of proposed guidelines for Caribou management (Racey *et al.*, 1992). Caribou numbers have been declining for a number

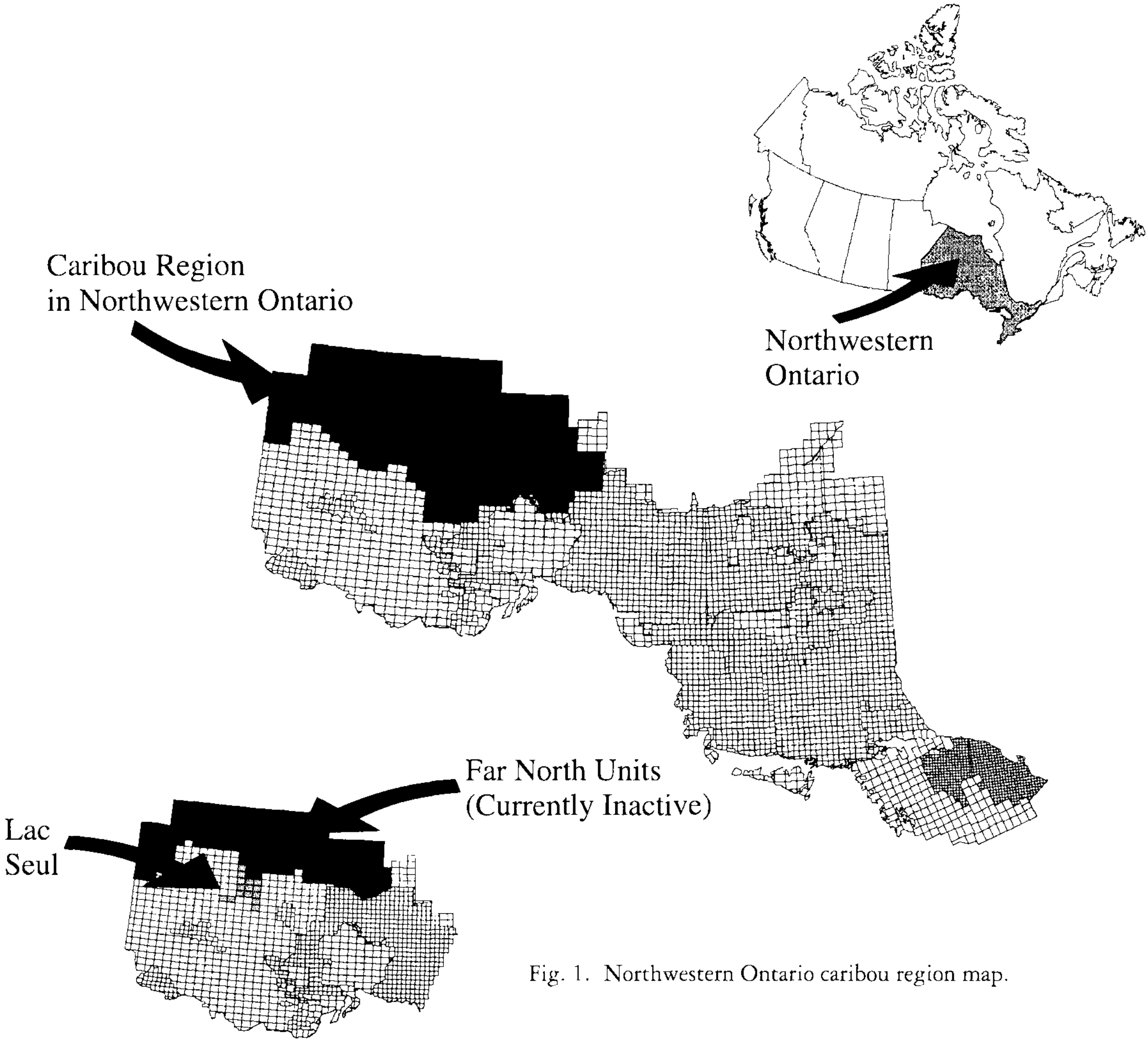


Fig. 1. Northwestern Ontario caribou region map.

of reasons but in a manner that roughly parallels the northern extent of timber harvesting operations. The caribou guidelines call for the maintenance of large tracts of older forest to provide for caribou habitat. These large tracts are identified in a mosaic which ensures special consideration of caribou winter habitat, areas used for calving and travel opportunities. This strategy suggests a set of spatial constraints to balance wood supply and habitat concerns that are somewhat different than most resource planning problems.

LP models allow the management problem to be set up in a number of ways although typically it involves maximising an objective such as the Net Present Value (NPV) of management activities through time. Effects of management on forest growth and yield are modelled for each land unit. The range of potential costs of management and benefits, usually a measure of stumpage value, associated with each land unit or activity are discounted by a rate of interest to derive a net value in today's dollars. In theory, the management strategy selected is the combination of activities through time that maximises the NPV. In practice, many scenarios and assumptions are examined to formulate actual management strategies.

Although it is possible to directly include nonwood values like wildlife habitat in objective functions of LP models, very few empirical studies actually do so. One reason is the difficulty in obtaining willingness-to-pay measures (i.e. prices) for nonmarket goods. Hence nonmarket values are usually identified as constraints on management in LP models. One example is maintaining a target total amount of area in particular age classes because some wildlife species associations prefer certain age classes. The cost of these constraints can be determined by running the model with and without the constraints. The difference in NPV represents the potential economic cost of that constraint. Decision makers can then use personal judgement and/or other information to assess whether the cost is worth while.

We examined changes in caribou habitat for one particular Management Unit in the region using three different objective functions, i.e. maximise net present value, maximise wood production, and maximise net present value subject to a constraint on changes in caribou habitat. A no timber management scenario is also presented. The second set of analyses simulates changes in caribou habitat on three far north management units in the region assuming no timber management. In this case the changes in caribou habitat arise as a result of fire regimes and natural forest succession. Data availability and the nature of LP make it difficult to explicitly examine some of the spatial aspects of this problem over the entire region.

Methods and data

The Strategic Forest Management Model (SFMM) is a PC based interactive forest modelling system that allows users to represent large forested areas at a strategic level (Davis, 1996). SFMM has been and continues to be developed by the Forest Resource Assessment Project of the OMNR. The modelling system is based on linear programming techniques, and is designed specifically for Ontario's forest conditions and strategic planning requirements. SFMM provides a flexible framework to represent a forest as it evolves through time, in response to natural dynamics and active intervention. Users can evaluate a variety of forest management objectives and targets, and explore long-term strategies and tradeoffs. Through a graphical interface, users can:

1. Define the current forest and non-forest land base;
2. Simulate the forest's natural development through time;
3. Describe their silvicultural options; and

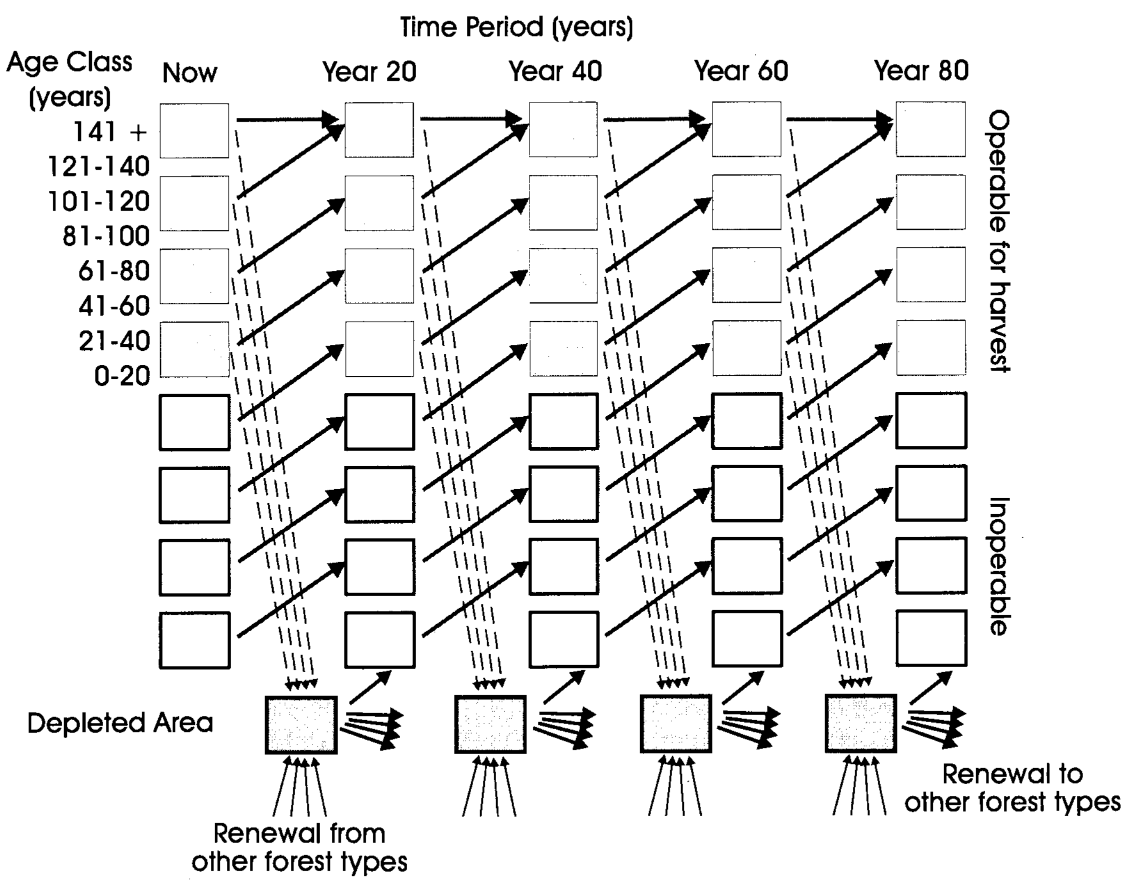


Fig. 2. A simplified view of SFMM's model III network srructure.

4. Explore management alternatives and scenarios to design a forest management strategy that provides an appropriate mix of benefits.

Results of a model run are provided through graphics and text in seven categories: forest condition, forest dynamics, areas treated, finances, volumes harvested, wildlife habitat and forest diversity.

The structure of SFMM is known as a "Model III" network (Fig. 2). The model is built upon a series of similar linked networks that together represent the various forest types within a large forest land base. The simplified network shown in Fig. 2 represents a single forest unit. Each box represents an age class within the forest unit. The arrows represent how area transfers between these age classes to represent growth, harvesting, and renewal through time. Linkages with other, similar networks (not shown) can also transfer to and from other forest types. Land might change in status from one forest type to another through natural succession, tending treatments, or harvesting and renewal treatments that do not return all the area harvested to the same forest unit.

Like most planning problems, four basic types of information were required for this study:

1. Forest Resource Inventory (FRI) data describing the forest stands within each township, base map or map unit in general in the region;
2. Projections of forest dynamics, i.e. growth and yield estimates, natural succession rules, and natural disturbance rates (probability estimates);
3. Information regarding eligibilities and costs of forest types for harvesting and renewal treatments; and
4. Standing timber values.

Forest Resource Inventory data

The FRI contains information on species composition, age, stocking and the area for each forest stand. These data for northwestern Ontario was obtained from the OMNR's Forest Resource Assessment Project. It was available in summary form by map sheet for the 17 active and currently inactive Management Units of interest for this analysis. Information on non-forested land types, and areas reserved from harvesting (e.g. protection forest) were also included as part of this analysis.

To simplify the model construction and interpretation, the FRI data was aggregated as: "White Birch" when it was 60% or more of the stand composition; "Jack Pine" when it was 60% or more; "Poplar" when 60% or more; "Spruce" when 60% or more black or white spruce and; "Mixed" for the remaining forest types which are primarily combinations of these species assemblages.

The region is heavily dominated by spruce age 90 years and older. However there is also a large amount of 50-90 year old jack pine and mixed forest.

Growth & yield estimates and forest dynamics

Growth and yield estimates describe the changes in timber volumes at different ages or through time for each of the different forest types. Very little is known about spatial variations in growth rates across northwestern Ontario, hence the same growth and yield estimates were used for each map unit. Average growth and yield estimates were developed for each of the forest types described above in consultation with OMNR Forest Resource Assessment Project. These values and assumptions regarding successional pathways, natural and fire disturbance rates were derived from previous work and historical data (see Arlidge, 1995). It is important to note that volumes decline over time as these forests become over-mature due to successional change.

Silvicultural options

Planning models developed previously by foresters in the region were used to derive the silvicultural options for this study. These included specific options and costs for forest harvesting and renewal treatments. Forest renewal options were $10 per hectare for basic; intermediate renewal at a cost of $300 per hectare, and intensive renewal at a cost of $1300 per hectare (Arlidge, 1995).

Standing timber values

In most planning models that involve an economic component a value of standing timber is required. The value of standing timber to society has long been a subject of debate. Forecasting the value through time further complicates the problem. The stumpage fees that are charged by the OMNR are administratively set, not through a competitive market process. The implication is that these fees would therefore not correspond to the true value of standing timber by standard economic criteria. Although the OMNR has recently changed its pricing policy to more closely correspond to current market conditions, determining the actual numerical value of standing timber to wood producers remains a contentious and difficult issue. A residual value approach is commonly used to determine standing timber values and has been applied in Ontario (Nautiyal *et al.*, 1994). This approach quantifies the difference between the final product value and the cost of producing the good. For example in the case of lumber, the standing timber value would be the market value of lumber less the cost of harvesting, transportation to the mill and an allowance for profit (Nautiyal *et al.*, 1994). This number represents the maximum amount the firm would be willing to pay for the right to harvest the standing timber.

A variant of this residual valuation approach was used to derive standing timber values for the study areas:

MWTP = (Starting MWTP - Hauling Cost)

where MWTP stands for "Mill Willingness to Pay" ($ per cubic metre), and "Starting MWTP" is intended to represent the maximum amount a mill would be willing to pay for standing timber if it was situated next to the mill. Given the difficulty in determining a single number this approach enables different views of long run standing timber values to be considered. Results presented here used a starting MWTP of $30 per cubic metre and existing mill locations (see McKenney & Nippers, 1996 for additional analyses). These MWTP values were adjusted by hauling costs for each map unit. The average of these values was then calculated to determine the average MWTP for the entire Management Unit. There is an inherent, though debatable, assumption, that harvest costs would not vary spatially.

Hauling costs are the $ costs/cubic metre of transporting wood from the harvest site to the mill. The further away wood is from a mill, the more it will cost to haul. Hauling costs were calculated as follows:

HAULING COST = (Distance to mill (km) * 0.0772(cents/cubic metre/km))

0.0772, the transportation cost factor used was based on Nautiyal *et al.* (1994) and OMNR, 1994). Distances were calculated using a Geographic Information System (GIS) algorithm and data on road locations and map units. The distance from each map unit centroid to the nearest major road was calculated for each map unit (e.g. township or Ontario Base Map). The GIS also calculated the distance to the mill that had primary rights to the standing timber for each Forest Management Unit. The distance to the mill used in the hauling cost calculations was the sum of these two values i.e. the "map centroid to nearest primary road distance" and the distance from there to the mill.

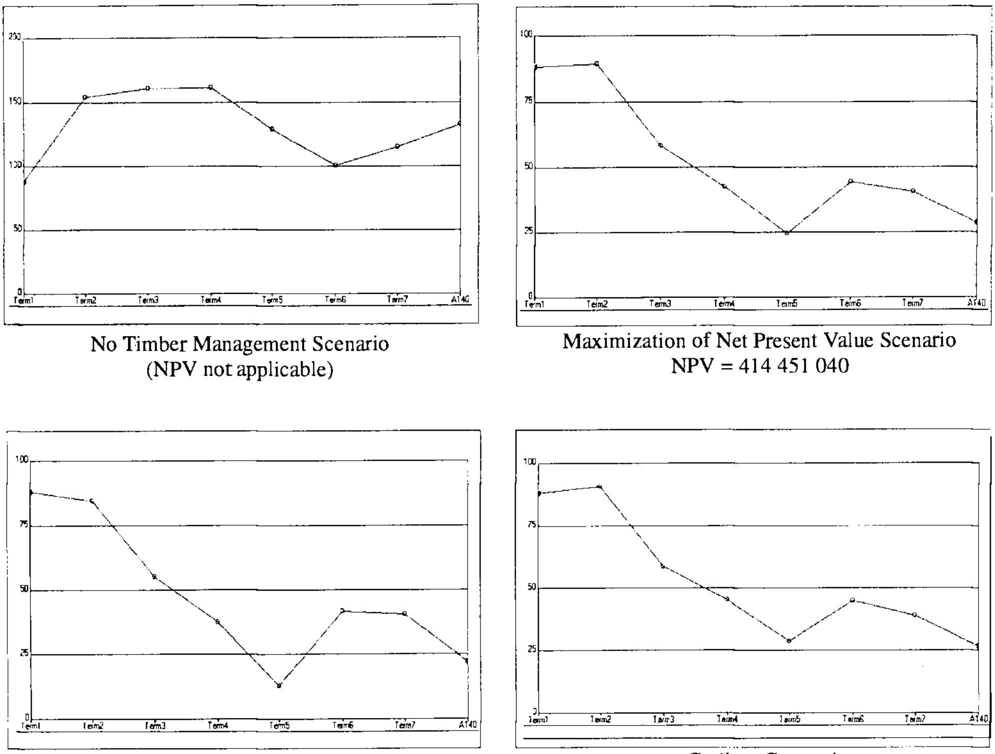
In summary, the genetal SFMM caribou model template tracked caribou habitat by using growth and yield projections based on other SFMM analyses in the region, inventory data summarised at the Map Unit level, standing timber values that were adjusted by hauling distance for each Map Unit and possible silviculture costs ranging from $10/ha-$1300/ha. Planning periods were 10 years and the planning horizon was 100 years. Prime caribou habitat was defined as hectares of spruce, jack pine and mixed forest aged 80 years and older.

Several SFMM analyses were performed on the Lac Seul Management Unit representing different objectives: no timber management (NTM), maximise NPV, maximise timber harvest volumes (MTH), and maximise NPV subject to maintaining a specified amount of caribou habitat in each planning period. This Unit was assumed to be representative of the active Management Units in the region. A major challenge in this type of analysis is sifting through the large volume of output to focus on the major issues. The results presented here are particularly salient. In addition some no timber management scenarios were run for 3 far north units which are not currently being harvested (see Fig. 1).

Results and discussion

Fig. 3 portrays the likely aggregate changes in caribou habitat over time for the different possible management strategies on the Lac Seul Unit. In the NTM scenario, caribou habitat fluctuated between 100 000 and 150 000 hectares. In the timber management strategies, caribou habitat dropped from near 100 000 ha currently to below 13 000 ha. After several trials, a set of constraints were developed that maintained total caribou habitat above 28 000 ha. No constraints could be found that would maintain a higher level of habitat.

The habitat results are driven by changes to the aggregate projected age class distributions. The NTM scenario skews the age classes to the older levels. Timber management scenarios result in very little of the older classes by the 5th decade. The magnitude of the drops could not have been easily



No Timber Management Scenario
(NPV not applicable)

Maximization of Net Present Value Scenario
NPV = 414 451 040

Maximization of Total Harvest Volumes Scenario
NPV = 292 120 347

Caribou Constraints
NPV = 406 373 488

* x axis = planning period; y axis = 000's of hectares of prime caribou habitat

Fig. 3. Lac Seul caribou habitat summaries.

ascertained without this type of modelling tool. SFMM makes such assessments straightforward.

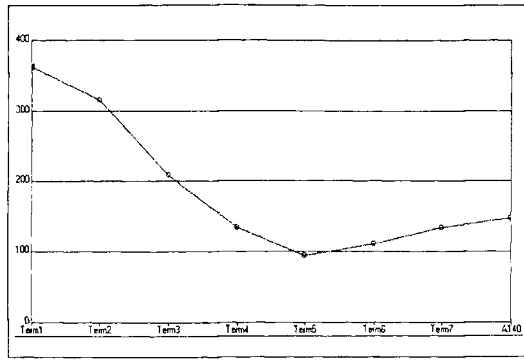
The total NPV of various scenarios can be used to gauge the cost effectiveness of different management strategies. The cost in terms of NPV of the maximise timber harvest objective is approximately $122.3 million. This is the difference between maximise NPV scenario and the MTH run ($414.5 million versus $292.1 million). This amount should be weighed against the difference in the amount of caribou habitat between scenarios (which appears relatively insignificant - see Figure 3). In fact, prime caribou habitat reaches the lowest levels in the maximise timber scenario. The NPV of the habitat constraint scenario is $406.4 million. Thus, the cost of maintaining this level of habitat is $8.1 million over 100 years or roughly $324 000 per year (using a 4% discount rate). This translates into 0.07 percent of the NPV. This value represents what Ontario residents would have to be willing to pay to justify the constraint on economic efficiency grounds (about 3 cents per person in Ontario per year). Interestingly, additional analyses (not shown) which included even-flow, plus or minus 20%, timber constraints had much lower net present values $90 to $115 million depending on harvest constraint. Even flow constraints are often used in forest management to try to reduce volatility in harvest levels (Buongiorno & Gilless, 1987). In these runs caribou habitat reached low levels comparable to the MTH scenario.

Whether this 25 000 or 50 000 hectares of habitat in the Lac Seul Unit are sufficient to sustain the caribou population in the larger region is an important biological question but beyond the scope of this analysis. There may be alternative, more cost-effective means to maintain a population of caribou in the region at large. For example, timber harvesting could, in principle, be restricted in the far-north units. This fibre is potentially less valuable to industry because of the large hauling distances involved and may therefore involve less of a sacrifice if forgone. However, even if timber management was eliminated from these units, natural forest succession and fire patterns will affect habitat quality and quantity over time.

To investigate this issue, no timber management scenarios were developed for several far north management units (Ogoki, Lake St. Joseph and Berens River units - see Fig. 1). These scenarios examined potential changes in habitat given minimal fire suppression activities and natural succession. The fire probability disturbance rate was 0.015 as compared to 0.004 85 in Lac Seul where fire suppression activities are more common (Tithecott, pers. comm.).

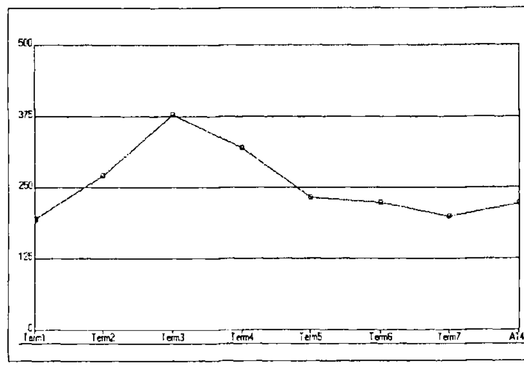
Fig. 4 shows the implications of no timber management on 3 far north units on the expected aggregate amount of caribou habitat over time. Except for the Berens River Unit, caribou habitat substantially decreases over time relative to current levels. This is attributed to the existing old forest condition (age class structure) of these units. Note that the absolute amount of caribou habitat varies considerably across each of the units. More research is likely required to understand the actual spatial variation in habitat quality across these units. For example, would 50 000 hectares of "caribou habitat" in the Berens River Unit be better than 100 000 hectares in the Lake St. Joseph Unit because of the quality of overwintering areas?

Ogoki



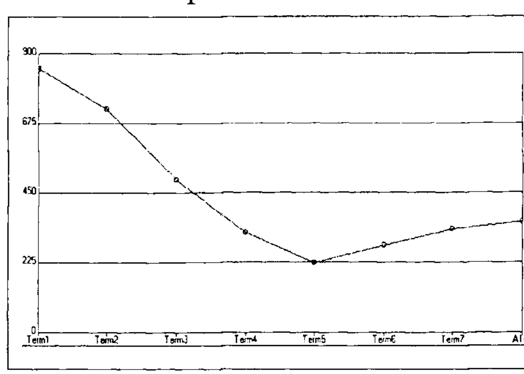
Potential Caribou Habitat over time

Berens River



Potential Caribou Habitat over time

Lake St. Joseph



Potential Caribou Habitat over time

* x axis = planning period;
y axis = 000's of hectares

Fig. 4. Caribou habitat in far north units with no timber management.

Conclusions

This paper demonstrates how a generic linear programming based forest planning model can be used to investigate caribou, wood supply and forest economic issues. The implications of the proposed caribou guidelines are difficult to quantify in precise terms over such a large region. There is a complex array of trade-offs between wood supply and the value of standing timber and the spatial arrangement of caribou habitat. Models such as SFMM and other forest planning tools help planners and stakeholders to clearly identify and organise what is known and not known. This quantifies trade-offs more clearly. What makes the caribou management problem unique is the nomadic nature of the animal hence many Forest Management Units could be affected by policy directives. Wood supply issues may need to be co-ordinated over a much larger geographic area than is currently taking place.

The Lac Seul analyses presented here suggest that it will be difficult to maintain caribou habitat in a single management unit once timber harvesting occurs depending on the amount of habitat explicitly required. The results support the notion that co-ordination among management units may be necessary to maintain caribou range across the currently occupied portion of northwestern Ontario. Extrapolating this result to other Forest Management Units in the region is nevertheless difficult. The composition (species) and structure (age classes) of each unit is different. Maintaining small patches of habitat within harvested areas across the entire region may in fact be a less cost effective approach to maintaining the species (see Hyde, 1989 for a similar recommendation in the context of a forest dwelling bird species). More analyses are required to investigate this assertion.

The no timber management scenarios on the far north units also suggest that prime caribou habitat is likely to fluctuate considerably over the next 100 years regardless of timber management activities. This is due to the preponderance of mature/over mature spruce forest in the region that is susceptible to fire. Woodland caribou may be more reliant on these areas than they have been in the past because of harvesting activities south of these units. Despite the likely declines in prime caribou habitat, timber harvesting may not be an economically viable proposition for these units. Restricting timber harvesting in these far north units may still be the most cost effective way of maintaining caribou in the region at large.

Clearly maintenance of caribou habitat in any given area that includes timber harvesting will require rigorous spatial analysis on the layout of harvest patches. Co-ordinated planning efforts with surrounding Management Units is necessary to minimise the impacts on both wood supply and habitat. Linear programming by itself will likely be of limited value in such broad scale planning. Forest planners will need to take advantage of a wider range of tools such as Geographic Information Systems, and other simulation and optimization tools to provide additional insights. (e.g. McKenney & Nippers, 1996).

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