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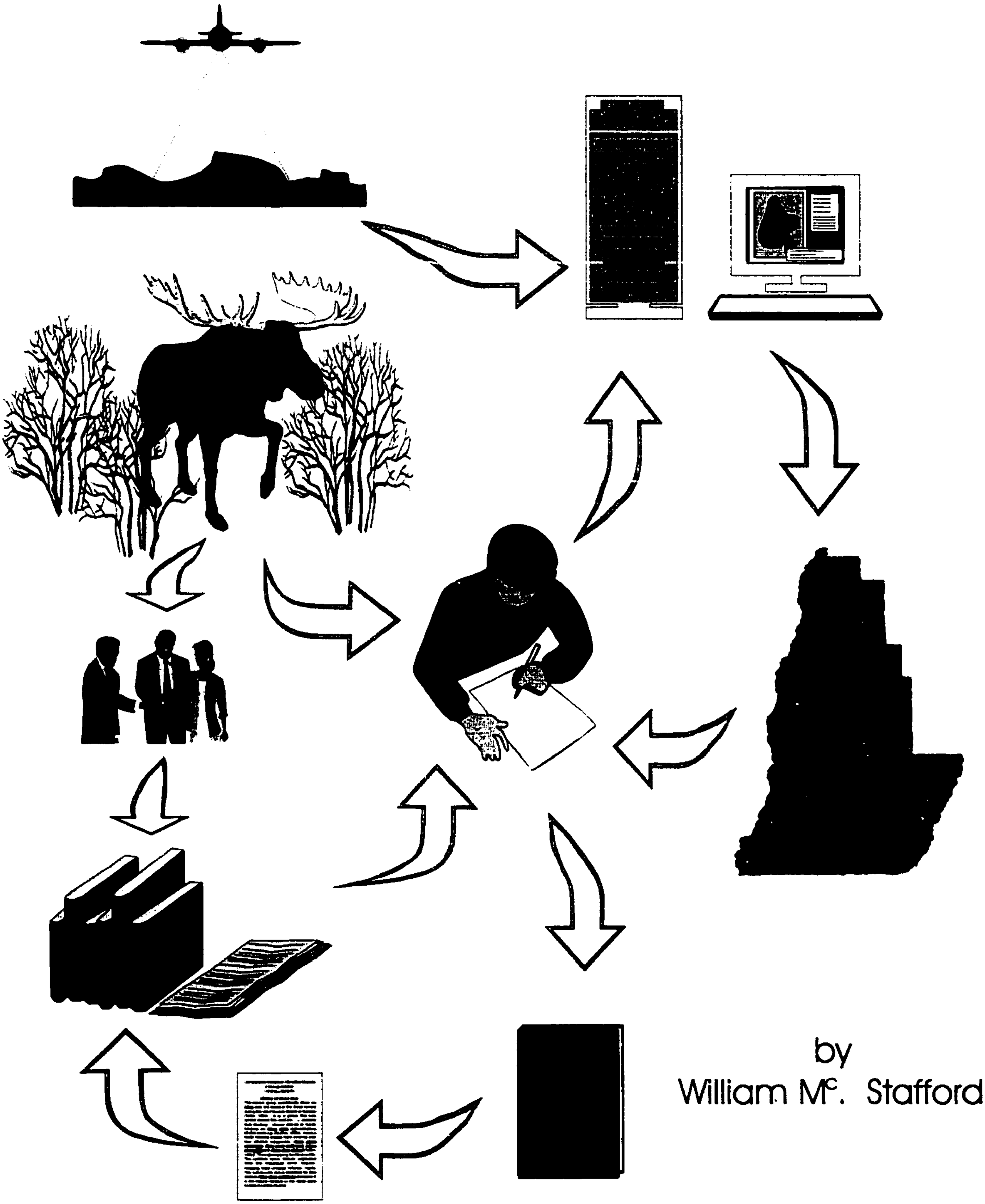
Comparative Analysis of Alternative Models of Moose Habitat Carrying Capacity



by
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ABSTRACT

Stafford, William M^c^Gregor. 1999. Comparative Analysis of Alternative Models of Moose Carrying Capacity. Unpublished M.Sc.F. thesis, Faculty of Forestry and the Forest Environment, Lakehead University, Thunder Bay, Ontario. 233 p. Supervisor: Dr. Peter N. Duinker.

Key Words: habitat carrying capacity, forest simulation, habitat suitability index, model comparison, moose modelling, population modelling, simulation, wildlife modelling.

The focus of the project was to compare the performance of several alternative models in predicting the potential impacts of timber harvesting on a moose population northwest of Edmonton, Alberta, in terms of moose density. The results would be used in strategic forest management planning for the area under study. Four models that estimate density were compared and contrasted for their suitability in prediction of timber harvesting impacts on the moose population. The final model results were compared to known moose population values from the area as a validation technique.

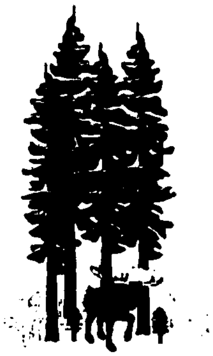
Two of the models tested were habitat suitability index models, another was a habitat carrying capacity model, and the fourth was a population energetics model. The four models were applied to a 10,495 ha study area where timber harvest was simulated using Harvest Schedule Generator 3.0 over a 200-year time period. Three timber harvesting simulations were applied to the landscape using a philosophy of long-run sustained timber yield . A basic harvest level was developed to represent the way the present forest grows using normal timber yield curves. The second simulation represents a higher long-run sustained timber yield gained through intensive silviculture. The last simulation was designed to act as a control and it simulated the forest growth and development when no timber harvest takes place.

The first part of the project was to provide background information with respect to the study area, models, moose models, modelling used in adaptive management, and modelling as it applies to strategic forest management planning. The next part explains how the models were developed and applied to the three forest simulations, followed by a discussion of the results from each model. Lastly, the results from each moose model were compared to estimates of the resident moose population and conclusions were drawn.

The thesis results indicate that the Weldwood Winter Habitat Suitability Index Model predicts a 50% decline in moose carrying capacity for all forest simulations from 1996 to 2116 after which the simulated populations remains stable. The Chair in Forest Management and Policy Winter Habitat Suitability Index Model predicts that moose numbers will double for the two harvest scenarios in the first 50 years, after which the predictions remain stable, while the control indicates a stable population for the whole simulation. The Higgelke Habitat Model predicts a population increase between 2106 and 2126 for the harvesting simulations, after which there is a slow decline in moose carrying capacity values to approximately their starting values. The control simulation predicts that moose densities will decline by approximately 22% over 200 years. The Duinker Population Model predicts the same increase in moose numbers for the two harvesting simulations between 2106 and 2126 and a similar decline in values to Higgelke's model; however, the moose populations recover to their original peak values by the end of the simulation. The no-harvesting control in the Duinker model predicts a fairly steady moose population.

The simulation results indicate no real match to aerial moose inventory values, which was not unexpected. Models of this nature need to be compared to field results over many years before there will be any indication of which model(s) correlate to field observations. The benefit of the multiple model hypotheses and comparisons resides in the overall trend that three of the models predict a population increase after timber harvesting, which corresponds to published literature.

The practical benefit of this exercise was to present to the managing forester and public forest management advisory committee's the potential impacts of different harvesting strategies on a moose population from multiple models that track the same indicator.



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From a family presceiptive I would like to thank my parents Verna and Bill Stafford for putting up with a stubborn kid who always wanted his way and to know what was on the other side of the hill. I can not forget my siblings Heather and John who encouraged me in my scholastic endeavours. Lastly, I would like to thank Carrie Hutchison, my partner in life who has supported and encouraged me to finish this project. To her credit, Carrie hung in there when the stress associated with doing a M.Sc.F. project almost got the best of the both of us..

This concludes my acknowledgements. If I've missed anyone I apologize. I'm sure I'll remember once the thesis is bound, at which point its to late. However, you may take solace in knowing that I will feel guilty for not recognizing you.

INTRODUCTION

The Canadian forest sector has provided our country with materials to build homes and wealth to increase our standard of living. In the past, the forest products industry has only been concerned with harvesting trees and the accumulation of personal wealth as exemplified by John R. Booth's (Bond 1968) empire built around white pine *(Pinus strobus* L.) in the 18th century. However, today this approach is no longer condoned by the public or forestry professionals. Today, across Canada, the public and the forest sector are jointly trying to develop integrated forest management plans that guarantee forest sustainability and respect for other uses. To achieve truly integrated forest management, society must have an idea of what the future effects of different forest management practices might be on various vertebrate species.

Toward that end, J. Russell of Millar Western Forest Products Ltd. (MWFP) of Whitecourt, Alberta, approached Dr. P. Duinker and L. Van Damme at Lakehead University to see if they could put together a suite of models for predicting the impacts of different timber management regimes on several wildlife species endemic to MWFP's licensed public forest land. From this larger project, the present thesis was developed.

This thesis explores and compares a small array of moose (*Alces alces*) habitat carrying capacity models. Each model was applied to the same landbase with three levels of silviculture treatment. The objective was to determine the degree of convergence or divergence of model outcomes and to understand reasons for any differences. Differences need to be analysed and the outcomes compared to moose census data. This comparison will serve as a test of validity for the alternative models. Additionally, the comparison will illustrate whether the predicted habitat carrying capacity for moose for each model is realistic.

Problem Statement

Researchers (e.g., Verner *et al.* 1986; Schuerholz *et al.* 1988; Wedeles *et al.* 1991; Duinker 1994; and Higgelke 1994) and wildlife habitat planners (e.g. Bonar *et al.* 1990) are developing alternative models of habitat carrying capacity for a range of forest-dwelling vertebrate wildlife species. Some models are relatively simple and account only for habitat dynamics (e.g., Higgelke 1994 and Allen *et al.* 1987) whereas others are comparatively complex and account for population dynamics (e.g. Duinker 1986; Hanley and Rogers 1989; Duinker 1993; and Duinker *et al.* 1996). A third type of model now appearing in the literature includes some components of the other two but adds some type of "artificial intelligence" for the species being modelled (e.g. Saarenmaa *et al.* 1988 and Roese *et al.* 1991).

Two major problems arise for wildlife habitat modellers. The first problem is the long time-frame during which field measurements must be taken before habitat models can be empirically tested. The best way to answer this problem would be to perform the required surveys, e.g. how much browse was consumed; what is an animal's home range size; how many predators are there, etc. However, there is insufficient time in my schedule to allow that. The second problem is the modeller's inability to judge in advance how much detail must be put into a model before it does an adequate job for long-term forest-level planning. This difficulty can be partially overcome by comparing the performance of several models of habitat carrying capacity, for the same species, in the same landscape, and across the same range of forest-management strategies. This process is also interactive with respect to time, since conditions are always evolving. Initially the first run results can be reinforced by comparing the models to moose inventories, for areas of similar habitat structure and forest-management strategies (Brown 1995; Duinker 1995). The same is also true for future runs, fortunately; with an historical record on moose numbers and model predictions, the choice of an appropriate model will become easier.

Scientific Justification

The purpose of the project is to determine whether the use of complex models of species-specific habitat carrying capacity, such as linked habitat-population models, is justified in long-term, broad-scale wildlife habitat planning, or whether simple habitat suitability index models will suffice and are preferable.

Study Objectives

The objectives are as follows:

Objective 1. To calibrate at least three moose habitat carrying capacity models (Bonar *et al.* 1990; Duinker 1993; Higgelke 1994) for part of the MWFP's Forest Management Agreement (FMA) area near Whitecourt, Alberta;

Objective 2. To apply the models in forecasting moose habitat carrying capacity for the MWFP FMA under a range of forest-management strategies;

Objective 3. To evaluate model performance and relative reliability by comparing their outputs to moose survey data from similar habitat types; and

Objective 4. To draw conclusions about model complexity and usefulness in strategic forest-planning decision-making.

There are essentially two outcomes of the model comparison, and each can be seen to be a competing hypothesis:

1. The models make essentially the same predictions for moose carrying capacity. In this case, initially one would probably conclude that, for strategic forest-planning purposes, the simplest model can be relied upon since it produces results similar to more complex models.

2. The models make substantially different predictions for moose carrying capacity. In this case, one would need to delve into the biological and computational basis for the differences, and attempt to rank the relevant assumptions as to their degree of uncertainty, and thus the overall confidence in each model's predictions. One might assume that the more complex models are more realistic, but this remains to be seen from analysis of the predictions.

Expected Results from Objectives

Objective 1. Will yield three alternative models, of strongly different structures, for the same wildlife species' habitat in the same forest.

Objective 2. Will yield the forecasts or predictions required to assess relative model performance.

Objective 3. Will yield performance evaluations for each model relative to the others.

Objective 4. Will yield advice to forest habitat researchers and planners regarding the use of species-specific habitat models of varying degrees of complexity.

STUDY AREA

The study area is delineated on the east and west by two creek systems. The east boundary is dominated by Oldman Creek and its tributaries, while the west and north extent are entrenched by Wind Fall Creek and its tributaries. The area between the two creeks is dominated by both pure and mixedwood stands of conifer and deciduous species. Furthermore, there are small grassland, swamp, bog and shrub areas that dot the landscape. This part of MWFP's allocation was chosen because it was to be the first area to be re-inventoried and I was scheduled to get the new inventory data.

Geographic Location

The study area is located 50 km west/southwest of Whitecourt, Alberta (Figure 1). Whitecourt is situated 150 km west/northwest of Edmonton. The study area is designated as forest license agreement area W90008 by Alberta Environmental Protection and is enclosed by township and range maps T58R15M5, T58R16M5, T59R15M5 and T59R16M5.

Climate

The climate of the area is classified as dry continental. Mean temperature values in January and July are -20°C and 20°C respectively (Anon 1989). The mean total precipitation for the area is 750 mm per year. The greatest mean precipitation occurs in May and October, with January and July being the two driest months.

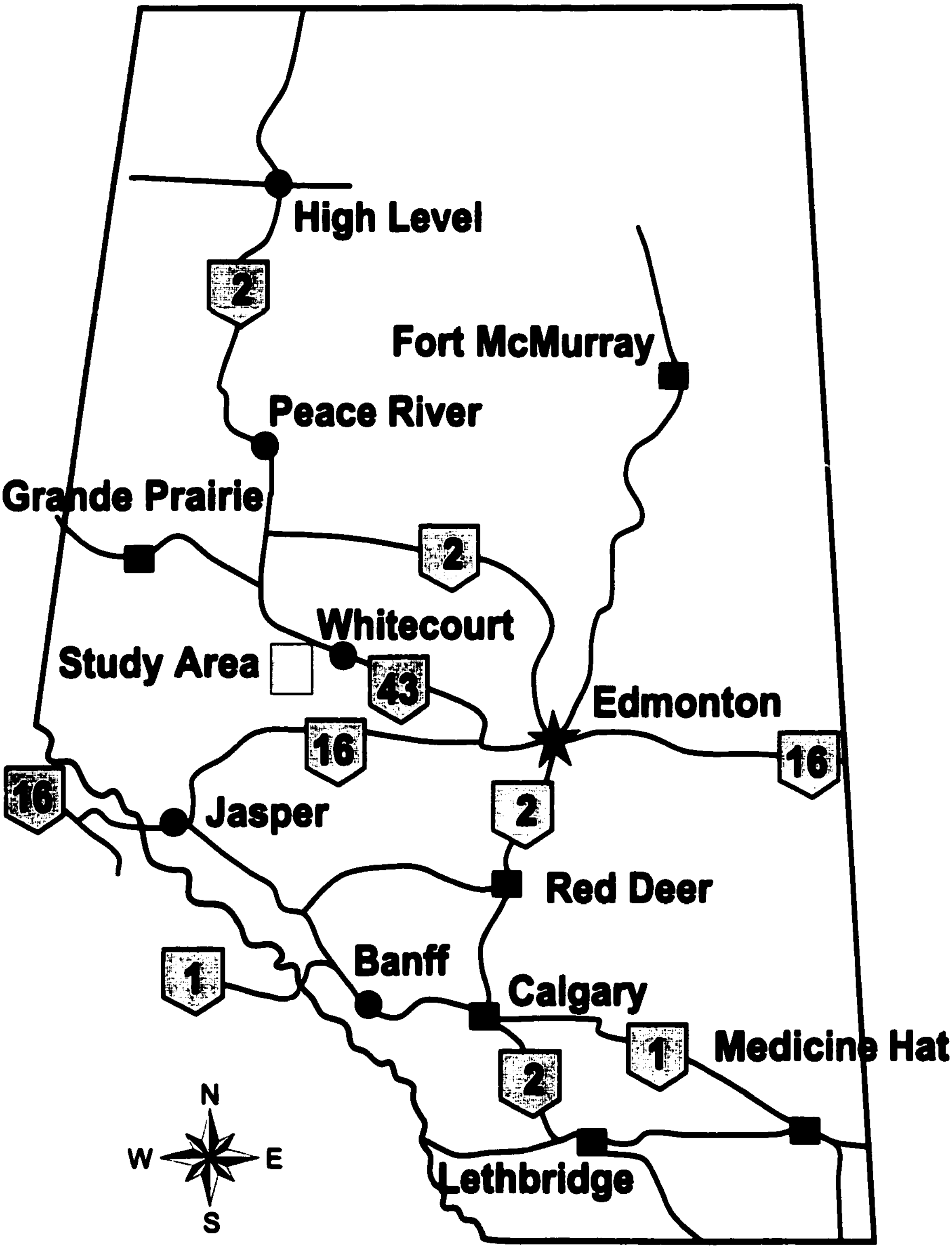


Figure 1: Study area location map.
Map not to scale
Source: http://www.agt.net/public/access/accintro.htm

Geology and Geomorphology

Geologically the area is underlain by sedimentary rock originating from the Cretaceous period. The study area lies in the interior plains landform region (Anon 1989). The sedimentary rocks and glacial tills of the study area have spawned a Grey Wooded soil great group. The Grey Wooded soils overlie various forms of glacial till.

Grey Wooded soils are characteristically composed of greater than 30% silt and/or clay which makes them prone to slumping when they are at or near field moisture capacity (Boul *et al.* 1989). Because of their fine texture, Grey Wooded soils are also susceptible to water erosion if not revegetated after disturbance. These soils have two advantages; one is high field moisture capacity, and the other is that they can hold moisture for long periods of time. Both advantages are beneficial to the growth of several tree species groups, specifically spruce, fir and poplar.

Topography

The terrain is hummocky from deep glacial deposits that have experienced significant water erosion since the last ice age. The lowest elevation is 800 m above sea level (ASL) while the highest area is approximately 1300 m ASL (Figure 2). Slopes in the study area range from 2% to 50%.

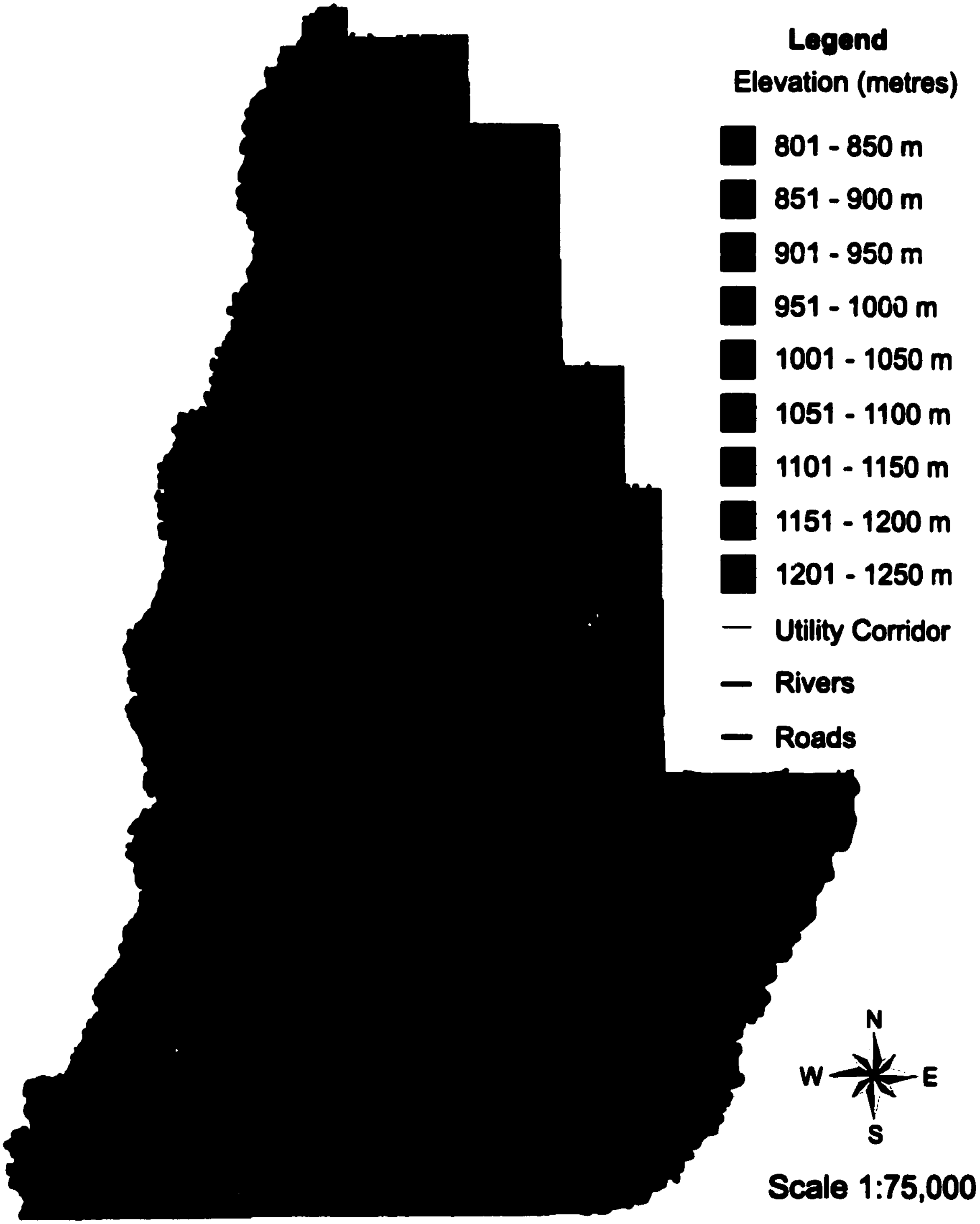


Figure 2: Elevation map of study area W90008.

LITERATURE REVIEW

Habitat Modelling

To understand habitat models we need to understand each component of the term habitat model. Habitat is the physical environment an organism lives in; habitat provides food, cover and reproductive security so that the organism can survive and reproduce successfully. The quality of habitat, i.e. its goodness, is the amount and mixture of food, cover and reproductive security. To define models I will use the Nyberg (1990) definition that models are "... *quantitative abstractions of the essential parts of the real-world situations*", with quantitative meaning "*1 concerned with quantity, or 2 that can be measured*" (Avis *et al.* 1983). When habitat and models are merged we are trying to create quantitative abstractions of real-world situations that relate to habitat. With respect to this thesis, the above definition fits well with the procedures and doctrine used in scientific investigation and is therefore applicable here.

Models linking wildlife to forest attributes first appeared in the 1960's and were developed by teams of researchers and managers (Bunnell 1989). Since the 1960's Bunnell (1989) has found that: (1) the variety of models has continued to grow, (2) resource managers have begun to use models, and (3) the misuse of models produces invalid results. About the same time, the first computers were being developed and porting models to computers was a relatively simple task since most models of the 60's were of a simple mathematical nature. Since then the complexity and operational scale of models has increased in step with computing power and has allowed us to model very complex systems such as climates and oceans over longer temporal and broader geographic scales (Scott *et al.* 1993).

One of the most important components of modelling any system is the validation procedure during model development and upon completion. Validation must be used throughout the modelling process. Berry (1986) cites Farmer *et al.* (1982) and Marcot *et al.* (1983) that validation, invalidation and verification are critical processes and must receive more attention. It is necessary to validate or invalidate all parts of a model, i.e., inputs, relationships and results. Without critical validation, the use of models comes into question, since the weaknesses in the model's assumptions, inputs and results are unknown, which could lead to faulty resource management decisions.

From my standpoint as a modeller, the best models are developed within the framework of adaptive management. In adaptive management, one takes existing information, develops a model that examines a component(s) of a system that could be affected by various management decisions, and uses it to project what the impacts might be. Within this framework the model's assumptions, inputs and results are examined for their veracity (Hurley 1986). As time progresses the model may be enhanced, modified or replaced as new information becomes available in an adaptive management context. This cycling and comparison of reality to model results through time give such modelling in adaptive management its strength.

Types of Habitat Models

Conceptual Habitat Models

Conceptual models provide an opportunity to display graphically the linkages between key factors in the environment that may affect the entity being modelled.

The model developed may be the end product or a middle step on the way to a more complex model. In the latter case, conceptual models are a way to display key concepts visually and processes for problem identification and scoping to take place.

Habitat Suitability Index Models

Habitat Suitability Index (HSI) models were developed in the United States to evaluate the impacts of environmental projects that might hinder the growth and development of various wildlife species (Schamberger and Farmer 1978) and provided a bridge between the fields of science and resource management (Schamberger and O'Neil 1986). HSI models examine a range of habitat components in the landscape that are considered important to the species of interest. HSI models require numerous assumptions and can never fully represent the real world (Schamberger and O'Neil 1986). However, if those simplifications of reality are done properly, one can normally retain the key systems dynamics while removing non-essential information.

Generally, HSI models contain environmental components strongly related to the subject species life requisites. Those requisites are rated on a scale from 0.0 to 1.0, with 1.0 being the optimum value. The resulting component values are usually multiplied together and raised to the reciprocal of the number of components in the model (Equation 1).

HSI models are difficult to validate on their own and across studies, since there are no standard methods for defining and measuring habitat quality. Modellers often lack reliable quantitative habitat data with which to build models, and the data that do exist are in different formats. Finally, models are developed

Equation 1

Example HSI Equation for Deer Yards

$$HSI = (S1 \cdot S2 \cdot S3)^{1/3}$$

S1 = Tree Height
S2 = Canopy Closure
S3 = Browse Density

around the concepts of habitat and carrying capacity, terms which have no standard definitions and are difficult to quantify (Schamberger and O'Neil 1986). Schamberger and O'Neil (1986) provide a set of ideas regarding HSI model testing which were used as a guide for evaluating the HSI and other models in this thesis.

Carrying Capacity Models

The most comprehensive view of carrying capacity is that it is a function of all factors that interact to limit a population (Schamberger and O'Neil 1986). It is also thought to be a theoretical limit of the habitat to provide the life requisites of a species. HSI models "recognize the basic requirements of food, cover and physical habitat that serve to define the potential of a land base to support wildlife populations" (Thompson and Stewart 1998). Furthermore, their use is restricted to a specific land-use study and a specific geographic area and they are designed to be practical, operational planning models to assess impacts (Schamberger and O'Neil 1986).

Carrying capacity models and HSI models are differentiated by the types of data used. HSI models focus on the basics required to sustain a population on a land base, while carrying capacity models examine a greater number of variables that affect the success of a population such as behaviour, climate, competition, diseases, disturbances, fecundity, mortality, parasites, predation, reproduction and habitat variables (Schamberger and O'Neil 1986).

Spatial Habitat Models

Spatial habitat models developed in conjunction with Geographic Information Systems (GIS), because GIS's are able to track the spatial arrangement of objects via topology. Spatial models differ from the previous two types in that they take into account the juxtaposition of habitat features in relation to other specific habitat features around them. These types of models have the potential to improve the representation of how the landscape is utilized by a species because they take into account what habitat features are spatially important. This additional information allows the model to make calculations for habitat features that are spatially related.

Utilizing the Carrying Capacity Approach

The carrying capacity approach was taken in thesis project for two reasons: (a) the carrying capacity concept would be easier for managers to understand, which would make moose population objectives easier for them to set and implement and (b) I needed a way to compare and contrast the results from different models. If the HSI approach was left on its own i.e. HSI values between 0.0 and 1.0 then I could not of compared the population dynamics CC model to a static HSI model. Both reasons were important; however, presenting information to a manager or planning team that is concise, easy to understand and defendable is paramount, because it allows them to make informed decisions with good information.

Use of Models

Nyberg (1990) highlights three uses of forestry-wildlife models: (1) to further understanding, (2) to predict responses or trends, and (3) to communicate knowledge. Bunnell (1989) and Morrison *et al.* (1992) only identify Nyberg's first two uses as relevant. Bunnell (1989) describes models for understanding as "*...best guesses or hypotheses in a theoretical statement about how a system operates...*" while models for prediction are "*...designed to provide accurate, quantitative predictions of the response of one (or more) variable(s) ... to changes in another...*". Nyberg (1990) describes the last use as best fulfilled using word models that describe the model's quantitative aspects and the underlying model relationships which are important for learning to take place within an adaptive management framework.

In this study all of Nyberg's uses were employed. First the models were examined conceptually to see if they fit what is known and reported in the literature and to further our understanding of what others thought was important. Next they were used to predict outcomes (moose/km^2) using data associated with three timber harvest scenarios. Lastly, they are to be used to communicate knowledge back to the managing forester regarding what level of model complexity is advisable for local, regional and landscape-level planning.

Of Nyberg's (1990) three uses, prediction is most likely to garner the most attention. Berry (1986) divides prediction models into three classes: (1) single-species models, (2) multiple-species or community models, and (3) habitat-analysis models. Berry (1986) defines simple correlations, presence/absence, statistical, habitat suitability index models, habitat capability models and pattern recognition models as single-species models. Multiple-species or community models include the U.S. integrated habitat inventory and classification system, the U.S. life-form system and community guild models (a guild is a group of animals that have a large number of the same life requisites). Lastly, habitat-analysis models include the U.S. habitat evaluation procedures, optimization models, and economic-analysis models. Berry (1986) notes that habitat-analysis models can overlap with single-species models.

The models used in this thesis can be placed in two categories. The Weldwood Winter Habitat Suitability Index Model (WWHSIM) and the Chair in Forest Management and Policy Winter Habitat Suitability Index Model (CFMP-WHSIM) would be classified as single-species models, while the Higgelke Habitat Model (HHM) and Duinker Population Model (DPM) are habitat-analysis models.

Benefits of Habitat Modelling

Nyberg (1990) identified five reasons why predictive models are beneficial to researchers and managers. Predictive models can be computerized, thereby allowing rapid responses to repetitive simple equations or the determination of complex 3- dimensional equations used in flow mechanics or thermodynamics. Today, predictive models are incorporated into GIS's to examine 2- and 3-dimensional spatial characteristics as well as the fourth dimension of time. Predictive models, according to Nyberg (1990), allow us to filter out the extraneous information regarding wildlife and forest relationships while maintaining the key ecological relationships. The ability to predict with models allows us the opportunity to try different management scenarios and assess the impacts with few environmental or monetary costs. Finally, models allow us to explore the potential results of our actions when real data are insufficient or sketchy, such as global climate models.

Moose Habitat Modelling

The first widely known moose habitat model, called the Habitat Suitability Index Model: Moose, Lake Superior Region, was developed by Allen *et al.* (1987). Several implementations of this model were developed for different regions (e.g. Higgelke 1994, Puttock *et al.* 1995 and Hepinstall *et al.* 1996). Another common type of habitat model developed for moose followed the Habitat Evaluation Procedures developed by the U.S. Fish and Wildlife Service in the 1970's such as Manitoba Model Forest's Habitat Suitability Index Model for Moose (Terrestrial & Aquatic Environmental Managers Inc. 1995).

The next evolution of moose habitat models was to include spatial components within the model. Higgelke (1994) utilized a raster-based roving window method to account for the natural ecotone between stands. The spatial component examined the spatial arrangement of food stands in relation to early-winter cover stands. Duinker *et al.* (1996) extended the work of Higgelke (1994) and used the early-winter cover and food values produced from the Higgelke model and applied them to a population energetics model. The moose energetics model attempts to account for the impacts of hunting, predators, diseases, and other mortality.

Model Uncertainty and the Quantification of Error

Uncertainty exists in both model inputs and relationships. In traditional science, specifically ANOVA-based experiments, one can quantify by known methods the uncertainty of specific variables. In simulation modelling, this becomes difficult if not impossible. However, at the base level i.e. level of the individual input such as tree height, one can determine the range of variance of that input across a landscape, by species, site class, age etc. through the use of simple experimental designs. The difficulty comes when one starts to combine these baseline inputs together in a model and determine their joint “variance”. I am sure that one could design and implement field experiments that examined the height co-efficient by species and how it relates to food. It was my assumption from field experience and literature reviews that as height increases the amount of food decreases. But the cost of doing such field research to lower uncertainty of that interaction would not be worth it; that money should be used elsewhere to provide more important and useful baseline information. A specific baseline study could examine just how much food is out there under different stand compositions or how much time do moose spend in specific and discrete habitat types.

My justification for not being able to quantify the interaction effects comes from the difficulty involved in trying to measure all interaction effects in a system that is infinitely dynamic. It is a task that would be considered impossible today and most likely into the near future. If one can not quantify error or variance in the interaction effects then one will not be able to measure error in the final forecasts. The best the modeller can do is lower the uncertainty as much as possible in the baseline data and make the equations involving those variables as simple as possible so that interaction effects can be monitored and adjusted for if necessary.

Scale

Scale, both temporal and spatial, have significant effects on modelling investigations. Wiens *et al.* (1985) identified numerous spatial and temporal scales. The spatial scales identified were: (1) area used by an individual, (2) local population or patch, (3) regional scale, and (4) biogeographical scale; temporal scales were: (1) the time required for an individual's response, (2) the life time of an individual, (3) the time span of several generations, and (4) the time needed for evolutionary change. With respect to moose, Telfer (1984) proposes that habitat be studied at three scales: the site or compartment scale of a few hundred ha, the local scale from 100 to 999 km^2, and finally the regional scale of 1,000 km^2 or more. Similarly, one should examine the impacts that temporal scales have on models that deal with moose or any wildlife species. The temporal scales of interest are the time needed for an individual's response to a stimulus, an individual's life time, and the time span of several generations.

Individual moose have the ability to affect their site or compartment environment, while many moose may have the ability to effect change at the local scale but little if any effect at a regional scale. Conversely, "*nature*" can affect moose at all three scales since fire, drought, insect infestations and wind storms have the ability to alter site, local, regional and biogeographical zones and those effects can occur at all temporal scales. Finally, humans, like "*nature*", can manipulate the environment of the moose at all scales temporally and spatially.

The interventions of humans with respect to moose are initiated and controlled from a moose management plan developed in association with a forest-products company (Thompson and Stewart 1998) or a government organization. The plan is developed in consultation with biologists, foresters and/or citizens advisory committee.

From research done on human interventions there now appears to be enough evidence to conclude that habitat management could have a positive influence on moose numbers (Thompson and Stewart 1998). Conversely, the benefits of management directed at specific habitat components, e.g., late-winter cover, are not as strong at the local or landscape level (Thompson and Stewart 1998). Finally, Thompson and Stewart (1998) state that "*...there remains a general lack of evidence to support the hypothesis that at the unit level, moose populations have been increased through directed management of habitat over the long term*". From the statements of Thompson and Stewart (1998) above, it seems that moose have taken advantage of human disturbances through time and increased their numbers and expanded their range, but they have not benefited in a statistically proven way from direct habitat manipulation. However, the statistical proof may come once the Centre for Northern Ecosystem Research, Ontario Ministry of Natural Resources publishes the results from research on the effects of Ontario's Guidelines for Moose Habitat Management in Ontario (1984).

This thesis examines the response of several moose models to different timber harvest regimes by manipulating forest dynamics and structure at the first two spatial scales - site and local scale - and over the middle two temporal scales - an individual's life time and the time span of several generations. The thesis was restricted to the first two spatial scales because the data provided for the project cover only 10,495 ha. However, with the forest modelling program Harvest Schedule Generator (HSG) (Moore and Lockwood 1990, Gooding 1995), I was able to simulate different timber harvest strategies for 200 years, which covers the middle two temporal scales.

Effects of Scale on Management and Planning

For wildlife managers, the spatial and temporal scales at which to implement habitat management are variable. Thompson and Stewart (1998) suggest a spatial scale of 1,000 km^2 (regional scale) or more be used for habitat management with respect to strategic forest management planning. The regional scale seems most appropriate because it is the area occupied by numerous moose and it is the normal scale of a forest management license. Additionally, it is enough real estate to test multiple hypotheses simultaneously as required by adaptive management. With respect to temporal scale, Wiens *et al.* (1985) suggests that responses to interventions be measured at temporal scales appropriate to the interventions (experiments) implemented and the response variables measured. Therefore, experiments dealing with forest management and silvicultural practices would have a time frame of several decades. The discussed time frames are long enough to observe changes in forest growth and development as well as the health and habits of the resident moose population.

Quoted, Thompson and Stewart (1998) relate several issues that managers have to deal with when managing habitat: "*should managers manipulate moose habitat everywhere and all the time and should managers be concerned only or* *primarily with the immediate supply of suitable habitat relative to some population objectives and finally should moose habitat be actively managed only in specific areas and for local populations or ... for an entire unit"*. It is felt by Thompson and Stewart (1998) that *"moose should be managed at a spatial scale large enough to ensure that population objectives can be achieved at a time scale consistent with the optimal forest rotation"*. Therefore, with respect to the models in this thesis, moose should be managed on a time frame of 40-60 years for the High Harvest Scenario (HHS), 40-80 years for the Basic Harvest Scenario (BHS) and 80-120 years for the No Harvest Scenario (NHS). I think the time frames for the HHS and BHS are too short because mature forest ecosystems require longer time periods to develop. If the only concern were fibre production, then those time frames would be valid; however, fibre production is not the only concern on Crown lands. Today's forest managers need to develop management strategies in an adaptive management framework that are ecologically sustainable.

Adaptive Management

Overview

Adaptive management is defined as a *"formal process for continually improving management policies and practices by learning from their outcomes"* (Taylor *et al.* 1997). Adaptive management in its simplest form is about dealing with uncertainty (Walters 1995). It evolved out of an approach developed by Holling (1978) and its application to forest management was enhanced by Baskerville (1985). The management policies developed are structured so that learning can take place at every step of management implementation and the knowledge gained is used to refine both the management strategies and their implementation. The greatest learning occurs in the shortest time when the management activities are designed at the outset as controlled and replicated experiments with quantifiable measures that test hypotheses about how the system responds to management interventions (Taylor *et al.* 1997). Adaptive management makes explicit the fact that any intervention in an ecosystem can be treated more or less as an experiment and that we can learn from interventions by carefully recording the outcomes and applying the knowledge to the design of future interventions.

Adaptive management concepts are powerful in situations where interventions are to occur in large ecosystems, but the outcomes of the interventions are unknown or potentially harmful. Lee (1993) notes that "*the greater the surprise, the more valuable the information gained, but the costs of information often seem too high to those who do not foresee such surprise*". It is the unknown that makes all managers wary, but it should not paralyse us from implementing practices that monitor change so that science and society can learn how to manage uncertainty.

For adaptive management to function well in large ecosystems, Lee (1993) expounds that adaptive management be linked to a bounded conflict system. Bounded conflict to Lee (1993) is the "*pragmatic application of politics that protects the adaptive process by disciplining the discord of unavoided error(s)*". Finally, Lee (1993) thinks that "*together both processes can bring about learning over the decades required to move from unsustainability towards an enduring social order*".

What are the advantages and hurdles when applying adaptive management? Excised in brief from Taylor *et al.* (1997) the advantages of adaptive management are:

(1) *"Well-designed experiments allow managers to evaluate reliably the effectiveness of alternative management actions".*
(2) *"Adaptive management increases understanding of how ecosystems function".*
(3) *"Adaptive management allows managers to proceed systematically and responsibly in the face of uncertainty, gaps in understanding and disagreement".*
(4) *"Management experiments may provide the only opportunity for learning about large scale, ecosystem relationships".*
(5) *"Adaptive management encourages more efficient and effective monitoring".*
(6) *"Adaptive management helps to define the boundaries between activities that are ecologically sustainable and activities that are not".*

The hurdles that need to be overcome during implementation of adaptive management were outlined by Taylor *et al.* (1997). The dominant challenges identified were: (1) technical, (2) economic, (3) ecological, (4) institutional and social.

Different adaptations of adaptive management are being employed by forest products companies such as Alberta Pacific in Boyle, Alberta (Hebert 1996) and Millar Western Forest Products Ltd. (MWFP) of Whitecourt, Alberta (Van Damme 1998). A common component of each company's approach to adaptive management is the use of simulation models to identify uncertainty, uncover assumptions and explore alternative management strategies. They are modelling specific components and processes and their impacts on the system as a whole. Each has or will have workshops that include decision-makers, politicians, scientists and public participants to identify together what the impacts might be and develop ways of mitigating them.

How This Project Fits Within Adaptive Management

This thesis project is a modelling exercise to examine the effect of alternative timber harvesting scenarios on moose habitat using four moose habitat carrying capacity models. For MWFP, moose is considered one of the featured species. Therefore, it is important to understand the potential impacts that timber harvesting may have on moose within MWFP's license areas. Duinker (1995) suggested the use of multiple models of the same indicator as a way of evaluating how to provide realistic estimates of impacts from different timber harvest strategies, given the present state of data availability and level of technology. There are also questions of model complexity - does strategic forest planning need highly detailed models, or are simple HSI models good enough? It was also thought that disparity between model results might indicate a parameter(s) that was difficult to quantify or sensitive to variation. Finally, if multiple models produced similar results or trends, then the acceptability of those results would be higher than those of a single model.

The results of this work are intended to be used in the development of long-term timber harvest regimes, silvicultural systems and annual cut-block layouts. It may also help identify how moose sport harvest levels or predators might be altered to maintain a healthy and viable moose population.

MODELS APPLIED IN PROJECT

Weldwood Winter Habitat Suitability Index Model

The Weldwood Winter Habitat Suitability Index Model (WWHSIM) for moose (Romito *et al.* 1995) was developed for the Foothills Model Forest near Hinton, Alberta. It is based on habitat suitability indices for food, cover and a ratio of food/cover in an ideal habitat. The HSI indices for each variable range from 0.0 to 1.0, with 1.0 being the best value possible. The WWHSIM component for food is composed of three variables: S1 is the percent shrub canopy closure, S2 is the distance of food from cover (m), and S3 is the distance from access (primarily transport features) (m) (Figure 3)

Variable S1 describes the percentage of shrub canopy closure. Romito *et al.* (1995) stated that the best feeding areas during late winter are in areas with 50% shrub canopy cover or better (HSI=1.0). Areas with less shrub canopy closure receive proportionally lower HSI values. S2, the distance-from-cover variable, was identified by Romito *et al.* (1995) as important because moose are known to stay close to cover while feeding. Moose seem to prefer to be within 100 m of cover; however, occasionaly they feed further away. Therefore, when food areas are close (between 0 and 100 m from cover), they get the highest HSI value of 1.0; feeding areas further away receive a proportionally lower HSI value. The S3 value for distance from access is considered important because food habitat is considered degraded when it is within 100 m of any access corridor, such as roads, cut lines or seismic lines. The rationale is that access corridors are used by humans and predators, thus disturbing moose.

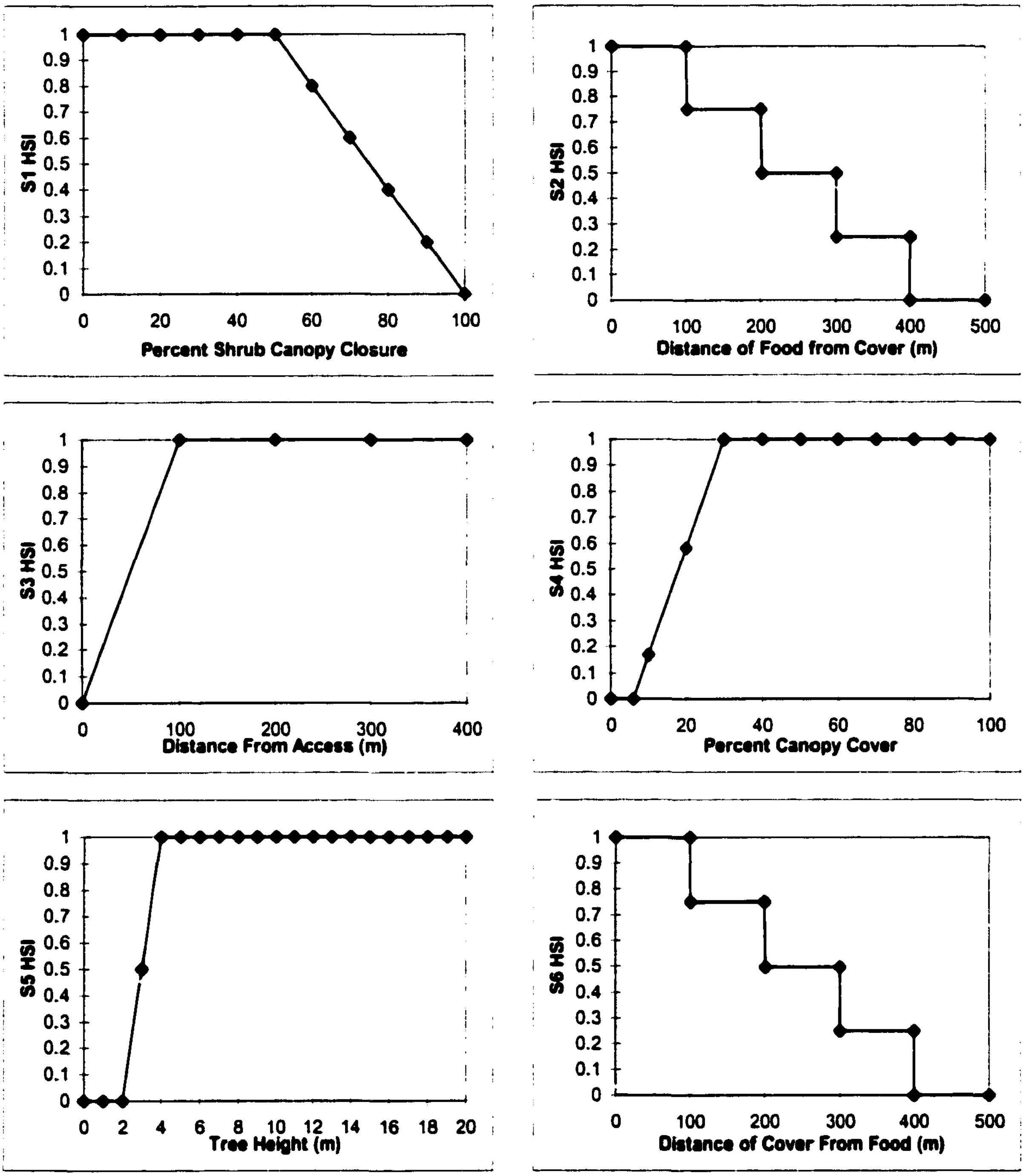
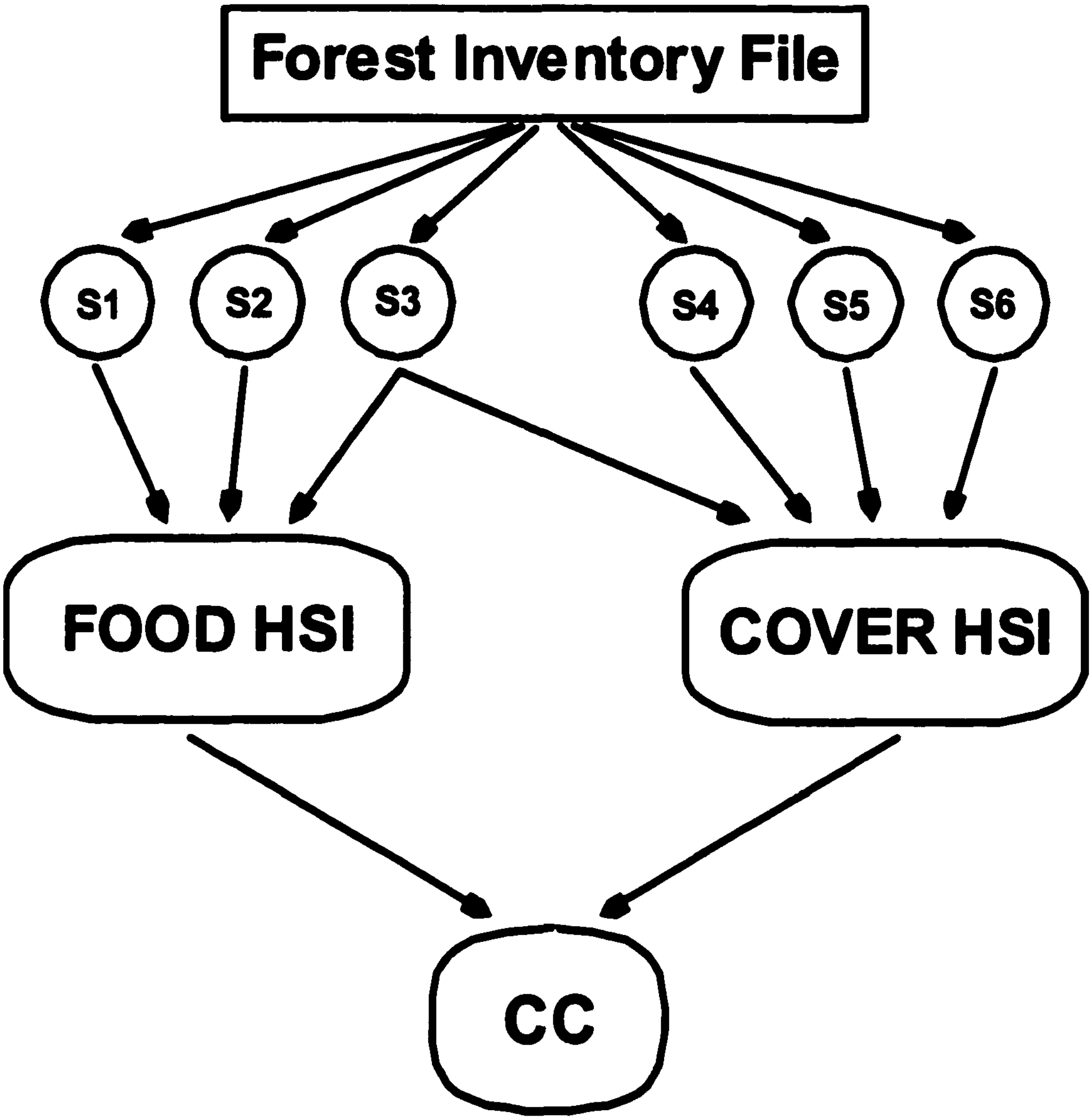


Figure 3: HSI curves S1-S6 used in the Weldwood Winter Habitat Suitability Index Model.

The WWHSIM component for cover is composed of four variables: S3 is the distance from access (primarily transport features) (m), S4 is the percent tree canopy closure, S5 is tree height (m), and S6 is distance of cover from food (m). S3 is also included in the cover calculation for the reason stated above i.e. disturbance and predators. For S4, Romito *et al.* (1995) stated that 30% and greater canopy cover was considered optimal cover habitat (S4 = 1.0), while less than 6% canopy cover had no value at all (S4 = 0.0). For tree height S5, Romito *et al.* (1995) found from the literature that trees needed to be greater than 2.0 m tall before they provided any cover and the best cover occurs when tree heights are greater than or equal to 4.0 m (S5 = 1.0). Finally, S6 is similar to S2 in that cover must be within 400 m of food for it to be beneficial. Cover is considered optimum when it is between 0 and 100 m from food (S6 = 1.0). Distances greater than 100 m receive proportionally lower values, since moose may feel less secure further from cover.

Conceptually, the model calculates six independent variables, of which three are merged to form the HSI for food, while four merge to form the cover HSI. The two results are compared and used to determine carrying capacity (Figure 4).

The WWHSIM components for food and cover for each cell are calculated by multiplying together their associated variables (Equation 2). From literature research done by Romito *et al.* (1995), it is assumed that in ideal moose habitat, the ratio of food-to-cover is 65:35. This ratio is used to calculate the Effective Units of Food (EUF) from the landscape by making the limiting WWHSIM component either food or cover. This is determined by comparing the food value to the cover value multiplied by the food-to-cover ratio 65:35. The resulting minimum value of either food or cover equals EUF. The EUF is divided by the food portion of the ratio to



S1: Percent Shrub Canopy Closure
S2: Distance of food from cover (m)
S3: Distance from access (m)
S4: Cover variable based on percent canopy closure
S5: Cover variable based on tree height (m)
S6: Distance of cover from food (m)
HSI: Habitat suitability index equation
CC: Carrying capacity equation

Figure 4: Calculation flowchart of the Weldwood Winter Habitat Suitability Index Model.

Equation 2

HSI Food = S1 • S2 • S3
HSI Cover = S3 • S4 • S5 • S6
Effective Units of Food = Min[(HSI Food),(HSI Cover • 65% / 35%)]
Effective Units of Winter Habitat = Effective Units of Food/0.65
Carrying Capacity = Effective Units of Winter Habitat • 0.025 moose/ha

where:
S1 = Percent Shrub Canopy Cover
S2 = Distance of Food from Cover (m)
S3 = Distance from Human Disturbance (primarily transportation features) (m)
S4 = Percent Tree Canopy Closure
S5 = Tree Height (m)
S6 = Distance of Cover from Food (m)

Note: 0.025 moose/ha is the known value for moose in the best moose habitat in the study area

give the Effective Units of Winter Habitat (EUWH). Finally, carrying capacity is calculated when the EUWH are multiplied by the expected moose density in ideal habitat (0.025 animals/ha).

Chair in Forest Management and Policy Winter Habitat HSI Model

The Chair in Forest Management and Policy Winter Habitat Suitability Index Model (CFMP-WHSIM) was based on the WWHSIM, but was refined to improve the approximations of conditions in the study area. This model is composed of 7 HSI variables (Figure 5). S1-S3 are merged to form the food HSI while S4-S7 are merged together to form the cover HSI. The HSI values for food and cover are summed across the landscape and used to determine carrying capacity (Figure 6).

The CFMP-WHSIM S1 determines a food bonus for cells that are adjacent to seismic or utility corridors. For the food bonus of S1, it is assumed that utility

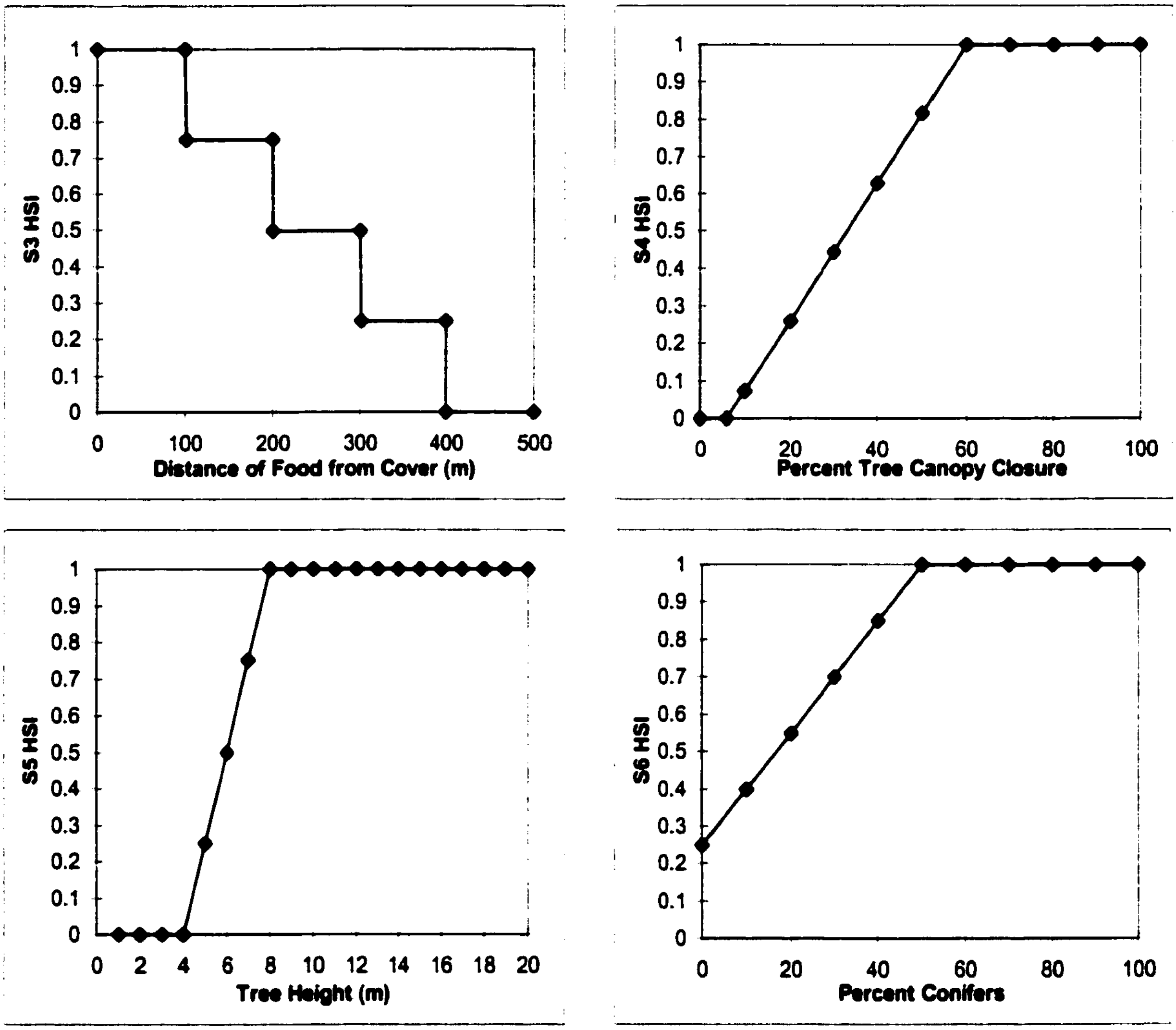
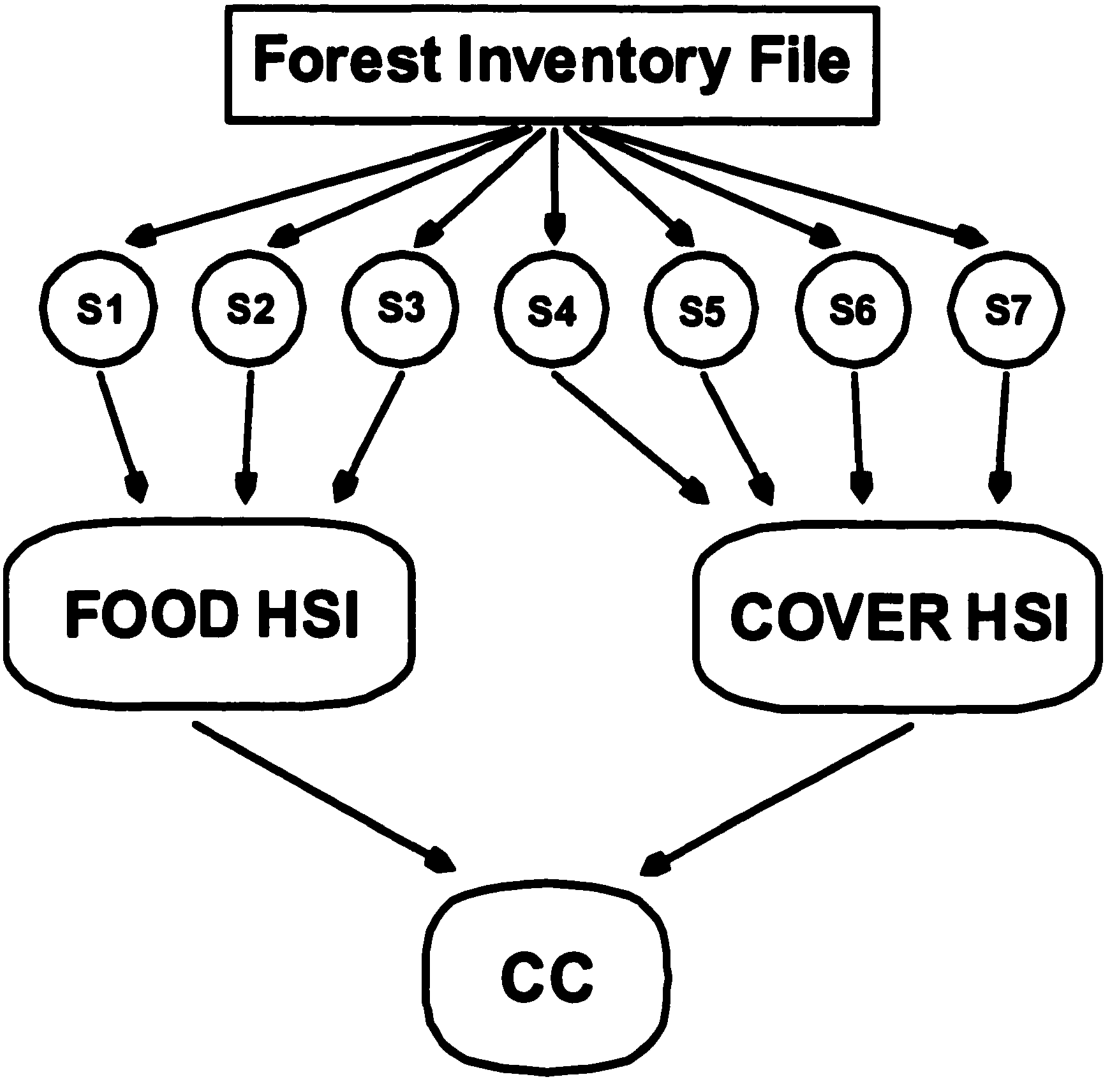


Figure 5: HSI curves S3-S6 used in the Chair in Forest Management and Policy Winter Habitat Suitability Index Model.



S1: Food bonus variable from seismic or utility corridors
S2: Food variable available from percent shrub cover that is favorable for moose
S3: Proximity of food to cover variable with reward declining to 0 at 400 meters
S4: Cover variable based on stand canopy closure
S5: Cover variable based on stand height (m)
S6: Cover variable based on percent conifer in stand
S7: Cover variable bonus for increased stand complexity
HSI: Habitat suitability equation
CC: Carrying capacity equation

Figure 6: Calculation flowchart of the Chair in Forest Management and Policy Winter Habitat Suitability Index Model.

Table 1: Favourable browse species habitat suitability index values (x10) for tree species on site classes 1-2 and 3-4 with hardwood components of 0-50 and 51-100%, through development stages 1-5 and the initial area of each classification.

Classification	La		Sb		Pl		Bw		Sw		Fb		Aw	
	HIS	Area ha	HIS	Area ha	HIS	Area ha	HIS	Area ha	HIS	Area ha	HIS	Area ha	HIS	Area ha
Dev1 Scl 1-2 Hw% 51-100	4		6		7		10		10		10		10	
Dev2 Scl 1-2 Hw% 51-100	3		5		4		6		7		8		9	93
Dev3 Scl 1-2 Hw% 51-100	0		3		2		3		5		6		5	276
Dev4 Scl 1-2 Hw% 51-100	0		2		2		2		3		4		4	87
Dev5 Scl 1-2 Hw% 51-100	3		5		5		6		7		8		9	544
Dev1 Scl 1-2 Hw% 0-50	1		3		4	362	8		8		7	20	10	
Dev2 Scl 1-2 Hw% 0-50	1		3		2	1,797	5	30	4	27	4		7	
Dev3 Scl 1-2 Hw% 0-50	0		1		0	1,148	2	162	2	7	3		4	
Dev4 Scl 1-2 Hw% 0-50	0		0		0	2,966	1	13	2	485	2		3	
Dev5 Scl 1-2 Hw% 0-50	0		0		3		5		4	3	5		6	
Dev1 Scl 3-4 Hw% 51-100	2		4		5		6		9		8		9	22
Dev2 Scl 3-4 Hw% 51-100	2		3		3		4		5		5		6	11
Dev3 Scl 3-4 Hw% 51-100	1		2		1		1		3		5		4	4
Dev4 Scl 3-4 Hw% 51-100	0		0		1		0		3		3		3	6
Dev5 Scl 3-4 Hw% 51-100	1		3		4		3		5		6		6	8
Dev1 Scl 3-4 Hw% 0-50	1		3		3	73	4		5	6	6		7	
Dev2 Scl 3-4 Hw% 0-50	0		1	23	2	589	3	7	2		3		4	
Dev3 Scl 3-4 Hw% 0-50	0		0	18	0	85	0	19	1		2		3	
Dev4 Scl 3-4 Hw% 0-50	0		0	193	0	162	0		0	8	1		3	
Dev5 Scl 3-4 Hw% 0-50	0		0	2	0		0		3		4		5	

Dev = Development Stage
Scl = Site Classes
Hw% = Percent of Hardwood in Species Composition

Coniferous Development Stages
Dev 1 0-30 = Young
Dev 2 31-60 = Pole
Dev 3 61-100 = Immature
Dev 4 101-150 = Mature
Dev 5 >150 = Over Mature

Deciduous Development Stages
Dev 1 0-20 = Young
Dev 2 21-40 = Pole
Dev 3 41-60 = Immature
Dev 4 61-100 = Mature
Dev 5 >100 = Over Mature

La = *Larix laricina*
Sb = *Picea mariana*
Pl = *Pinus contorta*
Bw = *Betula papyrifera*
Sw = *Picea glauca*
Fb = *Abies balsamea*
Aw = *Populus tremuloides*
Pb = *Populus balsamifera*

corridors are permanent and seismic lines are temporary. A bonus value of 1.0 is given to any food cell one cell away from either a utility corridor or seismic line. The S2 food table was developed from a moose literature review that describes food density and preference by moose (Appendix 1). Lastly, S3 gives CFMP-WHSIM values related to the distance that food is from cover.

The values for S2 were developed for tree species endemic to the study area as they relate to food availability, quantity and their palatability for moose. S2 assigns a food HSI value to cells based on the queried cells' species compositions, site class, percent hardwood and development stage (Table 1). S2 values are at their maximum in young aspen stands, and are minimal in dense mature coniferous stands. The S3 variable is similar to the S2 variable in the WWHSIM and the same rationale regarding distance from cover applies here. However, this S3 variable has fixed values between distances from cover, i.e. 1.0 when food cells are 0-100 m from cover, 0.75 for 100-200, 0.50 for 200-300 and 0.25 for 300-400 m, and 0.0 for distances greater than 400 m.

Variables S4-S7 examine habitat characteristics that relate to cover for moose. S4 represents tree canopy closure and is derived from a stand's stocking value. S5 is derived from tree height. S6 is determined from the percentage of conifers in the stand, and finally, S7 is a bonus equal to 1.0 for stand areas that have a complex overstorey.

S4 is derived from stand stocking. The minimum of 6% (below which S4 = 0) was chosen for the same reasons as in the WWHSIM. This model uses 60% and above as the values where cover is considered optimum. We chose 60% because it was found in the literature as being the minimum starting value that provides reasonable snow interception, reduced windchills and thermal protection. For stocking values between 6 and 60%, we used linear interpolation to determine S4.

S5 is derived from tree height. The minimum value of 4.0 m (below which S5 = 0.0) was chosen because the literature review suggested that trees greater than 4 m high start to provide thermal protection. The maximum of S5 = 1.0 is reached for trees equal to and greater than 8.0 m. For tree heights between 4 and 8 m, we used linear interpolation to determine S5.

Variable S6 percent conifer has a minimum value of S6 = 0.25 when there are no softwoods present. 0.25 was chosen for no conifers because deciduous trees do reduce wind chills but provide little snow interception and thermal protection. When conifers compose 50% and greater of the species composition, the literature suggests that there are sufficient wind chill reductions, snow interceptions and thermal protection to warrant preferential use by moose. For conifer densities between 0.0 and 50%, we used linear interpolation to determine S6.

The S7 bonus for complex overstories is awarded to cells that reside in stands that have complex overstories and/or are multistoried. Complex overstories are tree canopies that have a vertically uneven canopy or are multistoried in the canopy, an example being a mature white spruce and white poplar stand, where the poplar is overtopping the white spruce giving two distinct canopies. The bonus was awarded for these types of stands because of their greater ability to provide moose with lower snow depths, greater thermal protection and reduced wind chill factors.

The CFMP-WHSIM uses the same calculations for determining EUF, EUWH and the final carrying capacity value (0.025 animals/ha) as WWHSIM (Equation 3).

Higgelke Habitat Model

The Higgelke Habitat Model (HHM) was designed for the Aulneau Peninsula in Ontario. It provides an estimate of the number of animals/km^2 at carrying capacity at three times in the year: summer, early-winter and late-winter (Higgelke 1994). This model was modified to calculate only early-winter carrying capacity values for this project. The model is divided into two parts. Part one's components are: classification of subdominance in stands, covertype identification, and the calculation of food. Part two's components are: use of early-winter cover index curves, and adjustment of early-winter browse and cover values based on edge effects. Lastly, the estimated food values are summed and a calculation of early-winter carrying capacity is made (Figure 7).

Equation 3

$$\text{HSI Food} = ((S2 \cdot S3)^{0.5} + S1)$$
$$\text{HSI Cover} = ((S4 \cdot S5 \cdot S6)^{0.33} + S7)$$
$$\text{Effective Units of Food} = \text{Min}[(\text{HSI Food}), (\text{HSI Cover} \cdot 65\% / 35\%)]$$
$$\text{Effective Units of Winter Habitat} = \text{Effective Units of Food}/0.65$$
$$\text{Carrying Capacity} = \text{Effective Units of Winter Habitat} \cdot 0.025 \text{ moose/ha}$$

where:
S1 = Bonus for Cells adjacent to Utility Corridors or Seismic Lines
S2 = Food Density and Preference
S3 = Distance of Food from Cover (m)
S4 = Percent Tree Canopy Closure
S5 = Tree Height (m)
S6 = Percent Conifer in Stand
S7 = Bonus for Cells in Complex Overstories

Note: 0.025 moose/ha is the known value for moose in the study area

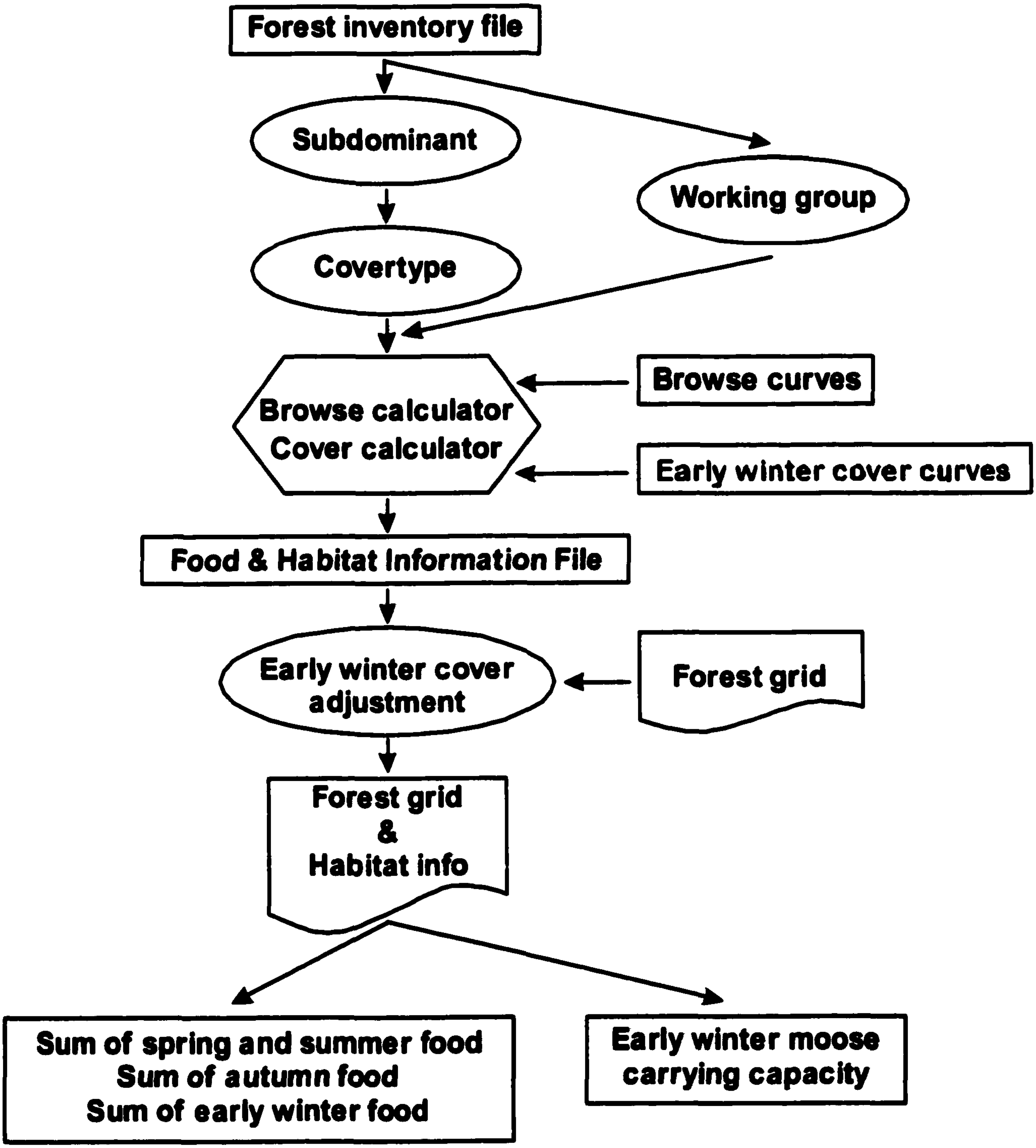


Figure 7: Calculation flowchart for the Higgelke Habitat Model.

Table 2: Covertype categories used for the Alberta study area.

Covertype Group	Value
Pines	1
Pines with Hardwood	2
Black Spruce	3
Black Spruce with Hardwood	4
Black Spruce Site Class 4	5
White Spruce	6
White Spruce with Hardwood	7
Balsam Fir with Softwood	8
Balsam Fir with Hardwood	9
Poplar with Softwood	10
Poplar with Hardwood	11
Balsam Poplar with Softwood	10
Balsam Poplar with Hardwood	11
Birch with Softwood	12
Birch with Hardwood	13
All Other	17

Part one's subdominance classification examines a stand's species composition, exclusive of the working group, to determine whether the stand is hardwood-dominated or softwood-dominated. If a stand has a species composition of $Aw_5Sb_2B_1Bw_1Sw_1$ for example , it would have a subdominance classification for softwood because, exclusive of the Aw_5 working group, the remaining species composition is softwood-dominated ($Sb_2+B_1+Sw_1=4$ which is greater than $Bw_1=1$). Conversely, a species composition of $Aw_5Bw_3Sw_1Pb_1$ produces a hardwood subdominance designation, since $Bw_3+Pb_1=4$ versus $Sw_1=1$.

Part one's covertype classification assigns a covertype value to stands so that they become more meaningful with respect to the calculation of browse and cover index values for moose habitat requirements. Stands were aggregated into groups that I felt appear to moose as similar habitats even though their species compositions may vary. Fourteen unique covertypes were created for this study.

The value assigned to each cover type is used for tracking purposes in the model see Table 2.

Food calculations for part one of Higgelke's model were developed from browse curves based on a stand's potential to produce browse (Appendix 2, Figures A2-4 to A2-13) (Higgelke 1994). These curves were developed from a literature review and were examined by professionals in Alberta to see if the amounts of browse estimated were reasonable. Browse values for stands that were not at either 10% or 100% stocking were derived from linear interpolation between the two extremes.

Part two's early-winter cover indexes were determined from the stand's working group and subdominance via cover index curves (Appendix 2, Figures A2-14 to A2-19). The values obtained are an indication of a stand's early-winter cover potential. Stands that contain a mix of conifers and non-conifers species at 50% stocking provide the best early-winter habitat (Appendix 1, Early-Winter Habitat).

The adjustment for early winter food and cover is developed by using a roving 3*3 window of 100 metre cells across the area of interest. Early-winter food values were adjusted by multiplying it by the highest cover index amongst its eight neighbours and itself. Similarly, cover values were adjusted by multiplying each cell's value by the highest adjacent food value including its own. This was an attempt by Higgelke (1994) to capture the ecotone effect found between stands, which moose arre known to use preferentially.

The adjusted food values for early-winter are summed up and the calculation for moose early-winter carrying capacity completed according to Equation 4. The

Equation 4

$$MCC = ((EWF \bullet 0.6) / (4 \bullet 60)) / MU\_Area$$

where:
MCC = Early Winter Moose Carrying Capacity (moose/km^2)
EWF = Total Early Winter Food (kg)
0.6 = Early Winter Browsing Factor
4 = 4 kg of browse/day for a moose
60 = 60 days in the early winter time period
Mu_Area = Management Unit Area (km^2)

early-winter browsing factor represents the inability of moose to find and eat all the theoretically edible browse on a site. Higgelke (1994) used 4 kg/ha as the amount of browse required per day for a cow moose to meet its energy needs. It was not altered because my literature review found it to be a reasonable estimate (Appendix 1). Sixty days was chosen as an average amount of time during which moose are normally associated with early-winter habitat; in reality this value lengthens and shortens from year to year depending on climate variability (Appendix 1).

Duinker Population Model

The Duinker Population Model (DPM) (Duinker *et al.* 1996) was created to determine the impact of different timber-harvest and hunting regimes on moose in the Lake Abitibi Model Forest in Northeastern Ontario. The model inputs are food values determined by the HHM food curves and other inputs that describe moose bio-energetics.

The DPM has three major elements: mortality; reproduction, and weight change, all of which are related to the amount of food determined from the browse curves. In the model, feeding occurs in spring/summer, autumn and early winter, but there is no food available in late winter since it is thought that moose cannibalize body reserves during this period of inactivity and heat-stress avoidance (Figure 8).

The moose population is tracked over time and is divided into cohorts based on sex (male, female) and age (11 classes representing ages 0-10 years). For all cohorts, two variables are tracked: the number of animals and the average weight per animal. The model also divides up the year into four segments: spring/summer (April 15 - September 14), fall (September 15 - December 14), early-winter (December 15 - February 14) and late-winter (February 15 - April 14).

The equations and starting values used to predict the number of animals in each cohort and their weights are described below while the equations and equation variable descriptions reside at Appendix 2 and Tables A2-23, A2-24, and A2-25.

Growth

The growth of animals in the DPM is simulated through changes in weight for each cohort. This is accomplished by converting the HHM food values into energy. A change in weight is calculated for each cohort in each season by distributing the available food supply for each season amongst all cohorts. Total food supply is determined by the browse curves for each harvest scenario and time slice of ten years in the 200-year simulation. Since the enumeration of moose in the DPM occurs annually but the total food supply is calculated at ten-year intervals, it is assumed that the abundance of food is the same for all ten years. The annual food

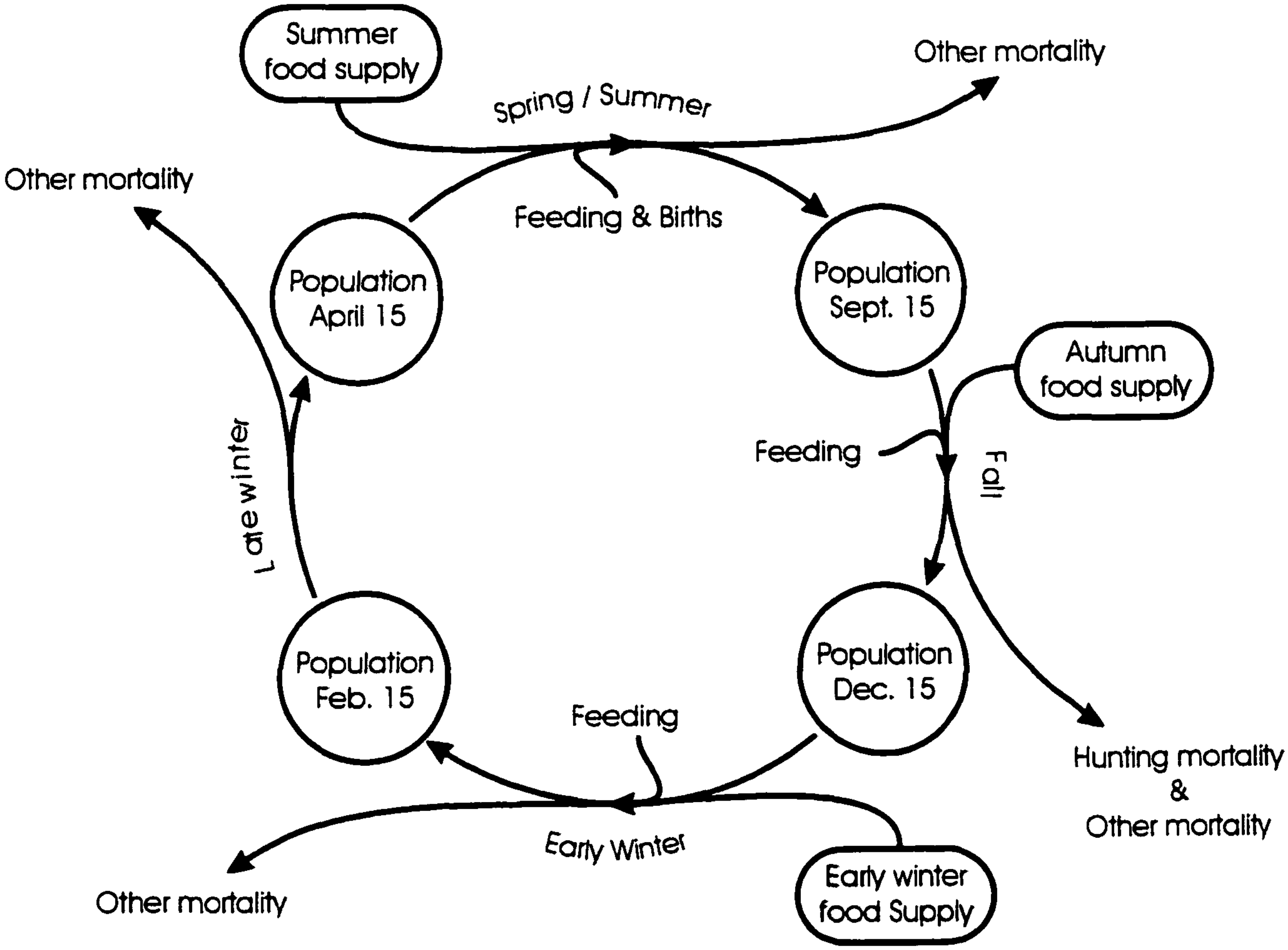


Figure 8: Input - output schematic of the Duinker Population Model.

Table 3: Moose weights derived from weight regression equations developed by Franzmann *et al.* (1978) and Schwartz *et al.* (1987) cited in Schwartz (1998).

Season	**Classification**	**Days**	**Estimated Maximum Body Weight kg**		**Time Years**	**Source of Weights**
			Male	**Female**		
15-Apr	Birth	0	15	15	0.00	Schwartz 1998
15-Sep	Calf	150	160	145	0.40	Franzmann *et al.* 1978[1]
15-Dec	Calf	240	150	140	0.66	"
15-Feb	Calf	300	150	140	0.83	"
Yearly Average			119	110		
15-Apr	Yearling	360	160	150	1.00	Franzmann *et al.* 1978[1]
15-Sep	Yearling	510	365	330	1.40	Schwartz *et al.* 1987[2]
15-Dec	Yearling	600	340	359	1.66	"
15-Feb	Yearling	660	422	376	1.83	"
Yearly Average			322	304		
15-Apr	Adult	720	398	337	2.00	"
15-Sep	Adult	870	487	420	2.40	"
15-Dec	Adult	960	434	434	2.66	"
15-Feb	Adult	1020	524	442	2.83	"
Yearly Average			461	408		
15-Apr	Adult	1080	484	384	3.00	"
15-Sep	Adult	1230	566	463	3.40	"
15-Dec	Adult	1320	494	470	3.66	"
15-Feb	Adult	1380	590	473	3.83	"
Yearly Average			534	447		
15-Apr	Adult	1440	539	406	4.00	"
15-Sep	Adult	1590	618	483	4.40	"
15-Dec	Adult	1680	533	486	4.66	"
15-Feb	Adult	1740	633	488	4.83	"
Yearly Average			581	466		
15-Apr	Old Adult	1800	575	416	5.00	"
15-Sep	Old Adult	1950	651	492	5.40	"
15-Dec	Old Adult	2040	559	494	5.66	"
15-Feb	Old Adult	2100	661	495	5.83	"
Yearly Average			612	474		
15-Apr	Old Adult	2160	598	421	6.00	"
15-Sep	Old Adult	2310	673	497	6.40	"
15-Dec	Old Adult	2400	575	498	6.66	"
15-Feb	Old Adult	2460	679	498	6.83	"
Yearly Average			631	478		

[1] as cited in figure 69, page 168 of Schwartz 1998

[2] as cited in figure 70, page 169 of Schwartz 1998

Rut weight loss of 15% applied at December 15 as cited on page 169 of Schwartz 1998
12 to 19 % weight loss Franzmann *et al.* 1978, Schwartz *et al.* 1987

Birth loss of 15% applied at April 15, from Schwartz 1998

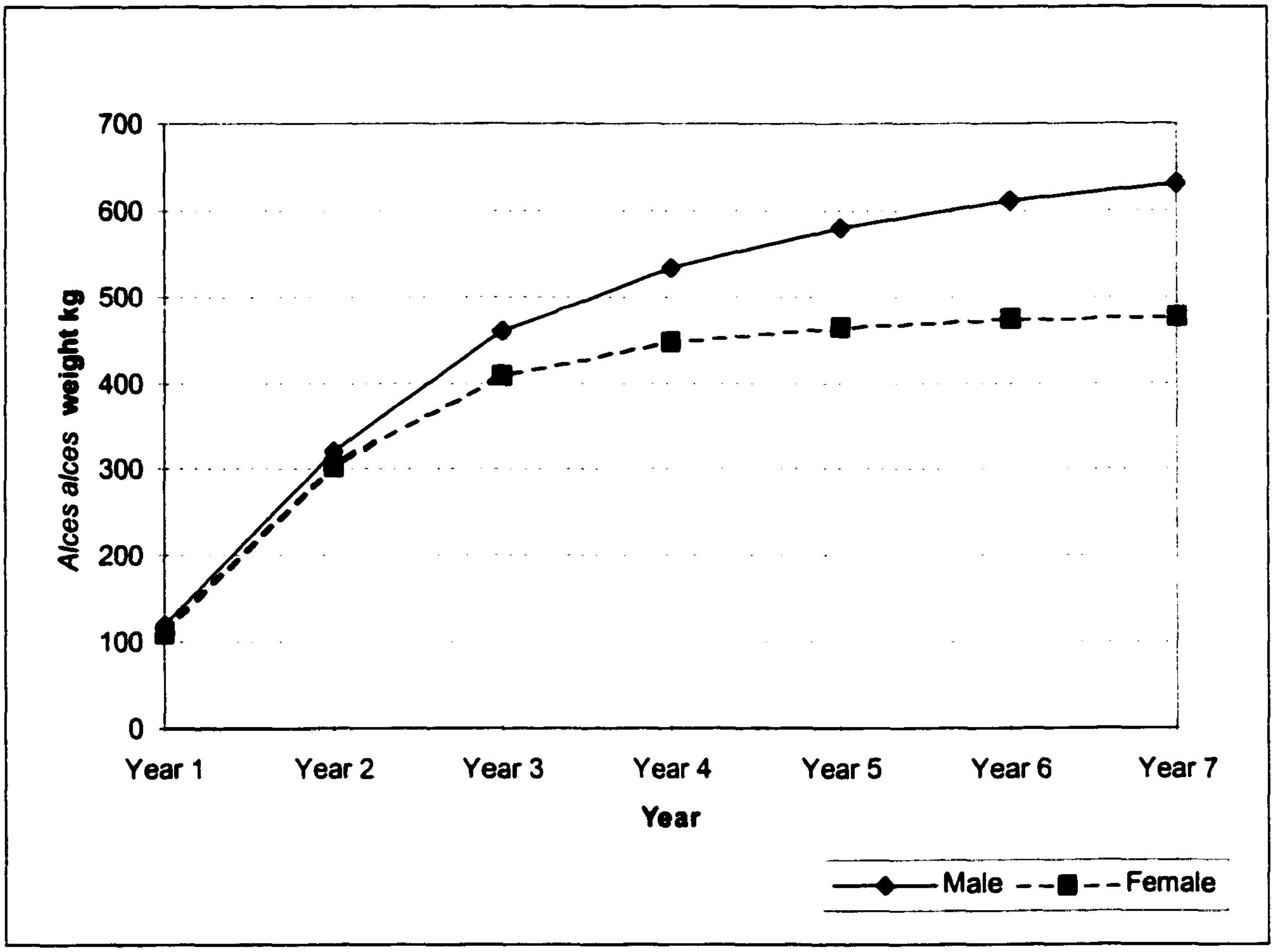


Figure 9: Moose estimated average yearly weights by sex derived from Table 3.

supply is converted into metabolizable energy for each season (Appendix 2, Equation 5). Total available energy is distributed among all cohorts for each season (Appendix 2, Equation 6). The result is the energy available to each animal in each cohort. This value is then used to calculate the average weight gained or lost for each cohort.

The starting weights and maximum weights for each sex of moose was based on expert knowledge and work done by Franzmann *et al.* (1978) and Schwartz *et al.* (1987) as cited in Schwartz (1998) (Table 3, Figure 9). The yearly average results of their equations were used as guidelines for estimating the maximum weights of both sexes. The maximum weights were kept below estimated maximums, since Alaskan moose are thought to be larger than those found in the study area.

The first life requisite for each cohort of animals is the metabolizable energy needed for maintenance throughout the year (Appendix 2, Equation 7). The surplus or deficit of energy is calculated by removing the energy required for maintenance from available energy (Appendix 2, Equation 8). If the value is positive, a weight gain occurs for each animal in that cohort; if negative, each animal loses weight (Appendix 2, Equation 9). A maximum body weight is assigned to each cohort to prevent the model from calculating biologically impossible weight gains when food is plentiful.

Starvation Mortality

Mortality from starvation is calculated in all four seasons for all cohorts. Starvation mortality occurs when the average weight for a cohort is compared to a minimum weight below which starvation mortality occurs. To determine the number of individuals that would starve, a normal distribution of weights is produced along with an assumed standard deviation expressed as a proportion of the mean weight. It is assumed that the weights of individuals is normally distributed and that the proportion of animals with weights below the starvation threshold weight are the ones that die. The post-starvation mean weight for the cohort is then recalculated to reflect properly the loss of the individuals that starved.

Other Mortality

Other mortality (exclusive of starvation and hunting) occurs in all seasons and is set as an initial starting parameter (Appendix 2, Equation 10).

Hunting Mortality

Hunting mortality is determined in the fall of each year. Firstly, the DPM calculates the level of harvest for the area being modelled. This procedure follows the Heydon *et al.* (1992) tag allocation process used in Ontario. Initially the DPM calculates the target harvest rate for cows. This is done by comparing the total density of animals over the area of interest and the desired animal density input by a user. The created ratio is used to determine the overall harvest rate for cows. The relationship between that ratio and the cow harvest rate is defined by the user as a series of points, between which the model interpolates linearly to define the entire curve (Appendix 2, Figure 25). The cow harvest rate is thus defined (Appendix 2, Equation 11). The number of bulls and calves harvested are a function of the user-supplied bull-cow and calf-cow harvest ratios (Appendix 2, Equations 12, 13). Now that the number of cows, bulls and calves to be harvested is known, those harvest values can be distributed over the area of interest as a function of abundance and hunting pressure.

Hunting pressure for the area of interest is assumed to be related to road access and time since timber harvest. It is assumed that the more recent the cut is, the greater the access and the greater the probability that an animal will be harvested. To determine this access criterion, the model uses the Access Factor * Forest Area divided by the Forest Area (Appendix 2, Equation 14) as a surrogate. The access coefficient is a user-supplied factor between 0 and 1 that weights each of the forested age-classes. The 0-10 year age-class has the highest value while the lowest is the 31-40 year age-class. The DPM assumes that areas with age classes greater than 40 years will not contribute significantly to access (Appendix 2, Figure 26).

The relative fall hunting pressure is calculated as a function of access, which is user-defined as a series of points between which the model interpolates linearly to define the entire curve (Appendix 2, Figure 27). Lastly, the model determines the hunting mortality for cows, bulls and calves (Appendix 2, Equations 14, 15), and the total harvest is constrained so as not to exceed the total number of available animals in each cohort.

Births

The number of calves born into the population is calculated by the DPM yearly during the spring season. The number of calves born in each cohort is the product of the number of cows in the population times the cohort's average birth rate (Appendix 2 Equation 16). The birth rate for each cohort's cows is a function of the average cow's weight in each cohort as determined last fall. The relationship between birth rate and weight is defined as a set of user-defined birth-rate-to-weight points, between which the model interpolates linearly to define the entire curve. Each calf born in the model is assigned an initial starting weight and sex (Appendix 2 Equation 17, 18).

METHODS

Below I illustrate the processes used in getting projected forest inventory data to produce carrying-capacity values for moose from the four moose carrying-capacity models. The approach taken in this study was to:

(1) Use a stand-based forest projection model to create spatially discrete inventory projections for a GIS.

(2) Apply the four moose carrying capacity models.

(3) Compare and analyse the results of the four moose carrying capacity models.

Forest Projection Model

The forest inventory data sets for this study were developed using a forest projection model called Harvest Schedule Generator (HSG) Version 3.0 (Gooding 1995). Forest inventory data, appropriate yield curves (Appendix 3), succession or state table (Appendix 5) and long-term sustainable forest management scenarios for no timber harvesting, basic timber harvesting and high timber harvesting were provided to HSG 3.0 for the forest development simulation. The starting forest inventory data (Figure 10) and management scenarios were acquired from MWFP. A succession or state table was developed to describe how HSG was to evolve stands once they were harvested or they started to break up and decline in old age. Volume curves for each species found in the study area were created from existing age/volume tables, but silviculturally managed age/volume curves for site classes M1-M3 were enhancements on site classes 1-3 by approximately 1.5 times. The enhanced volume curves reflect what MWFP personnel believe the forest can

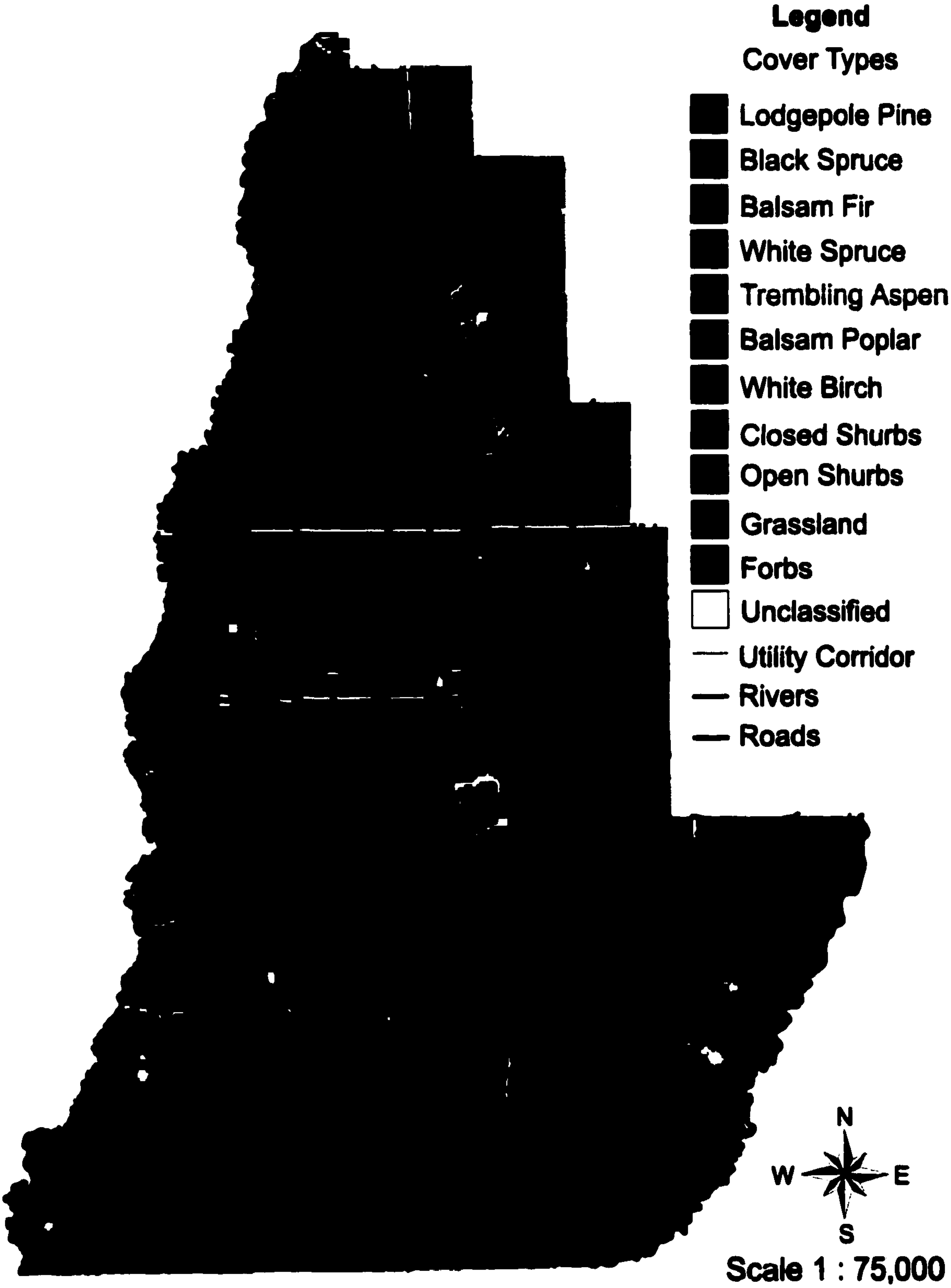


Figure 10: Dominant forest cover types for MWFP's study license area of W90008.

produce given reasonable management regimes. The volume curves and state table for the forest growth simulations were created in consultation with:

Les Walsh, Silviculture Forester for Millar Western Forest Products, Whitecourt, Alberta.
Laird Van Damme, Silvicultural Specialist, KBM Forest Consultants, Thunder Bay, Ontario.
Dr. Peter Duinker, Thesis Supervisor, Lakehead University, Thunder Bay, Ontario.
Doug Walker, Forest Modelling Specialist, Pearson Timberline, Edmonton, Alberta.

The forest simulations developed using HSG consisted of three management scenarios: the No, Basic and High Harvest Scenarios (NHS, BHS and HHS). The NHS was to act as a control with no timber harvesting taking place; BHS was implemented to follow the present operating strategy and known age/volume curves used by MWFP; HHS was developed to mimic the expected volume increases from new silvicultural treatments being employed by MWFP on site classes 1-3.

The management scenarios were run in the HSG simulation for 200 years and inventory files were created at every 10-year time step. Several simulations were required until a 200-year sustainable harvest level was identified for the BHS and the HHS. I identified a long-run sustained yield (LRSY) of 27,500 m^3/yr for the BHS and 32,000 m^3/yr for the HHS for 200 years. The NHS did not require the identification of a LRSY, since no timber was harvested, but natural succession was examined to ensure that it was operating as expected.

The resulting 21 data sets for each harvesting scenario individually constitute a new forest inventory containing species composition, age, height, stocking and volumes, at every ten-year time step. The stand projections were linked back to the forest vector coverage, and stand boundaries remained constant throughout the analysis.

Preliminary Data Manipulation

The suite of models used in this project utilize data from the forest simulator HSG. The HSG data file contains several variables only some of which were extracted for use. The extracted variables were unique stand identifier, tree species, tree species stocking, site class and age. Since HSG does not contain a height variable, tree height was calculated using equations. Unique equations to determine height from age were developed for White Spruce (*Picea glauca* (Moench) Voss), Black Spruce - Balsam Fir (*Picea mariana* (Mill.) B.S.P. - *Abies balsamea* (L.) Mill.), Aspen - Balsam Poplar - Birch (*Populus tremuloides* Michx. - *Populus balsamifera* L. - *Betula papyrifera* Marsh.), and Lodgepole Pine - Jack Pine (*Pinus contorta* Dougl. - *Pinus banksiana* Lamb.) (Figure 11). The results were incorporated into the database used for model calculations.

Weldwood Winter Habitat Suitability Index Model

The WWHSIM was altered slightly to fit conditions of the study area. The variable moose/ha was increased from Bonar *et al.* moose/ha value of 0.016 to 0.025 moose/ha which better represents the study area's moose density. The input data for this model were the projected forest inventories. From the inventories, each model component S1-S6 was calculated. Variables S1, S4 and S5 were simple database manipulations, while S2, S3, and S6 contained a two-dimensional spatial calculation. Finally, the determination of carrying capacity was a numeric calculation (Appendix 10). There were two outputs: the carrying capacity (animals/

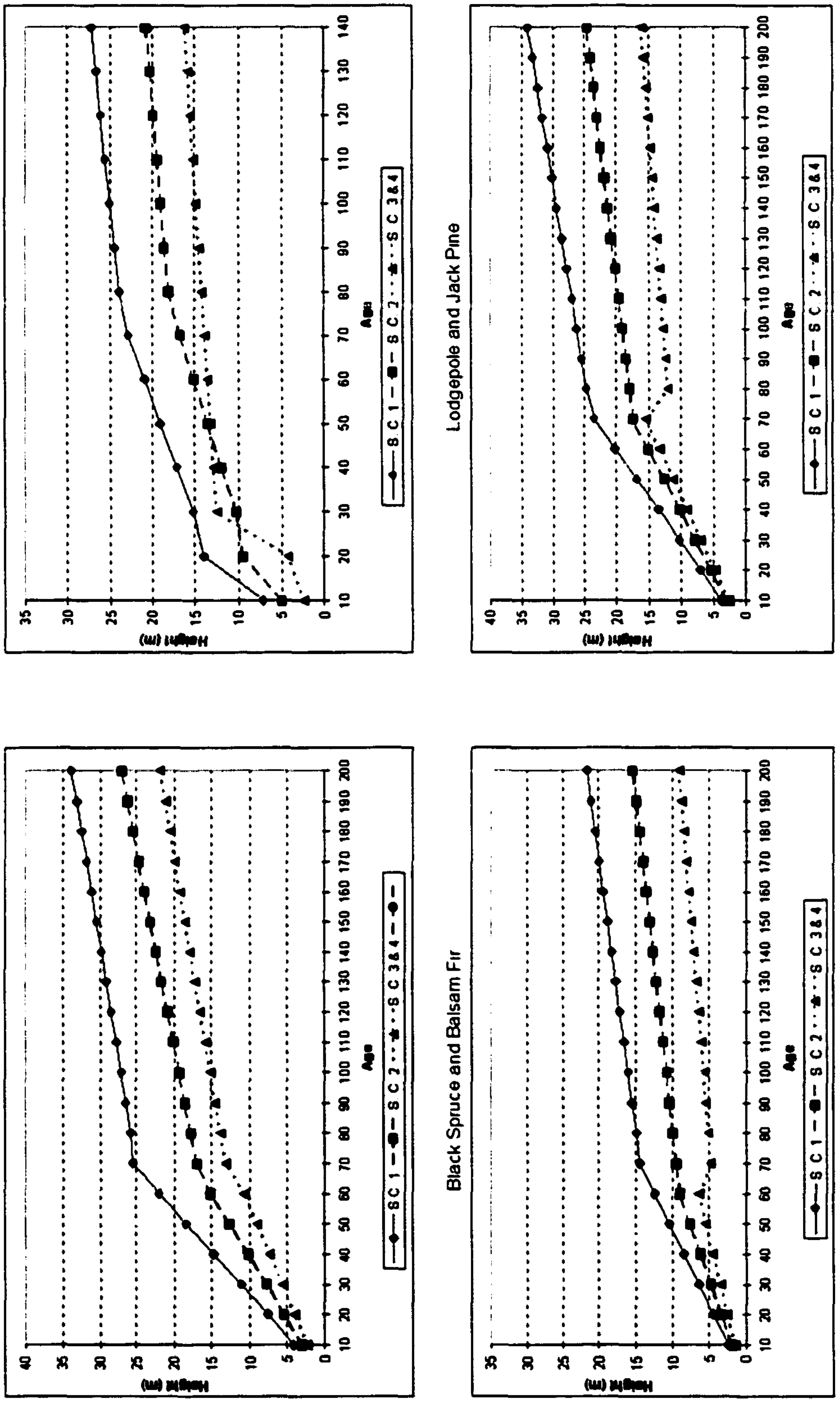


Figure 11: Tree height determination curves used for all models.

km^2) for the landscape, and maps which contain food and cover values for each 200x200 m cell across the landscape for each 10-year time step.

Chair in Forest Management and Policy Winter Habitat Suitability Index Model

The CFMP-WHSIM was designed as an improvement on the WWHSIM. The addition of a food bonus for seismic lines was thought to be important because of their prevalence in the study area and their ability to produce browse. Further, the use of an available browse table based on development stage, site index and species better describes the potential browse available in the landscape. The last variable S7 was added to reflect the importance and frequency with which complex stand overstories are found in the study area. It was felt by the modelling team and found in the literature that complex overstories provided better cover with higher understory food potential than single-story stands.

The input data for this model were the projected forest inventories. From the inventories, variables S2, S4, S5, S6 and S7 were database calculations, while S1 and S3 contained a two-dimensional spatial calculation. The final determination of carrying-capacity was a numeric calculation (Appendix 11). There were two outputs: the carrying-capacity (animals/km^2) for the landscape, and maps which contain food and cover values for each 200x200 m cell across the landscape for each 10-year time step.

Higgelke Habitat Model

The HHM was modified for this project to project only carrying capacity values for early-winter. The inputs for the HHM were the projected forest inventories. To identify covertypes in the HHM, it was first necessary to exclude stands with working groups that are 80% or more of the species composition, since their covertype is their working group. The remaining stands with mixed compositions were analysed to determine if the stand was dominated by hardwood or softwood. The calculation procedure for subdominance is the same as that of Higgelke (1994) and Duinker *et al.* (1996) except that this adaptation of the model has some different covertype categories which are more representative of the study area.

The general shapes of the browse curves were developed from a literature review, which indicates that at time 0 little browse is available, but between 5-20 years after a disturbance the amount of available browse rises, crests, then falls to a lower level where it stays until the stand starts to breakup. Once break-up begins, the amount of available browse starts to rise, but the rise is significantly lower than the first increase. The general browse curve shape was applied to all browse curves, but the maximums and minimums vary by species e.g. poplar stands have higher maximums and minimums than does a black spruce stand (Appendix 2 Figures A2-4 to A2-13).

The browse curve minimums and maximums were created from several field studies conducted in Alberta which examined the amount of browse available on the landscape in different forest types and at different ages (Table 4). Generally, the maximum values used for this study were similar to Stelfox (1988) and Willoughby and Downing (1995). The minimum values for mature stands were also extrapolated from Stelfox (1988) as well as Westworth (1981), Brusnyk and Westworth (1988), Downing (1995), and Willoughby and Downing (1995). The age and duration of maximum browse production was developed from Joyal (1987),

Table 4: Sources of information for browse curves used in the Higgelke Habitat and Duinker Population Models. Values are in kilograms of browse after drying.

Season	Stand Type	Years since clear cutting					Source
		5	17	26	32	Mature	
Winter	Spruce	392[1]	834[1]	782[1]	870[1]	236.9[1]	Stelfox 1988
Winter	Pine			1107[1]	1081[1]		
Winter	Mixedwood			400[1]	247[1]		
		Young Clearcut	Mature Adj. Forest	Mature Forest			
Winter	Aspen	194[2]	20[2]	27[2]			Brusnyk and Westworth 1988
		Clearcut	Mature				
Winter	Mixedwood	258	21				Usher 1978
		Stand Ages (Closed Canopy)					
		12	30	60			
Winter	Aspen	38[3]	27[3]	13[3]			Westworth 1981
		Closed canopy mature stands					
Summer	White Birch	286[4]					Willoughby and Downing 1995
Summer	Aspen	260[4]					
		Closed canopy mature stands					
Winter	Aspen	156[5]					Downing 1995
Summer	Aspen	490[5]					
Notes:							
In aspen, browse in clearcuts was 12 times the adjacent uncut aspen forest							Usher 1978
Browse kg/ha continues to increase and reaches a maximum 10-15 years after a cut							Timmerman 1990
Forage production peaks 5-20 years after timber harvesting							Crête 1988
Maximum browse production occurs 5-15 years after timber harvesting							Joyal 1987

[1] From Table 2, values were averaged and coverted to dry weights, Stelfox 1988

[2] From Table 6, Brusnyk and Westworth 1988

[3] From Table 3 Westworth 1981

[4] From Table 4 Willoughby and Downing 1995

[5] From Table 1, values were converted from pounds/acre to kg/ha

Crête (1988) and Timmermann (1990). The estimated browse curves were compared against each other and the values were adjusted so that they were in proportion to each other based on published literature values and common sense.

The early-winter cover index curves for this study are similar to those of Higgelke (1994). The curves were adjusted slightly to reflect some of the differences found between the Aulneau Peninsula and the study area of this project. A notable example is the high occurrence of multistoried white spruce stands which provide better cover and food than single storied white spruce stands. Therefore, I adjusted certain early-winter cover index curves upwards to reflect that condition. The number of days used in the calculation for early-winter food was based on 60 days compared to 105 days used by Higgelke (1994). The period was shortened to better reflect the climate and animal movement patterns in the study area.

Three data sets resulted. The first is the early-winter carrying-capacity values for moose for every 10-year time step and harvest scenario. The second consists of the food and cover raster maps, while the third is browse food values in kg/ha and areas in the four age classes used for access determination in the data sets used in the DPM.

Duinker Population Model

The data sets used for this model were derived from the same browse and early-winter cover index curves calculated for the HHM. This model requires spring/summer, autumn and early-winter food values, early-winter cover indexes, and total areas in ages classes 0-10, 11-20, 21-30 and 31-40 for each time step and scenario.

The starting parameters used in the DPM (Appendix 2, Table 2) required slight alterations. However, the maximum weights and starting densities (animals/km^2) by sex and age class were increased. The maximum weights were increased to reflect a larger average animal size found in the study area (Table 5). Similarly, the expected animals/km^2 was raised from the Lake Abitibi Model Forest simulation of 0.27 animals/km^2 to this study's 2.5 animals/km^2 since that value better represents the potential moose density found in the study area (Todd 1996). The starting densities (animals/km^2) for each sex and age class are adjusted averages that represent the field values found in the study area from three aerial surveys (Table 6). Finally, the

Table 5: Maximum weight differences between the Lake Abitibi Model Forest simulation and this study using the Duinker Population Model.

	Males				**Females**			
Age	**Calf**	**Yearling**	**Mature**	**Old**	**Calf**	**Yearling**	**Mature**	**Old**
Lake Abitibi Model Forest	170	300	450	485	160	250	400	445
This Study	180	360	550	600	180	300	420	460

Table 6: Determination and starting densities by sex and age class from aerial surveys conducted by the Alberta Environmental Protection Agency in 1975, 1982 and 1988 over study area.

Date	**Density**	**Cows**	**Bulls**	**Calves**	**Sum**
1975	0.70	100	49	55	
1982	0.85	100	23	55	
1988	0.72	100	18	47	
Mean	0.76	100	30	52.3	
Ratio		1.00	0.30	0.52	1.82
Survey Mean		0.76	0.228	0.397	1
Coversion		0.76/1.82	0.228/1.82	0.397/1.82	
Animals/km^2		0.417	0.125	0.218	0.760

Starting animals/km^2 by sex and age class.

Males				**Females**				**Sum**
Calf	**Yearling**	**Mature**	**Old**	**Calf**	**Yearling**	**Mature**	**Old**	**Animals/km^2**
0.109	0.0417	0.0417	0.0417	0.109	0.139	0.139	0.139	0.7601

cow, bull and calf harvest rates are the same as those used for the Lake Abitibi Model Forest simulation (Table 7).

The resulting data sets contain information for each year, season and scenario of the simulation with respect to: animals/km^2 by sex and age class, mortality by sex and age class, weight by sex and age class, and sport harvest taken by sex and age class.

Table 7: Harvest densities for cows, bulls and calves.

Cow Harvest Density Curve Pairs	
Actual Density / Target Density	**Cow Harvest Density**
0	0
0.25	0.02
0.5	0.04
0.75	0.06
1	0.085

Harvest Ratio to 1 Cow	
Bulls to Cow	3.5
Calf to Cow	1.67

RESULTS AND DISCUSSION

Weldwood Winter Habitat Suitability Index Model

Results

The starting results of the simulation in 1996 are 1.912 moose/km^2 for all harvest scenarios. The finishing values are 0.250, 0.359 and 0.634 moose/km^2 for the HHS, BHS and NHS respectively. Generally, the number of moose/km^2 for all scenarios declines from 1996 to 2106. The rate of decline is highest in the HHS, then BHS, and finally the NHS. The minimum values of 0.225, 0.301 and 0.604 moose/km^2 for the HHS, BHS and NHS are reached in 2116, 2166 and 2116 respectively. Over the simulation there are 86.9, 81.2 and 66.8% decreases in moose/km^2 for the HHS, BHS and NHS respectively. After the minimum values are reached, the numbers remain stable between that time and the end of the simulation in 2196. The model exhibits no unique changes through time other than the steady decline of values from the outset (Figure 12, Table 8).

Discussion

In the WWHSIM, the age classes change from a predominantly old forest to a young forest in both the HHS and BHS resulting in the rapid decline of moose/km^2. The decline is tied to the increase in stand stocking values because sensitivity analysis on stand stocking displayed that moose carrying capacity values recovered i.e., rise when stand stocking was reduced by 25 and 50%.

The source of this impact i.e., increased stand stocking, originates in the HSG state table. For HSG it was decided that new stands would have high stocking values i.e. 0.8, 0.9 and 1.0. Those high stocking values had the effect of depressing

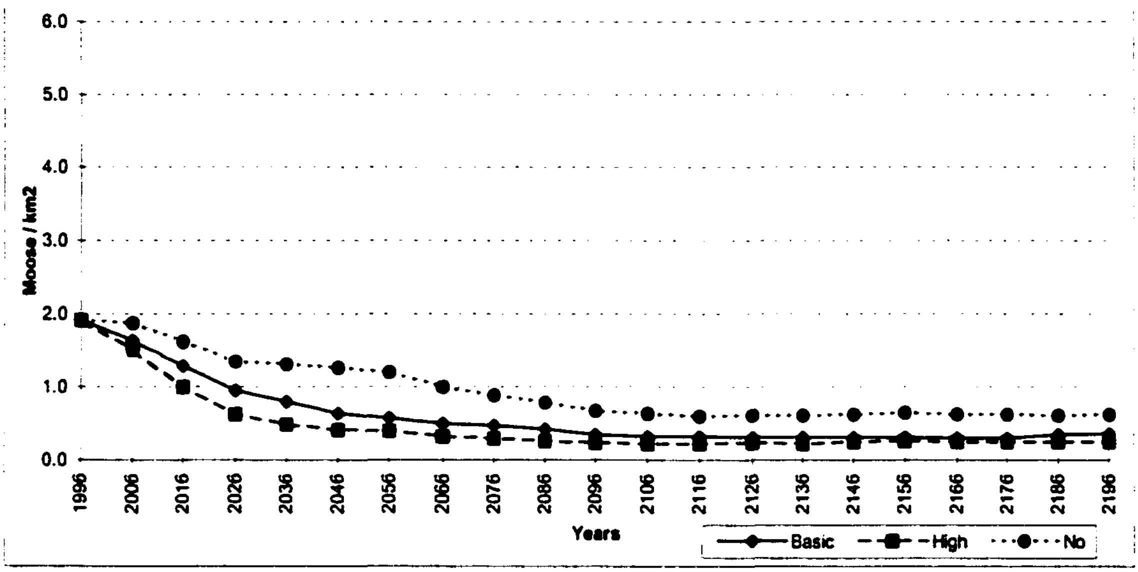


Figure 12: Weldwood Winter Habitat Suitability Index Model results for the High, Basic and No harvest scenarios.

Table 8: Weldwood Winter Habitat Suitability Index Model results for the High, Basic and No harvest scenarios.

Year	Basic	High	No
1996	1.912	1.912	1.912
2006	1.630	1.518	1.869
2016	1.291	1.009	1.616
2026	0.960	0.627	1.352
2036	0.808	0.490	1.322
2046	0.636	0.413	1.266
2056	0.577	0.397	1.204
2066	0.507	0.320	0.998
2076	0.474	0.295	0.894
2086	0.427	0.261	0.789
2096	0.354	0.237	0.675
2106	0.331	0.227	0.644
2116	0.328	0.225	0.604
2126	0.314	0.238	0.610
2136	0.314	0.226	0.616
2146	0.316	0.248	0.632
2156	0.308	0.259	0.654
2166	0.301	0.255	0.632
2176	0.302	0.256	0.625
2186	0.352	0.250	0.621
2196	0.359	0.250	0.634

Minimum			
1996	1.912	1.912	1.912
2116		0.225	0.604
2166	0.301		
% Change	-84.261	-88.226	-68.431

Overall Change from 1996 to 2196			
% Change	-81.243	-86.939	-66.871

the model's moose carrying capacity values because shrub stocking was determined from stand stocking. Thus high overstorey stocking values meant low food values, therefore low carrying capacity values. In reality, even highly stocked young pine stands still have a large amount of browse available to moose until the canopies close. On average it is not until the stand reaches age 15 to 25 years that the deciduous plant species decline significantly unless the area is sprayed with a herbicide.

The explanation for the decline is further supported in the result that the NHS shows a decline in moose carrying capacity numbers as well. The major change is that old stands are replaced by younger stands that have higher stocking values from HSG and subsequently lower food HSI values which ultimately depress the model's outputs.

The decline in carrying capacity values is similar to the decline in HSI cover values, which for many cells change from 1.0 to 0.0 for all three scenarios (Figure 13). A similar trend is also observed in the food HSI values; however, the conversion there is mainly from HSI values of 0.6 to 0.0 for the BHS and HHS, while in the NHS they go mainly from 0.6 to 0.1 (Figure 14). The difference in food HSI values between the two harvesting scenarios HSI = 0 and the control HSI = 0.1 is why the control scenario's moose carrying capacity values declines slower and remain above the BHS and HHS carrying capacity values over the simulation.

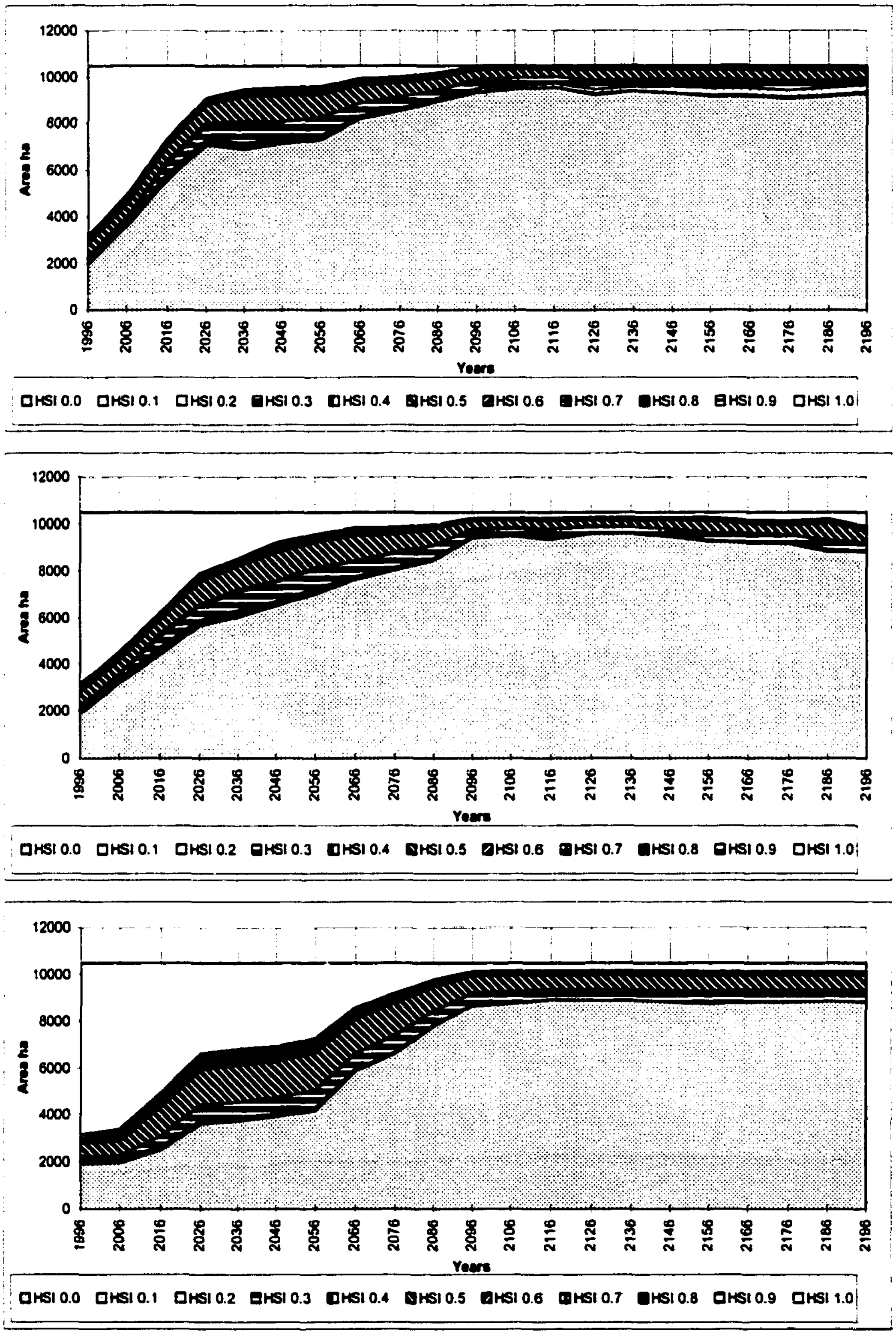


Figure 13: Weldwood Winter Habitat Suitability Index Model cover HSI results for the High, Basic and No harvest scenarios.

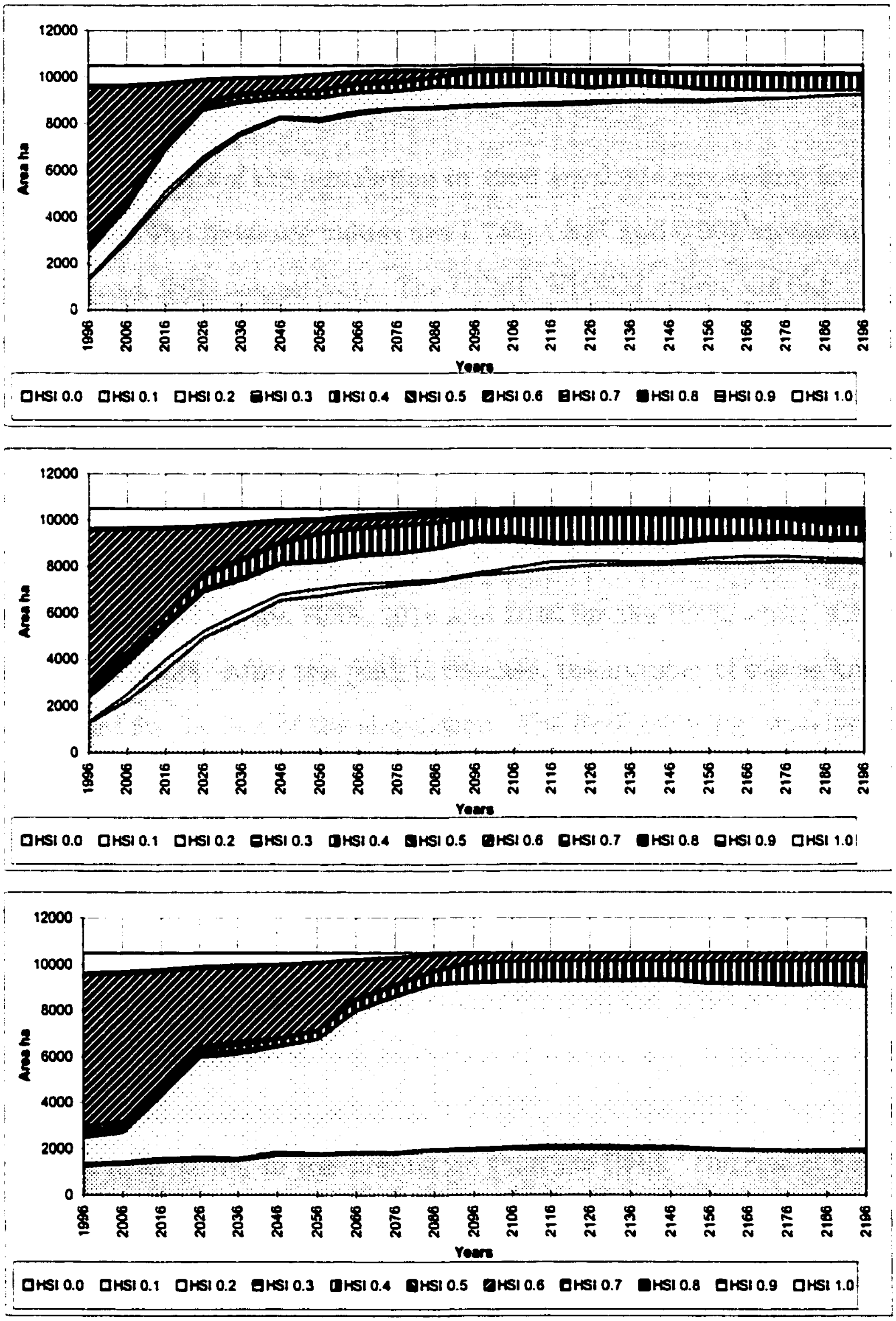


Figure 14: **Weldwood Winter Habitat Suitability Index Model food HSI results for the High, Basic and No harvest scenarios.**

Chair in Forest Management and Policy Winter Habitat HSI Model

Results

The starting results of the simulation in 1996 are 0.974 moose/km^2 for all harvest scenarios. The finishing values are 1.745, 1.821 and 0.901 moose/km^2 for the HHS, BHS and NHS respectively. The CFMP-WHSIM starts out flat, whereupon the number of moose/km^2 rises for the HHS, BHS and NHS after 2016. The rate of increase in moose/km^2 is greatest with the HHS, then BHS, and finally NHS. The HHS, BHS and NHS attain values of 1.874, 1.773 and 1.186 moose/km^2 at 2036, 2046 and 2026, respectively, once they have reached their respective crests. For the HHS, BHS and NHS there is a 92.4, 82.0 and a 21.8% increase respectively between 2016 and 2036 for the HHS, 2016 and 2046 for the BHS, while NHS was between 2016 and 2026. After the peak is reached, the number of moose/km^2 remains constant for the rest of the simulation. The final carrying capacity values for the HHS, BHS and NHS are 1.745, 1.821 and 0.901 or a 79.2, 87.0 and a -7.5% percent change for the harvest scenarios respectively (Figure 15, Table 9).

Discussion

The rise in moose carrying capacity values for both the HHS and BHS are attributable to the conversion of late-winter cover stands to stands that have higher food values. The impact occurs earlier in the HHS, since the HHS is harvesting timber on more area earlier in the simulation than the BHS. The rise of both the HHS and BHS is directly related the HSG state table and the S2 food variable. The change in food HSI values for both the BHS and HHS starts after 2016 (Figure 16). There is a conversion from stands with HSI food values of 0.0 to values of

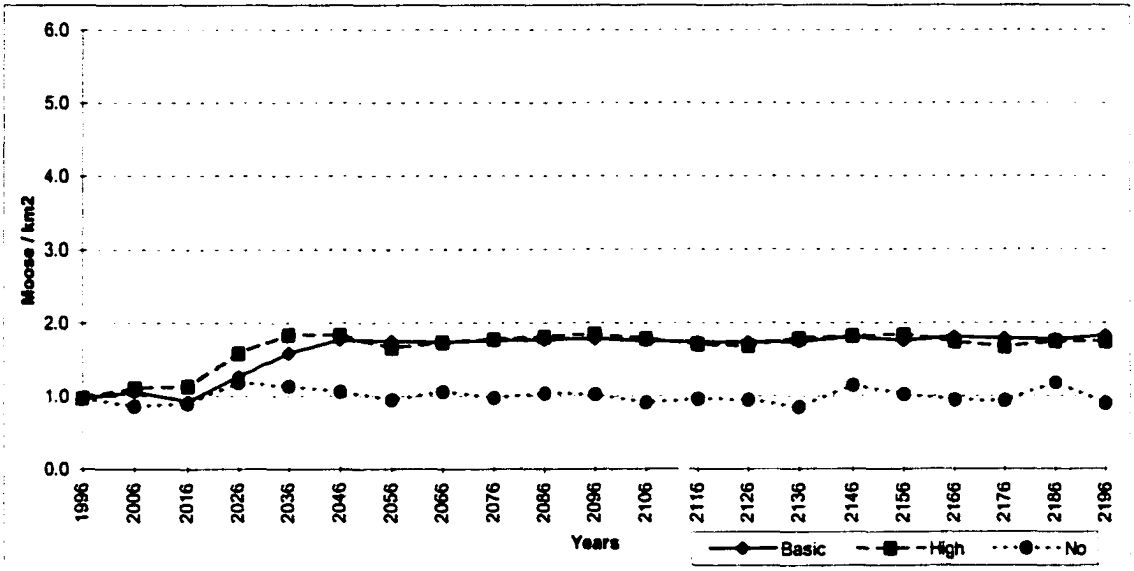


Figure 15: Chair in Forest Management and Policy Winter Habitat Suitability Index Model results for the High, Basic and No harvest scenarios.

Table 9: Chair in Forest Management and Policy Winter Habitat Suitability Index Model results for the High, Basic and No harvest scenarios.

Year	Basic	High	No
1996	0.974	0.974	0.974
2006	1.062	1.119	0.868
2016	0.924	1.131	0.903
2026	1.272	1.581	1.186
2036	1.587	1.836	1.138
2046	1.773	1.840	1.060
2056	1.753	1.661	0.948
2066	1.735	1.741	1.060
2076	1.768	1.776	0.972
2086	1.781	1.813	1.032
2096	1.792	1.848	1.024
2106	1.761	1.781	0.916
2116	1.737	1.708	0.958
2126	1.738	1.685	0.946
2136	1.749	1.789	0.850
2146	1.814	1.822	1.146
2156	1.766	1.834	1.028
2166	1.808	1.749	0.954
2176	1.790	1.672	0.940
2186	1.778	1.753	1.190
2196	1.821	1.745	0.901

Maximum			
1996	0.974	0.974	0.974
2026			1.186
2046	1.773	1.840	
% Change	81.985	88.887	21.732

Overall Change from 1996 to 2196			
% Change	86.893	79.182	-7.547

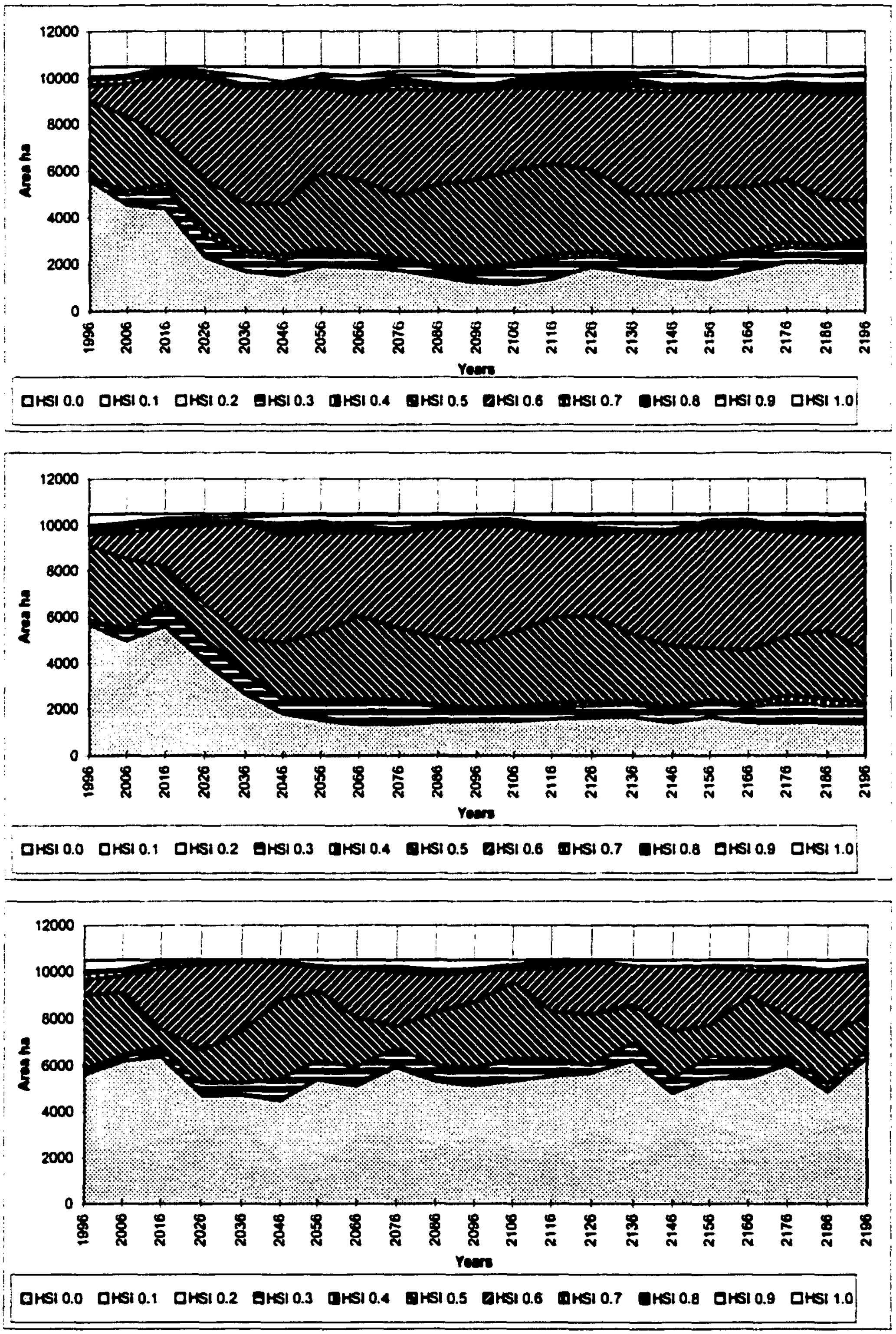


Figure 16: Chair in Forest Management and Policy Winter Habitat Suitability Index Model food HSI results for the High, Basic and No harvest scenarios.

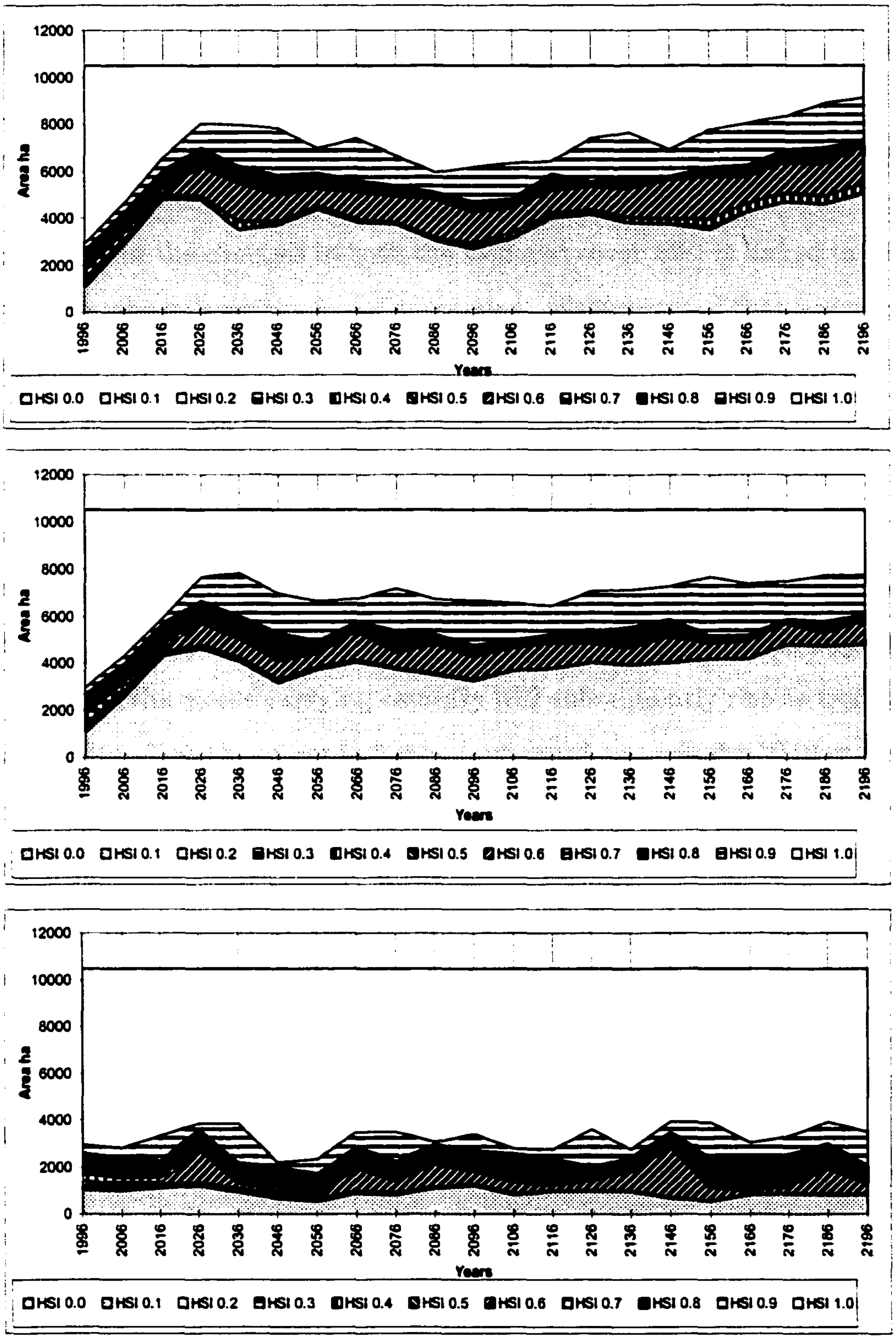


Figure 17: **Chair in Forest Management and Policy Winter Habitat Suitability Index Model cover HSI results for the High, Basic and No harvest scenarios.**

either 0.5 or 0.6. This rise in food values precipitates the rise in moose carrying capacity values. Conversely, the cover values decline in quality, since there is a shift from stands with HSI's of 1.0 to stands with HSI's of 0.9 and 0.7 (Figure 17).

The reason for the changes in both the food and cover HSI is linked to the HSG behaviour which describes forest succession. HSG dictated that harvested stands that had any proportion of aspen would have the same amount of aspen or more, usually more, in the regenerating stand. The increase in aspen increased the food and cover HSI's in the middle range because mixed stands with aspen do not provide as much food as pure aspen stands or as good as cover as the original conifer mixedwood stands (Table 1). The study area has a large portion of the stands that have an aspen component (Table 1), so the S2 variable will improve after cutting, and the moose carrying capacity will subsequently rise as typified in the model results. This argument is further enhanced because the NHS results remain constant, since there is no real disturbance to the landscape i.e. no timber harvesting that would cause HSG to change the development path of stands to stands that would have a greater proportion of aspen and subsequently raise the moose carrying capacity values.

Higgelke Habitat Model

Results

The starting results of the simulation in 1996 are 2.841 moose/km^2 for all harvest scenarios. The finishing values are 2.076, 2.737 and 1.995 moose/km^2 for the HHS, BHS and NHS respectively. Between 1996 and 2006 the HHS has a decline in moose/km^2 while the NHS and BHS exhibit only slight declines. There is a rise in moose/km^2 for the HHS, BHS and NHS starting after 2006. The rise is greatest for the HHS, then BHS and finally the NHS. The maximum values for moose/km^2 are 3.801, 3.632 and 3.02 or a 33.8, 27.8 and a 6.3% increase over the 1996 values for the HHS, BHS and the NHS at 2036, 2026 and 2026 respectively.

Following the peak of 3.801 moose/km^2 for the HHS, the HHS has the fastest and greatest decline in moose/km^2 numbers, with a decline of 131.3% to a value of 1.643 moose/km^2 in 2106. The NHS declines 59.0% in a undulating fashion from 3.02 to 1.90 moose/km^2 in 2116, while the BHS declines 44.1% relatively smoothly except for a single spike at 2076 from 3.632 to 2.521 moose/km^2 in 2126. The final moose/km^2 for the HHS, BHS and NHS are 2.076, 2.737 and 1.995 which translates into declines of 24.3, 0.2, 27.2% respectively when compared to the starting values (Figure 18, Table 10).

Discussion

Once the minimum values are reached in the HHS at 2106, it exhibits a steady behaviour at those lower values until the end of the simulation. Conversely, both the BHS and NHS exhibit noticeable fluctuations through time; they both rise and fall at approximately the same time. The fluctuations are artifacts of the forest age-class structure and stand composition which are controlled by the HSG state table. The rise in both the BHS and NHS at approximately 2076, 2146, 2186 are linked to the harvesting of mature stands for the BHS and the collapse of stands in NHS at that time which produce increases in younger stands that have higher food values.

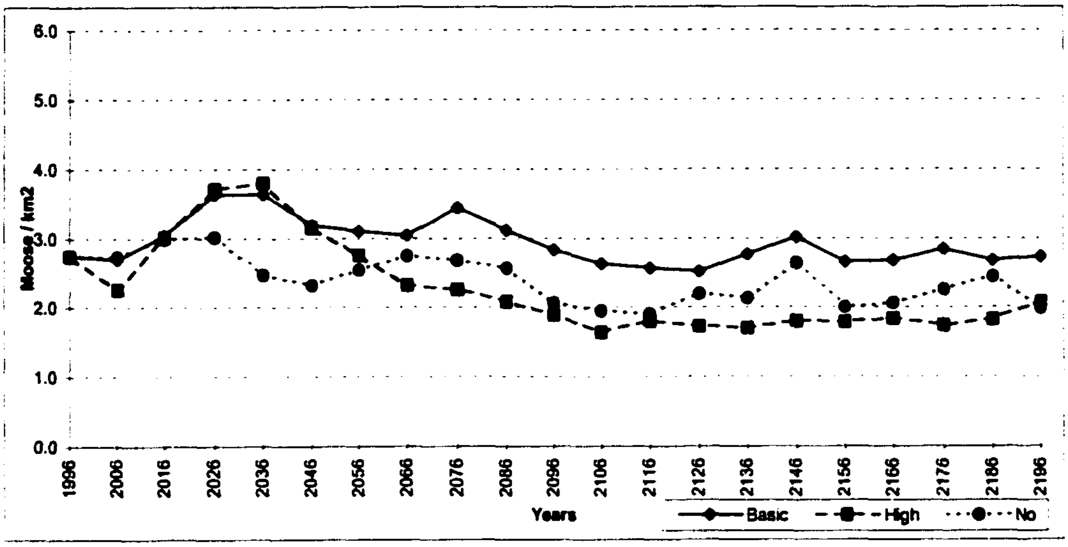


Figure 18: Higgelke Habitat Model results for the High, Basic and No harvest scenarios.

Table 10: Higgelke Habitat Model results for the High, Basic and No harvest scenarios.

Year	Basic	High	No
1996	2.741	2.741	2.741
2006	2.703	2.268	2.735
2016	3.045	3.016	2.993
2026	3.632	3.706	3.020
2036	3.632	3.801	2.469
2046	3.189	3.161	2.323
2056	3.108	2.764	2.550
2066	3.047	2.329	2.741
2076	3.437	2.270	2.684
2086	3.123	2.093	2.569
2096	2.831	1.898	2.066
2106	2.634	1.643	1.955
2116	2.573	1.809	1.899
2126	2.521	1.731	2.204
2136	2.765	1.708	2.135
2146	3.013	1.801	2.642
2156	2.666	1.791	2.007
2166	2.680	1.849	2.067
2176	2.841	1.740	2.261
2186	2.690	1.835	2.452
2196	2.737	2.076	1.995

Maximum			
1996	2.741	2.741	2.741
2026	3.632		3.020
2036		3.801	
% Change	32.503	38.649	10.154

Minimum			
2116			1.899
2126	2.521		
2106		1.643	
% Change	-44.081	-131.316	-58.983

Overall Change from 1996 to 2196			
% Change	-0.176	-24.276	-27.224

The decline in moose/km^2 that occurs between 1996 and 2006 is the result of the lag time between removing forest cover stands and their rejuvenation into food-producing areas for moose. The removal of cover stands lowers the quality of the landscape for moose so there is a lower carrying capacity value at 2006. This effect is most pronounced in the HHS since it removes the most cover stands and it takes ten years before the model implements the increase in food after the cut. The food flush is visible after 2006 when the moose population climbs because more food is now available for consumption.

The BHS and NHS maintain higher moose carrying capacity values than the HHS, because those two strategies maintain a greater portion of stands that are suitable for cover, which raises the early-winter moose carrying capacity values because of the spatial calculation done in the model. The BHS has the highest overall moose/km^2 through time. This is attributable to the increase in food that occurs after cutting; however, enough stands with good early-winter cover are left to provide moose with adequate early-winter cover. Conversely, the extra cutting in the HHS increased the availability of food but lowered the amount of early-winter habitat and subsequently moose carrying capacity values become suppressed according to the model.

The spatial calculation within the HHM penalizes landscapes that have too much of one type of habitat i.e., food or cover. Specifically, the HHS produces too much food and not enough cover; the converse is true in the NHS, with too much cover and not enough food. However, the NHS fairs better in the simulation over all because older stands have lower stocking values and subsequently higher food values than young stands with higher stocking values.

The BHS produces a landscape that supports the most moose/km^2 of the three scenarios, because enough timber is extracted to produce high food supplies and enough timber is left to provide adequate cover. However, at the end of the simulation there is only a 3% difference between the BHS starting and finishing values. Futhermore, the BHS results are relatively calm after 2146, which may indicate that an equilibrium has been reached and the simulation will remain stable from there on. If so, this indicates that the timber harvest level taken stand by stand according to this simulation does not significantly affect the moose population.

Duinker Population Model

Predation and Hunting Active

Results

The starting results of the simulation in 1996 are 1.972 moose/km^2 for all harvest scenarios. The finishing values are 3.96, 3.91 and 2.07 moose/km^2 for the HHS, BHS and NHS respectively. Between 1996 and 2006 the HHS has a decline in moose/km^2, while the NHS has a slight decline and the BHS has a slight increase. For all scenarios there is a rise in moose/km^2 starting after 2006. The rise is greatest for the HHS, then BHS, and finally the NHS. The maximum moose/km^2 values are 4.27, 3.94 and 2.67 or a 116, 100 and 35% increase over the 1996 values for the HHS, BHS and the NHS at 2036, 2036 and 2026 respectively.

Following the peak of 4.27 moose/km^2, the HHS simulation has the fastest and greatest decline in moose/km^2 numbers of the three forest management scenarios, with a decline of 38% to a value of 2.62 moose/km^2 between 2036 and 2106 in a stepped fashion with a plateau at 2076. The NHS declines 31% from 2.67 to 1.81 moose/km^2 in two falls with a recovery at the midpoint of 2066. The BHS declines 16% from 3.94 to 3.30 moose/km^2 from 2036 to 2106 in a similar fashion to the NHS but with a weaker recovery at 2086 (Figure 19, Table 11).

Discussion

Once the minimum is reached by the HHS simulation in 2106, it exhibits a steady climb from its minimum to overtake the BHS in 2196. Similarly, the BHS falls and then rises but not as dramatically as the HHS. Finally, the NHS exhibits some fluctuations up and down but overall it appears stable with those fluctuations tied to the state table in HSG.

The decline in moose/km^2 between 1996 and 2006 occurs for the same reason as stated in the HHM discussion, i.e., there is a lag time between forest cover removal and browse production since the DPM uses the food values produced by the HHM.

From the three scenarios the BHS portrays the best balance between fibre removal and the moose population, since the moose population is consistently higher than the HHS. The BHS does better because of the spatial calculation used in determining early-winter food values and the calculation used for determining hunting pressure. Specifically, in the BHS there is more area that is suitable as early-winter cover than in the HHS, hence higher cover values and a more viable moose population. Secondly, the population may be higher because the overall hunting success would be lower because the area in 0-10, 11-20, 21-30 and 31-40 age classes is less than that in the HHS.

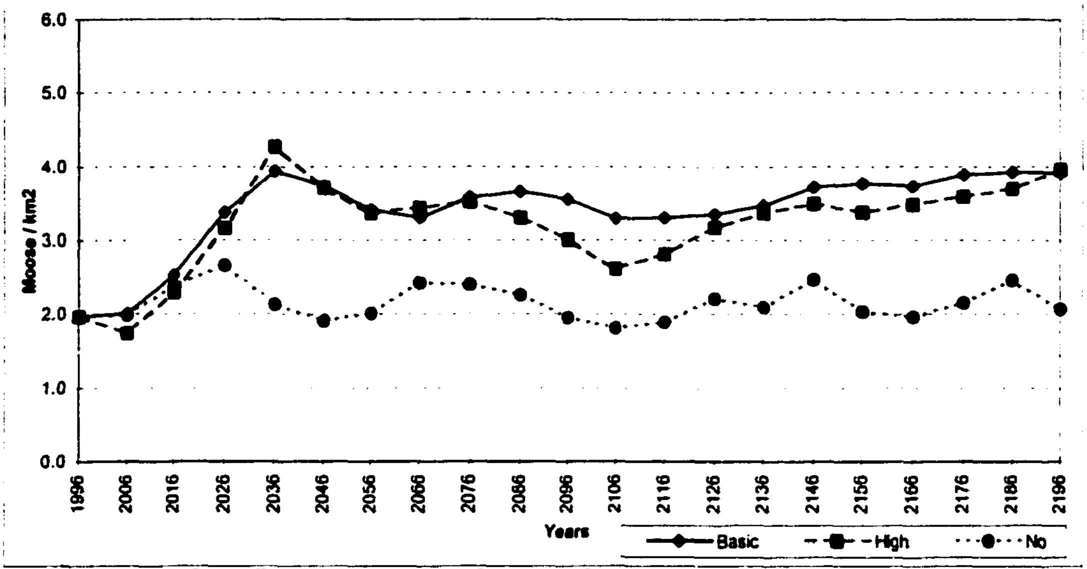


Figure 19: Duinker Population Model results for the High, Basic and No harvest scenarios with hunting and predation active.

Table 11: Duinker Population Model results for the High, Basic and No harvest scenarios with hunting and predation active.

Year	Basic	High	No
1996	1.972	1.972	1.972
2006	2.016	1.740	1.987
2016	2.533	2.306	2.379
2026	3.376	3.163	2.665
2036	3.940	4.266	2.130
2046	3.731	3.715	1.907
2056	3.410	3.372	2.017
2066	3.313	3.441	2.431
2076	3.580	3.527	2.406
2086	3.662	3.311	2.266
2096	3.561	3.007	1.954
2106	3.301	2.619	1.813
2116	3.314	2.823	1.902
2126	3.351	3.184	2.212
2136	3.474	3.373	2.099
2146	3.728	3.493	2.480
2156	3.771	3.385	2.041
2166	3.741	3.492	1.974
2176	3.884	3.589	2.159
2186	3.927	3.696	2.466
2196	3.911	3.957	2.070

Maximum			
1996	1.972	1.972	1.972
2026			2.665
2036	3.940	4.266	
% Change	99.822	116.343	35.159

Minimum			
2106	3.301	2.619	1.813
% Change	-16.212	-38.610	-31.961

Overall Change from 1996 to 2196			
% Change	98.352	100.672	4.970

The NHS remains fairly even through out the simulation. It seems to indicate that the model is performing as intended. Hence, the moose predictions are following the peaks and valleys that are related to food, and those peaks and valleys can be traced back to the forest's age-class distribution and the HSG state table. The peaks occur at times when large numbers of similar stands of approximately the same age are collapsing and providing an influx of food to the system which translates into more moose/km^2.

Predation Active and No Hunting

Results

The starting results of the simulation in 1996 are 2.238 moose/km^2 for the HHS, BHS and NHS. The finishing values are 4.568, 4.252 and 2.297 moose/km^2 for the HHS, BHS and NHS respectively. Between 1996 and 2006, the HHS has a noticeable decline in moose/km^2, while the NHS has a very slight increase and the BHS has a significant increase. For all management strategies there is a noticeable rise in moose/km^2 starting after 2006. The rise is greatest for the HHS, then BHS, and finally the NHS. At the top of rise the moose/km^2 are 5.106, 4.52 and 3.06 or a 128.1, 102.0 and 36.8% increase over the 1996 values for the HHS, BHS and the NHS at 2036, 2036 and 2026 respectively.

Following the peak of 5.106 moose/km^2, the HHS has the fastest and greatest decline in moose/km^2, of the scenarios with a decline of 42.9% to a value of 2.916 moose/km^2 in a stepwise decline between 2036 - 2056 then 2076 - 2106. The NHS declines 33.3% from 3.063 to 2.042 moose/km^2 between 2026 and 2106, in two falls with a midpoint recovery at 2066. Similarly, the BHS declines 17.4% from 4.520 to

3.736 moose/km^2 from 2036 to 2126 with a recovery point at 2086 (Figure 20, Table 12).

Discussion

Once the minimum of 2.916 moose/km^2 is reached by the HHS simulation in 2106, the population begins a steady increase and rises above the BHS value in 2186. Both the BHS and NHS react similarly and have similar levels of fluctuations in them. However, their median points between 2026 and 2196 points are different, with BHS at approximately 4.2 moose/km^2 and NHS at 2.5 moose/ km^2.

The general effect of removing hunting from the simulation, when compared to the previous DPM simulation, is noisier results (i.e. greater variance) and higher overall moose/km^2 values for all three scenarios.

No Predation and No Hunting

Results

The starting results of the simulation in 1996 are 2.30 moose/km^2 for the HHS, BHS and NHS. The finishing values are 4.711, 4.518 and 2.369 moose/km^2 for the HHS, BHS and NHS respectively. Between 1996 and 2006, the HHS has a noticeable decline in moose/km^2, while the NHS and BHS have a very slight increase. For all scenarios there is a rise in moose/km^2 starting after 2006. The rise is greatest for the HHS, then BHS, and finally the NHS. At the top of the curve, the moose/km^2 are 5.256, 4.635 and 3.159 or a 128.56, 101.56 and a 37.37% increase

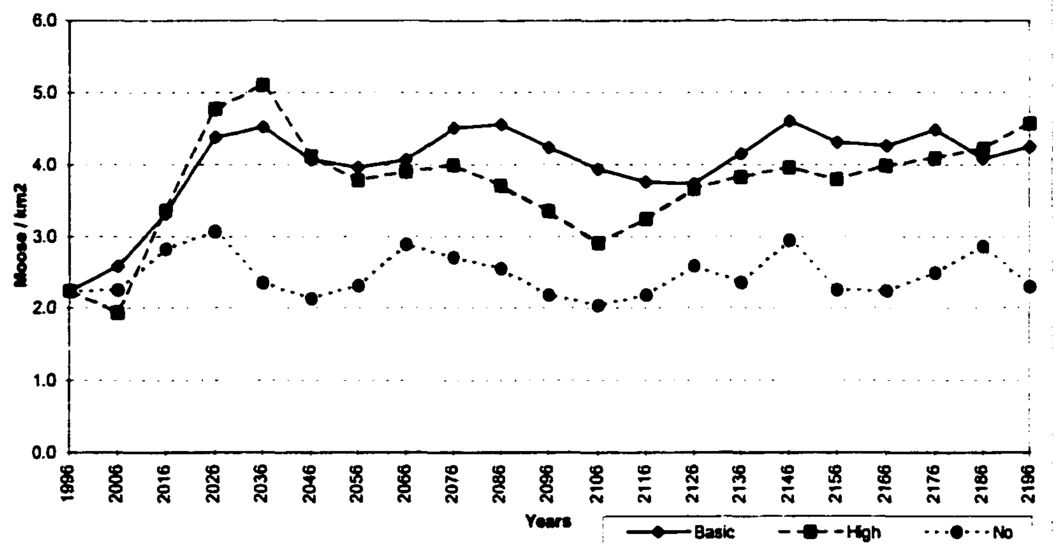


Figure 20: Duinker Population Model results for the High, Basic and No harvest scenarios with no hunting and predation active.

Table 12: Duinker Population Model results for the High, Basic and No harvest scenarios with no hunting and predation active.

Year	Basic	High	No
1996	2.238	2.238	2.238
2006	2.589	1.944	2.258
2016	3.312	3.362	2.825
2026	4.377	4.774	3.063
2036	4.520	5.106	2.355
2046	4.064	4.114	2.140
2056	3.960	3.783	2.317
2066	4.074	3.905	2.884
2076	4.514	3.997	2.710
2086	4.557	3.705	2.553
2096	4.231	3.357	2.179
2106	3.933	2.916	2.042
2116	3.753	3.245	2.179
2126	3.736	3.667	2.591
2136	4.150	3.834	2.356
2146	4.600	3.962	2.943
2156	4.302	3.799	2.257
2166	4.255	3.980	2.238
2176	4.486	4.088	2.493
2186	4.079	4.225	2.866
2196	4.252	4.568	2.297

Maximum			
1996	2.238	2.238	2.238
2026			3.063
2036	4.520	5.106	
% Change	101.955	128.113	36.837

Minimum			
2106		2.916	2.042
2126	3.736		
% Change	-17.350	-42.883	-33.328

Overall Change from 1996 to 2196			
% Change	89.981	104.088	2.602

above the 1996 values for the HHS, BHS and the NHS at 2036, 2036 and 2026 respectively.

Following the peak of 5.256 moose/km^2, the HHS has the fastest and greatest decline in moose/km^2 of the scenarios, with a decline of 43.38% to a value of 2.976 moose/km^2 in two stages, 2036 - 2056 and then again at 2076 - 2106. The NHS declines 33.93% from 3.159 to 2.087 moose/km^2 between 2026 and 2106 in two stages with a recovery at 2066. Similarly the BHS declines 18.13% from 4.635 to 3.795 moose/km^2 in two steps with a recovery at 2076 from 2036 to 2106 (Figure 21, Table 13).

Discussion

After the minimum is reached for the BHS and HHS in 2106, the moose populations begin to rise and HHS surpasses the BHS in 2196. However, the rate of increase is greatest for the HHS and the scenarios run closer together than they do in the DPM with no hunting.

Similar to the No Hunting DPM results above, both the HHS and NHS have very similar results. Conversely, the BHS results are quite different; the No Hunting BHS is a noisier run than the No Predation No Hunting run, where the BHS is relatively uniform after 2106.

Duinker Population Model Within-Model Comparisons

The effects of hunting and predation are examined within the DPM. Of the two variables hunting and predation, hunting has the greatest impact on the moose population and those impacts vary among harvest scenarios. On average over the

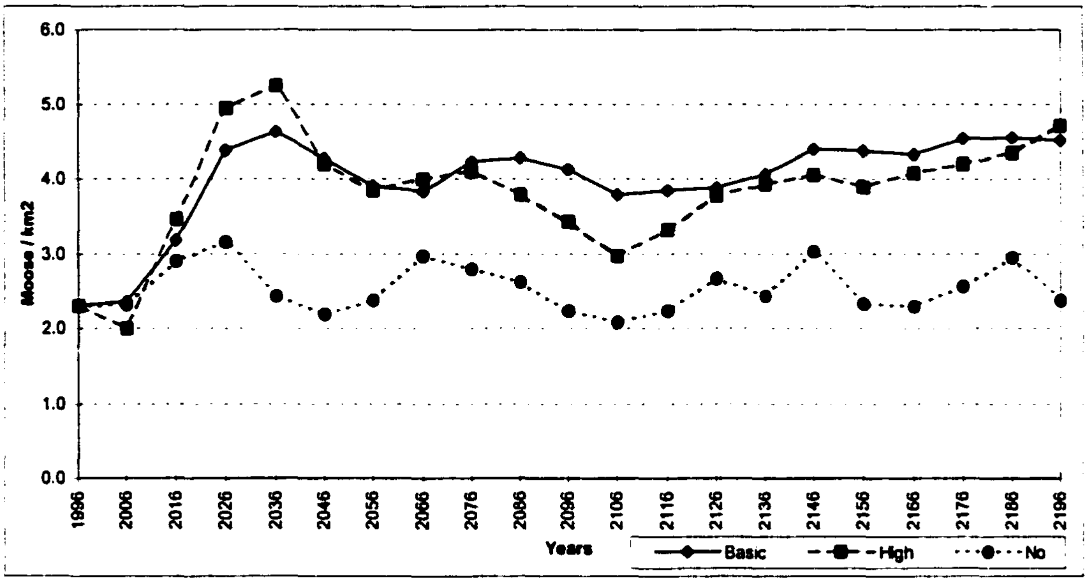


Figure 21: Duinker Population Model results for the High, Basic and No harvest scenarios with no hunting and no predation.

Table 13: Duinker Population Model results for the High, Basic and No harvest scenarios with no hunting and no predation.

Year	Basic	High	No
1996	2.300	2.300	2.300
2006	2.360	1.996	2.320
2016	3.186	3.466	2.906
2026	4.389	4.947	3.159
2036	4.635	5.256	2.427
2046	4.269	4.196	2.183
2056	3.903	3.852	2.370
2066	3.840	4.005	2.970
2076	4.233	4.100	2.799
2086	4.281	3.788	2.623
2096	4.125	3.427	2.232
2106	3.795	2.976	2.087
2116	3.843	3.326	2.234
2126	3.889	3.773	2.667
2136	4.066	3.934	2.431
2146	4.395	4.064	3.025
2156	4.378	3.891	2.329
2166	4.328	4.087	2.288
2176	4.538	4.199	2.557
2186	4.551	4.349	2.950
2196	4.518	4.711	2.369

Maximum			
1996	2.300	2.300	2.300
2026			3.159
2036	4.635	5.256	
% Change	101.555	128.561	37.367

Minimum			
2106	3.795	2.976	2.087
% Change	-18.129	-43.376	-33.930

Overall Change from 1996 to 2196			
% Change	96.467	104.871	3.033

simulation, hunting has the effect of creating a 17.96 % change in the BHS, 16.83% in the HHS and only 14% within the NHS, while predation affects the BHS -0.25%, HHS 2.62% and NHS 2.76% (Figure 22).

From Figure 22, one observes that the BHS has an erratic behaviour with respect to percent difference between the three DPM runs of normal parameters (N), no hunting with predation active (NH) and no hunting and no predation active (NH NP). The effect of hunting and predation can be seen clearly in the HHS and NHS runs; however, the BHS runs are more chaotic in behaviour by criss crossing each other.

I believe that the erratic behaviour found in the percent difference of the BHS is linked to two factors: a lower timber harvest level and the linking of hunting pressure to access level determined by total area in younger age classes. The lower harvesting regime meant that the average age of the forest was higher than that in the HHS. This creates a situation where food supplies and early-winter cover indexes fluctuate more than in either the HHS or the NHS, because you have greater age and stocking differences between ajoining stands that are examined by the roving window function in the HHM which produces the food values for the DPM. Those fluctuations are further aggravated by the determination of hunting pressure in the DPM which uses total area of younger age classes. Finally, access is used for determining the level of cow harvest which then determines the harvest rate for both bulls and calves. If the area in younger age classes were erratic then the harvest quotas will be erratic and subsequently the moose/km^2 outputs with hunting active would be erratic.

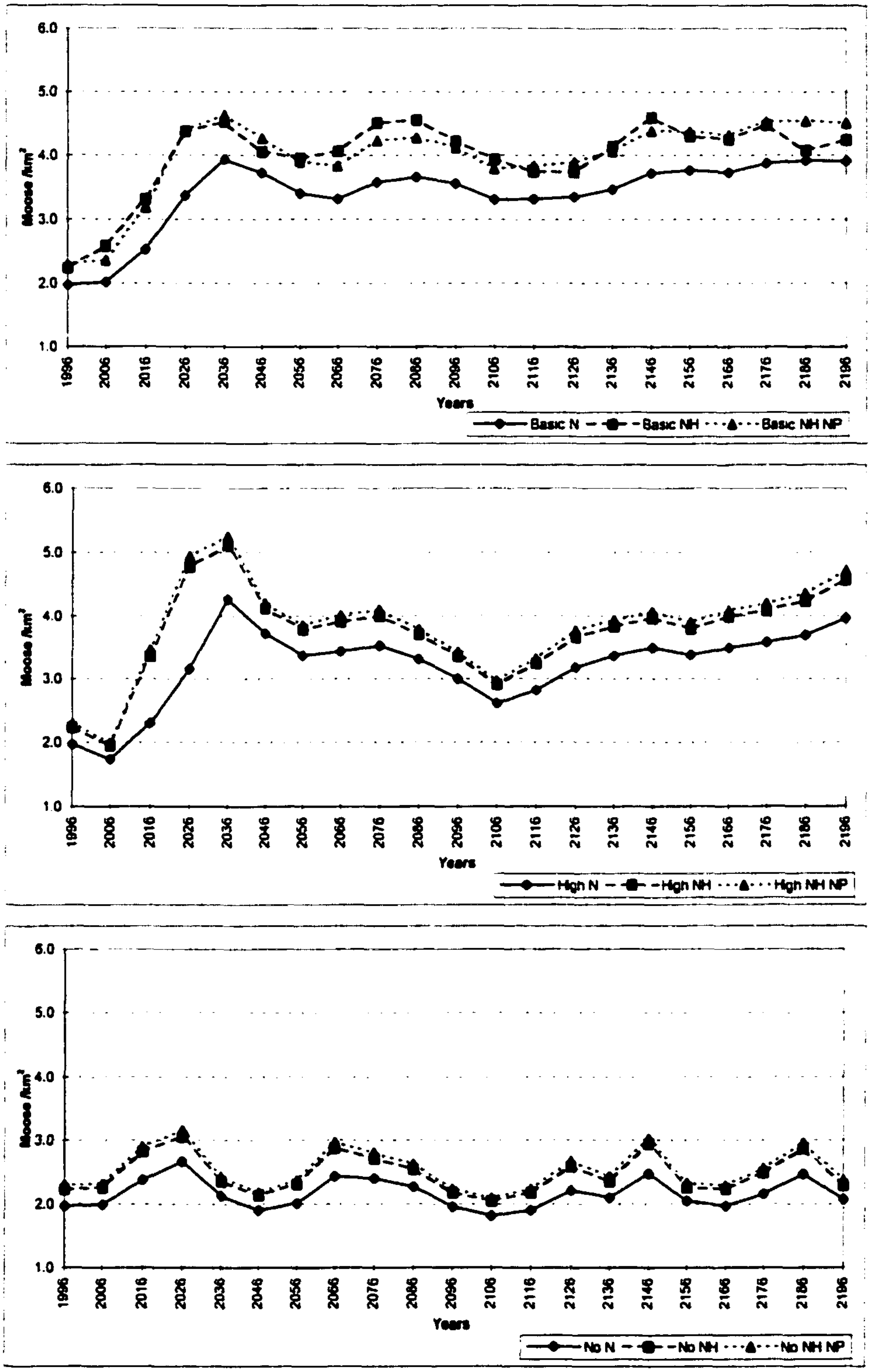


Figure 22: Within harvest scenario comparison of the PDM with normal parameters hunting and predation active (N), no hunting with predation active (NH) and no hunting and no predation active (NH NP).

The difference could be attributable to the input parameters used or the way the model does the calculations. Predation is set to remove 60% of the calf population, 4% of the yearling and adult population and 7% of the old moose population, while hunting pressure was developed from access which in turn was developed from the amount of area found in younger age classes. When one compares the NHS to HHS and BHS across the three DPM simulations, one observes that the hunting pressure calculation is applied because the HHS has the largest differences at 2026-2036 and 2076-2086 between normal, and no hunting with predation. Those time frames correspond to times when the area in younger stands is greatest, so the hunting pressure is the greatest.

Generally, all the HHS, BHS and NHS simulations reach the first and subsequent peak at the same times during the simulation. Futhermore, the highest individual values for the HHS, BHS and NHS all occur when hunting and predation are turned off.

Carrying Capactiy Peaks / Dips and Thier Link to HSG

The peaks and valleys found in the HHM and the DPM were linked to HSG and the starting age-class structure and species composition of stands. The results also showed a decline in the magnitude of those peaks and valleys past 50 years. HSG is the dominant force because the results from the CC models track similarly with the area harvested results from HSG. HSG harvested more area initially and less later on because the future forest was producing more volume per hectare as the forest became normalized i.e. <=60 years of age. Furthermore, HSG targeted lodgepole pine at the start because of its age-class structure and it produces higher volumes per hectare earlier than other species. Specifically, lodgepole pine comprises 7,182 ha and 2,966 ha of that is 60-100 years old, which makes those stands prime candidates for harvest. Therefore, when those extra hectares are harvested a large flush of food becomes available which increased the moose CC values, since moose CC values are area-dependant.

Model Variable and Application Comparison

The model assumptions and parameters in Table 14 outline some of the similarities and differences in the applied moose models. The ease of use, implementation and model adaptability was best for the two HSI models, while the HHM was moderate and the DPM was moderate to difficult. Other parameters examined showed no strong differences.

Relative Merits of Models Biologically

To this point of the thesis, each model's merits have been examined on a technical basis e.g. how large are the uncertainties of each variable, what are the interaction effects, how close do the predictions match reality. It is now necessary to examine each model on its biological value or biological truthfulness.

The WWHSIM has two crucial variables that do not represent their biological function well. Specifically, the S1 variable Percent Shrub Canopy Cover (Figure 3) could be improved by using data developed to correlate stand composition and age to the amount of available browse (i.e. Table 1). The other concern biologically for this model is the determination of the food-to-cover and cover-to-food criterion, since the model documentation contained no definition of what constitutes a food or cover

Table 14: Model comparisons of spatial relationships, variables and outputs.

Criteria		Models			
		WWHSIM	CFMP-WHSIM	HHM	DPM
Model adaptability to new biological information		H	H	M	H
Input data adaptability		H	H	L	M
Complexity		L	L	M	H
Ease of use		H	H	M	L
Geographic area developed for		Foot Hills AB	Central AB	Northwest ON	Northeast ON
Adaptability to other ungulate species		CRW	CRW	CRW	SM
Hardware requirements		M	M	M	L
Geographic transferability / Modification level after transfe		MT / MM	MT / MM	MT / HM	HT / SM
Model scales[1]	Sub-home range (SHR)	A	A	N	N
	Home range (HR)	A	A	A	A
	Local population (LP)	D	D	D	D
	Region of LP's (R)	A	A	A	A
	Closed system (CS)	N	N	N	N
Spatial component complexity		L	M	H	H
Number of spatial variables		3	2	2	3
Examined parameters	Tree height	Y	Y	N	N
	Species composition	N	N	Y	Y
	Stand age	N	N	Y	Y
	Stand stocking	Y	Y	Y	Y
	Distance from cover	Y	Y	Y	Y
	Distance from food	Y	Y	Y	Y
	Distance from disturbance	Y	N	N	Y
	Browse availability estimate	Y	Y	Y	Y
	Browse density kg/ha	N	N	Y	Y
	Population assessment	N	N	N	Y
	Mortality assessment	N	N	N	Y
	Hunting effects	N	N	N	Y
	Illegal hunting	N	N	N	P
	Starvation effects	N	N	N	Y
	Predation effects	N	N	N	Y
	Other mortaility	N	N	N	Y
	Disease effects	N	N	N	Y[2]
	Parasite effects	N	N	N	Y[2]
Output parameters	Population estimate	N	N	N	Y
	Carrying capacity	Y	Y	Y	N
	Maps	Y	Y	N	N

AB	Alberta
ON	Ontario
HR	The area used by a single individual it's entire life (10•10 km)
LP	The area occupied by several individuals (100•100 km)
R	The area used by many local populations linked by dispersal (Boreal Forest)
CS	The area that contains a closed system (North America)
A	Can be applied at this level
D	Designed for this level
H	High
M	Moderate
L	Low

MT	Moderately transferable
HT	Highly transferable
SM	Requires slight modifications
MM	Require moderate modifications
HM	Require high modifications
CRW	Complete rewrite of model
Y	Yes
N	No
P	Possible

Note: Value judgments are targeted to average users or end users

[1] From Wiens *et al*. 1985

[2] This capability exists in the model but was not utilized

cell. Therefore, it was my assumption that if it had a non-zero value for food or cover then it could be used in the calculation of food and cover values and subsequent HSI and carrying capacity calculations.

The other variables S3 Distance from Access, S4 Percent Canopy Cover, and S5 Tree Height have sound biological backing in their representation. Specifically, the further an area is from access (S3) the less likely a moose will be shot; the higher the canopy cover (S4) the better thermal extremes will be minimized; and the taller the trees (S5) the better the snow interception should be.

Once the output from the WWHSIM was examined, the results were rejected because they did not make logical sense as previously discussed. As stated this model could be improved if corrections were implemented for S1 and how the model is structured i.e. eliminate zero HSI values.

The CFMP-WHSIM representation of biological information regarding food was an improvement over the WWHSIM. The CFMP-WHSIM utilized a food table (Table 1, S2) based on field data. The Distance of Food from Cover (S3) was based on field data describing moose feeding preferences (Appendix 1), and the S1 food bonus from seismic lines was based on reasoning that moose would feed in those areas, because of their proximity to cover.

The variables used for determining cover were comparable to but improved over the WWHSIM. It was felt that Percent Tree Canopy (S4) was not optimum for thermal protection and snow interception until 60%, versus 30% in the WWHSIM. Tree Height quantification was similar between the two HSI models and differences between them were of little impact. However, the addition of Percent Conifer (S6) to the CFMP-WHSIM was a large improvement over the WWHSIM, since it is known that conifers provide better thermal protection and precipitation interception than deciduous stands and should therefore be included in the model (Appendix 1). The CFMP-WHSIM also added a bonus to the cover calculation when stands were considered complex, i.e. multistoried, which further improved a stand's, capability for thermal protection and precipitation interception. The additions and improvements made to the CFMP-WHSIM over the WWHSIM significantly improved its ability to represent properly the moose biology and habitat interaction that occurs in nature.

The HHM is an enhancement of the HSI approach because it further refines the amount of food that is on the landscape at different stand ages and stocking levels. That refinement was better able to represent what we know from science regarding abundance of browse, because actual field data could be converted into browse curves by working group or species group. The HHM also instituted an ecotone effect, which occurs between stands, which is a natural biological function that was not incorporated in the two HSI models. The better use and implementation of browse field data and the ecotones in the HHM improved its usefulness to managers. It does fall short, however, by not accounting for predation, hunting and other mortality features, components shown to have large impacts on a moose population (Appendix 1).

The DPM expands on the HHM by incorporating specific growth and death functions for moose. Growth rates depend on abundance given kg of browse/ha and mortality adjustments for predation, hunting and disease. The growth rates were derived from research on moose metabolizm and growth rates given different foods (Appendix 1). The mortality functions developed from literature reviews were applied against the growing population to lower its productivity as would occur in nature.

The use of growth and mortality functions enabled the DPM to represent some moose population dynamics that are present in reality but difficult to incorporate in a model. The data used to develop the growth and mortality rates were drawn from the literature. However, use of those data in the model through input parameters and equations was never compared to the real moose population modelled over time to calibrate it. This lack of field calibration of inputs and equations is worrisome.

Of the equation groups, the growth equations inspire the most confidence because of all of research conducted on farm animals with respect to growth and development. Conversely, the predation, hunting and natural mortality equations are based on scarce information; in addition, predation and hunting have the largest impacts on the model results (Appendix 6). Those two factors combined to lower my confidence level in the DPM below the HHM with respect to biological truthfulness.

Of the four models, I would rate the HHM the best to use today for forest management planning followed by the DPM and CFMP-WHSIM. This rating is based on how I felt the biological information on moose was being applied in the model and how well I could trace results back to model inputs and equations. The WWHSIM was not considered in the ratings because its results and therefore the model itself were considered invalid.

Model Selection Framework

To answer the question of which model to use, I developed a framework that could compare the models and determine which one would be preferred overall. The points I chose to consider in the evaluation framework were: modelling objectives, does the model represent a complete moose life cycle; model relationships, complexity; input availability; the outputs are reasonable and applicable; adaptability of model to other species/uses; and the ability to invalidate a model. Points were given to each model criterion, with 10 being the best and 0 worst. Then I applied a weighting factor to each criterion since I felt that some criteria were more important than others. The applied weight factors for the criteria were 5, 2, 4, 1, 3, 3, 5, and 5 respectively. Finally, the points would be totalled and the highest value should represent the optimum model or models (Table 15).

The evaluation totals indicate the use of the DPM followed by the HHM and then CFMP-WHSIM and the WWHSIM. The results above and the preferred model could change depending on the initial points given and the weighting another user would apply to the criteria. Therefore, if the end users know their modelling objectives, available data and financial constraints, then they should be able to choose one of those models based on the information presented in Table 15.

Comparison of Modelled Moose Population Estimates for 1996 to Aerial Moose Inventories

All models estimates for starting moose populations were higher than the estimated aerial inventories in 1996. The highest difference occurs with the HHM which predicts that there should be 261% more moose/km^2 than what was

Table 15: Model selection framework.

		Model			
Selection Criteria	**Weight**	**WWHSIM**	**CFMP-WHSIM**	**HHM**	**DPM**
Modelling[1] objectives are they satisfied	5	12.5	12.5	37.5	50
Does the model represent a full life cycle[2]	2	5	5	5	20
Model relationships[3]	4	10	10	30	40
Model complexity[4]	1	10	7.5	5	2.5
Input availability[5]	3	30	22.5	22.5	15
Outputs are reasonable and appliacable[6]	3	7.5	22.5	30	22.5
Adaptability[7] of model structure to model other species	5	50	50	25	12.5
Ability to invalidate a model[8]	5	50	50	37.5	37.5
Total Points		175	180	192.5	200

Notes:

[1] The modelling objectives was to predict moose/km^2 values for all seasons.

[2] Life cycle runs from birth to death.

[3] Number of model relationships incorporated

[4] Model complexity represented by how long would it take an average GIS user to implement the model with increased time being bad.

[5] Difficulty to get the required information to get the model going

[6] Are the results reasonable and reflect known biology.

[7] Is the model structure highly adaptable for other species.

[8] How easy is it to invalidate the model.

estimated in 1996. Conversely, the closest starting estimate came from the CFMP-WHSIM which only predicted 28% more moose than aerial inventories in 1996, while the DPM with P&H and the WWHSIM both predicted over-estimations of 159 and 152% respectively.

The population over-estimation is reversed for the WWHSIM by 2096 because it predicts a significant decline in moose numbers between 1996 and 2096. Conversely, the CFMP-WHSIM population estimates increase between 2016 and 2046 when harvesting is active, but the no harvesting scenario for the CFMP-WHSIM shows little change between 1996 and 2196.

The general over-estimations of populations were expected for this project because it is known that carrying capacity is a theoretical limit and no populations will ever reach those levels, because it assumes that every piece of food or cover is accessible and utilized by the population in question.

Comparison of Modelled Moose Population Estimates in 2196 to Aerial Moose Inventories

All models except the WWHSIM estimated moose carrying capacity values through time greater than what was found from aerial surveys in 1996. The WWHSIM produced values that were 67, 53, and 17% lower for the HHS, BHS and NHS respectively than the aerial survey mean of 0.76 moose/km^2. The greatest difference was in the DPM when the predation and hunting functions were turned off; that version of the DPM overestimated the carrying capacity by 520, 494 and 212% for the HHS, BHS and NHS respectively. Therefore, the order of models from the smallest to largest difference with respect to numeric distance from observed aerial values is: WWHSIM, CFMP-WHSIM, HHM, DPM with predation and hunting, DPM with predation and no hunting, and finally DPM with no predation and no hunting (Table 16).

It is important to remember that the model results are estimates of habitat carrying capacity and are therefore likely to be higher than observed values (Schamberger and O'Neil 1986). There is also error to be found in the aerial inventory results. Le Resche and Rausch (1974) found that experienced and inexperienced observers only saw 68 and 47% of the moose in a penned study area. Therefore, it is possible that the actual mean population of moose could be 58% higher or 1.2 moose/km^2. If that is the case, then the CFMP-WHSIM carrying

Table 16: Summary table for all model results with minimum, maximum and percent change indicated.

Model	Harvest Scenario	Start 1996 moose/km^2	First Peak moose/km^2	% Change 1996 to First Peak	First Peak Date	Minimum Post Peak moose/km^2	Minimum Post Peak Date	% Change Peak to Minimum	Finnish 2196 moose/km^2	Net Change moose/km^2 +/-	% Net Change +/-	Aerial Moose Inventory Mean^1 moose/km^2	Percent Difference from aerial values and start of simulation moose/km^2	Percent Difference from aerial values at end of simulation moose/km^2
WWHSIM	HHS	1.912	NA	NA	1996	0.225	2116	-88.2	0.250	-1.662	-86.9	0.760	151.6	-67.1
	BHS	1.912	NA	NA	2006	0.301	2166	-84.3	0.359	-1.553	-81.2	0.760	151.6	-52.8
	NNH	1.912	NA	NA	2026	0.604	2116	-68.4	0.634	-1.278	-66.8	0.760	151.6	-16.6
CFMP-WHSIM	HHS	0.974	1.840	88.9	2036	NA	NA	NA	1.745	0.771	79.2	0.760	28.2	129.6
	BHS	0.974	1.773	82.0	2046	NA	NA	NA	1.821	0.847	87.0	0.760	28.2	139.6
	NNH	0.974	1.186	21.8	2026	NA	NA	NA	0.901	-0.073	-7.5	0.760	28.2	18.6
HHM	HHS	2.741	3.801	38.7	2036	1.643	2106	-40.1	2.076	-0.665	-24.3	0.760	260.7	173.2
	BHS	2.741	3.632	32.5	2026	2.521	2126	-8.0	2.737	-0.004	-0.1	0.760	260.7	260.1
	NNH	2.741	3.020	10.2	2026	1.900	2116	-30.7	1.995	-0.746	-27.2	0.760	260.7	162.5
DPM P&H	HHS	1.972	4.266	116.3	2036	2.616	2106	-38.7	3.957	1.985	100.7	0.760	159.5	420.7
	BHS	1.972	3.940	99.8	2036	3.301	2106	-16.2	3.911	1.939	98.3	0.760	159.5	414.6
	NNH	1.972	2.665	35.1	2026	1.813	2106	-32.0	2.070	0.098	5.0	0.760	159.5	172.4
DPM P&NH	HHS	2.238	5.106	128.2	2036	2.916	2106	-42.9	4.568	2.330	104.1	0.760	194.5	501.1
	BHS	2.238	4.520	102.0	2036	3.736	2126	-17.3	4.252	2.014	90.0	0.760	194.5	459.5
	NNH	2.238	3.060	36.7	2026	2.042	2106	-33.3	2.297	0.059	2.6	0.760	194.5	202.2
DPM NP&NH	HHS	2.300	5.256	128.5	2036	2.976	2106	-43.4	4.711	2.411	104.8	0.760	202.6	519.9
	BHS	2.300	4.635	101.5	2036	3.795	2106	-18.1	4.518	2.218	96.4	0.760	202.6	494.5
	NNH	2.300	3.159	37.3	2026	2.087	2106	-33.9	2.369	0.069	3.0	0.760	202.6	211.7

WWHSIM	Weldwood Winter Habitat Suitability Index Model
CFMP-WHSIM	Chair in Forest Management and Policy Winter Habitat Suitability Index Model
HHM	Higgelke Habitat Model
DPM P&H	Duinker Population Model Predation and Hunting Active
DPM P&NH	Duinker Population Model Predation Active No Hunting
DPM NP&NH	Duinker Population Model No Predation No Hunting
HHS	High Harvest Scenario
BHS	Basic Harvest Scenario
NHS	No Harvest Scenario

capacity estimates of 1.7, 1.8 and 0.9 moose/km^2 for the BHS, HHS and NHS are the closest estimates. However, the CFMP-WHSIM does not take into account the effects of predation and hunting on a population as does the DPM. Therefore, the estimates of the DPM may be more realistic, since it tries to factor in the effects of hunting and predation. The higher ending values of 4.0, 4.0 and 2.0 moose/km^2 for the HHS, BHS and NHS respectively would be lower if other mortality effects (i.e. diseases or road kills) were factored in. Other mortality was excluded from the simulation because reliable data are sparse and the interaction effects with other variables would be cumbersome to separate out.

Of the four models examined, the HHM has ending values for all three harvest scenarios that are closer together than those of any other model. As well, HHM generated results closest to the actual values from aerial inventories if the bias of aerial inventories is factored in for an aerial inventory of 1.2 moose/km^2.

The differences between the HHS and BHS are explained for the most part by the timber harvest intensity. It is natural to expect more moose when more food becomes available in a system that is short of food habitat (i.e. the BHS). Conversely, when too much late-winter habitat is removed and converted to food, the number of moose declines i.e. the HHS. Finally, the NHS for the majority of the simulation rests in between the two extremes of the BHS and HHS. The NHS resides in the middle because it has more cover habitat than the HHS but less food than the BHS. From sensitivity analysis it is clear that the population fluctuations over the simulation are directly related to forest succession which is dictated by the HSG state table.

Implication of this Project to the Application of Adaptive Management for Millar Western Forest Products

From the outset, results of this project were to be used for strategic forest management planning. The HHS, BHS and NHS, or similar strategies, are expected to be examined in the forest management planning process. The HHS will be represented as a 1.5-2.0 times increase in fibre production in the new stands. The BHS will be implemented in harvest areas where intensive forest management does not take place, while the NHS will be associated with areas set aside by MWFP in reserves and other uncut areas. Since the stated forest management strategies will exist in the next forest management plan, the concepts of adaptive management using models as scoping tools and problem identifiers will be implemented not only on the present study area but on the whole management unit.

From the analysis it seems that all the models in this thesis project could be implemented within the confines of long-term management strategies, available data, manpower, computer processing and government regulation. This strategy's benefits would be greater than relying on any one modelling strategy. Not one of the four models examined has been field tested to indicate that it adequately represents the impacts of forest management strategies on moose. However, these and other models will be applied to the landbase and the results monitored through time to ascertain their applicability to strategic forest management planning. Therefore multiple models may allow for better interpretation. Thus, for example, if all the models state that the population is going to rise, there is a relatively strong inference that the population will indeed rise, because we are modelling moose habtiat components that have shown a relationship to moose life requisits. By tracking model outputs through time against aerial moose inventories, we will learn which model best represents the impacts of timber harvest on moose.

Caveats with this project are many since each model has its own set of weaknesses and they need to be stated clearly for adaptive management to work. From a forest manager's perspective trying to implement adaptive management, the largest caveat is the forest projection model used. The program outputs indicate that the whole forest will be converted from older to younger stands, stands under 60 years of age. This is not likely to happen in reality, because present legislation requires that forests are managed on a ecologically sustainable basis (Van Damme 1998). It is a requirement of all forest management plans that all plants and animals that occupy the forest ecosystem be represented in future forests (Van Damme 1998).

The proponents of mimicking natural disturbance and concurrent foresters would like to see a landscape with good representation of all age classes; however, the numbers of stands and area in each age-class may be a contentious issue. Environmental proponents would like to see age-class distributions within historical ranges, while industry foresters driven by economic considerations would like a forest where stands are harvested at their best economic value or before significant volume losses start to occur in each stand. The rule of thumb being discussed today for forest management is to follow the inverse "J" relationship. Typically, the inverse "J" area-over-age relationship has a relatively large area in younger age classes and progressively less area as ages increase. Past areas in each age class are now being determined from fire disturbance records. The natural fire return cycle for the study area was identified at approximately 80 years. Therefore, the majority of the landscape would be in stands that range from 0 to 80 years; however, this does not preclude the potential for some stands to be about 200 years old e.g., overmature white spruce stands.

The forest age-class issue is being dealt with in MWFP's forest management planning process through use of a forest scheduling and harvesting model that better simulates and controls the age at which stands are harvested as well as the spatial implementation of a two-or-three-pass cutting system. The two-pass cutting system, for example, means that for example only half of a large stand's area would be harvested initially, with a significant delay before the other half could be harvested.

When the DPM model is implemented and results become available, they will aid the strategic forest planning team by allowing the visualization of the impacts of timber harvest strategies on moose. This model like the others will allow planners to do what-if analysis based on different management strategies, wood product requirements, harvest levels, silvicultural systems, road access constraints but the DPM has the added benefit of examineing issues around predation control and hunting restrictions. Two factors that have significant impacts on the moose population but have not been modelled before in forest management planning.

The results can be used to argue for a certain type of timber harvest prescription, changes to forest harvest licenses, e.g. amalgamating licenses or reducing the licensing complexities, changes to provincial legislation e.g. increasing clear-cut sizes, removing the two-pass harvest system, managing predators and resetting moose harvest limits.

Model Dynamics and its Implcations to Managers

The results presented for the CFMP-WHSIM, HHM and DPM show strong fluctuations in the first fifty years for the BHS and HHS after which the results stabilize or level out. There are strong dynamics in the first fifty years because of the starting age-class structure of the forest. Initially the majority of the forest is considered mature or overmature, but by the middle of the simulation the age-class structure is considered young, i.e., <=60 years. This shift in age classes occurred parallel to a shift in species composition and growth rates. The new forest had higher growth rates and stocking values on average because of silviculture, which produced more wood. Therefore, the forest produced higher wood volumes from each hectare of land. The increased volume/ha in later periods allowed the model to harvest less area then at the start of the simulation to meet its LRSY target. Since the carrying capacity models are area-based, an increase in the area harvested at the start resulted in more food, which translates to higher moose densities. Furthermore, as the area harvested declined because of higher volumes/ha in the future the number of moose/km^2 also declined. Therefore, once the forest was normalized into younger age-classes (e.g. <=60 years) there was very little change in the food or cover variables because the area harvested from period to period remained relatively constant.

The implication for managers is that in the first fifty years there will be a rapid increase in moose/km^2, followed by a decline and then a subsequent rise.

These large fluctuations have implications to moose hunters and predators, both of whom will be happy initially as populations increase. However, once the decline starts forest managers will be questioned to explain where all the moose have gone. To avoid such conflicts forest managers could lower harvest rates initially and then raise rates as the new forest comes online. Alternatively, forest managers could be more proactive with advertisements indicating what is likely to happen in the near future. Future conflicts could be avoided or minimized through those two efforts.

Model Uncertainties and its Implications to Managers

To lessen uncertainty from a manager's perspective, Nyberg (1990) suggests that: (a) managers work closely with model developers; (b) the builders provide clear and concise documentation; (c) the model should be practical; and finally (d) it should be validated against results from the real world.

With respect to this thesis, a manager should become concerned over a model's usefulness when results appear inconsistent with professional knowledge. Such was the case with the WWHSIM in this project. Specifically, the WWHSIM showed a decline in moose carrying capacity for all scenarios. Those results went against present knowledge that suggests when a disturbance occurs (e.g. timber harvesting), the moose population usually increases. The converse is also true, if results show moose/km^2 are too high, i.e. values greater than 5-6 moose/km^2 which are considered the best in Canada, then the results are suspect or invalid. Both problems indicate errors in the model being executed, because they produce results that are outside the realm of normality, as we know it.

From the results presented for the small landscape analyzed, the forest managers and/or planning team should conclude that timber harvesting operations tend to have a positive impact on moose/km^2 in the study area. I conclude this because three of the four models showed an increase in moose/km^2.

To increase one's level of comfort around the predicted results, a monitoring program should be established to reduce uncertainty in each of the models. The monitoring program should target model inputs and relationships to which model outputs were sensitive and where the level of uncertainty is high, because we lack key knowledge or understanding of the system. Therefore, several monitoring programs should be set up to reduce uncertainty.

To reduce uncertainty in the CFMP-WHSIM, one should examine and ground-truth the relationship between the amount of food available in each development stage and cover type (Table 1) since that variable has the most uncertainty. Uncertainty can be reduced in the HHM and the DPM by examining and ground-truthing the browse and early winter cover index curves because those curves have a significant impact on model results. Finally, the WWHSIM could be improved by a re-evaluation of and changes to its main components and then a re-implementation to check its results.

Moose Model Comparisons to Other Moose Model Studies

HSI Model Comparisons

The WWHSIM and the CFMP-WHSIM were compared to the moose model developed for the Manitoba Model Forest (MMF) (Terrestrial & Aquatic

Environmental Managers Inc. 1995). The MMF moose model uses the Habitat Evaluation Procedure developed by the U.S. Fish and Wildlife Service. All three models have the same winter HSI format i.e., winter food HSI determination, winter cover HSI determination, and then an aggregating equation which adjusts winter food by 0.65 and cover 0.35, the results of which are combined.

A major difference between the model in this thesis and the MMF moose model is that MMF model does calculations to determine both a summer and winter HSI value, each of which are then multiplied by 0.5 and finally added together for an overall HSI value for a particular cell. A strong advantage of the MMF model is the use of a geometric mean calculation of HSI variables when one of the variables is 0.0 and would force the net HSI to zero.

The MMF method takes a mean of all variables including zero values when one of the component input variables is zero inorder to forestall the occurrence of a zero HSI result. Subseqently, a zero HSI would only occur if all the component variables are zero. It is my assumption that there would have been higher moose carrying capacity values had that technique been employed in the WWHSIM when one of its' component variables went to zero. Through time the number of 0 values increased in both the food and cover HSI data layers resulting in lower moose carrying capacity values. By the middle of the simulation (2096), 75% of the cover HSI values were 0, and by the end (2196) that value had risen to 90%.

Higgelke Habitat Model

The early-winter component of the HHM used in this thesis was compared to Higgelke's original thesis work on the Aulneau Peninsula (Higgelke 1994). The simulation and results can only be compared for the first 25 years since Higgelke's work only simulated 25 years.

I found similar results to Higgelke (1994) in the first 25 years. Results from my work and his show a decline in moose carrying capacity from 0-10 years followed by a increase in moose between 11-25 for the early-winter when heavy timber harvest takes place in both simulations. There were also similarities between the results from my BHS and his guidelines scenario; both simulations show a slight increase in moose carrying capacity values from 0-25 years.

Higgelke's (1994) and my results with high timber harvest levels result in a minimum moose carrying capacity value of approximately 2.2 moose/km^2 ten years after the start of the simulation. However, my starting values were 2.741 vs Higgelke's of 4.05 moose/km^2, indicating that Higgelke's implementation of the model had early-winter values drop significantly more than my run over the same time period. The differences between the two could be linked to the differences in habitat types, or my food and cover curves were too generous.

Duinker Population Model Comparison

The DPM used in this thesis was compared to Duinker *et al.* (1996) results with hunting active. Duinker *et al.* (1996) results for the DPM with two timber harvest levels and a no-harvest control predicted moose population values between 0.05 and 0.1 moose/km^2. Futhermore, there was also very little fluctuation in this results over 100-year simulation. The results from my work have moose population values that range from 1.7 to 4.3 moose/km^2 and the simulation displays stronger fluctuations than those in the Duinker *et al.* (1996) results.

The major difference between the two implementations is the effect of the condition of the habitat ecosystems. The Duinker *et al.* (1996) implementation was on a poorly drained, clay belt, Boreal landscape in Lake Abitibi Model Forest in Ontario populated by large black spruce stands and few forage areas. My study area is a moderately well drained, Alberta foothills, Boreal mixedwood landscape that has good browse-producing areas. Another difference between the two implementations that would affect the results at each time interval of the simulation is the size of the landscape analysed. Duinker *et al.* (1996) applied the model to a landscape of 795,660 ha while my study area is 10,495 ha. Duinker *et al.* (1996) simulation smoothed out the local effects at the regional level by using an area mean, which was not done in my implementation. It is my belief that if the two habitats were similar in type and size, then the resulting moose populations would be similar.

Possible Improvements in the Moose Carrying Capacity Models Used

Weldwood Winter Habitat Suitability Index Model Improvements

The implementation of the WWHSIM could be improved by using the averaging approach developed for the MMF moose model to forestall the occurrence of 0.0 HSI results. The other component that needs improvement is the determination of food based on shrub cover which was derived from stand stocking. This problem should be fixed when the new inventory becomes available, because it will have an air-photo interpreter's judgement of the actual shrub canopy if one is present. From those interpretations the shrub variable will be improved and should better represent reality.

Chair in Forest Management and Policy Winter Habitat HSI Model Improvements

The main improvement recommended for the CFMP-WHSIM is the inclusion of the averaging function to correct for 0.0 HSI values. The other variables to examine in greater detail are the bonus values for pipeline corridors and stand complexity. Their impact on the final results for the study area were insignificant; however, they may play a bigger role when adjacent forest areas are considered, because there appear to be more such corridors in areas outside the study area than in. The impact of the stand complexity variable will certainly increase, because more detailed attention is being paid to it in the field cruising part of the inventory process. The results will be included in the new inventory dataset.

Higgelke Habitat Model Improvements

The strongest improvement to the HHM is a lowering of uncertainty with respect to kilograms of browse per hectare in different stand types and the adjustment of early-winter cover curves to reflect MWFP's forest license area. This could be accomplished through a field sampling program or a workshop with experts who are familiar with the browse production potential in Alberta. I expect that lowering these uncertainties will improve the model's predictive output. Higgelke (1996) recognized these aspects when consulted and suggested that the new inventory process be adjusted to capture that.

Duinker Population Model Improvements

The DPM would also benefit from the suggestions to the HHM above, since the DPM uses the food values output from the HHM. Other improvements to the

DPM is the gathering of information to implement the other-mortality component of the model, through workshops with moose biology professionals. Other mortality factors include such things as diseases, ticks infestations, estimates of Aboriginal hunting rates, poaching rates and road kills. Once those variables are better accounted for, I feel that the DPM will better represent the dynamics of the moose population in the MWFP license area.

CONCLUSIONS

The objectives of this study were to (1) calibrate three moose models, (2) apply the models to forecast moose populations, (3) evaluate model performance and finally (4) to draw conclusions with respect to strategic forest planning. Objective (1) was enhanced to four models which were the Weldwood Winter Habitat Suitability Index Model (WWHSIM), Chair in Forest Management and Policy Winter Habitat Suitability Index Model (CFMP-WHSIM), Higgelke Habitat Model (HHM) and the Duinker Population Model (DPM). The models were applied, as stated in objective (2), to projected forest inventory data and moose population or moose carrying capacity values were obtained. In objective (3), model performance was examined with respect to model assumptions, variable integrity to sensitivity analysis, model integrity to sensitivity analysis, a model comparison and contrast of model assumptions, inputs and results against each other and against other moose model studies. Finally, objective (4) conclusions with respect to forest planning were accomplished.

The model results associated with objective 3 were diverse. One model indicates that timber harvesting in the study area is "bad" for moose while three others say timber harvesting is "good". The WWHSIM indicates that timber harvesting is detrimental for moose, but would probably indicate that timber harvesting were neutral or beneficial if variables that were zero where replaced with values close to zero i.e. 0.01 to keep the model from producing zero HSI values which does not really occur in nature. The results from the other three models indicate that harvesting is beneficial for moose, a conclusion that is generally consistent with the moose literature. What is not clear, or easy to determine, is which of the three models is *"most accurate"* in its predictions. The ultimate way to determine which of the models is *"correct"* is to follow the model's predictions and moose inventories through time to see which model's predictions are following the real moose populations most closely.

If through time we find that one model tracks reality better than the others, then the confidence in using that model will be higher, but we should not disregard the other models, because they can still provide useful insights into the nature of the real relationships between moose and their habitat. Therefore, it is important to have multiple models tracking the system one are interested in (Lee 1993), as well as multiple hypotheses about how the system works (Holling 1978) in an adaptive management framework.

The choice to use model-to-model comparisons as a validation technique was based on my contention that if different models produced the same general outputs from the same general inputs, then the models are supporting each other's general conclusions. In this thesis that conclusion was that moose populations will rise in the face of a timber harvesting disturbances which is consistent with data from the literature.

To be clear I was not looking for a perfect numbers match e.g. all models said that moose/km^2 will increase 1.5 times; rather, I was looking for confirmation of a trend e.g. moose/km^2 will rise. I found that confirmation between three of the models, while the fourth was considered invalid.

My thesis results indicate that I am on the right track with respect to the modelling exercise; however, it is now important to focus on how much the moose numbers might actually increase. The DPM, HHM and the CFMP-WHSIM predict approximate long-term moose CC values of 3.6, 2.8 and 1.8 respectively. Now, given the spread of the numbers and my knowledge of moose and what people have told me, I would indicate to forest managers and the planning teams that if they chose the BHS strategy, I would expect to see a 2 and 2.8 moose/km^2 increase on the landscape over the long term i.e. 50 years or more. If the HHS were chosen, then I would expect to see higher initial values followed by a lower overall values than the BHS because more of the forest is in younger age classes which is less conducive to moose growth. Pursuant to that statement I would strongly suggest a rigorous monitoring program to reduce the uncertainty associated with some of the model variables and a re-evaluation of these models as new information become available.

Futhermore, model validation by model comparison becomes a useable validation technique when the models were created by various authors. All the model authors took available information and created an abstraction of a natural system independently, which they believe to be valid and applicable. The models they created are normally validated on their own to see if they represent a system or function in a predictable way. Therefore, if multiple models by various authors indicate a trend, one may have relatively high confidence that the trend is valid. I believe it is the trend which is important in model-to-model comparisons. In this thesis three of the four models point in the same direction i.e. moose populations rise when harvesting is initiated. It is my contention that comfort level regarding a model's prediction rises when different models indicate the same results. One always feels better when independent sources state the same general feeling or conclusion.

The adaptive management process will allow MWFP's forest managers to adapt to errors in management or changes to environmental conditions faster and more confidently than any other management styles. The learning and adaptation takes place faster because of the internal feedback loop from estimating impacts and then monitoring for them to see if the two coincide. This thesis project is only one part of a larger project examining and projecting the possible impacts of different timber harvest strategies on numerous wildlife species. These results and others are to be used in strategic forest management planning for MWFP license areas in an adaptive management framework. The work completed in this thesis provides estimates of what could happen to moose populations given the different harvesting levels. To determine which of the models is "correct" we need to implement the different timber harvesting strategies outlined in this thesis (or other ones) in several areas and monitor via aerial moose inventories to see which model best predicts the fluctuations in the moose population over the years and decades to come. Futhermore, the monitoring procedures should also include other species or environmental indicators that are thought to be indicators of ecosystem health and vigour.

Invalidation is an important criterion in deciding whether to state that a model is valid. In doing this project and given the results, I have three models indicating that harvesting timber results in higher moose densities while one shows the opposite-more cutting, less moose. I would have to say that the WWHSIM is invalid because it preforms contrary to the other three models. The reasoning for this invalidation harkens back to the discussion of multiple model comparisons previously.

Looking at the issue of invalidation from a probability standpoint it is more likely that the WWHSIM is wrong than the other three, given that all four models were developed by different groups or individuals. It is in the interest of each author to do the best possible job they can given the best data, tools, and knowledge available. However, as a student of science I can not ignore the possibility that the opposite is true i.e. the other three models are wrong and the WWHSIM is correct. Therefore, it behooves me to investigate why each model acted as it did and discover why they disagree. It was through such a process that I discovered the problem with zero HSI components that force the aggregated HSI values to zero in the WWHSIM and some parts of the CFMP-WHSIM.

It is known that deterministic and stochastic models behave erratically after start-up. This irregularity was noted in the DPM and was accounted for by having it start 100 years before present with a basic food supply and initial parameters that would allow it to equilibrate before the derived food values started to change at time 0 and above. Conversely, the other three models took data as it was without any equilibrium period and started to produce moose densities. The results show that the greatest fluctuations occur between 1996 and 2046 before settling down after that time.

I have confidence in 3 out of 4 model's ability to predict moose habitat carrying capacities in both time periods because the models are following the changes that are occurring in the age-class structure and species composition of the forest through time. Initially, once cutting starts there is a great influx of food and sufficient late-winter cover is present. Therefore, the potential for a population increase exists and that is observed in the results. However, once several decades have passed and the amount of good to excellent late-winter habitat declines, we see a drop in moose densities and a subsequent period of stable moose densities. The decline and stable period in moose densities is linked to the normalizing of the forest that occurs during forest harvesting. This normalized forest support a lower number of animals compared to the first peak that occurs forty years from now, because its age-class distribution and species mix is more favourable to foresters than moose. The normalized forest is unfavourable to moose because it is populated by younger age-classes which are growing rapidly and are not defined as favourable late-winter cover. Therefore, one would expect the moose densities to be lower and this was observed in the results. The initial increase in moose densities occurs because the harvesting creates feeding areas in a habitat short on food but still retains significant portions of favourable late-winter habitat.

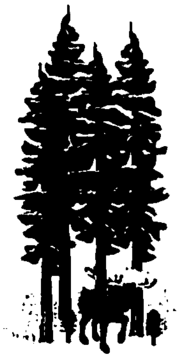
A point of concern with this thesis was the small study area which was used to determine the forest harvest levels and then the moose population values. Work in this thesis indicates that on a small study area, differences between the models that utilized the HSI format i.e., WWHSIM and CFMP-WHSIM tend to have less variation in their simulation results through time than does the HHM or the DPM. I expect those differences to reduce as the size of the area under investigation increases because of the windowing function applied in the HHM and DPM with larger landscapes. The averaging of values over the landscape should smooth out the peaks and valleys that were present in my results. The final results should display the long-term trends without the noise that was present in my implementation of those models. The only caveat with increasing the land area analysed is that the processing time increases, potentially in the order of days to finish one model's simulation. If multiple forest management strategies are being examined, the use of a simple raster-based HSI model may be the most appropriate because of faster processing time and the level of accuracy required for large-scale planning. Since the objective is strategic forest management planning, the scale of rasters employed should equal 200*200 m instead of the mixed 100*100m and 200*200m used in thesis, because of the smaller study area.

To answer the question of which hypothesis is correct, I accepted that hypothesis two, i.e. "the models make substantially different predictions for moose carrying capacity" (page 4) is correct. I chose hypothesis two because the models do make significantly different predictions of moose/km^2. This decision is based on the fact that the WWHSIM was considered invalid, since it showed a decrease in moose/km^2 while the others showed an increase in moose/km^2 after disturbance. Moose density increases after disturbance are considered the norm based on field studies and other modelling exercises (Higgelke 1994, Terrestrial & Aquatic Environmental Managers Inc. 1995, Duinker *et al.* 1996). Furthermore, the three models that do indicate increased moose densities showed significant differences in their results.

Any work that involves modelling should examine model invalidation, since it is a major criteria in determining if a model is useful. Model invalidation is a process by which a model, its components or its results can be considered invalid because they produce or show a response or behaviour that is inconsistent with known facts. To invalidate a model, it is best to set up tests at different levels i.e. model assumptions, model variables, model components, and overall model output (Schamberger and O'Neil 1986).

Of all of the models examined in this thesis, the WWHSIM was considered invalid because it presented a response i.e. moose/km^2 that declined after a disturbance which is considered incorrect given present biological knowledge. The declining response can be traced back to the model's calculation procedure i.e. model components (Schamberger and O'Neil 1986) HIS (Food) = $S1 \cdot S2 \cdot S3$ and HIS (Cover) = $S3 \cdot S4 \cdot S5 \cdot S6$ which were considered incorrect because it failed to deal with "S1-6" components that went to zero and created a zero HSI for either food or cover which is not a good representation or reality.

From undertaking this thesis project, it is my opinion that the DPM would provide the most useful information regarding moose population health for long-term strategic forest management planning, while the other two winter habitat suitability index models are best suited to indicate the effects of different harvesting levels on late-winter habitat. The latter are also more applicable in areas where snow depth is more limiting. Finally, the HHM is a mix of the other two model types and therefore excels at neither function i.e. predicting population levels or indicating the loss or expansion of late-winter habitat. It does, however, show components of both and how they are affected by different harvesting levels.



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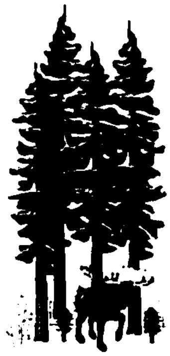


APPENDIX 1 MOOSE

History

Alces is Latin for elk and that monicker was given to the "European Moose" as its genus, species and subspecies name by Linnaeus in 1758 (Peterson 1955). Since then, *Alces alces alces* has been used to identify an animal that is uniquely adapted to live in challenging ecosystems of the north hemispheres. In North America the common name "Moose" for *Alces alces* originated from the Algonquin word "Musee" meaning "eater of twigs" (Stelfox 1993).

Moose first appear in the fossil record during the late Pliocene or early Pleistocene Epoch in Europe (Telfer 1984). From Eurasia the species spread into the northern hemisphere, arriving in North America approximately 80,000 years ago (Peterson 1955; Stelfox 1993). Across North America, moose evolved into four subspecies: *Alces alces americana* Clinton, *Alces alces andersoni* Peterson, *Alces alces gigas* Millar and *Alces alces shirasi* Nelson (Peterson 1955; Telfer 1984). The subspecies modelled this study is *Alces alces andersoni*, because it is the natural resident of the study area in central Alberta (Figure A1-1).

Distribution

Alces Alces gigas is a resident of Alaska and the Western Yukon. *A. alces shirasi* is found in southwestern Alberta and south into Wyoming, Idaho and western Montana. *A. alces andersoni* has the largest range reaching from the Central Yukon in the northwest to Thunder Bay in the east where it inhabits the Boreal forest zone. *A. alces americana* exists between Thunder Bay in the west to

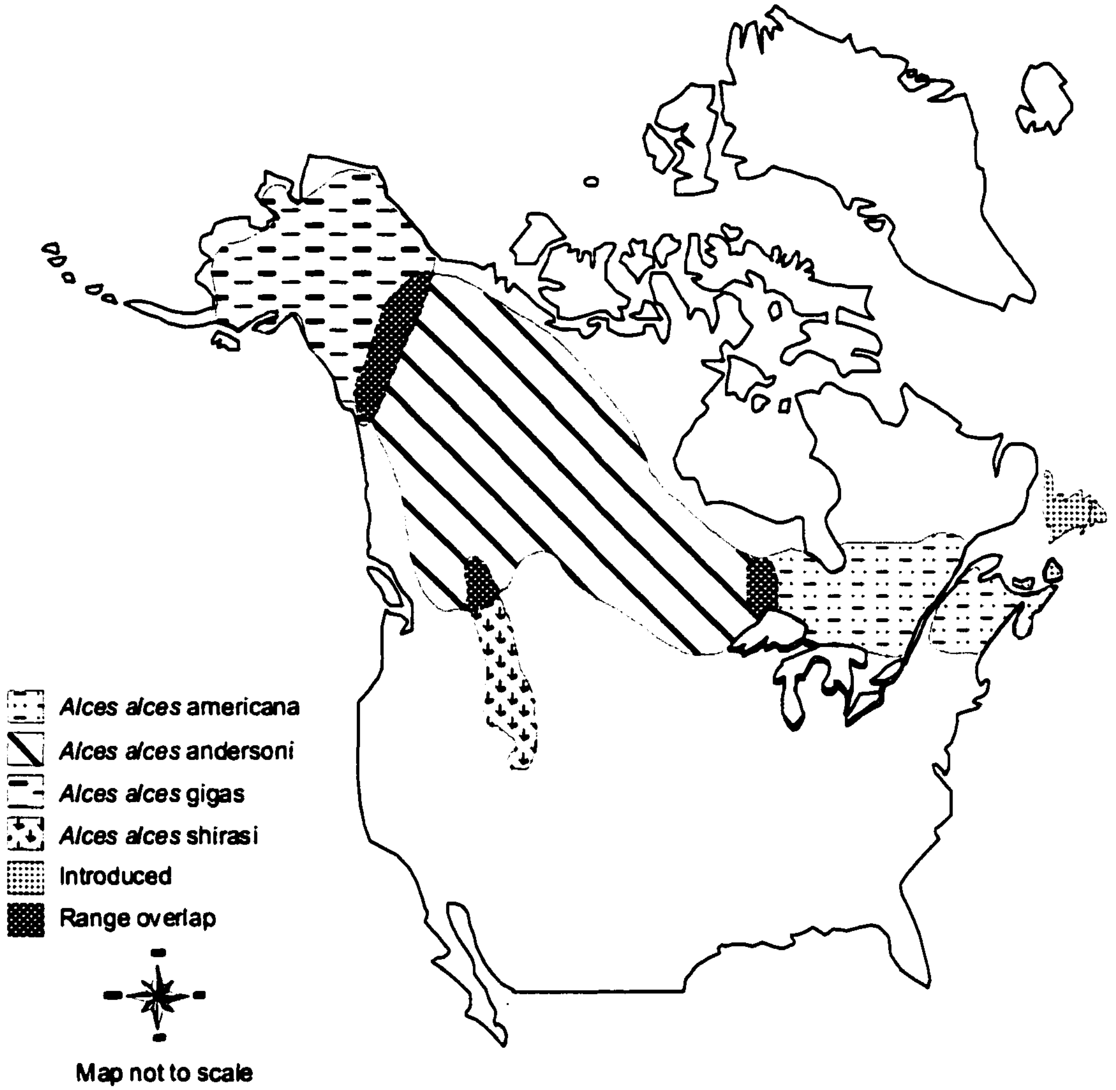


Figure A1-1: Distribution of Moose in North America. Source: Peterson 1955

Maine and Nova Scotia in the east (Figure A1-1) (Peterson 1955). *Alces alces americana* was introduced into Newfoundland in 1878 and 1904 (Pimlot 1953).

Telfer (1984) suggested that, globally, moose are potentially excluded from the southern hemisphere by two factors: the 20°C isotherm that occurs in summer, and a roundworm parasite of moose called the brain worm *Parelaphostrongylus tenuis* (Irwin 1985). The brain worm is lethal to moose, but not to deer, *Odocoileinae spp.*, its normal host (Stelfox 1993). Of the two constraints, the 20°C isotherm is likely the most important limiting factor for defining the southern range for moose (Renecker and Hudson 1986a). During past glaciations the range of moose extended further south (Peterson 1955); however, moose was probably still limited by the two constraints mentioned above.

Today, as in the past, moose occupy the same habitat regions globally. Their numbers have been reduced in various districts of their range, particularly in Europe, while in North America, moose have maintained most of their historic distribution. In certain areas, the range has extended via reintroduction efforts (Figure A1-1) (Telfer 1984; Kufeld and Bowden 1996).

Habitat Characteristics

Telfer (1984) states that moose are limited by landform, climate, food supply, predation and human activities. However, within those constraints they have found suitable habitats. Globally moose habitat has been generalized into five categories: the Boreal Forest zone, the Mixedwood Forest, the Tundra and Sub-Alpine Shrub Communities, Flood Plains, and the Stream Valley Shrub Riparian zone (Telfer 1984).

The Boreal Forest

The Boreal forest complex is a glaciated landscape; it is therefore hummocky with a conglomeration of lakes, bogs, and evergreen dominated forest areas (Telfer 1984). In the Boreal forest, timber harvesting, fires, and some insect outbreaks are the dominant disturbances that influence habitat for moose. Browsing habitat is normally its best 10-20 years after a disturbance (Telfer 1984); however, the same disturbance may have removed another necessary component of their habitat, such as late-winter cover.

The Boreal forest is the largest contiguous forest zone in Canada. It forms a continuous belt from Newfoundland in the east to the Rocky Mountains in the west, and northward to Alaska (Hosie 1979). At the northern limit the forest is dominated by stunted coniferous species. The middle section is a mix of coniferous and deciduous species while at the southern limit deciduous species dominate. South of the Boreal forest is the Mixedwood forest zone east of the prairies.

The Mixedwood Forest

Mixedwood forests are situated between the Deciduous forest and the Boreal forest. Mixedwood forests are composed of evergreen and deciduous tree and plant species that can form mixed or discrete stands. Fire is not considered a dominating force in this zone; therefore, gap dynamics and understory shrubbery play a major role in providing moose with suitable accessible browse (Telfer 1984). The gaps are produced from insect and disease outbreaks, wind throw and occasional fires. This forest type provides moose with a permanent year-round habitat that is quite suitable (Telfer 1984).

The Tundra and Sub-Alpine Shrub

Tundra and sub-alpine shrub communities are found along river courses in tundra areas of Ungava, and in the northern mountainous areas of the Northwest Territories, the Yukon and parts of Alaska (Telfer 1984). Although tundra and sub-alpine shrub communities have low productivity, all forage is palatable and available for browsing by moose. These spartan regions have severe winters which cause mortality to moose (Telfer 1984).

The Flood Plains

Flood plains, or alluvial habitats, are considered the optimum habitat for moose. Telfer (1984) describes them as "*stable unstable*" habitats. They are stable during the lifetime of moose because there is a constant food source, but unstable because of annual flooding and the meandering habit of rivers (Telfer 1984). The seasonal flooding and the meandering habit of rivers prohibits the development of a mature forest, thereby creating ideal browse procurement areas for moose.

The Stream Valley Shrub Riparian Zone

Stream valley shrub riparian habitats occur in mountainous regions such as the Rocky Mountains that cover British Columbia, Alberta and the Yukon. These stream valley habitats are dominated by riparian areas populated with *Salix spp.* (Telfer 1984). Moose can survive here year-round or migrate to higher or lower elevations as environmental conditions change and latitude dictates (Telfer 1984). The elevational movement by moose is an adaptive response to escape heavy snowfall and find suitable thermal tolerance zones (Telfer 1984).

Habitat Productivity Levels

Of the habitat types outlined by Telfer (1984), the optimum habitat for moose is comprised of large flood plains; conversely the most marginal habitats are located in stream valley shrub riparian and Boreal forest habitats, while the tundra sub-alpine shrub and mixedwood forest habitats fall in the middle. The study area for this thesis is composed of upland Boreal forest habitat.

Seasonal Habitat Types

Moose obtain two main things from their habitat: food and cover. These items must be secured from the landscape at all points in the year. The amount of food obtained from the landscape varies across time and space as does the type and density of cover required. The juxtaposition of both components in the landscape is important to moose survival and growth. Moose generally have four range types: spring, summer-fall, early-winter and late-winter (Telfer 1984). These types are normally found within the home range of most moose; however, moose have been known to migrate to fulfil habitat requirements (Rolley and Keith 1980; Telfer 1984; Ballard *et al.* 1991). Cederlund and Okarma (1988) found that cow-calf groups tended to avoid mature stands and bogs while clear cuts and young stands were preferred, presumably taking advantage of the large quantities of browse. Leptich and Gilbert (1989) and Schwab and Pitt (1990) indicated that habitat choice is closely linked to heat and cold stress avoidance in an effort to conserve energy.

Spring Habitat

Spring range for cow moose consists of lowland bogs (LeResche *et al.* 1974; Leptich and Gilbert 1989), and islands or peninsulas (Peterson 1955). Cows may choose these areas for calving because they confound predators, offer the opportunity for escape by water (Peterson 1955), and provide higher quality food earlier in the year because they are the first areas to green up (Berg and Phillips 1974; Cederlund and Sand 1994). The early green-up of these areas provides female moose the opportunity to replenishes body reserves; therefore, this habitat type may be the most important for cows who have recently given birth or are still pregnant (Hauge and Keith 1981).

Summer - Fall Habitat

Summer ranges are usually close to water bodies containing aquatic plants. For two reasons, one moose need the sodium that is contained in the aquatic plants and two, the water acts as a haven from insects (Flook 1959 as cited in Timmermann and McNicol 1988), and as a cooling agent, while the edges of lakes and bogs provide a large quantity of high quality browse plants. The amount of time spent near aquatic feeding areas by moose was found to be proportional to the presence of aquatic feeding areas in the landscape (Leptich and Gilbert 1989).

During summer and fall, moose get the most energy from their food supply with the least cost (Renecker and Hudson 1986b). For moose that live in non-mountainous areas, summer is the time of greatest activity (Phillips *et al.* 1973) and general dispersal across the landscape (Telfer 1984). The summer range is usually the largest of the four ranges utilized (Phillips *et al.* 1973; Cederlund and Okarma 1988; Ballard *et al.* 1991).

Early-Winter Habitat

Normally, early-winter habitat has a high component of available browse and some form of thermal protection. Early-winter ranges for moose can be characterized in some locations as concentration areas. Concentration areas are places that have high quantities of accessible woody browse, are young in age, have some type of east or south exposure and some elevational change. Concentration areas are considered the optimum habitat type for moose during early-winter. Bulls are usually the first to arrive in early-winter areas and are therefore more numerous than cows (Hauge and Keith 1981). Bulls are there to replenish fat reserves lost in the rut (Peek *et al.* 1976). Similarly, cows are there to gain back energy lost from giving birth and/or nursing calves.

In Alberta, Stelfox *et al.* (1995) found that young aspen stands contained a higher number of animals (0.61/km^2) than did mature aspen stands (0.37/km^2). Similar results were found by Nowlin (1978) and Rolley and Keith (1980). Alternatively, where young aspen stands are infrequent, moose search out gap areas in denser stands (Stelfox *et al.* 1995) or treed muskeg areas (Hauge and Keith 1981) for feeding.

A regression analysis of habitat characteristics by Schwab and Pitt (1990) found that food availability and type are the main reasons why some early-winter habitats are chosen over others. As Telfer (1984) stated, river valleys and deltas are preferred locations during early-winter. Similar results have been found by others who did telemetry work on moose (Boonstra and Sinclair 1984; Ballard *et al.* 1991; Gasaway *et al.* 1992).

Late-Winter Habitat

Late-winter habitat satisfies several requirements for moose. It provides thermal protection from heat stress, reduction of wind chill factors and cold stress in northern areas, and lower and softer snow packs for easier locomotion (Balsom *et al.* 1996). Such late-winter habitat characteristics are normally found in dense conifer stands (Telfer 1970; Van Ballenberghe and Peek 1971; Peek *et al.* 1976). In some habitats, late-winter cover is plentiful but the specific stand choice is strongly related to food availability (Schwab and Pitt 1990).

The major trigger which initiates the movement of animals to late-winter habitat varies with geographic location, climate, and animal condition. From the literature two factors appear key: thermal protection and snow pack. However, in their regressions Schwab and Pitt (1990) found that food availability is also significant.

Thermal protection is important because moose become heat-stressed when ambient temperatures rise above their thermal tolerance limits of -5°C to -2°C (Renecker and Hudson 1993). At this time moose find dense coniferous stands favourable because their ambient temperatures are below moose thermal limits. Futhermore, the dense stands keep wind chills from exceeding moose low thermal tolerance of -30°C (Renecker and Hudson 1986a). Snow pack is important because lower snow loads allow for easier food gathering and predator avoidance.

According to a literature review by Balsom *et al.* (1996), snow packs become important to moose when they are >65 cm deep since mobility becomes restricted at that depth. When snow packs exceed 90 cm, the ability of moose to move becomes severely limited. In areas where snowfall is heavy and travel is impeded, moose may move into forested muskeg with clumps of *Picea mariana* (black spruce) (Rolley and Keith 1980) where travel is thought to be easier. Conversely, when snow packs are not as deep, mobility is not restricted and moose may remain in their early-winter habitat much longer (Ballard *et al.* 1991).

In drier climates, such as in Alberta, moose move into larger aspen stands (Phillips *et al.* 1973), with closed-canopy where snow packs are shallower and softer (Telfer 1970; Peek *et al.* 1976; Nowlin 1978; Rolley and Keith 1980; Hauge and Keith 1981; Stelfox *et al.* 1995), and browse-producing open shrub lands (Cairns and Telfer 1980). Studies in Minnesota indicate that moose leave late-winter cover once the majority of the snow has gone (Phillips *et al.* 1973) and move into spring habitat.

The use of dense coniferous cover is not necessarily limited to late-winter as moose have been known to enter this habitat during times of heat stress in the summer (Timmermann and McNicol 1988; Jackson *et al.* 1991; Demarchi and Bunnell 1995) when the habitat is near good summer feeding areas.

Movement Patterns

The movement patterns of moose are governed by several factors: food, thermal cover, escape cover, slopes, aspect, traditional use areas, and snow depth (Ballard *et al.* 1991). The most important factor is snow depth; as snow depth increases, movement decreases (Hauge and Keith 1981; Thompson and Vukelich 1981; Ballard *et al.* 1991).

The daily activity patterns of moose vary with time of year, time of day and night-time light levels. Some researchers indicate that the activity level of moose is highest at sunset, with spring and summer being the most active times during the year (Phillips *et al.* 1973; Best *et al.* 1979). However, other studies indicate that their activity is greatest during the morning and night (Van Ballenburg and Miquelle 1990) and another states that night is the most active for bulls during the rut (Phillips *et al.* 1973). Night-time activity seems related to the amount of available light. When skies are clear and the moon is full, there appears to be more activity (Phillips *et al.* 1973).

Home Ranges

Moose are thought to exhibit a strong bond to certain areas of their habitat since they relocate there annually (Gasaway *et al.* 1980; Cederlund and Okarma 1988; Leptich and Gilbert 1989; Ballard *et al.* 1991). Habitat homogeneity and uniformity in elevation is thought to result in a more resident moose population than where the habitat is more heterogeneous (Cederlund and Okarma 1988).

The sizes of bull moose home ranges in Sweden were found to be related to their ages; the size of a bull's home ranges increases with age (Cederlund and Sand 1994). Cederlund and Sand (1994) thought that this observation was related to the greater social activity during the rut. Similarly, the largest home ranges for cow moose in the Northwest Territories were found in autumn but those home range sizes were not significantly different than at other times (Stenhouse *et al.* 1995).

The home range sizes of cow and calf groups are smaller than those of bulls during the spring (LeResche *et al.* 1974; Ballard *et al.* 1980 in Ballard *et al.* 1991;

and Cederlund and Sand 1994). In addition, Leptich and Gilbert (1989) found that summer home range sizes were not different between the sexes even when cows had calves. Cederlund and Sand (1994) suggested that this disparity in spring home range size between cow calf groups and bulls is linked to nutritional demands.

The mean home range size for cow moose near my study site is 39 km^2 (Table A1-1). The Alberta average from two studies is 68 km^2 . This value is lower than the overall average value of 79 km^2 for studies found. The overall means identified in Table A1-1 masks the differences among seasons. As discovered by Phillips *et al.* (1973) in Minnesota, the seasonal home ranges varied from 11 km^2 for cows and 9 km^2 for bulls during the summer and fall, to winter ranges of 2 km^2 for cows and 1.9 km^2 for bulls.

Biology

Moose are the largest members of the deer family *Cervidae*. Large adult bulls have weights up to 650 kg (Stelfox 1993). In Alberta, the average weight, body length and shoulder height for bulls are 450 kg, 274 cm and 190 cm, respectively, while cows average 418 kg, 185 cm, and 188 cm for the same measurements respectively (Stelfox 1993).

Moose have a life expectance of approximately 25 years in the wild (Stelfox 1993). Bulls produce antlers annually that weight 35 kg on average once they are fully mature. The size of antlers is dependent on age and condition of an animal. Antlers start growth in the spring and they become fully developed by August or September. During development, antlers are covered by a velvet-like skin that contains blood vessels carrying nutrients to the growing antlers. Once the antlers

Table A1- 1: Mean home range sizes moose from selected studies.

Mean Home Range Size km²	Sex Collared	Study Area	Source
13	C	Sweden	Cederlund and Okarma 1988
20	C + B	Sweden	Cederlund and Sand 1994
10	C + B	Minnesota, Northwestern	Phillips *et al*. 1973
43	C + B	Ontario, Northwest	Addison *et al*. 1980
97	C + B	Alberta, Northeast	Hauge and Keith 1981
39	C	Alberta, Central	Lynch and Morgantini 1984
174	C	Northwest Territories, Mackenzie Valley	Stenhouse *et al*. 1995
290	C	Alaska, South-central	Ballard *et al*. 1991
40	C	Alaska, Southeast	Doerr 1983
68		Alberta	Average
79.4		All Studies	Average

C = Cows, B = Bulls

Source: Adapted from Table 4, Stenhouse *et al*. 1995 are fully developed they are freed from the velvet when moose rub them on shrubs and trees. Antlers can be cast between November and March; however, the majority fall off between December and February (Peterson 1955).

Nutrition

Moose are considered browsing ruminants, because their food sources are generally plants other than grasses. The food is cut by incisors, crushed by molars and passed down the esophagus to the rumen. The rumen is the first chamber of a four-chambered stomach used by ruminants to break down vegetable matter. The rumen is a fermenting vessel that uses bacteria in a symbiotic relationship to break down larger food fragments; the bacteria have enzymes that break down cellulose and other complex sugars into digestible sugars. The finer particles from the rumen are passed into the reticulum for further fermentation and breakdown. Food particles from the reticulum are passed to the omasum. The omasum is the separator between the fermenting chambers of the rumen and reticulum and the acidic environment of the abomasum (Robbins 1993). The omasum also absorbs water and some nutrients. The abomasum is the true stomach where enzymatic and acid hydrolysis break down fine food particles (Robbins 1993). Finally, the food particles are passed into the small and then the large intestine for nutrient and water absorption (Robbins 1993).

The dietary requirements of moose vary with the time of year. In the spring before leaf out, moose diet consists mainly of woody browse species and leaf litter (Stelfox 1993). After leaf out in late spring and early summer, moose consume large amounts of aquatic vegetation. The amount of aquatic plants consumed is proportional to their availability in the habitat (Aho and Jordan 1976). During the summer, moose will feed on the current year's growth of preferred browse species, aquatic plants and herbaceous plants (Table A1-2). In fall their diet consists predominantly of woody browse species, and finally in winter, their diet is dominated by evergreen and deciduous woody browse (Histol and Hjeljord 1993; Stelfox 1993).

Aquatic plants are eaten because they contain higher levels of salts, specifically sodium, than terrestrial vegetation. The salts obtained from aquatic plants are essential minerals required for basic metabolism. If aquatic plants are in short supply or mineral licks are readily available, moose will increase their sodium levels by frequenting mineral licks to consume water, dirt and/or rocks high in sodium (Telfer 1984; Belovsky and Jordan 1981).

In summer, non-lignified plants, i.e. forbs, account for 25% of moose diet, while browse, a lignified plant material, accounts for the rest. Since summer food is highly digestible, moose are only moderately selective in their food choices at this time (Renecker and Hudson 1986b). In fall, the studies examined by Stelfox (1993) showed variation in the amounts of browse and forbs consumed. The percentage of woody browse consumed ranged from 55-100% depending on the study. During this time and later into early-winter, moose become more selective by choosing foods that have greater digestibility (Renecker and Hudson 1986b). In early-winter, the diet is predominantly woody browse, but Renecker and Hudson (1986b) stated that if moose can muzzle through the snow layer to fallen leaves, they will consume them. Unfortunately, normal freeze-thaw action which produces snow crusts often precludes this action.

Table A1-2: Food plants of moose from selected studies in North America.

Food type	***Common Name***	**Scientific Name**	**Study Authors**							
			Ritcey and Verbeek 1969	Peek 1974	Peek *et al*. 1976	Nowlin 1978	Thompson and Vukelich 1981	Crete and Jordan 1982	Fraser *et al*. 1984	Irwin 1985
Woody Browse Plants	Red-osier dogwood	*Cornus stolonifera*	x		x	x	x			x
	Mountian maple	*Acer spicatum*			x		x	x	x	x
	Mountian ash	*Sorbus spp.*			x		x			
	Willow	*Salix spp.*	x		x	x	x	x	x	x
	Balsam fir	*Abies balsamea*			x		x	x		
	White birch	*Betula papyrifera*			x	x	x	x		x
	Trembling aspen	*Populus tremuloides*			x	x	x	x	x	x
	Beaked hazel	*Corylus cornuta*			x	x	x	x		x
	Juneberry	*Amelanchier spp.*			x	x	x	x		x
	Balsam poplar	*Populus balsamifera*			x	x	x			
	Alder	*Alnus spp.*			x	x	x			x
	Raspberry	*Ribes spp.*					x			x
	Vibrunums	*Viburnum spp.*				x	x			
	Honeysuckles	*Lonicera spp.*					x			
	Cherry	*Prunus spp.*			x	x	x	x	x	x
	Red Maple	*Acer rubrum*								x
	Black spruce	*Picea mariana*					x			
	Tamarack	*Larix spp.*					x			
	White spruce	*Picea glauca*					x			
	Elderberry	*Sambucus spp.*					x			
	White cedar	*Thuja occidentalis*					x			
Aquatic Plants	Millfoil	*Myriophyllum spp*		x					x	
	Bladderwort	*Utricularia vulgaris*		x					x	
	Pondweed	*Potamogeton spp.*	x	x					x	
	Bur-Reeds	*Sparganium spp*	x						x	
	Horsetail	*Equisetum spp.*	x							
	Pond lily	*Nuphar spp*		x						
	Water lilly	*Nymphaea spp*							x	
Herbaceous Plants	Clover	*Trifolium spp.*								
	Indian paint brush	*Castilleja spp.*								
	Bunchberry	*Cornus canadensis*								x
	Primrose	*Epilobium spp.*								x

Several studies have examined the consumption rate of food by moose during the summer with varying results. Belovsky *et al.* (1973) found that moose consumed 4.2 kg of dry weight forage/day for the summer. Similarly Gasaway and Coady (1974) recorded 4.6 kg/day and Verme (1970) found that 4.6 - 5.4 kg/day were consumed.

The winter consumption rate was lower than in summer averaging 3.6-4.6 kg/day (Verme 1970; Gasaway and Coady 1974). Gasaway and Coady (1974) suggested that the lower rates are related to slower digestion times of woody browse. The lowest values found in the literature are by Hjeljord *et al.* (1994) who found that cow moose on good to medium quality winter ranges consumed 10 - 17 kg/day of wet weight browse, which translates to 2.0-3.4 kg/day of dry weight browse assuming a 80% moisture content and a digestibility of 40%.

The daily activity of moose is linked to browse quality, because when forage quality declines, the amount of time spent ruminating increases, the feeding areas become smaller and the amount of browse consumed is larger (Sæther and Andersen 1990). Generally, moose spend >90% of their day foraging, resting/ruminating or walking between bedding sites (Stelfox 1993).

Several authors have determined that digestible energy and crude protein are important components in food for moose (Oldemeyer *et al.* 1977; Stelfox 1993). Of the browse that is consumed, Timmermann's (1990) review found that somewhere between 29.6 and 72.7% of the summer food is digestible, while only 27.1-51.3% of winter food is digestible. This compares well with Hjeljord *et al.* (1994) as discussed previously. A review of several studies by Timmermann and McNicol (1988) found that crude protein reaches its highest value, 36%, in May and falls linearly to 7% by October, where it remains until leaf out in spring.

As stated previously, moose obtain the majority of their nutrients from aquatic plants, woody browse, and forbs. The most common food species across studies are *Betula papyrifera,* white birch; *Salix spp*., willow; *Acer spicatum*, mountain maple; *Popular tremulodies*, aspen; *Corylus cornuta*, beaked hazel; and *Amelanchier spp*., juneberry (Table A1-2). From Nowlin's (1978) fall and winter study in Alberta, *Amelanchier spp*. and *Salix spp*. were the species most preferred by moose.

Energy Budget

Renecker and Hudson (1986a) studied several moose individuals and found a seasonal change in the body weight for both sexes. In the spring and early summer (May - early July), cows and bulls gained an average of 1.03 kg/day and 0.90 kg/day respectively. During the summer (mid July - late August), weights of both sexes declined slightly or were static. During the rut (September - October), bulls lost up to 1.3 kg/day while cows lost 0.70 kg/day. In early-winter (November - early January), cows and bulls regained some of their lost weight, but then in late-winter (Mid January - late March) their body mass declined by 7-25% . This decline in body mass is a result of poor food quality and moose' limited ability to seek forage due to snow conditions. A survival strategy developed by moose is to lower their metabolic rate during late-winter to minimize weight loss and thereby conserve energy (Renecker and Hudson 1986a).

Activity Budget

Renecker and Hudson (1989) studied two cow moose for a year. In the spring, both animals spent 53.9% of the day bedded, mostly ruminating. Feeding activity consumed 42% on average for the year. The amount of time spent feeding peaked in spring at 45%. Feeding time peaks in spring because it is the time of year when food quality, availability and energy needs are the highest. Energy requirements are high for cows because of lactation. From spring the amount of time spent feeding declines slowly through the rest of the year (Renecker and Hudson 1989).

Energy Expenditure

Belovsky and Jordan (1978) studied moose energy expenditures rates at Isle Royal, Michigan, and found that moose have a daily metabolic energy requirement of 170 kcal/kg$^{0.75}$/day. This translates into approximately 14,000 kcal/day for the average moose (Duinker *et al.* 1996).

In Alberta, the resting metabolic rate (RMR) for moose outlined by Stelfox (1993) is 768 kJ/kg$^{0.75}$/day in spring. Therefore, on a daily basis an average bull or cow would utilize 184 kcal/kg$^{0.75}$/day. This value climbs linearly from spring to a midsummer high of 984 kJ/kg$^{0.75}$/day (235 kcal/kg$^{0.75}$/day). The rate then declines to 648 kJ/kg$^{0.75}$/day (155 kcal/kg$^{0.75}$/day) at the start of autumn. From the start of autumn to late-winter the rate declines further but less rapidly to a low of 600 kJ/kg$^{0.75}$/day, (144 kcal/kg$^{0.75}$/day) (Table A1-3). The Belovsky and Jordan (1978) values are lower than the numbers identified by Stelfox (1993) (Table A1-3).

Table A1-3: Energy intake and expenditure values for moose from selected studies.

	Energy $Kj/kg^{-0.75}/day$				
Fasting metabolic rate	**Spring Summer**	**Early Winter**	**Late Winter**	**Sex**	**Source**
	940^3		430^4	C and B	Renecker and Hudson 1985
310 - 450 μ = 380^5	904			C and B	Regelin *et al*. 1985
			552	C and B	Regelin *et al*. 1985
356^6				C and B	Regelin *et al*. 1985
768^9	768^7 - 984^8	648^9	600^9		Stelfox 1993
		573 - 803^1 μ = 688	533^2	C	Hjeljord *et al*. 1994
		414 - 920^1 μ = 667	414 - 920^1 μ = 667	Ca	Hjeljord *et al*. 1994
			594 - 705 μ = 649	C	Schwartz *et al*. 1988
368	922	677.5	566.2		Averages

[1] range from poor habitat to good habitat

[2] *early winter mean reduced by* 22.5% *from a range of* 15-30% reduction from early winter to late winter Hjeljord *et al*. 1994

[3] Maximum value found

[4] Minimum value found

[5] Estimate of fasting metabolic rates from November to April

[6] Estimate of fasting metabolic rates from Summer

[7] Spring resting metabolic rate

[8] Summer resting metabolic rate

[9] Resting metabolic rate

C = Cows, B = Bulls, Ca = Calves

Stelfox's (1993) low rate of 600 kJ/kg$^{0.75}$/day for winter is almost twice the value that Regelin *et al.* (1985) found in Alaska for moose in March at 360 kJ/kg$^{0.75}$/day; however, values at other times of the year for RMR found by Regelin *et al.* (1985) are similar to Stelfox (1993).

Life Cycle

Moose cows give birth to their young in the latter part of May and into June. The calves are born in secluded places such as islands, peninsulas (Peterson 1955), or in high spots of swampy areas (LeResche *et al.* 1974). Calves range from 11-20 kg at birth (Peterson 1955). Peterson (1955) found that cows will protect their calves from predators. Calves will stay with their mothers for 14 months (Ballard *et al.* 1991). If calves remain with the mother after the 14 months, they are driven away by aggressive behaviour of cows or bulls during the rut (Ballard *et al.* 1991).

Once on their own, yearlings will generally stay in the same area as the mother until they become sexually mature. A literature review by Peterson (1955) indicated that some cows reach sexual maturity around 16 months and produce offspring the next year but the majority are not successful at carrying a calf until they have reached 4 years of age (Stelfox 1993). Furthermore, Rolley and Keith (1980) found better twinning rates with older cows. Conversely, males generally do not start breeding until their sixth or seventh year even though they have been sexually mature since their second year (Peterson 1955). This may occur because larger bulls can out-compete the young bulls for cows.

Average sex ratios and twinning percents in Alberta are 68, 38.9 and 37% for calves:100 cows, bulls:100 cows and twinning percent, respectively (Table A1-4).

Table A1-4: Sex ratios and twinning rates for moose from selected studies in North America.

Calf:100 Cow Ratio	Bull:100 Cow Ratio	Twinning Percent	Study Area	Time of Year of Study	Source
37		$\mu = 12$	Newfoundland	F & W	Pimlot 1959[1]
17		10	Isle Royale	F	Peterson 1977[1]
59		3	Montana	Su	Peek 1962[1]
54		3	Montana	W	Stevens 1970[1]
59		5	Wyoming	W	Houston 1968[1]
82		$\mu = 33$	Alberta, Fort McMurry	Sp	Hauge and Keith 1981
106	80	$\mu = 41$	Alberta, Rochester	W	Rolley and Keith 1980
86	40		Alberta, Unhunted Aspen Parkland	W	Bjorge 1996
74	47		Alberta, Hunted Aspen Parkland	W	Bjorge 1996
55	49		Alberta, Wildlife Management Unit 346	W	Hall *et al*. 1975[1]
55	23		Alberta, Wildlife Management Unit 346	W	Birkholz and Cook 1982
47	18		Alberta, Wildlife Management Unit 346	W	Smith *et al*. 1988
39	15		Alberta, Wildlife Management Unit 347	W	Anon 1993
17		$\mu = 8$	Alaska	F	Faro and Franzmann 1978
38		$\mu = 14$	Alaska	W	Spencer and Chatelain 1953[1]
37			Alaska	W	Bishop and Rausch 1974[1]
113		$\mu = 32$	Mackenzie Valley, Northwest Territories	Sp	Stenhouse *et al*. 1995
47	35	< 1.0%	Newfoundland, Barrens 1983	W	Albright and Keith 1987
33	20	< 1.0%	Newfoundland, Barrens 1984	Sp	Albright and Keith 1987
68.0	38.9	37.0	Alberta		Averages
55.5	36.3	16.1	All Studies except Newfoundland		Averages

F = Fall, W = Winter, Sp = Spring and Su = Summer

[1] as cited in Rolley and Keith 1980

Source: Adapted from Table 5, of Rolley and Keith 1980

Alberta's values are greater than the overall averages of 55.5, 36.3 and 16.1 for calves:100 cows, bulls:100 cows and twinning percent respectively. For my study area which is part of Wildlife Management Unit 346 (WMU 346) and Wildlife Management Unit 347 (WMU 347), there has been a drop from 49 bulls:100 cows to 15 bulls:100 cows between 1975 and 1994 (Smith *et al.* 1988). A similar result is found in the calves:100 cows ratio, however; the decline is not as precipitous as the bulls:100 cows ratio. These values indicate that the population is in decline in that part of the province. The decline may result from human, wolf/bear, or human and wolf/bear additive mortality.

***Predators of* Moose**

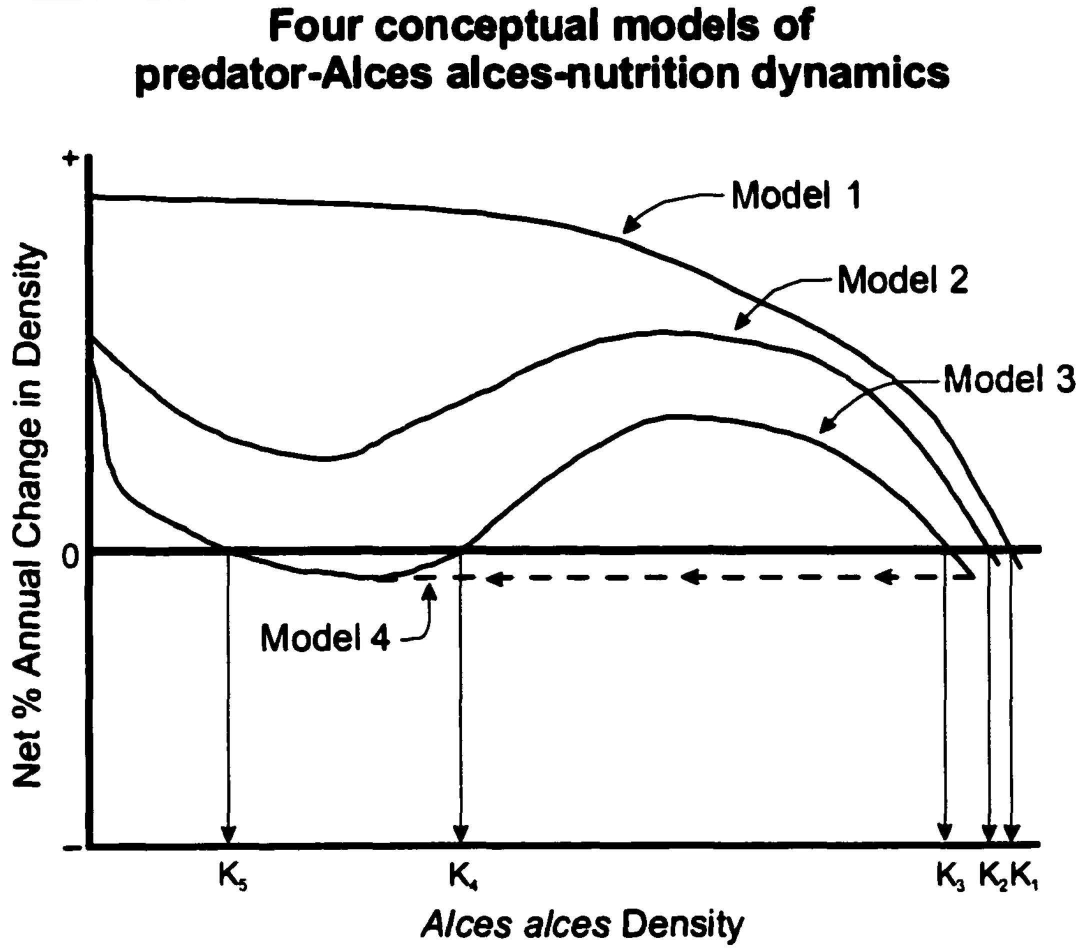
Moose are targeted for food by humans *(Homo erectus)*, cougars *(Felis concolor)* wolves *(Canis lupus)*, grizzly bears *(Ursus arctos)* and occasionally black bears *(Ursus americanus)*. Of the bears, *U. arctos* are the most successful predators because of their larger body size. In fact, moose can make up to 92% of *U. arctos* diet in a year (Boertje *et al.* 1988; Ballard *et al.* 1991). Black bear predation is highest when calves are under two months of age (Franzmann *et al.* 1980). Gasaway *et al.* (1983) found that predation of moose by wolves, grizzly or black bears, and in some areas cougars individually or in some combination, have a large impact on moose populations.

Gasaway *et al.* (1983) identified wolf predation rates between 13 and 34% for the winters and summers of 1973-74 and 1974-75. Hauge and Keith (1981) found that wolves take 29% of the calves annually while 39% of the first month's mortality was attributed to black bears. Peterson's (1955) review revealed that

Canis lupus were more likely to attack moose in late-winter when snow depth and crusting hinders their prey's movements. However, stomach analysis by Gasaway *et al.* (1992) found that moose made up to 29% of a wolf's diet during the spring and summer. When moose are the main prey species, their density in the landscape can be a major controlling factor on population levels of predators (Gasaway *et al.* 1992) exclusive of humans.

Pimlot (1967) hypothesized, and is supported by Bergerud *et al.* (1983) and Gasaway *et al.* (1983), that in *Canis lupus* and moose systems, the number of moose and *C. lupus* may stabilize at low predator and prey densities. It is thought by Messier (1984) that when densities of *moose* reach 0.2/km^2 and there are no other prey present, this population density of moose maybe the lowest density that can support the existence of a wolf pack.

Gasaway *et al.* (1992) put forward four conceptual models of predator-prey dynamics based on work by Messier and Crete (1985). Conceptually, the models predict different moose population levels that are possible when it is the only food source being preyed upon by no predators, wolves only, bears only, and both wolves and bears. Briefly, when no predators are present moose populations are close to the landscape's carrying capacity (Figure A1-2; Model 1). When one predator is present the carrying capacity is slightly lower than carrying capacity (Figure A1-2; Model 2). When two predators are present, there is the possibility of two equilibrium points: one at a low density (Figure A1-2; Model 4), and the other at the higher moose density (Figure A1-2; Model 3).



Assumptions:	Predator populations are assumed to be unharvested or lightly harvested, and moose are the primary food source of the predators.
Model 1:	Predators are absent, moose populations fluctuate near K carrying capacity (K_1).
Model 2:	Where a single predator species occurs or both black and grizzly bears occur, moose densities fluctuate near K_2.
Model 3:	Where bears and wolves occur, two or more relatively stable equilibria are possible; high-density, nutrition-induced equilibrium (K_3) fluctuates near carrying capacity and the low density dynamic equilibrium LDDE (K_4) is maintained by predation. Additional one or more unstable equilibria are possible between K_5 and K_4.
Model 4:	Where bears and wolves occur, moose densities fluctuate near LDDE (K_4). If rare natural events allow moose to increase above LDDE, then moose may follow model 3 to a higher density but will return to the LDDE via a series of years with negative net change in density (dashed line). These negative net changes would likely result from periodic severe winters and predation.

Figure A1-2: Predator Prey Nutrition Model for Moose from Gasaway *et al.* (1992).

If the population of moose in model 3 is at the lower density of K_4 and they had several good years with high quality food and easy winters, they may attain a higher moose density equilibrium of K_3. The high density of moose in model 3 at K_3 may return to the lower equilibrium of K_4 or model 4 if severe winters occurred in successive years (Figure A1-2). The described models seem to be gathering favour with researchers in the field (Gasaway *et al.* 1992).

For managers, these models have strong implications. If wolves keep moose at the lower population density K_4, managers have two options to increase the herd. One is to wait possibly decades before the moose population recovers naturally. Alternatively managers can intervene and remove some of the predators so that the population can move towards K_3 (Gasaway *et al.* 1983). However, success of this measure could be thwarted if environmental conditions change or another predator appears.

Population Densities

Moose densities vary depending on predation, habitat and climate. Generally moose densities for sub-arctic, better Boreal and exceptional habitats are 0.1, 0.1-0.3 and 0.4-1.0 animals/km^2 (Telfer 1984). Many studies (Table A1-5) found the density of moose populations across North America and Europe to vary from 0.2/km^2 to 5.6/km^2. The overall average from studies in Alberta is 0.95 animals/km^2 which is slightly lower than the total overall average of 1.01 animals/km^2 for all studies identified. When the highest and lowest values are excluded, the overall average is 0.88.

The density of moose found in WMU 346 was 0.70 (Hall *et al.* 1975), 0.85 (Birkholz and Cook 1982), 0.72 ± 32.2% (Smith *et al.* 1988) moose/km^2, for the years 1975, 1982, and 1988 respectively (Table A1-5). The most recent survey was in February 1993 for WMU 347, an area 10 km to the northwest of the study area which returned 0.45 ± 19.8% animals/km^2 (Anon 1993). The data underpinning these values were collected with a rotary-wing aircraft using a stratified system in 1988 and 1993 and a square-block system in 1975 and 1982.

Hunting Pressure

The ability of moose to deal with human hunting pressure is enhanced when predator control is exercised (Gasaway *et al.* 1992). Humans can produce a cyclic predator-prey response similar to moose-wolf cycles by preying heavily when the food population is high and less when the food population is low or declining (Ferguson and Messier 1996). This response may become unpredictable when humans control predators, hunt and manipulate the landscape simultaneously. Under these conditions, a moose population may grow large enough that food does become the limiting factor (Van Ballenberghe and Ballard 1994) model 1 K_1 or the population could crash and follow model 4 K_5 (Figure A1-2).

Humans were the largest source of bull mortality in the Ballard *et al* (1991) study. Ferguson and Messier (1996) found that humans had the highest hunting success rates in Newfoundland when moose densities were at 1.4 animals/km^2. Gasaway *et al.* (1983) found that harvest rates for Alaska were between 6 and 19% annually and the mean harvest rate equalled the mean yearling recruitment.

Table A1-5: Moose densities from selected studies.

Alces Alces / km2	Study Location	Source
0.31 - 1.15 μ = 0.73	Sweden	Sand *et al*. 1995
4.7	Newfoundland	Bergerud and Manuel 1968
0.5 - 4.1 μ = 2.4	Newfoundland	Oosenburg and Ferguson 1992
0.78	Newfoundland 1973	Albright and Keith 1987
0.8	Newfoundland 1984	Albright and Keith 1987
0.0 -0.1 μ = 0.005	Labrador, Goose Bay	Trimper *et al.* 1996
0.2	Québec, Southwest	Messier 1984
0.4	Québec, Southwest	Messier 1984
1.5 - 2.6 μ = 2.0	Michigan, Isle Royal	Peterson 1977
0.4	Ontario, Northwest	Bergerud *et al*. 1983
0.18	Alberta, Northeast	Hauge and Keith 1981
0.225	Alberta, Northeast	Fuller and Keith 1980
0.016 - 0.75 μ = 0.38	Alberta, Northeast	Rolley and Keith 1980
0.18	Alberta, Aspen Parkland Eco-Region	Bjorge 1996
0.7	Alberta, Wildlife Management Unit 346, 1975	Hall *et al*. 1975[2]
0.85	Alberta, Wildlife Management Unit 346, 1982	Birkholz and Cook 1982[2]
0.72	Alberta, Wildlife Management Unit 346, 1988	Smith *et al*. 1988
0.45	Alberta, Wildlife Management Unit 347, 1994	Anon 1993
1.2	Alberta, Shiningbank study area	MacCallum 1983[1]
0.89	Alberta, Shiningbank study area	Wingert 1984[1]
0.56	Alberta, Shiningbank study area	Smith and Myrholm 1985[1]
0.79	Alberta, Shiningbank study area	Smith and Edmonds 1988
5.6	Alberta, Elk Island National Park	McGillis 1972
1.3	Alberta, Northwest, 1977 - 1979	Bjorge and Gunson 1989
0.7 - 0.8 μ = 0.75	Alberta, Northwest, 1972 - 1975	Bjorge and Gunson 1989
0.47	Alberta, Apsen Mixedwoods	Stelfox *et al*. 1995
0.16	Northwest Territories, Mackenzie Valley	Stenhouse 1995
0.8	Alaska, South (Kenai Peninsula)	Peterson *et al*. 1984
0.71	Alaska, South-central, 1980 mean	Ballard *et al*. 1991
0.84	Alaska, South-central, 1983 mean	Ballard *et al*. 1991
0.95	Alberta	Average
1.01	All Studies	Average

[1] as cited in Brusnyk and Westworth (1988)

[2] as cited in Smith *et al*. (1988)

Source: Adapted from Table 3, of Messier (1984)

Similarly, Albright and Keith (1987) found harvest rates of 19% which account for 76-100% of adult mortality.

The success rate for legal hunters in Alberta averages 18% during the past half-century, it has risen over the decades from 10% in the 1950's through 15% in the 1960's to 22.5% during the 1970's and 1980's. This value is similar to findings by Albright and Keith (1987) above.

The estimated average population of moose in Alberta from 1950 to 1991 was approximately 147,786 up from the average of 113,778 between 1980 to 1991 (Table A1-6). Overall, the moose population was in decline from the late 1980's to the early 1990's according to statistics gathered by Stelfox (1993). The harvest data for the study area specifically (Table A1-7) show that. The average number of male and antlerless moose harvested between 1984 and 1987 is 455.5 and 116.5 respectively. The average hunter-days per male and hunter-days per antlerless animal are 42.6 and 9.7, respectively The ratio of hunters to male and hunters to antlerless moose is 6.6:1 and 3.24:1 with a combined hunter to animal ratio of 6.05:1. On average it takes 33.0 days for a hunter to harvest a bull but only 7.9 days to harvest a cow in WMU 346.

The mortality associated with Aboriginal hunting is hard to estimate (Hauge and Keith 1981). However, "*Alberta Fish and Wildlife Division recognizes that the annual harvest of big game by Indians and poachers is at least equivalent to licensed fall harvest by hunters*" (Stelfox 1993, page 117). Therefore, in 1991 9,000 animals were estimated to be removed from the population by unregistered hunters. If the above statement is true, the impact to moose is significant and it

Table A1-6: **Hunting tag allocation, sport hunting take, percent hunting success and population estimates for moose in Alberta, 1952 - 1991.**

Year	Estimated Sport Harvest	Hunting Tags Sold	Percent Hunting Success	Population Estimate
1952	2740	N/A	N/A	N/A
1953	514	6628	7.8	N/A
1954	684	8853	7.7	N/A
1955	5540	25068	22.1	N/A
1956	2173	28697	7.6	N/A
1957	2554	33590	7.6	N/A
1958	3538	45576	7.8	N/A
1959	3496	47250	7.4	45000
1960	4465	62398	7.2	N/A
1961	4486	59504	7.5	N/A
1962	5129	67915	7.6	N/A
1963	4975	65302	7.6	N/A
1964	4527	59111	7.7	N/A
1965	3313	42373	7.8	N/A
1966	9483	48756	19.4	N/A
1967	7427	62029	12.0	N/A
1968	17318	48729	35.5	N/A
1969	20161	53631	37.6	N/A
1970	13686	57406	23.8	N/A
1971	14291	59699	23.9	N/A
1972	10764	44661	24.1	N/A
1973	12948	54359	23.8	N/A
1974	7432	41960	17.7	250000
1975	8488	41758	20.3	250000
1976	9339	44052	21.2	250000
1977	10547	42258	25.0	250000
1978	14387	59606	24.1	N/A
1979	12930	65482	19.7	N/A
1980	14200	63635	22.3	118000
1981	14846	65106	22.8	120000
1982	14506	63971	22.7	120000
1983	14410	63662	22.6	120000
1984	8622	53677	16.1	118000
1985	9839	56148	17.5	120000
1986	14151	59893	23.6	118000
1987	14110	59196	23.8	N/A
1988	14371	58920	24.4	100000
1989	13233	56919	23.2	N/A
1990	11796	48586	24.3	90000
1991	10463	36785	28.4	N/A
Average 1950 - 1959	2655	27952	10	45000
Average 1960 - 1969	8128	56975	15	N/A
Average 1970 - 1979	11481	51124	22	250000
Average 1980 - 1991	12879	57208	23	113778
Average 1950 - 1991	9297	50337	18	147786

Source: **Adapted from Table 8.2, of Stelfox (1993).**

Table A1-7: **Post-harvest data for moose wildlife management unit 346 in Central Alberta from 1984 to 1987.**

Year	License Type	Number of Hunters	Total Hunter Days	Number of Hunter Days / Animal	Number of Animals Harvested
1984	M	2538	18643	48.6	383.6
	A	N/S	N/S	N/S	N/S
	C	2538	18643	48.6	383.6
1985	M	3077	17965	42.7	420.7
	A	409	979	10.1	96.9
	C	3486	18935	36.6	517.3
1986	M	3050	18835	30.9	609.5
	A	208	563	13.1	43.0
	C	3258	19398	29.7	653.1
1987	M	3360	19720	48.3	408.3
	A	516	1216	5.8	209.7
	C	3876	20936	34.0	615.8
	Sum M	12025.0	75163.0	170.5	1822.2
	Sum A	1133.0	2758.0	29.0	349.6
	Sum Total	13158.0	77921.0	199.5	2171.7
	Average M	2405.0	15032.6	42.6	455.5
	Average A	377.7	919.3	9.7	116.5
	Average of M + A	3289.5	19478.0	37.2	542.5

Success Ratio H:M	6.6:1
Success Ratio H:A	3.24:1
Success Ratio H:C	6.05:1
Hunter Days Ratio D:M	33.0:1
Hunter Days Ratio D:A	7.9:1
Hunter Days Ratio D:M + A	35.9:1

M = Male, A = Anter-less, C = Combined, H = Hunters, D = Days

Source: Adapted from Table 4, of Smith *et al*. (1988).

puts into question any type of management strategies that have been cooperatively worked out between stake-holders other than First Nations and the government.

From historical information, Kay (1997) found that it was not until Aboriginal populations were decimated by diseases and resettlement programs were instituted by governments that moose populations increased throughout North America. From archeological evidence, moose and other ungulate populations were only healthy in areas between warring nations or in refugia (Kay 1997). This statement suggests that aboriginals were a significant predator to moose in areas controlled by one aboriginal nation. In areas external to those moose populations were healthier, because the threat of being attacked by another nation while hunting was not beneficial to hunting or the vitality of the community.

When hunting is sanctioned and controlled by governments, it is important that the tag allocation reflect the observed age-sex ratios. Otherwise the additive mortality of hunting when numerous predators are present may initiate a population decline (Van Ballenberghe and Dart 1982).

Economic Return from Hunting

Moose are a sought-after game species in North America. The income they produce for local and regional economies is significant. In Alberta, between 1981 and 1982, each resident moose hunter spent $376.09 while the non-resident hunter spent $1024.08 on a season's hunting opportunity in Alberta (Stelfox 1993). Total expenditures for 1981-1982 for resident and non-resident hunters was $24,485,715 and $1,530,999 dollars respectively. Therefore, the greatest economic activity generated is from resident hunters who purchased 65,106 licenses, while nonresidents only purchased 1,495 (Stelfox 1993). In 1991, outfitted big-game hunters contributed $11,676,600 dollars while the whole outfitting industry contributed $23,082,400 dollars to the provincial economy of Alberta (Stelfox 1993). Therefore, it is safe to assume the majority of the money being spent by hunters is staying in local or regional communities where hunters purchase their supplies and lodging while hunting.

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APPENDIX 2

Duinker Population Model supporting information.

Equation 5

$$\text{Total Energy}_{w,i} = \text{Available Forage}_{w,i} \cdot \text{Unit Size}_{w} \cdot \text{Energy/Forage}$$

Equation 6

$$\text{Available Energy}_{w,i,s,a} = \frac{\text{Total Energy}_{w,i} \cdot \text{Animals}_{w,i,s,a}}{\sum_{s=0}^{1} \sum_{a=0}^{10} \text{Animals}_{w,i,s,a}}$$

Equation 7

$$\text{Maintenance Energy}_{w,i,s,a} = \text{Daily Maintenance Energy}_{n,s,a} \cdot \text{Weight}_{w,i,s,a}^{0.75} \cdot \text{Season Length}_{n} \cdot \text{Animals}_{w,i,s,a}$$

Equation 8

$$\text{Energy Surplus}_{w,i,s,a} = \text{Available Energy}_{w,i,s,a} - \text{Maintenance Energy}_{w,i,s,a}$$

Equation 9

$$\text{Weight}_{w,i,s,a} = \text{Weight}_{w,i-1,s,a} + \frac{\text{Energy Surplus}_{w,i,s,a}}{\text{Growth Energy}_{s,a}} \qquad \text{if Energy Surplus}_{w,i,s,a} >= 0$$

$$= \text{Weight}_{w,i-1,s,a} + \frac{\text{Energy Surplus}_{w,i,s,a}}{\text{Loss Energy}_{s,a}} \qquad \text{otherwise}$$

$$\text{Weight}_{w,i,s,a} = \text{Max Weight}_{n,s,a} \qquad \text{if Weight}_{w,i,s,a} > \text{Max Weight}_{n,s,a}$$

Equation 10

$$\text{Other Mortality}_{w,i,s,a} = \text{Other Mortality Rate}_{n,s,a} \cdot \text{Animals}_{w,i,s,a}$$

Equation 11

$$\text{Target Cow Harvest}_{i} = \text{Cow Harvest Rate} \cdot \sum_{\text{all } w} \sum_{a=1}^{10} \text{Animals}_{w,i,s,a} \qquad \text{if } i \in \text{fall}$$

Equation 12

$$\text{Target Bull Harvest}_{i} = \text{Bull to Cow Harvest} \cdot \text{Target Cow Harvest}_{i} \qquad \text{if } i \in \text{fall}$$

Equation 13

$$\text{Target Calf Harvest}_{i} = \text{Calf to Cow Harvest} \cdot \text{Target Cow Harvest}_{i} \qquad \text{if } i \in \text{fall}$$

Equation 14

$$\text{Prop Access}_{wi} = \frac{\sum_{f=0}^{3} \text{Access Factor}_f \cdot \text{Forest Area}_{wif}}{\sum_{f=0}^{3} \text{Forest Area}_{wif}} \qquad \text{if } i \in \text{fall}$$

Equation 15

$$\text{Hunting Mortality}_{wisa} = \frac{\text{Target Calf Harvest}_i \cdot \text{Animals}_{wis0} \cdot \text{Prop Access}_{wi}}{\sum_{\text{all } w} \sum_{s=0}^{1} (\text{Animals}_{wis0} \cdot \text{Prop Access}_{wi})} \qquad \text{if } a=0$$

$$= \frac{\text{Target Bull Harvest}_i \cdot \text{Animals}_{wi0a} \cdot \text{Prop Access}_{wi}}{\sum_{\text{all } w} \sum_{s=0}^{10} (\text{Animals}_{wi0a} \cdot \text{Prop Access}_{wi})} \qquad \text{if } a>0 \text{ and } s=0$$

$$= \frac{\text{Target Cow Harvest}_i \cdot \text{Animals}_{wi1a} \cdot \text{Prop Access}_{wi}}{\sum_{\text{all } w} \sum_{s=0}^{10} (\text{Animals}_{wi1a} \cdot \text{Prop Access}_{wi})} \qquad \text{if } a>0 \text{ and } s=1$$

Equation 16

$$\text{Births}_{wi} = \sum_{a=0}^{10} \text{Animals}_{wi1a} \cdot \text{Fecundity}_{wia} \qquad \text{if } i \in \text{spring/summer}$$

$$= 0 \qquad \text{otherwise}$$

$$\text{Weight}_{wis0} = \text{Birth Weight} \qquad \text{if } i \in \text{spring/summer}$$

Equation 17

$$\text{Animals}_{wis0} = (1 - \text{Sex Ratio}) \cdot \text{Births}_{wi} \qquad \text{for } i \in \text{spring/summer } s=0$$

Equation 18

$$= \text{Sex Ratio} \cdot \text{Births}_{wi} \qquad \text{for } i \in \text{spring/summer } s=1$$

Table A2-1: Variable descriptions used in the Duinker Population Model.

Variable	Description
s	Index representing sex (0=males, 1=females)
a	Index representing moose age class (11 classes: ages 0-10+)
ii	Index representing seasonal model time step (4 census periods for each year of simulation, corresponding to the seasons spring/summer, fall, early winter, and late winter
n	Index representing seasons (0=spring/summer, 1=fall, 2=early winter, 3=late winter)
f	Index representing forest age class (0=ages 0-10, 1=ages 11-20, 2=ages 21-30, 3=ages 31-40)
w	Index representing habitat window
Total Energy$_{w,i}$	Total metabolizable energy supply for the population in period i and window w (kcal)
Available Forage$_{w,i}$	Density of available forage (dry weight) in period i and window w (kg/ha)
Unit Size$_w$	Total area of the habitat window w (ha)
Energy/Forage	Metabolizable energy per unit of available forage (kcal/kg)
Available Energy$_{w,i,s,a}$	Metabolizable energy available, in period i and window w, for cohort with sex s and age a (kcal)
Animals$_{w,i,s,a}$	Number of animals, in period i and window w, for cohort with sex s and age a (number of animals)
Weight$_{w,i,s,a}$	Mean animal weight, in period i and window w, for cohort with sex s and age a (kg)
Maintenance Energy$_{w,i,s,a}$	Total metabolizable energy required for maintenance, in period i and window w, for cohort with sex s and age a (kcal)
Daily Maintenance Energy$_{n,s,a}$	Daily maintenance metabolizable energy required per unit of metabolic body weight, in season n, for cohort with sex s and age a (kcal kg$^{-0.75}$/days)
Season Lenght$_n$	Duration of season n (days)
Energy Surplus$_{w,i,s,a}$	Total surplus metabolizable energy over and above maintenance requirements, in period i and window w, for cohort with sex s and age a (kcal)
Growth Energy$_{s,a}$	Metabolizable energy required for a unit increase in average weight of an animal in cohort with sex s and age a (kcal/kg)
Loss Energy$_{s,a}$	Metabolizable energy required for a unit decrease in average weight of an animal in cohort with sex s and age a (kcal/kg)
Max Energy$_{n,s,a}$	Ideal weight of an animal, in season n, for cohort with sexs and age a (kg)
Death Weight$_{n,s,a}$	Weight below which individual animals will die due to starvation, in season n, for cohort with sex s and age a (kg)
SD Weight$_{n,s,a}$	Standard deviation of the weight distribution expressed as a proportion of the cohort's mean weight, in season n, for cohort with sex s and age a (a>0)

Table A2-1: Continued

Variable	Description
Other Mortality$_{w,i,s,a}$	Mortality due to factors other than starvation and hunting, in period i and window w, for cohort with sex s and age a (number of animals)
Predation Rate$_{n,s,a}$	Mortality rate due to factors other than starvation and hunting, for season n, for cohort with sex s and age a (0-1)
Target Density	Target animals density used in calculation of harvest rate (number of animals/km^2)
Cow Harvest Rate$_i$	Overall target harvest for cows in period i (0-1)
Target Cow Harvest$_i$	Target for total cows harvested in period i (number of animals)
Target Bull Harvest$_i$	Target for total bulls harvested in period i (number of animals)
Target Calf Harvest$_i$	Target for total calves harvested in period i (number of animals)
Bull to Cow Harvest	Target ratio of bull harvest to cow harvest (>=0)
Calf to Cow Harvest	Target ratio of calf harvest to cow harvest (>=0)
Prop Access$_{w,i}$	Proportion of habitat window w that is accessible in period I (0-1)
Access Factor$_f$	Weighting factor specifying the relative contribution of forest class f in the calculation of the proportion access (0-1)
Forest Area$_{w,i,f}$	Area of the habitat window w in the forest f for period i (ha)
Hunting Pressure$_{w,i}$	Relative hunting pressure for the habitat window w in period i (>0)
Hunting Mortality$_{w,i,s,a}$	Mortality due to hunting, in period i and window w, for cohort with sex s and age a (number of animals)
Births$_{w,i}$	Births in period i and window w (number of animals)
Fecundity$_{w,i,a}$	Average number of calves born, in period i and window w, per female of age a (>=0)
Birth Weight	Average birth weight of calves (kg)
Sex Ratio	Proportion of calves born as males (0-1)

Table A2-2: Initial starting values for the Duinker Population Model.

Variables		Males				Female						Source
		C	Y	A	O	C	Y	A	O			
Initial Density (Animals/km^2)		0.1090	0.0417	0.0417	0.0417	0.1090	0.1390	0.1390	0.1390			Smith *et al.* 1988
Initial Weight (kg)		150	250	450	485	150	230	400	445			OMNR 1990, Schwartz 1998
Maximum Weight (kg)	Summer	160	250	550	680	155	230	450	500			Schwartz 1998
	Fall	160	250	467	578	155	230	450	500			
	Early Winter	150	230	467	578	150	220	425	450			
	Late Winter	140	220	431	534	140	210	375	415			
Death Weight (kg)	Summer	104	162	357	442	100	149	292	325			
	Fall	104	162	303	375	100	149	292	325			
	Early Winter	97	149	303	375	97	143	276	292			
	Late Winter	97	143	280	347	91	136	243	269			
Sd Weight	Summer	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08			Duinker *et al.* 1996
	Fall	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08			
	Early Winter	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08			
	Late Winter	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08			
Birth Weight (kg)		13.5										Stelfox 1993
Sex Ratio Males to Females		0.5										Duinker *et al.* 1996
Predation Rate	Summer	0.20	0.01	0.01	0.01	0.20	0.01	0.01	0.01			Ballard and Ballenberghe 1998
	Fall	0.10	0.01	0.01	0.01	0.10	0.01	0.01	0.01			
	Early Winter	0.10	0.01	0.01	0.02	0.10	0.01	0.01	0.02			
	Late Winter	0.20	0.01	0.01	0.03	0.20	0.01	0.01	0.03			
Other Mortality	Summer	0	0	0	0	0	0	0	0			
	Fall	0	0	0	0	0	0	0	0			
	Early Winter	0	0	0	0	0	0	0	0			
	Late Winter	0	0	0	0	0	0	0	0			
Cropping Rate		0.2	0.6	0.6								Duinker *et al.* 1996
Prop Energy Weight		0										Duinker *et al.* 1996
Energy/Forage (kcal/kg)		3100										Blackwell 1983
Daily Maintenance Energy (kcal$^{-0.75}$kg/day)	Summer	170	170	170	170	170	170	170	170			Belovsky and Jordan 1978
	Fall	170	170	170	170	170	170	170	170			
	Early Winter	170	170	170	170	170	170	170	170			
	Late Winter	170	170	170	170	170	170	170	170			
Growth Energy (kcal)		9800	9800	9800	9800	9800	9800	9800	9800			Gasaway and Coady 1974
Loss Energy (kcal)		8140	8140	8140	8140	8140	8140	8140	8140			Gasaway and Coady 1974
Fecundity Weight (kg)(x,y pairs)	Calf	0	0.00	100	0.00	200	0.00	300	0.00	400	0.00	Greenwood *et al.* 1982
	Yearling	0	0.00	100	0.00	200	0.30	300	0.30	400	0.30	
	Mature 2-5 yrs	0	0.00	100	0.00	200	0.95	300	1.57	400	2.00	
	Older > 5yrs	0	0.00	100	0.00	200	0.70	300	1.37	400	1.57	
Fecundity Season (1=Spring/Summer)		1										
Target Density (Animals/km^2)		0.76										Smith *et al.* 1988, Todd 1996
Bull to Cow (Harvest Ratio)		3.5										Greenwood *et al.* 1982
Calf to Cow (Harvest Ratio)		1.67										Greenwood *et al.* 1982
Cow Harvest Rate (Paired x,y vertices for curve)		0.00	0.00	0.25	0.02	0.50	0.04	0.75	0.06	1.00	0.085	Greenwood *et al.* 1982
Access Factor (For ages classes 0-10, 11-20, 21-30 and 31-40)		1	0.5	0.25	0.125							Duinker *et al.* 1996
Hunting Pressure 1:1 Ratio for Access to Hunting		0.00	0.00	0.25	0.70	0.50	1.00	0.75	1.00	1.00	1.00	Duinker *et al.* 1996

C = Calf (<1 year) . Y = Yearling (>1<2 years), A = Adult (>2<5 years), O = Old (>6 years)

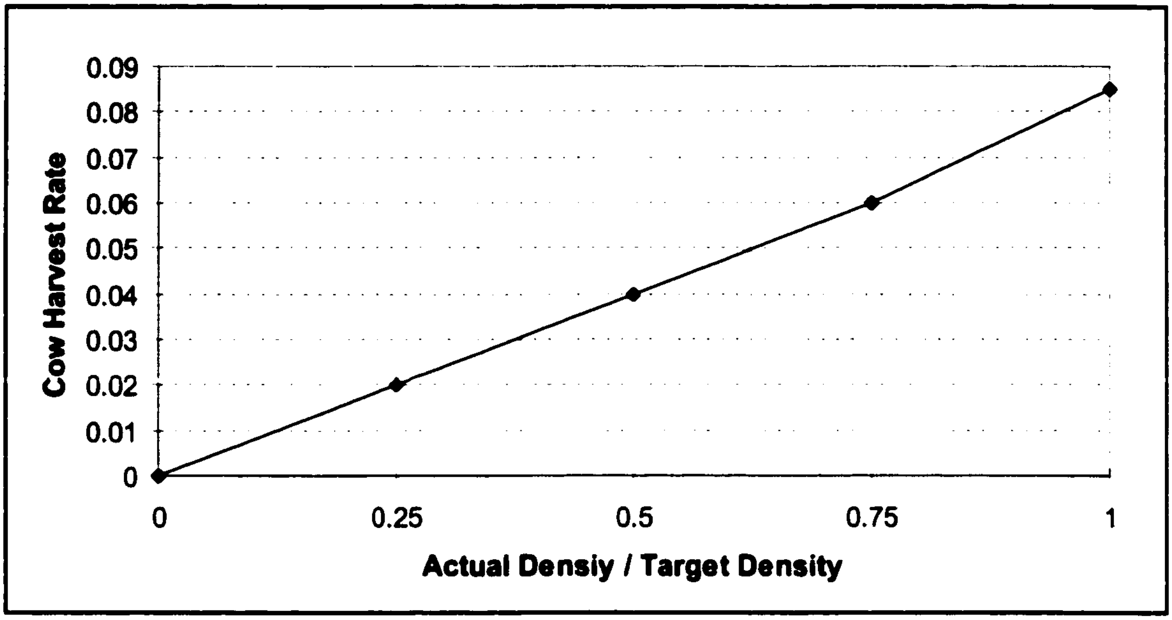


Figure A2-1: Cow harvest rate for the Duinker Population Model.

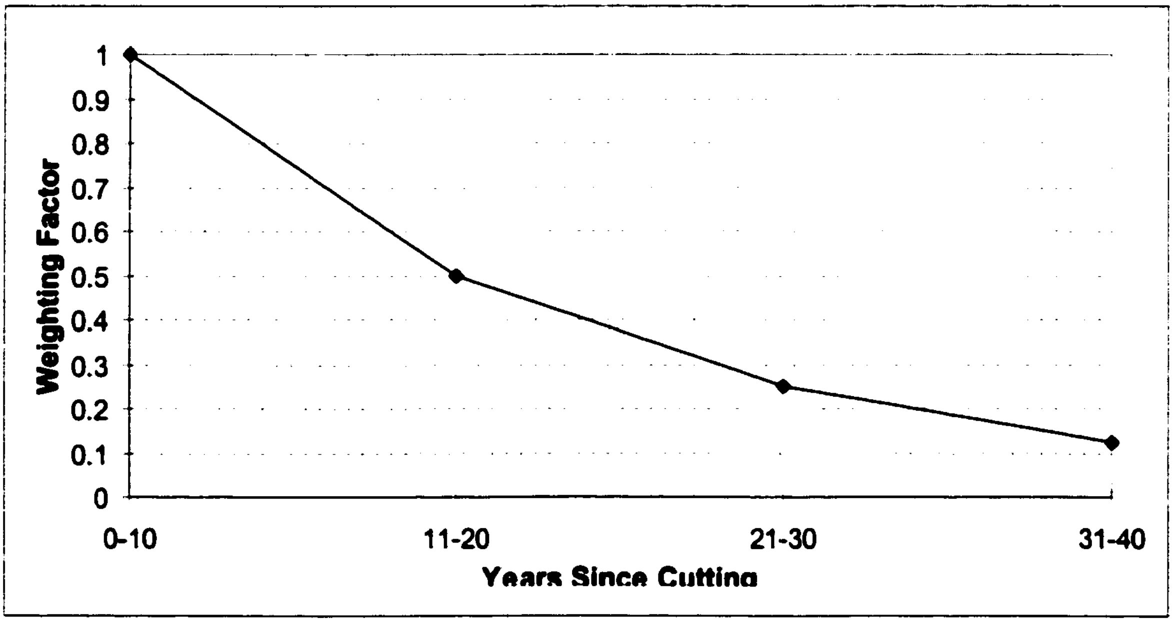


Figure A2-2: Access hunting pressure values for the Duinker Population Model.

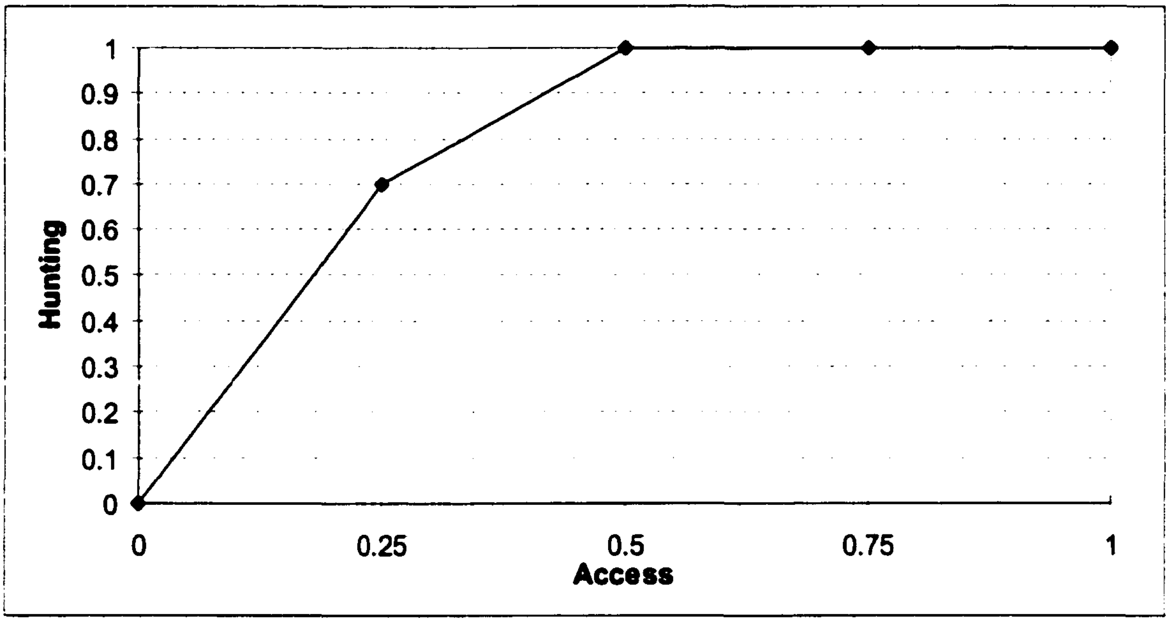
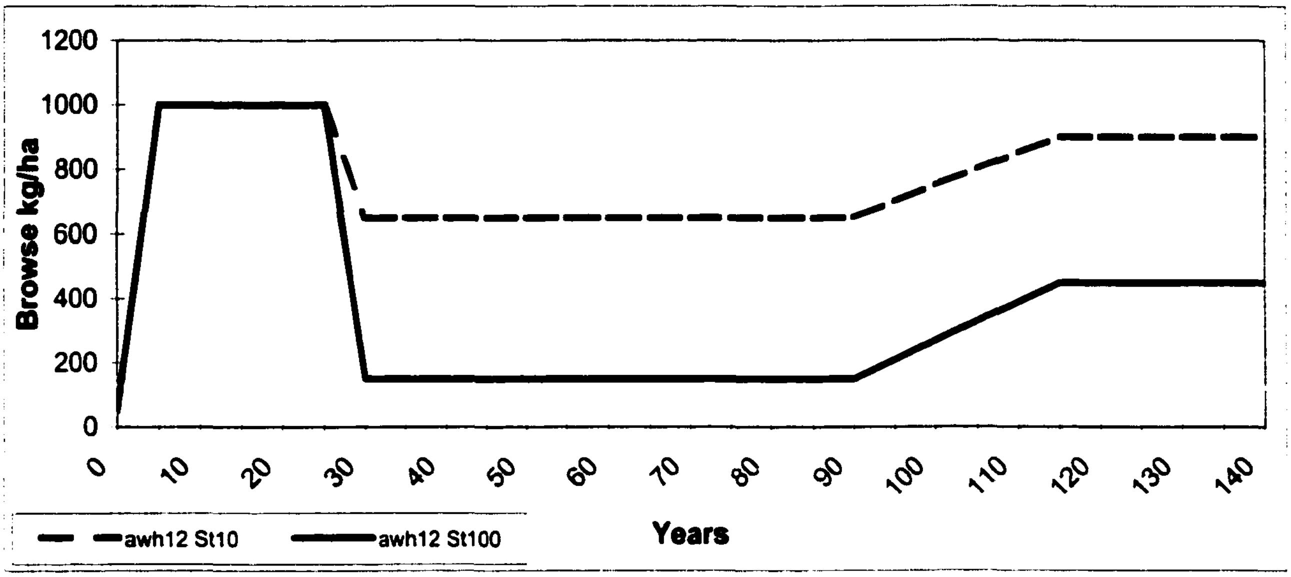


Figure A2-3: Relative hunting pressure as a function of access rate for the Duinker Population Model.



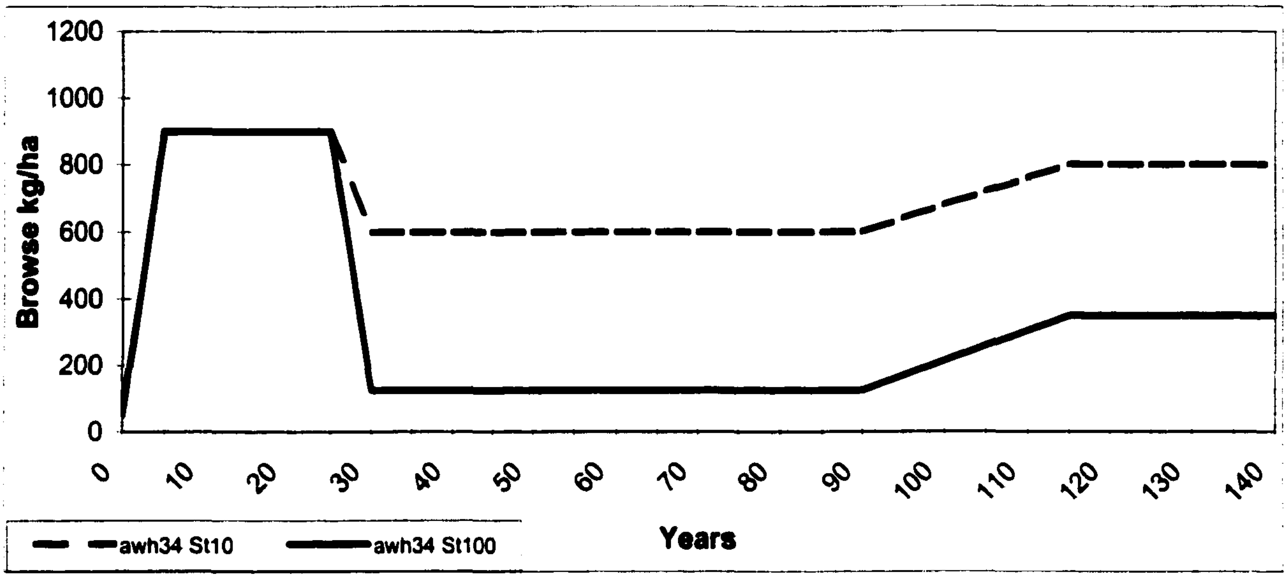
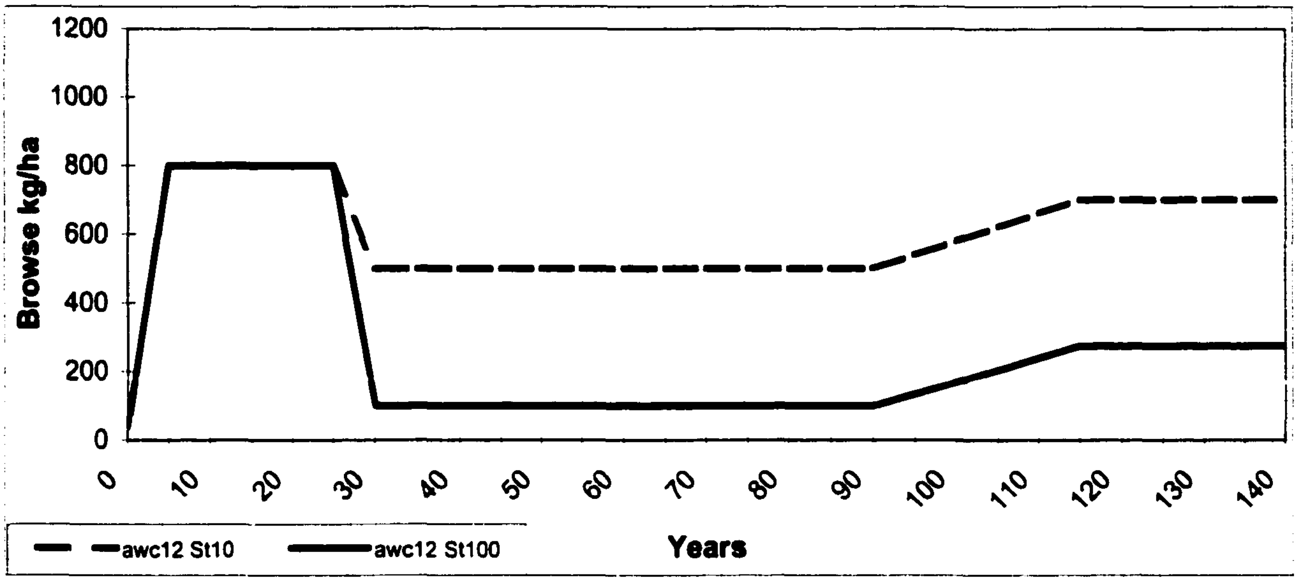


Figure A2-4: Poplar with other hardwoods spring and summer browse curves site classes 1-4.



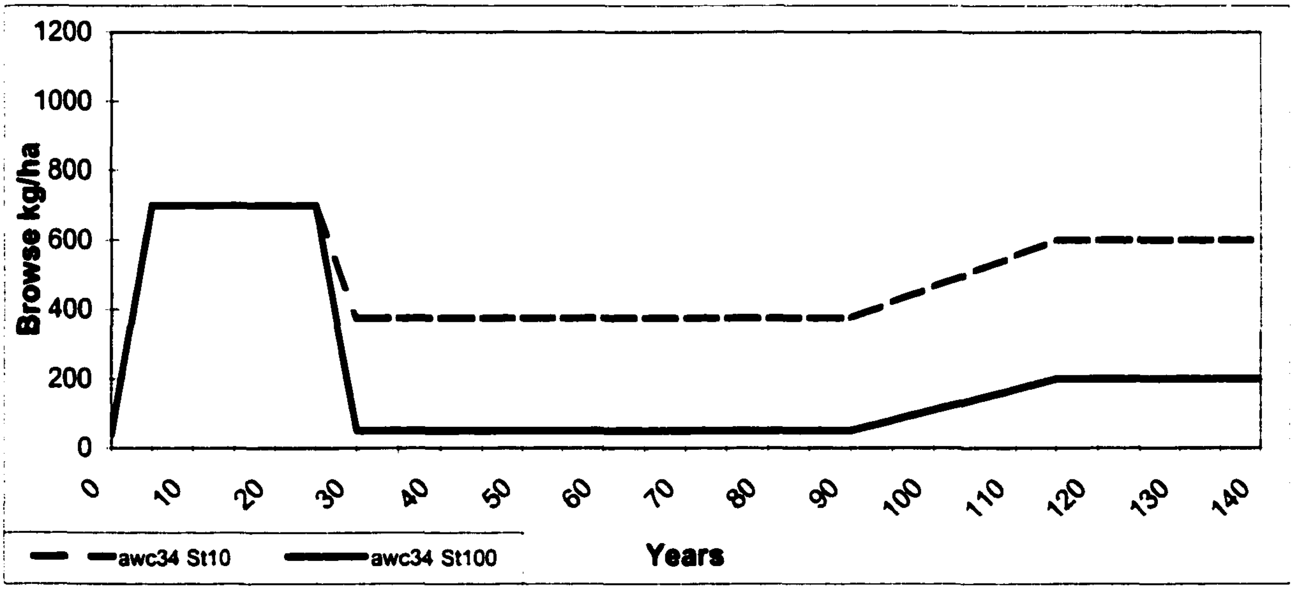
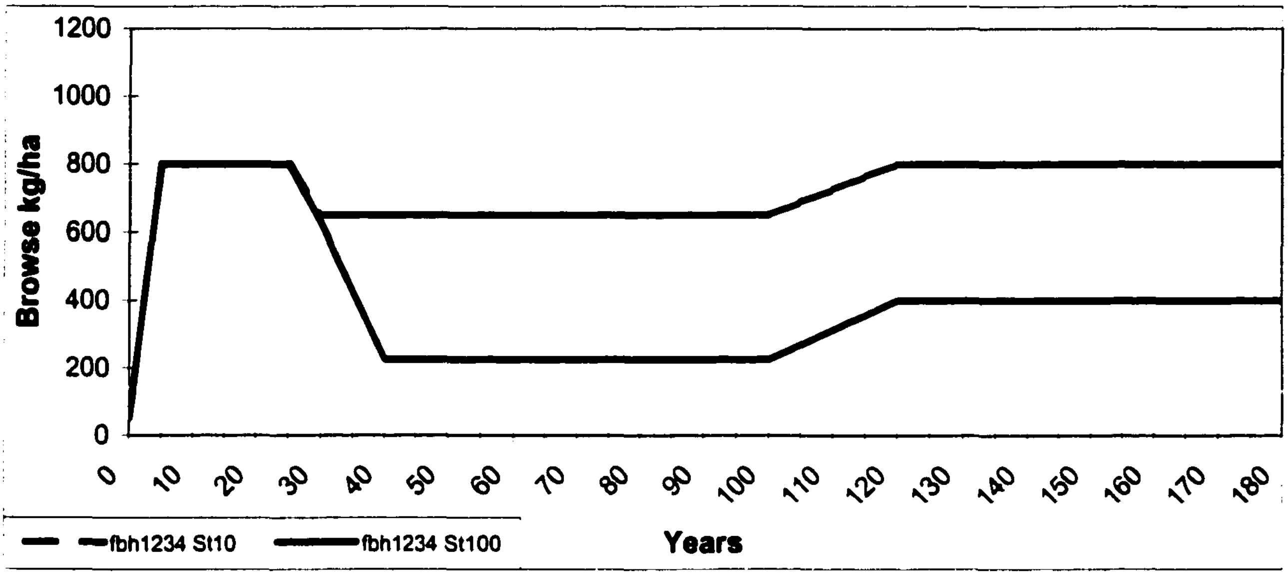


Figure A2-5: Poplar with conifers spring and summer browse curves site classes 1-4.



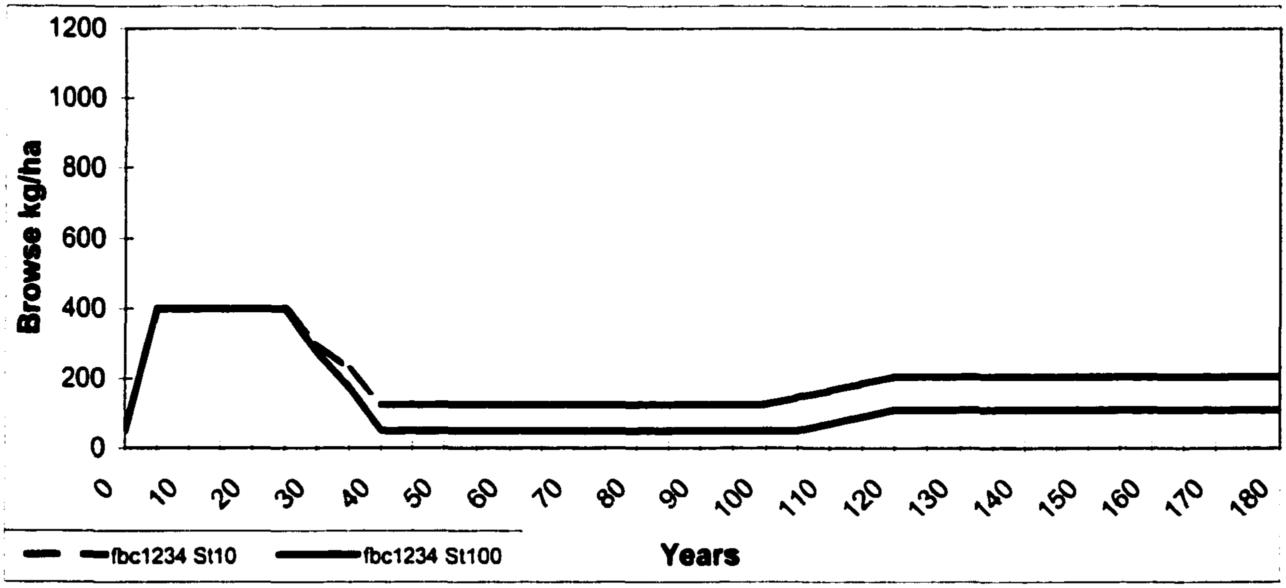


Figure A2-6: Balsam fir with hardwoods and other conifers spring and summer browse curves site classes 1-4.

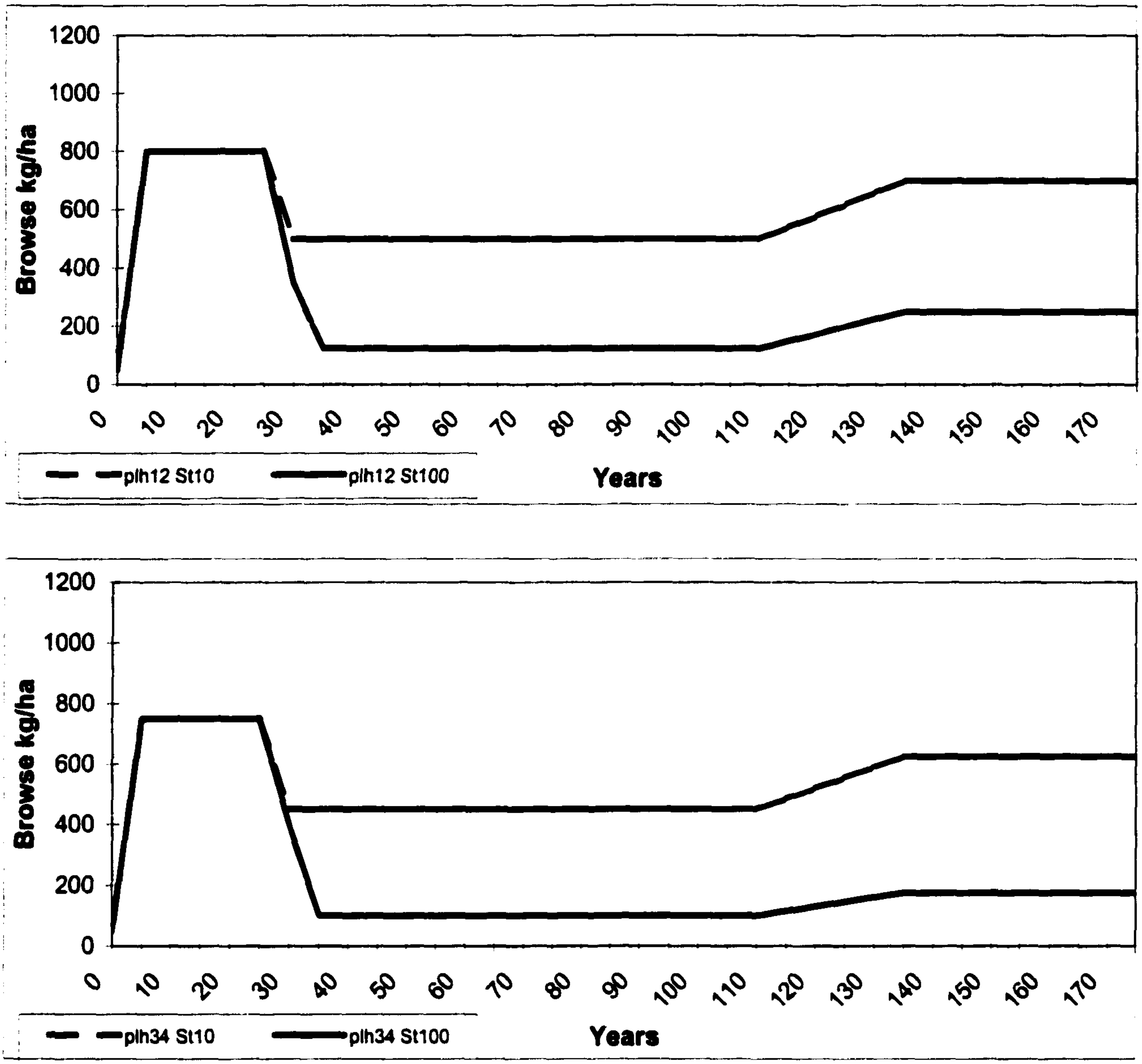
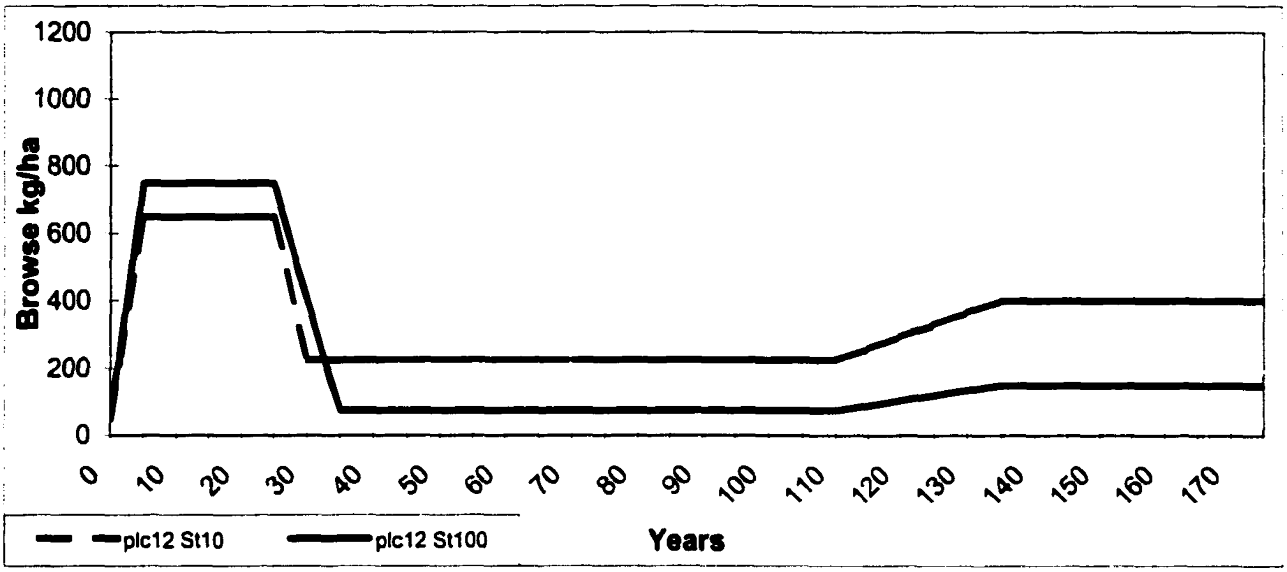


Figure A2-7: Lodgepole pine with other hardwoods spring and summer browse curves site classes 1-4.



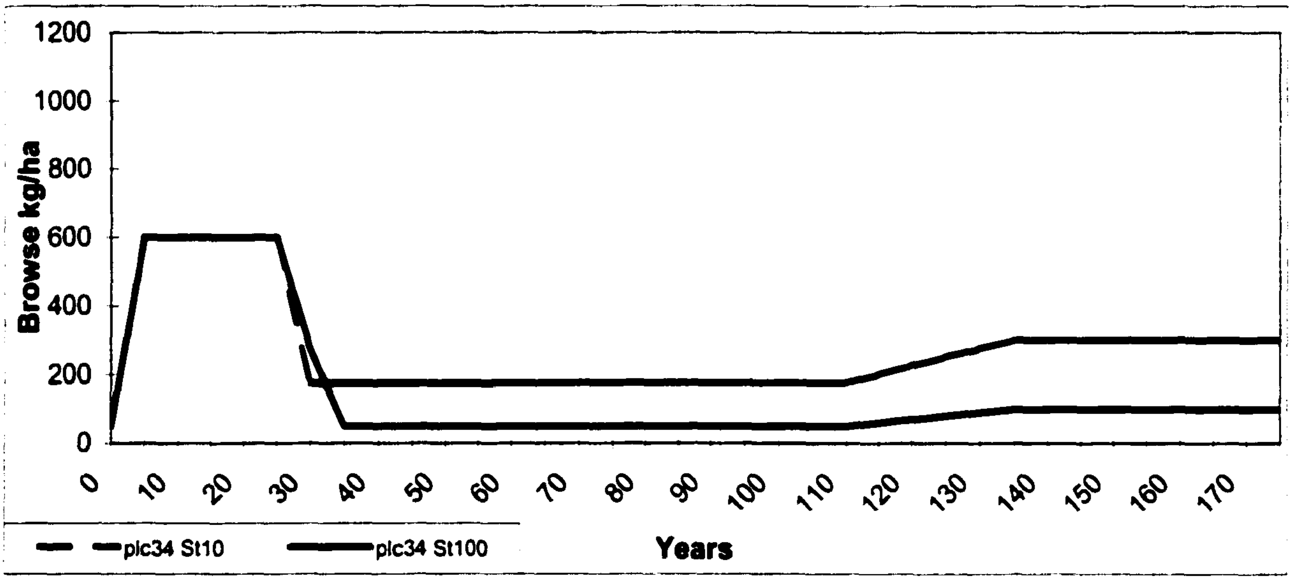
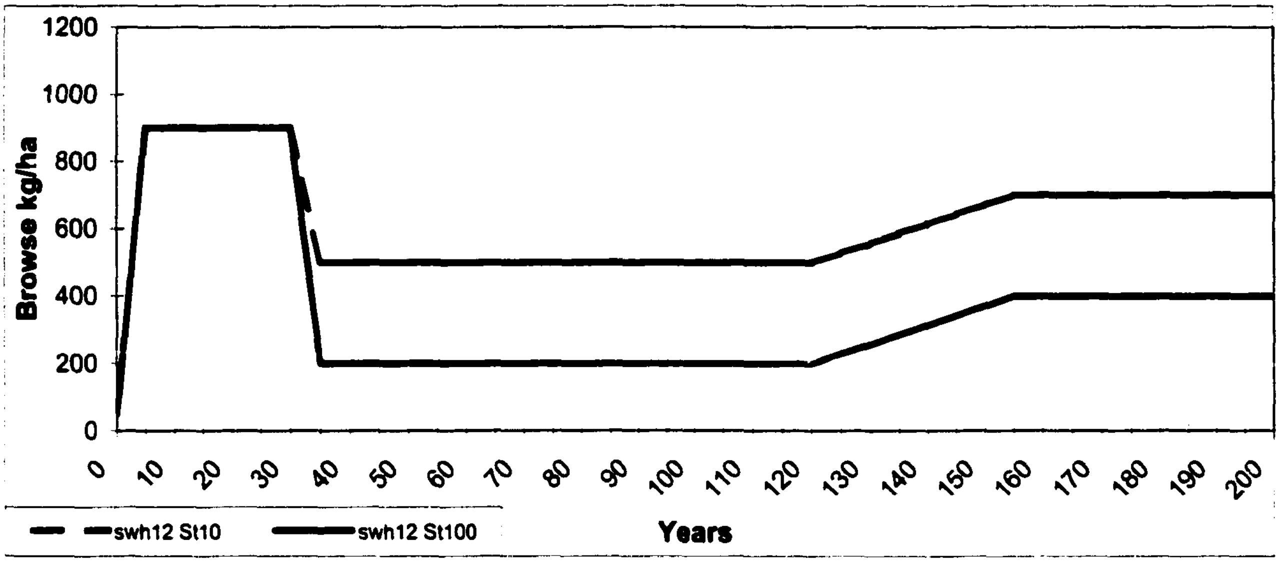


Figure A2-8: Lodgepole pine with other conifers spring and summer browse curves site classes 1-4.



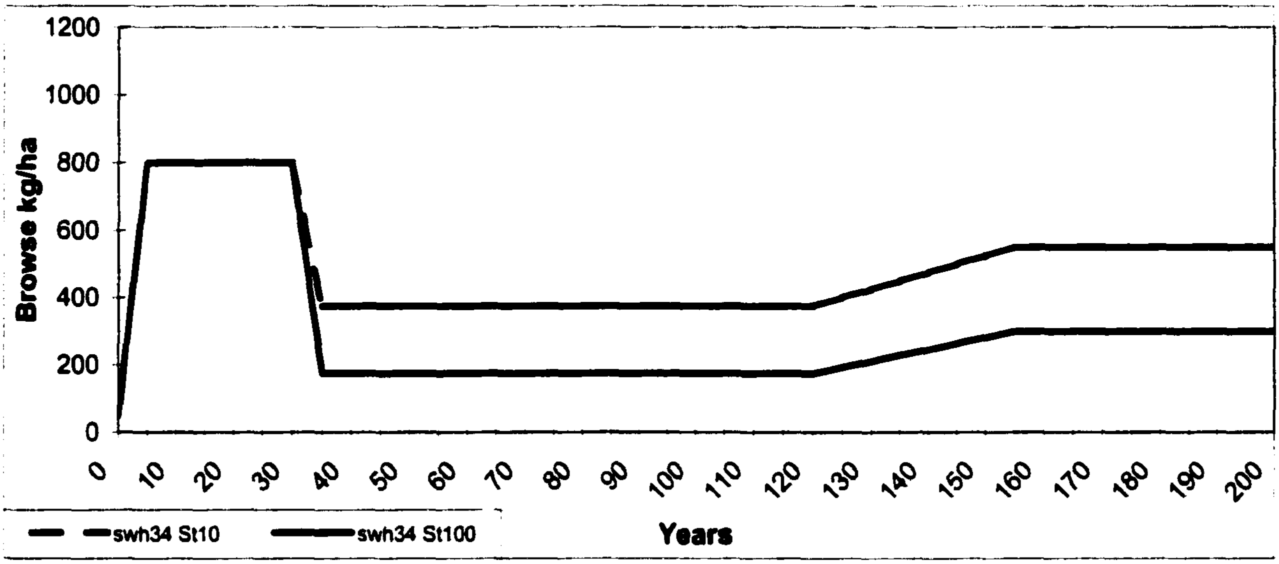
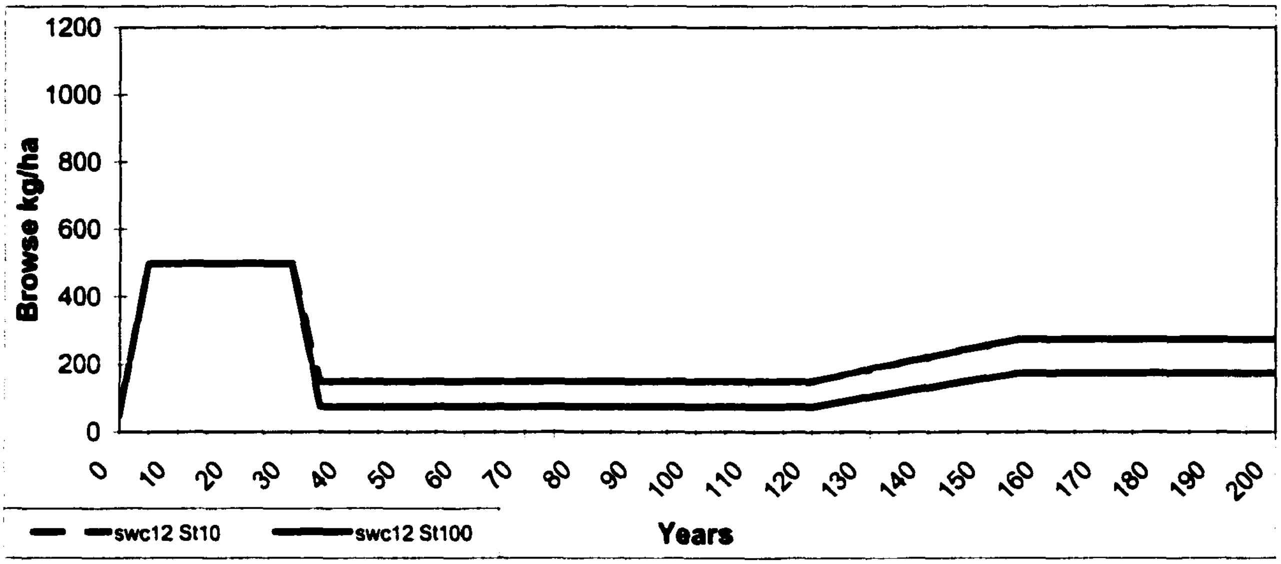


Figure A2-9: White spruce with other hardwoods spring and summer browse curves site classes 1-4.



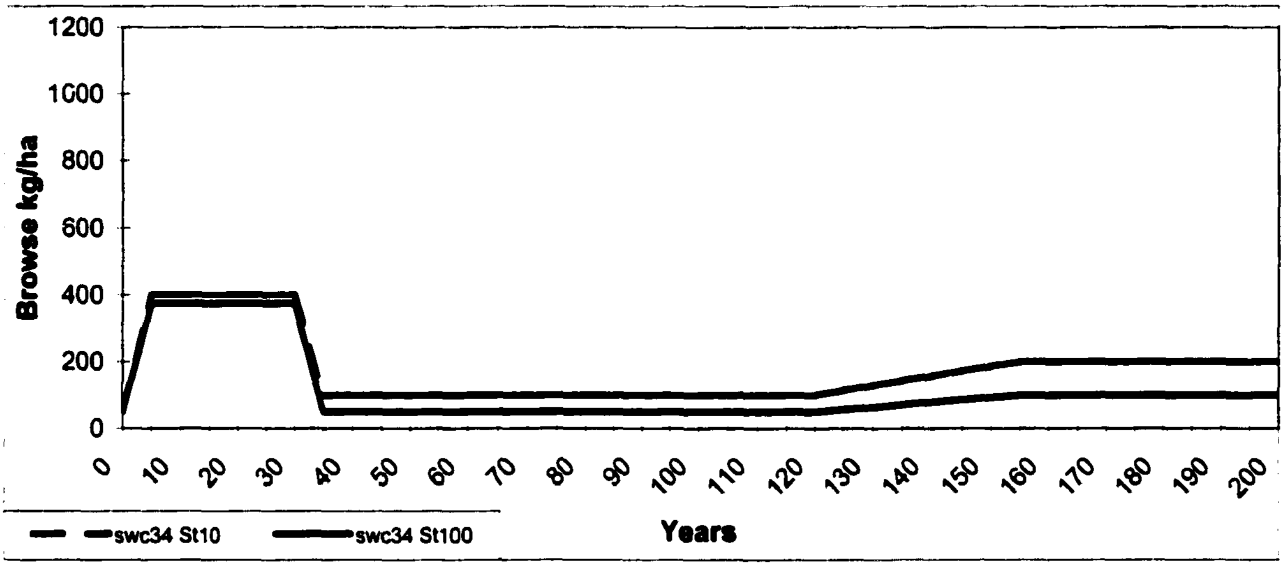
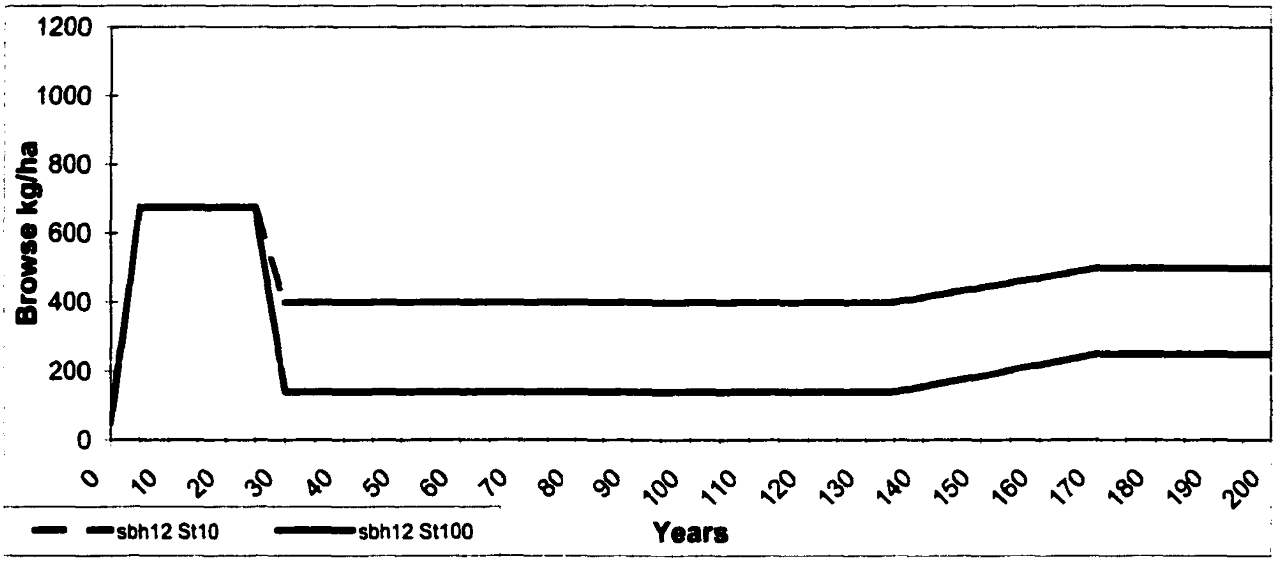


Figure A2-10: White spruce with other conifers spring and summer browse curves site classes 1-4.



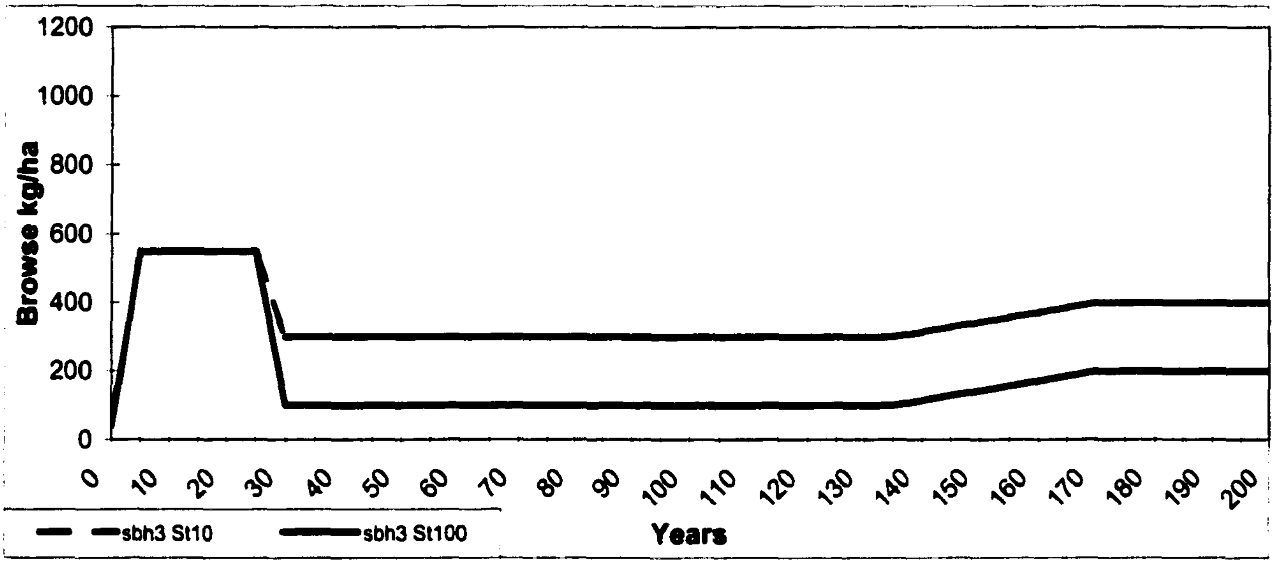
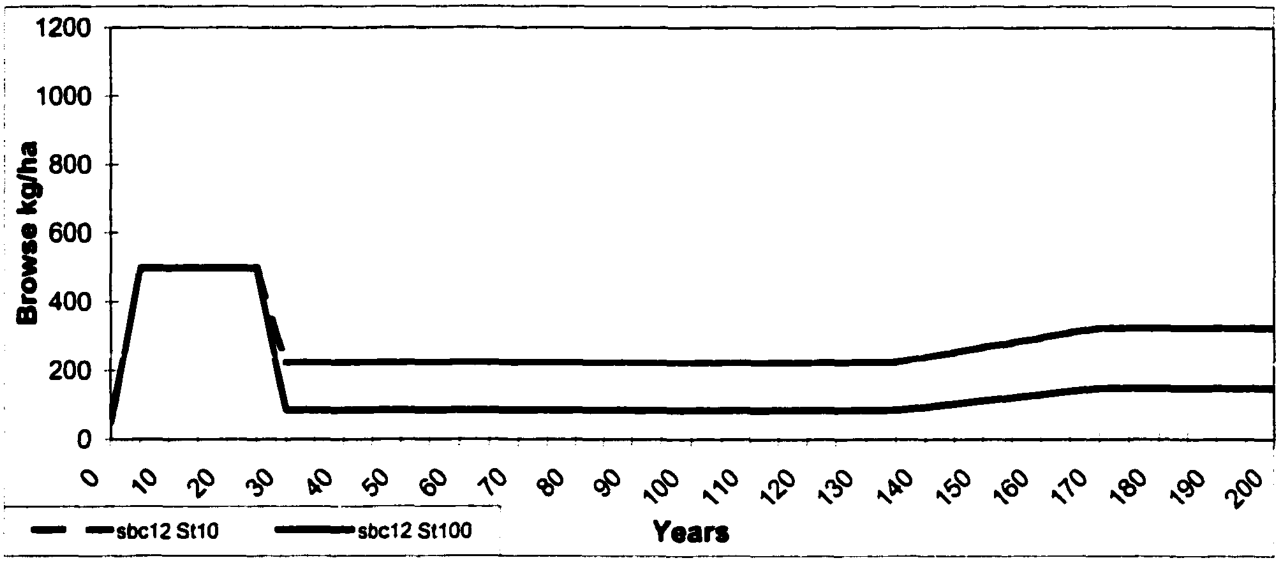


Figure A2-11: Black spruce with other hardwoods spring and summer browse curves site classes 1-3.



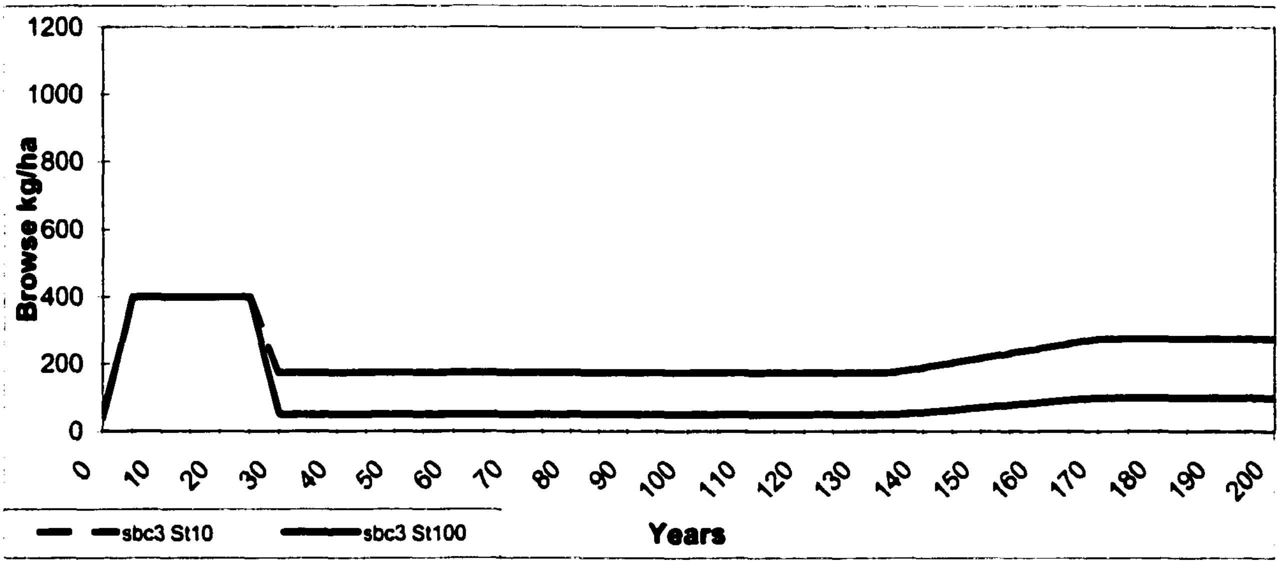


Figure A2-12: Black spruce with other conifers spring and summer browse curves site classes 1-3.

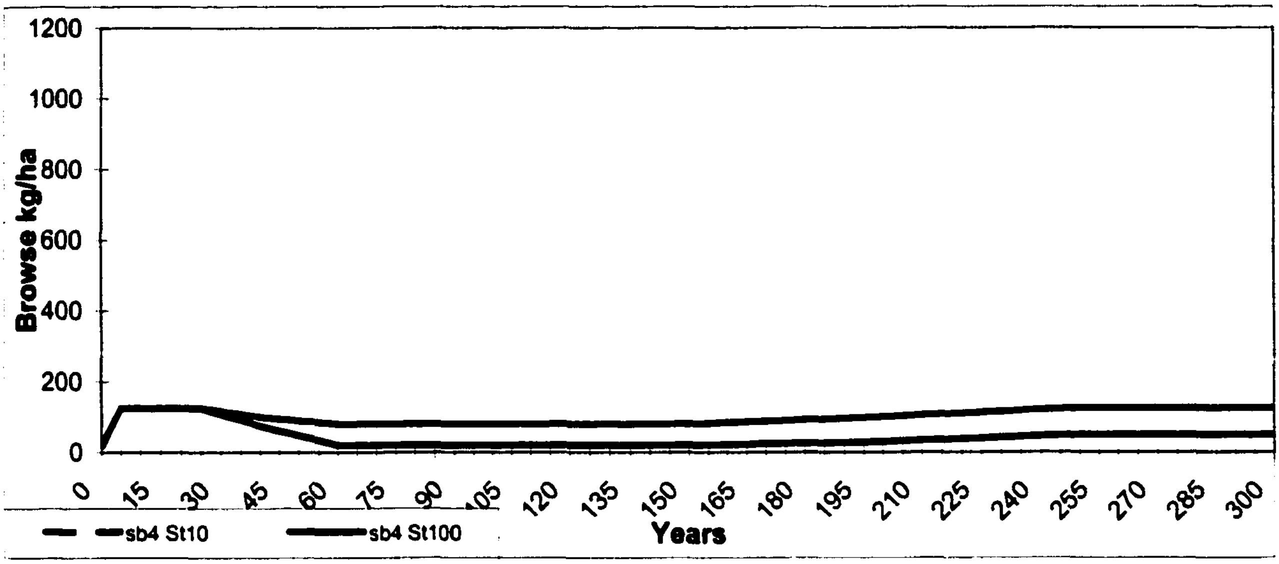
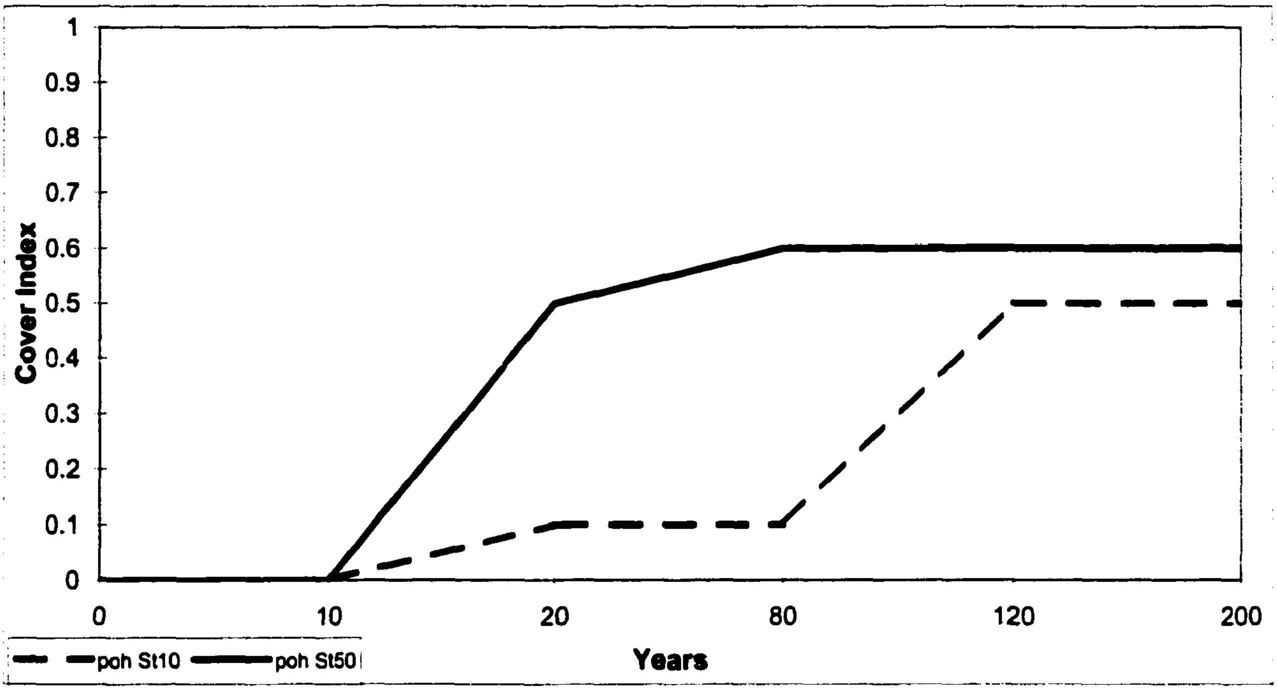


Figure A2-13: Black spruce with other hardwoods and conifers spring and summer browse curves site class 4.



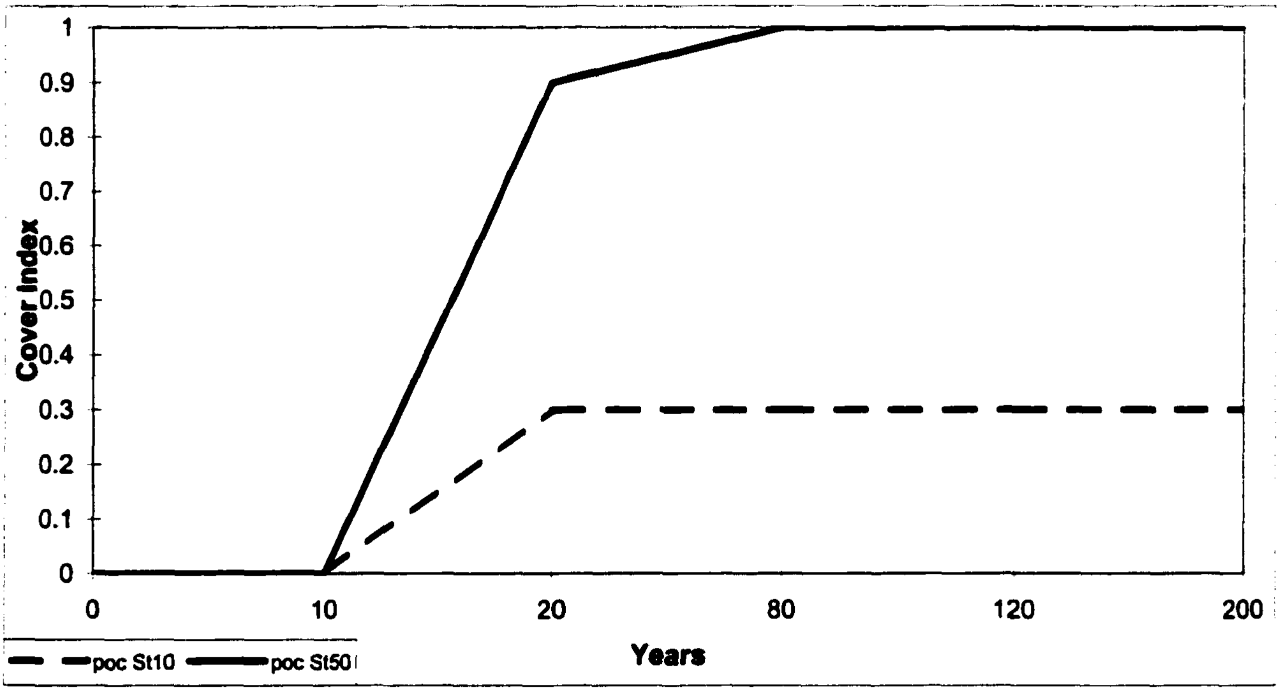
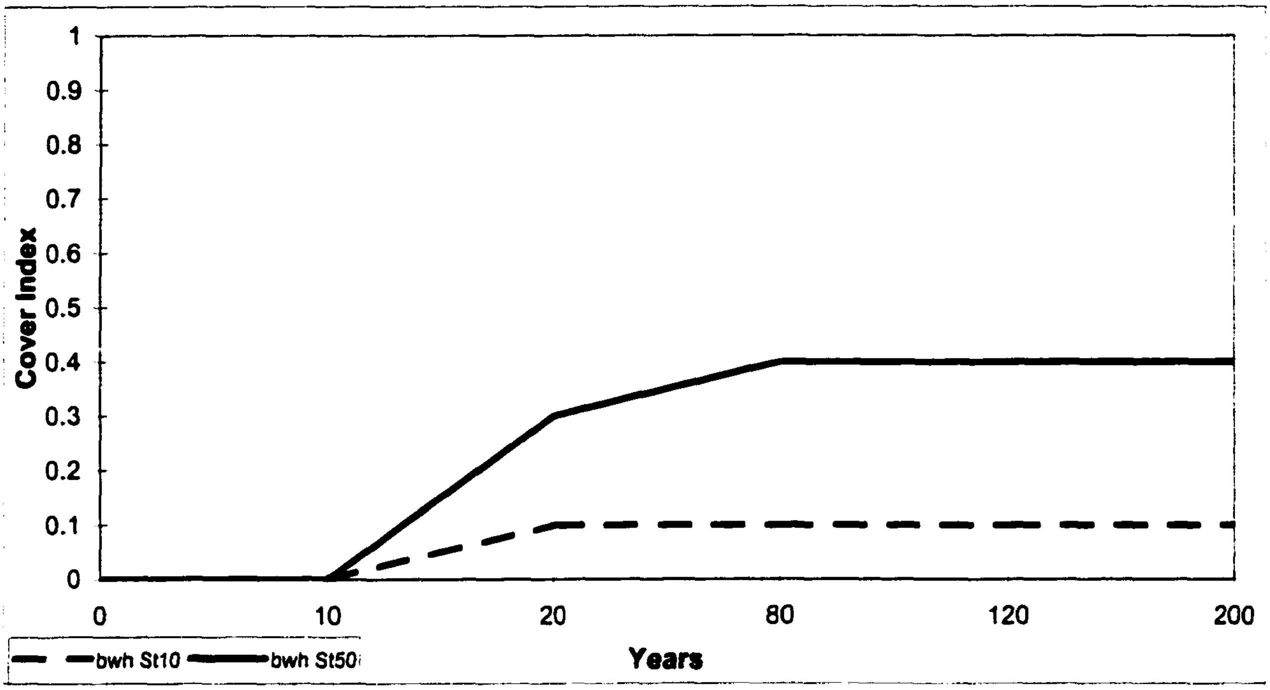


Figure A2-14: Poplar with other hardwoods and conifers early-winter cover index curves for all site classes.



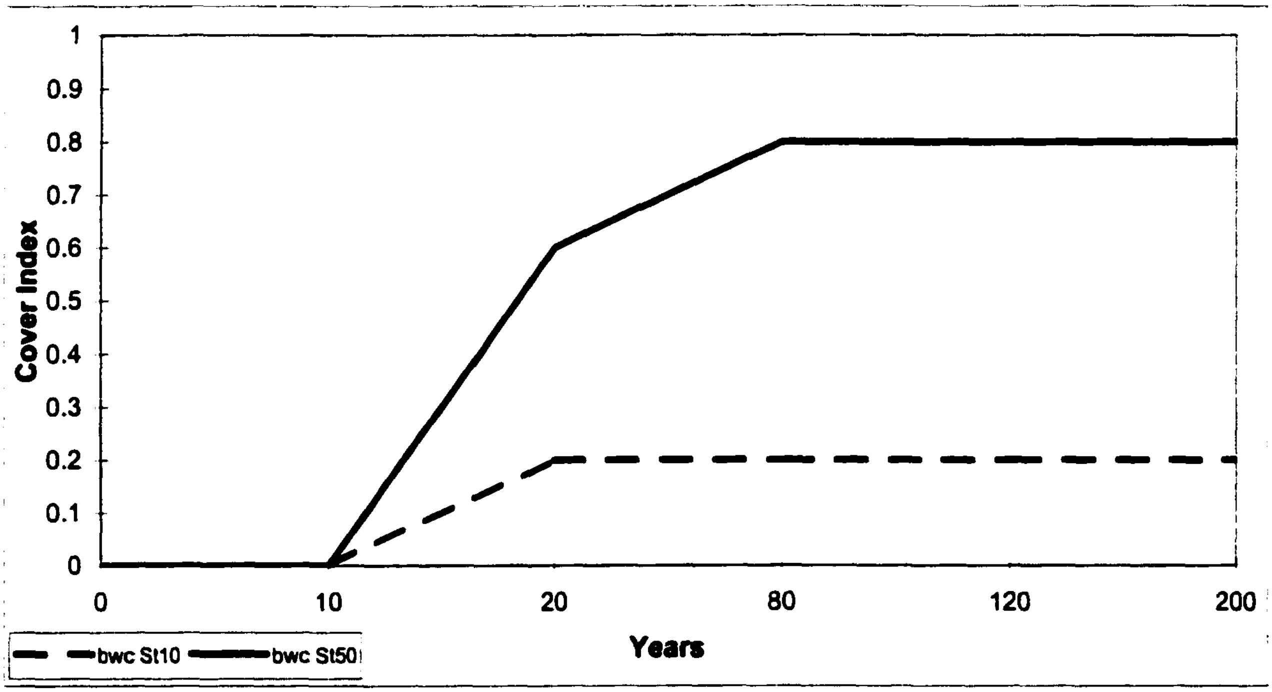
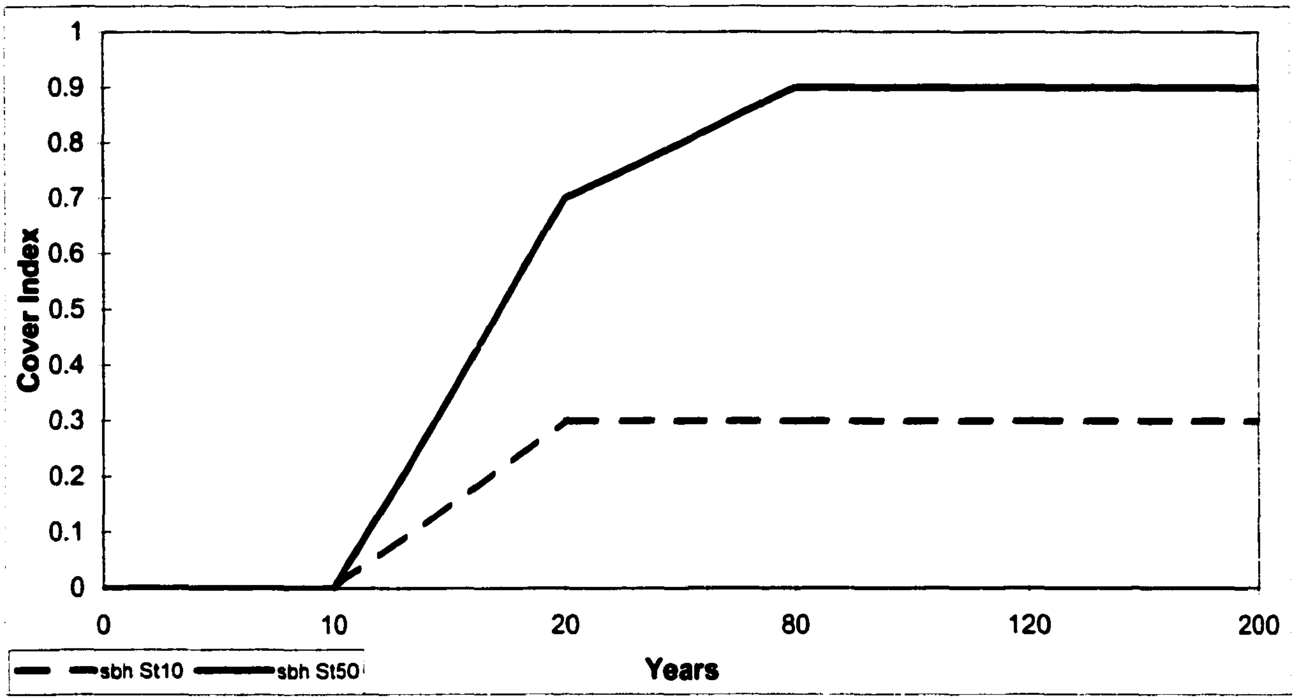


Figure A2-15: White birch with other hardwoods and conifers early-winter cover index curves for all site classes.



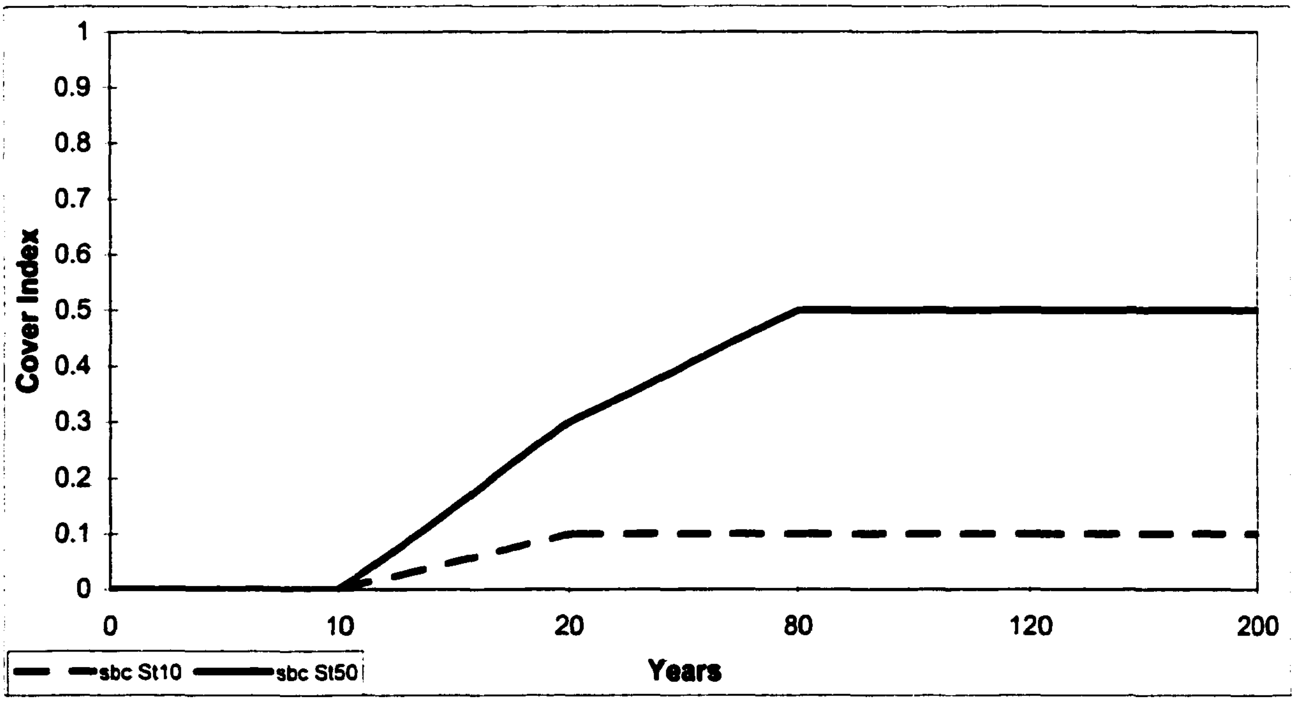
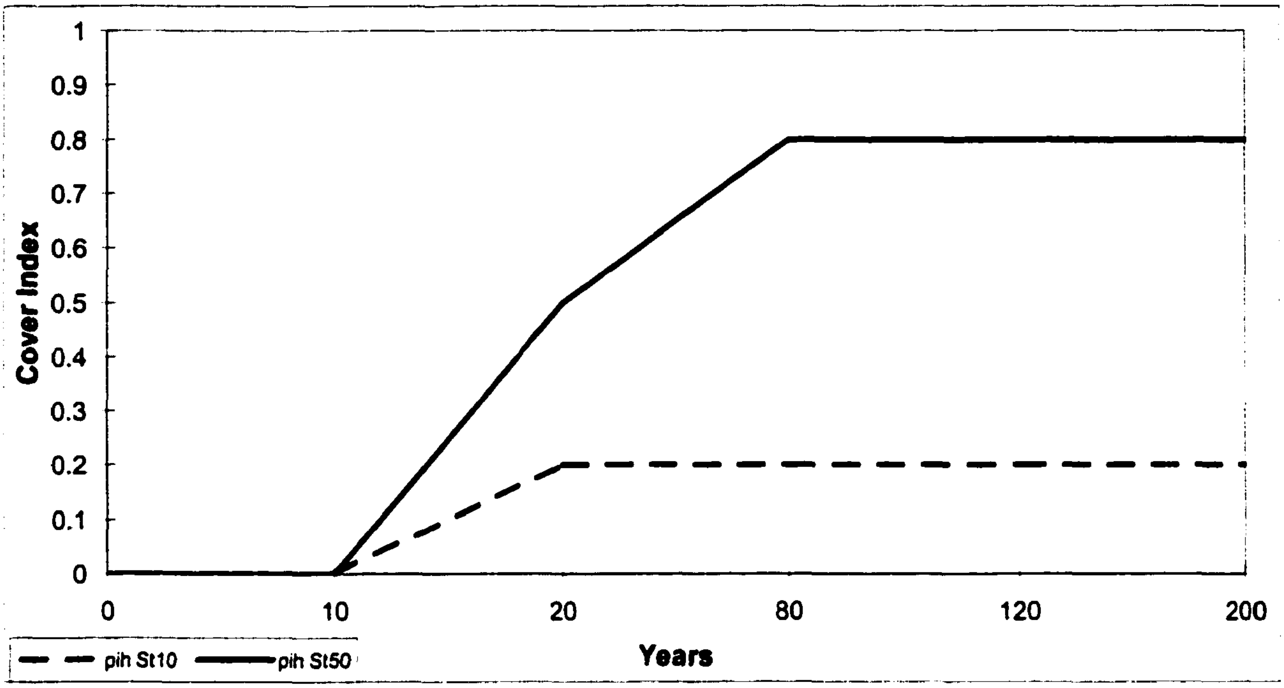


Figure A2-16: Black spruce with other hardwoods and conifers early-winter cover index curves for all site classes.



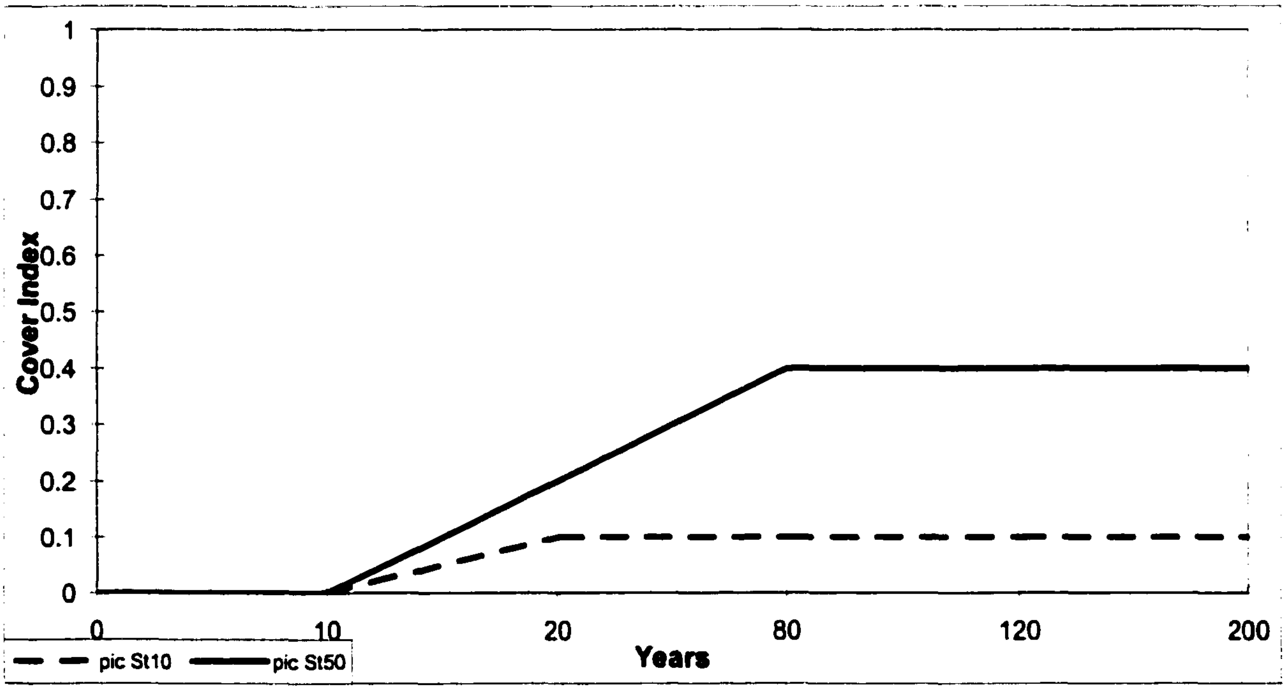


Figure A2-17: Lodgepole pine with other hardwoods and conifers early-winter cover index curves for all site classes.

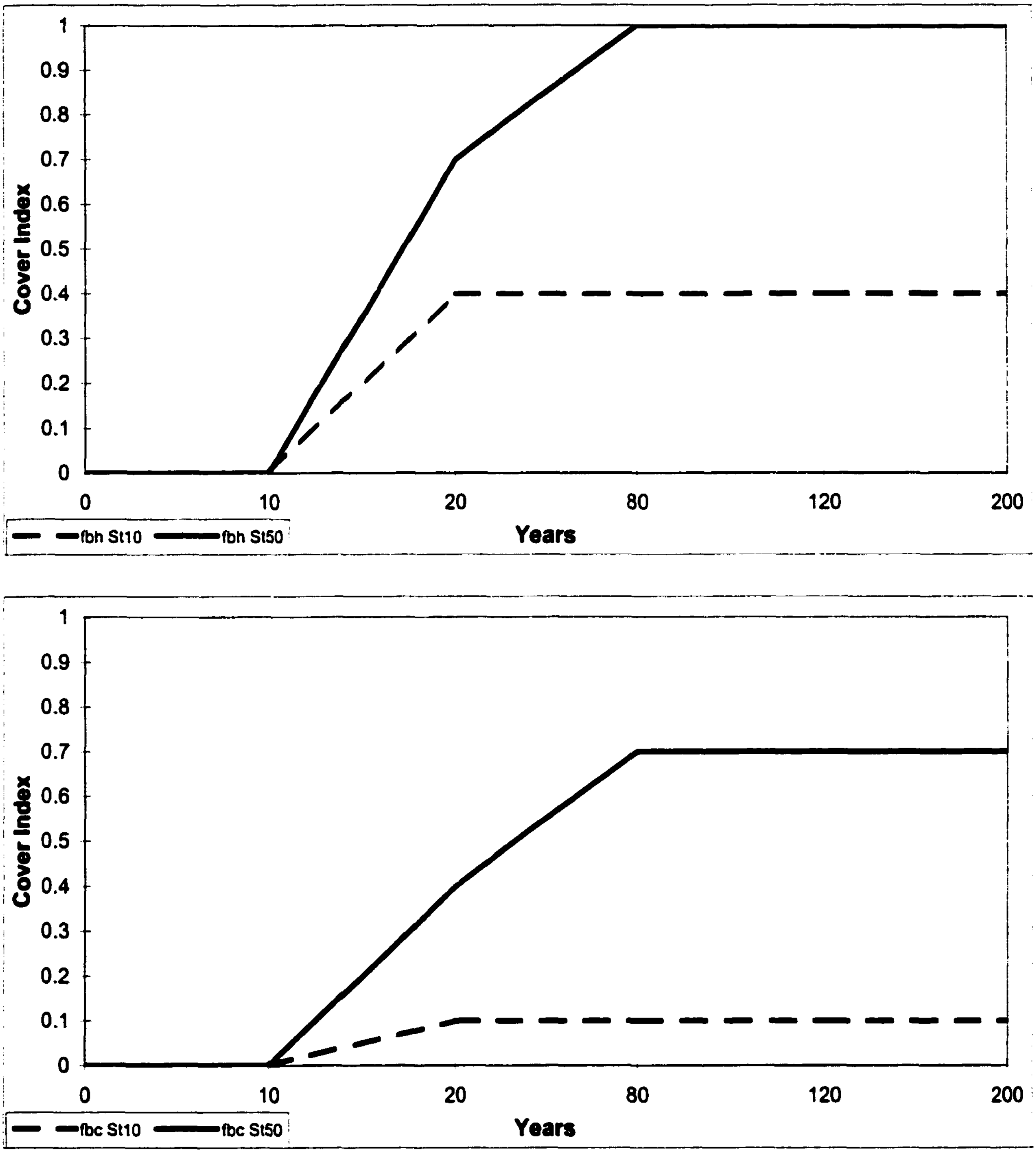
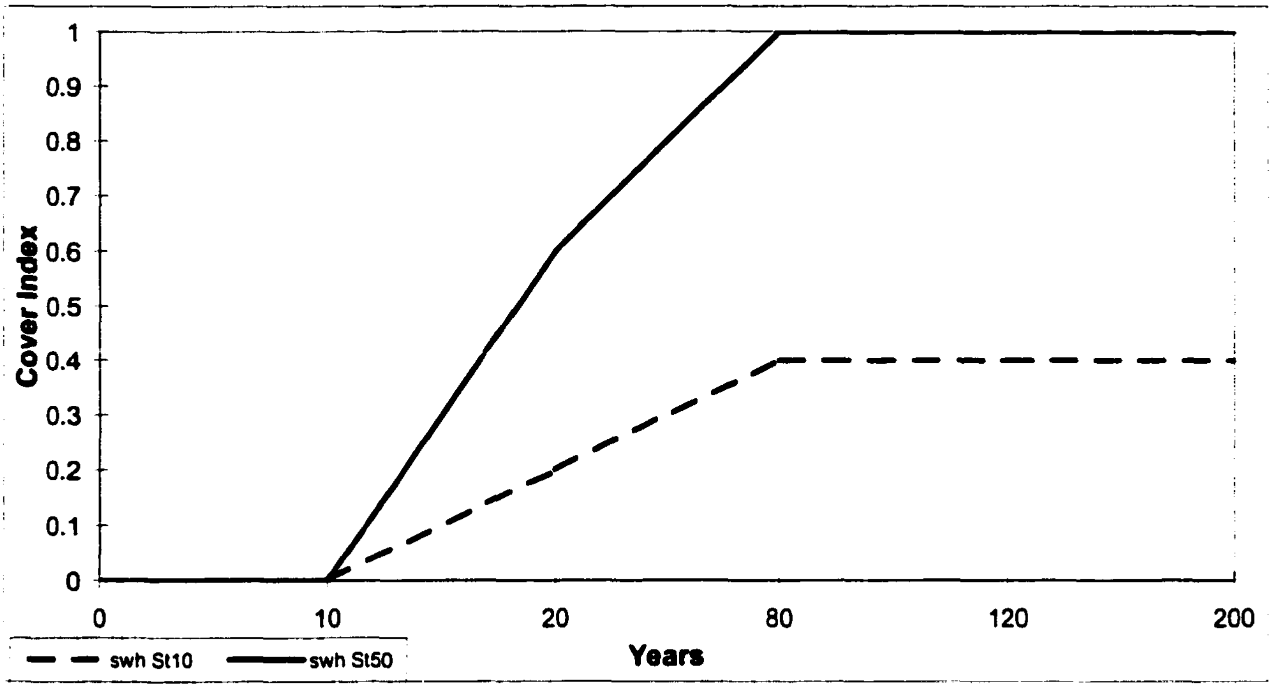


Figure A2-18: **Balsam fir with other hardwoods and conifers early-winter cover index curves for all site classes.**



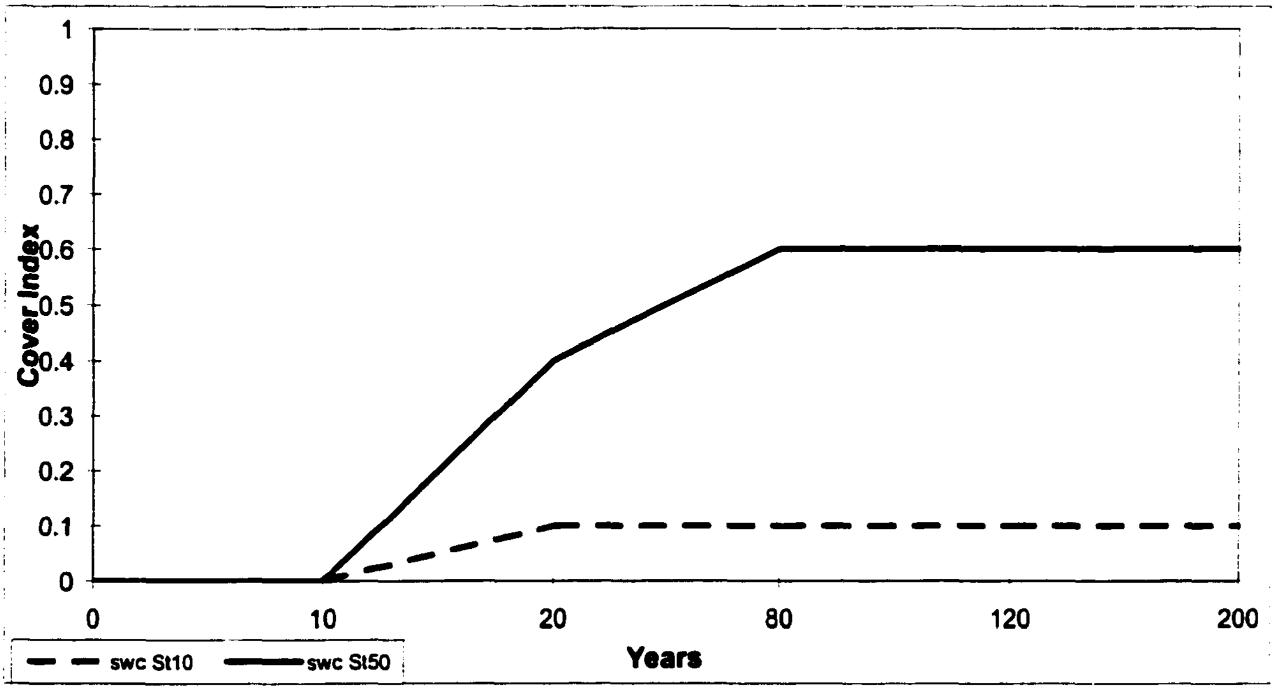


Figure A2-19: White spruce with other hardwoods and conifers early-winter cover index curves for all site classes.

APPENDIX 2 REFERENCES

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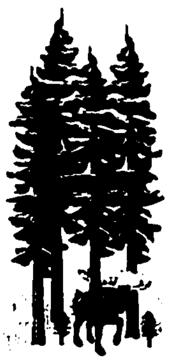

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Todd, A. 1996. ***Personal communication.*** Whitecourt, Alberta.

APPENDIX 3

Age vs volume curves used in the HSG harvesting simulation.

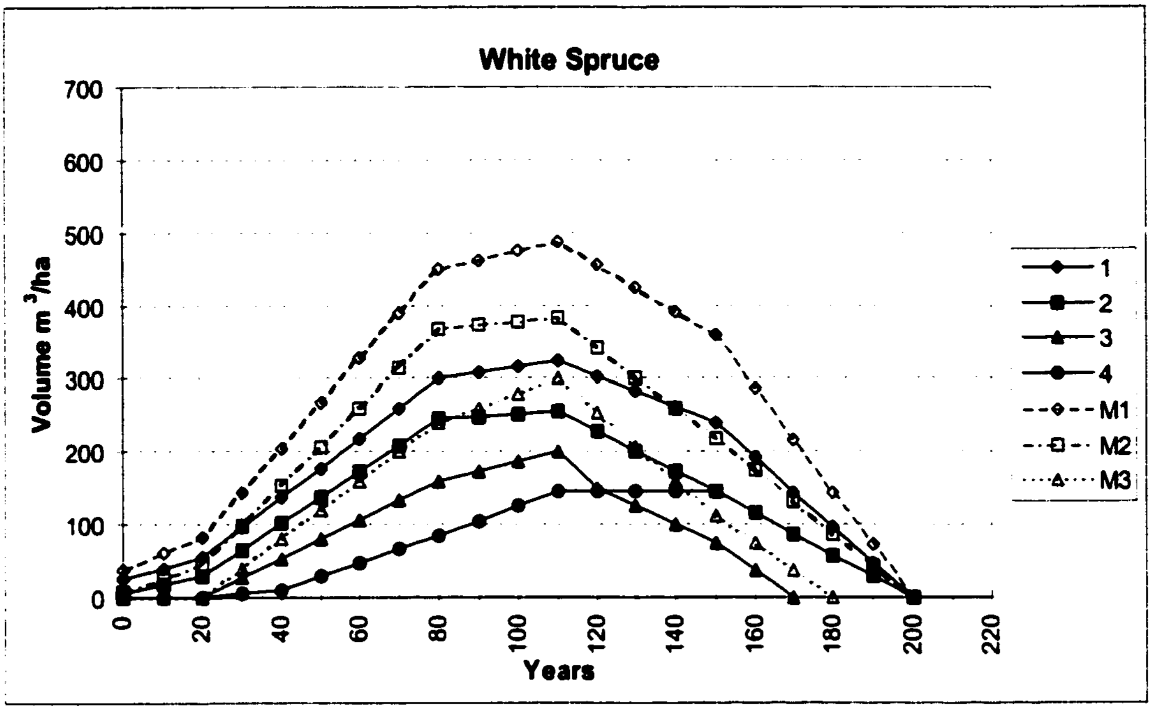


Figure A3-1: White spruce volume over age yield curves.

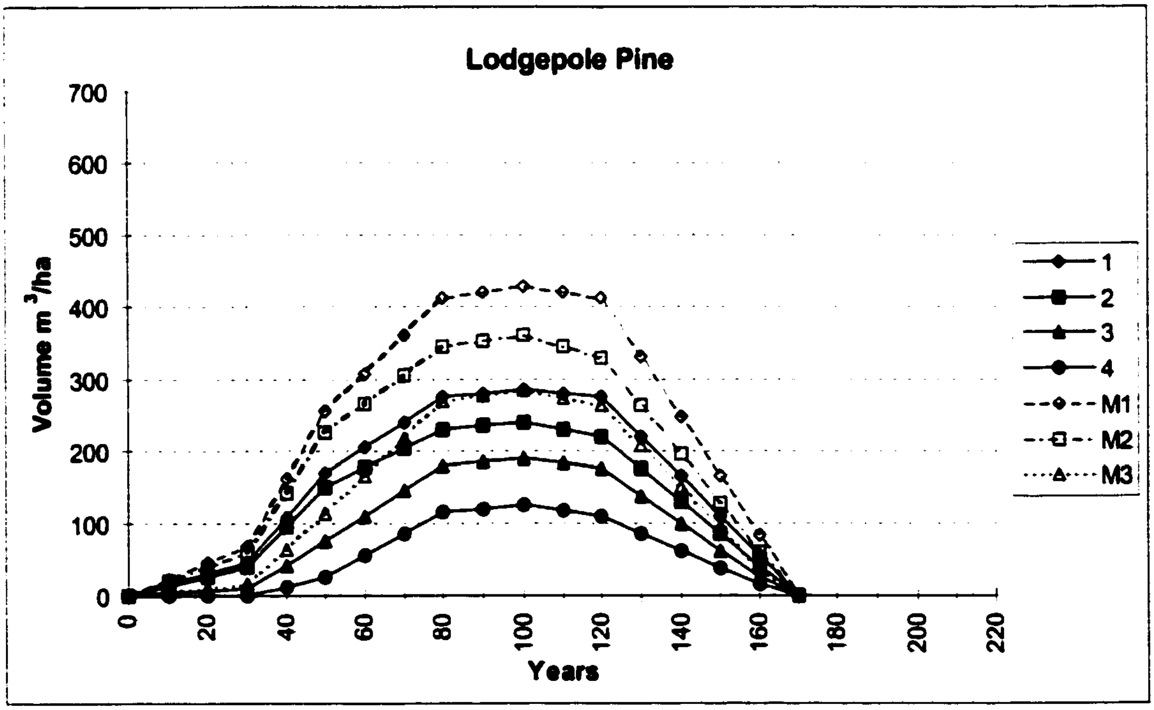


Figure A3-2: Lodgepole pine volume over age yield curves.

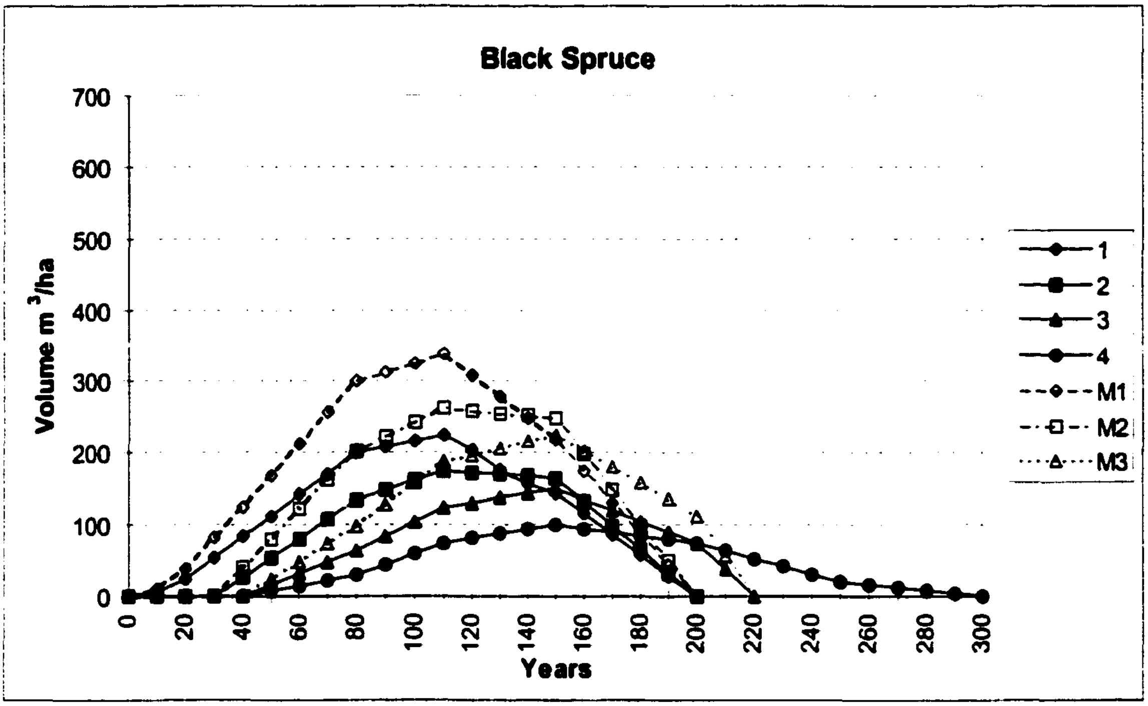


Figure A3-3: Black spruce volume over age yield curves.

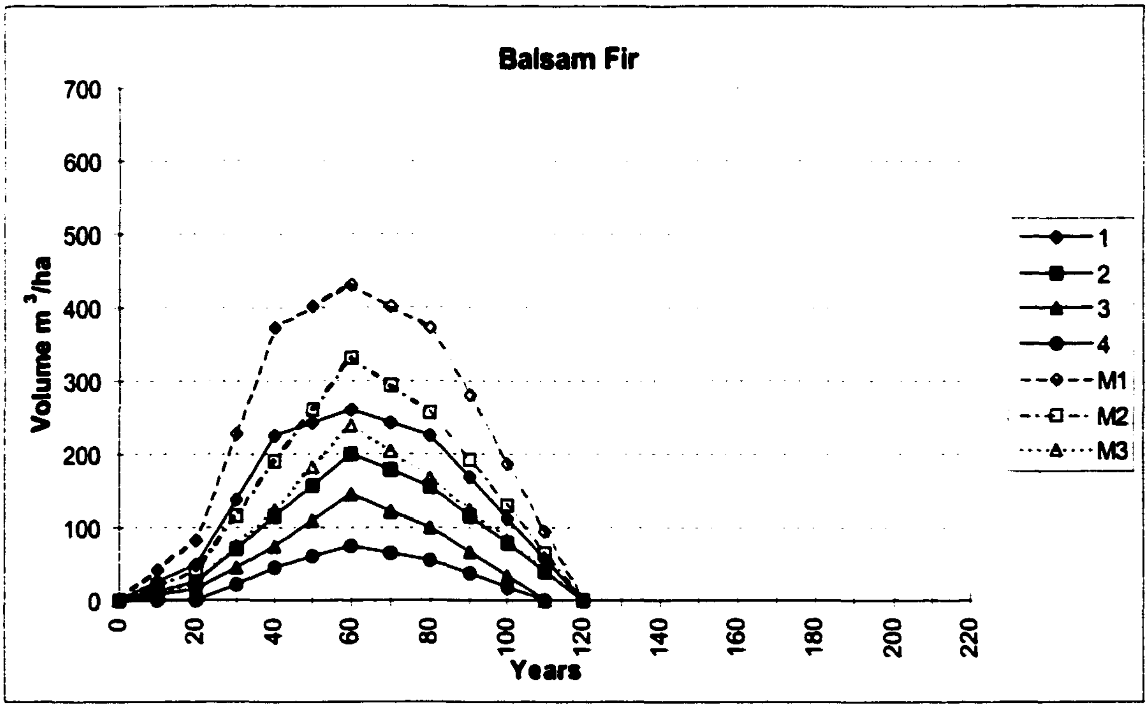


Figure A3-4: Balsam fir volume over age yield curves.

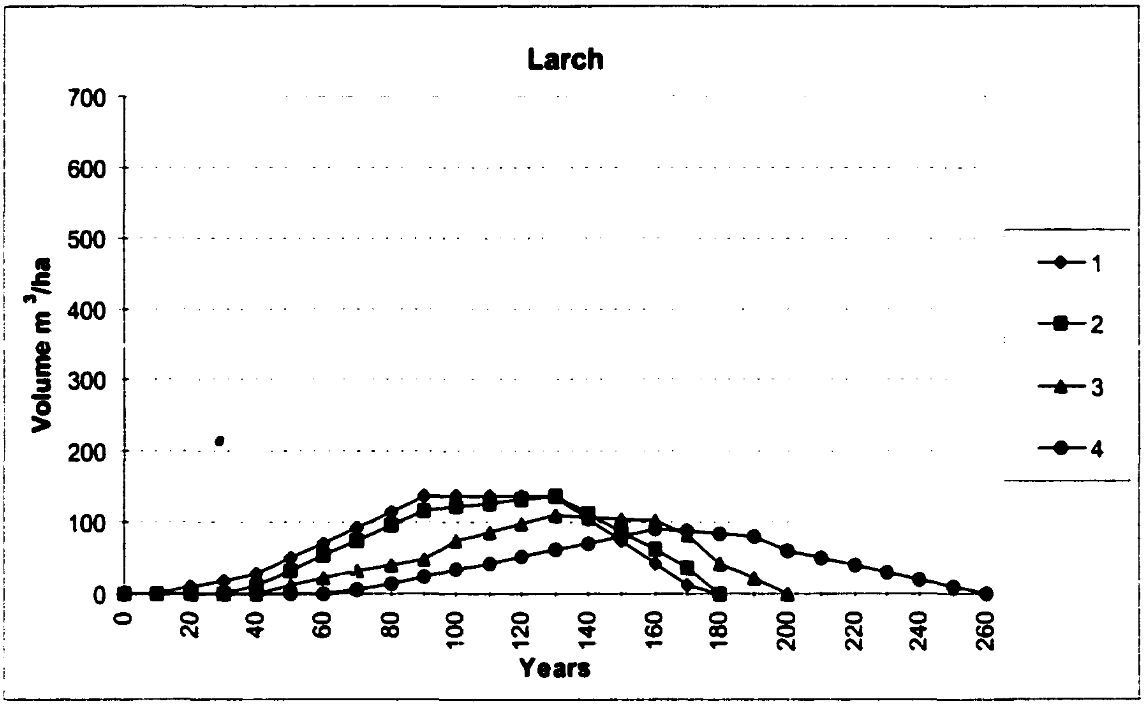


Figure A3-5: Larch and cedar volume over age yield curves.

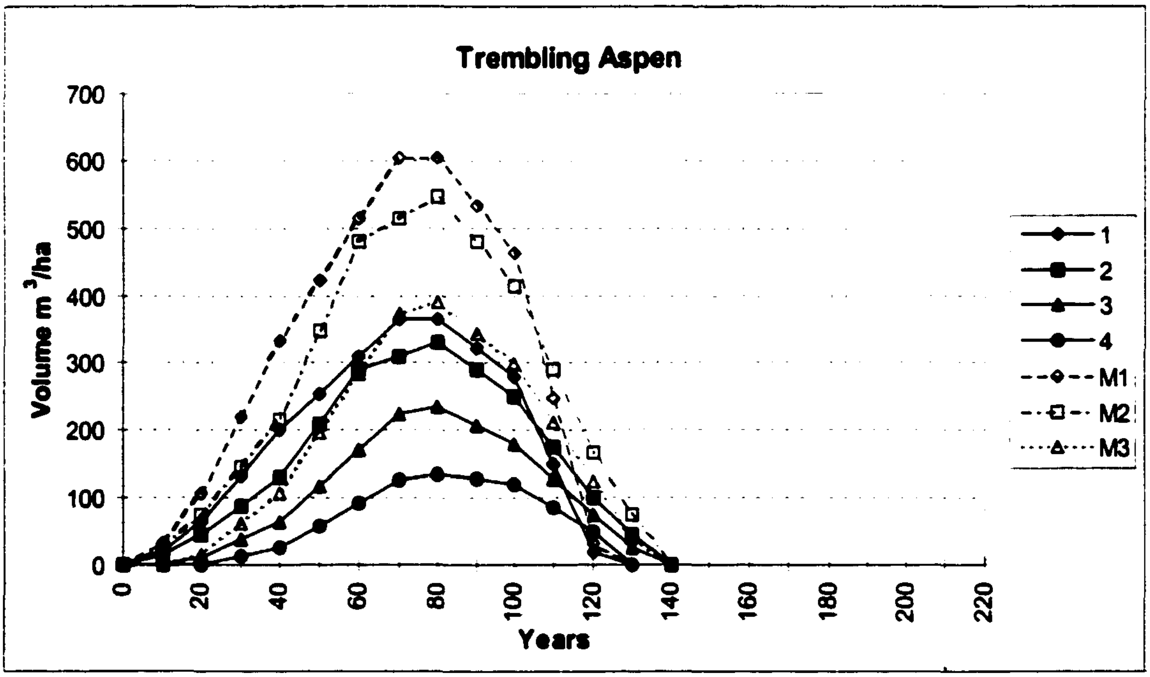


Figure A3-6: Trembling aspen and balsam poplar volume over age yield curves.

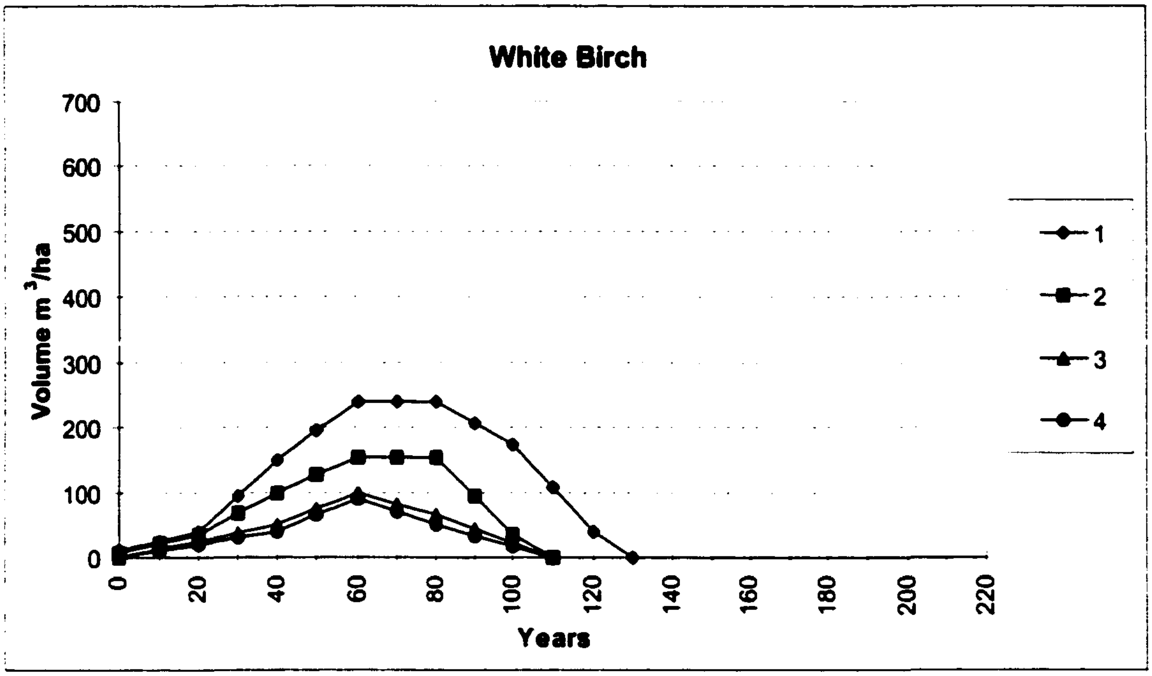
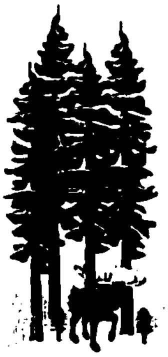


Figure A3-7: White birch volume over age yield curves.



APPENDIX 4

Results from HSG forest simulation.

Area by age-class graphs from HSG runs.

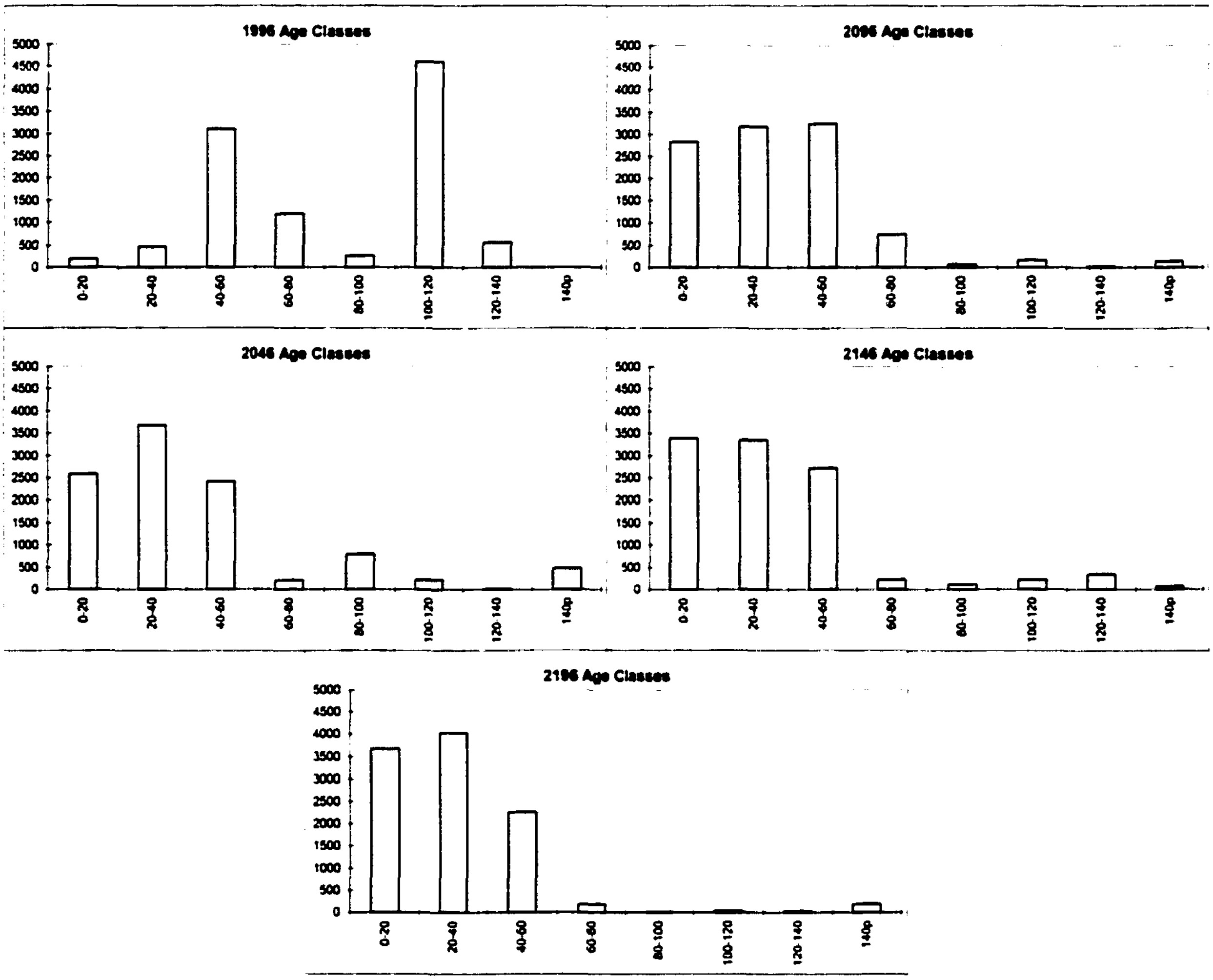


Figure A4-1: Basic-harvest age-class distributions by area.

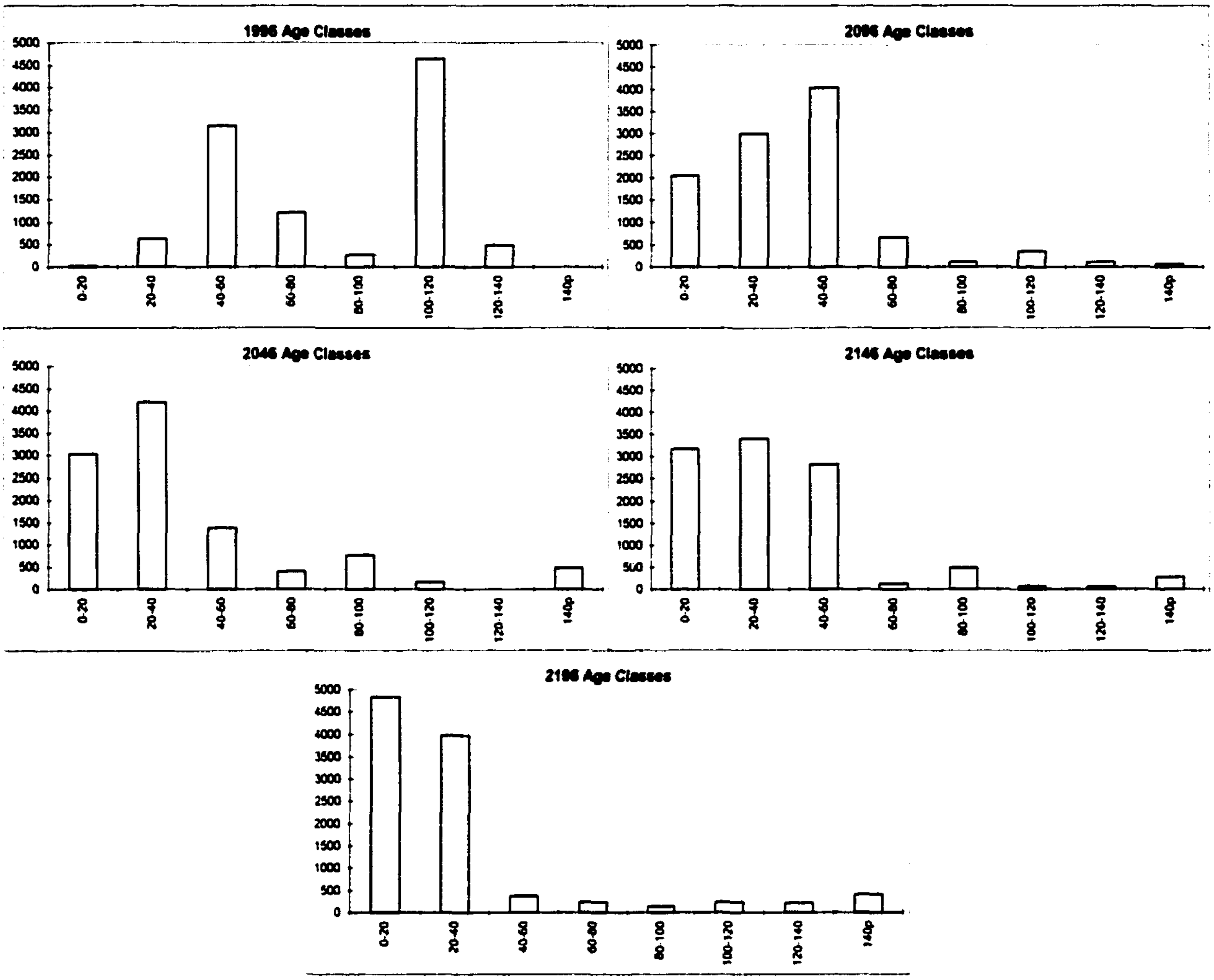
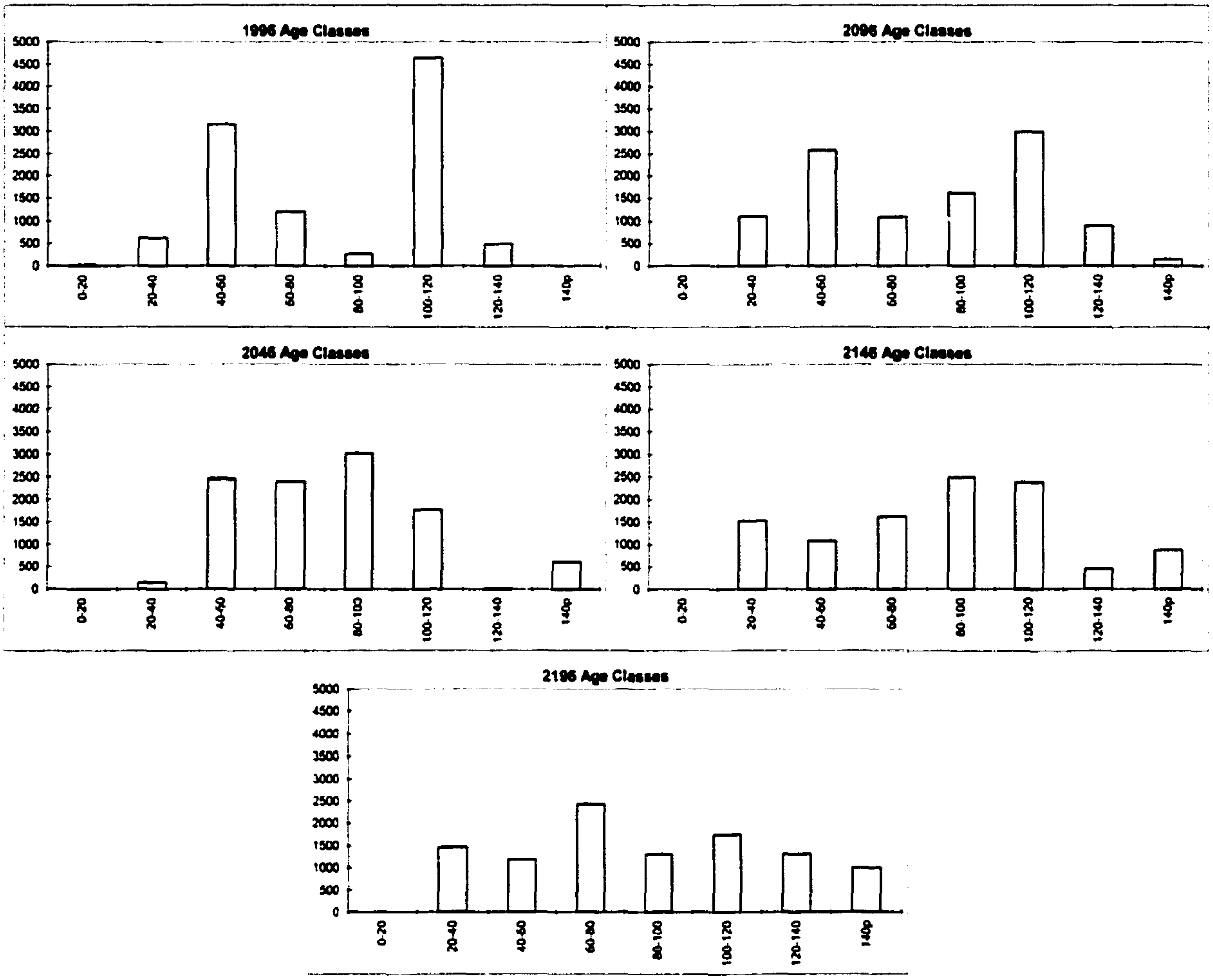


Figure A4-2: High-harvest age-class distributions by area.



1996 Age Classes

2096 Age Classes

2046 Age Classes

2146 Age Classes

2196 Age Classes

Figure A4-3: No-harvest age-class distributions by area.

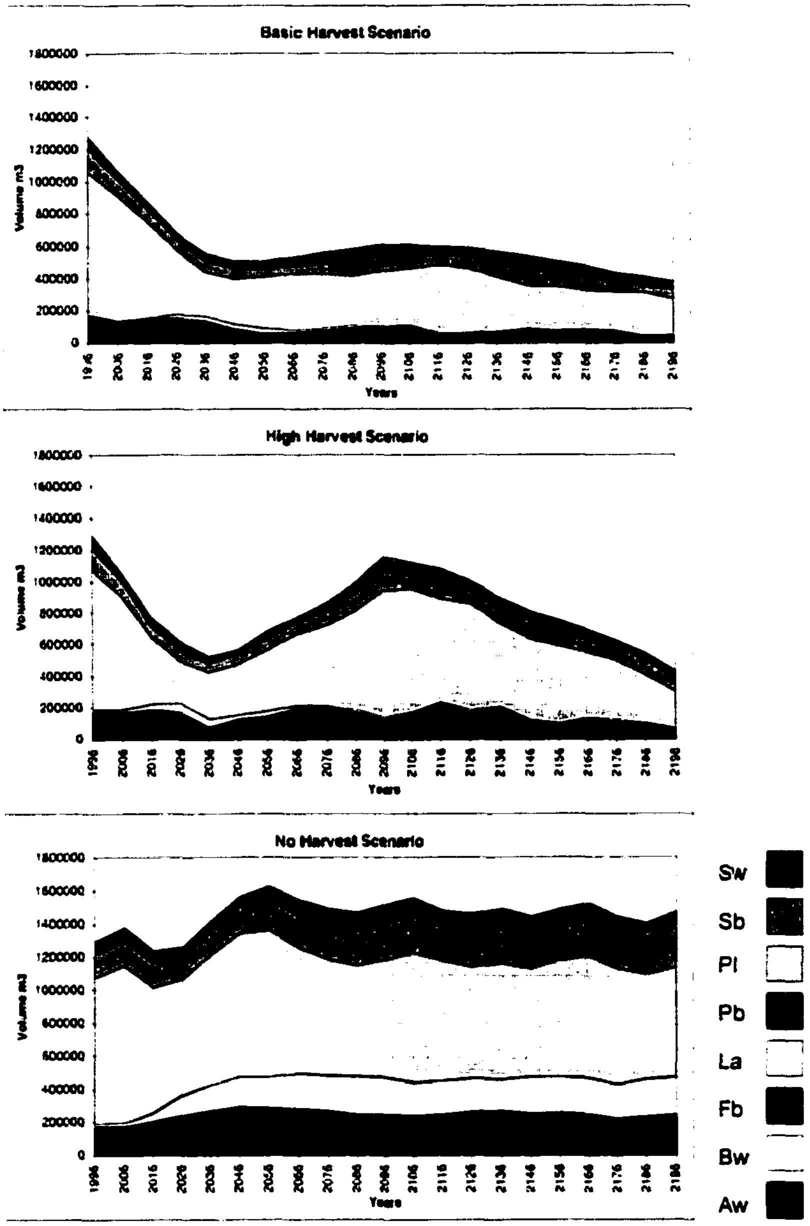


Figure A4-4: Species volume estimates for the Basic, High and No harvest HSG simulations.

APPENDIX 5

Table A5-1: State table used as input to HSG for forest simulations.

Species	Site	Age	Aw Stk	Type	Treatment		Sp1	St1	Ag1	Stk1	Sp2	St2	Ag2	Stk2	Sp3	St3	Ag3	Stk3	Sp4	St4	Ag4	Stk4
Aw	1	•	>0&<0.3	silv	basic	/	Sw	1	0	0.8	Aw	1	0	0.2								
Aw	1	•	>0&<0.3	silv	intensive	/	Sw	M1	0	0.9	Aw	M1	0	0.1								
Aw	1	•	>0&<0.5	silv	extensive	/	Aw	1	0	0.6	Fb	1	0	0.3								
Aw	1	•	>0.3&<0.6	silv	basic	/	Sw	1	0	0.5	Aw	1	0	0.3								
Aw	1	•	>0.3&<0.6	silv	intensive	/	Sw	M1	0	0.8	Aw	M1	0	0.2								
Aw	1	•	>0.5&<0.6	silv	extensive	/	Aw	1	10	0.6	Fb	1	20	0.3								
Aw	1	•	>0.6	silv	basic	/	Sw	1	0	0.5	Aw	1	0	0.4								
Aw	1	•	>0.6	silv	intensive	/	Aw	M1	10	1												
Aw	1	•	>0.6&<0.7	silv	extensive	/	Aw	1	10	0.6	Fb	1	20	0.2								
Aw	1	•	>0.7&<0.8	silv	extensive	/	Aw	1	10	0.8	Fb	1	20	0.1								
Aw	1	•	>0.8&<0.9	silv	extensive	/	Aw	1	10	1												
Aw	1	•	>0.9	silv	extensive	/	Aw	1	10	1												
Aw	1	>115	>0&<0.5	invt	none	/	Sw	1	45	0.5	Fb	1	45	0.2	Aw	1	45	0.3				
Aw	1	>115	>0.5&<0.6	invt	none	/	Sw	1	45	0.4	Fb	1	45	0.1	Aw	1	45	0.3				
Aw	1	>115	>0.6&<0.7	invt	none	/	Aw	1	35	0.7	Sw	1	45	0.2								
Aw	1	>115	>0.7&<0.8	invt	none	/	Aw	1	35	0.7	Sw	1	45	0.1	Fb	1	45	0.1				
Aw	1	>115	>0.8&<0.9	invt	none	/	Aw	1	35	0.9	Sw	1	45	0.1								
Aw	1	>115	>0.9	invt	none	/	Aw	1	35	1												
Aw	2	•	>0&<0.3	silv	basic	/	Sw	2	0	0.7	Aw	1	0	0.2								
Aw	2	•	>0&<0.3	silv	intensive	/	Sw	M2	0	0.9	Aw	M1	0	0.1								
Aw	2	•	>0&<0.5	silv	extensive	/	Aw	2	10	0.4	Fb	2	20	0.3								
Aw	2	•	>0.3&<0.6	silv	basic	/	Sw	2	0	0.6	Aw	1	0	0.3								
Aw	2	•	>0.3&<0.6	silv	intensive	/	Sw	M2	0	0.8	Aw	M1	0	0.1								
Aw	2	•	>0.5&<0.6	silv	extensive	/	Aw	2	10	0.5	Fb	2	20	0.3								
Aw	2	•	>0.6	silv	basic	/	Sw	2	0	0.5	Aw	1	0	0.5								
Aw	2	•	>0.6	silv	intensive	/	Aw	M2	10	1												
Aw	2	•	>0.6&<0.7	silv	extensive	/	Aw	2	10	0.6	Fb	2	20	0.2								
Aw	2	•	>0.7&<0.8	silv	extensive	/	Aw	2	10	0.8	Fb	2	20	0.1								
Aw	2	•	>0.8&<0.9	silv	extensive	/	Aw	2	10	1												
Aw	2	•	>0.9	silv	extensive	/	Aw	2	10	1												
Aw	2	>125	>0&<0.5	invt	none	/	Sw	2	45	0.5	Fb	2	45	0.2	Aw	2	35	0.3				
Aw	2	>125	>0.5&<0.6	invt	none	/	Sw	2	45	0.4	Fb	2	45	0.1	Aw	2	35	0.3				
Aw	2	>125	>0.6&<0.7	invt	none	/	Aw	2	35	0.7	Sw	2	45	0.2								
Aw	2	>125	>0.7&<0.8	invt	none	/	Aw	2	35	0.7	Sw	2	45	0.1	Fb	2	45	0.1				
Aw	2	>125	>0.8&<0.9	invt	none	/	Aw	2	35	0.9	Sw	2	45	0.1								
Aw	2	>125	>0.9	invt	none	/	Aw	2	35	1												
Aw	3	•	>0&<0.3	silv	basic	/	Sw	3	0	0.7	Aw	1	0	0.2								
Aw	3	•	>0&<0.3	silv	intensive	/	Sb	M2	10	0.9	Aw	M1	0	0.1								
Aw	3	•	>0&<0.5	silv	extensive	/	Aw	3	10	0.4	Fb	3	20	0.3								

Table A5-1: Continued.

Species	Site	Age	Aw Stk	Type	Treatment		Sp1	St1	Ag1	Stk1	Sp2	St2	Ag2	Stk2	Sp3	St3	Ag3	Stk3	Sp4	St4	Ag4	Stk4
Aw	3	•	>0.3&<0.6	silv	basic	/	Sw	3	0	0.6	Aw	1	0	0.3								
Aw	3	•	>0.3&<0.6	silv	intensive	/	Sb	M2	0	0.9	Aw	M1	0	0.1								
Aw	3	•	>0.5&<0.6	silv	extensive	/	Aw	3	10	0.5	Fb	3	20	0.3								
Aw	3	•	>0.6	silv	basic	/	Sw	3	0	0.5	Aw	1	0	0.5								
Aw	3	•	>0.6	silv	intensive	/	Aw	M2	0	0.9												
Aw	3	•	>0.6&<0.7	silv	extensive	/	Aw	3	10	0.6	Fb	3	30	0.2								
Aw	3	•	>0.7&<0.8	silv	extensive	/	Aw	3	10	0.7	Fb	3	30	0.1								
Aw	3	•	>0.8&<0.9	silv	extensive	/	Aw	3	10	0.8												
Aw	3	•	>0.9	silv	extensive	/	Aw	3	10	0.9												
Aw	3	>130	>0&<0.5	invt	none	/	Sw	3	35	0.3	Sb	2	45	0.2	Aw	3	35	0.1				
Aw	3	>130	>0.5&<0.6	invt	none	/	Sb	2	35	0.4	Aw	3	45	0.2	Sw	3	35	0.1				
Aw	3	>130	>0.6&<0.7	invt	none	/	Sb	2	35	0.6	Aw	3	45	0.2								
Aw	3	>130	>0.7&<0.8	invt	none	/	Aw	3	35	0.6	Sb	2	45	0.3								
Aw	3	>130	>0.8&<0.9	invt	none	/	Aw	3	35	0.7	Sb	2	45	0.2								
Aw	3	>130	>0.9	invt	none	/	Aw	3	15	0.8	Sb	2	15	0.1								
Aw	4	•	>0&<0.5	silv	extensive	/	Aw	4	10	0.4	Sb	3	30	0.3								
Aw	4	•	>0.5&<0.6	silv	extensive	/	Aw	4	10	0.5	Sb	3	30	0.3								
Aw	4	•	>0.6&<0.7	silv	extensive	/	Aw	4	10	0.6	Sb	3	30	0.2								
Aw	4	•	>0.7&<0.8	silv	extensive	/	Aw	4	10	0.6	Sb	3	30	0.1								
Aw	4	•	>0.8&<0.9	silv	extensive	/	Aw	4	10	0.7												
Aw	4	•	>0.9	silv	extensive	/	Aw	4	10	0.7												
Aw	4	>140	>0&<0.5	invt	none	/	Sb	3	40	0.4	Aw	4	35	0.1								
Aw	4	>140	>0.5&<0.6	invt	none	/	Sb	3	40	0.4	Aw	4	35	0.2								
Aw	4	>140	>0.6&<0.7	invt	none	/	Sb	3	40	0.6	Aw	4	35	0.2								
Aw	4	>140	>0.7&<0.8	invt	none	/	Sb	3	40	0.6	Aw	3	35	0.2								
Aw	4	>140	>0.8&<0.9	invt	none	/	Sb	3	40	0.5	Aw	3	35	0.3								
Aw	4	>140	>0.9	invt	none	/	Sb	3	20	0.4	Aw	3	15	0.4								
Aw	M1	•	0	silv	intensive	/	Aw	M1	0	1												
Aw	M1	•	>0&<1.1	silv	intensive	/	Aw	M1	0	1												
Aw	M2	•	0	silv	intensive	/	Aw	M2	0	1												
Aw	M2	•	>0&<1.1	silv	intensive	/	Aw	M2	0	1												
Aw	M3	•	0	silv	intensive	/	Aw	M2	0	1												
Aw	M3	•	>0&<1.1	silv	intensive	/	Aw	M3	0	1												
Bw	1	•	0	silv	basic	/	Pl	1	0	0.8	Bw	1	0	0.2								
Bw	1	•	0	silv	extensive	/	Pl	1	10	0.4	Bw	1	10	0.3	Sb	1	20	0.1				
Bw	1	•	0	silv	intensive	/	Pl	M1	0	0.8	Bw	1	0	0.1								
Bw	1	•	>0&<0.45	silv	basic	/	Pl	1	0	0.8	Aw	3	0	0.2								
Bw	1	•	>0&<0.45	silv	extensive	/	Aw	3	10	0.5	Bw	1	20	0.2	Pl	1	10	0.1				
Bw	1	•	>0&<0.45	silv	intensive	/	Pl	M1	0	0.7	Bw	1	0	0.1								
Bw	1	•	>0.45	silv	basic	/	Pl	1	0	0.6	Aw	3	0	0.3								

Table A5-1: Continued.

Species	Site	Age	Aw Stk	Type	Treatment		Sp1	St1	Ag1	Stk1	Sp2	St2	Ag2	Stk2	Sp3	St3	Ag3	Stk3	Sp4	St4	Ag4	Stk4
Bw	1	•	>0.45	silv	extensive	/	Aw	3	10	0.8	Fb	3	20	0.1								
Bw	1	•	>0.45	silv	intensive	/	Pl	M1	0	0.7	Bw	1	0	0.1								
Bw	1	>70	0	invt	none	/	Pl	3	30	0.5	Bw	1	30	0.2	Sb	2	30	0.2				
Bw	1	>70	>0&<0.25	invt	none	/	Pl	3	30	0.5	Bw	1	30	0.3	Sb	2	30	0.1				
Bw	1	>70	>0.25&<0.4	invt	none	/	Pl	3	30	0.5	Bw	1	30	0.1	Aw	3	30	0.1	Sb	2	30	0.1
Bw	1	>70	>0.45	invt	none	/	Aw	3	30	0.4	Sw	3	40	0.3	Pl	1	30	0.1	Sb	2	30	0.1
Bw	2	•	0	silv	basic	/	Pl	2	0	0.7	Bw	2	0	0.2								
Bw	2	•	0	silv	extensive	/	Pl	1	10	0.4	Bw	1	10	0.4								
Bw	2	•	0	silv	intensive	/	Pl	M2	0	0.7	Bw	1	0	0.1								
Bw	2	•	>0&<0.45	silv	basic	/	Pl	2	0	0.7	Aw	3	0	0.2								
Bw	2	•	>0&<0.45	silv	extensive	/	Aw	3	10	0.6	Bw	2	10	0.2	Pl	2	10	0.1				
Bw	2	•	>0&<0.45	silv	intensive	/	Pl	M2	0	0.7	Bw	2	0	0.2								
Bw	2	•	>0.45	silv	basic	/	Pl	2	0	0.6	Aw	3	0	0.3								
Bw	2	•	>0.45	silv	extensive	/	Aw	3	10	0.8	Fb	3	20	0.1								
Bw	2	•	>0.45	silv	intensive	/	Pl	M2	0	0.7	Bw	2	0	0.2								
Bw	2	>80	0	invt	none	/	Pl	2	30	0.4	Bw	2	35	0.3	Sb	2	40	0.2				
Bw	2	>80	>0&<0.25	invt	none	/	Pl	2	30	0.4	Aw	3	30	0.1	Bw	2	35	0.3				
Bw	2	>80	>0.25&<0.4	invt	none	/	Pl	2	30	0.3	Aw	3	30	0.3	Sb	2	35	0.2				
Bw	2	>80	>0.45	invt	none	/	Aw	3	30	0.4	Pl	2	30	0.3	Sb	2	35	0.2				
Bw	3	•	0	silv	basic	/	Pl	3	0	0.6	Bw	3	0	0.3								
Bw	3	•	0	silv	extensive	/	Pl	3	10	0.3	Bw	3	10	0.3	Sb	2	20	0.2				
Bw	3	•	0	silv	intensive	/	Pl	M3	0	0.6	Bw	3	0	0.1								
Bw	3	•	>0&<0.45	silv	basic	/	Pl	3	0	0.7	Aw	2	0	0.2								
Bw	3	•	>0&<0.45	silv	extensive	/	Aw	2	10	0.5	Bw	3	10	0.2	Sb	2	20	0.2				
Bw	3	•	>0&<0.45	silv	intensive	/	Pl	M3	0	0.6	Bw	3	0	0.2								
Bw	3	•	>0.45	silv	basic	/	Pl	3	0	0.5	Aw	2	0	0.4								
Bw	3	•	>0.45	silv	extensive	/	Aw	2	10	0.6	Fb	2	20	0.1								
Bw	3	•	>0.45	silv	intensive	/	Pl	M3	0	0.6	Bw	3	0	0.2								
Bw	3	>90	0	invt	none	/	Sb	3	40	0.5	Bw	3	30	0.2	Pl	3	35	0.1				
Bw	3	>90	>0&<0.25	invt	none	/	Sb	3	40	0.5	Aw	2	30	0.1	Bw	3	35	0.2				
Bw	3	>90	>0.25&<0.4	invt	none	/	Pl	3	30	0.5	Bw	3	30	0.3	Fb	2	35	0.2				
Bw	3	>90	>0.45	invt	none	/	Aw	2	30	0.6	Pl	3	30	0.2	Fb	2	35	0.2				
Bw	4	•	>0&<0.45	silv	extensive	/	Aw	2	10	0.6	Bw	3	10	0.2								
Bw	4	•	>0.45	silv	extensive	/	Aw	2	10	0.8	Fb	2	20	0.1								
Bw	4	>100	0	invt	none	/	Sb	3	40	0.4	Bw	4	10	0.2	Pl	4	35	0.1				
Bw	4	>100	>0&<0.25	invt	none	/	Sb	3	40	0.4	Aw	3	30	0.2	Pl	4	35	0.2				
Bw	4	>100	>0.25	invt	none	/	Sb	3	40	0.7	Bw	4	30	0.1								
Fb	1	•	0	silv	basic	/	Sw	1	0	0.8	Sb	2	0	0.2								
Fb	1	•	0	silv	extensive	/	Fb	1	20	0.8												

Table A5-1: Continued.

Species	Site	Age	Aw Stk	Type	Treatment		Sp1	St1	Ag1	Stk1	Sp2	St2	Ag2	Stk2	Sp3	St3	Ag3	Stk3	Sp4	St4	Ag4	Stk4
Fb	1	•	0	silv	intensive	/	Sw	M1	0	1												
Fb	1	•	>0&<0.25	silv	basic	/	Sw	1	0	0.8	Sb	2	0	0.1	Aw	1	0	0.1				
Fb	1	•	>0&<0.25	silv	extensive	/	Fb	1	10	0.8	Sb	2	20	0.1								
Fb	1	•	>0&<0.25	silv	intensive	/	Sw	M1	0	0.9	Fb	M1	0	0.1								
Fb	1	•	>0.25&<0.4	silv	basic	/	Sw	1	0	0.7	Aw	1	0	0.2								
Fb	1	•	>0.25&<0.4	silv	extensive	/	Fb	1	10	0.7	Aw	1	10	0.2								
Fb	1	•	>0.25&<0.4	silv	intensive	/	Sw	M1	0	0.8	Aw	M1	0	0.2								
Fb	1	•	>0.45	silv	basic	/	Sw	1	0	0.7	Aw	1	0	0.3								
Fb	1	•	>0.45	silv	extensive	/	Aw	1	10	0.7	Fb	1	10	0.1								
Fb	1	•	>0.45	silv	intensive	/	Sw	M1	0	0.7	Aw	M1	0	0.3								
Fb	1	>70	0	invt	none	/	Fb	1	40	0.6	Sw	1	50	0.4								
Fb	1	>70	>0&<0.25	invt	none	/	Fb	1	40	0.6	Sw	1	50	0.4								
Fb	1	>70	>0.25&<0.4	invt	none	/	Fb	1	40	0.6	Sw	1	50	0.2	Aw	1	20	0.1				
Fb	1	>70	>0.45	invt	none	/	Fb	1	40	0.5	Sw	1	50	0.2	Aw	1	20	0.2				
Fb	2	•	0	silv	basic	/	Sw	2	0	0.8	Sb	2	0	0.2								
Fb	2	•	0	silv	extensive	/	Fb	1	30	0.8												
Fb	2	•	0	silv	intensive	/	Sw	M2	0	1												
Fb	2	•	>0&<0.25	silv	basic	/	Sw	2	0	0.8	Sb	2	0	0.1	Aw	1	0	0.1				
Fb	2	•	>0&<0.25	silv	extensive	/	Fb	2	20	0.8	Sb	3	30	0.1								
Fb	2	•	>0&<0.25	silv	intensive	/	Sw	M2	0	0.8	Fb	M2	0	0.2								
Fb	2	•	>0.25&<0.4	silv	basic	/	Sw	2	0	0.7	Aw	1	0	0.2								
Fb	2	•	>0.25&<0.4	silv	extensive	/	Fb	2	20	0.7	Aw	2	10	0.2								
Fb	2	•	>0.25&<0.4	silv	intensive	/	Sw	M2	0	0.7	Aw	M2	0	0.1								
Fb	2	•	>0.45	silv	basic	/	Sw	2	0	0.7	Aw	1	0	0.3								
Fb	2	•	>0.45	silv	extensive	/	Aw	2	10	0.7	Fb	2	20	0.1								
Fb	2	•	>0.45	silv	intensive	/	Sw	M2	0	0.6	Aw	M2	0	0.2								
Fb	2	>80	0	invt	none	/	Fb	2	30	0.6	Sw	2	40	0.3								
Fb	2	>80	>0&<0.25	invt	none	/	Fb	2	30	0.5	Sw	2	40	0.3	Aw	2	20	0.1				
Fb	2	>80	>0.25&<0.4	invt	none	/	Fb	2	30	0.6	Sw	2	40	0.2	Aw	2	30	0.1				
Fb	2	>80	>0.45	invt	none	/	Fb	2	30	0.5	Sw	2	40	0.2	Aw	2	30	0.2				
Fb	3	•	0	silv	basic	/	Pl	1	0	0.8	Sb	2	0	0.2								
Fb	3	•	0	silv	extensive	/	Fb	1	20	0.7												
Fb	3	•	0	silv	intensive	/	Pl	M1	0	1												
Fb	3	•	>0&<0.25	silv	basic	/	Pl	1	0	0.8	Sb	2	0	0.1	Aw	1	0	0.1				
Fb	3	•	>0&<0.25	silv	extensive	/	Sw	3	20	0.3	Fb	3	20	0.3	Aw	3	20	0.2				
Fb	3	•	>0&<0.25	silv	intensive	/	Pl	M1	0	0.8	Fb	M3	0	0.1								
Fb	3	•	>0.25&<0.4	silv	basic	/	Pl	1	0	0.7	Aw	3	0	0.2								
Fb	3	•	>0.25&<0.4	silv	extensive	/	Aw	3	10	0.6	Fb	3	20	0.3								
Fb	3	•	>0.25&<0.4	silv	intensive	/	Pl	M1	0	0.7	Aw	M3	0	0.1								

Table A5-1: Continued.

Species	Site	Age	Aw Stk	Type	Treatment		Sp1	St1	Ag1	Stk1	Sp2	St2	Ag2	Stk2	Sp3	St3	Ag3	Stk3	Sp4	St4	Ag4	Stk4
Fb	3	•	>0.45	silv	basic	/	Pl	1	0	0.7	Aw	3	0	0.3								
Fb	3	•	>0.45	silv	extensive	/	Aw	3	10	0.6	Fb	3	20	0.2								
Fb	3	•	>0.45	silv	intensive	/	Pl	M1	0	0.6	Aw	M3	0	0.2								
Fb	3	>90	0	invt	none	/	Sw	3	50	0.6	Aw	3	35	0.1	Fb	3	40	0.1				
Fb	3	>90	>0&<0.25	invt	none	/	Sw	3	50	0.6	Aw	3	35	0.1	Fb	3	40	0.1				
Fb	3	>90	>0.25&<0.4	invt	none	/	Fb	3	40	0.5	Aw	3	35	0.2	Sw	3	50	0.2				
Fb	3	>90	>0.45	invt	none	/	Fb	3	20	0.5	Aw	3	15	0.4								
Fb	4	•	0	silv	extensive	/	Pl	2	20	0.4	Sb	2	30	0.3								
Fb	4	•	0	silv	intensive	/	Pl	M2	0	1												
Fb	4	•	>0&<0.25	silv	extensive	/	Pl	2	20	0.6	Sb	2	30	0.1								
Fb	4	•	>0&<0.25	silv	intensive	/	Pl	M2	0	0.6	Sb	M2	0	0.1								
Fb	4	•	>0.25&<0.4	silv	extensive	/	Pl	2	20	0.6	Fb	2	30	0.2								
Fb	4	•	>0.25&<0.4	silv	intensive	/	Pl	M2	0	0.5	Aw	M3	0	0.1								
Fb	4	•	>0.45	silv	extensive	/	Pl	2	20	0.6	Fb	2	20	0.1	Aw	4	20	0.1				
Fb	4	•	>0.45	silv	intensive	/	Pl	M2	0	0.5	Aw	M3	0	0.2								
Fb	4	>100	0	invt	none	/	Sb	2	40	0.5	Pl	2	30	0.1								
Fb	4	>100	>0&<0.25	invt	none	/	Sb	2	40	0.5	Pl	2	30	0.1								
Fb	4	>100	>0.25&<0.4	invt	none	/	Sb	2	40	0.5	Aw	4	35	0.2	Pl	2	30	0.1				
Fb	4	>100	>0.45	invt	none	/	Sb	2	40	0.5	Aw	4	35	0.4	Pl	2	30	0.1				
Pb	1	•	0	silv	basic	/	Sw	1	0	0.8												
Pb	1	•	0	silv	extensive	/	Sw	1	20	0.5	Pb	1	10	0.4								
Pb	1	•	0	silv	intensive	/	Sw	M1	0	1												
Pb	1	•	>0&<0.3	silv	basic	/	Sw	1	0	0.8	Aw	1	0	0.1								
Pb	1	•	>0&<0.3	silv	extensive	/	Sw	1	20	0.4	Pb	1	10	0.3	Aw	1	10	0.2				
Pb	1	•	>0&<0.3	silv	intensive	/	Sw	M1	0	0.9	Aw	M1	0	0.1								
Pb	1	•	>0.3&<0.6	silv	basic	/	Sw	1	0	0.6	Aw	1	0	0.3								
Pb	1	•	>0.3&<0.6	silv	extensive	/	Pb	1	10	0.3	Sw	1	20	0.3	Aw	1	10	0.2				
Pb	1	•	>0.3&<0.6	silv	intensive	/	Sw	M1	0	0.8	Aw	M1	0	0.2								
Pb	1	•	>0.6	silv	basic	/	Sw	1	0	0.4	Aw	1	0	0.4								
Pb	1	•	>0.6	silv	extensive	/	Aw	1	10	0.4	Pb	1	10	0.2	Sw	1	20	0.2	Sb	2	20	0.2
Pb	1	•	>0.6	silv	intensive	/	Sw	M1	0	0.6	Aw	M1	0	0.4								
Pb	1	>90	0	invt	none	/	Sw	1	45	0.6	Pb	1	35	0.3								
Pb	1	>90	>0&<0.3	invt	none	/	Sw	1	45	0.6	Pb	1	30	0.2	Sb	2	40	0.2				
Pb	1	>90	>0.3&<0.6	invt	none	/	Sw	1	45	0.4	Pb	1	30	0.2	Aw	1	35	0.2	Fb	1	35	0.1
Pb	1	>90	>0.6	invt	none	/	Aw	1	35	0.4	Pb	1	30	0.4	Sw	1	40	0.1				
Pb	2	•	0	silv	basic	/	Sw	2	0	0.8	Pb	2	0	0.1								
Pb	2	•	0	silv	extensive	/	Sw	2	30	0.4	Pb	2	10	0.4								
Pb	2	•	0	silv	intensive	/	Sw	M2	0	0.9												

Table A5-1: Continued.

Species	Site	Age	Aw Stk	Type	Treatment		Sp1	St1	Ag1	Stk1	Sp2	St2	Ag2	Stk2	Sp3	St3	Ag3	Stk3	Sp4	St4	Ag4	Stk4
Pb	2	•	>0&<0.3	silv	basic	/	Sw	2	0	0.7	Aw	2	0	0.1	Fb	2	0	0.1				
Pb	2	•	>0&<0.3	silv	extensive	/	Sw	2	30	0.4	Pb	2	10	0.3	Aw	2	10	0.2				
Pb	2	•	>0&<0.3	silv	intensive	/	Sw	M2	0	0.8	Aw	M2	0	0.1								
Pb	2	•	>0.3&<0.6	silv	basic	/	Sw	2	0	0.6	Aw	2	0	0.3								
Pb	2	•	>0.3&<0.6	silv	extensive	/	Pb	2	10	0.3	Sw	2	20	0.3	Aw	2	10	0.2				
Pb	2	•	>0.3&<0.6	silv	intensive	/	Sw	M2	0	0.8	Aw	M2	0	0.2								
Pb	2	•	>0.6	silv	basic	/	Sw	2	0	0.4	Aw	2	0	0.4								
Pb	2	•	>0.6	silv	extensive	/	Aw	2	10	0.4	Pb	2	10	0.2	Sw	2	20	0.2	Sb	2	20	0.2
Pb	2	•	>0.6	silv	intensive	/	Sw	M2	0	0.6	Aw	M2	0	0.4								
Pb	2	>100	0	invt	none	/	Sw	2	45	0.6	Pb	2	35	0.3								
Pb	2	>100	>0&<0.3	invt	none	/	Sw	2	45	0.6	Pb	2	30	0.2	Sb	2	50	0.2				
Pb	2	>100	>0.3&<0.6	invt	none	/	Sw	2	45	0.4	Pb	2	30	0.2	Aw	2	35	0.2	Fb	2	45	0.1
Pb	2	>100	>0.6	invt	none	/	Aw	2	35	0.4	Pb	2	30	0.4	Sw	2	40	0.1				
Pb	3	•	0	silv	basic	/	Sw	2	0	0.6	Pb	3	0	0.2								
Pb	3	•	0	silv	extensive	/	Sw	3	30	0.4	Pb	3	10	0.4								
Pb	3	•	0	silv	intensive	/	Sw	M3	0	0.8												
Pb	3	•	>0&<0.3	silv	basic	/	Sw	3	0	0.6	Fb	3	0	0.1								
Pb	3	•	>0&<0.3	silv	extensive	/	Sw	3	30	0.3	Pb	3	10	0.2	Aw	3	10	0.1				
Pb	3	•	>0&<0.3	silv	intensive	/	Sw	M3	0	0.7												
Pb	3	•	>0.3&<0.6	silv	basic	/	Sw	3	0	0.5	Aw	3	0	0.3								
Pb	3	•	>0.3&<0.6	silv	extensive	/	Pb	3	10	0.2	Sw	3	30	0.2	Aw	3	10	0.1				
Pb	3	•	>0.3&<0.6	silv	intensive	/	Sw	M3	0	0.7	Aw	M3	0	0.3								
Pb	3	•	>0.6	silv	basic	/	Sw	3	0	0.3	Aw	3	0	0.3								
Pb	3	•	>0.6	silv	extensive	/	Aw	3	10	0.3	Pb	3	10	0.2	Sw	3	20	0.2	Sb	2	30	0.2
Pb	3	•	>0.6	silv	intensive	/	Sw	M3	0	0.5	Aw	M3	0	0.3								
Pb	3	>110	0	invt	none	/	Sw	3	25	0.4	Pb	3	25	0.4								
Pb	3	>110	>0&<0.3	invt	none	/	Sw	3	45	0.5	Pb	3	40	0.2	Sb	2	50	0.2				
Pb	3	>110	>0.3&<0.6	invt	none	/	Sw	3	45	0.3	Pb	3	40	0.2	Aw	3	35	0.2	Fb	3	45	0.1
Pb	3	>110	>0.6	invt	none	/	Aw	3	35	0.3	Pb	3	40	0.4	Sw	3	50	0.1				
Pb	4	•	0	silv	basic	/	Sb	3	0	0.5	Pb	4	0	0.1								
Pb	4	•	0	silv	extensive	/	Sb	3	20	0.4	Pb	4	20	0.3								
Pb	4	•	>0&<0.3	silv	basic	/	Sb	3	0	0.4	Pb	4	0	0.2								
Pb	4	•	>0&<0.3	silv	extensive	/	Sb	3	20	0.3	Pb	4	10	0.2	Aw	3	10	0.1				
Pb	4	•	>0.3&<0.6	silv	basic	/	Sb	3	0	0.4	Pb	4	0	0.2	Aw	4	0	0.1				
Pb	4	•	>0.3&<0.6	silv	extensive	/	Sb	3	20	0.2	Pb	4	20	0.2	Aw	4	10	0.2				
Pb	4	•	>0.6	silv	basic	/	Sb	3	0	0.3	Aw	4	0	0.2								
Pb	4	•	>0.6	silv	extensive	/	Aw	4	0	0.3	Sb	3	0	0.3	Pb	4	0	0.1				
Pb	4	>120	0	invt	none	/	Pb	4	25	0.4	Sb	2	25	0.3								
Pb	4	>120	>0&<0.3	invt	none	/	Pb	4	30	0.2	Sb	2	40	0.2								

Table A5-1: Continued.

Species	Site	Age	Aw Stk	Type	Treatment		Sp1	St1	Ag1	Stk1	Sp2	St2	Ag2	Stk2	Sp3	St3	Ag3	Stk3	Sp4	St4	Ag4	Stk4
Pb	4	>120	>0.3&<0.6	invt	none	/	Pb	4	30	0.2	Aw	3	35	0.2	Fb	3	35	0.1	Sb	3	40	0.1
Pb	4	>120	>0.6	invt	none	/	Aw	4	30	0.4	Pb	3	35	0.3	Sw	3	20	0.1				
Pj	1	•	0	silv	basic	/	Pj	1	0	1												
Pj	1	•	0	silv	extensive	/	Pj	1	10	0.8	Sb	1	30	0.2								
Pj	1	•	0	silv	intensive	/	Pj	M1	0	1												
Pj	1	•	>0&<0.25	silv	basic	/	Pj	1	0	0.8	Bw	1	0	0.1								
Pj	1	•	>0&<0.25	silv	extensive	/	Pj	1	10	0.6	Bw	1	10	0.2	Aw	3	15	0.1				
Pj	1	•	>0&<0.25	silv	intensive	/	Pj	M1	0	1												
Pj	1	•	>0.25&<0.4	silv	basic	/	Pj	1	0	0.8	Aw	3	0	0.2								
Pj	1	•	>0.25&<0.4	silv	extensive	/	Pj	1	10	0.7	Aw	3	20	0.2								
Pj	1	•	>0.25&<0.4	silv	intensive	/	Pj	M1	0	0.9	Aw	M3	0	0.1								
Pj	1	•	>0.45	silv	basic	/	Pj	1	0	0.7	Aw	3	0	0.3								
Pj	1	•	>0.45	silv	extensive	/	Pj	1	10	0.7	Aw	3	20	0.3								
Pj	1	•	>0.45	silv	intensive	/	Pj	M1	0	0.7	Aw	M3	0	0.2								
Pj	1	>110	0	invt	none	/	Pj	1	30	0.8	Fb	1	30	0.2								
Pj	1	>110	>0&<0.25	invt	none	/	Pj	1	30	0.6	Fb	1	30	0.2	Aw	3	20	0.1				
Pj	1	>110	>0.25&<0.4	invt	none	/	Pj	1	30	0.6	Aw	3	20	0.2	Bw	1	20	0.1				
Pj	1	>110	>0.45	invt	none	/	Pj	1	30	0.5	Aw	3	20	0.3	Bw	1	20	0.1				
Pj	2	•	0	silv	basic	/	Pj	2	0	0.9	Sb	2	0	0.1								
Pj	2	•	0	silv	extensive	/	Pj	2	10	0.8	Bw	2	10	0.2	Sb	2	30	0.1				
Pj	2	•	0	silv	intensive	/	Pj	2	0	1												
Pj	2	•	>0&<0.25	silv	basic	/	Pj	2	0	0.8	Bw	2	0	0.1								
Pj	2	•	>0&<0.25	silv	extensive	/	Pj	2	10	0.7	Bw	2	10	0.2	Aw	3	20	0.1				
Pj	2	•	>0&<0.25	silv	intensive	/	Pj	M2	0	1												
Pj	2	•	>0.25&<0.4	silv	basic	/	Pj	2	0	0.8	Aw	3	0	0.2								
Pj	2	•	>0.25&<0.4	silv	extensive	/	Pj	2	10	0.7	Aw	3	10	0.2								
Pj	2	•	>0.25&<0.4	silv	intensive	/	Pj	M2	0	0.9	Aw	M3	0	0.1								
Pj	2	•	>0.45	silv	basic	/	Pj	2	0	0.7	Aw	3	0	0.3								
Pj	2	•	>0.45	silv	extensive	/	Pj	2	10	0.7	Aw	3	10	0.2								
Pj	2	•	>0.45	silv	intensive	/	Pj	M2	0	0.7	Aw	M3	0	0.2								
Pj	2	>110	0	invt	none	/	Pj	2	20	0.5	Fb	2	15	0.2	Bw	2	20	0.1				
Pj	2	>110	>0&<0.25	invt	none	/	Pj	2	30	0.5	Fb	2	35	0.2	Aw	2	20	0.1	Bw	1	20	0.1
Pj	2	>110	>0.25&<0.4	invt	none	/	Pj	2	30	0.5	Aw	2	15	0.2	Bw	2	20	0.1				
Pj	2	>110	>0.45	invt	none	/	Pj	2	30	0.6	Aw	2	15	0.2								
Pj	3	•	0	silv	basic	/	Pj	1	0	0.7	Sb	2	0	0.1								
Pj	3	•	0	silv	extensive	/	Pj	3	0	0.7	Bw	1	0	0.1	Sb	1	0	0.1				
Pj	3	•	0	silv	intensive	/	Pj	3	0	0.7	Sb	2	0	0.2								
Pj	3	•	>0&<0.25	silv	basic	/	Pj	3	0	0.7	Bw	3	0	0.2								
Pj	3	•	>0&<0.25	silv	extensive	/	Pj	3	10	0.6	Bw	3	10	0.1	Aw	2	10	0.2				

Table A5-1: Continued.

Species	Site	Age	Aw Stk	Type	Treatment		Sp1	St1	Ag1	Stk1	Sp2	St2	Ag2	Stk2	Sp3	St3	Ag3	Stk3	Sp4	St4	Ag4	Stk4
Pj	3	*	>0&<0.25	silv	intensive	/	Pj	M3	0	1												
Pj	3	*	>0.25&<0.4	silv	basic	/	Pj	3	0	0.7	Aw	2	0	0.3								
Pj	3	*	>0.25&<0.4	silv	extensive	/	Pj	3	10	0.7	Aw	2	10	0.3								
Pj	3	*	>0.25&<0.4	silv	intensive	/	Pj	M3	0	0.7	Aw	M2	0	0.2								
Pj	3	*	>0.45	silv	basic	/	Pj	3	0	0.6	Aw	2	0	0.4								
Pj	3	*	>0.45	silv	extensive	/	Pj	3	10	0.6	Aw	2	10	0.4								
Pj	3	*	>0.45	silv	intensive	/	Pj	M3	0	0.7	Aw	M2	0	0.3								
Pj	3	>120	0	invt	none	/	Sb	2	40	0.6	Pj	3	15	0.2	Bw	3	15	0.1				
Pj	3	>120	>0&<0.25	invt	none	/	Sb	2	40	0.6	Aw	2	15	0.2	Pj	3	15	0.1				
Pj	3	>120	>0.25&<0.4	invt	none	/	Sb	2	40	0.6	Aw	2	15	0.2								
Pj	3	>120	>0.45	invt	none	/	Sb	3	40	0.5	Aw	2	15	0.3								
Pj	4	*	0	invt	extensive	/	Sb	3	30	0.5	Pj	4	20	0.2								
Pj	4	*	>0&<0.25	silv	extensive	/	Sb	3	30	0.5	Pj	4	20	0.2								
Pj	4	*	>0.25&<0.4	silv	extensive	/	Sb	3	30	0.4	Aw	3	20	0.3								
Pj	4	*	>0.45	silv	extensive	/	Sb	3	30	0.3	Aw	3	20	0.3								
Pj	4	>130	0	invt	none	/	Sb	3	65	0.6	Pj	4	20	0.2								
Pj	4	>130	>0&<0.25	invt	none	/	Sb	3	65	0.6	Pj	4	30	0.2								
Pj	4	>130	>0.25&<0.4	invt	none	/	Sb	3	65	0.6	Aw	3	30	0.3								
Pj	4	>130	>0.45	invt	none	/	Sb	3	45	0.5	Aw	3	30	0.4								
Pj	M1	*	0	silv	intensive	/	Pj	M1	0	1												
Pj	M1	*	>0&<0.25	silv	intensive	/	Pj	M1	0	1												
Pj	M1	*	>0.25&<0.4	silv	intensive	/	Pj	M1	0	0.8	Aw	M2	0	0.1								
Pj	M1	*	>0.45	silv	intensive	/	Pj	M1	0	0.7	Aw	M2	0	0.3								
Pj	M2	*	0	silv	intensive	/	Pj	M2	0	1												
Pj	M2	*	>0&<0.25	silv	intensive	/	Pj	M2	0	1												
Pj	M2	*	>0.25&<0.4	silv	intensive	/	Pj	M2	0	0.8	Aw	M2	0	0.1								
Pj	M2	*	>0.45	silv	intensive	/	Pj	M2	0	0.8	Aw	M2	0	0.3								
Pj	M3	*	0	silv	intensive	/	Pj	M2	0	1												
Pj	M3	*	>0&<0.25	silv	intensive	/	Pj	M2	0	1												
Pj	M3	*	>0.25&<0.4	silv	intensive	/	Pj	M2	0	0.8	Aw	M3	0	0.1								
Pj	M3	*	>0.45	silv	intensive	/	Pj	M2	0	0.8	Aw	M3	0	0.1								
Pl	1	*	0	silv	basic	/	Pl	1	0	1												
Pl	1	*	0	silv	extensive	/	Pl	1	10	0.8	Sb	1	30	0.2								
Pl	1	*	0	silv	intensive	/	Pl	M1	0	1												
Pl	1	*	>0&<0.25	silv	basic	/	Pl	1	0	0.9	Bw	1	0	0.1								
Pl	1	*	>0&<0.25	silv	extensive	/	Pl	1	10	0.7	Bw	1	10	0.1	Aw	3	10	0.1				
Pl	1	*	>0&<0.25	silv	intensive	/	Pl	M1	0	1												
Pl	1	*	>0.25&<0.4	silv	basic	/	Pl	1	0	0.8	Aw	3	0	0.2								
Pl	1	*	>0.25&<0.4	silv	extensive	/	Pl	1	10	0.7	Aw	3	10	0.2								

Table A5-1: Continued.

Species	Site	Age	Aw Stk	Type	Treatment		Sp1	St1	Ag1	Stk1	Sp2	St2	Ag2	Stk2	Sp3	St3	Ag3	Stk3	Sp4	St4	Ag4	Stk4
Pl	1	•	>0.25&<0.4	silv	intensive	/	Pl	M1	0	0.9	Aw	M3	0	0.1								
Pl	1	•	>0.45	silv	basic	/	Pl	1	0	0.7	Aw	3	0	0.3								
Pl	1	•	>0.45	silv	extensive	/	Pl	1	10	0.7	Aw	3	10	0.3								
Pl	1	•	>0.45	silv	intensive	/	Pl	M1	0	0.7	Aw	M3	0	0.2								
Pl	1	>120	0	invt	none	/	Pl	1	20	0.6	Fb	1	20	0.2	Bw	1	20	0.1				
Pl	1	>120	>0&<0.25	invt	none	/	Pl	1	30	0.6	Fb	1	30	0.2	Aw	3	30	0.1				
Pl	1	>120	>0.25&<0.4	invt	none	/	Pl	1	30	0.5	Aw	3	30	0.2	Bw	1	30	0.1	Fb	1	30	0.1
Pl	1	>120	>0.45	invt	none	/	Pl	1	30	0.4	Aw	3	30	0.3	Bw	1	20	0.1	Fb	1	30	0.1
Pl	2	•	0	silv	basic	/	Pl	2	0	0.9	Sb	2	0	0.1								
Pl	2	•	0	silv	extensive	/	Pl	2	10	0.8	Bw	1	10	0.1	Sb	1	20	0.1				
Pl	2	•	0	silv	intensive	/	Pl	M2	0	1												
Pl	2	•	>0&<0.25	silv	basic	/	Pl	2	0	0.8	Bw	2	0	0.1								
Pl	2	•	>0&<0.25	silv	extensive	/	Pl	2	10	0.7	Bw	2	10	0.2	Aw	2	10	0.1				
Pl	2	•	>0&<0.25	silv	intensive	/	Pl	M2	0	1												
Pl	2	•	>0.25&<0.4	silv	basic	/	Pl	2	0	0.8	Aw	3	0	0.2								
Pl	2	•	>0.25&<0.4	silv	extensive	/	Pl	2	10	0.7	Aw	3	10	0.2								
Pl	2	•	>0.25&<0.4	silv	intensive	/	Pl	M2	0	0.9	Aw	M3	0	0.1								
Pl	2	•	>0.45	silv	basic	/	Pl	2	0	0.7	Aw	3	0	0.3								
Pl	2	•	>0.45	silv	extensive	/	Pl	2	10	0.7	Aw	3	10	0.2								
Pl	2	•	>0.45	silv	intensive	/	Pl	M2	0	0.7	Aw	M3	0	0.2								
Pl	2	>130	0	invt	none	/	Pl	2	20	0.5	Fb	2	40	0.3	Bw	2	20	0.1				
Pl	2	>130	>0&<0.25	invt	none	/	Pl	2	20	0.6	Fb	2	40	0.2	Bw	2	20	0.1				
Pl	2	>130	>0.25&<0.4	invt	none	/	Pl	2	20	0.5	Aw	2	15	0.2	Fb	2	40	0.1				
Pl	2	>130	>0.45	invt	none	/	Pl	2	20	0.4	Aw	2	15	0.3	Fb	2	40	0.1				
Pl	3	•	0	silv	basic	/	Pl	1	0	0.7	Sb	2	0	0.1								
Pl	3	•	0	silv	extensive	/	Pl	3	10	0.7	Bw	1	10	0.1	Sb	1	20	0.1				
Pl	3	•	0	silv	intensive	/	Pl	M3	0	0.8	Sb	M2	0	0.2								
Pl	3	•	>0&<0.25	silv	basic	/	Pl	3	0	0.7	Bw	3	0	0.2								
Pl	3	•	>0&<0.25	silv	extensive	/	Pl	3	0	0.6	Bw	3	0	0.1								
Pl	3	•	>0&<0.25	silv	intensive	/	Pl	M3	0	1												
Pl	3	•	>0.25&<0.4	silv	basic	/	Pl	3	0	0.7	Aw	2	0	0.3								
Pl	3	•	>0.25&<0.4	silv	extensive	/	Pl	3	10	0.7	Aw	2	10	0.3								
Pl	3	•	>0.25&<0.4	silv	intensive	/	Pl	M3	0	0.7	Aw	M2	0	0.2								
Pl	3	•	>0.45	silv	basic	/	Pl	3	0	0.6	Aw	2	0	0.4								
Pl	3	•	>0.45	silv	extensive	/	Pl	3	10	0.6	Aw	2	10	0.4								
Pl	3	•	>0.45	silv	intensive	/	Pl	M3	0	0.7	Aw	M2	0	0.3								
Pl	3	>135	0	invt	none	/	Sb	3	40	0.6	Pl	2	15	0.2	Fb	2	40	0.1				
Pl	3	>135	>0&<0.25	invt	none	/	Sb	3	40	0.6	Pl	2	15	0.2	Aw	2	15	0.1	Fb	2	20	0.1

Table A5-1: Continued.

Species	Site	Age	Aw Stk	Type	Treatment		Sp1	St1	Ag1	Stk1	Sp2	St2	Ag2	Stk2	Sp3	St3	Ag3	Stk3	Sp4	St4	Ag4	Stk4
Pl	3	>135	>0.25&<0.4	invt	none	/	Sb	3	40	0.6	Aw	2	15	0.2	Fb	2	40	0.1				
Pl	3	>135	>0.45	invt	none	/	Sb	3	40	0.5	Aw	2	15	0.3	Fb	2	40	0.1				
Pl	4	•	0	invt	extensive	/	Sb	3	0	0.5	Pl	4	20	0.2								
Pl	4	•	>0&<0.25	silv	extensive	/	Sb	3	0	0.5	Pl	4	20	0.2								
Pl	4	•	>0.25&<0.4	silv	extensive	/	Sb	3	0	0.4	Aw	3	20	0.3								
Pl	4	•	>0.45	silv	extensive	/	Sb	3	0	0.3	Aw	3	20	0.3								
Pl	4	>140	0	invt	none	/	Sb	3	40	0.5	Pl	4	20	0.2	Fb	3	40	0.1				
Pl	4	>140	>0&<0.25	invt	none	/	Sb	3	40	0.4	Fb	3	40	0.1	Pl	4	20	0.1	Aw	3	20	0.1
Pl	4	>140	>0.25&<0.4	invt	none	/	Sb	3	40	0.6	Aw	3	20	0.2	Fb	1	20	0.1				
Pl	4	>140	>0.45	invt	none	/	Sb	3	40	0.4	Aw	3	20	0.3	Fb	3	40	0.1				
Pl	M1	•	0	silv	intensive	/	Pl	M1	0	1												
Pl	M1	•	>0&<0.25	silv	intensive	/	Pl	M1	0	1												
Pl	M1	•	>0.25&<0.4	silv	intensive	/	Pl	M1	0	0.8	Aw	M2	0	0.1								
Pl	M1	•	>0.45	silv	intensive	/	Pl	M1	0	0.7	Aw	M2	0	0.3								
Pl	M2	•	0	silv	intensive	/	Pl	M2	0	1												
Pl	M2	•	>0&<0.25	silv	intensive	/	Pl	M2	0	1												
Pl	M2	•	>0.25&<0.4	silv	intensive	/	Pl	M2	0	0.8	Aw	M2	0	0.1								
Pl	M2	•	>0.45	silv	intensive	/	Pl	M2	0	0.8	Aw	M2	0	0.3								
Pl	M3	•	0	silv	intensive	/	Pl	M2	0	1												
Pl	M3	•	>0&<0.25	silv	intensive	/	Pl	M2	0	1												
Pl	M3	•	>0.25&<0.4	silv	intensive	/	Pl	M2	0	0.8	Aw	M3	0	0.1								
Pl	M3	•	>0.45	silv	intensive	/	Pl	M2	0	0.8	Aw	M3	0	0.1								
Sb	1	•	0	silv	basic	/	Sb	1	0	0.9												
Sb	1	•	0	silv	extensive	/	Sb	1	0	0.7												
Sb	1	•	0	silv	intensive	/	Sb	M1	0	1												
Sb	1	•	>0&<0.35	silv	basic	/	Sb	1	0	0.7	Aw	2	0	0.3								
Sb	1	•	>0&<0.35	silv	extensive	/	Sb	2	20	0.6	Aw	2	10	0.3								
Sb	1	•	>0&<0.35	silv	intensive	/	Sb	M1	0	0.8	Aw	M2	0	0.2								
Sb	1	•	>0.35	silv	basic	/	Aw	2	0	0.6	Sb	1	0	0.4								
Sb	1	•	>0.35	silv	extensive	/	Aw	2	10	0.8	Sb	1	20	0.2								
Sb	1	•	>0.35	silv	intensive	/	Sb	M1	0	0.7	Aw	M2	0	0.3								
Sb	1	>130	0	invt	none	/	Sb	1	50	0.9												
Sb	1	>130	>0&<0.35	invt	none	/	Sb	1	50	0.6	Aw	2	35	0.3								
Sb	1	>130	>0.35	invt	none	/	Aw	2	30	0.8	Sb	1	50	0.2								
Sb	2	•	0	silv	basic	/	Sb	2	0	0.8												
Sb	2	•	0	silv	extensive	/	Sb	2	25	0.6	Pl	2	10	0.2	Fb	3	20	0.1				
Sb	2	•	0	silv	intensive	/	Sb	M2	0	0.9												
Sb	2	•	>0&<0.35	silv	basic	/	Sb	2	0	0.7	Aw	3	0	0.3								

Table A5-1: Continued.

Species	Site	Age	Aw Stk	Type	Treatment		Sp1	St1	Ag1	Stk1	Sp2	St2	Ag2	Stk2	Sp3	St3	Ag3	Stk3	Sp4	St4	Ag4	Stk4
Sb	2	•	>0&<0.35	silv	extensive	/	Sb	2	25	0.5	Aw	3	15	0.3	Fb	3	20	0.1				
Sb	2	•	>0&<0.35	silv	intensive	/	Sb	M2	0	0.7	Aw	M3	0	0.2								
Sb	2	•	>0.35	silv	basic	/	Sb	2	0	0.5	Aw	3	0	0.5								
Sb	2	•	>0.35	silv	extensive	/	Aw	3	15	0.6	Sb	2	20	0.2	Fb	3	20	0.1				
Sb	2	•	>0.35	silv	intensive	/	Sb	M2	0	0.7	Aw	M3	0	0.2								
Sb	2	>150	0	invt	none	/	Sb	2	60	1	Bw	2	30	0.1	Fb	2	40	0.1				
Sb	2	>150	>0&<0.35	invt	none	/	Sb	2	60	0.6	Aw	3	30	0.1	Bw	2	30	0.1				
Sb	2	>150	>0.35	invt	none	/	Sb	3	60	0.6	Aw	2	30	0.2	Fb	2	40	0.1				
Sb	3	•	0	silv	basic	/	Sb	3	0	0.6												
Sb	3	•	0	silv	extensive	/	Sb	3	25	0.4	Pj	3	10	0.3								
Sb	3	•	0	silv	intensive	/	Sb	M3	0	0.7												
Sb	3	•	>0&<0.35	silv	basic	/	Sb	3	0	0.5	Aw	4	0	0.1	Fb	3	0	0.2				
Sb	3	•	>0&<0.35	silv	extensive	/	Sb	3	25	0.5	Aw	4	10	0.1	Fb	3	20	0.2				
Sb	3	•	>0&<0.35	silv	intensive	/	Sb	M3	0	0.7	Aw	M3	0	0.1	Fb	M3	0	0.1				
Sb	3	•	>0.35	silv	basic	/	Sb	3	0	0.4	Aw	4	0	0.3	Fb	2	0	0.2				
Sb	3	•	>0.35	silv	extensive	/	Aw	4	10	0.5	Sb	3	20	0.2	Fb	3	20	0.2				
Sb	3	•	>0.35	silv	intensive	/	Sb	M3	0	0.6	Aw	M3	0	0.2	Fb	M2	0	0.1				
Sb	3	>160	0	invt	none	/	Sb	3	60	0.5	Fb	3	40	0.2	Bw	3	30	0.1				
Sb	3	>160	>0&<0.35	invt	none	/	Sb	3	60	0.4	Aw	4	30	0.1	Fb	3	40	0.2				
Sb	3	>160	>0.35	invt	none	/	Sb	3	60	0.3	Aw	4	30	0.2	Fb	3	40	0.2				
Sb	4	•	0	silv	extensive	/	Sb	4	20	0.3	La	3	20	0.1								
Sb	4	•	>0&<0.35	silv	extensive	/	Sb	4	20	0.4	La	3	20	0.1								
Sb	4	•	>0.35	silv	extensive	/	Sb	4	20	0.2	La	3	20	0.1								
Sb	4	>170	0	invt	none	/	Sb	4	70	0.6	La	2	50	0.2								
Sb	4	>170	>0&<0.35	invt	none	/	Sb	4	70	0.5	La	2	50	0.1								
Sb	4	>170	>0.35	invt	none	/	Sb	4	70	0.4	Aw	4	20	0.1	La	2	50	0.1				
Sb	M1	•	0	silv	intensive	/	Sb	M1	0	1												
Sb	M1	•	>0&<0.25	silv	intensive	/	Sb	M1	0	0.9												
Sb	M1	•	>0.25&<0.3	silv	intensive	/	Sb	M1	0	0.7	Aw	M3	0	0.1								
Sb	M1	•	>0.35	silv	intensive	/	Sb	M1	0	0.7	Aw	M3	0	0.3								
Sb	M2	•	0	silv	intensive	/	Sb	M1	0	0.1												
Sb	M2	•	>0&<0.25	silv	intensive	/	Sb	M1	0	0.9												
Sb	M2	•	>0.25&<0.3	silv	intensive	/	Sb	M1	0	0.7	Aw	M3	0	0.1								
Sb	M2	•	>0.35	silv	intensive	/	Sb	M1	0	0.7	Aw	M3	0	0.3								
Sb	M3	•	0	silv	intensive	/	Sb	M2	0	0.9												
Sb	M3	•	>0&<0.25	silv	intensive	/	Sb	M2	0	0.8												
Sb	M3	•	>0.25&<0.3	silv	intensive	/	Sb	M2	0	0.7	Aw	M3	0	0.2								
Sb	M3	•	>0.35	silv	intensive	/	Sb	M2	0	0.6	Aw	M3	0	0.3								

Table A5-1: Continued.

Species	Site	Age	Aw Stk	Type	Treatment		Sp1	St1	Ag1	Stk1	Sp2	St2	Ag2	Stk2	Sp3	St3	Ag3	Stk3	Sp4	St4	Ag4	Stk4
Sw	1	•	0	silv	basic	/	Sw	1	0	0.8												
Sw	1	•	0	silv	extensive	/	Sw	1	30	0.6	Fb	1	30	0.3								
Sw	1	•	0	silv	intensive	/	Sw	M1	0	1												
Sw	1	•	>0&<0.35	silv	basic	/	Sw	1	0	0.6	Aw	1	0	0.3								
Sw	1	•	>0&<0.35	silv	extensive	/	Sw	1	20	0.4	Aw	1	10	0.2	Fb	1	20	0.2				
Sw	1	•	>0&<0.35	silv	intensive	/	Sw	M1	0	1	Aw	M1	0	0.1								
Sw	1	•	>0.35	silv	basic	/	Sw	1	0	0.5	Aw	1	0	0.5								
Sw	1	•	>0.35	silv	extensive	/	Aw	1	10	0.5	Sw	1	20	0.2	Fb	1	20	0.2				
Sw	1	•	>0.35	silv	intensive	/	Sw	M1	0	1	Aw	M1	0	0.2								
Sw	1	>195	0	invt	none	/	Sw	1	65	0.5	Fb	1	40	0.2								
Sw	1	>195	>0&<0.35	invt	none	/	Sw	1	65	0.4	Aw	1	30	0.2	Fb	1	40	0.2				
Sw	1	>195	>0.35	invt	none	/	Sw	1	65	0.3	Aw	1	30	0.3	Fb	1	40	0.2				
Sw	2	•	0	silv	basic	/	Sw	2	0	0.8												
Sw	2	•	0	silv	extensive	/	Sw	2	20	0.4	Fb	2	20	0.3								
Sw	2	•	0	silv	intensive	/	Sw	M2	0	1												
Sw	2	•	>0&<0.35	silv	basic	/	Sw	2	0	0.6	Aw	2	0	0.3								
Sw	2	•	>0&<0.35	silv	extensive	/	Fb	2	20	0.3	Sw	2	20	0.3	Aw	2	10	0.2				
Sw	2	•	>0&<0.35	silv	intensive	/	Sw	M2	0	0.8	Aw	M2	0	0.1								
Sw	2	•	>0.35	silv	basic	/	Sw	2	0	0.5	Aw	2	0	0.5								
Sw	2	•	>0.35	silv	extensive	/	Fb	2	20	0.4	Aw	2	10	0.3	Sw	2	20	0.2				
Sw	2	•	>0.35	silv	intensive	/	Sw	M2	0	0.6	Aw	M2	0	0.2								
Sw	2	>195	0	invt	none	/	Sw	2	65	0.5	Fb	2	45	0.2								
Sw	2	>195	>0&<0.35	invt	none	/	Sw	2	65	0.4	Aw	2	30	0.2	Fb	2	45	0.2				
Sw	2	>195	>0.35	invt	none	/	Sw	2	65	0.3	Aw	2	30	0.3	Fb	2	45	0.2				
Sw	3	•	0	silv	basic	/	Sw	3	0	0.8												
Sw	3	•	0	silv	extensive	/	Sw	3	20	0.3	Fb	3	20	0.3								
Sw	3	•	0	silv	intensive	/	Sw	M3	0	0.8												
Sw	3	•	>0&<0.35	silv	basic	/	Sw	3	0	0.5	Aw	3	0	0.4								
Sw	3	•	>0&<0.35	silv	extensive	/	Fb	3	20	0.4	Sw	3	20	0.2	Aw	3	10	0.1				
Sw	3	•	>0&<0.35	silv	intensive	/	Sw	M3	0	0.8	Aw	M3	0	0.1								
Sw	3	•	>0.35	silv	basic	/	Aw	3	0	0.4	Sw	3	0	0.3								
Sw	3	•	>0.35	silv	extensive	/	Fb	2	20	0.4	Sw	3	20	0.2	Aw	3	10	0.2				
Sw	3	•	>0.35	silv	intensive	/	Sw	M3	0	0.7	Aw	M3	0	0.3								
Sw	3	>195	0	invt	none	/	Sw	3	60	0.5	Fb	3	20	0.3								
Sw	3	>195	>0&<0.35	invt	none	/	Fb	3	45	0.4	Aw	3	30	0.2	Sw	3	60	0.2				
Sw	3	>195	>0.35	invt	none	/	Aw	3	45	0.4	Fb	3	40	0.1	Sw	3	60	0.1				
Sw	4	•	0	silv	basic	/	Pl	3	0	0.8												
Sw	4	•	0	silv	extensive	/	Sb	2	20	0.5	Pj	2	10	0.3								

Table A5-1: Continued.

Species	Site	Age	Aw Stk	Type	Treatment		Sp1	St1	Ag1	Stk1	Sp2	St2	Ag2	Stk2	Sp3	St3	Ag3	Stk3	Sp4	St4	Ag4	Stk4
Sw	4	•	>0&<0.35	silv	basic	/	Sb	2	0	0.5	Aw	4	0	0.1								
Sw	4	•	>0&<0.35	silv	extensive	/	Sb	2	20	0.6	Aw	4	10	0.2								
Sw	4	•	>0.35	silv	basic	/	Sb	2	0	0.5	Aw	4	0	0.1								
Sw	4	•	>0.35	silv	extensive	/	Sb	2	20	0.6	Aw	4	10	0.1								
Sw	4	>200	0	invt	none	/	Sb	2	65	0.5												
Sw	4	>200	>0&<0.35	invt	none	/	Sb	2	65	0.4	La	1	30	0.2								
Sw	4	>200	>0.35	invt	none	/	Sb	2	65	0.4	La	1	40	0.2								
Sw	M1	•	0	silv	intensive	/	Sw	M1	0	1												
Sw	M1	•	>0&<0.25	silv	intensive	/	Sw	M1	0	0.9												
Sw	M1	•	>0.25&<0.3	silv	intensive	/	Sw	M1	0	0.9	Aw	M1	0	0.1								
Sw	M1	•	>0.35	silv	intensive	/	Sw	M1	0	0.8	Aw	M1	0	0.2								
Sw	M2	•	0	silv	intensive	/	Sw	M2	0	1												
Sw	M2	•	>0&<0.25	silv	intensive	/	Sw	M2	0	0.9												
Sw	M2	•	>0.25&<0.3	silv	intensive	/	Sw	M2	0	0.8	Aw	M1	0	0.1								
Sw	M2	•	>0.35	silv	intensive	/	Sw	M2	0	0.8	Aw	M1	0	0.2								
Sw	M3	•	0	silv	intensive	/	Sw	M2	0	0.9												
Sw	M3	•	>0&<0.25	silv	intensive	/	Sw	M2	0	0.8												
Sw	M3	•	>0.25&<0.3	silv	intensive	/	Sw	M2	0	0.7	Aw	M2	0	0.1								
Sw	M3	•	>0.35	silv	intensive	/	Sw	M2	0	0.7	Aw	M2	0	0.3								

APPENDIX 6

Sensitivity Analysis for the Duinker Population Model

Overview

Once the normal parameters for the Duinker Populaiton Model (DPM) were established, sensitivity analysis was conducted on variables that were thought to affect the performance of the DPM. Five parameters were selected; Cow Harvest Rate, Fecundity, Predation, Target Density and Bull Harvest Rate. The sensitivity of each parameter was examined by selecting a range of resonable values and comparing those to the normal runs of no-harvest, high-harvest and basic-harvest scenarios. The results were examined visually for parameters that significantly controlled outputs of the DPM, or contributed odd output behaviours.

Cow Harvest Rate Sensitivity

The CHR parameters used in sensitivity analysis were linear increases of 1.5x, 1.25x and decrease of 0.75x, 0.5x and 0.25x of the normal parameters Table A6-1.

Table A6-1: Cow harvest rate values used for the cow harvest rate sensitivity analysis with the Duinker Population Model.

Actual Density / Target Density	Normal CHR	1.5 x CHR	1.25 x CHR	0.75 x CHR	0.5 x CHR	0.2 x CHR
0	0	0	0	0	0	0
0.25	0.02	0.03	0.025	0.015	0.01	0.004
0.5	0.04	0.06	0.05	0.03	0.02	0.008
0.75	0.06	0.09	0.075	0.045	0.03	0.012
1	0.085	0.128	0.106	0.064	0.043	0.017

Results and Discussion

The sensitive spot for CHR is between normal and 1.25x of normal. This sensitivity analysis illustrates (Figure A6-1) the effect of having a cow harvest rate that is too high for the birth rate to keep pace with, i.e. 1.25x and 1.5x assuming fecundity, predation and other mortality stay constant. The removal of spikes between the normal and 1.25x lines illustrate the shift from a population controlled by habitat (specifically food) to a population controlled by recruitment. When the CHR increases further from 1.25x to 1.50x, the populations crash as illustrated by the straight line for 1.50x in the HHS (Figure A6-2).

The sensitivity multiples of 0.75x, 0.5x and 0.25x have a slight effect on the population of moose. There is a linear increase in moose numbers as the CHR declines below normal. However, for the HHS a slight reduction to 0.8x of normal

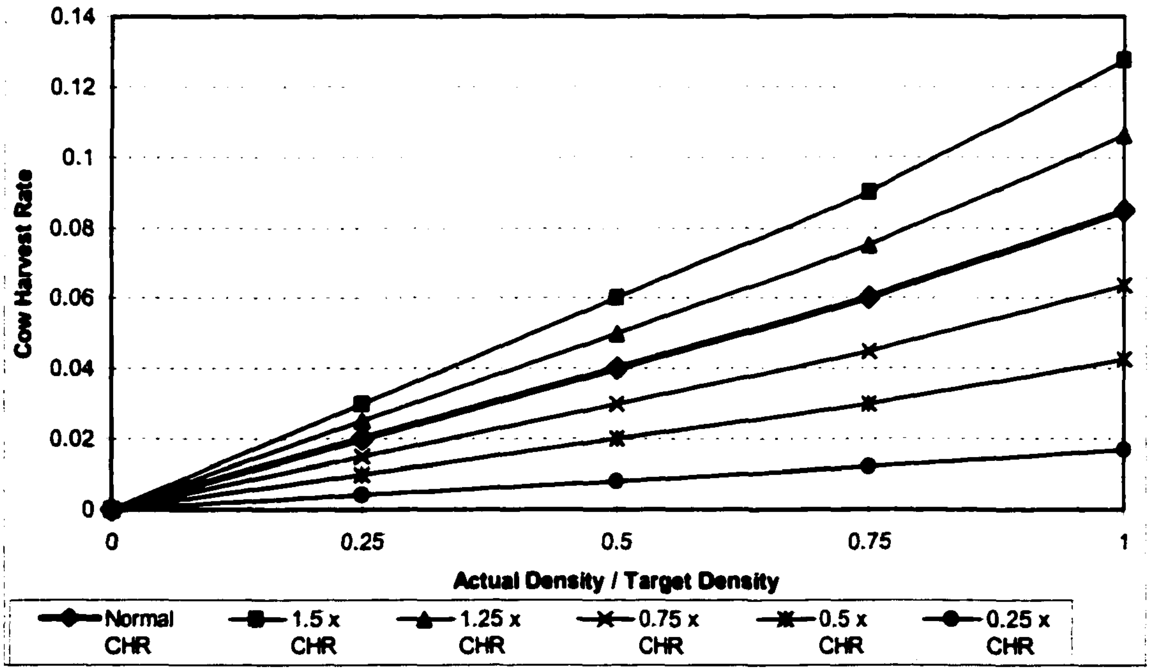


Figure A6-1: Cow harvest rate X,Y pairs used for sensitivity analysis in the Duinker Population Model.

Year	No N	No 1.5	No 1.25	No 0.75	No 0.5	No 0.25
1996	1.97	0.50	1.78	2.06	2.13	2.19
2006	1.99	0.50	1.79	2.08	2.15	2.21
2016	2.38	0.50	1.87	2.56	2.67	2.75
2026	2.67	0.50	1.96	2.80	2.91	2.99
2036	2.13	0.50	1.99	2.20	2.26	2.31
2046	1.91	0.50	1.79	1.98	2.04	2.09
2056	2.02	0.50	1.78	2.12	2.20	2.26
2066	2.43	0.50	1.87	2.61	2.73	2.81
2076	2.41	0.50	1.96	2.50	2.58	2.65
2086	2.27	0.50	2.02	2.36	2.43	2.50
2096	1.95	0.50	1.85	2.02	2.08	2.13
2106	1.81	0.50	1.69	1.89	1.95	2.00
2116	1.90	0.50	1.69	2.00	2.07	2.13
2126	2.21	0.50	1.76	2.36	2.45	2.53
2136	2.10	0.50	1.84	2.18	2.25	2.31
2146	2.48	0.50	1.92	2.66	2.78	2.87
2156	2.04	0.50	1.92	2.10	2.16	2.21
2166	1.97	0.50	1.81	2.06	2.13	2.19
2176	2.16	0.50	1.86	2.28	2.36	2.43
2186	2.47	0.50	1.95	2.61	2.71	2.80
2196	2.07	0.50	1.94	2.14	2.20	2.25

Year	H N	H 1.50	H 1.25	H 0.75	H 0.5	H 0.25
1996	1.97	0.50	1.78	2.06	2.13	2.19
2006	1.74	0.50	1.64	1.80	1.86	1.90
2016	2.31	0.50	1.70	2.87	3.13	3.26
2026	3.16	0.50	1.79	4.27	4.50	4.65
2036	4.27	0.50	1.88	4.69	4.86	4.99
2046	3.71	0.50	1.98	3.84	3.94	4.03
2056	3.37	0.50	2.08	3.50	3.61	3.70
2066	3.44	0.50	2.18	3.60	3.72	3.82
2076	3.53	0.50	2.29	3.69	3.82	3.91
2086	3.31	0.50	2.41	3.44	3.55	3.63
2096	3.01	0.50	2.52	3.12	3.21	3.29
2106	2.62	0.50	2.46	2.71	2.79	2.86
2116	2.82	0.50	2.46	2.97	3.08	3.17
2126	3.18	0.50	2.58	3.36	3.49	3.59
2136	3.37	0.50	2.71	3.54	3.66	3.75
2146	3.49	0.50	2.84	3.66	3.78	3.88
2156	3.39	0.50	2.96	3.52	3.63	3.72
2166	3.49	0.50	3.04	3.66	3.79	3.89
2176	3.59	0.50	3.11	3.77	3.90	4.00
2186	3.70	0.50	3.18	3.89	4.03	4.14
2196	3.96	0.50	3.28	4.19	4.35	4.47

Year	B N	B 1.50	B 1.25	B 0.75	B 0.5	B 0.25
1996	1.97	0.50	1.78	2.06	2.13	2.19
2006	2.02	0.50	1.80	2.11	2.18	2.24
2016	2.53	0.50	1.89	2.78	2.92	3.02
2026	3.38	0.50	1.98	3.82	4.00	4.14
2036	3.94	0.50	2.08	4.14	4.28	4.40
2046	3.73	0.50	2.19	3.88	4.00	4.10
2056	3.41	0.50	2.30	3.54	3.65	3.74
2066	3.31	0.50	2.41	3.45	3.57	3.67
2076	3.58	0.50	2.54	3.77	3.91	4.03
2086	3.66	0.50	2.66	3.83	3.96	4.07
2096	3.56	0.50	2.80	3.71	3.83	3.93
2106	3.30	0.50	2.91	3.43	3.54	3.63
2116	3.31	0.50	2.96	3.46	3.58	3.68
2126	3.35	0.50	3.00	3.50	3.62	3.71
2136	3.47	0.50	3.07	3.64	3.77	3.87
2146	3.73	0.50	3.18	3.92	4.06	4.18
2156	3.77	0.50	3.29	3.94	4.07	4.17
2166	3.74	0.50	3.36	3.90	4.03	4.14
2176	3.88	0.50	3.42	4.07	4.21	4.33
2186	3.93	0.50	3.50	4.10	4.24	4.35
2196	3.91	0.50	3.53	4.08	4.21	4.32

N = Normal
No = No Harvest Scenario
H = High Harvest Scenario
B = Basic Harvest Scenario

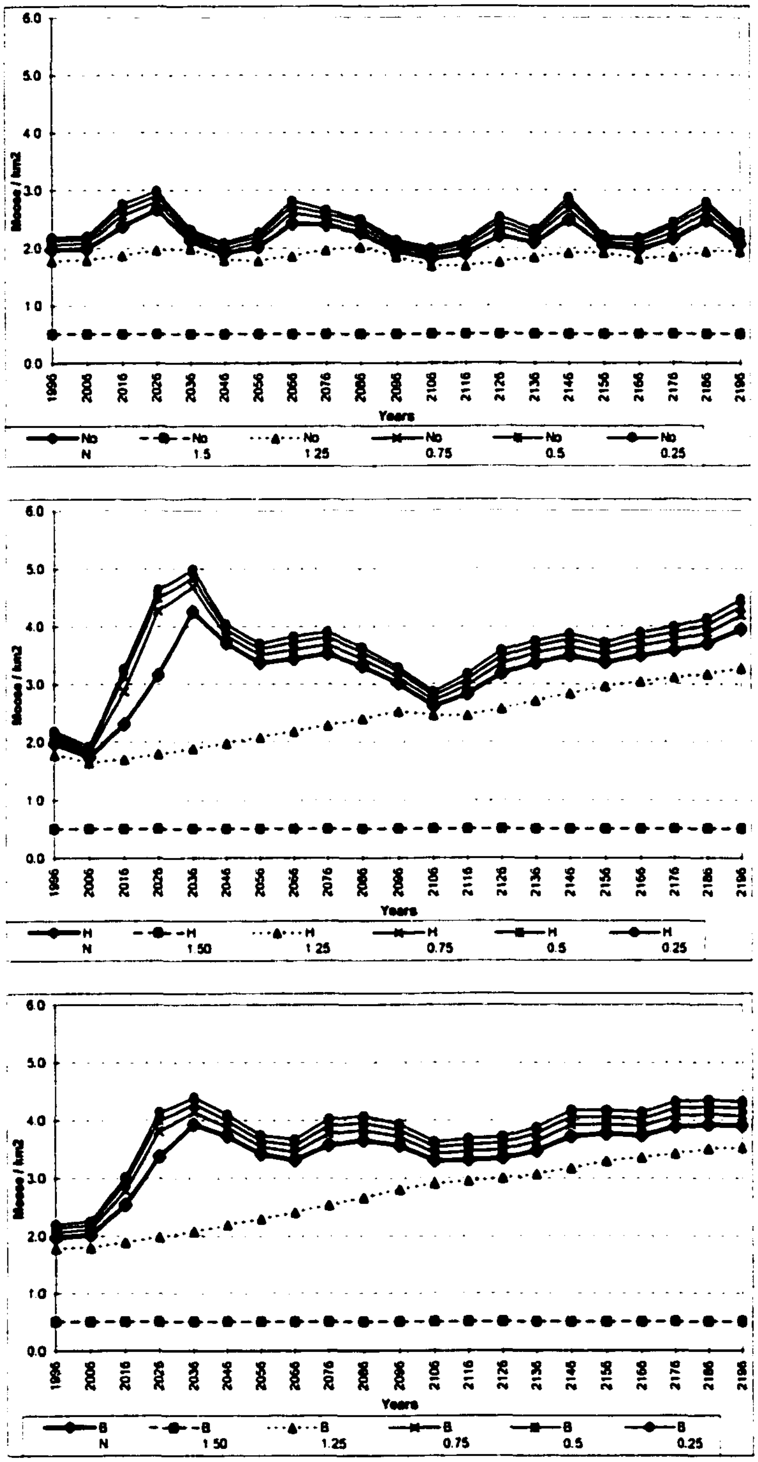


Figure A6-2: Cow harvest rate sensitivity results from the Duinker Population Model for the No, High and Basic harvest scenarios.

CHR would improve the population numbers dramatically between 2016 and 2046, after which the benefit disappears. The drop in CHR is beneficial, because the extra calves produced by the greater number of cows have a very abundant food source until 2046.

Fecundity Rate Sensitivity

The fecundity rate (FR) is a function of age and weight of cow moose in the DPM. The highest fecundity of 2.0 is found with cows that are 400 kg or greater and are mature i.e. 2-5 years old. Cows that are older and or lighter have lower fecundity rates (Table A6-2). The fecundity rates used for sensitivity analysis were increases of 1.10x, 1.15x, 1.2x, 1.25x and decreases of 0.90x 0.85x and 0.80x from the normal run parameters (Table A6-2).

Results and Discussion

The DPM is sensitive to fecundity rates below the normal values used in this study. Any values below the normal produces a moose population that is controlled by recruitment and not by food. Once recruitment falls below 0.9x of the normal FR, the DPM population crashes, because there is insufficient recruitment to sustain the population. From the sensitivity analysis it is clear that even the normal FR used shows a population that is not utilizing all available food between 2006 and 2046 in all harvest scenarios; however, after that period the normal FR line follows a similar trace as the higher fecundity rate lines of 1.10x, 1.15x, 1.2x and 1.25x.

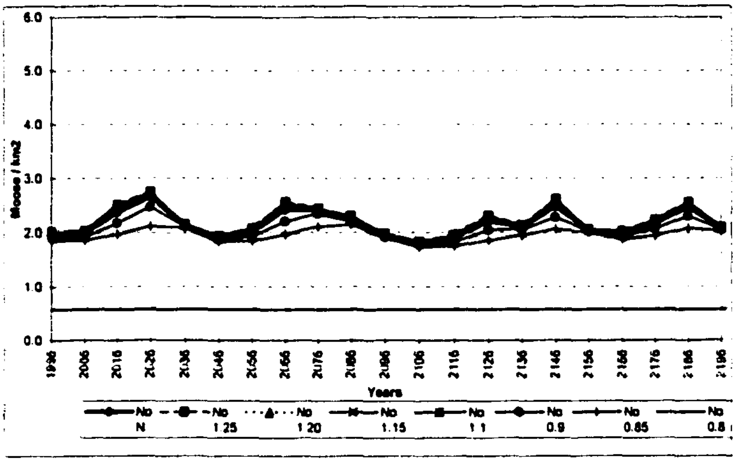
Table A6-2: **Fecundity rates used for the fecundity sensitivity analysis in the Duinker Population Model.**

Fecundity Multiples	Age Class	Cow Weights				
		0	100	200	300	400
Normal	C	0.000	0.000	0.000	0.000	0.000
	Y	0.000	0.000	0.300	0.300	0.300
	M	0.000	0.000	0.950	1.570	2.000
	O	0.000	0.000	0.700	1.370	1.570
1.25 x	C	0.000	0.000	0.000	0.000	0.000
	Y	0.000	0.000	0.375	0.375	0.375
	M	0.000	0.000	1.188	1.963	2.500
	O	0.000	0.000	0.875	1.713	1.963
1.2 x	C	0.000	0.000	0.000	0.000	0.000
	Y	0.000	0.000	0.360	0.360	0.360
	M	0.000	0.000	1.140	1.884	2.400
	O	0.000	0.000	0.840	1.644	1.884
1.15 x	C	0.000	0.000	0.000	0.000	0.000
	Y	0.000	0.000	0.345	0.345	0.345
	M	0.000	0.000	1.093	1.806	2.300
	O	0.000	0.000	0.805	1.576	1.806
1.10 x	C	0.000	0.000	0.000	0.000	0.000
	Y	0.000	0.000	0.330	0.330	0.330
	M	0.000	0.000	1.045	1.727	2.200
	O	0.000	0.000	0.770	1.507	1.727
0.9 x	C	0.000	0.000	0.000	0.000	0.000
	Y	0.000	0.000	0.270	0.270	0.270
	M	0.000	0.000	0.855	1.413	1.800
	O	0.000	0.000	0.630	1.233	1.413
0.85 x	C	0.000	0.000	0.000	0.000	0.000
	Y	0.000	0.000	0.255	0.255	0.255
	M	0.000	0.000	0.808	1.335	1.700
	O	0.000	0.000	0.595	1.165	1.335
0.8 x	C	0.000	0.000	0.000	0.000	0.000
	Y	0.000	0.000	0.240	0.240	0.240
	M	0.000	0.000	0.760	1.256	1.600
	O	0.000	0.000	0.560	1.096	1.256

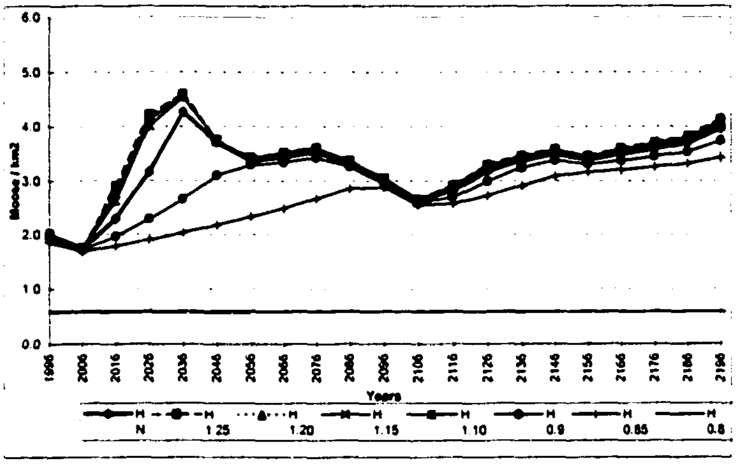
C = Calf < 1 year old
Y = Yearling 1 year old
M = Mature 2-5 years old
O = Older > 5 years old

For recruitment values greater than normal, the population is limited by food illustrated by the grouping of 1.25x, 1.20x, 1.15x and 1.10x lines in all scenarios (Figure A6-3). If fecundity rates could be increased by as little as 1.10x, the excess food available in the HHS between 2006 and 2046 could be captured and converted

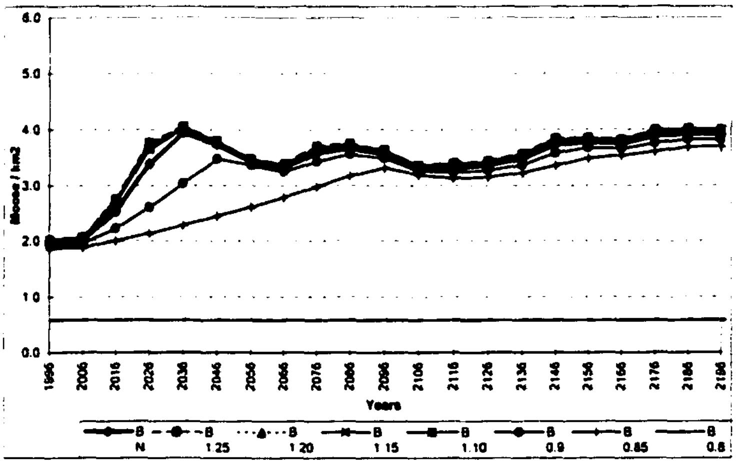
Year	No N	No 1.25	No 1.20	No 1.15	No 1.1	No 0.9	No 0.85	No 0.8
1996	1.97	2.01	2.01	2.00	2.00	1.92	1.86	0.58
2006	1.99	2.03	2.02	2.02	2.01	1.93	1.87	0.58
2016	2.38	2.51	2.50	2.48	2.46	2.17	1.98	0.58
2026	2.67	2.74	2.73	2.72	2.71	2.47	2.11	0.58
2036	2.13	2.14	2.14	2.14	2.14	2.12	2.09	0.58
2046	1.91	1.93	1.93	1.93	1.92	1.88	1.85	0.58
2056	2.02	2.07	2.07	2.06	2.05	1.94	1.86	0.58
2066	2.43	2.56	2.55	2.53	2.51	2.20	1.98	0.58
2076	2.41	2.44	2.44	2.43	2.43	2.35	2.11	0.58
2086	2.27	2.30	2.30	2.29	2.29	2.22	2.15	0.58
2096	1.95	1.97	1.97	1.97	1.96	1.93	1.91	0.58
2106	1.81	1.84	1.84	1.83	1.83	1.78	1.75	0.58
2116	1.90	1.95	1.95	1.94	1.93	1.83	1.76	0.58
2126	2.21	2.31	2.30	2.29	2.27	2.05	1.86	0.58
2136	2.10	2.13	2.12	2.12	2.12	2.06	1.95	0.58
2146	2.48	2.61	2.60	2.59	2.56	2.28	2.06	0.58
2156	2.04	2.05	2.05	2.05	2.05	2.03	2.01	0.58
2166	1.97	2.01	2.01	2.00	2.00	1.93	1.88	0.58
2176	2.16	2.23	2.22	2.21	2.20	2.06	1.94	0.58
2186	2.47	2.56	2.55	2.54	2.52	2.30	2.07	0.58
2196	2.07	2.08	2.08	2.08	2.08	2.05	2.02	0.58



Year	H N	H 1.25	H 1.20	H 1.15	H 1.10	H 0.9	H 0.85	H 0.8
1996	1.97	2.01	2.01	2.00	2.00	1.92	1.86	0.58
2006	1.74	1.76	1.76	1.75	1.75	1.72	1.70	0.58
2016	2.31	2.90	2.84	2.75	2.63	1.96	1.79	0.58
2026	3.16	4.21	4.18	4.13	4.01	2.29	1.91	0.58
2036	4.27	4.59	4.58	4.56	4.54	2.66	2.05	0.58
2046	3.71	3.74	3.74	3.73	3.73	3.10	2.19	0.58
2056	3.37	3.42	3.41	3.41	3.40	3.30	2.34	0.58
2066	3.44	3.52	3.51	3.50	3.49	3.34	2.50	0.58
2076	3.53	3.61	3.60	3.59	3.57	3.42	2.67	0.58
2086	3.31	3.36	3.36	3.35	3.34	3.25	2.85	0.58
2096	3.01	3.05	3.04	3.04	3.03	2.96	2.88	0.58
2106	2.62	2.65	2.64	2.64	2.63	2.59	2.56	0.58
2116	2.82	2.91	2.90	2.89	2.88	2.70	2.57	0.58
2126	3.18	3.29	3.28	3.27	3.25	3.00	2.73	0.58
2136	3.37	3.46	3.45	3.44	3.42	3.24	2.91	0.58
2146	3.49	3.58	3.57	3.56	3.54	3.37	3.09	0.58
2156	3.39	3.45	3.44	3.43	3.42	3.30	3.16	0.58
2166	3.49	3.60	3.58	3.57	3.55	3.36	3.20	0.58
2176	3.59	3.70	3.68	3.67	3.65	3.45	3.26	0.58
2186	3.70	3.82	3.81	3.79	3.77	3.54	3.32	0.58
2196	3.96	4.12	4.11	4.08	4.05	3.73	3.43	0.58



Year	B N	B 1.25	B 1.20	B 1.15	B 1.10	B 0.9	B 0.85	B 0.8
1996	1.97	2.01	2.01	2.00	2.00	1.92	1.86	0.58
2006	2.02	2.06	2.06	2.05	2.04	1.96	1.88	0.58
2016	2.53	2.74	2.72	2.70	2.67	2.23	2.00	0.58
2026	3.38	3.76	3.73	3.70	3.64	2.60	2.14	0.58
2036	3.94	4.05	4.04	4.02	4.00	3.03	2.28	0.58
2046	3.73	3.79	3.78	3.77	3.76	3.48	2.44	0.58
2056	3.41	3.46	3.45	3.45	3.44	3.35	2.61	0.58
2066	3.31	3.37	3.37	3.36	3.35	3.24	2.79	0.58
2076	3.58	3.69	3.68	3.66	3.64	3.42	2.97	0.58
2086	3.66	3.74	3.73	3.72	3.71	3.56	3.17	0.58
2096	3.56	3.62	3.62	3.61	3.60	3.48	3.30	0.58
2106	3.30	3.35	3.34	3.34	3.33	3.25	3.18	0.58
2116	3.31	3.39	3.38	3.37	3.36	3.22	3.13	0.58
2126	3.35	3.42	3.41	3.40	3.39	3.26	3.15	0.58
2136	3.47	3.56	3.55	3.54	3.52	3.36	3.22	0.58
2146	3.73	3.83	3.82	3.81	3.79	3.58	3.36	0.58
2156	3.77	3.85	3.84	3.83	3.82	3.67	3.49	0.58
2166	3.74	3.81	3.81	3.80	3.78	3.65	3.52	0.58
2176	3.88	3.98	3.97	3.96	3.94	3.76	3.60	0.58
2186	3.93	4.01	4.00	3.99	3.98	3.82	3.68	0.58
2196	3.91	3.99	3.98	3.97	3.96	3.81	3.69	0.58



N = Normal
No = No Harvest Scenario
H = High Harvest Scenario
B = Basic Harvest Scenario

Figure A6-3: **Fecundity rate sensitivity results from the Duinker Population Model for the No, High and Basic harvest scenarios.**

into moose. Similarly to CHR, the benefit of this action i.e. producing more moose, disappears after 2046 in all scenarios.

Predation Rate Sensitivity

Predation rate (PR) is a function of age and season of year in DPM. The highest mortality by age and season occurs with calves in the spring and late-winter followed by old animals in late-winter then yearling and adults. The predation rates used for sensitivity analysis were increases of 1.05x, 1.10x, 1.15x, 1.20x and decreases of 0.90x, 0.80x and 0.50x from the normal predation rates (Table A6-3).

Results and Discussion

The DPM is very sensitive to variations in the PR. The model displays significant changes in moose/km^2 for values greater than the normal values used for the simulation. This parameter displays similar behaviour to CHR and FR in that the moose population can be depressed or increased by slight changes to the parameter.

For PR values lower than normal, the increases in population are similar to those observed in the CHR and FR when those parameters are adjusted in a positive way, i.e. CHR was decreased and FR was increased (Figures A6-2, A6-3 and A6-4). If PR could be adjusted positively, i.e. decrease predation by a factor of 0.90x, the extra animals would be able to capture a greater portion of the food source in the HHS between 2006 and 2046 and produce more moose for viewing or sport hunting.

Table A6-3: **Predation rates used for the predation rate sensitivity analysis in the Duinker Population Model.**

Predation Multiples	Season	Moose Age Classes							
		B C	B Y	B A	B O	C C	C Y	C A	C O
Normal	S	0.200	0.010	0.010	0.010	0.200	0.010	0.010	0.010
	F	0.100	0.010	0.010	0.010	0.100	0.010	0.010	0.010
	E W	0.100	0.010	0.010	0.020	0.100	0.010	0.010	0.020
	L W	0.200	0.010	0.010	0.030	0.200	0.010	0.010	0.030
1.2 x	S	0.240	0.012	0.012	0.012	0.240	0.012	0.012	0.012
	F	0.120	0.012	0.012	0.012	0.120	0.012	0.012	0.012
	E W	0.120	0.012	0.012	0.024	0.120	0.012	0.012	0.024
	L W	0.240	0.012	0.012	0.036	0.240	0.012	0.012	0.036
1.15 x	S	0.230	0.012	0.012	0.012	0.230	0.012	0.012	0.012
	F	0.115	0.012	0.012	0.012	0.115	0.012	0.012	0.012
	E W	0.115	0.012	0.012	0.023	0.115	0.012	0.012	0.023
	L W	0.230	0.012	0.012	0.035	0.230	0.012	0.012	0.035
1.1 x	S	0.220	0.011	0.011	0.011	0.220	0.011	0.011	0.011
	F	0.110	0.011	0.011	0.011	0.110	0.011	0.011	0.011
	E W	0.110	0.011	0.011	0.022	0.110	0.011	0.011	0.022
	L W	0.220	0.011	0.011	0.033	0.220	0.011	0.011	0.033
1.05 x	S	0.210	0.011	0.011	0.011	0.210	0.011	0.011	0.011
	F	0.105	0.011	0.011	0.011	0.105	0.011	0.011	0.011
	E W	0.105	0.011	0.011	0.021	0.105	0.011	0.011	0.021
	L W	0.210	0.011	0.011	0.032	0.210	0.011	0.011	0.032
0.9 x	S	0.180	0.009	0.009	0.009	0.180	0.009	0.009	0.009
	F	0.090	0.009	0.009	0.009	0.090	0.009	0.009	0.009
	E W	0.090	0.009	0.009	0.018	0.090	0.009	0.009	0.018
	L W	0.180	0.009	0.009	0.027	0.180	0.009	0.009	0.027
0.8 x	S	0.160	0.008	0.008	0.008	0.160	0.008	0.008	0.008
	F	0.080	0.008	0.008	0.008	0.080	0.008	0.008	0.008
	E W	0.080	0.008	0.008	0.016	0.080	0.008	0.008	0.016
	L W	0.160	0.008	0.008	0.024	0.160	0.008	0.008	0.024
0.5 x	S	0.100	0.005	0.005	0.005	0.100	0.005	0.005	0.005
	F	0.050	0.005	0.005	0.005	0.050	0.005	0.005	0.005
	E W	0.050	0.005	0.005	0.010	0.050	0.005	0.005	0.010
	L W	0.100	0.005	0.005	0.015	0.100	0.005	0.005	0.015

S = Summer
F = Fall
E W = Early Winter
L W = Late Winter

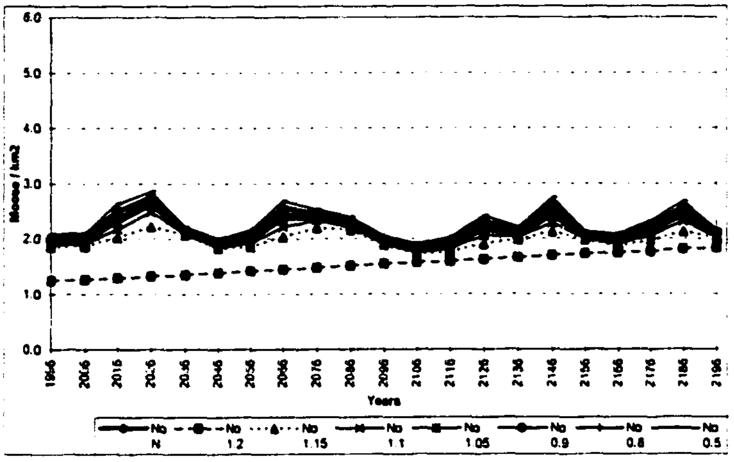
B C = Bull Calf
B Y = Bull Yearling
B A = Bull Adult
B O = Bull Old

C C = Cow Calf
C Y = Cow Yearling
C A = Cow Adult
C O = Cow Old

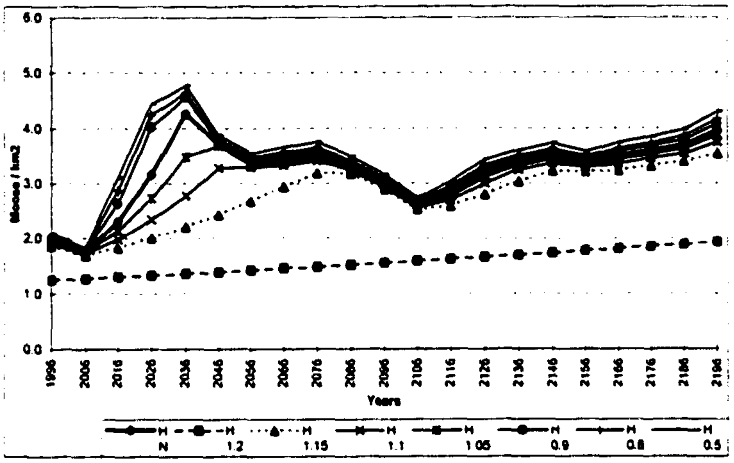
Target Density

Target Density (TD) is a function that describes the future density desired by wildlife managers. The normal value of 0.76 was used while sensitivity values of

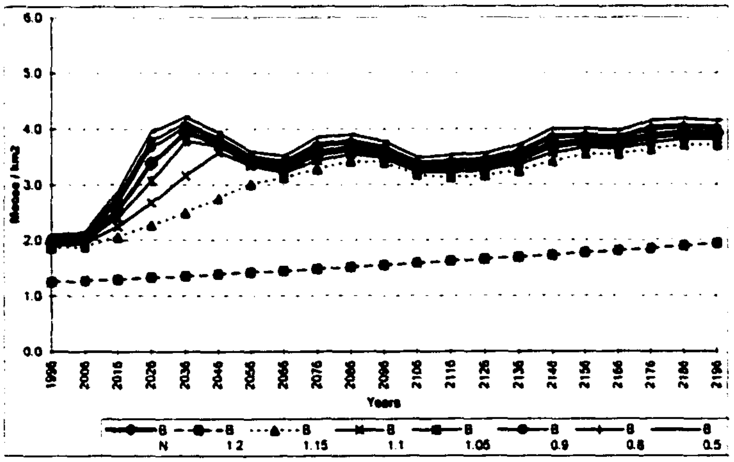
Year	No N	No 1.2	No 1.15	No 1.1	No 1.05	No 0.9	No 0.8	No 0.5
1996	1.97	1.24	1.86	1.91	1.95	2.01	2.04	2.09
2006	1.99	1.27	1.87	1.93	1.96	2.03	2.05	2.11
2016	2.38	1.30	2.02	2.18	2.30	2.48	2.53	2.63
2026	2.67	1.33	2.23	2.50	2.61	2.73	2.77	2.86
2036	2.13	1.36	2.08	2.10	2.12	2.15	2.17	2.21
2046	1.91	1.39	1.84	1.87	1.89	1.94	1.96	2.00
2056	2.02	1.42	1.87	1.93	1.98	2.07	2.10	2.16
2066	2.43	1.45	2.04	2.22	2.35	2.53	2.59	2.68
2076	2.41	1.48	2.20	2.34	2.38	2.44	2.47	2.53
2086	2.27	1.51	2.16	2.21	2.24	2.30	2.33	2.39
2096	1.95	1.55	1.90	1.92	1.94	1.98	2.00	2.04
2106	1.81	1.57	1.74	1.77	1.79	1.84	1.86	1.91
2116	1.90	1.60	1.77	1.83	1.87	1.95	1.98	2.03
2126	2.21	1.63	1.91	2.06	2.15	2.29	2.33	2.41
2136	2.10	1.67	1.99	2.05	2.08	2.13	2.15	2.20
2146	2.48	1.71	2.14	2.29	2.40	2.58	2.64	2.74
2156	2.04	1.74	1.99	2.01	2.03	2.06	2.08	2.12
2166	1.97	1.75	1.88	1.92	1.95	2.01	2.04	2.09
2176	2.16	1.78	1.97	2.06	2.12	2.22	2.25	2.32
2186	2.47	1.82	2.14	2.31	2.41	2.54	2.59	2.67
2196	2.07	1.84	2.02	2.04	2.06	2.09	2.11	2.15



Year	H N	H 1.2	H 1.15	H 1.1	H 1.05	H 0.9	H 0.8	H 0.5
1996	1.97	1.24	1.86	1.91	1.95	2.01	2.04	2.09
2006	1.74	1.27	1.68	1.71	1.72	1.76	1.78	1.82
2016	2.31	1.30	1.83	1.98	2.14	2.63	2.88	3.11
2026	3.16	1.33	2.01	2.35	2.73	4.02	4.24	4.44
2036	4.27	1.36	2.21	2.78	3.48	4.57	4.64	4.78
2046	3.71	1.39	2.43	3.28	3.69	3.76	3.79	3.86
2056	3.37	1.42	2.68	3.29	3.34	3.42	3.46	3.54
2066	3.44	1.45	2.94	3.33	3.39	3.51	3.56	3.66
2076	3.53	1.48	3.19	3.41	3.48	3.60	3.65	3.75
2086	3.31	1.51	3.17	3.24	3.28	3.36	3.40	3.48
2096	3.01	1.55	2.90	2.94	2.98	3.05	3.08	3.15
2106	2.62	1.58	2.54	2.57	2.60	2.65	2.68	2.74
2116	2.82	1.62	2.59	2.69	2.77	2.90	2.94	3.03
2126	3.18	1.65	2.80	3.00	3.12	3.27	3.33	3.43
2136	3.37	1.69	3.04	3.24	3.32	3.45	3.50	3.60
2146	3.49	1.73	3.22	3.37	3.44	3.57	3.62	3.72
2156	3.39	1.77	3.21	3.29	3.34	3.44	3.49	3.57
2166	3.49	1.81	3.24	3.36	3.44	3.57	3.63	3.74
2176	3.59	1.85	3.32	3.45	3.53	3.67	3.73	3.84
2186	3.70	1.89	3.40	3.54	3.63	3.79	3.86	3.98
2196	3.96	1.93	3.54	3.75	3.87	4.08	4.16	4.30



Year	B N	B 1.2	B 1.15	B 1.1	B 1.05	B 0.9	B 0.8	B 0.5
1996	1.97	1.24	1.86	1.91	1.95	2.01	2.04	2.09
2006	2.02	1.27	1.89	1.95	1.99	2.06	2.09	2.14
2016	2.53	1.30	2.06	2.25	2.41	2.68	2.76	2.88
2026	3.38	1.33	2.27	2.67	3.06	3.67	3.79	3.95
2036	3.94	1.36	2.50	3.16	3.78	4.03	4.10	4.21
2046	3.73	1.39	2.75	3.58	3.69	3.79	3.83	3.92
2056	3.41	1.42	3.01	3.34	3.38	3.46	3.50	3.58
2066	3.31	1.45	3.12	3.22	3.27	3.37	3.42	3.50
2076	3.58	1.48	3.27	3.42	3.51	3.67	3.73	3.84
2086	3.66	1.51	3.42	3.54	3.61	3.73	3.79	3.89
2096	3.56	1.55	3.39	3.47	3.52	3.62	3.67	3.76
2106	3.30	1.58	3.17	3.23	3.27	3.35	3.39	3.47
2116	3.31	1.62	3.13	3.21	3.27	3.38	3.43	3.52
2126	3.35	1.65	3.16	3.25	3.31	3.42	3.46	3.55
2136	3.47	1.69	3.24	3.35	3.42	3.55	3.60	3.70
2146	3.73	1.73	3.41	3.57	3.66	3.82	3.88	3.99
2156	3.77	1.77	3.54	3.65	3.72	3.84	3.90	3.99
2166	3.74	1.81	3.54	3.63	3.69	3.81	3.86	3.96
2176	3.88	1.85	3.62	3.74	3.82	3.97	4.03	4.14
2186	3.93	1.89	3.70	3.81	3.88	4.00	4.06	4.17
2196	3.91	1.93	3.70	3.80	3.86	3.98	4.04	4.14



N = Normal
No = No Harvest Scenario
H = High Harvest Scenario
B = Basic Harvest Scenario

Figure A6-4: Predation rate sensitivity results from the Duinker Population Model for the No, High and Basic harvest scenarios.

1.0+x or 1.76, 2.0+x or 2.76, and 3.0+x or 3.76 and decreases of 0.50x or 0.38 and 0.25x or 0.19 were used for sensitivity analyses in the DPM.

Results and Discussion

The DPM is insensitive with respect to the TD parameter. Large changes positively or negatively have a very small impact on the overall moose population through time. The changes observed are most noticeable in the HHS where there is a large food supply between 2006 and 2046. The higher TD allows the model to produce more moose before greater hunting pressure is allowed. However, after 2046 the benefit is completely negated and all sensitivity analysis lines follow the normal trace (Figure A6-5).

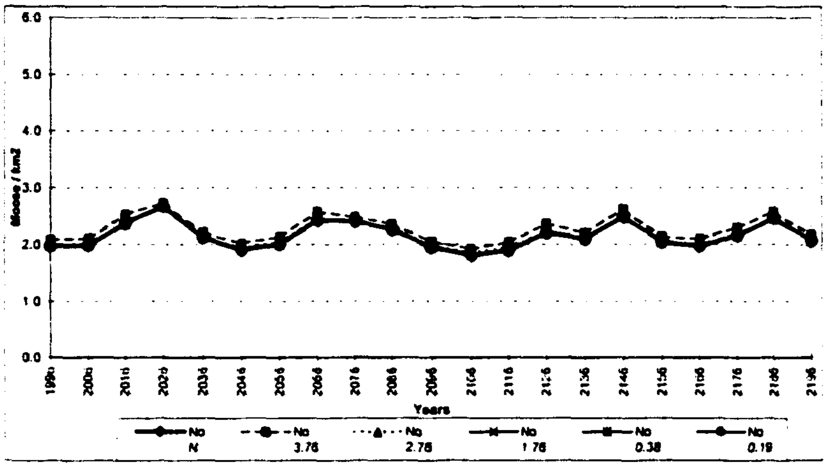
Bull to Cow Harvest Ratio

Bull to Cow Harvest Ratio (BCHR) is the function that controls the rate of bull harvest based on the number of cows in a population. The normal value used in the modelling was 3.5 bulls to 1 cow. The values used for sensitivity analysis were 3, 2 and 0.5 bulls to 1 cow.

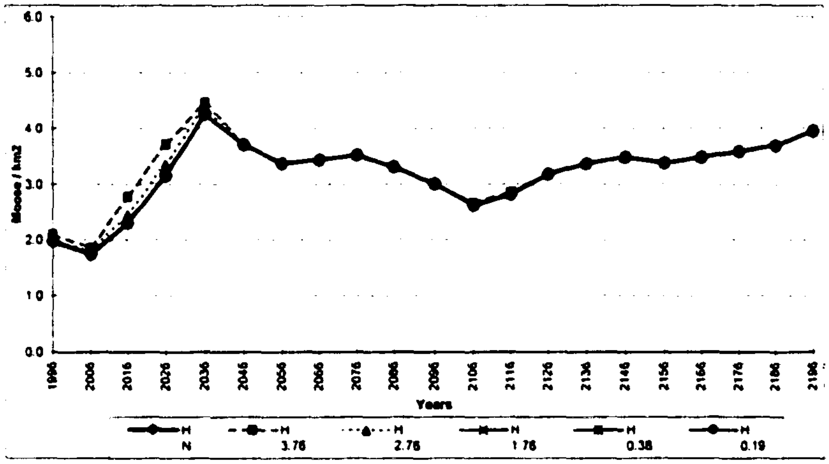
Results and Discussion

The DPM was not sensitive to any changes in the BCHR (Figure A6-6). The only indication of any change was in the HHS between 2016 and 2036 when the BCHR was reduced by 50% or 1.75 bulls to 1 cow. The fluctuation is visible there because with 1.75:1.0 harvest rate there were more bulls around to impregnate the cows and produce more calves. Furthermore, between 2016 and 2036 there is a excess food supply thereby improving the likelihood of survival for those cows.

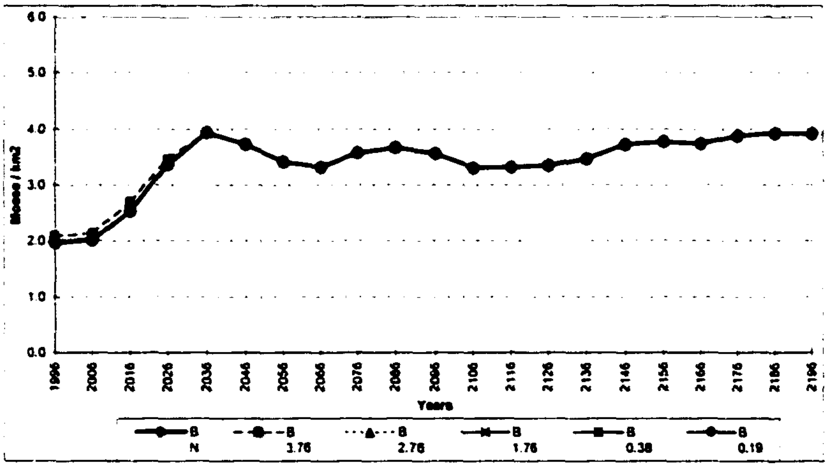
Year	No N	No 3.76	No 2.76	No 1.76	No 0.38	No 0.19
1996	1.97	2.09	2.00	1.97	1.97	1.97
2006	1.99	2.10	2.01	1.99	1.99	1.99
2016	2.38	2.52	2.38	2.38	2.38	2.38
2026	2.67	2.72	2.67	2.67	2.67	2.67
2036	2.13	2.21	2.13	2.13	2.13	2.13
2046	1.91	2.01	1.94	1.91	1.91	1.91
2056	2.02	2.14	2.05	2.02	2.02	2.02
2066	2.43	2.57	2.43	2.43	2.43	2.43
2076	2.41	2.48	2.41	2.41	2.41	2.41
2086	2.27	2.35	2.27	2.27	2.27	2.27
2096	1.95	2.05	1.98	1.95	1.95	1.95
2106	1.81	1.92	1.86	1.81	1.81	1.81
2116	1.90	2.03	1.95	1.90	1.90	1.90
2126	2.21	2.35	2.22	2.21	2.21	2.21
2136	2.10	2.19	2.10	2.10	2.10	2.10
2146	2.48	2.61	2.48	2.48	2.48	2.48
2156	2.04	2.13	2.05	2.04	2.04	2.04
2166	1.97	2.09	2.00	1.97	1.97	1.97
2176	2.16	2.29	2.16	2.16	2.16	2.16
2186	2.47	2.57	2.47	2.47	2.47	2.47
2196	2.07	2.16	2.07	2.07	2.07	2.07



Year	H N	H 3.76	H 2.76	H 1.76	H 0.38	H 0.19
1996	1.97	2.09	2.00	1.97	1.97	1.97
2006	1.74	1.84	1.79	1.74	1.74	1.74
2016	2.31	2.78	2.45	2.31	2.31	2.31
2026	3.16	3.73	3.35	3.16	3.16	3.16
2036	4.27	4.46	4.39	4.27	4.27	4.27
2046	3.71	3.71	3.71	3.71	3.71	3.71
2056	3.37	3.37	3.37	3.37	3.37	3.37
2066	3.44	3.44	3.44	3.44	3.44	3.44
2076	3.53	3.53	3.53	3.53	3.53	3.53
2086	3.31	3.31	3.31	3.31	3.31	3.31
2096	3.01	3.01	3.01	3.01	3.01	3.01
2106	2.62	2.66	2.62	2.62	2.62	2.62
2116	2.82	2.85	2.82	2.82	2.82	2.82
2126	3.18	3.18	3.18	3.18	3.18	3.18
2136	3.37	3.37	3.37	3.37	3.37	3.37
2146	3.49	3.49	3.49	3.49	3.49	3.49
2156	3.39	3.39	3.39	3.39	3.39	3.39
2166	3.49	3.49	3.49	3.49	3.49	3.49
2176	3.59	3.59	3.59	3.59	3.59	3.59
2186	3.70	3.70	3.70	3.70	3.70	3.70
2196	3.96	3.96	3.96	3.96	3.96	3.96



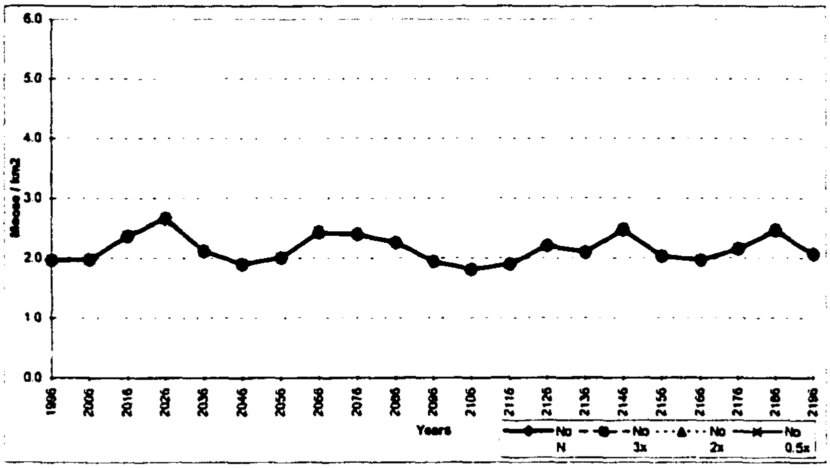
Year	B N	B 3.76	B 2.76	B 1.76	B 0.38	B 0.19
1996	1.97	2.09	2.00	1.97	1.97	1.97
2006	2.02	2.13	2.04	2.02	2.02	2.02
2016	2.53	2.70	2.54	2.53	2.53	2.53
2026	3.38	3.46	3.38	3.38	3.38	3.38
2036	3.94	3.94	3.94	3.94	3.94	3.94
2046	3.73	3.73	3.73	3.73	3.73	3.73
2056	3.41	3.41	3.41	3.41	3.41	3.41
2066	3.31	3.31	3.31	3.31	3.31	3.31
2076	3.58	3.58	3.58	3.58	3.58	3.58
2086	3.66	3.66	3.66	3.66	3.66	3.66
2096	3.56	3.56	3.56	3.56	3.56	3.56
2106	3.30	3.30	3.30	3.30	3.30	3.30
2116	3.31	3.31	3.31	3.31	3.31	3.31
2126	3.35	3.35	3.35	3.35	3.35	3.35
2136	3.47	3.47	3.47	3.47	3.47	3.47
2146	3.73	3.73	3.73	3.73	3.73	3.73
2156	3.77	3.77	3.77	3.77	3.77	3.77
2166	3.74	3.74	3.74	3.74	3.74	3.74
2176	3.88	3.88	3.88	3.88	3.88	3.88
2186	3.93	3.93	3.93	3.93	3.93	3.93
2196	3.91	3.91	3.91	3.91	3.91	3.91



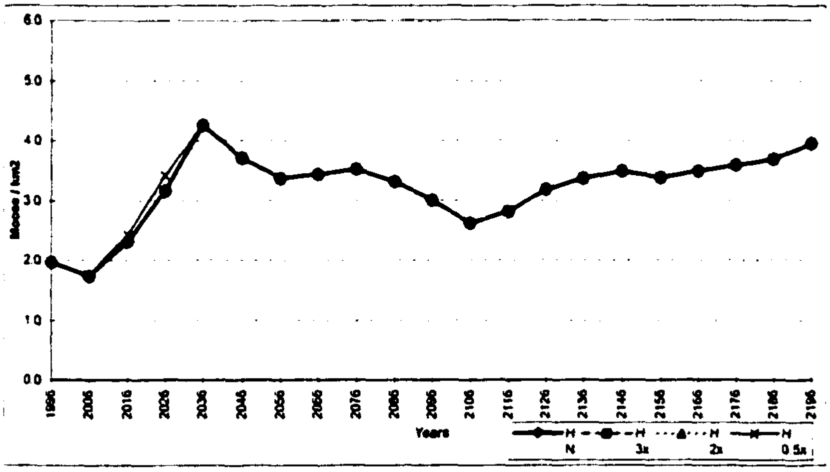
N = Normal
No = No Harvest Scenario
H = High Harvest Scenario
B = Basic Harvest Scenario

Figure A6-5: Target density rate sensitivity results from the Duinker Population Model for the No, High and Basic harvest scenarios.

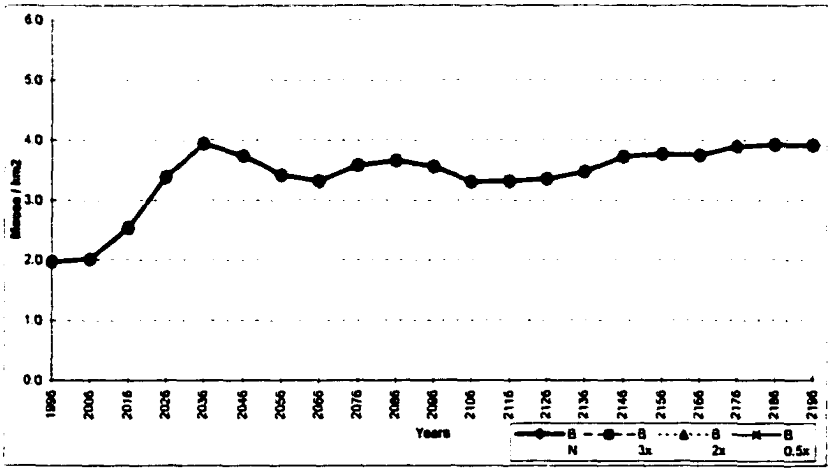
Year	No N	No 3x	No 2x	No 0.5x
1996	1.97	1.97	1.97	1.98
2006	1.99	1.99	1.99	1.99
2016	2.38	2.38	2.38	2.39
2026	2.67	2.67	2.67	2.67
2036	2.13	2.13	2.13	2.13
2046	1.91	1.91	1.91	1.91
2056	2.02	2.02	2.02	2.02
2066	2.43	2.43	2.43	2.44
2076	2.41	2.41	2.41	2.41
2086	2.27	2.27	2.27	2.27
2096	1.95	1.95	1.95	1.96
2106	1.81	1.81	1.81	1.82
2116	1.90	1.90	1.90	1.91
2126	2.21	2.21	2.21	2.22
2136	2.10	2.10	2.10	2.10
2146	2.48	2.48	2.48	2.49
2156	2.04	2.04	2.04	2.05
2166	1.97	1.97	1.97	1.98
2176	2.16	2.16	2.16	2.16
2186	2.47	2.47	2.47	2.47
2196	2.07	2.07	2.07	2.07



Year	H N	H 3x	H 2x	H 0.5x
1996	1.97	1.97	1.97	1.98
2006	1.74	1.74	1.74	1.74
2016	2.31	2.31	2.31	2.42
2026	3.16	3.16	3.16	3.42
2036	4.27	4.27	4.27	4.27
2046	3.71	3.71	3.71	3.72
2056	3.37	3.37	3.37	3.38
2066	3.44	3.44	3.44	3.45
2076	3.53	3.53	3.53	3.53
2086	3.31	3.31	3.31	3.32
2096	3.01	3.01	3.01	3.01
2106	2.62	2.62	2.62	2.62
2116	2.82	2.82	2.82	2.83
2126	3.18	3.18	3.18	3.19
2136	3.37	3.37	3.37	3.38
2146	3.49	3.49	3.49	3.50
2156	3.39	3.39	3.39	3.39
2166	3.49	3.49	3.49	3.49
2176	3.59	3.59	3.59	3.59
2186	3.70	3.70	3.70	3.70
2196	3.96	3.96	3.96	3.96



Year	B N	B 3x	B 2x	B 0.5x
1996	1.97	1.97	1.97	1.98
2006	2.02	2.02	2.02	2.02
2016	2.53	2.53	2.53	2.55
2026	3.38	3.38	3.38	3.41
2036	3.94	3.94	3.94	3.95
2046	3.73	3.73	3.73	3.74
2056	3.41	3.41	3.41	3.42
2066	3.31	3.31	3.31	3.32
2076	3.58	3.58	3.58	3.59
2086	3.66	3.66	3.66	3.67
2096	3.56	3.56	3.56	3.57
2106	3.30	3.30	3.30	3.31
2116	3.31	3.31	3.31	3.32
2126	3.35	3.35	3.35	3.36
2136	3.47	3.47	3.47	3.48
2146	3.73	3.73	3.73	3.74
2156	3.77	3.77	3.77	3.78
2166	3.74	3.74	3.74	3.75
2176	3.88	3.88	3.88	3.89
2186	3.93	3.93	3.93	3.93
2196	3.91	3.91	3.91	3.92



N = Normal
No = No Harvest Scenario
H = High Harvest Scenario
B = Basic Harvest Scenario

Figure A6-6: Bull to cow harvest ratio sensitivity results from the Duinker Population Model for the No, High and Basic harvest scenarios.

Food - Summer Browse vs Early-Winter Adjusted Browse

The DPM food values were developed from food curves based on the dominant tree species, stand age, site class and stocking of the stands. To perform sensitivity analysis based on food, the BHS was used as the test case and resonable food ranges were chosen for both the summer browse (SB) values and early-winter adjusted browse (EWAB) values based on the outputs from a normal model using the browse curves. The range of SB went from 30 to 300 kg/ha while the EWAB ranged from 2 to 20 kg/ha. The DPM was run for each SB/EWAB interaction (Table A6-4).

Results and Discussion

There is clearly little interaction taking place between the SB and EWAB. From (Figure A6-7) I was looking for a trade-off zone, where a good food supply in the summer could compensate the animals when early-winter food was relatively lacking and vice versa. A trade-off zone (represented by the enclosed area in Figure A6-7 is present but it is narrow when compared to Duinker's (1986) PhD work. The trade-off zone is largest where SB is largest 240-300 kg/ha and EWAB is moderate 10-16 kg/ha. The model has such a narrow trade-off area because the determination of EWAB is a mathematical calculation based on the SB values in the DPM. Finally, the DPM illustrates that poor food in the summer season is only compensated to a small degree by better food in the early-winter season.

Comparison of the Sensitivity Analysis Values for Three Sensitivity Analysis

A comparison was conducted of the results from three sensitivity analysis: cow harvest rate, fecundity and predation. The means from each 200 year simulation

Table A6-4: Moose/km^2 values based on the sensitivity analysis of food values used for the summer browse vs early-winter adjusted browse normal results.

Summer Browse kg/ha	Early Winter Adjusted Browse kg/ha									
	2	4	6	8	10	12	14	16	18	20
30	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
60	0.7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
90	0.7	1.4	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
120	0.7	1.5	2.0	2.1	2.1	2.1	2.1	2.1	2.1	2.1
150	0.7	1.5	2.2	2.5	2.6	2.6	2.6	2.6	2.6	2.6
180	0.7	1.5	2.2	2.9	3.1	3.1	3.1	3.1	3.1	3.1
210	0.7	1.5	2.2	2.9	3.4	3.6	3.6	3.6	3.6	3.6
240	0.7	1.5	2.2	2.9	3.6	4.0	4.1	4.1	4.2	4.2
270	0.7	1.5	2.2	2.9	3.7	4.3	4.5	4.6	4.7	4.7
300	0.7	1.5	2.2	2.9	3.7	4.4	4.9	5.0	5.1	5.2

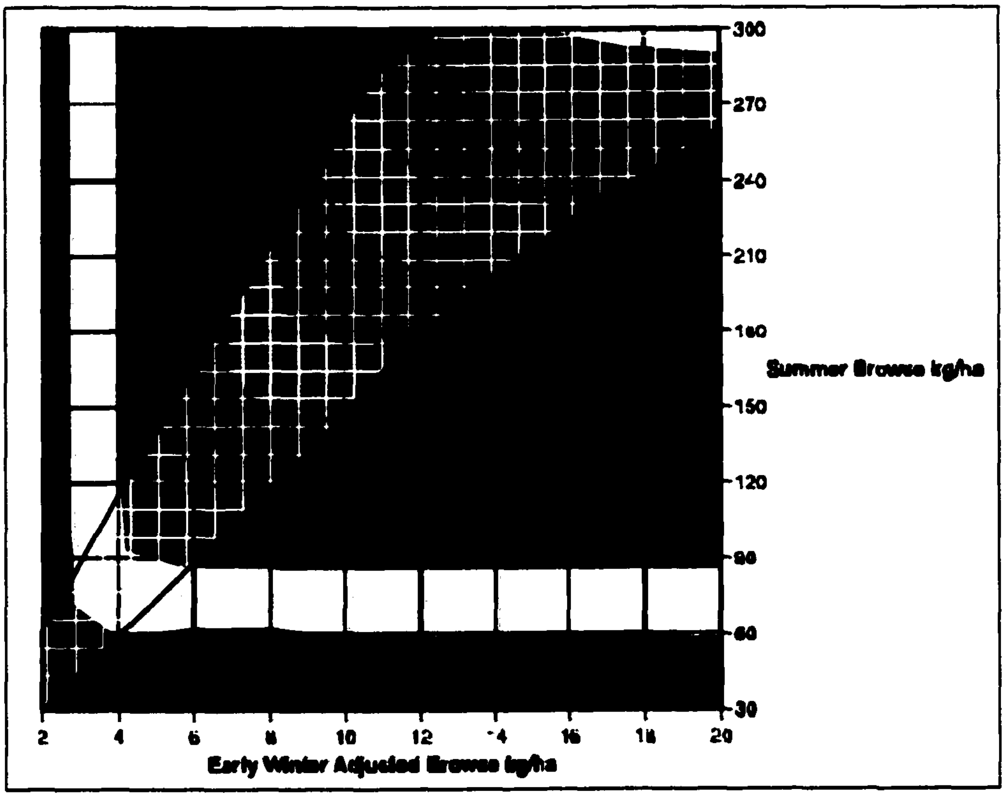


Figure A6-7: Food sensitivity results from the Duinker Population Model for the Basic harvest scenario.

were plotted for each sensitivity analysis level done (Table A6-5, Figure A6-8). Asymptotes were graphically observed for the three variables used in sensitivity analysis.

Table A6-5: Comparison of 200 year averages across the sensitivity analysis values used for three different sensitivity analysis variables within the Duinker Population Model.

Normal Value Multiples	1.5	1.25	1.2	1.15	1.1	1.05	1	0.9	0.85	0.8	0.75	0.5	0.25
Cow Harvest Rate Sensitivity	-83.6	-23.2					0.0				7.2	11.2	14.3
Fecundity Sensitivity		5.1	4.7	4.2	3.4		0.0	-7.2	-17.3	-81.0			
Predation Sensitivity			-50.0	-13.4	-6.9	-3.1	0.0	4.0		6.2		9.4	

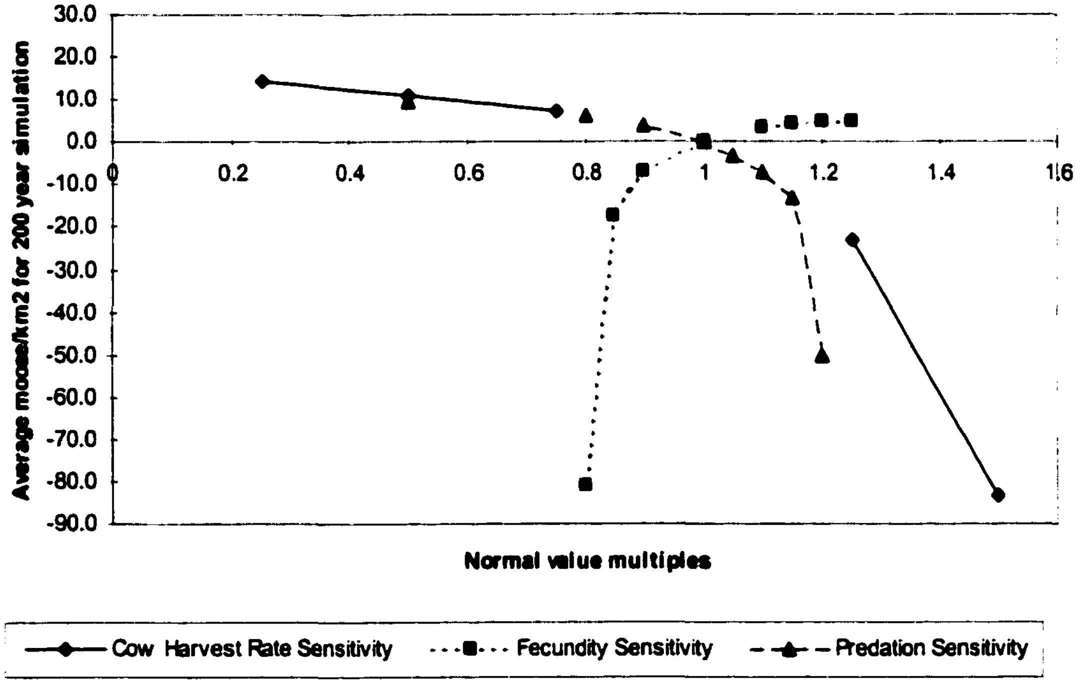


Figure A6-8: Comparison of 200 year averages across the sensitivity analysis values used for three different sensitivity analysis variables within the Duinker Population Model.

Results and Discussion

The asymptotes identify the possible range of values that work in the sensitivity analysis for the three variables. From this information one can see the possible sensitivity analysis values if they were selected and conducted, i.e. a cow harvest rate of 0.8 would produce an average 200-year estimated value of 6.0. This value was identified by estimating its position given the graphic results of Figure A6-8. The exact location of each asymptote for each variable is unclear but my two visual estimates for each variable are; cow harvest rate 0x and 1.8x; fecundity 0.75x and 1.4x; predation 0.2x and 1.3x. It is safe to assume that any values between the two extremes could be used for each respective variable in sensitivity analysis or a normal run.

Of the three variable used cow harvest rate, fecundity and predation, fecundity has the narrowest range of possible values before an asymptote is approached, whereas cow harvest rate has the largest range and predation resides between the two. This information was derived by visually examining Figure A6-8. A possible implication of this comparison is that fecundity would be the most sensitive to variation and therefore exhibits the greatest influence of all the variables analysed in the DPM. This assumption was borne out when the results of other sensitivity analyses were cross compared and it was observed that, on an incremental basis, fecundity affected the model results the greatest.

Overall Discussion for Sensitivity Analysis in the Duinker Population Model

Of the parameters modelled using DPM the model is most sensitive to the fecundity parameter, followed by predation, cow harvest rate, target density and finally bull-to-cow harvest ratio. The first two variables (fecundity and predation) are the most sensitive since individually they have the most significant impacts on the moose population. Fecundity is controlling because higher birth rates mean more moose right way and thier probability of survival is highly correlated to food supplies. For the most part if the food supply is there, then new calves are likely to survive. Conversely, predation is a direct attack on new calf survival, since that cohort of animals has the highest mortality rate of 60% in the first year using the normal run parameters. For the same rate of increase between fecundity and predation when all other variables are set to their normal run values, fecundity will move the output values the most, followed by predation. This behaviour is most likely attributable to the observations displayed in Figure A6-8, i.e. fecundity has the narrowest range of usable values before a asymptote is encountered at 0.75x or 1.4x.

Of the remaining three variables, only cow harvest rate is of note with respect to sensitivity analysis, since the other two do not alter the results of the DPM to any appreciable degree. Model output is sensitive to Cow harvest rate manipulation since the number of surviving cows dictates the number of new calves. The fewer the cows that survive the hunt, the fewer calves will be born in the spring. The converse is also true, where more cows means more calves and a greater population in subsequent years.

APPENDIX 7

Sensitivity Analysis for the Weldwood Winter Habitat Suitability Index Model

Overview

Sensitivity analysis for the Weldwood Winter Habitat Suitability Index Model (WWHSIM) was undertaken to find variables that might have a large impact on the model results when small changes were made. The variable selected for analysis from the model was the Euctrans variable. The Euctrans

Table A7-1: Moose carrying capacity values and their percentage change from normal simulation runs using the Weldwood Winter Habitat Suitability Index Model and the No, Basic and High harvest simulations.

Year	B H N	B H E0	H H N	H H E0	N H N	N H E0	B H D	H H D	N H D
1996	1.91	1.98	1.91	1.97	1.91	1.97			
2006	1.63	1.71	1.52	1.58	1.87	1.92			
2016	1.29	1.38	1.01	1.07	1.62	1.67			
2026	0.96	1.02	0.63	0.67	1.35	1.40			
2036	0.81	0.87	0.49	0.52	1.32	1.36			
2046	0.64	0.69	0.41	0.43	1.27	1.28			
2056	0.58	0.61	0.40	0.41	1.20	1.22			
2066	0.51	0.54	0.32	0.35	1.00	1.01			
2076	0.47	0.50	0.30	0.33	0.89	0.91			
2086	0.43	0.45	0.26	0.28	0.79	0.80			
2096	0.35	0.39	0.24	0.25	0.68	0.76	9.40	6.93	11.86
2106	0.33	0.39	0.23	0.24	0.64	0.74	16.72	6.12	14.61
2116	0.33	0.36	0.23	0.23	0.60	0.73	9.49	3.76	21.26
2126	0.31	0.33	0.24	0.26	0.61	0.73	5.88	11.16	20.09
2136	0.31	0.33	0.23	0.25	0.62	0.73	5.09	12.77	18.75
2146	0.32	0.34	0.25	0.25	0.63	0.73	8.64	2.29	15.50
2156	0.31	0.34	0.26	0.26	0.65	0.74	10.56	1.84	13.56
2166	0.30	0.34	0.25	0.26	0.63	0.75	14.42	1.93	17.96
2176	0.30	0.39	0.26	0.26	0.62	0.75	28.31	3.14	20.03
2186	0.35	0.39	0.25	0.26	0.62	0.75	10.23	2.56	20.70
2196	0.36	0.38	0.25	0.25	0.63	0.76	7.02	0.72	19.26
Average							11.43	4.84	17.60

B H N = Basic Harvest Normal
B H E0 = Basic Harvest Euctrans = 0
H H N = High Harvest Normal
H H E0 = High Harvest Euctrans = 0
N H N = No Harvest Normal
N H E0 = No Harvest Euctrans = 0

B H D = Basic Harvest Difference
H H D = High Harvest Difference
N H D = No Harvest Difference

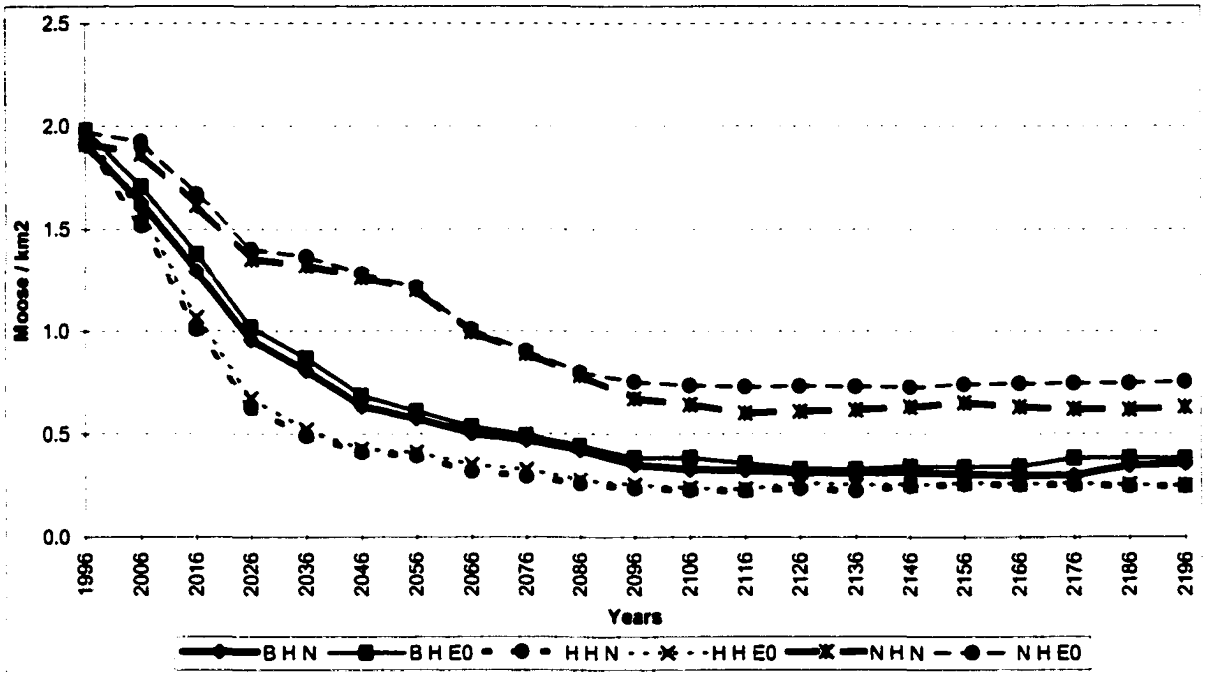


Figure A7-1: Euctrans sensitivity results for the Weldwood Winter Habitat Suitability Index Model with the Basic, High and No harvest scenarios.

variable is the result of merged grid with cells containing information relevant to the distance a cell is from a human disturbance (specifically, an access corridor). Basically, any cell within 100 m of an access corridor gets an HSI of 0 and any cell greater than 100 m from an access corridor gets an HSI of 100. Therefore, the sensitivity analysis test was to set the Euctrans variable to zero to evaluate its impact on the model output.

Results and Discussion

The results indicate that the Euctrans variable plays a minor role in the WWHSIM. From Figure A7-1 it is evident that the greatest effect occurs in the

NHS, followed by the BHS and HHS in the second hundred years. The average percentage change from the normal between 2096 and 2196 for the No, Basic and High harvest scenarios was 14.91, 10.00 and 4.49 % (Table A7-1). The effect is greatest in the NHS because, that simulation contains the greatest late-winter habitat i.e. old coniferous stands, and would benefit the most when the negative impact from roads is removed.

APPENDIX 8

Sensitivity Analysis for the Higgelke Habitat Model

Overview

Sensitivity analysis for the HHM was undertaken to find variables that might have a large impact on the model results when small changes were made. Two variable were selected, the early-winter cover index curves (EWCIC) and the browse curves (BC). The early-winter cover index curves describe the early-winter cover indices assigned to specific stand types while the browse curves estimate the amount of browse in kg/ha that would be present on the landscape in various stand types (Higgelke 1994).

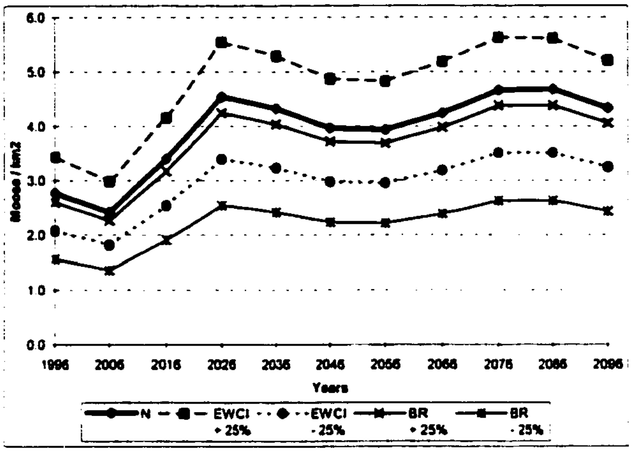
Both the EWCIC and BC were adjusted +/- 25 and 50% of their original values and the simulations run for 100 years, 1996-2096. Values for EWCIC were not raised above the 1.1 maximum, while the browse curves were allowed to rise to their numerically determined value.

Results and Discussion

The results indicate that any manipulation of the EWCIC produces a very predictable response of a uniform increase or decrease of a normal model simulation (Figure A8-1). On average over a 100 years, a 25% increase in the EWCIC produces a 21.59, 21.97 and 23.26% increase in moose carrying capacity for the No, Basic and High harvest scenarios. Similarly, a 25% decrease produces 100-year average carrying capacities that are -25.13, -25.09 and - 25.28% for the No, Basic and High harvest scenarios (Table A8-1).

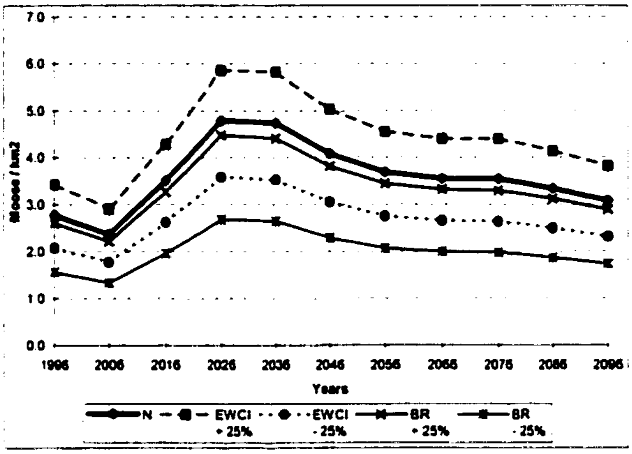
Basic Harvest

Year	N	EWCI + 25%	EWCI - 25%	BR + 25%	BR - 25%
1996	2.78	3.43	2.08	2.60	1.56
2006	2.42	2.99	1.82	2.27	1.36
2016	3.41	4.16	2.54	3.18	1.91
2026	4.55	5.55	3.40	4.25	2.55
2036	4.33	5.30	3.23	4.04	2.42
2046	3.97	4.87	2.98	3.72	2.23
2056	3.94	4.83	2.95	3.69	2.22
2066	4.24	5.19	3.19	3.99	2.39
2076	4.67	5.64	3.51	4.39	2.63
2086	4.68	5.61	3.51	4.39	2.63
2096	4.33	5.21	3.25	4.06	2.43



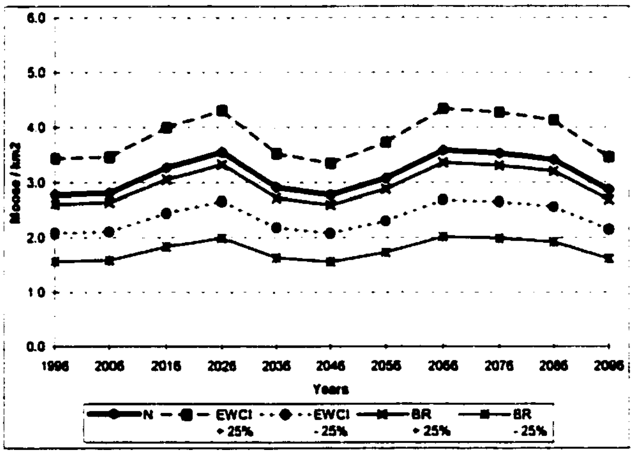
High Harvest

Year	N	EWCI + 25%	EWCI - 25%	BR + 25%	BR - 25%
1996	2.78	3.43	2.08	2.60	1.56
2006	2.37	2.91	1.78	2.22	1.33
2016	3.52	4.29	2.62	3.28	1.96
2026	4.79	5.86	3.58	4.48	2.69
2036	4.74	5.82	3.53	4.41	2.65
2046	4.09	5.03	3.05	3.81	2.29
2056	3.69	4.55	2.76	3.45	2.07
2066	3.55	4.41	2.66	3.33	2.00
2076	3.55	4.40	2.64	3.30	1.98
2086	3.34	4.14	2.50	3.12	1.87
2096	3.09	3.82	2.32	2.90	1.74



No Harvest

Year	N	EWCI + 25%	EWCI - 25%	BR + 25%	BR - 25%
1996	2.78	3.43	2.08	2.60	1.56
2006	2.81	3.46	2.10	2.64	1.58
2016	3.27	3.99	2.44	3.05	1.83
2026	3.55	4.31	2.66	3.32	1.99
2036	2.91	3.52	2.18	2.72	1.63
2046	2.77	3.34	2.07	2.59	1.55
2056	3.07	3.72	2.30	2.88	1.73
2066	3.58	4.34	2.68	3.36	2.01
2076	3.53	4.27	2.64	3.30	1.98
2086	3.41	4.13	2.56	3.20	1.92
2096	2.86	3.45	2.14	2.68	1.61



N = Normal values

EWCI - 25% = Early winter cover index curves decreased 25% of normal

EWCI + 25% = Early winter cover index curves increased 25% of normal

BR + 25% = Browse curves increased 25% of normal

BR - 25% = Browse curves decreased 25% of normal

Figure A8-1: Early-winter cover index curve and browse curve sensitivity results for the Higgelke Habitat Model with the Basic, High and No harvest scenarios.

Table A8-1: Percentage change of moose carrying capacity in the Higgelke Habitat Model with respect to a normal simulation using the No, Basic and High harvest scenarios.

No Harvest Percent

Year	N	EWCI + 25%	EWCI - 25%	Br + 25%	BR - 25%
1996	2.78	23.67	-25.00	-6.24	-43.76
2006	2.81	23.11	-25.14	-6.15	-43.71
2016	3.27	22.07	-25.41	-6.74	-44.06
2026	3.55	21.51	-25.13	-6.40	-43.85
2036	2.91	21.03	-25.15	-6.44	-43.87
2046	2.77	20.86	-25.13	-6.40	-43.85
2056	3.07	21.14	-25.10	-6.36	-43.83
2066	3.58	21.16	-25.01	-6.24	-43.75
2076	3.53	21.05	-25.15	-6.43	-43.86
2086	3.41	21.19	-25.03	-6.28	-43.77
2096	2.86	20.65	-25.16	-6.43	-43.86
Average	3.14	21.59	-25.13	-6.37	-43.83

Basic Harvest

Year	N	EWCI + 25%	EWCI - 25%	Br + 25%	BR - 25%
1996	2.78	23.67	-25.00	-6.24	-43.76
2006	2.42	23.30	-24.97	-6.11	-43.79
2016	3.41	22.01	-25.43	-6.81	-44.08
2026	4.55	22.09	-25.24	-6.55	-43.94
2036	4.33	22.28	-25.41	-6.75	-44.06
2046	3.97	22.77	-25.01	-6.26	-43.76
2056	3.94	22.40	-25.08	-6.34	-43.82
2066	4.24	22.24	-24.91	-6.07	-43.65
2076	4.67	20.75	-24.82	-6.02	-43.63
2086	4.68	19.90	-25.02	-6.34	-43.76
2096	4.33	20.22	-25.12	-6.40	-43.85
Average	3.94	21.97	-25.09	-6.35	-43.83

High Harvest

Year	N	EWCI + 25%	EWCI - 25%	Br + 25%	BR - 25%
1996	2.78	23.67	-25.00	-6.24	-43.76
2006	2.37	23.14	-24.96	-6.17	-43.73
2016	3.52	21.94	-25.48	-6.84	-44.11
2026	4.79	22.20	-25.24	-6.56	-43.93
2036	4.74	22.71	-25.61	-7.01	-44.21
2046	4.09	23.14	-25.42	-6.75	-44.09
2056	3.69	23.29	-25.35	-6.72	-44.02
2066	3.55	24.15	-25.05	-6.34	-43.78
2076	3.55	23.91	-25.68	-7.11	-44.27
2086	3.34	24.06	-25.22	-6.52	-43.93
2096	3.09	23.61	-25.07	-6.33	-43.81
Average	3.59	23.26	-25.28	-6.60	-43.97

The 25% EWCIC increase produced outputs that were lower than the expected average increase of 25% over normal. This anomaly was caused by the imposition of a 1.1 cover index curve limit. If that restriction were not in place, evidence suggests that a average increase of 25% would be observed over the 100-year simulation. I suggest this explanation because of the output results determined in the -25% decrease of the EWCIC.

The sensitivity analysis on browse curves produced some interesting results. Both the 25% increase and decrease produced carrying capacity values lower than the normal run. The output from the 25% decrease of normal browse curves gave a 100-year average of -43.83, -43.83 and -43.97% for the No, Basic and High harvest scenarios respectively, while a 25% increase in browse gave 100-year average reductions of -6.37, -6.35 and -6.60% of normal values for the No, Basic and High harvest scenarios.

The speculated reason behind the differences lies in the interaction of the food, early-winter cover index curves and the adjusted early-winter food supply from a 3x3 roving window spatial calculation. The calculation of adjusted early-winter food is derived from a spatial calculation using a roving window that tries to adjust food supplies based on the proximity of food to cover and cover to food. It is my contention that the extra food available produces a habitat that is of lower quality in the early-winter and therefore provides food values and subsequently carrying capacity values that are slightly lower than the normal run.

APPENDIX 9

Sensitivity Analysis of Stand Stocking on the Weldwood Winter HSI Model and the Chair in Forest Management and Policy Winter HSI Model

Overview

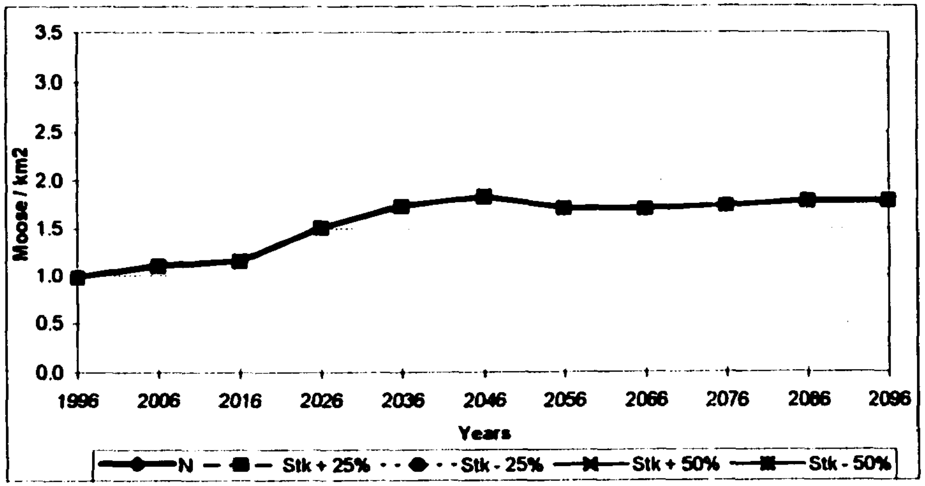
The sensitivity of the Weldwood Winter HSI Model (WWHSI) and Chair in Forest Management and Policy Winter HSI Model (CFMP-WHSI) model to stand stocking was explored by increasing and decreasing stand stocking by 25 and 50%. A maximum stand stocking was arbitrarily set to 1.0, therefore any stands that had stocking values that exceeded 1.0 after the increases of 25 and 50% were arbitrarily reset to 1.0. Conversely, when the stocking reduction of -25 and -50% were calculated those values were allowed to stand, since any reduction of any stocking number will always be a theoretically acceptable value. The simulation was conducted for 100 years to see if altering stocking would affect either habitat suitability index model.

Results and Discussion

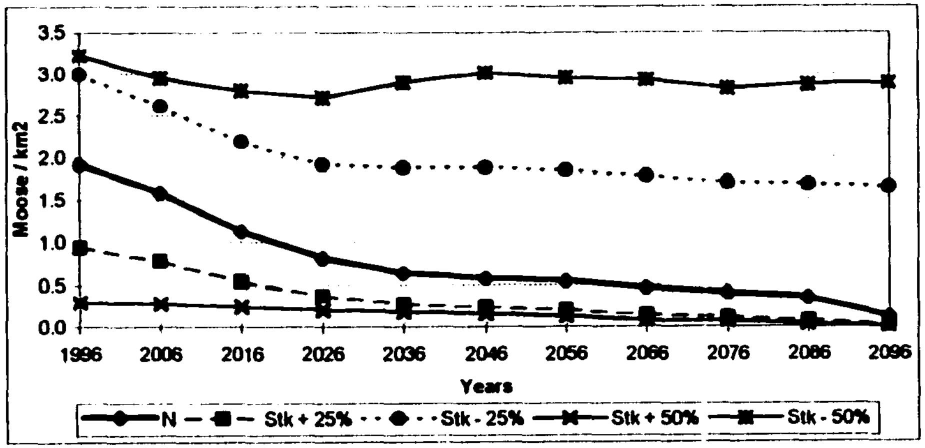
The results of the sensitivity analysis indicate that stocking has no effect on the CFMP-WHSI model; however, stocking did have a significant but predictable impact on the WWHSI model (Figure A9-1). There was an impact on the WWHSI model because stocking was used as a surrogate for determining food supplies i.e. variable S1. With lower stocking values, S1 values were significantly higher which in turn increased the final moose carrying capacity values. From Figure A9-1 the Stk -50% line on the WWHSI model is fairly linear during the 100-year simulation, while the lines with higher stocking values (normal, Stk +25% and +50%) showed falling moose carrying capacity numbers in the period 1996 - 2096. This indicates

Figure A9-1: Sensitivity analysis of stand stocking on the Weldwood Winter Habitat Suitability Index Model and the Chair in Forest Management and Policy Winter Habitat Suitability Index Model using only the Basic harvest scenarios for 100 years.

Year	N	Stk +	Stk - 25%	Stk +	Stk - 50%
1996	0.98	0.98	0.98	0.98	0.98
2006	1.11	1.11	1.11	1.11	1.10
2016	1.15	1.15	1.15	1.15	1.14
2026	1.51	1.51	1.51	1.51	1.50
2036	1.73	1.73	1.73	1.74	1.73
2046	1.83	1.83	1.83	1.83	1.83
2056	1.71	1.71	1.71	1.72	1.71
2066	1.70	1.70	1.70	1.70	1.70
2076	1.74	1.74	1.74	1.74	1.74
2086	1.78	1.78	1.78	1.78	1.78
2096	1.79	1.79	1.79	1.79	1.79



Year	N	Stk +	Stk - 25%	Stk +	Stk - 50%
1996	1.91	0.94	2.99	0.29	3.22
2006	1.59	0.78	2.61	0.27	2.95
2016	1.13	0.55	2.18	0.24	2.80
2026	0.82	0.37	1.92	0.20	2.72
2036	0.64	0.27	1.88	0.18	2.89
2046	0.58	0.24	1.88	0.16	3.01
2056	0.54	0.20	1.85	0.13	2.95
2066	0.46	0.14	1.78	0.09	2.92
2076	0.40	0.11	1.70	0.07	2.82
2086	0.35	0.07	1.68	0.04	2.87
2096	0.12	0.02	1.65	0.01	2.88



N = Normal Basic harvest scenario values
Stk + 25% = Stand stocking increased 25%
Stk - 25% = Stand stocking decreased 25%
Stk + 50% = Stand stocking increased 50%
Stk - 50% = Stand stocking decreased 50%

that the S1 variable has a significant impact on the model's final moose carrying capacity numbers. Therefore, by relaxing the restrictions of the S1 variable (i.e. lowering the stand stocking values thereby increasing the food supply) the model responds by calculating greater moose carrying capacity values.

The dip in the Stk -50% line of the WWHSI model Figure A9-1 is the model's response to the heavy cutting of late-winter habitat that takes place in the early part of the simulation under the BHS. The rise that follows is the forest rebounding as some stand conversion takes place done and re-established stands may have a 0.1 point lower stocking, because that was defined in the HSG's state table. Those state table stocking values were lower because herbicides are not permitted for competition control in Alberta. Therefore, replanted stands are expected to have slightly lower stocking values.

APPENDIX 10

Step-by-step process for the Weldwood Winter HSI model.

Weldwood Model

Starting Files

Forest	Grid cover	100x100
Roads	Line cover	

Step 1: Determine Shrub Canopy Closure (S1)

Stand Stocking (%)	HSI * 100
<50 %	100
60 %	80
70 %	60
80 %	40
90 %	20
100 %	0

Step 2: Determine Tree Canopy Closure (S4)

Stand Stocking (%)	HSI * 100
>= 30 %	100
20 %	58
10 %	17
< 6 %	0

Step 3: Determine Tree Height (S5)

Tree Height (m)	HSI * 100
< 2.0	0
3.0	50
>= 4.0	100

Step 4 Join Forest grid to HSG inventory file

Step 5 Distance from Human Disturbance (S3)

Covert line cover to grid at 100x100 cells
Create a 100x100 outline of roads
Creates a merged grid of distances out from roads

Step 6 Distance of Cover from Food (S6)

Identifies any food cells within 400 metres of a cover cell
A food cell is any cell that has a Shrub Cover Value x Distance from Disturbance > 5000
All cells are searched at one hundred metres
A food grid is created with values of 1 to signify a food cell
Rectangle search parameters are used around "food cells" looking for cover cells

HSI values of:	100	for cells from 0-100 m away
	75	for cells between 100-200 m away
	50	for cells between 200-300 m away
	25	for cells between 300-400 m away

Step 7 Distance of Food from Cover (S2)

Identifies any cover cells within 400 metres of a food cell

A cover cell is any cell that has a Closed Tree Canopy x Tree Height x Distance from Disturbance > 5000

All cells are searched at one hundred metres

A cover grid is created with values of 1 to signify a cover cell

Rectangle search parameters are used around "cover cells" looking for food cells

HIS values of:	100	for cells from 0-100 m away
	75	for cells between 100-200 m away
	50	for cells between 200-300 m away
	25	for cells between 300-400 m away

Step 8 Calculation of HSI Food

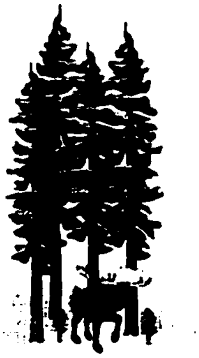
S1 x S2 x S3 / 10,000

Step 9 Calculation of HSI Cover

S3 x S4 x S5 x S6 / 1,000,000

Step 10 Calculation of Carrying Capacity

Sum HSIfood from grid
Sum HSIcover from grid
CoveradjFood = (HSIcover * 65) / 35
HU_units = Min HSIfood or CoveradjFood
Hu_winter = Hu_units / 0.65
CC = Hu_winter x 0.025 moose/ha



APPENDIX 11

Step-by-step process for the Chair in Forest Management and Policy HSI model.

Chair Model

Starting Files

Forest	Grid cover	100x100
Seismic, Utility	Line cover	
Inventory file	Database	

Step 1 Shrub Composition and Percent Favorable Browse (S2)

Determine Development Stages Coniferous

One	<31 years
Two	>30 and < 61
Three	>60 and < 101
Four	>100 and < 151
Five	>150

Determine Development Stages Deciduous

One	< 21 years
Two	> 20 and < 41
Three	> 40 and < 61
Four	> 60 and < 101
Five	> 100

Determine Site Class

Determine Browse from forestgrid

Step 2 Tree Canopy Closure (S4) Database Calculation

>60 %	= 100
50 %	= 81
40 %	= 63
30 %	= 44
20 %	= 26
10 %	= 7
< 6 %	= 0

Step 3 Tree Height (S5)	Database Calculation
>= 8 m	= 100
= 7 m	= 75
= 6 m	= 50
= 5 m	= 25
<= 4 m	= 0

Step 4 Percent Conifer (S6) Database Calculation
>50 % Conifer = 100
40 % Conifer = 85
30 % Conifer = 70
20 % Conifer = 55
10 % Conifer = 40
0 % Conifer = 25

Step 5 Stand Structure Bonus (S7) Database Calculation
Find C,c,M,m = 100

Step 6 Distance of Food from Cover (S3)
Identifies any food cell within 400 m of cover
Determine cover cells by:
A cell is cover if: $((S4 \times S5 \times S6)^{33} + S7) > 0.49$
Search rectangle around each cover cell
1.5 cell distance 0-100 = 100
2.5 cell distance 100-200 = 75
3.5 cell distance 200-300 = 50
4.5 cell distance 300-400 = 25

Step 7 Food Bonus for Seismic Utility Corridors (S1)
Create grid coverage from utility and seismic line coverages
Merge grids for bonus of 100

Step 8 Attach spatial and no spatial variables to MOOSE1 grid

Step 9 Calculate HSI
Food $= ((S2 \times S3)^{0.5} + S1)$
Cover $= ((S4 \times S5 \times S6)^{0.33} + S7)$

Step 10 Calculate Carrying Capacity
Sum Food from grid
Sum Cover from grid

Coveradj = (Cover x 65) / 35
Hu_units = Min Food or Coveradj
Hu_winter = Hu_units / 0.65
CC = Hu_winter * 0.025 moose/ha

APPENDIX 12

Step-by-step process for the Higgelke Habitat Model.

Higgelke Model
Starting Files

Forest	Grid cover	200x200
Inventory file	Database	

Step 1 Determine sub-dominance of stand species

Step 2 Compute working group

Step 3 Determine cover type

Step 4 Determine food and cover values using moose.c

Step 5 Create a habitat file for linking to the forest polygons to the food and cover values previously calculated

Step 6 Adjust early winter food values based on proximity of early winter cover.
The early winter food value is multiplied by the adjusted early winter cover index.
Done in a 3x3 windows across the landscape

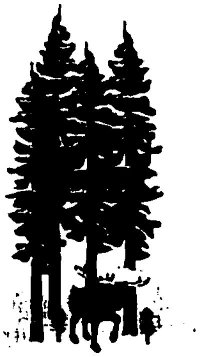
Step 7 Window analysis, in this case only one window.

Step 8 Summation of food supplies
- Sum of Summer food
- Sum of Autumn food
- Sum of Early Winter food

Step 9 Early Winter Moose Carrying Capacity

EWCCC = (early winter food total x 0.6 / (4 kg of browse / day x 60 days)
(forest area ha / 100 ha)

Step 10 Food values for Summer Autumn and Early Winter food output.



APPENDIX 13

Step by step process for the Duinker Population Model.

Duinker Population Model

Starting Files

Moose Biology	moosein.txt
Habitat	habrun.txt
Food	forage.txt

Step 1 Develop a starting-parameter file for moose

The file contains data describing the biological parameters of the moose population in question.

Step 2 Develop habitat window file

The file contains the length of the simulation i.e. 200 years, the length of each season in days and the size of habitat windows in hectares of the coverage analyzed.

Step 3 Develop the food values and harvested area text file

The file contains food values for summer, autumn, and early winter for each habitat window by simulation year as well as the area harvested.

Step 4 Run the model