

LONG-TERM EFFECTS OF TIMBER MANAGEMENT ON MARTEN (*Martes americana*) HABITAT POTENTIAL IN AN ONTARIO BOREAL FOREST

by

Ian Ross McCallum ©

A Graduate Thesis Submitted

In Partial Fulfilment of the Requirements

for the Degree of Master of Science in Forestry

School of Forestry

Lakehead University

September, 1993

ProQuest Number: 10611867

All rights reserved

INFORMATION TO ALL USERS

The quality of this reproduction is dependent upon the quality of the copy submitted.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if material had to be removed, a note will indicate the deletion.



ProQuest 10611867

Published by ProQuest LLC (2017). Copyright of the Dissertation is held by the Author.

All rights reserved.

This work is protected against unauthorized copying under Title 17, United States Code
Microform Edition © ProQuest LLC.

ProQuest LLC.
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106 - 1346



National Library
of Canada

Acquisitions and
Bibliographic Services Branch

395 Wellington Street
Ottawa, Ontario
K1A 0N4

Bibliothèque nationale
du Canada

Direction des acquisitions et
des services bibliographiques

395, rue Wellington
Ottawa (Ontario)
K1A 0N4

Your file *Votre référence*

Our file *Notre référence*

The author has granted an irrevocable non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of his/her thesis by any means and in any form or format, making this thesis available to interested persons.

L'auteur a accordé une licence irrévocable et non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de sa thèse de quelque manière et sous quelque forme que ce soit pour mettre des exemplaires de cette thèse à la disposition des personnes intéressées.

The author retains ownership of the copyright in his/her thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without his/her permission.

L'auteur conserve la propriété du droit d'auteur qui protège sa thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

ISBN 0-315-86183-5

Canada

ABSTRACT

McCallum, I.R. 1993. Long-term effects of timber management on marten habitat potential in an Ontario boreal forest. 190 pp. Advisor: Dr. P.N. Duinker

Key Words: marten (*Martes americana*), Habitat Suitability Index (HSI), Ontario boreal forest, simulation modelling, Harvest Schedule Generator (HSG), Geographic Information System (GIS).

To evaluate the hypothesis that current forest management practices in the boreal forest are decreasing the quantity and quality of long-term marten habitat, and alternative, more suitable strategies exist, a Geographic Information System (GIS)-based simulation study was initiated to determine the habitat suitability for marten of a boreal forest under various timber-management strategies. Two simulation models were used in this study. The first was the Harvest Schedule Generator (HSG), a wood-supply model created at the Petawawa National Forestry Institute (Forestry Canada). The second was a marten Habitat Suitability Index (HSI) model developed for this study. Each of the timber harvest strategies decreased the amount of long-term marten habitat. However, slight decreases in the level of spruce harvest provide significant future increases in suitable habitat. In the short term, delayed harvest of mature black spruce stands provides an improvement in marten habitat suitability. The procedures developed in this study provide valuable quantitative information which can be used to aid in forest management decision making.

TABLE OF CONTENTS

	Page
ABSTRACT	iii
LIST OF TABLES	vii
LIST OF FIGURES	viii
ACKNOWLEDGEMENTS	xi
CHAPTER 1 - INTRODUCTION	1
STUDY OBJECTIVE	3
SCIENTIFIC JUSTIFICATION	4
APPROACH TO THE STUDY	4
CHAPTER 2 - MARTEN LIFE REQUIREMENTS	8
LIFE HISTORY	9
TERRITORIAL BEHAVIOUR	10
FOOD REQUIREMENTS	11
ENERGY REQUIREMENTS	12
PHYSICAL HABITAT REQUIREMENTS	13
Canopy Closure	13
Canopy Composition	15
Subnivean Access and Coarse Woody Debris	18
Nest Sites and Habitat	19
Denning/Resting Sites and Habitat	21
PREDATION	24
CHAPTER 3 - PLANNING TOOLS FOR INTEGRATING TIMBER AND WILDLIFE MANAGEMENT AT THE LANDSCAPE LEVEL	26
MODELLING	27
Model Evaluation	29
HABITAT MODELLING	30
Habitat Suitability Index	31
CHAPTER 4 - STUDY AREA	36
FOREST DISTURBANCE	39
SILVICULTURAL PRACTICES	40

Modified Logging	41
CHAPTER 5 - METHODS	43
TOOLS SELECTED FOR ANALYSIS	43
FOREST RESOURCE INVENTORY DATABASE	44
DATABASE PREPARATION	47
YIELD CURVES	48
OPERATIONAL DESCRIPTION OF HARVEST SCHEDULE GENERATOR	49
DATASET PREPARATION FOR HSG	53
WOOD-SUPPLY ANALYSES	55
DEFINITIONS OF HARVEST SCENARIOS	59
NOHARVEST	59
EXTENSIVE	59
BASIC/INTENSIVE	60
SPRUCE + 10	60
DELAY-10	60
SPRUCE-10/SPRUCE-20	61
QUNO	62
MARTEN-HABITAT MODEL DESCRIPTION	62
Effective Working Groups	63
Habitat Rating	63
Cover	64
Stocking	65
Species Composition	66
Age	69
Denning/Resting Bonus	71
Cover Equations	72
Food	73
Final Habitat Suitability Index And Spatial Analysis	74
Final HSI Equations	76
MODEL OUTPUT	77
MODEL VERIFICATION	77
Sensitivity analysis	77
CHAPTER 6 - RESULTS AND DISCUSSION	79
WOOD-SUPPLY ANALYSES	79
MARTEN MODEL HABITAT MAPS	82
SCENARIO COMPARISONS OF MARTEN HABITAT	85
NOHARVEST/EXTENSIVE/BASIC	86
NOHARVEST/BASIC/INTENSIVE	89
NOHARVEST/SPRUCE + 10/INTENSIVE	91
NOHARVEST/BASIC/SPRUCE-20	91
NOHARVEST/DELAY-10/SPRUCE-10	93

NOHARVEST/QUNO/BASIC	96
MODEL VERIFICATION	97
Sensitivity Analysis	97
CHAPTER 7 - CONCLUSIONS	109
RESEARCH NEEDS	112
Age suitability in model cover equations	112
Female Nesting Habitat Requirements	112
Marten Use Of Areas After Modified Logging	113
Relationship Of Marten To Variables In The FRI	114
Spatial Habitat Requirements Of Marten Populations	114
Field Testing Of The Marten Habitat Model	115
Delayed harvest of black spruce stands	115
LITERATURE CITED	117
APPENDIX I	
A COMPARISON OF EXISTING MARTEN HSI MODELS	129
APPENDIX II	
A LITERATURE REVIEW OF MARTEN FOOD REQUIREMENTS, HOME RANGE AND POPULATION SIZES, AND MANAGING FOR TIMBER AND MARTEN	130
APPENDIX III	
OPERABILITY LIMITS AND THE TIMMINS FOREST NET MERCHANTABLE VOLUME (NMV) PURE SPECIES YIELD CURVES	168
APPENDIX IV	
STATE TABLE - SUCCESSIONAL AND SILVICULTURAL RULES USED TO SIMULATE FOREST GROWTH IN HSG	171
APPENDIX V	
BASIC HSG ACTIVITY FILE	177
APPENDIX VI	
SILVICULTURAL TREATMENT PRIORITY LISTS	181
APPENDIX VII	
RELATIONSHIPS AND EQUATIONS FOR FOOD HSI	182

LIST OF TABLES

Table	Page
1. Present area classification of the Timmins Forest.	38
2. Summary of productive forest area by working group for the Timmins Forest as of 1993	38
3. Silvicultural regimes used to regenerate the Timmins Forest since the FMA came into effect.	41
4. Specifications of the forest-management scenarios.	58
5. Age and site-class requirements for SPRUCE EWG stands with a minimum of 20% Sw/Ce to receive a bonus.	72
6. Changes to the original HSI area results from a negative shift in age curves.	107
7. Changes to the original HSI area results from a positive shift in age curves.	107
8. Sensitivity tests to original stand ages for denning bonus	108

LIST OF FIGURES

Figure	Page
1. An example of poor marten habitat.	17
2. An example of moderate marten habitat.	17
3. An example of optimal marten habitat.	18
4. Study area situated in Ontario's boreal forest	37
5. Black spruce working group age class structure in 1993.	39
6. View from within a harvest trail in an area of modified logging.	42
7. Flowchart of operations within HSG	51
8. Altered black spruce NMV yield curves operating in conjunction with the DELAY-10 scenario	61
9. Stocking curves used in marten cover equations.	66
10. Percent spruce in pine/hardwood stands.	68
11. Percent pine/hardwood in spruce stands.	68
12. Percent black spruce in 100% Sb/Sw/B/Ce stands.	69
13. Age suitability in pine/hardwood stands.	70
14. Age suitability in spruce stands.	71
15. 5 x 5 cell window placed over each cell in the database to perform the calculations for the final HSI values	76
16. The 1993-1998 QUNO Corp. allocation in the Timmins Forest showing harvest blocks shaded by working groups.	80

17. A comparison of the 1993-1998 QUNO Corp. allocation with the HSG allocation for the same period.	81
18. Marten habitat suitability in year 1993.	83
19. Marten habitat suitability in year 2093 resulting from the NOHARVEST scenario.	84
20. Marten habitat suitability in year 2093 resulting from the EXTENSIVE scenario.	84
21. Marten habitat suitability in year 2093 resulting from the INTENSIVE scenario.	85
22. The 1993 HSI rating for the Timmins Forest.	86
23. Comparison of area in HSI classes resulting from NOHARVEST/EXTENSIVE/BASIC scenarios	88
24. Comparison of area in HSI classes resulting from NOHARVEST/BASIC/INTENSIVE scenarios	90
25. Comparison of area in HSI classes resulting from NOHARVEST/SPRUCE + 10/INTENSIVE scenarios	92
26. Comparison of area in HSI classes resulting from NOHARVEST/BASIC/SPRUCE-20 scenarios	94
27. Comparison of area in HSI classes resulting from NOHARVEST/DELAY-10/SPRUCE-10 scenarios	95
28. Comparison of area in HSI classes resulting from NOHARVEST/QUNO/BASIC scenarios.	97
29. The original stocking curves with: (a) negative; and (b) positive shifts.	99
30. Area in HSI classes for the 1993 NOHARVEST base run resulting from negative and positive shifts to the original stocking curves	99
31. The original % SPRUCE EWG in PINE/HARDWOOD EWG curves with: (a) negative; and (b) positive shifts	100

32.	Area in HSI classes for the 1993 NOHARVEST base run resulting from negative and positive shifts to the original % SPRUCE EWG in PINE/HARDWOOD EWG curves	101
33.	The original % PINE/HARDWOOD curves with: (a) negative; and (b) positive shifts.	102
34.	Area in HSI classes for the 1993 NOHARVEST base run resulting from negative and positive shifts to the original % PINE/HARDWOOD curves.	102
35.	The original % black spruce in the SPRUCE EWG curves with negative and positive shifts.	103
36.	Area in HSI classes for the 1993 NOHARVEST base run resulting from negative and positive shifts to the original % black spruce in the SPRUCE EWG curves.	103
37.	The original age curves with: (a) negative and positive shifts to PINE/HARDWOOD EWG curves. Negative shifts were applied to the SPRUCE EWG curves with: (b) site classes X and 1; and (c) site classes 2, 3 and 4. Positive shifts were applied to the SPRUCE EWG curves with: (d) site classes X and 1; and (e) site classes 2, 3 and 4.	105
38.	Area in HSI classes for the 1993 NOHARVEST base run resulting from negative and positive shifts to the original age curves. . .	106
39.	Area in HSI classes for the 1993 NOHARVEST base run resulting from negative and positive shifts to the original bonus ages. . .	108

ACKNOWLEDGEMENTS

A study of this nature is only possible with the help of several organizations and many individuals. Working with and receiving help from the following people made this project an enjoyable and productive learning experience.

My academic supervisor, Peter Duinker, provided solid guidance and support throughout the entire study. His time and effort both on and off campus in seeing this study through to completion, is greatly appreciated. Many thanks to my academic committee members, Harold Cumming and Ulf Runesson, and my external examiner John Bissonette. They provided me with thorough reviews of my thesis under tight time constraints.

Wildlife Habitat Canada provided funding for this project through a two-year graduate student scholarship and I sincerely appreciate their support. The Ontario Ministry of Natural Resources (OMNR), Northeastern Science and Technology (NEST), provided funding and technical support for this project. Special thanks to Bob Watt for his involvement. The Chair in Forest Management and Policy at Lakehead University provided additional

funding and support.

Tom Moore, Cary Lockwood and John Tymoshuk of Forestry Canada were instrumental to the completion of this thesis, providing technical support throughout the study. QUNO Corporation offered the Timmins Forest as the study area. Thanks to Laing Bennett and John Russell, and the staff at QUNO for their cooperation in this study.

I am indebted to Nancy Bookey for her technical expertise, programming skills and good spirits. Nancy devoted many personal hours to this study and her efforts are greatly appreciated. Thanks to JoAnn Crichlow for help and encouragement throughout the study.

Thanks to Milan Vukelich, Russ Williams and Nolan Shortt at Timmins District, OMNR. Thanks also to Dave Archibald at NEST. Ian Thompson and Midge Strickland provided helpful comments along the way. Dan Beaudette and Mike Sullivan provided an early review of model results and structure. Many thanks to Tony Joanis and Ken Pennanen for visits to their traplines.

A special thanks to my family, Kelly and friends for support throughout this study.

CHAPTER 1

INTRODUCTION

In Ontario, as in other areas of North America, resource managers have recognized that explicit strategies are necessary to integrate wildlife habitat concerns with forest management activities (Wedeles *et al.*, 1991).

Currently, only moose (*Alces alces*) habitat is considered explicitly in the management of Ontario's publicly owned boreal forests, with featured species status for the moose and timber management guidelines (OMNR, 1988) for its habitat. Although the habitat needs of some species may be satisfied in featured species management, the restricted nature of the approach creates a situation in which others may not be accounted for (Wedeles *et al.*, 1991). Wildlife interests are at a disadvantage with this approach to forest management (Duinker, 1989).

One alternative to the use of guidelines based on single featured species is to employ a habitat supply analysis in which measures of the quantity and quality of habitat features to be produced by a management prescription are used to project future habitat quality for wildlife (Greig *et al.*, 1991). Habitat supply analyses are made possible by the development of habitat

supply models which may be used to rank or rate different habitats for species suitability. When combined with a simulation model of forest development, a habitat supply model can provide forest managers with an analytical framework which can be used to search for management alternatives which promote both timber and wildlife (Greig *et al.*, 1991).

The importance of habitat quality cannot be overemphasized as an important factor determining the health and size of furbearer populations on a long-term basis (Storm and Tzilkowski, 1982). In the coniferous and mixedwood forests of North America, this statement is especially true of marten (*Martes americana*), a north American furbearer. Marten, among all the boreal furbearers, appears to be one of the few species that occurs in highest densities in mature and overmature conifer forests, although utilizing a variety of forest habitats if food and cover are present (Marshall, 1951; Koehler and Hornocker, 1977; Mech and Rogers, 1977; Soutiere, 1979; Masters, 1980; Steventon and Major, 1982; Taylor and Abrey, 1982; Raine, 1983; Spencer *et al.*, 1983; Buskirk, 1984; Spencer, 1987; Buskirk *et al.*, 1989; Thompson *et al.*, 1989).

Mature and overmature coniferous forests are currently the staple of the timber supply in many Canadian provinces. Ontario's softwood demand is forecast to increase 24% over the next 50 years (OMNR, 1992).

Harvesting large amounts of mature and overmature coniferous forest in marten habitat may significantly reduce marten numbers (Bissonette *et al.*, 1989; Thompson, 1986). Marten in Newfoundland are recognized nationally as a threatened subspecies (COSEWIC, 1986). Marten are extirpated in Prince Edward Island, mainland Nova Scotia, and nine northern States, and are reduced to remnant populations in Newfoundland, Cape Breton Island, and six States (Thompson, 1991). The long time needed to attain the characteristic structure of overmature coniferous stands, even with silvicultural practices, suggests that a good deal of planning is necessary to manage simultaneously for timber production and for maintenance and enhancement of marten habitat (Bissonette *et al.*, 1989). Forest managers may choose to manage a landbase for marten habitat because: (1) marten prefer habitat types that are also important for timber; and (2) marten are a significant source of income to northern trappers.

STUDY OBJECTIVE

To determine how alternative long-term timber management strategies might alter the quantity and quality of potential female marten winter habitat across space and through future time, in an Ontario boreal forest.

Female marten are specified because they must obtain suitable habitat to raise kits, including nest sites.

SCIENTIFIC JUSTIFICATION

It is hypothesized that current forest management practices in the boreal forest are decreasing the quantity and quality of marten habitat into the future, while alternative, more suitable strategies exist. The hypothesis will be evaluated using a Habitat Suitability Index (HSI) model of marten habitat requirements developed for this study. Several marten habitat models have been developed using the HSI procedure (Allen, 1984; Ritter, 1985; Suring *et al.*, 1988; Bonar, 1990; Martelle, 1990; NBDNRE, 1990) (see Appendix I) but none were adequate for the Timmins Forest in Ontario's boreal forest region. Thus, a new HSI model was created for this study.

APPROACH TO THE STUDY

Two simulation models were required. The first is the Harvest Schedule Generator (HSG) created at the Petawawa National Forestry Institute (PNFI, Forestry Canada). The second is a marten HSI model developed specifically

for this study. HSG simulates forest inventory changes over time in a spatially explicit manner, altering stand descriptions in the inventory database to reflect succession. The effects of management actions (e.g. timber harvest, regeneration) are simulated, yielding forecasts of the structural composition of the future forest. Various timber harvest strategies were developed for application of the marten habitat model. The marten habitat model interprets the future forest structure to determine potential winter habitat suitability for female marten.

The habitat model makes quantitative interpretations of the output from HSG. Stand characteristics from the forest database are used to retrieve indices from habitat suitability curves. The marten habitat model calculates cover indices using stocking, species composition, and age from the forest inventory to assign a cover value to each stand. Age refers to the age when stands provide both suitable cover and nesting sites. The model uses age, species composition, disturbance and silvicultural treatment codes to assign a food value (representing snowshoe hare (*Lepus americanus*) habitat) to each stand. Final calculations are made by comparing the food and cover values for each stand and incorporating spatial analysis. Comparisons of impact on future marten habitat are then made between the various timber management strategies developed in HSG. Output in the form of graphs and maps illustrate the impacts. The

marten habitat model developed for this study is programmed in C-code and available upon request.

Construction of the curve sets and relationships in the marten habitat model were guided by a comprehensive literature review, previous marten habitat models, a workshop dealing with initial model structure and output, field trips to the study area, personal communication with local forestry staff and trappers, and expert opinion. Sensitivity analyses were performed on the cover curves to determine the importance of uncertainties in each curve. Economic considerations were not included in this study, and although their importance cannot be denied, addressing them would have inflated the scope of the analysis to an unmanageable level.

The knowledge necessary to perform a complete analysis of the impacts of potential courses of forest management actions on wildlife habitat does not exist and probably never will (Thomas, 1979a). Walters and Holling (1990) claimed that managers cannot predict with certainty either the ecological effects of their activities, or the efficacy of most measures aimed at regulating or enhancing them. However, a great deal of knowledge and understanding about marten and their habitat requirements does exist (Thompson, 1988; Bissonette *et al.*, 1989). To claim that too little is known at present to make better informed management decisions is to take

refuge behind a half-truth and ignore the fact that decisions will be made regardless of the amount of information available (Thomas, 1979a). It is, therefore, in many situations, possible and desirable to examine available knowledge, combine it with expert opinion on how the system operates, and make predictions about the consequences of alternative management strategies (Thomas, 1979a).

CHAPTER 2

MARTEN LIFE REQUIREMENTS

A substantial amount of information has been published on marten and their life requisites. The literature reviewed for this chapter provided the basis for the marten habitat model. An extended literature review appears in Appendix II.

Marten are members of the Family Mustelidae, Order Carnivora. Marten are similar in size to a small housecat. Their body is long and slender with a well-furred tail that constitutes about one-third of their total length, and short legs (Strickland and Douglas, 1987). Marten are trapped for their valuable fur which achieves a variety of colours. When prime, the fur is usually mid-brown, with darker legs and tail, a light coloured head, and a distinctive orange or yellow patch on the throat or chest (Strickland and Douglas, 1987). Males weigh 0.75 - 1.40 kg with females weighing 0.68 - 0.85 kg (Burt, 1976). Males are larger than females, and adults are heavier but not longer than juveniles (Strickland and Douglas, 1987).

LIFE HISTORY

The breeding season of marten spans from late June to early September (Lensink, 1953). Marten are induced ovulators with delayed implantation at the blastocyst stage lasting 7 to 8 months. Implantation occurs in February or March followed by a pregnancy of 27 days. Young are born between mid-March and late April. The average litter size of captive marten is 2.9. There is no evidence that the male is directly involved with the care and rearing of the young (Strickland and Douglas, 1987). Marten are usually solitary except during brief mating liaisons in summer (Martin and Barret, 1983). Young weigh approximately one ounce (28 g) at birth and are blind, helpless and sparsely furred (Brassard and Bernard, 1939). Their ears open around day 24, with their eyes opening around day 39 (Strickland and Douglas, 1987). By the third month the young are nearly adult length (Brassard and Bernard, 1939), although for several more months they continue to increase in weight, especially males (Strickland and Douglas, 1987). Marten are born at nearly a 1:1 sex ratio with the sexes having similar longevity (Strickland and Douglas, 1987). Both males and females rarely mate until their second summer. Marten are relatively long-lived and Strickland and Douglas (1987) have aged wild marten to 14.5 years.

Marten are nonhibernators with high metabolic demands (Buskirk *et al.*, 1988) and require about 80 kcal/day while at rest (More, 1978; Worthen and Kilgore, 1981), equivalent to about three voles (Buskirk, 1983). This places stringent demands on marten to be an extremely effective predator (Buskirk and Harlow, 1989). Thompson (1986) concluded that marten must hunt on a nearly continual basis. Buskirk *et al.* (1988) showed that marten forage daily in winter, leaving resting sites each evening during all but the most severe weather conditions.

TERRITORIAL BEHAVIOUR

On an annual basis, mustelid populations are composed of residents, transients and immatures (Francis and Stephenson, 1972). Populations are structured around male territories which are usually large and well-defined. These territories are less rigidly defended in winter (Clark, 1975), as marten must focus on survival. Members of the opposite sex and immatures are often tolerated (Strickland and Douglas, 1987). By excluding other adult males from its territory, a male may enhance its opportunities for mating. Major (1979) reported that between 1 and 4 female home ranges may overlap a single male home range (although the sex ratio is 1:1), possibly with transients and immatures also present if the habitat is optimal. This

territorial behaviour in marten may limit the densities that can be attained even in optimal habitat. The biology of marten makes it likely that a sample of individuals captured at a locality is composed of related individuals (Mitton and Raphael, 1990).

FOOD REQUIREMENTS

From the literature, marten appear to be microtine specialists with underlying specific preferences, supplementing their diets by opportunistically consuming a wide variety of food items. Marten will prey on items ranging from insects to snowshoe hare, and consume plant matter and carrion. In Ontario, red-backed voles and snowshoe hare are important diet items (Thompson, 1986). Use of hare is especially related to spatial characteristics of heterogeneous habitat (Bissonette, 1993). They have also displayed cannibalistic behaviour towards the young when food is scarce (Thompson, 1986). Prey consumption by marten is greatly affected by seasonal variation (Cowan and MacKay, 1950; Buskirk and MacDonald, 1984; Hargis and McCullough, 1984), as many food supplies are cyclic or irregular in occurrence (Strickland and Douglas, 1987). Availability and abundance of preferred prey and of alternate foods also accounts for variations in foods reported seasonally and geographically (Strickland and

Douglas, 1987). Quick (1955) noted that marten are not entirely dependent of any one food item, but in an unexploited population are probably limited by the availability and vulnerability of all forms of prey.

ENERGY REQUIREMENTS

Thompson (1986) suggested that marten reduce energy loss during late winter by reducing activity, eating larger prey, and being active only during the warmest part of the day. Energy requirements suggest that marten could not survive in late winter solely by eating small rodents (Thompson, 1986). In Thompson's (1986) study, larger prey types contributed more than 80% of the energy acquired by marten. The energy requirements of the adult female may be the most difficult to satisfy. Prenatal development, juvenile dependency, and breeding season activities place excessive demands upon the food-gathering abilities of the adult female (Hawley and Newby, 1957). This may be especially true during periods of food scarcity.

PHYSICAL HABITAT REQUIREMENTS

Marten populations exist across Canada from coast to coast, including the Northwest Territories and the Yukon, also extending into Alaska and the northern, mid-western, and western United States. In Ontario, marten populations are currently limited to areas north of and including Algonquin Park (Strickland and Douglas, 1987). At one point they occurred in southern Ontario (Hagmeir, 1956). The loss of habitat is cited as the major cause of extirpation of marten from parts of its original range (Thompson, 1988). In some areas where fragmented habitat persisted, over-trapping caused local extirpation (Strickland and Douglas, 1987). Presently, marten are being re-introduced into many areas of their original range where suitable habitat has persisted or has been restored.

Canopy Closure

Spencer *et al.* (1983) discovered that marten preferred stands with 40-60% canopy closure at both resting and foraging sites, and avoided stands with < 30% canopy closure. Buskirk (1984) in Alaska found most resting sites were in overmature spruce with a canopy closure > 70%. Hargis and McCullough (1984) and Hargis (1982) determined that marten in California selected forest stands containing 100% cover < 3 m above the snow

when foraging and resting. Koehler *et al.* (1975) reported that during winter, marten avoid stands with $< 30\%$ canopy closure. Slough (1989) found marten to show an affinity for occupying (permanently and temporarily) late seral or climax coniferous forest types. Hargis and McCullough (1984) followed marten tracks through forested areas and noted a preference for 100% cover. Successful trap sites in western Newfoundland occurred in proximity to trees with a diameter at breast height (d.b.h.) of at least 15 cm and overhead cover $> 50\%$ (Snyder and Bissonette, 1987). Burnett (1981) recorded marten in Montana showing a strong preference for canopy cover $> 17\%$, with stands used by marten averaging 35% canopy cover. Recent work in Newfoundland and Wyoming finds marten using defoliated and canopy burned stands during winter and summer as long as tree boles are available as vertical escape routes (Bissonette, 1993).

Although marten avoid large forest openings in all seasons, some studies indicate marten having a preference for the edges between old-growth stands and meadows (non-forested, grassy or herbaceous areas) with abundant herbaceous vegetation (Simon, 1980; Spencer *et al.*, 1983). Spencer *et al.* (1983) suggested that marten preferred to be within 60 m of a meadow, especially while active, and rarely used sites more than 400 m from meadows. Marten home ranges in Montana were noted to coincide

with the edges of large openings, confining their activities to the dense portions of the forest (Hawley and Newby, 1957).

Hargis and McCullough (1984) stated that marten may avoid large openings in the winter because of the energy expenditure of obtaining prey beneath the snow. Koehler and Hornocker (1977) related marten preference for dense stands to snow depth and condition. Winter canopies were substantially greater in uncut areas compared to all ages of regenerating forest (Thompson, 1993a). Marten avoid rivers and lakes in all winter periods (Raine, 1983), likely because of deeper snow compared with forested areas, a lack of prey species and lack of protection from predators. Preference by marten for coniferous canopy cover may be a reflection of their need for security and thermal cover, and a function of the type of forest suitable for foraging and denning (Lofroth and Steventon, 1990). In a California study, all of the snags known to be used by marten were sheltered, at least partially, by an overstorey canopy (Simon, 1980).

Canopy Composition

Marten have been reported using a variety of habitat with varying tree species composition. Lodgepole pine (*Pinus contorta*), subalpine fir (*Abies lasiocarpa*) and mixed conifers are used in Washington and Oregon (Thomas, 1979b). Marten in south-central Alaska prefer forest woodlands

dominated by black spruce (*Picea mariana*) and white spruce (*Picea glauca*) (Buskirk and MacDonald, 1984). Spencer *et al.* (1983) reported the use of riparian lodgepole pine in California. In undisturbed eastern forest, marten activity is highest in conifer-dominated mixed stands and lowest in hardwood stands (de Vos, 1952; Francis and Stephenson, 1972; Soutiere, 1979). Marshall (1951) found marten during the winter months using dense alpine fir most intensively, along with ponderosa pine (*Pinus ponderosa*) stands. Marten regularly frequent cedar (*Thuja occidentalis*) swamps in Ontario, likely due to the presence of voles (de Vos, 1952). Mature stands of black spruce or a mixture of black spruce and jack pine (*Pinus banksiana*) appear to be poorer habitat than stands containing white spruce in Ontario, possibly because of a shortage of voles in the former (de Vos, 1952). Meslow *et al.* (1981) stated that extensive old growth forests are the mainstay of marten populations in the Pacific states of the U.S.. These forests provide all marten requisites, since they have many excellent den sites (Spencer, 1981) and favoured marten prey (voles and hare) are abundant in them (Zielinski, 1981). For the purposes of clarification, marten habitat has been classified into three broad classes of poor, moderate and optimal to help the reader visualize the differences (see Figures 1, 2, and 3).



Figure 1. An example of poor marten habitat.



Figure 2. An example of moderate marten habitat.



Figure 3. An example of optimal marten habitat.

Subnivean Access and Coarse Woody Debris

Over the winter, as the snowpack increases in depth, it becomes increasingly necessary for marten to gain access to the subnivean (below the snow) space, in order to rest and forage for small mammals. Coarse Woody Debris (CWD) in the form of stumps, root-mats, limbs, and logs in various stages of decay occur in most natural forest ecosystems to varying degrees (Brown, 1985), providing marten with access into and under the snow layer (i.e. subnivean access). Subnivean space is also a function of the amount of CWD and clumps of shrub-sized vegetation which, after

fresh snowfalls, facilitate the development of air pockets and hollows in the snowpack under the buried branches. As snow depth increases, branches of mature trees replace saplings in providing low cover. Live trees may also be used as avenues to the subnivean space as the snow settles, leaving a melt zone around the trunk.

Subnivean access points are increasingly plentiful in overmature stands due to the great volumes of wood and high rates of tree mortality. In uncut forested areas, Thompson (1986) found 147 potential subnivean access points/kilometre in November (82/km in cutovers) with 20 cm of snow, and 53/km between January and March with 80 cm of snow (26/km in cutovers). Thompson (1993b) determined that marten in cutovers examined fewer logs and stumps than did marten in uncut sites. Despite less subnivean access and fewer investigations in post-logging forests, marten in cutovers and uncut areas hunted beneath the snow at similar rates (Thompson, 1993b). Therefore, Thompson (1993b) suggested that CWD, while necessary, does not limit marten populations in Ontario. In the Ontario boreal forest, it is likely that use of CWD as a variable in a model would have little discriminatory power (Bissonette, 1993).

Nest Sites and Habitat

Nest sites are structures used by female marten for the purpose of raising

kits. The female prepares a birth nest with grass, moss and leaves in a cavity, often high up in a large tree (Seton, 1953). Wynne and Sherburne (1984) found females nested in tree cavities when kits were largely inactive and defenceless (5 to 6 weeks old). At this time, above-ground nests may be necessary in order to protect kits from wet spring ground conditions (Wynne and Sherburne, 1984) and predation. When kits were 7 to 8 weeks old in June, females moved them an average of 330 m from tree-cavity nests to ground-level CWD nests with good overhead cover. Wynne and Sherburne (1984) witnessed females bringing small mammals to the kits. By mid-July, when kits were 12 to 15 weeks old and nearly adult size, both females and their litters nested in 50 to 60 cm dbh cedar trees (Wynne and Sherburne, 1984), with the kits becoming independent by August. Wynne and Sherburne (1984) observed a female limiting the size of her home range when she had a litter. Large trees for natal denning may have influenced selection of older forests by marten in Ontario, but experimental data are lacking (Thompson, 1993a).

Wynne and Sherburne (1984) found five of six nest sites in hollow cedar logs or overmature cedar trees (range, 40 -70 cm dbh), and the remaining nest in a mature sugar maple (*Acer saccharum*). Thompson (1993b) located 2 natal dens in uncut forest, both located in large diameter (> 50 cm dbh) cedar trees. Entrances to these nests were at the bases of the

trees, and resting chambers were approximately 1 m above ground level inside the bole. Nest selection by females may reflect special logistic and energetic requirements related to kit rearing. These include an abundant food source being in close proximity to the nest, cover to decrease the risk of predation, and thermal protection.

Denning/Resting Sites and Habitat

Marten are opportunistic to a degree in den selection, with deadwood sites providing preferred den locations; but where densities of snags, stumps and logs are not high, other habitat features may be utilized including tree canopies, willow clumps, other brush, rock slides and subnivean dens (Martin and Barrett, 1983). Steventon and Major (1982) felt that marten probably selected suitable microhabitats, such as decaying stumps, fallen logs, or tree crowns, within the habitats in which they happened to be travelling, hunting or foraging. Bergerud (1969) suggested that den site availability may limit marten populations.

Martin and Barret (1983) found marten to occupy a den for one or two days, shifting to another within a few hundred meters of the first. Dens within one specific area of the home range were often used for a few weeks, with the marten completely shifting activity and den occupation to another area of its home range. Specific den sites were often used

repeatedly and by different marten (Martin and Barret, 1983).

The location and characteristics of dens used by marten may have thermoregulatory importance (Wynne and Sherburne, 1984). Marten winter dens have been found in well-insulated or subnivean sites (Steventon, 1979), whereas summer dens were found primarily in tree canopies (Wynne and Sherburne, 1984). This seasonal pattern of den use may be related to temperature within coniferous forests (Wynne and Sherburne, 1984). In a spruce/fir forest in Maine, Steventon and Major (1982) found that of 31 winter den sites examined, all but one were beneath the snow in natural cavities formed around large decayed stumps. All permanent winter dens encountered were subnivean and usually had been excavated further by the marten in early winter (Thompson, 1986). Hargis (1982) recorded marten digging down to logs that were covered with snow but were distinguishable in outline at the snow surface. Raine (1981) located three subnivean dens in renovated red squirrel middens on jackpine ridges, and two summer dens on a jackpine ridge under the roots of fallen trees. Of particular importance are large, dead trees such as firs that are prone to the formation of cavities near ground level, since these provide ideal shelter during winter (Spencer, 1987).

Marten are selective in choosing a resting site (Raphael *et al.*, 1991).

Resting sites may reduce thermoregulatory costs and provide protection from predators during winter (Buskirk, 1984). When snow cover was continuous, resting sites beneath the snow were used exclusively, with 91% of subnivean observations associated with logs, stumps and snags (live trees were not used) (Spencer, 1987). In winter, most resting sites (46%) were in association with subnivean logs, 50% of which were located in mature spruce/fir associations (Raphael *et al.*, 1991). The importance of resting where CWD is available to provide thermal cover may explain the apparent dependence of marten on old-growth forest in winter (Buskirk *et al.*, 1989).

Spencer *et al.* (1983) found riparian areas were used more for activity than resting, and mixed conifers were used more for resting than activity. The potential importance of resting sites to marten may permit more reliable evaluation of habitat quality and may explain the seasonal absence of marten when other habitat factors are optimal (Buskirk, 1984). Simon (1980) found that marten regularly returned to familiar rest areas for daytime resting, suggesting that quality rest areas are important in marten habitat. Marten are familiar with the locations of subnivean rest-sites in their home ranges, and tend to reuse them in winter (Steventon and Major, 1982; Spencer, 1987; Buskirk *et al.*, 1989).

PREDATION

Marten have been found preyed upon in various portions of their range by fishers (*Martes pennanti*), wolverines (*Gulo luscus*), lynx (*Lynx canadensis*), mountain lions (*Felis concolor*), coyotes (*Canis latrans*), red foxes (*Vulpes vulpes*), golden eagles (*Aquila chrysaetos*), bald eagles (*Haliaeetus leucocephalus*), hawk owls (*Surnia ulula*) and great horned owls (*Bubo virginianus*) (Marshall, 1951; de Vos, 1952; Davis, 1978; Raine, 1981; Hargis and McCullough, 1984; Bissonette, 1993).

Hawley and Newby (1957) stated that marten avoid large openings in forest cover, due in part to predator avoidance. A more open canopy in young regenerating forests provides less protection from avian predators (Hargis and McCullough, 1984) than would a dense canopy in uncut coniferous forest (Thompson, 1993a). Regenerating forests also contain higher populations of potential terrestrial predators of marten, including red fox and lynx, than do old coniferous forests (Thompson *et al.*, 1989). The greater number of layers of vegetation in uncut forest compared to cutovers likely affords greater protection from perching avian predators (Thompson, 1993a), and tree stems in the uncut forest provide an escape route from terrestrial predators. The predation rate on marten in uncut forest was lower than that in post-logging forests, making the latter less

attractive habitat (Thompson, 1993a). Data from an Ontario study indicated that 16% of marten were killed by predators (Thompson, 1993a).

CHAPTER 3

PLANNING TOOLS FOR INTEGRATING TIMBER AND WILDLIFE
MANAGEMENT AT THE LANDSCAPE LEVEL

Quantitative predictions cannot normally be made, nor hypotheses tested, without a firm foundation in measurement (Beanlands and Duinker, 1983). Measurement in ecosystems is usually difficult due to high levels of natural variability, large time and space scales, and limited funds and resources. It may not be possible to establish true experimental controls under field conditions, nor to undertake the sampling programs required to meet normally accepted confidence limits in statistical analyses (Beanlands and Duinker, 1983). Recognizing these inherent difficulties in impact assessment, quantitative simulation modelling has developed as a tool to improve the science of impact assessment.

Forest management disturbances take place over time and space scales that defy true field replication (Duinker and Baskerville, 1986). However, analysts must have a reference or control situation for comparison in order to determine impact. This could take any of three forms: (1) measurement

in a similar area; (2) measurements before development in an area; and (3) reference forecasts. The forecasts produced in pre-development impact analysis, with the use of simulation models, provide the fundamental basis for the difference calculation of impact before development occurs, as well as during and after (Duinker and Baskerville, 1986).

MODELLING

A model is any representation or abstraction of a system or process (Walters, 1986). Modelling uses the results of experimental science, but identifies gaps, suggests alternatives, and evaluates the consequences of planned and unplanned interventions in a whole system (Walters and Holling, 1990). Never does one have all the information at the start of a modelling exercise to build a model that can be used unchanged forever (Starfield and Bleloch, 1988). The modelling process itself improves models. The quality of a model does not depend on how realistic it is, but on how well it performs in relation to the purpose for which it was built (Starfield and Bleloch, 1988). There are no single, best all-purpose models (Levins, 1968). It is not possible to simultaneously maximize generality, realism, and precision as one is always sacrificed (Levins, 1968).

A model must address the essence of the system rather than attempt to reproduce each individual process within the system (Duinker, 1991). We build models to help us: (1) force assumptions to become explicit; (2) formulate and test hypotheses; (3) identify research needs to guide data collection; (4) force careful, unambiguous system description; (5) organize concepts and ideas; (6) test and make impact predictions; (7) suggest appropriate mitigation and monitoring; and (8) provide an effective teaching and communication tool (Beanlands and Duinker, 1983).

The task of building a model highlights the aspects of the system that are crucial at the decision-making level of interest (Starfield and Bleloch, 1988). Analysis without the use of some sort of model, explicit or otherwise, is impossible (Majone and Quade, 1980). Those who collect data without building models run the risk of discovering, when they eventually analyze their data, that they have collected the wrong data (Starfield and Bleloch, 1988).

Modelling is useful for determining the impact of landscape scale disturbances such as timber harvest. If research is performed only at a local level, functions within ecological systems may completely hide the potential effects that would result from a larger intervention (Holling, 1978). Modelling provides decision-makers with a powerful tool to

forecast the impact of disturbance at the landscape level.

Model Evaluation

Model evaluation should be an ongoing exercise during the formation and application of a model. There are two phases of model evaluation: (1) verification (sensitivity analysis), which is directed toward evaluating how well the model matches the modeller's expectations; and (2) testing, which determines how the modeller's perceptions fare in the real world (Farmer *et al.*, 1982).

Sensitivity analysis is the primary technique for understanding model uncertainty, although uncertainties cannot be eliminated from the modelling process (Majone and Quade, 1980). Variability in parameter values must be expected due to measurement errors or future change, and if the model predictions change radically as a result, then these predictions must be treated very cautiously during assessment (Holling, 1978). Sensitivity testing can also be thought of as a test of the consequences of inaccuracies in the database being used. Modellers must determine how best to test the sensitivity of the model, taking into account all of the possible variations among parameters.

The model testing process is simply hypothesis testing, since models are

merely statements of hypotheses (Holling, 1978). This study did not involve field testing of the model. However, this study was developed in conjunction with a marten habitat project currently being undertaken by the Ontario Ministry of Natural Resources (OMNR). Results from the marten habitat model will be used to guide future field work, focusing on areas where knowledge is poorest, and results from the field work will be used to improve the model.

HABITAT MODELLING

From a wildlife perspective, forest management decisions are being made today despite the lack of data and understanding. Forest managers are faced with increasing demands to produce quantitative predictions of habitat and population responses to disturbance. Models provide a framework around which qualitative habitat information can be structured for decision-making, turning qualitative and quantitative relationships into testable hypotheses (Schamberger and O'Neil, 1988). An important advantage of models is that they can make the intuitive or invisible assumptions of the wildlife expert more visible and tangible (Kansas and Raine, 1990).

Habitat models generally fall under the categories of either empirical or theoretical (Morrison *et al.*, 1992). Biometric models are common examples of empirical models, while HSI models are commonly used forms of theoretical models. Empirical and theoretical modelling procedures can also be used in combination to produce wildlife habitat models. In this thesis, the theoretical approach was used to develop an HSI model.

Habitat Suitability Index

The HSI procedure attempts to evaluate the ability of key habitat components to supply the life requisites of selected species (USFW, 1980). Life requisites are any habitat requirements that are essential for species survival (USFW, 1981). HSI models are theoretical in nature because the underlying relationship between habitat capability and each environmental parameter is assumed from the outset, rather than from field observations (Morrison *et al.*, 1992). HSI models are based on the premise that habitat suitability can be linked to individual habitat variables, and that these variables can be combined into a meaningful index (Laymon and Barrett, 1986). This single index is intended to represent the suitability of a given patch of habitat for a particular wildlife species (Laymon and Barrett, 1986). The sensitivity of the resulting habitat index values to any one environmental variable is diminished as more variables are added to the model (Morrison *et al.*, 1992).

The common procedure used in developing theoretical HSI models involves both a literature review and expert opinion. The explicit structure of HSI models allow the combination of knowledge from a variety of sources. Field data are applied to the procedure in several ways. Often data from several experiments conducted by several researchers are available, and these are used to suggest a range of estimates for a parameter that are later refined through the evaluation process (Swartzman and Kaluzny, 1987). In many cases, quantitative data are sparse and variable. Because the models are mechanistic (contain process equations based on physical and biological rationale), it is often possible to reason what parameter values ought to be (Swartzman and Kaluzny, 1987).

HSI models are specifically designed for situations where land use, and therefore habitat condition, are expected to change. They are intended to allow assessments of resultant changes in potential habitat quality and availability for selected wildlife species (Schamberger and O'Neil, 1986). Variables included in the models are limited to those: (1) to which the species responds; (2) that can be measured or estimated readily; (3) whose value can be predicted for future conditions; and (4) that are vulnerable to change during the course of forest management (Schamberger and O'Neil, 1986).

Many factors known to influence animal populations are excluded from HSI models if they cannot be readily measured (e.g. predation), managed (e.g. weather) or predicted for future conditions (e.g. competition) (Schamberger and O'Neil, 1986). These factors exist in the real world, and may be important to a wildlife population, but often one is unable to model for them (Baskerville, 1991). This results in a model with a restricted definition of habitat, for a specific land-use study, and for a specific geographic area.

Generally, HSI models are: (1) mathematical (because of the explicit formulas used); (2) deterministic (only single values for environmental parameters are used, resulting in single solution values); and (3) analytic in form (because the mathematical formulas can be solved exactly for particular values of environmental parameters) (Morrison *et al.*, 1992). The calculations developed for HSI models generally make use of the geometric mean. The geometric mean presumably represents the best balance and interaction of the parameters involved (Morrison *et al.*, 1992). It is important that the index scale used in the HSI model be susceptible to mathematic manipulation. The geometric mean of a set of n positive numbers is the n^{th} root of their product (Freund and Williams, 1977). If the numbers are all the same, the geometric mean equals the arithmetic mean. Otherwise the geometric mean is always less than the arithmetic mean

(Freund and Williams, 1977). The geometric mean combines variables in such a way that the resulting index value is penalized by the lowest variable value more strongly than with the arithmetic mean. For example, the geometric mean of the numbers 1, 1, 2 and 8 equals 2, whereas their arithmetic mean equals 3 (Freund and Williams, 1977).

HSI models are useful for representing in a simple and understandable form the major environmental factors thought to influence strongly the occurrence and abundance of a wildlife species (Morrison *et al.*, 1992). HSI models are practical, operational planning models designed to assess impacts of change, providing a bridge between the fields of planning and science (Schamberger and O'Neil, 1986). Their value lies in documenting a repeatable assessment procedure and providing an index to particular environmental characteristics that can be compared under alternative management plans (Morrison *et al.*, 1992).

HSI models are best viewed as hypotheses of species-habitat relationships rather than as causal functions (Schamberger, 1982). They do not provide information on population size, trend, or behavioral response by individuals to shifts in resource conditions (Morrison *et al.*, 1992). HSI models should be used to represent relative environmental conditions and to generate hypotheses about species-habitat relationships, rather than as definitive

statements of cause-and-effect relations or reliable predictions of species response (Morrison *et al.*, 1992).

CHAPTER 4

STUDY AREA

The Timmins Forest, located southeast of Timmins, Ontario, lies entirely within the Ontario boreal forest region (see Figure 4). It has a total area of 189,492 ha, consisting of water, forested and non-forested land (see Table 1). The forested land is further divided into productive and non-productive forests, with the productive forests classified into species working groups (see Table 2). Non-productive forested land includes areas which cannot produce a commercial crop of timber owing to low productivity, such as: (1) treed muskeg; (2) open muskeg; (3) brush and alder; and (4) rock (OMNR, 1978). The black spruce working group dominates the forest, and this area is divided into age classes in Figure 5. The peak in area at age-class 20-40 is a result of past timber harvest. The peak at age-class 100-120 is likely a result of fire.

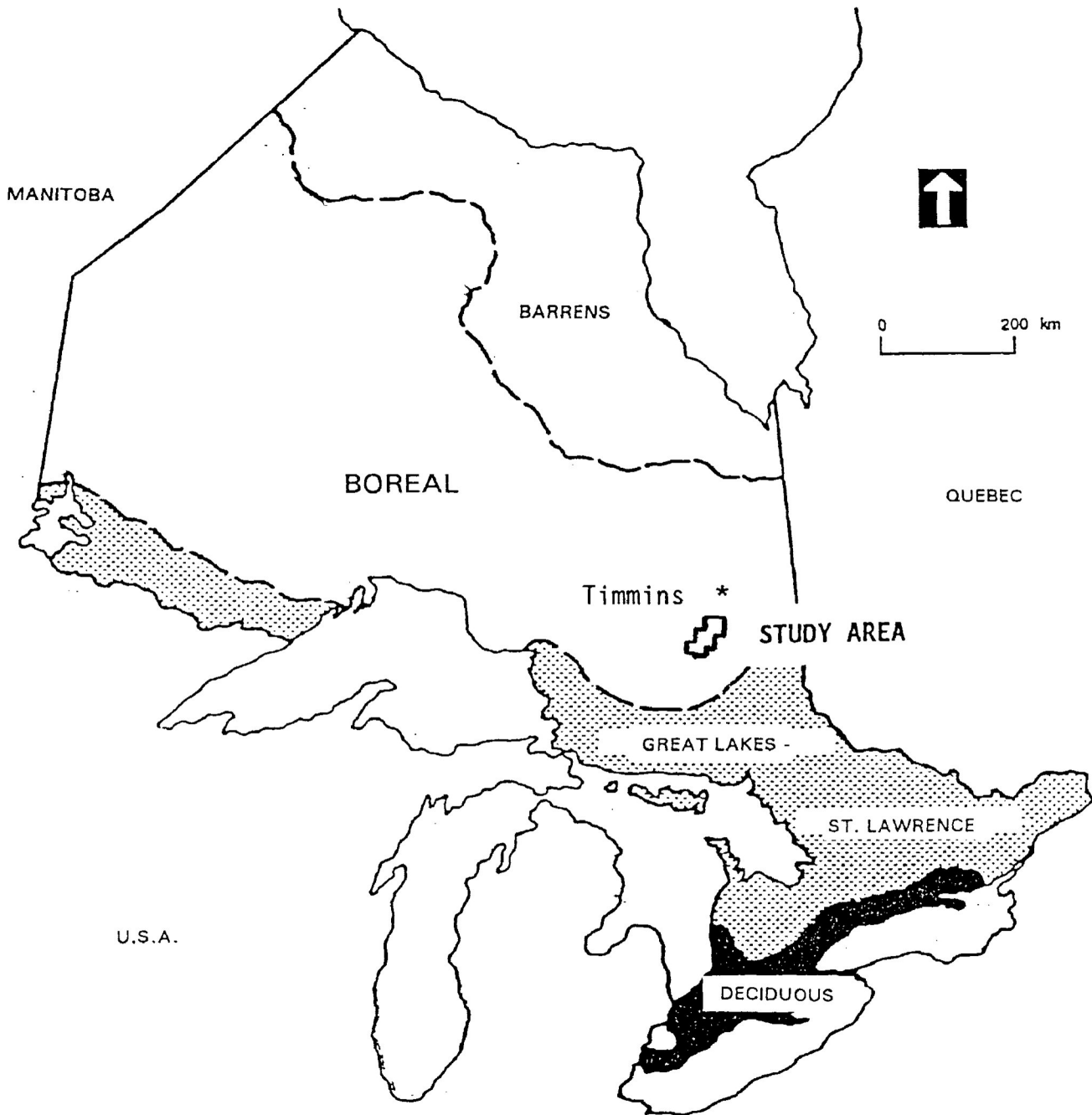


Figure 4. Study area situated in Ontario's boreal forest, located south of Timmins, Ontario.

Table 1. Present area classification of the Timmins Forest.
Source: QOPC, 1992.

Class	Area (ha)	%
Water	12,215	6
Non-forested	1,265	1
Forested		
Non-productive	15,634	8
Productive	160,378	85
Total	189,492	100

Table 2. Summary of productive forest area by working group for the Timmins Forest as of 1993.

Working Group Species	Area (ha)	%
White spruce (Sw)	3,000	2
Black spruce (Sb)	71,375	45
Balsam fir (B)	27,457	17
White cedar (Ce)	2,000	1
Other conifer (OC)	100	0
Jack pine (Pj)	21,842	14
Red pine (Pr)	100	0
White pine (Pw)	200	0
Poplar (Po)	21,651	13
White Birch (Bw)	12,553	8
Other hardwood (OH)	100	0
Total	160,378	100

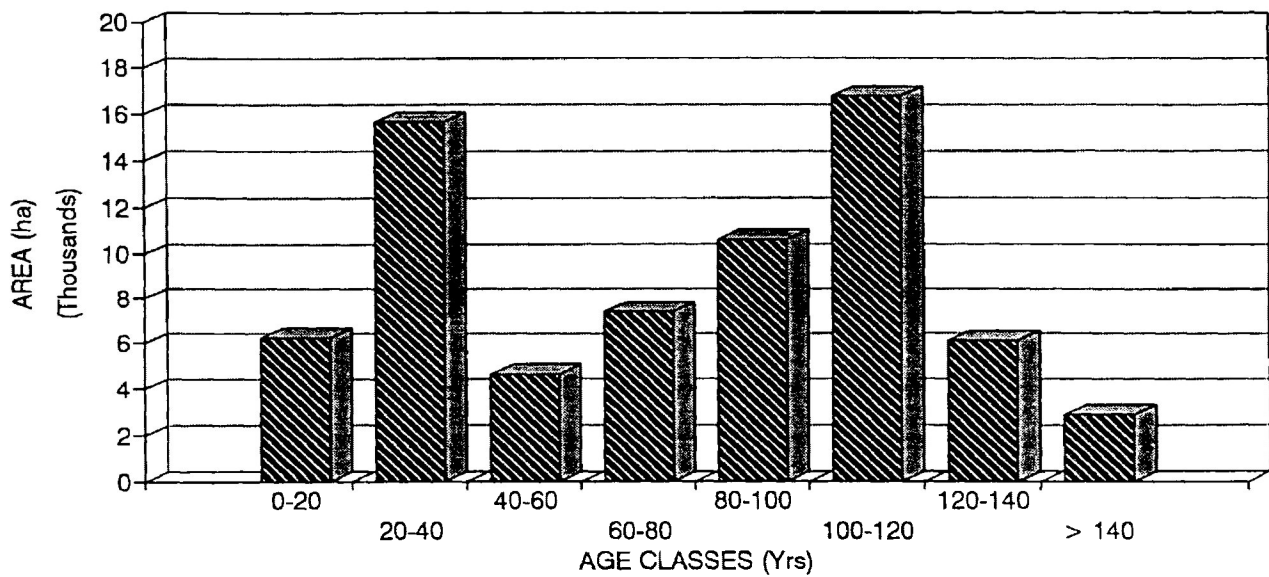


Figure 5. Black spruce working group age class structure in 1993.

FOREST DISTURBANCE

Evidence indicates that most of the Timmins Forest burned in the mid to late 1800's (QOPC, 1992). Several large fires again burnt the southern portions of the area between 1920 and 1939. In the mid 1970's, the forest was devastated by an Eastern Spruce Budworm (*Choristoneura fumiferana*) outbreak which resulted in virtually all balsam fir on the licence dying prior to 1980 (QOPC, 1992). Today, the former balsam fir stands (which were not silviculturally treated) are regenerating to a mixedwood type dominated by

hardwood with, in many cases, a balsam fir understory 2-3 metres in height (QOPC, 1992).

The first timber harvests in the Timmins area occurred around 1911 in response to the local mining industry's requirement for structural timbers (QOPC, 1992). In 1982, the Quebec and Ontario Paper Company (now called QUNO Corp.) signed a Forest Management Agreement (FMA) with the OMNR governing the management of the Timmins Forest to produce successive crops of timber on a sustainable yield basis. The FMA entered its third five-year term in 1993. Since the signing of the FMA, QUNO Corp. has harvested a total of 10,814 ha of the conifer working groups. Timber harvest is directed towards cutting the oldest stands first, in an effort to minimize volume loss due to stand decline. The majority of the timber harvests are clearcuts.

SILVICULTURAL PRACTICES

Since the signing of the FMA, QUNO has reforested 12,851 ha (including Not Satisfactorily Regenerated (NSR) areas) primarily by artificial regeneration (QOPC, 1992). Plantations of black spruce, white spruce and jack pine have been established throughout the forest using a variety of silvicultural regimes (see Table 3).

Table 3. Silvicultural regimes used to regenerate the Timmins Forest since the FMA came into effect. Source: QOPC, 1988.

Renewal and Maintenance Class	Description
Intensive	- Up to 2 S/P and planting - Tending before FTG, possible one after
Basic	- 1 S/P and seeding or natural regeneration - 1 tending as needed before FTG
Extensive	- Left for natural regeneration; no enhancement

where:

S/P = Site Preparation for planting

FTG = Free To Grow, meaning when trees have become established on a site

Modified Logging

Recently, there has been a movement away from the conventional system of low-cost timber harvest methods combined with high-cost site preparation, planting, and tending, towards a process termed modified logging which combines higher-cost harvesting techniques with less site preparation and planting (QOPC, 1992). Modified logging preserves existing advanced coniferous growth as much as possible. Modified logging will only occur in stands with: (1) primarily conifer composition; (2) smooth terrain; and (3) existing advanced coniferous growth. Timber harvest machines are confined to specific travel-ways, allowing non-merchantable trees, occasional seed

trees, and advanced growth to be left undisturbed in leave strips (see Figure 6). It is expected that the advanced growth and seed will contribute to stocking the site, with possible planting in the travel-ways to ensure full regeneration.



Figure 6. View from within a harvest trail in an area of modified logging.

CHAPTER 5

METHODS

TOOLS SELECTED FOR ANALYSIS

A Geographic Information System (GIS)-based simulation was selected over conventional field work as the procedure to follow in this study for several reasons, including: (1) it was the only procedure that suited the objective, the time frame, and the proposed budget of the study; (2) it could satisfy the time and space scales of the study objective; and (3) results from a GIS-based simulation model could be used to pinpoint where more research and field work were necessary to improve the model and thus improve understanding.

ARC/INFO (Revision 6.0) developed by the Environmental Systems Research Institute (ESRI), Redlands, California, running on a Sun workstation, was the GIS system used. HSG was developed with linkages to ARC/INFO, thus facilitating data preparation. The GIS facilities of the Lakehead University Centre for the Application of Resource Information

Systems were used.

HSG was chosen as the wood-supply model for this study principally because: (1) it has automated linkages to spatial databases, essential for modelling the spatial elements of marten relations to habitat; and (b) HSG was initially tested on a forest adjacent to the Timmins Forest, so its successful application in the study area was facilitated. In addition, the creators of HSG (Moore and Lockwood, 1990) offered assistance and support in this study.

FOREST RESOURCE INVENTORY DATABASE

This study utilized the digital Forest Resources Inventory (FRI) developed by the OMNR. The FRI data that can be used for habitat modelling are the same data currently used in wood-supply analyses (Greig *et al.*, 1991). At the present time, habitat modelling for forest wildlife species in Ontario must rely upon the FRI (Watt, 1991), as other databases are not yet complete or in digital format.

The FRI was designed to provide estimates of standing timber volume at regional levels (Watt, 1991). However, the FRI is currently used to

forecast timber supply in Ontario at the level of the individual forest management unit. The FRI provides stand-level information required as a basis for timber management planning (OMNR, 1978). The FRI is created mainly through the use of aerial photo-interpretation. A small amount of ground sampling is carried out to establish the validity of the type designation of the polygons (Baskerville, 1986).

The OMNR defines a stand in the FRI as an aggregation of trees possessing sufficient uniformity in composition, structure, and age arrangement or condition distinguishable from adjacent forest types (OMNR, 1978). The average minimum size of a stand classified by the FRI is 8 ha. The stand attributes used in this study were: (1) stand number and area; (2) species composition and working group; (3) age; (4) stocking; and (5) site class.

Species composition is indicated by species symbols followed by their percent proportion in a stand (OMNR, 1978). Working group refers to the dominant species within each forest stand. Stand age refers to the actual age of the major species in the stand.

Stocking is determined by dividing the actual basal area by the normal basal area, as obtained from the appropriate site class in the normal yield table, and is expressed as a decimal to one place (OMNR, 1978). Values

range between 0.3 and 1.0 in increments of 0.1 where 1.0 represents a 100% fully stocked stand. Some mixed stands may be overstocked (OMNR, 1978). A stand with stocking below 0.25 is classed as barren and scattered and treatment is required to restore these areas to productivity (Williams, 1987).

Site class is an indicator of growth rates of the working group species in the stand, and reflects a relationship between height and age at the time of inventory (OMNR, 1978). The FRI distinguishes five site classes (X, 1, 2, 3, and 4) with site class X representing the most productive sites and site class 4 representing the least productive sites. Generally, for a given age, the taller the tree, the better the site class (Jackson *et al.*, 1991).

The FRI is an inventory of the type, volume and extent of the timber resource of a management unit based on aerial photography (Jackson *et al.*, 1991). It is subject to: (a) errors in the measurement of trees (i.e. species composition and stand age) and stands (i.e. stand area); (b) sampling error because of the small proportion of the forest actually sampled; and (c) an imperfect correlation between the items measured (i.e. diameter, height) and the answers desired (i.e. volume, growth) (OMNR, 1978). However, the FRI provides a reasonable approximation of forest stand boundaries, tree species composition, stand age, height, and

stocking (Jackson *et al.*, 1991) for both habitat and wood-supply analysis.

DATABASE PREPARATION

The Timmins Forest FRI database is based on 1971 and 1981 inventories, updated by the OMNR in digital format for 1993 to include areas harvested since the inventory. As noted earlier, the Timmins Forest was subjected to a spruce budworm epidemic in the 1970's. Many of the stands that were attacked then are in the latter stages of decay now, although the database did not account for this. Therefore, stands in the inventory with a working group of balsam fir and age greater than 35 years old in 1993 were assigned a stocking of 0.2 for this study. A new stocking of 0.2 replaced the original stocking values assigned prior to the infestation. This more accurately represented these stands in the FRI and consequently lowered their value as marten habitat. In doing this, I may be underestimating the value of these stands for marten habitat.

In creating data files from the polygon attribute file, the OMNR has rounded the area of each stand such that area ≤ 0.4 ha equals 0 ha and area ≥ 0.5 ha equals 1.0 ha. This rounding of stand area has increased the total area of the Timmins Forest by approximately 3,000 ha. When the forest

inventory is converted from polygon to raster format, the total forest area is again increased by approximately 2,000 ha as grid cells along the boundary of the forest overlap. These exaggerations affect the amount of area forecast in each HSI class; however, these increases apply similarly to each simulation and they do not influence the determination of impact. Correcting these problems, although possible, would have required a substantial programming effort and was determined unnecessary in this study.

YIELD CURVES

Pure species yield curves depicting Net Merchantable Volume (NMV) for natural stands in the Timmins Forest, along with operability limits specifying merchantable volume in terms of minimum age and volume requirements, were provided by the OMNR, Timmins District (Appendix III). The curves were based on regional curves and edited to reflect volumes coming from the Malette and Timmins Forest FMA's using scaling data, annual reports and local knowledge (Williams, 1993). They were further refined by comparisons with timber cruising data from the Timmins Forest, Timmins Crown, and Malette Management Units (Williams, 1993). The curves were also tested by a contractor comparing the curves to cruise

data, and they were found to be reasonably accurate (Williams, 1993).

Plantation-yield curves were created for this study for black spruce and jack pine simply by shifting the yield curves for natural stands ten years earlier. Plantation yield curves structured on this basis may be considered conservative as they do not alter the shape of the curves or increase the volume peak. However, few data exist to predict future stand development on the basis of present stands in the context of a managed forest (Williams, 1987).

OPERATIONAL DESCRIPTION OF HARVEST SCHEDULE GENERATOR

HSG is a wood-supply model that operates by tracking the development of individual forest stands through time and space (Moore and Lockwood, 1990). To keep track of individual forest stands, it makes use of a relational database in a GIS. The relational database management system in the GIS provides a link between the stand records and the spatial descriptions of stand location. Maintaining the spatial identity of stands improves the forecasting system in two ways: (1) detailed stand-level data can be provided to the growth forecasting procedure; and (2) harvest allocation and silvicultural treatment are defined on a stand-by-stand basis.

Operation of HSG involves several steps, represented in Figure 7. The first step in using HSG for wood-supply analysis is the conversion of the FRI database into an acceptable format for HSG. In the database, each forest stand's original species composition is separated into individual species (sub-components), each with a separate site class, stocking and age. Individual stocking for each sub-component is the product of the original stocking and species composition for each species.

Aging and incrementing of time are simulated by advancing a clock internal to the model. This time step advances the age of each stand to the new date. After each time step has occurred, the model evaluates each stand description and records the changes that occurred since the previous period. Silvicultural and successional rules located in a state table (Appendix IV) are used at this stage in the simulation to describe changes caused by succession and silviculture.

Stand yields are then determined for the updated stand inventory. Yields are calculated independently for each stand sub-component using age and site class as the index to the yield curves. The value retrieved from the yield curve is multiplied by the sub-component stocking to provide the current sub-component yield.

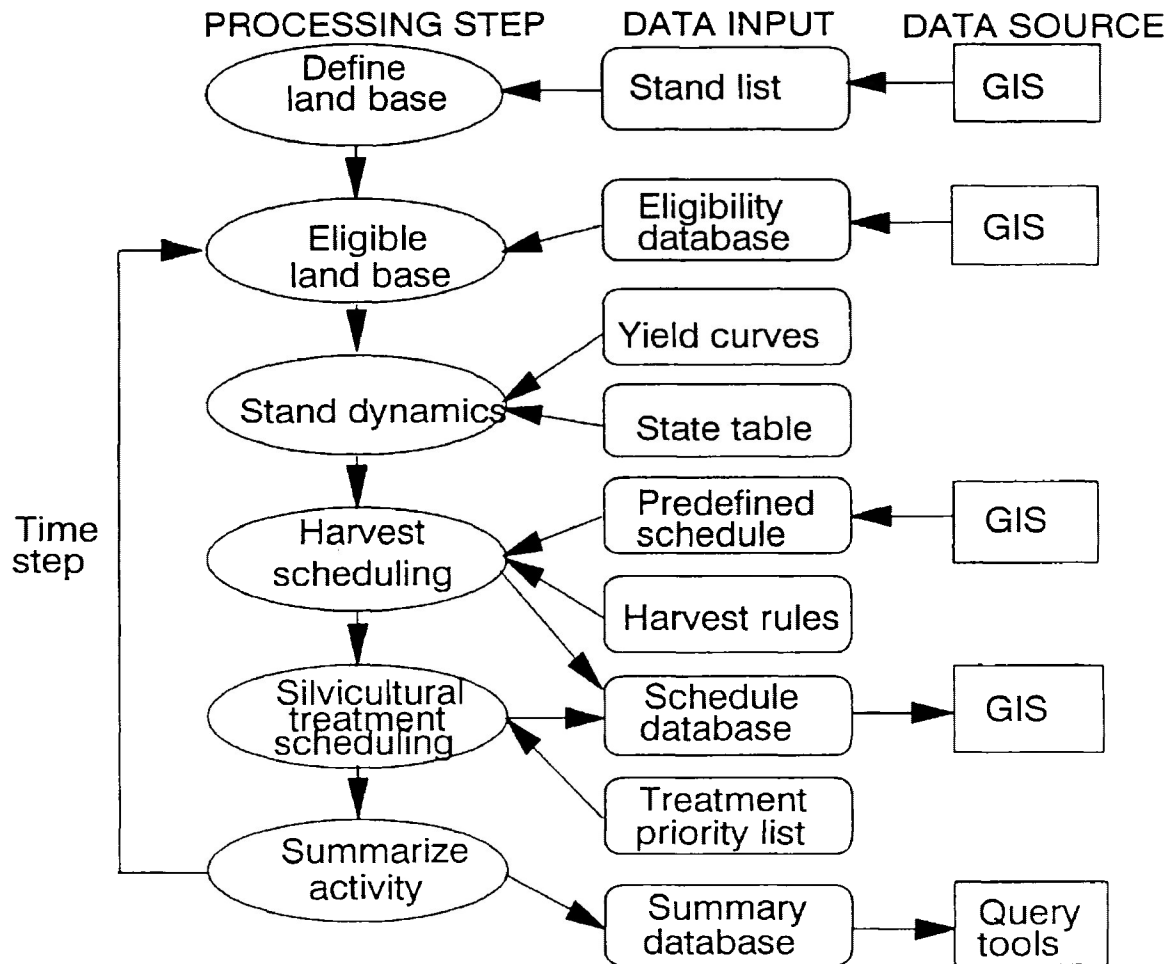


Figure 7. Flowchart of operations within HSG (Moore and Lockwood, 1990).

The final stage in the update process checks each stand against an eligibility database. This database provides the opportunity to specify when individual stands or groups of stands become ineligible or re-eligible for harvest.

Once the inventory has been updated to the current age, new yields have been calculated and the state table checked for stand break-up, harvest simulation begins. The harvest scheduling process begins by applying the pre-defined harvest schedule (a list of stands to be harvested, sorted by the year when harvest is to take place) if specified. Next, HSG schedules stands for harvest in order to satisfy user-defined harvest quotas, according to the user-defined harvest rule and operability limits (see Appendix V for rules in activity file). Minimum operable volume limits may be specified for both the stand and the individual species being harvested.

After harvest scheduling is complete, HSG simulates the allocation and scheduling of silvicultural treatments. The silvicultural and successional rules of the state table describe regeneration alternatives and new stand conditions that would result from the application of a treatment. Stands to be silviculturally treated in the current simulation are sorted and treated according to user-specified treatment priority lists (Appendix VI).

The treatment priority lists contain records specifying the order of treatments to be applied to stands with specific working group and site-class combinations. When the stand update process encounters a stand with a "CLEARCUT" disturbance code, it searches the state table for a matching working group, site-class and treatment code, and when a match is found the action part of the rule is applied. Stands are treated in order of appearance on the treatment priority list until a limit on treatable area has been exceeded. If harvested stands do not match records in the treatment priority list, or the treatable area limit is reached, they default to extensive silviculture.

Outputs of HSG simulation results are generated in three formats: (1) summary files for non-spatial, graphical information; (2) schedule files, for a stand-specific description of harvest and treatment; and (3) maps of future forest inventories to be displayed and manipulated in the GIS environment.

DATASET PREPARATION FOR HSG

One state table was developed for this study (Appendix IV), based on an original state table provided by Moore and Lockwood (1990). The rules of the state table embody an empirical understanding of successional patterns

of stand development. Thus, the original state table was altered by QUNO Corp. foresters to reflect better the Timmins Forest, and further modified to operate in this study.

Rules for modified logging were incorporated into the state table under basic silviculture for black spruce on site classes X, 1 and 2. Ages were advanced to 20 and 25 years for stands with < 30% poplar composition, to simulate a more rapid stand initiation phase due to advanced regeneration. Stands resulting from modified logging in areas with a zero percent poplar component will develop with 30% or 40% of the stand as spruce with an age of zero. This simulates area that is planted as it has no advanced regeneration. The majority of the stand regenerates at 20 or 25 years to simulate advanced regeneration. This will simulate modified logging, creating an uneven-aged stand with a reduced period to maturity, requiring less artificially regenerated area. The delay of natural regeneration may be shortened when advanced growth is left healthy after logging. A further benefit of retaining advanced growth is the preservation of the moss layer and shade, together providing ideal moisture conditions for young spruce (Williams, 1987).

Two treatment priority lists were developed for this study. The first attempted to simulate the future of silviculture in the Timmins Forest. It

relies less on conventional intensive silviculture and more on basic silviculture (modified logging). Stands with site class X receive intensive silviculture but stands with site classes 1 and 2 receive basic silviculture. Stand conversion is not considered with this "basic" silviculture treatment priority list. The second "intensive" treatment priority list combines both intensive silviculture and modified logging with stand conversion in an attempt to regenerate a forest for both timber and wildlife habitat.

WOOD-SUPPLY ANALYSES

Nine 100-year timber management strategies were developed for the study (see Table 4). The actual QUNO Corp. five-year (1993-1998) management plan scenario was the only schedule developed with a pre-defined schedule file. In the remainder of scenarios in this study, HSG scheduled productive stands for harvest regardless of spatial location. This was justified on the basis that: (1) QUNO Corp. harvests timber across the FMA and does not focus solely on one particular area for all of their volume requirements in a five-year term; (2) the determination of operationally feasible harvest blocks in the future (let alone individual stands) becomes an increasingly difficult and iterative process; and (3) the road layout in the Timmins Forest is extensive and most areas are accessible, therefore the majority of stands

selected for harvest by HSG would be accessible.

Over the short term, the HSG harvest schedules may not truly represent the harvest patterns of the QUNO Corp., although the harvested volumes are similar. However, over the long term, as more stands are harvested, the degree of similarity between HSG simulated harvest patterns and actual QUNO Corp. timber harvest patterns becomes less of an issue as the majority of stands scheduled for harvest by HSG would likely be harvested by QUNO Corp. within a similar timeframe.

For all timber management scenarios run in this study, only stands with a site class 4 were labelled as ineligible for harvest. An operability minimum of 40 m³/ha for any stand to be harvested was used in all scenarios. The harvest rule used in all timber-harvest scenarios minimized volume loss. Harvest volumes were specified on an even-flow basis.

The silvicultural area limits set for this study were either 0 ha, 770 ha or unlimited area, depending upon the scenario used. The 770 ha is based on previous planting and seeding patterns in the Timmins Forest. The area to be treated artificially in the future is expected to decrease with decreasing funding. However, with modified logging, the entire area harvested is considered treated with basic silviculture by HSG, although only a portion

of it needs to be artificially regenerated.

Conventional harvest levels used in this study were determined from averaging actual 1985-1991 QUNO harvest volumes. Poplar harvest volumes were increased to 30,000 m³/year due to recent mill demands from the Timmins Forest (Williams, 1993). Minimum volume (m³/ha) requirements for each species harvested were set according to the operability limits in Appendix III.

One scenario was created to simulate the harvest and treatment of stands actually scheduled for harvest by QUNO Corp. for the 1993-1998 management period (QUNO, 1993). As QUNO Corp. only schedules stands to be harvested for the next five-year term, this was the only truly spatial harvest scenario. Otherwise, HSG chose which stands were to be harvested according to harvest rules.

Table 4. Specifications of the forest-management scenarios.

Scenario Name	Annual Harvest Levels			HSG specifications		
	Poplar (Po) m3/yr	Pine (Pj) m3/yr	Spruce (Sb/Sw) m3/yr	Treatment Priority List	Silviculture Treatment Area (ha/yr)	Yield Curve File
NOHARVEST	0	0	0	-----	-----	C1
EXTENSIVE	30,000	36,000	57,000	-----	Unlim.	C1
BASIC	30,000	36,000	57,000	Basic	770	C1
INTENSIVE	30,000	36,000	57,000	Intensive	Unlim.	C1
SPRUCE + 10	30,000	36,000	62,700	Intensive	Unlim.	C1
DELAY-10	30,000	36,000	51,300	Basic	770	C2
SPRUCE-10	30,000	36,000	51,300	Basic	770	C1
SPRUCE-20	30,000	36,000	45,600	Basic	770	C1
QUNO	43,002	36,031	53,681	Basic	770	C1

Where:

Sb = Black spruce
Sw = White spruce
Pj = Jack pine
Po = Poplar
C1 = Pure species original yield curves
C2 = Altered black spruce yield curves

NOHARVEST = No Harvest/no silviculture
EXTENSIVE = Conventional harvest/extensive silviculture
BASIC = Conventional harvest/basic silviculture
INTENSIVE = Conventional harvest/intensive silviculture
SPRUCE + 10 = Increase Sb/Sw conventional harvest levels by 10%
DELAY-10 = Delayed harvest of mature black spruce stands
SPRUCE-10 = Decrease Sb/Sw conventional harvest levels by 10%
SPRUCE-20 = Decrease Sb/Sw conventional harvest levels by 20%
QUNO = 1993-1998 QUNO Corp. stand allocation

DEFINITIONS OF HARVEST SCENARIOS

NOHARVEST

The NOHARVEST scenario simulates growth of the forest without timber harvest (and, of course, without natural disturbances because these cannot be easily simulated with HSG). Only the successional rules in the state table guide the growth of the forest. In reality, natural disturbances act to regenerate forests and create young age classes. Succession without disturbance means that many stands can remain the same in perpetuity, which may not be realistic in the boreal forest. Other species which rely on disturbance to recur in the forest (e.g. jack pine) eventually disappear from the forest over a 100-year simulation. However, in the short-term this scenario can serve as a reasonable baseline comparison with other scenarios. Over the long-term it is a useful comparison, not of the true forest structure, but of the model forest structure, and can aid in understanding of the results of various scenarios.

EXTENSIVE

The EXTENSIVE harvest scenario was developed to determine the impact of timber harvesting at conventional levels followed by extensive silviculture, on the suitability of future marten habitat. Several harvest

strategies have been developed to simulate different types of silvicultural treatments and they can be compared to this scenario.

BASIC/INTENSIVE

The BASIC AND INTENSIVE scenarios were developed to compare results from application of the two different treatment priority lists used throughout the analysis. BASIC uses a treatment priority list that employs basic silviculture with a silvicultural treatment level of 770 ha, while INTENSIVE applies more conventional, intensive silviculture on unlimited area. Both of these scenarios use conventional harvest levels.

SPRUCE + 10

The SPRUCE + 10 scenario is similar to INTENSIVE except that the conventional spruce harvest levels have been increased over the entire forecast by 10%. The treatment priority lists and silvicultural treatment levels are the same.

DELAY-10

The DELAY-10 scenario attempts to confine the black spruce timber harvest to mature or very overmature stands, temporarily leaving overmature stands that have a high value for marten habitat. As those stands approach the final stages of overmaturity, they become eligible for

harvest. To simulate this, the original yield curves for black spruce were altered (see Figure 8). Setting the volume to zero for a 20-30 year period in site classes 1, 2 and 3 effectively forces the harvest algorithm to skip these stands during this period. To maintain even-flow sustainable harvest levels using this scenario, the spruce annual harvest levels had to be decreased 10% below conventional levels.

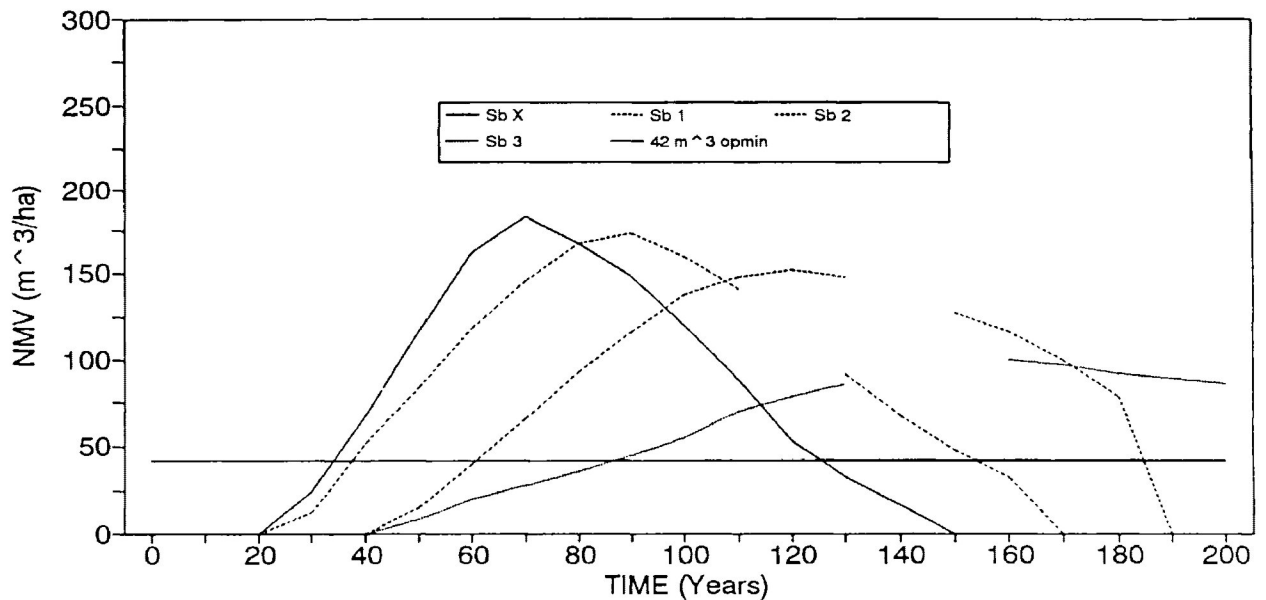


Figure 8. Altered black spruce NMV yield curves operating in conjunction with the DELAY-10 scenario. Gaps in the curves indicate the ages when stands tracking these curves cannot be harvested.

SPRUCE-10/SPRUCE-20

The SPRUCE-10 and SPRUCE-20 scenarios were created to simulate long-

term reductions in the conventional harvest levels of spruce by 10% and 20%. They were developed to be used in impact comparisons with DELAY-10 and BASIC. The only difference between the SPRUCE-10, SPRUCE-20 and BASIC scenarios is the lowering of the spruce harvest level. Therefore, the effects of this action on marten habitat should be obvious.

QUNO

The QUNO scenario harvests timber according to a user-defined harvest schedule created for the 1993-1998 term by QUNO Corp. Harvest volumes are similar to those based on past averages. The treatment priority list designed to simulate modified logging is used along with an annual silvicultural treatment area of 770 ha.

MARTEN-HABITAT MODEL DESCRIPTION

The marten habitat model was designed to account for winter habitat of female marten. Habitat is considered for the purposes of this model to include, food, cover, reproductive sites and spatial influences. Broad definitions of habitat may include other factors such as competition or climatic interactions (Schamberger and O'Neil, 1988), but these factors

have been excluded from this study as incorporating them would be too complex.

Effective Working Groups

To simplify assessment of habitat suitability, I aggregated each FRI stand into three possible forest types representing species with similar morphological characteristics. These are termed "Effective" Working Groups (EWG) in this study. The dominant EWG had to be chosen for each stand. Where species composition was equal between EWGs, the EWG was determined in order of SPRUCE, PINE, then HARDWOOD. The EWGs include the following FRI working groups:

- | | | |
|------------------|---|-----------------------|
| (1) SPRUCE EWG | = | Sb + Sw + B + Ce + OC |
| (2) PINE EWG | = | Pj + Pr + Pw |
| (3) HARDWOOD EWG | = | Po + Bw + OH |

Habitat Rating

HSI calculations were performed for each stand in the FRI, rating each stand from 0.1 to 1.0. All other areas without a tree species composition (i.e. treed muskeg, open muskeg) received a rating of 0.1. Water was not classified as habitat (although it is frozen in winter and may be crossed by marten).

The habitat suitability indices are classed according to this index:

0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
POOR			MODERATE				OPTIMAL		

For this study, the habitat suitability index is considered an interval scale.

A scale is called an interval scale because the intervals between categories are identical (Bryman and Cramer, 1990). On an interval scale the zero point is arbitrary, thus it is not possible to determine ratios. An important characteristic of interval scales is that they can be added, subtracted, multiplied and divided (Young and Veldman, 1972). Therefore, it is mathematically permissible to determine the geometric mean of indices from this scale.

Cover

Cover requirements as depicted by the model are determined for each stand with the updated information created by HSG. Cover calculations are made using stocking, species composition, and age of a forest stand.

These three variables represent the cover requirements of marten in the model. Relationships have been developed to determine index values based on each of these variables in combination for a particular stand. The highest index value that each variable can contribute to an equation is 0.9 and therefore the highest HSI value any stand can receive is 0.9.

However, a denning/resting bonus of 0.1 can be added to stands that meet certain requirements of species composition and age.

Stocking (S1)

Stocking is a measure taken directly from the forest inventory for each stand. Stocking is used in combination with the EWG to obtain a suitability index value of the stand's canopy cover (Figure 9). Good canopy cover is dependent not only on the stocking of the stand being acceptable, but also on the species' morphology. Stands with adequate main canopy cover benefit marten in many ways.

Species in the SPRUCE EWG maintain their canopy cover throughout the winter and provide main canopy cover both in high and low stocked stands. If stocking falls below 0.3 then the stand is considered barren and scattered by the FRI and contains no stocking value in the original inventory. However, I assigned balsam fir stands a stocking of 0.2 as these stands can still provide minimal cover for marten. Species in the PINE EWG maintain their needles throughout the winter but provide only moderate canopy cover and this usually occurs only in well-stocked stands. Species in the HARDWOOD EWG lose their leaves over winter and provide minimal canopy cover. However, in well-stocked stands some cover is afforded, compared to an open site.

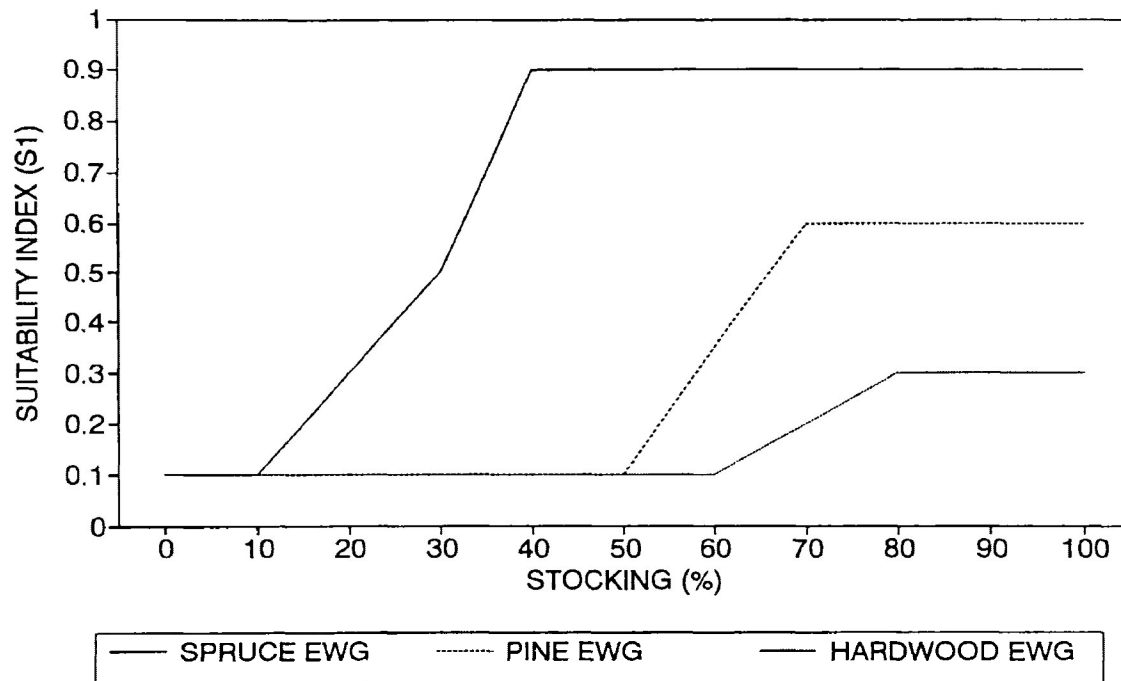


Figure 9. Stacking curves used in marten cover equations.

Species Composition (S2, S3, S4)

Relationships were developed to rate each forest stand depending upon its species composition. These relationships represented in Figure 10 and Figure 11 were designed to function as one variable in a cover equation. Comparisons of Figure 10 and Figure 11 do not produce meaningful results. Figure 10 was designed to increase the final cover value for PINE/HARDWOOD EWG stands dependent upon the amount of SPRUCE EWG they contained. All other variables in the cover equation for PINE/HARDWOOD EWG stands are less optimistic. Figure 11 was

designed to decrease the resultant cover value for SPRUCE EWG stands, as the other variables in the cover equation for SPRUCE EWG stands will tend to increase the final value.

If a stand was classed as either PINE EWG or HARDWOOD EWG, its rating was improved dependent upon the amount of SPRUCE EWG within its species composition (Figure 10). Generally, a PINE-SPRUCE EWG mix was considered more suitable for marten than a HARDWOOD-SPRUCE EWG mix. If a stand had zero percent SPRUCE EWG, it received a value of 0.1.

If a stand was determined to be of the SPRUCE EWG, its rating was decreased depending upon the amount of PINE EWG or HARDWOOD EWG present in the stand (Figure 11). Again, a SPRUCE-PINE EWG mix was considered more suitable for marten than a SPRUCE-HARDWOOD EWG mix. If a SPRUCE EWG stand contained both PINE EWG and HARDWOOD EWG, then the lower value of the two was used in the equation. If a SPRUCE EWG stand had zero percent PINE EWG or HARDWOOD EWG, it would receive a value of 0.9 for S3.

If a stand was classed as 100% SPRUCE EWG and was composed of > 70% black spruce, it received a minor penalty (Figure 12). This rule was developed because pure black spruce stands lack some of the optimal

qualities for marten. Pure black spruce stands tend not to provide the structure of other desirable conifers or of a coniferous mix. The minimum value that a SPRUCE EWG stand could receive under this rule was 0.6.

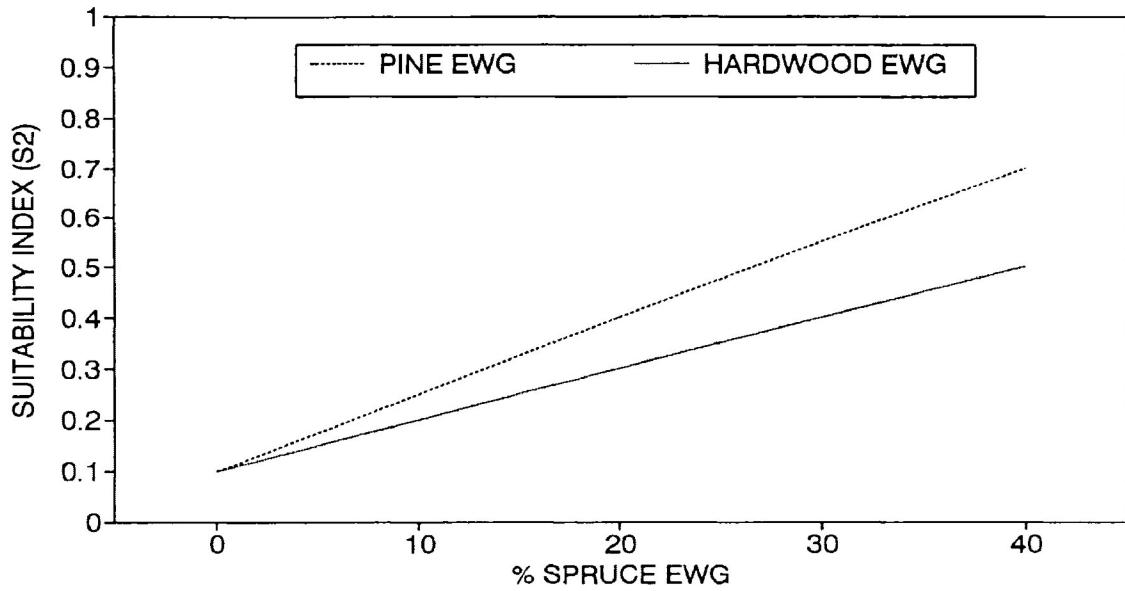


Figure 10. Percent spruce in pine/hardwood stands.

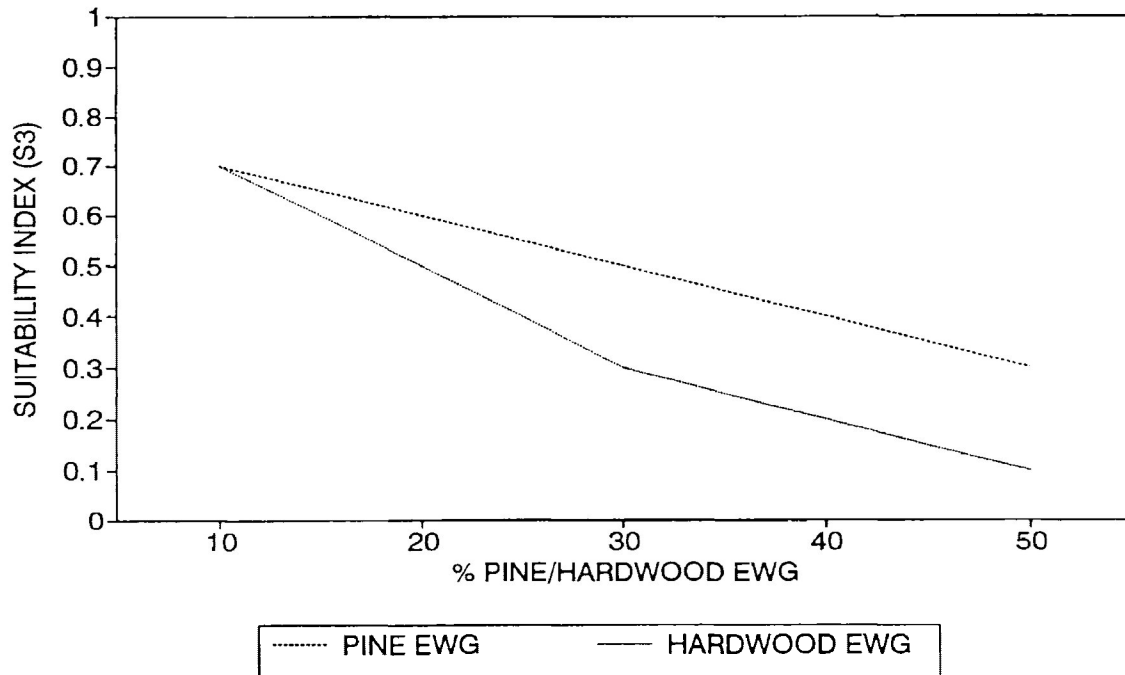


Figure 11. Percent pine/hardwood in spruce stands.

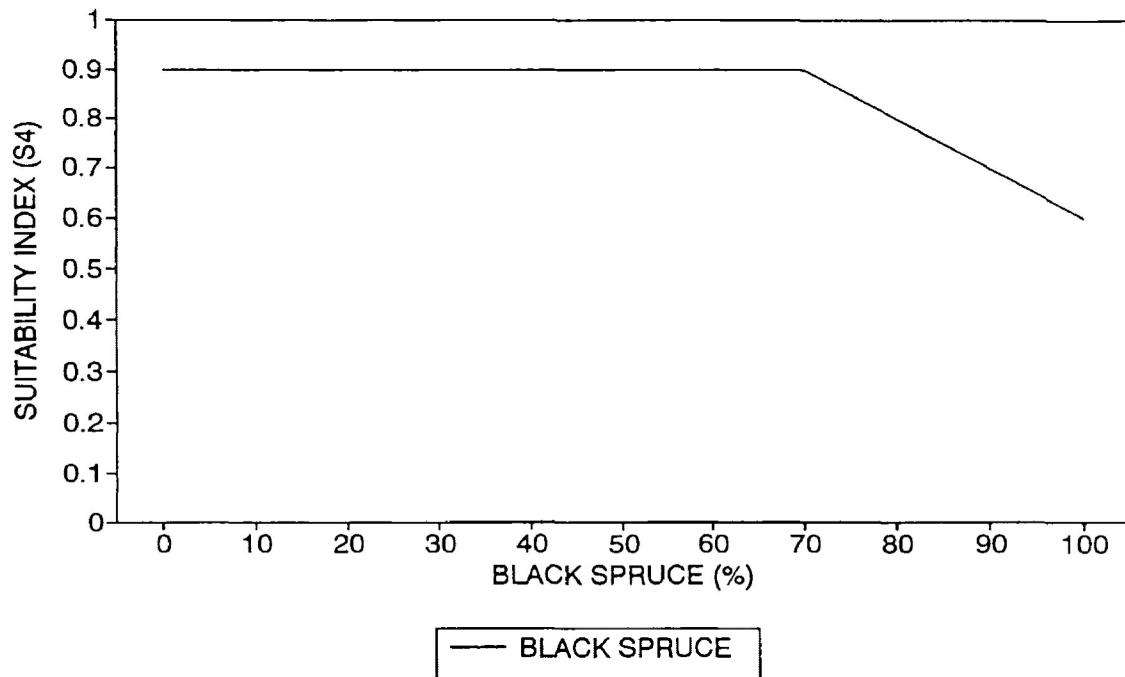


Figure 12. Percent black spruce in 100% Sb/Sw/B/Ce stands.

Age (S5)

Relationships were developed depicting for each EWG the age and suitability of stands in providing cover for marten (Figures 13 and 14). Age was used to represent a whole suite of assumptions about different site types. Because of its importance, age is given a weighting of two in the cover equations. Curves for the SPRUCE EWG were developed for each site class with the help of the pure species yield curves for black spruce. SPRUCE EWG stands on site class X, that contain < 80% black spruce and have optimum stocking, are rated as suitable at an early age as these stands are highly productive. On the other hand, balsam fir stands with

low site classes will not rate high on the SPRUCE EWG age curves as they experience stand break-up prior to the optimum index value being reached. Due to their morphology, PINE/HARDWOOD EWG stands do not provide ideal cover in winter. However, some form of shade-tolerant advanced regeneration will likely be present in these stands and their marten habitat characteristics will improve slightly as they age.

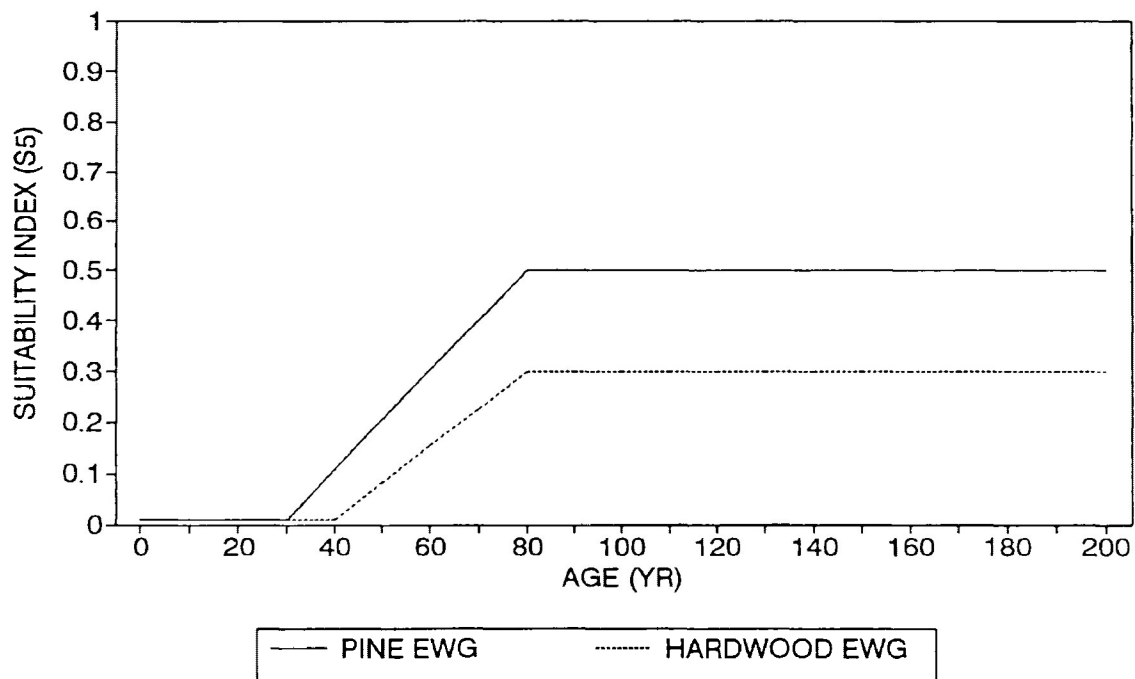


Figure 13. Age suitability in pine/hardwood stands.

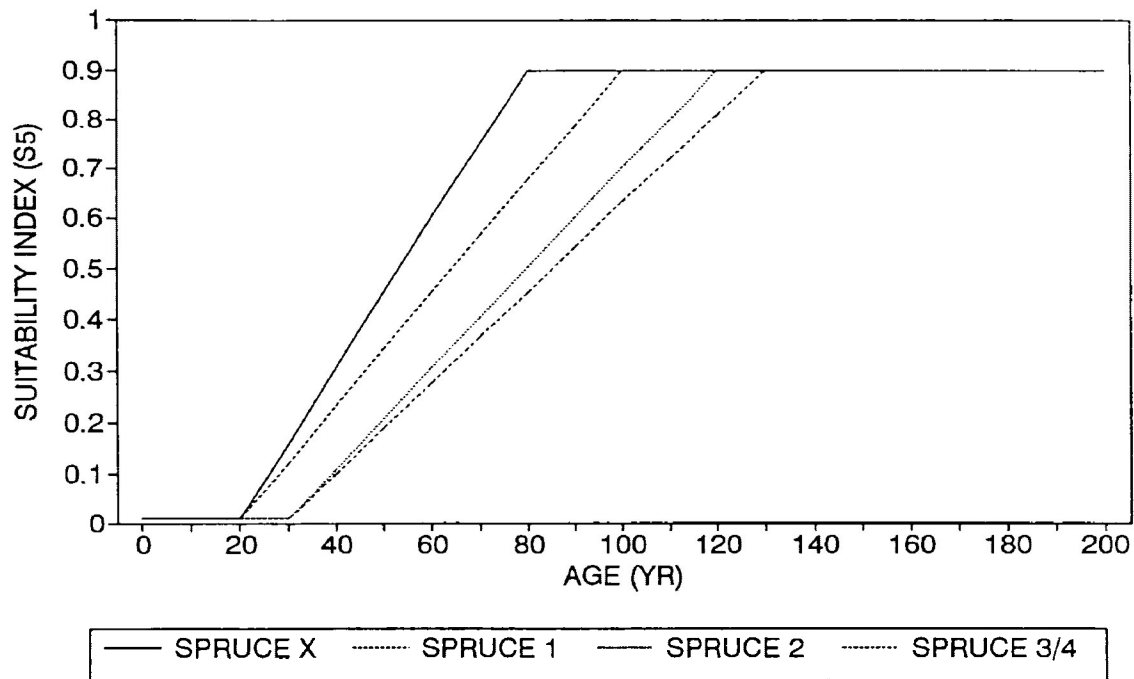


Figure 14. Age suitability in spruce stands.

Denning/Resting Bonus (S6)

Denning and resting bonuses are based on ages when stands are in decline, and were developed using timber yield curves (see Table 5). A stand must be of the SPRUCE EWG and white spruce or cedar must be $\geq 20\%$ of the SPRUCE EWG composition. 100% SPRUCE EWG stands with $> 70\%$ black spruce do not qualify for the bonus. Minimum age limits were chosen for white spruce and cedar stand types for each site class. If a stand type falls within this age class, it is rewarded with a bonus of 0.1 (added to its cover value). This bonus represents a stand that may be selected by marten because of its structural characteristics related to

denning and resting needs.

Table 5. Age and site-class requirements for SPRUCE EWG stands with a minimum of 20% Sw/Ce to receive a bonus.

Site Class	Age (\geq)
X	100
1	110
2,3,4	120

Cover Equations

The cover index (CI) for each stand is determined with these equations:

- (1) If EWG = PINE or HARDWOOD
then $CI = [S1 \times S2 \times S5^2]^{1/4}$
else
- (2) If EWG = SPRUCE, and PINE and HARDWOOD = 0 and $S_b > \%70$
then $CI = [S1 \times S4 \times S5^2]^{1/4}$
else
- (3) If EWG = SPRUCE, and PINE > 0 and HARDWOOD = 0
or HARDWOOD > 0 and PINE = 0
then $CI = [S1 \times S3 \times S5^2]^{1/4} + S6$
else
- (4) If EWG = SPRUCE, and PINE and HARDWOOD > 0
then $CI = [S1 \times S3 \times S5^2]^{1/4} + S6$
where S3 = lower of two values
else
- (5) EWG = SPRUCE, and PINE and HARDWOOD = 0
then $CI = [S1 \times 0.9 \times S5^2]^{1/4} + S6$

where:

- CI = Cover Index (0.1 - 1.0) assigned to a stand
- S1 = Stocking (0.1 - 0.9)
- S2 = % Spruce in pine/hardwood stands (0.1 - 0.9)
- S3 = % Pine/hardwood in spruce stands (0.1 - 0.9)

S4 = % Sb in 100% Sb/Sw/B/Ce stands (0.1 - 0.9)

S5 = Age suitability (0.1-0.9)

S6 = Denning/resting bonus (0.1)

Food

Relationships and equations were developed for this study to identify potential snowshoe hare habitat (Appendix VII). Unfortunately, many regenerating areas in the Timmins Forest database are missing height and stocking information. HSG does not simulate height growth over time so this variable is unavailable regardless. For regenerating stands, often only species composition and age are available in the FRI. However, HSG attaches codes to each stand describing the type of disturbance and treatment that has occurred. Snowshoe hare habitat suitability of a stand will likely change depending upon the various disturbances and treatments applied. I developed relationships which depict changes to snowshoe hare habitat suitability using the variables age and species composition for two disturbances and four treatments. Snowshoe hare habitat is not treated as a limiting factor to marten habitat potential. Every forest stand in the inventory is subjected to an HSI calculation for hare. These HSI ratings are then used in a spatial analysis of potential marten habitat. Stands with a high HSI rating for hare can contribute to a stand's overall suitability for marten. Areas with no species composition are assigned a value for hare habitat of 0.1.

Final Habitat Suitability Index And Spatial Analysis

Spatial analysis of marten habitat initially involves changing the forest polygons into grid cells. GRID, a raster module integrated with ARC/INFO, was used to perform spatial analysis of marten habitat. GRID is based upon a combined grid-cell spatial model, and a relational attribute model. The GRID process drapes square 1 ha cells (100 m x 100 m) over the vector inventory and assigns a code to each cell identifying the cell location.

Although the smallest stand size delineated by FRI is approximately 8 ha (stand sizes are further reduced in the GIS), a larger cell size tends to oversimplify the final image. The 1 ha cell size accurately represented the irregularities of stand boundaries in the FRI. Also, the 1 ha cell size is well under the 1% of home range recommended by Schulz and Joyce (1992). Increasing the cell size tends to smooth the output and is not suited to a heterogeneous landscape such as the one used in this study.

Once the grid has been draped over the coverage, each grid-cell can retrieve the information of the stand that passes through the centre of the cell (using the centroid method). Therefore, each grid-cell picks up an HSI value for cover and food from the stand which it represents. The two

values of food and cover were combined for each cell to determine a final HSI value for each cell using the spatial analysis capabilities of GRID.

Neighbouring cells are compared with the cell in question to determine if they provide suitable adjacent cover, food, and denning or resting sites. A 5 x 5 cell window was placed over each cell in the database (see Figure 15), and a neighbourhood search was performed around each cell. The cell in question was rewarded in terms of increased marten habitat suitability if certain criteria were met and the neighbouring cells were of a higher habitat suitability.

The spatial analysis begins with the grid-cell at the upper-left of the image and proceeds systematically from left to right, top to bottom, over the entire forest. Because the 5 x 5 window does not average values within the window, it does not misrepresent cells around the boundary of the study area. The window only checks to see if neighbouring cells meet certain requirements to increase the cell in question, or whether to leave it unaffected. However, cells around the boundary can only be improved in this study from other cells within the boundary, and stands just outside the Timmins Forest may have a real affect on boundary habitat that is not represented in this analysis. The windows for cells along the boundary are smaller than 5 x 5 cells.

Final HSI Equations

The model calculates the final HSI for each *i*th cell as follows:

- (1) If $DEN_i = 0$ and $Cl_i \geq 0.7$ and $DEN_n = 0.1$ then $Cl_i = Cl_i + 0.1$
and,
- (2) If $Fli \geq 0.7$ and $Cl_i \geq 0.7$ or $Cl_n \geq 0.7$
 $HSli = \text{Greater of } Fli \text{ or } Cl_i \text{ or } Cl_n$
else,
- (3) If $Fli < 0.7$ and $Cl_i \geq 0.7$ and $Fl_n \geq 0.7$
 $HSli = \text{Greater of } Cl_i \text{ or } Fl_n$
else,
- (4) $HSli = Cl_i$

where:

- $HSli$ = Habitat Suitability Index for each *i*th cell (0.1 - 1.0)
- DEN_i = Denning Index for each *i*th cell (0.1)
- Cl_i = Cover Index for each *i*th cell (0.1 - 1.0)
- DEN_n = Denning Index of neighbouring cell (0.1)
- Fli = Food Index for each *i*th cell (0.1 - 1.0)
- Cl_n = Cover Index of neighbouring cell (0.1 - 1.0)
- Fl_n = Food Index of neighbouring cell (0.1 - 1.0)

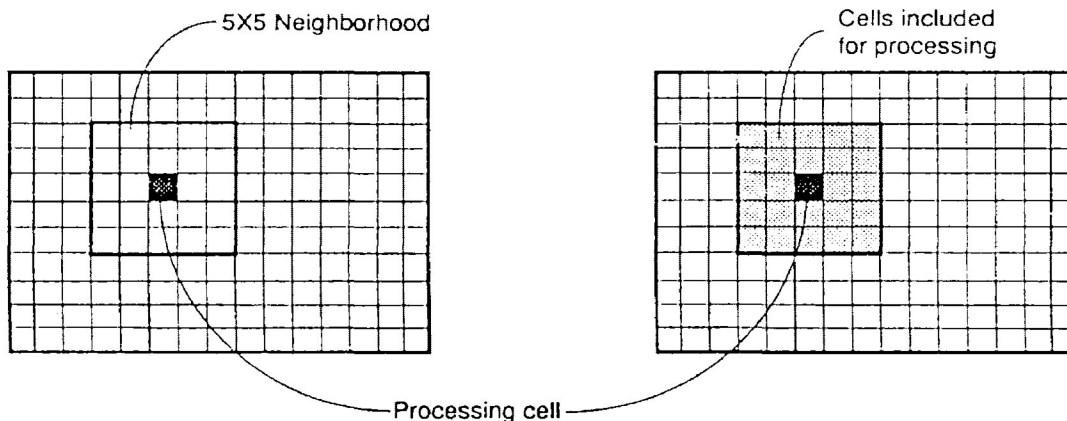


Figure 15. 5 x 5 cell window placed over each cell in the database to perform the calculations for the final HSI values (ESRI, 1991).

MODEL OUTPUT

Initial output of the model is a listing of the area of habitat in suitability classes. This information was displayed graphically to compare scenarios. Maps of potential female marten winter habitat were produced for each of the 20-year forest updates in each scenario of HSG. Maps were produced which combined the 10 HSI classes into three classes of poor, moderate and optimal. Poor habitat represented HSI classes 0.1 and 0.2, moderate habitat represented HSI classes 0.3 to 0.6, and optimal habitat contained HSI classes 0.7 to 1.0.

MODEL VERIFICATION

Sensitivity analysis

Steps in the sensitivity analysis included:

- (1) Identification of the response variables
- (2) Identification of the relationships/parameters to be tested
- (3) Identification of the default or base case
- (4) Determining the adjustments
- (5) Running the model with the changes
- (6) Analyzing the sensitivity of responses to changed assumptions

The response variables chosen were the area of habitat in each of the 10 HSI classes for the whole forest. Sensitivity testing can quickly become a cumbersome task, even when only a few parameters are tested. For this study, sensitivity testing was limited to the cover curves. The food curves were not tested with sensitivity analysis because they play a secondary role in determining the final HSI values. Sensitivity analyses were performed on the 1993 base run of the NOHARVEST scenario, and all results were compared to this base run using the original curve set. Results from each sensitivity test were compared to the base case to determine sensitivity. For each of the cover curves, the whole curve received negative and positive shifts of one increment on their respective x-axis. The same procedure was applied to each curve. The sensitivity of model output to parameter changes was used as a test of the robustness of model performance to changes in parameter estimates (Swartzman and Kaluzny, 1987). A large change in a relationship leading to a small response suggests insensitivity, and vice-versa.

CHAPTER 6

RESULTS AND DISCUSSION

WOOD-SUPPLY ANALYSES

The QUNO scenario depicting the actual 1993-1998 QUNO Corp. harvest schedule, harvested stands across the forest with a concentration of harvesting in the south-central portion of the forest (see Figure 16). When the QUNO scenario is compared to the HSG scenario for the same period, a similar pattern is visible although the harvest is less contiguous (see Figure 17). When HSG is used to develop timber harvest scenarios without spatial timber harvest constraints, the harvest pattern may be somewhat scattered. However, in this study, analysis was performed on the total area in HSI classes, so spatial location of habitat was of less concern. On the other hand, using HSG without spatial harvest constraints in this forest is realistic due in part to the abundant road access, and may be necessary to achieve the best mixture of timber harvest and marten habitat.

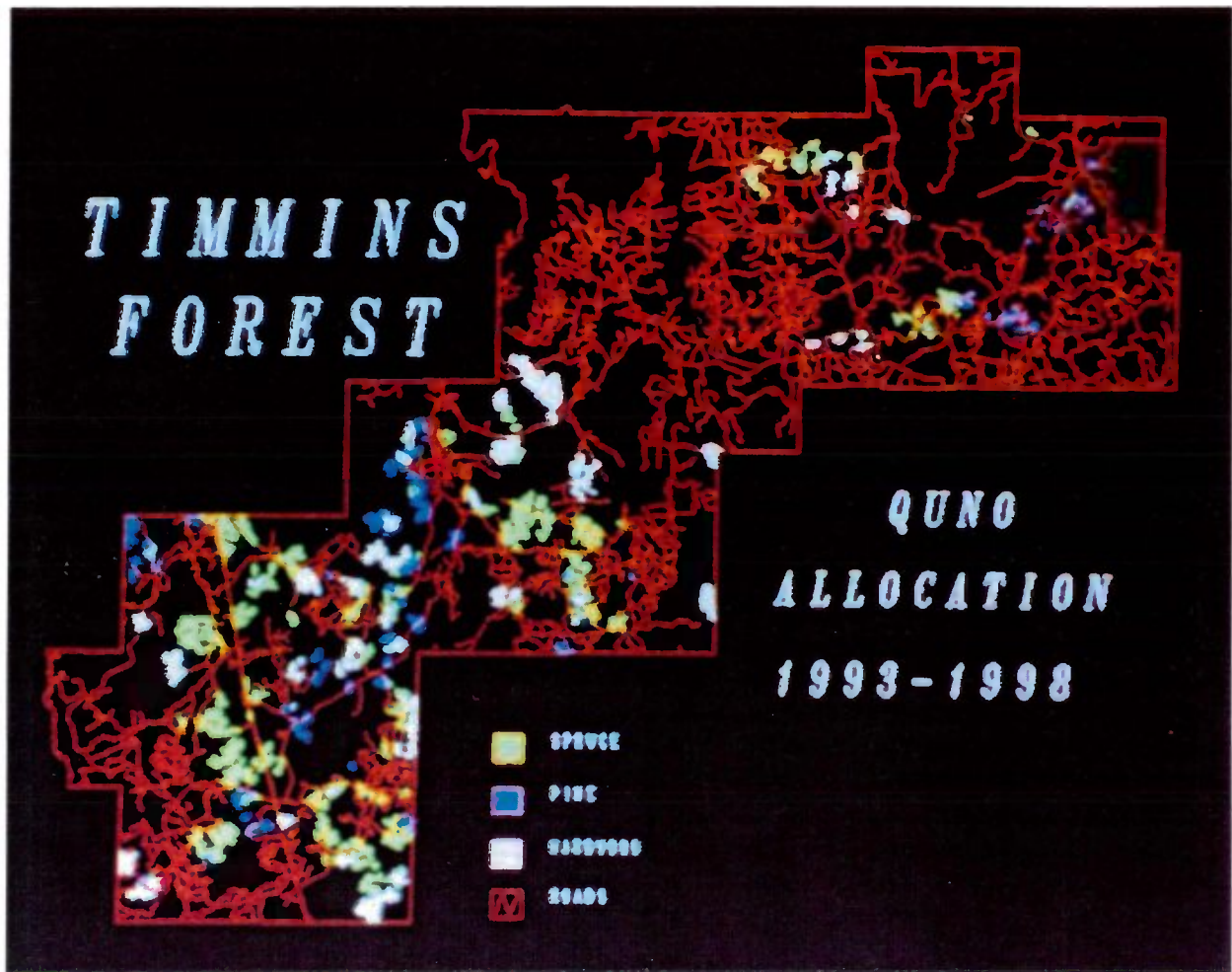


Figure 16. The 1993-1998 QUNO Corp. allocation in the Timmins Forest showing harvest blocks shaded by working groups.

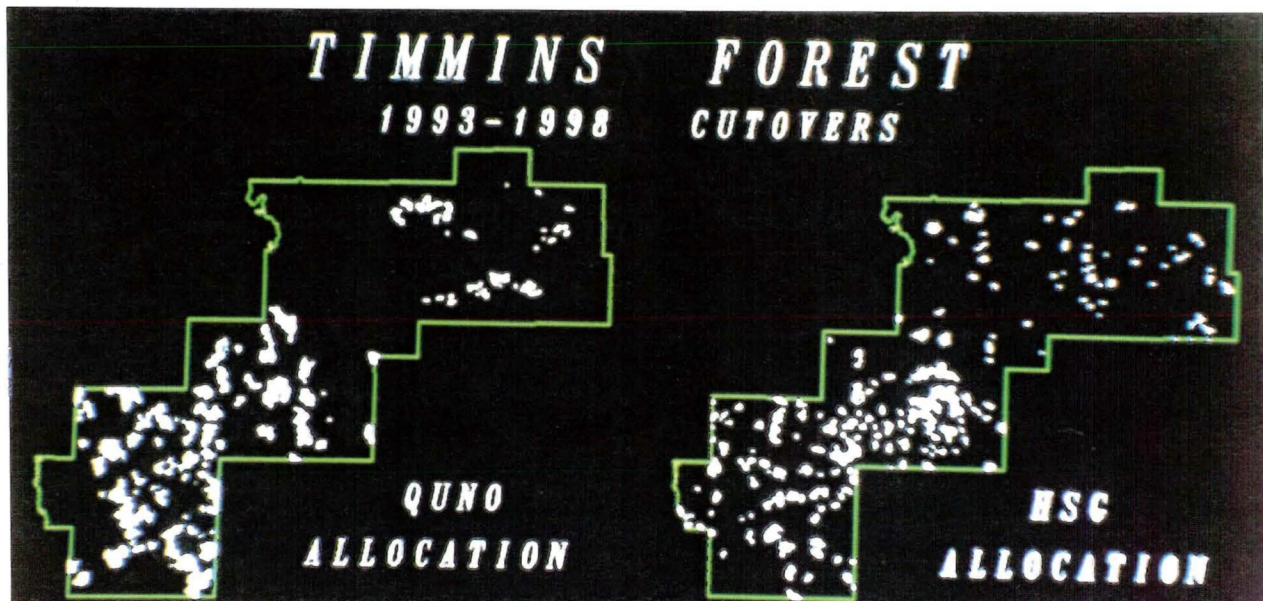


Figure 17. A comparison of the 1993-1998 QUNO Corp. allocation with the HSG allocation for the same period.

A 100-year simulation for the timber harvest scenarios was sufficient time for lagged effects to surface and eliminated the possibility of a short term, "exploitive" impact assessment (Erdle, 1983). It was not so long into the future as to become cumbersome computationally, nor meaningless operationally (Erdle, 1983). It is wise when performing wood-supply analyses to run simulations longer than the age of harvest of newly created stands. Surprises may occur in the available growing stock depending upon the original age-class structure of the forest, and a short-term assessment would miss these and perhaps permit false conclusions to be drawn about the future. Gaps in the present forest age-class structure may

cause changes to results in the long term. Even-flow harvest volumes were used in the analyses. While harvested volumes in reality differ from year to year, it would be too difficult to interpret changes in future habitat suitability if volume quotas were flexible in these simulations.

MARTEN MODEL HABITAT MAPS

Habitat maps were developed for selected scenarios depicting poor, moderate and optimal habitat. A map of marten habitat suitability in 1993 (Figure 18), and a map of marten habitat suitability in 2093 (Figure 19) resulting from the NOHARVEST scenario are presented. Initially in the study area there are many contiguous areas of optimal habitat. Over time without disturbance these areas decrease in size and the optimal habitat becomes fragmented. By the year 2093, optimal habitat is again appearing in contiguous areas and the amount of poor habitat that originated from logging has diminished. A map of the 2093 marten habitat suitability resulting from the EXTENSIVE scenario (Figure 20), depicts a large decrease in the amount of optimal habitat when compared to the 2093 NOHARVEST map. A map of the 2093 marten habitat suitability resulting from the INTENSIVE scenario (Figure 21), depicts significantly more optimal habitat than the EXTENSIVE scenario. Optimal habitat resulting from the

intensive scenario is spread out across the forest. These maps clearly show the need for analysis of patch size and contiguity, as the location of habitat is as important as the amount of habitat.

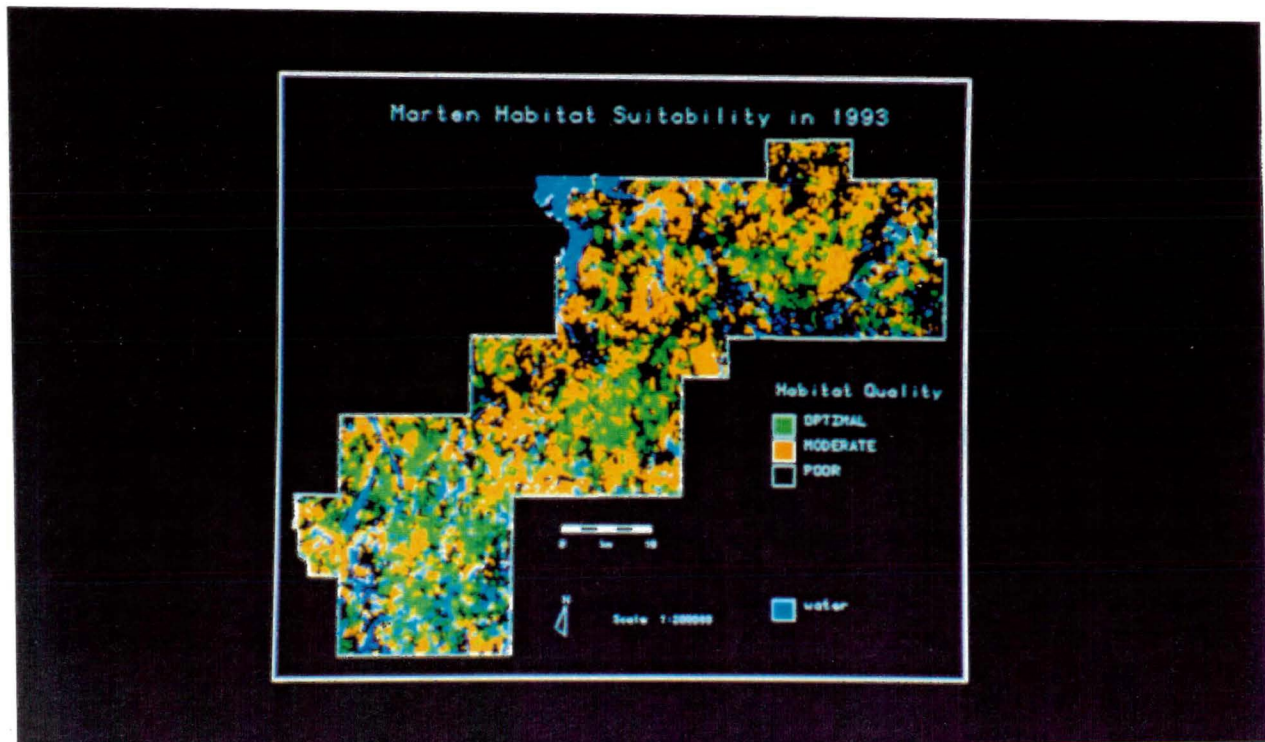


Figure 18. Marten habitat suitability in year 1993.

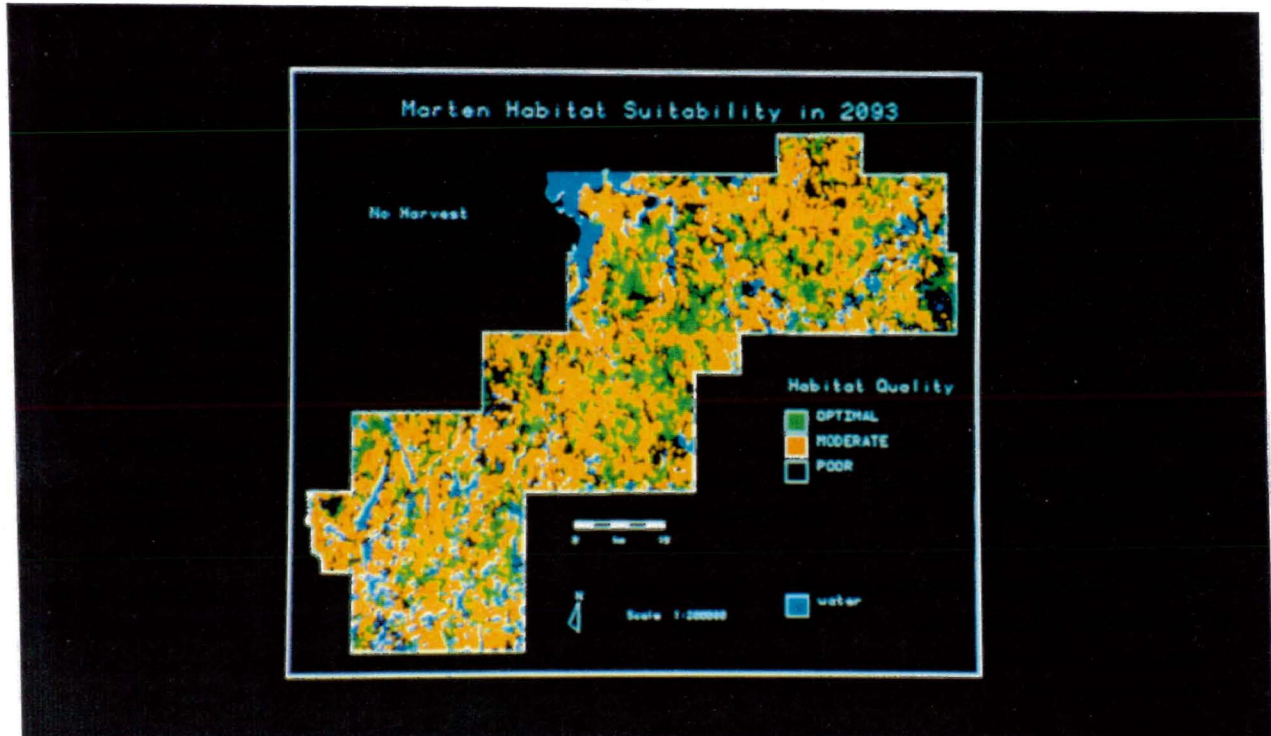


Figure 19. Marten habitat suitability in year 2093 resulting from the NOHARVEST scenario.

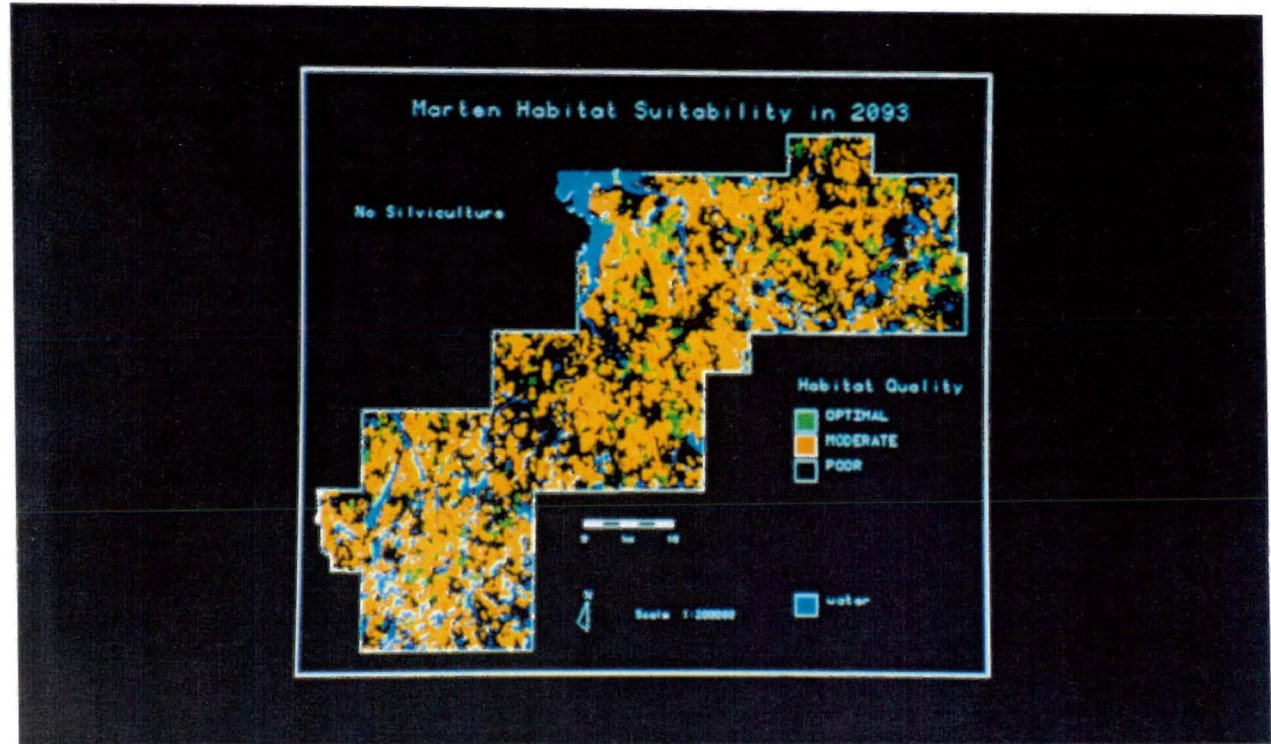


Figure 20. Marten habitat suitability in year 2093 resulting from the EXTENSIVE scenario.

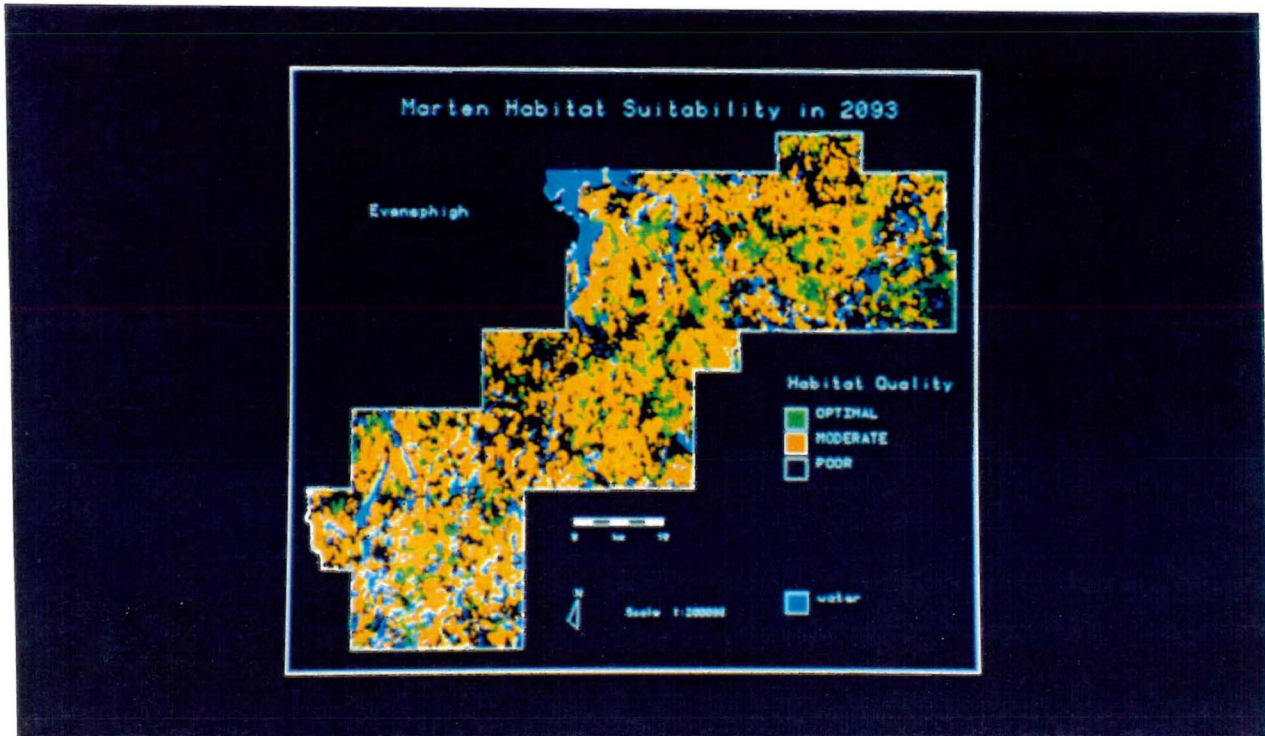


Figure 21. Marten habitat suitability in year 2093 resulting from the INTENSIVE scenario.

SCENARIO COMPARISONS OF MARTEN HABITAT

Impact comparisons of area in HSI classes are made with the nine forest management scenarios developed for this study. Habitat forecasts from the various scenarios are given for the years 2013, 2053 and 2093 (20, 60, and 100 years into the future). As some scenarios are repeated in several graphs for comparison purposes, they are described in detail only once. The NOHARVEST scenario is used as a reference in all of the

comparisons. The NOHARVEST scenario delivers better marten habitat than the other scenarios, which all simulate various levels of timber harvest. The amount of area currently in each of the 10 HSI classes is shown in Figure 22.

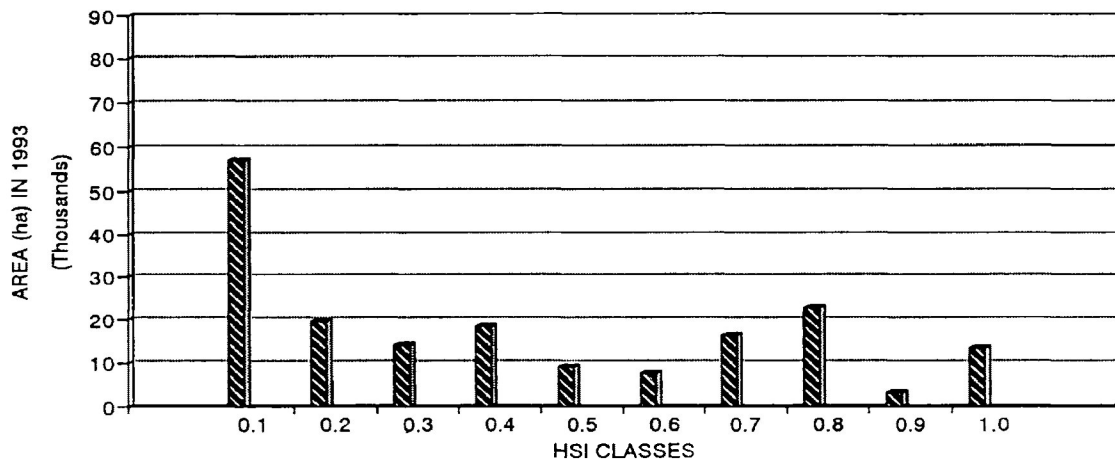


Figure 22. The 1993 HSI rating for the Timmins Forest.

NOHARVEST/EXTENSIVE/BASIC

The EXTENSIVE scenario and the BASIC scenario result in similar amounts of suitable habitat in 2013 (Figure 23). This is because the harvest levels are similar, and only the silviculture is different. In 20 years this difference cannot affect the better habitat. Compared to the NOHARVEST scenario,

timber harvest is clearly resulting in less optimal habitat. By 2053, the BASIC scenario results in slightly more suitable habitat than the EXTENSIVE scenario, but again both scenarios result in less suitable habitat compared to NOHARVEST. Because the EXTENSIVE scenario relies only on extensive silviculture, new stands have low stocking, mixed species and more hardwoods. In 2093, the EXTENSIVE scenario results in low amounts of suitable habitat, while the BASIC scenario maintains more than twice the EXTENSIVE amount.

The NOHARVEST scenario results in the best forecast for marten habitat, but it provides industry with no timber. This scenario does not accurately portray forest dynamics because natural disturbances such as fire and insect infestations are not accounted for. However, it demonstrates changes in forest structure over time according to the successional rules used in the model. The amount of area in optimal habitat decreases over time even without timber harvest. It would appear, however, that the forest is cyclic, as the area in the upper HSI classes by 2093 is improving.

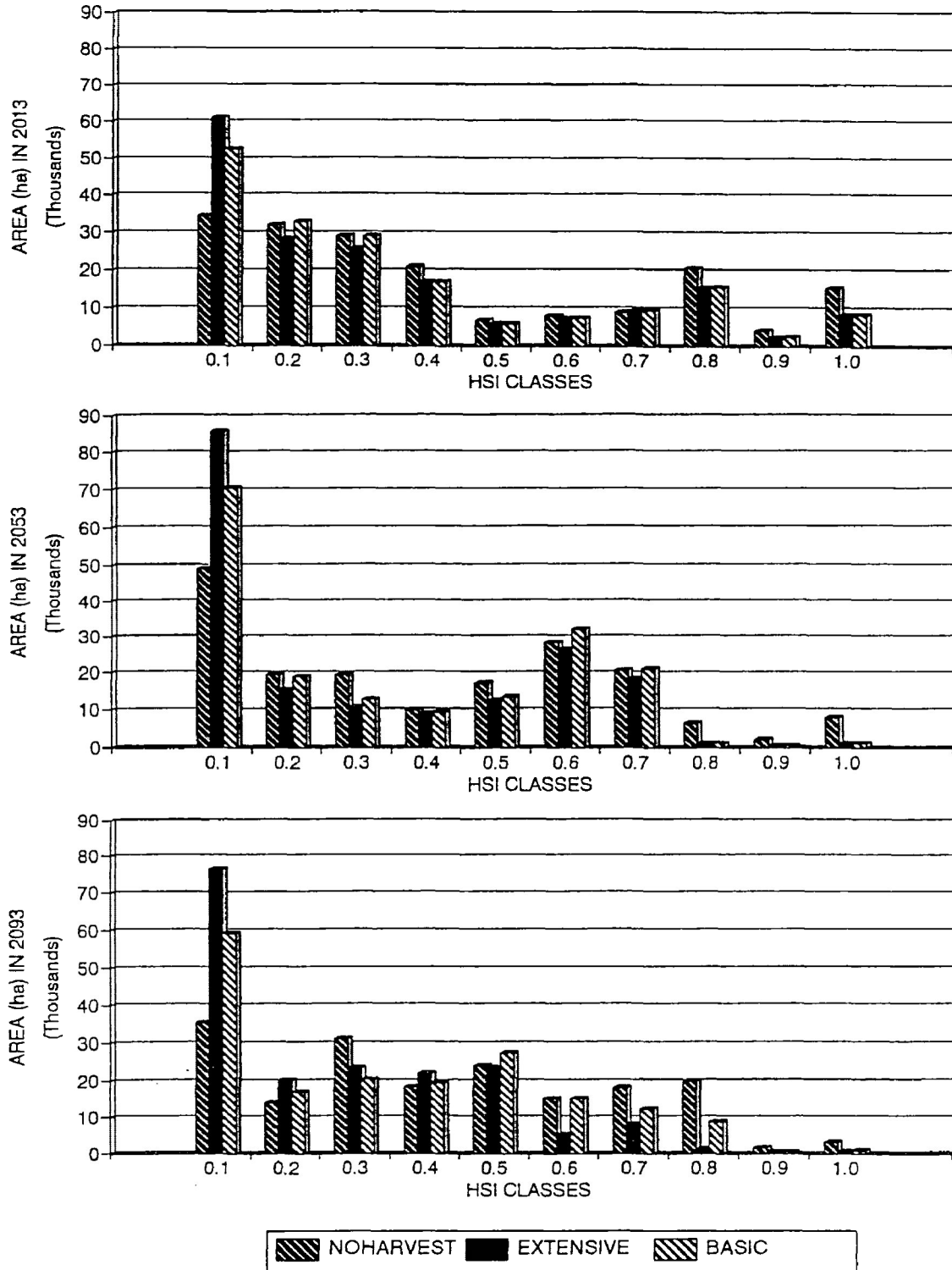


Figure 23. Comparison of area in HSI classes resulting from NOHARVEST/EXTENSIVE/BASIC scenarios.

The EXTENSIVE scenario clearly shows that future marten habitat in this forest would be quite diminished if some mix of intensive and basic silviculture were not implemented. However, the EXTENSIVE scenario also demonstrates that the majority of good habitat in the future will exist in stands created through clearcut harvesting and artificial regeneration. Thompson (1991) suggested that stands resulting from intensive silviculture would not produce habitat of a similar suitability for marten as would stands resulting from natural disturbance. Stands following logging may have less structural diversity than the original stands (Hansen *et al.*, 1991). Lofroth and Steventon (1990) however, claimed that marten will make use of regenerating stands if certain habitat elements are provided. If in fact forests resulting from conventional harvesting and silvicultural practices are of less value to marten, the marten model is overestimating the quality of marten habitat in the Timmins Forest.

NOHARVEST/BASIC/INTENSIVE

In this comparison, the BASIC and INTENSIVE scenarios have similar harvest levels with differing treatment priority lists and limits on treatable area. Differences in impact between the two scenarios are small (Figure 24). In 2093, slight increases in suitable habitat result from the INTENSIVE scenario in classes 0.7 and 0.8. Alterations

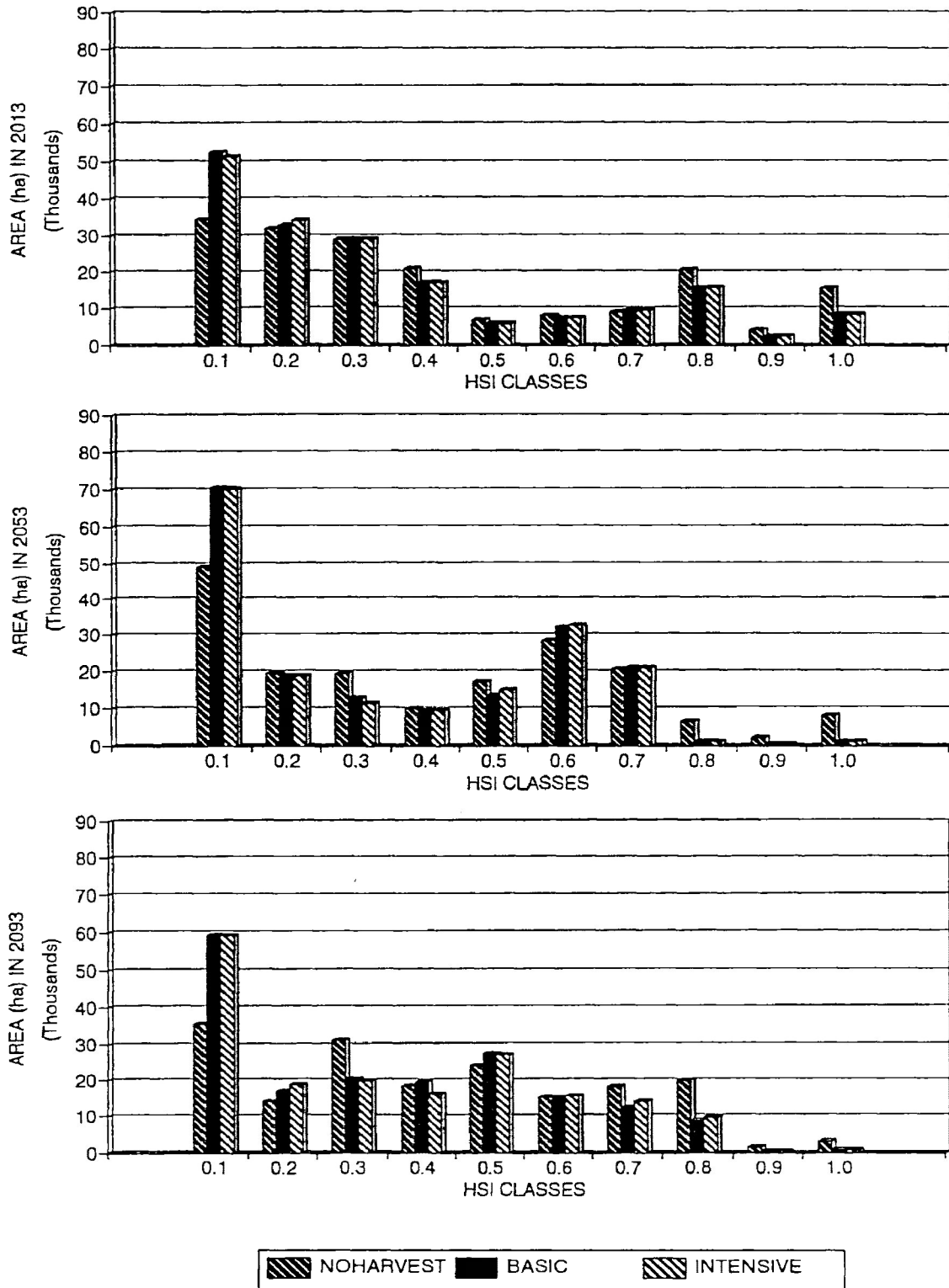


Figure 24. Comparison of area in HSI classes resulting from NOHARVEST/BASIC/INTENSIVE scenarios.

to the amount of area treated, and silvicultural intensity, appear to have little effect on the amount of suitable habitat as simulated in this study. Changes occur only in the distant future as the new stands mature. The results suggest that intensification of silviculture as simulated in this study, cannot be justified on the basis of marten habitat values alone.

NOHARVEST/SPRUCE + 10/INTENSIVE

The SPRUCE + 10 scenario harvests 10% more spruce m³/year than the INTENSIVE scenario. Otherwise these scenarios are similar. In 2013, only slight differences are apparent in favour of the INTENSIVE scenario in the better habitat (see Figure 25). Not until 2093 does SPRUCE + 10 differ greatly from INTENSIVE, the main difference being in the 0.8 HSI class. A small increase in the harvest level will only affect the amount of area in suitable habitat in the long term.

NOHARVEST/BASIC/SPRUCE-20

Silvicultural treatments in BASIC and SPRUCE-20 are the same, while the harvest levels are different. SPRUCE-20 harvests 20% less spruce m³/year than BASIC. Therefore, differences in area of suitable HSI classes are noticeable in 2013 (see Figure 26). These key differences occur in the most suitable HSI classes of 0.8 to 1.0 with the SPRUCE-20 scenario ensuring more area.

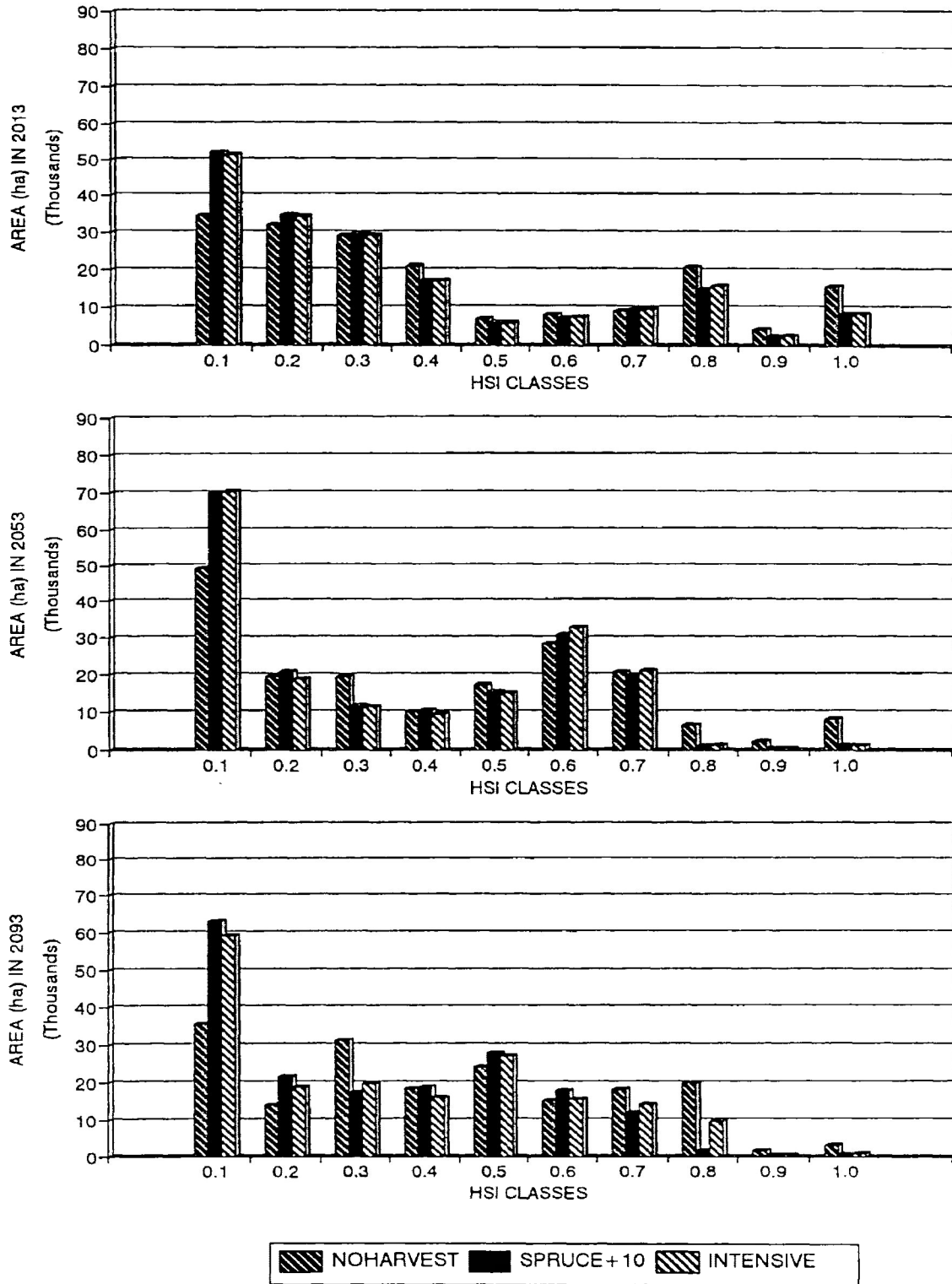


Figure 25. Comparison of area in HSI classes resulting from NOHARVEST/SPRUCE + 10/INTENSIVE scenarios.

By 2053, SPRUCE-20 provides twice the amount of optimal habitat (HSI classes 0.8 to 1.0) as BASIC. In 2093, the SPRUCE-20 scenario contains more habitat in the upper HSI classes, with the largest difference in HSI class 0.8.

NOHARVEST/DELAY-10/SPRUCE-10

Definitely, the most interesting results are those obtained from the DELAY-10 scenario (see Figure 27). Both DELAY-10 and SPRUCE-10 have annual spruce harvest levels lower than conventional levels by 10%. The other difference occurs in the yield curves, with the DELAY-10 curves being altered to allow mature and overmature black spruce stands to avoid harvest until they are approaching the final stages of overmaturity. In 2013, the DELAY-10 scenario contains more habitat in the HSI class 1.0 than SPRUCE-10 and less in HSI 0.8. In 2053, the scenario SPRUCE-10 contains more area classed as suitable habitat. By 2093 the SPRUCE-10 scenario contains more area in HSI class 0.8, but less in HSI class 0.7. In both 2053 and 2093, the SPRUCE-10 scenario provided more suitable habitat than DELAY-10.

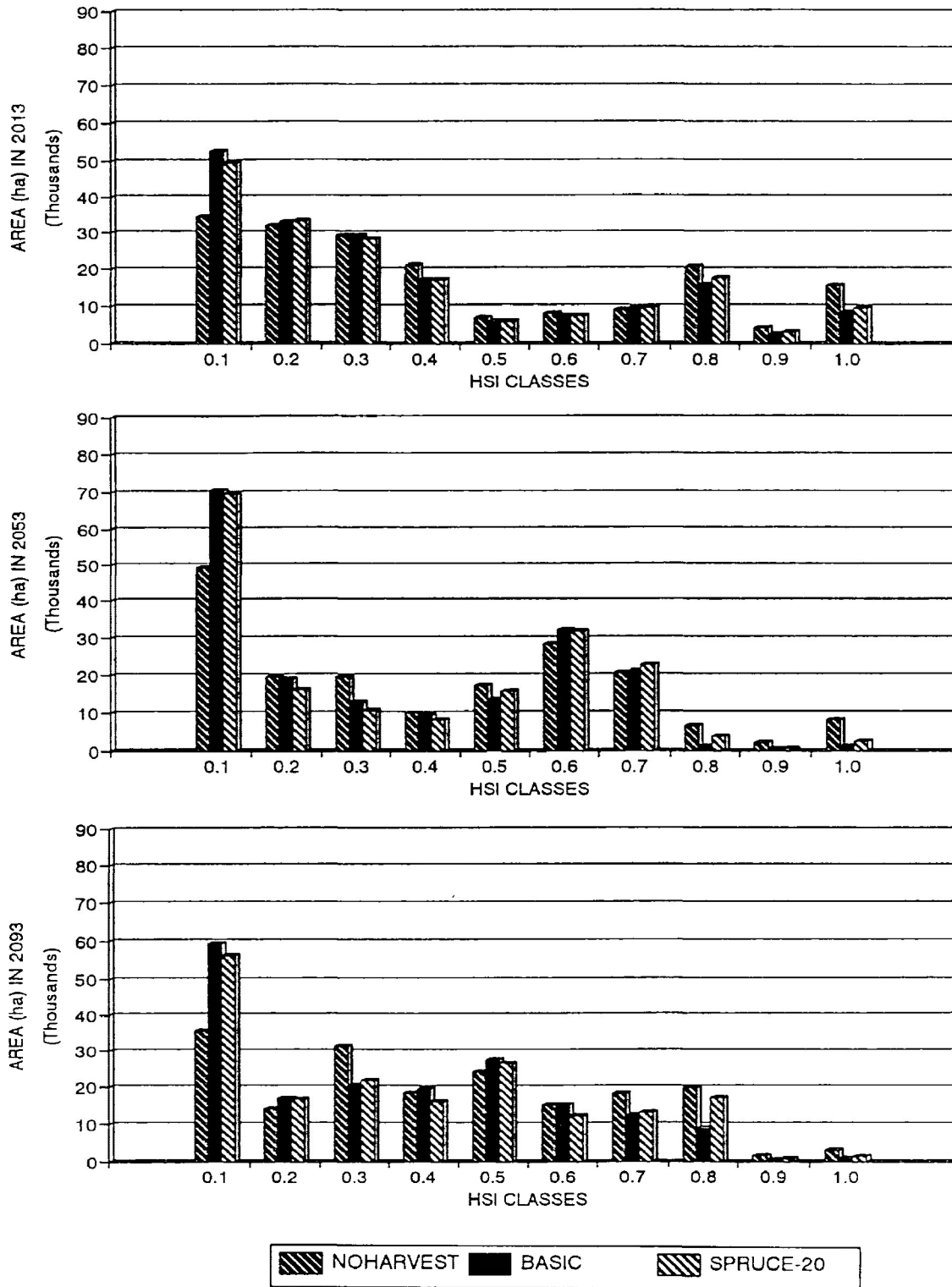


Figure 26. Comparison of area in HSI classes resulting from NOHARVEST/BASIC/SPRUCE-20 scenarios.

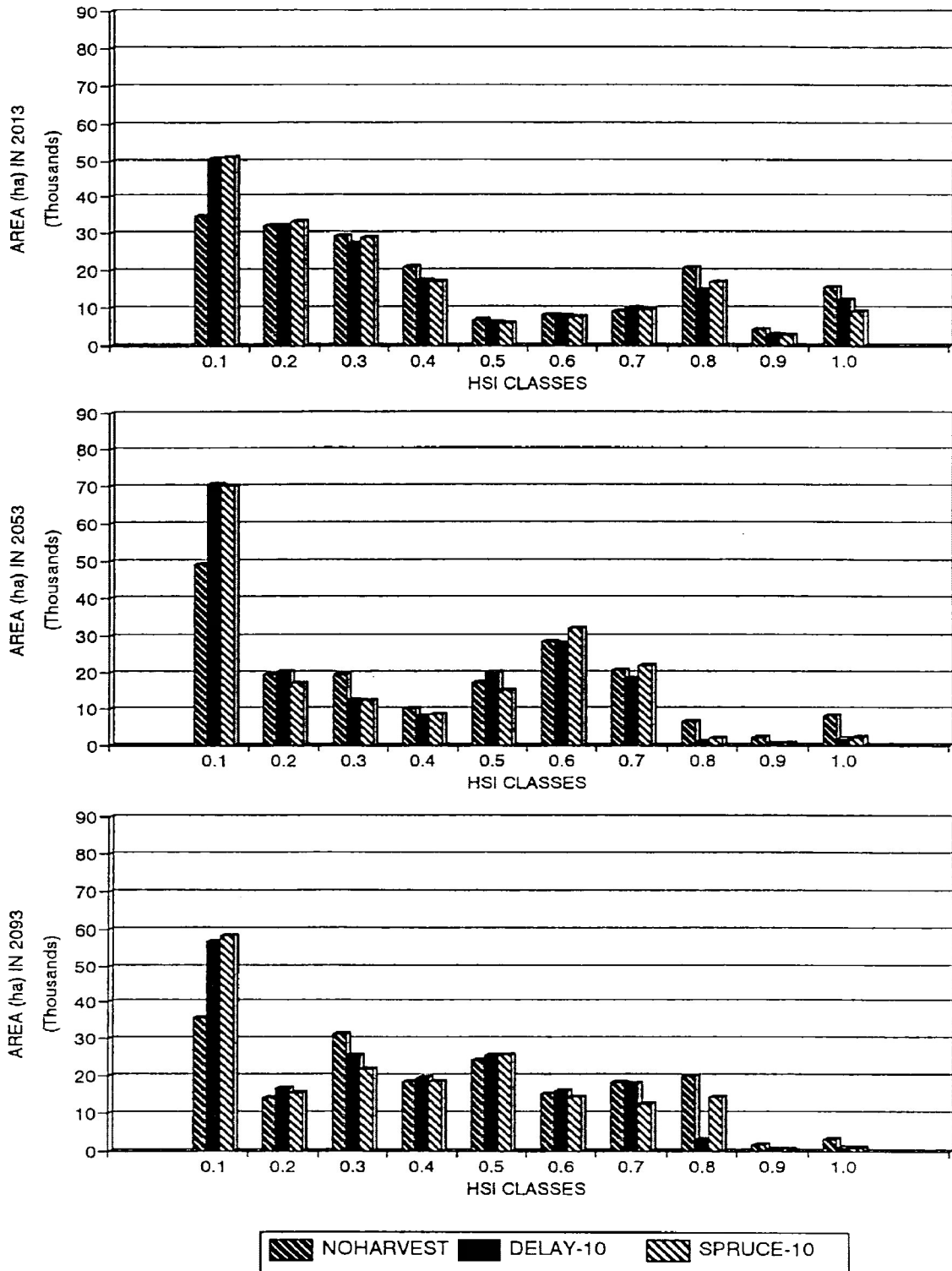


Figure 27. Comparison of area in HSI classes resulting from NOHARVEST/DELAY-10/SPRUCE-10 scenarios.

In the short term, the attempt at retaining more of the optimal habitat using DELAY-10 worked. In the long term the attempt failed. This change in suitability is due to the changing structure of the forest over time and serves as a reminder of how a good measure in the short term can become a problem in the future. However, the good results of DELAY-10 in the first 20 years suggest that there is an alternative here to provide for improved habitat with timber harvest.

Problems in managing the future forest may be the result of past timber harvest practices (Thompson and Welsh, 1993). The 1993 age-class structure of the black spruce working group in the Timmins Forest (see Figure 5) is partly a result of past practices. An unbalanced age structure of the forest will create problems in maintaining an adequate habitat supply regardless of the management regime applied (Thompson and Welsh, 1993). While a gap in the age-class structure of this kind in the Timmins Forest can perhaps be absorbed by neighbouring age classes in terms of wood-supply, it creates a noticeable dip in habitat when the poorly represented age class becomes optimal habitat.

NOHARVEST/QUNO/BASIC

In this comparison, the scenarios NOHARVEST, QUNO and BASIC are compared for the year 1998. Both timber harvest scenarios slightly

lowered the amount of area in optimal HSI classes (see Figure 28). In the short term, harvesting at the forest level does not cause drastic changes to overall marten habitat.

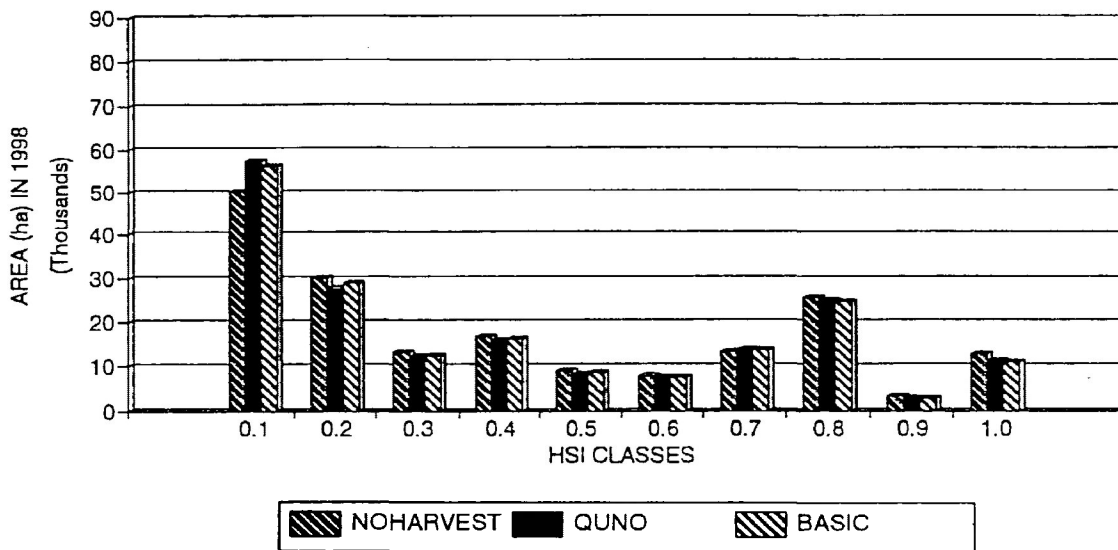


Figure 28. Comparison of area in HSI classes resulting from NOHARVEST/QUNO/BASIC scenarios.

MODEL VERIFICATION

Sensitivity Analysis

Negative and positive shifts were made to the original marten HSI cover curves and run with the 1993 NOHARVEST scenario. It was then possible

to determine the proportional difference of area within each HSI class to the NOHARVEST scenario with the original HSI cover curves. Because I was unable to trace the movement of habitat into new HSI classes resulting from a sensitivity test (except for the age curves), key information may be missing from these tests. Obviously, habitat in HSI class 0.1 can only increase or remain the same in rating, while habitat in HSI class 1.0 can only decrease or remain the same in rating. Regardless of how habitat has shifted HSI class ratings, if the area in suitable HSI classes remains similar to the base run, the habitat forecasts are insensitive to small shifts in parameters. For obvious reasons, I am most concerned with the accuracy in forecasting suitable marten habitat, as opposed to poor marten habitat.

Sensitivity tests were performed on the stocking curves used in the marten model (see Figure 29). Substantial deviations from the base run occur in both the negative and positive curve shifts, in the lower HSI classes (see Figure 30). Because all three EWG stocking curves were shifted simultaneously, it is difficult to pinpoint the cause. However, the area in HSI classes ≥ 0.6 remains similar to that of the base run. Therefore, the forecasts of suitable habitat are insensitive to shifts in the stocking curves.

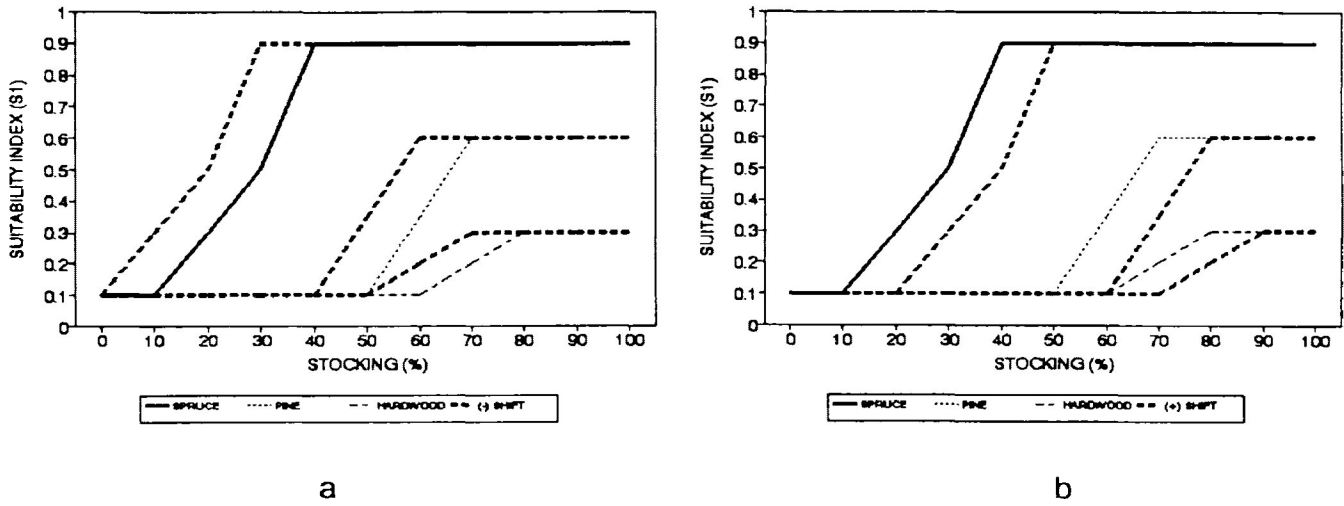


Figure 29. The original stocking curves with: (a) negative; and (b) positive shifts.

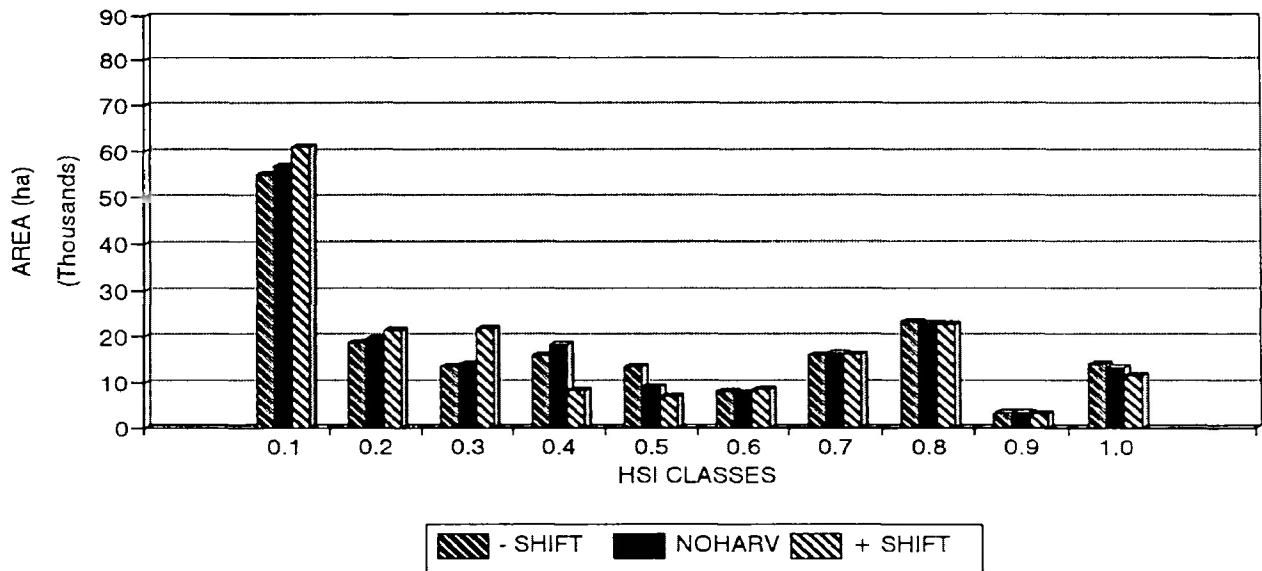


Figure 30. Area in HSI classes for the 1993 NOHARVEST base run resulting from negative and positive shifts to the original stocking curves.

Negative and positive shifts of the % SPRUCE EWG curves (see Figure 31) generate minor changes compared to the base run (see Figure 32). No differences are detected for HSI values > 0.6 because pine and hardwood stands cannot receive values for those HSI classes. The forecasts of suitable habitat are obviously insensitive to shifts in the % SPRUCE EWG curves.

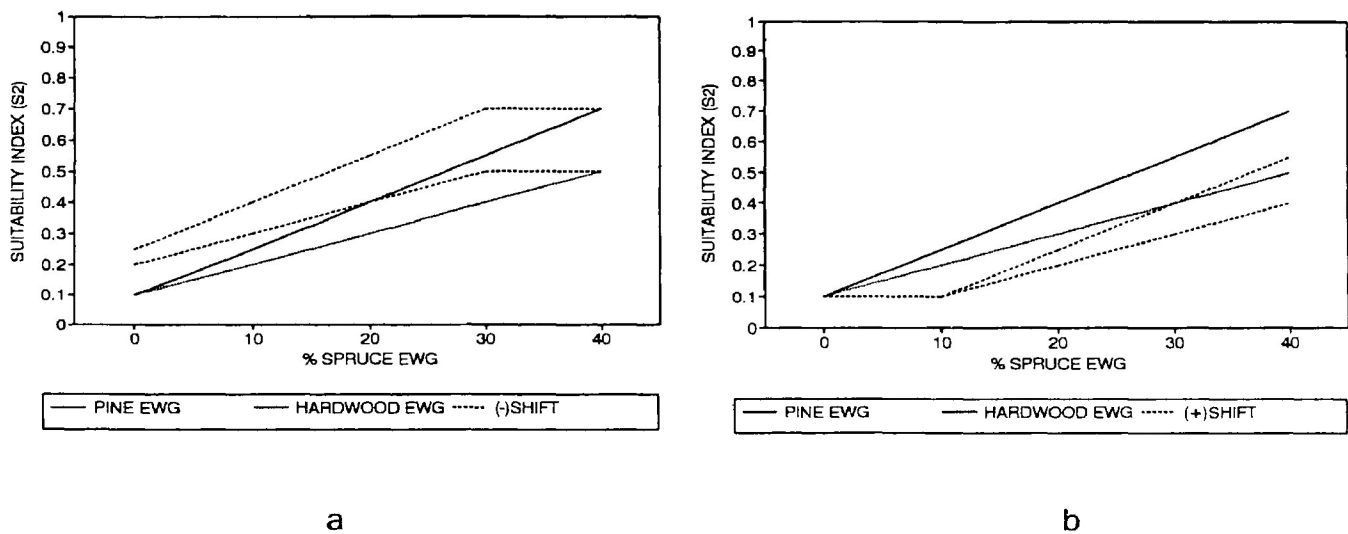


Figure 31. The original % SPRUCE EWG in PINE/HARDWOOD EWG curves with: (a) negative; and (b) positive shifts.

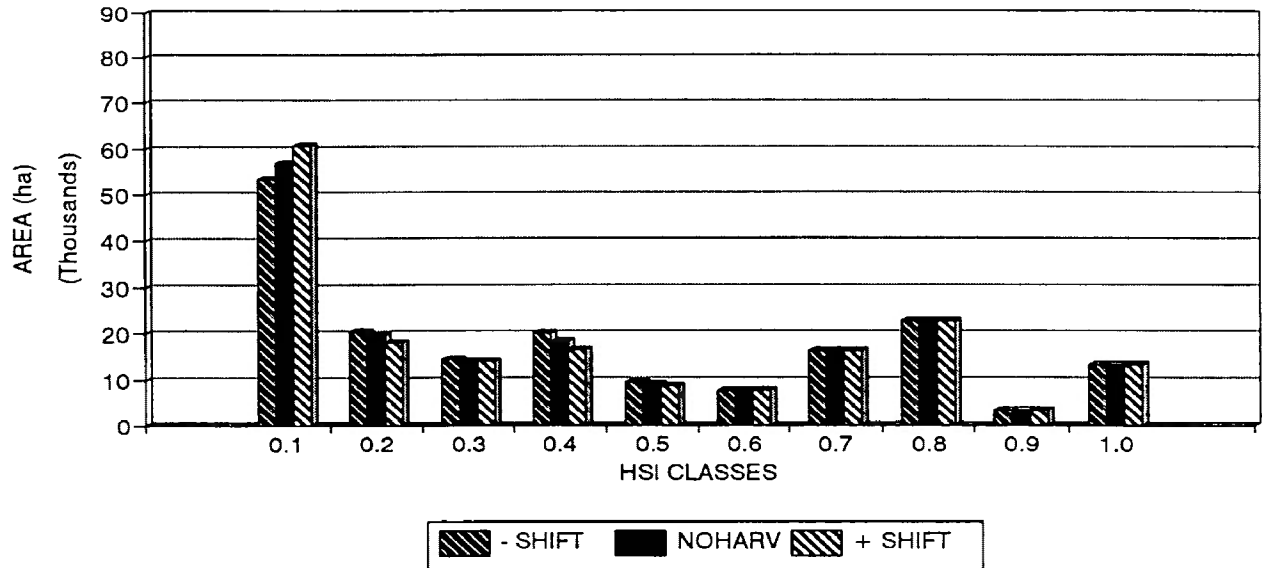


Figure 32. Area in HSI classes for the 1993 NOHARVEST base run resulting from negative and positive shifts to the original % SPRUCE EWG in PINE/HARDWOOD EWG curves.

The % PINE/HARDWOOD EWG curves apply only to SPRUCE EWG stands. They received negative and positive shifts to both curves (see Figure 33). Some large changes occur to the amount of area throughout all of the HSI classes resulting from negative and positive shifts (Figure 34). The forecasts of habitat in all HSI classes, especially HSI class 0.8, are sensitive to shifts in the % PINE/HARDWOOD EWG curves.

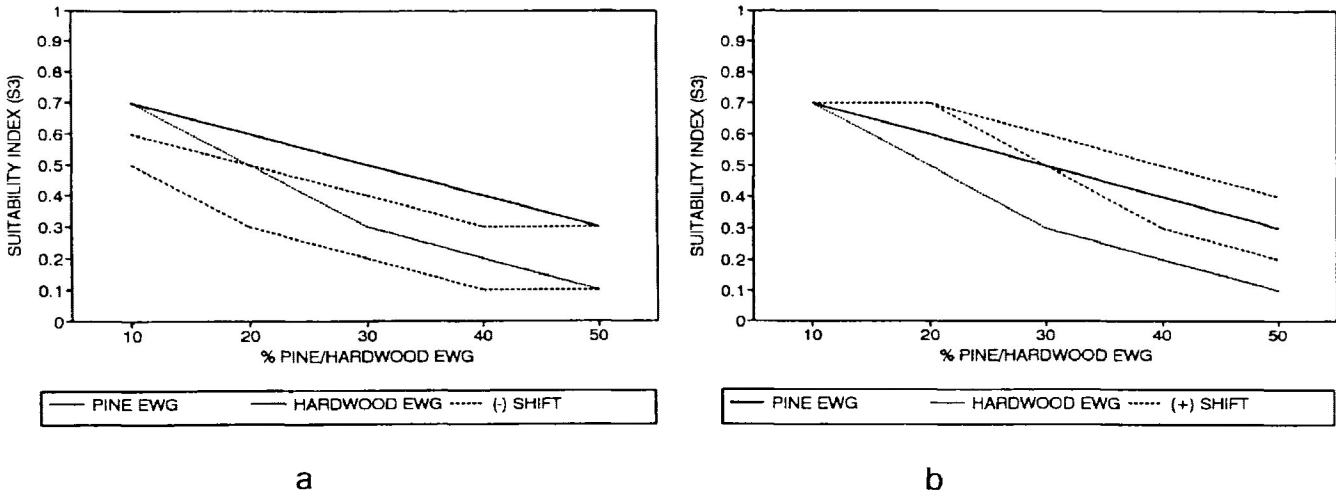


Figure 33. The original % PINE/HARDWOOD curves with: (a) negative; and (b) positive shifts.

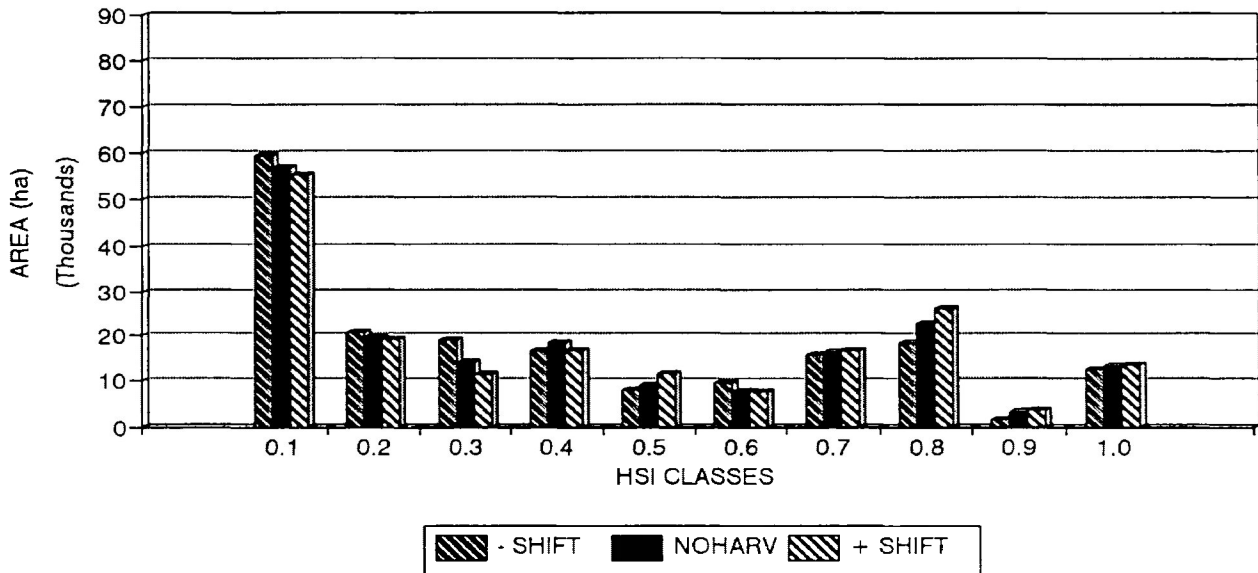
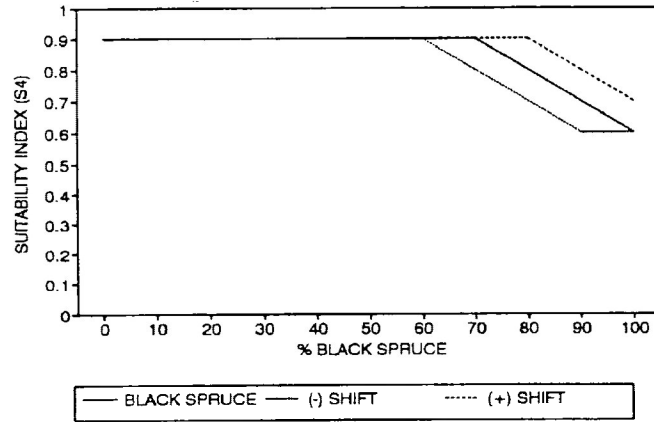


Figure 34. Area in HSI classes for the 1993 NOHARVEST base run resulting from negative and positive shifts to the original % PINE/HARDWOOD curves.

Sensitivity tests of the percent of black spruce in the SPRUCE EWG (see Figure 35) indicates that habitat forecasts are largely insensitive to small positive and negative shifts in the curve (see Figure 36). A positive shift in

the curve likely shifted area in HSI class 0.7 to HSI class 0.8, thus improving the habitat.



Figures 35. The original % black spruce in the SPRUCE EWG curves with negative and positive shifts.

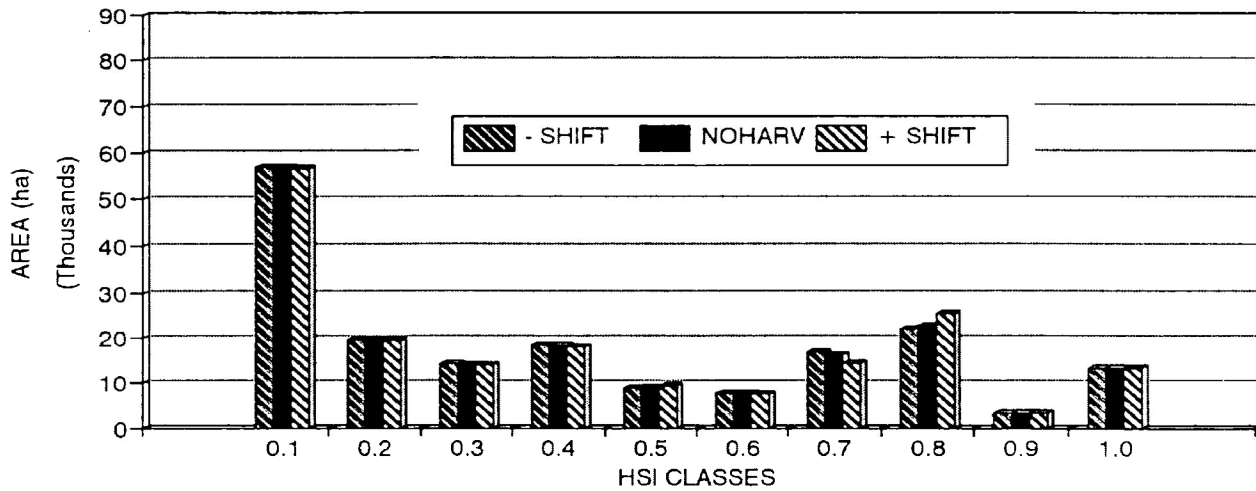
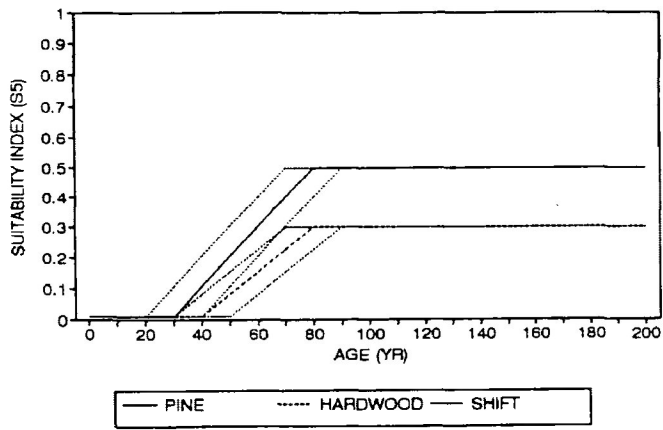
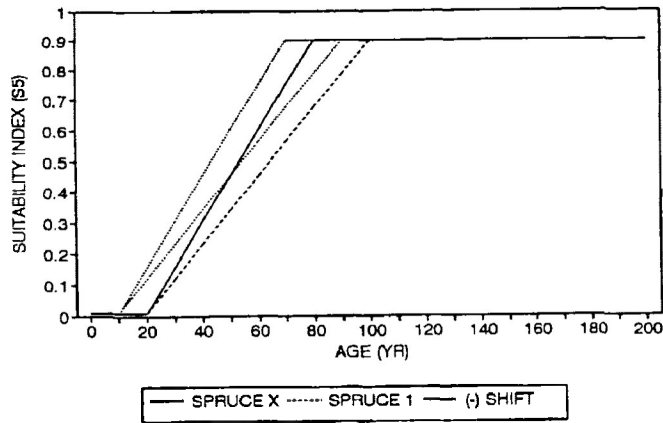


Figure 36. Area in HSI classes for the 1993 NOHARVEST base run resulting from negative and positive shifts to the original % black spruce in the SPRUCE EWG curves.

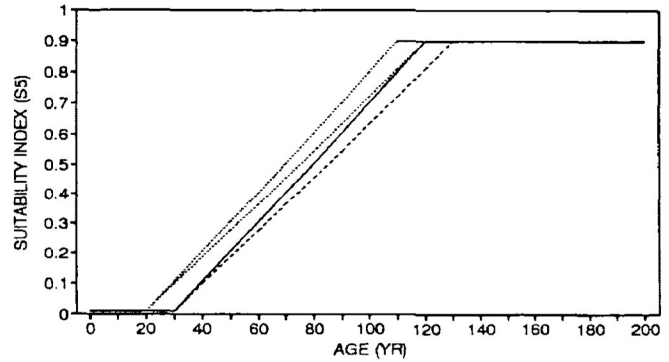
Sensitivity testing of the age curves (see Figure 37) results in habitat forecasts appearing very sensitive to curve changes (see Figure 38). These curves are important determinants of marten habitat value in the model (see cover equations) so adjustments to them can be expected to be strong. The majority of shifts show greater than 10% change to the base run.



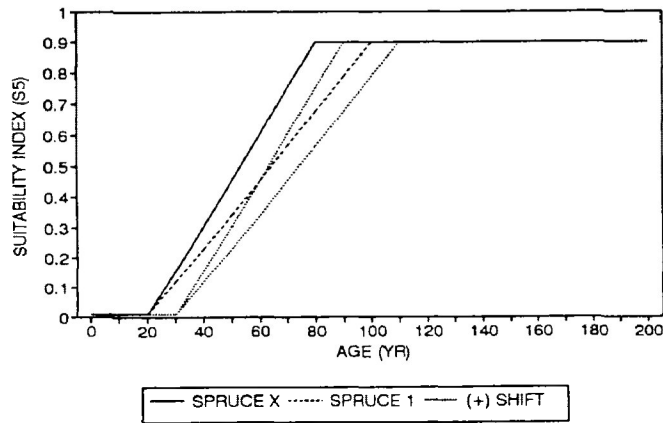
a



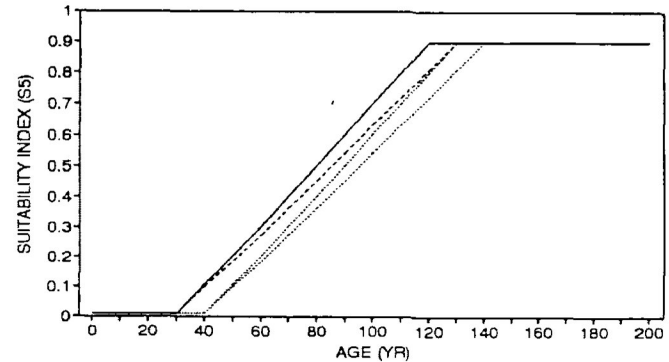
b



c



d



e

Figure 37. The original age curves with: (a) negative and positive shifts to PINE/HARDWOOD EWG curves. Negative shifts were applied to the SPRUCE EWG curves with: (b) site classes X and 1; and (c) site classes 2, 3 and 4. Positive shifts were applied to the SPRUCE EWG curves with: (d) site classes X and 1; and (e) site classes 2, 3 and 4.

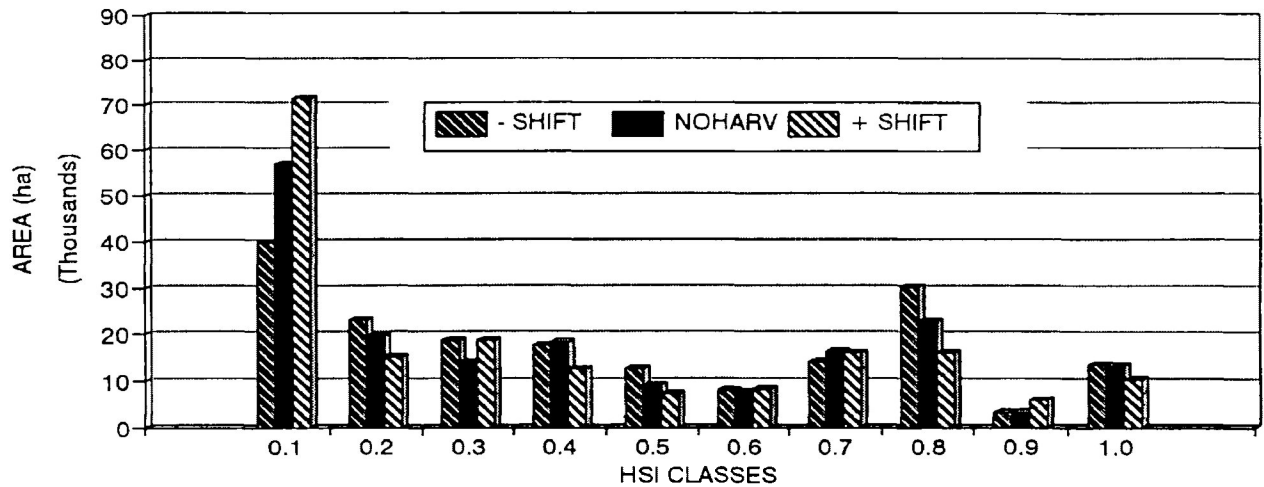


Figure 38. Area in HSI classes for the 1993 NOHARVEST base run resulting from negative and positive shifts to the original age curves.

In addition to Figure 38, Tables 6 and 7 were developed to determine the extent of the changes in HSI ratings from the sensitivity tests applied to the age curves. As was expected, a negative curve shift only improved HSI classes or left them the same. A positive shift had the opposite affect. The majority of habitat shifts were of only one HSI class. Large changes are visible for negative curve shifts in HSI class 0.1 and for positive curve shifts in HSI class 0.7. These result from the final HSI equations where stands are rewarded depending upon their HSI values for food and cover and those of their neighbours. Results from this test could likely be extrapolated to the other test results, with the conclusion that a curve shift moves habitat in a predictable manner.

The habitat forecasts can be considered sensitive to small changes in the bonus values (see Table 8) awarded to stands for denning and resting value (see Figure 39). Shifting of the ages when SPRUCE EWG stands become available for the bonus alters the optimal HSI classes. A negative shift in age does not appear to affect the habitat area as much as a positive shift. The positive shift removes a great deal of area (4230 ha) of habitat out of HSI classes 0.9 and 1.0.

Table 8. Sensitivity tests to original stand ages for denning bonus.

Site Class	- Shift	Original	+ Shift
X	90	100	110
1	100	110	120
2,3,4	110	120	130

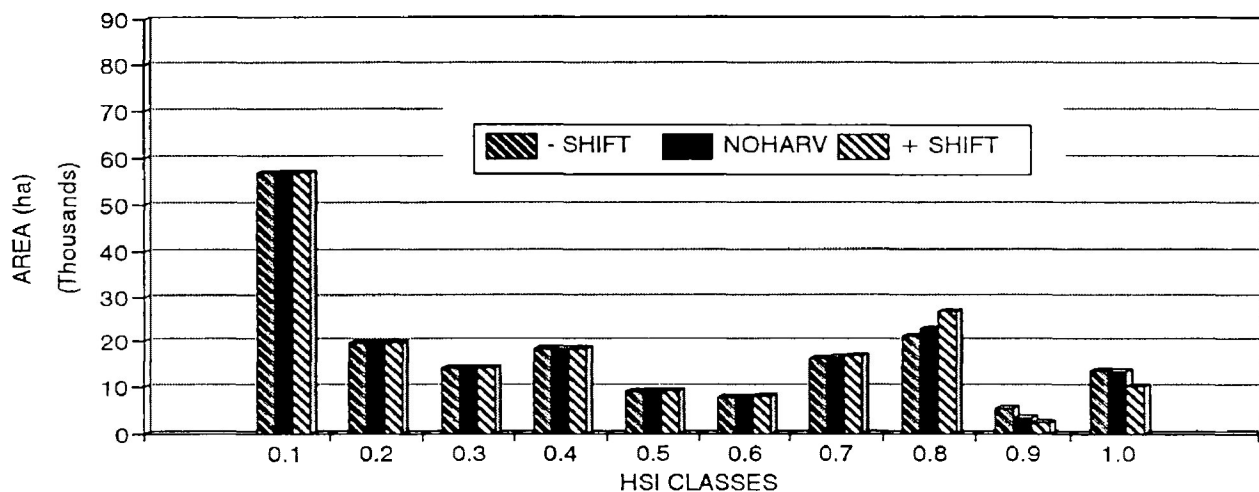


Figure 39. Area in HSI classes for the 1993 NOHARVEST base run resulting from negative and positive shifts to the original bonus ages.

CHAPTER 7

CONCLUSIONS

Results from the study show the hypothesis to be true. Current forest management practices in the boreal forest are decreasing the quantity and quality of long-term marten habitat, while suitable alternatives exist.

Results suggest that extensive silviculture in combination with conventional harvesting do not provide for adequate marten habitat in the long term.

Some form of basic or intensive silviculture is recommended to maintain marten habitat. Increases in spruce harvest levels are not recommended as even a small increase of 10 % significantly lowers the amount of suitable marten habitat. Decreases in the spruce harvest levels significantly improve future marten habitat in the Timmins Forest.

According to results from the marten HSI model, a forest manager may provide marten habitat through timber management by: (1) lowering spruce harvest levels; (2) delaying the harvesting of mature and overmature black spruce stands; and (3) possibly using of modified logging. Each of these options have costs in terms of lost wood production. Lowering spruce

harvest levels has an obvious direct cost. Delayed harvest means a loss of wood volume but stands are not totally removed from production.

Modified logging results in minimal costs but the benefits to marten are unknown. It is possible that marten will react differently to these areas than conventional clearcut areas. The results from this study suggest a compromise between timber harvest and habitat provision can be found through minimal decreases in spruce harvest, and a delay in harvesting mature and overmature stands.

With minor modifications, the marten habitat model created in this study should be applicable across the boreal forest of Ontario. The specific results of the HSI model used in this study pertain only to the Timmins Forest. This is because the results presented in this study are dependent upon the species composition and age-class structure of the Timmins Forest. Applying the marten model to another forest may produce different results. However, the approach taken could be used by anyone interested in determining the effects of various timber management strategies on marten habitat for a forest management area.

The use of a procedure other than GIS-based simulation to reach the study objective would have been extremely labour-intensive and limited the number of timber management scenarios that could be tested. With the

models used in this study, a variety of timber management scenarios were tested and many more scenarios could be created. GIS-based simulation allows the repetitive testing of an unrestricted number of timber harvest scenarios of various types. GIS-based simulation is also compatible with the simulation work being done in wood-supply analysis, and it may help to put wildlife on an equal footing with timber management. This would result from the ability to predict quantitatively the effects of any timber management scenario on wildlife habitat as opposed to a qualitative assessment of a management scenario. As increased emphasis is placed on long-term studies covering larger areas, GIS will play a greater role in data storage and analysis (Johnson, 1990). The GIS used in this study played a key role in meeting initial study objectives.

There are two possible solutions to the difficult problem of conflicting forest values (Thompson and Welsh, 1993). For two forest values such as marten and timber, a decision must be made with respect to a trade-off where: (1) one resource or the other is assigned primacy, in which case the trade-off is reduced use or presence of one of the resources; or (2) there is a clear effort to manage simultaneously for both resources. Higher timber production costs may result. There is clearly a need for rigorous long-term planning of forest management strategies to ensure that sufficient habitat is in constant supply for the marten population and sufficient levels of

timber are in constant supply for the industry.

RESEARCH NEEDS

Several key research needs were identified in this study. Some were encountered in the literature, and others during model creation, model use, sensitivity testing and field visits. Key research needs include:

- (1) Age suitability in model cover equations
- (2) Female nesting habitat requirements
- (3) Marten use of areas after modified logging
- (4) Relationship of marten to variables in the FRI
- (5) Spatial habitat requirements of marten populations
- (6) Field testing of the marten habitat model
- (7) Delayed harvest of black spruce stands

Age suitability in model cover equations

Habitat forecasts appeared very sensitive to alterations of the age curves in the cover equations. Because the shifts to the curves are small (only 10 years), it does raise concerns that the original curves are properly representing marten habitat. Field testing may be able to address this.

Female Nesting Habitat Requirements

There is a general lack of knowledge regarding female nesting habitat

requirements in the literature. Female marten with kits have decreased home ranges and must concentrate their hunting efforts near the nest. Therefore these areas must be of optimal quality, and the fewer of these there are, the harder it will be for females to survive and rear kits. A parameter exists in the model assigning a bonus to stands of suitable quality for denning. From the sensitivity analysis, simulation results are sensitive to changes in this parameter. This suggests that some research should be directed at nesting requirements.

Marten Use Of Areas After Modified Logging

Modified logging was simulated in this study only from a silvicultural perspective. In the short term marten could be highly susceptible to predation in these areas (Thompson, 1993a). However, it will likely be an improvement over conventional clearcut logging allowing an area to regenerate quickly with a stand structure more similar to one resulting from natural disturbance. If this harvest method is indeed beneficial to marten, it will improve the future forecasts of habitat supply. Marten may use areas after modified logging earlier than sites receiving intensive silviculture. Research should determine the use of areas after modified logging. Work is currently underway in Newfoundland (Bissonette, 1993).

Relationship Of Marten To Variables In The FRI

It was surprising to discover after initiating this project that although marten habitat use data had been collected in Ontario, few links had been made between stand descriptions in the FRI and marten. Marten tracking is underway in the Timmins region. This work will also establish links to the Forest Ecosystem Classification. Field work should also determine the structure of habitat being used by marten. Bissonette (1993) suggested that structure, not tree species, may be guiding marten habitat selection.

Spatial Habitat Requirements Of Marten Populations

While it is important and informative to compare the amounts of habitat in the various HSI classes for the different scenarios, it is necessary to go further than this and determine spatially how accessible and useable this habitat is. One potential weakness of this study is that measurements in terms of proximity and size of good habitat were not made. According to Thompson and Welsh (1993) minimum viable population size translates to the maintenance in mature age classes of 25,000 ha to 40,000 ha of prime forested land, based on home ranges reported for Ontario. The results from this study suggest that the Timmins Forest may meet the minimum requirements, but proximity needs to be considered.

Eventually, the ideal would be for forest managers to plan at the landscape

level where optimal habitat should occur. The model may forecast a gross abundance of excellent habitat but if the areas are not large or contiguous, then the total amount may not truly represent habitat suitability for marten. While determining the worth of future habitat based on its spatial context is difficult, it is highly desirable in future exercises of this sort.

Field Testing Of The Marten Habitat Model

Unfortunately, little testing of previously developed marten habitat models has taken place, although it is doubtful that they have played a major role in past decision-making that affected marten habitat. Efforts in Alberta (Bonar, 1990), New Brunswick (NBDNRE, 1990) and this study in Ontario are attempting to correct this problem. Initial models have been created in these areas, and testing and application of these models is currently underway.

Delayed harvest of black spruce stands

A timber harvest strategy designed to delay the harvest of black spruce stands, was simulated in this study. While the results were encouraging in the first 20 years of the simulation, the strategy did not work over the long term. This was due to the age class and volume structure of the Timmins Forest. However, these initial results were encouraging and further efforts should be made in this area to design a strategy effective over the long

term. Even so, this strategy would only be useful as a planning tool, and actual implementation of such a strategy also requires further study.

LITERATURE CITED

- Allen, A.W. 1984. Habitat suitability index models: marten. FWS/OBS-82/10.11 Revised. United States Department of the Interior. Fish and Wildlife Service, Fort Collins, Colorado. 13 pp.
- Allen, A.W. 1987. The relationship between habitat and furbearers. pp. 164-179 *in* M. Novak, J. A. Baker, M. E. Obbard and B. Malloch (editors), *Wild Furbearer Management and Conservation in North America*. Ontario Ministry of Natural Resources, Toronto, Ontario.
- Baskerville, G.L. 1986. An audit of management of the crown forests of Ontario. Ontario Ministry of Natural Resources, Toronto, Ontario. 97 pp.
- Baskerville, G.L. 1991. Designer habitats: edge, carrying capacity, diversity, etc. pp. 35-40 *in* J.P. Martel, R. Bonar (co-chairs), *Wildfor 91 - Wildlife and Forestry: Towards a Working Partnership*. Canadian Pulp and Paper Association, Montreal, Quebec.
- Beanlands, G.E. and P.N. Duinker. 1983. An ecological framework for environmental impact assessment in Canada. Institute for Resource and Environmental Studies, Dalhousie University, Halifax, Nova Scotia. 132 pp.
- Bergerud, A.T. 1969. The status of pine marten in Newfoundland. *Canadian Field-Naturalist* 83:128-131.
- Bissonette, J.A., R.J. Fredrickson and B.J. Tucker. 1989. American marten: a case for landscape-level management. 54th North American Wildlife and Natural Resources Conference 54:89-101.
- Bissonette, J.A. 1993. Personal communication.
- Bonar, R., R. Quinlan, T. Sikora, D. Walker and J. Beck. 1990. Integrated timber and wildlife management on Weldwoods Hinton Forest Management Agreement. Weldwood of Canada Ltd., Hinton, Alberta. Unpublished manuscript.

- Brassard, J.A. and R. Bernard. 1939. Observations on breeding and development of marten. *The Canadian Field-Naturalist* 53:15-21.
- Brown, E.R. (Technical Editor). 1985. Management of wildlife and fish habitats in forests of western Oregon and Washington. U.S. Department of Agriculture, Portland, Oregon. 332 pp.
- Bryman, A. and D. Cramer. 1990. Quantitative data analysis for social scientists. Routledge, Toronto, Ontario. 290 pp.
- Burnett, G.W. 1981. Movements and habitat use of American marten in Glacier National Park, Montana. M.Sc. Thesis. University of Montana, Missoula, Montana. 130 pp.
- Burt, W.H. 1976. Peterson field guide to the mammals. Houghton Mifflin Company, Boston, Massachusetts. 289 pp.
- Buskirk, S.W. 1983. The ecology of marten in southcentral Alaska. Ph.D. Dissertation. University of Alaska, Fairbanks, Alaska. 131 pp.
- Buskirk, S.W. 1984. Seasonal use of resting sites by marten in south-central Alaska. *Journal of Wildlife Management* 48:950-953.
- Buskirk, S.W. and H.J. Harlow. 1989. Body-fat dynamics of the American marten (*Martes americana*) in winter. *Journal of Mammalogy* 70:191-193.
- Buskirk, S.W., H.J. Harlow and S.C. Forrest. 1988. Temperature regulation in American marten in winter. *National Geographic Research* 4:208-218.
- Buskirk, S.W., S.C. Forrest, M.G. Raphael and H.J. Harlow. 1989. Winter resting site ecology of marten in the central rocky mountains. *Journal of Wildlife Management* 53:191-196.
- Buskirk, S.W. and S.O. MacDonald. 1984. Seasonal food habits of marten in south-central Alaska. *Canadian Journal of Zoology* 62:944-950.
- Clark, T.W. 1975. Analysis of pine-marten population organization and regulatory mechanisms in Jackson Hole, Wyoming. *National Geographic Society Research Report* 16:131-143.

- Clark, T.W. and T.M. Campbell. 1977. Short-term effects of timber harvests on pine marten behaviour and ecology. Idaho State University, Pocatello, Idaho. 60 pp.
- Cowan, I.M. and R.H. MacKay. 1950. Food habits of the marten (*Martes americana*) in the rocky mountain region of Canada. Canadian Field-Naturalist 64:100-104.
- COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 1986. Minutes of annual meeting. Canadian Wildlife Service, Secretariat, Ottawa. Unpublished Manuscript. (Cited in Thompson, 1991).
- Davis, D.H. 1978. Reintroduction of the pine marten into the Nicolet National Forest County, Wisconsin. M.Sc. Thesis. University of Wisconsin, Stevens Point, Wisconsin. 64 pp.
- de Vos, A. 1952. Ecology and management of fisher and marten in Ontario. Ontario Department of Lands and Forests, Toronto, Ontario. 90 pp.
- Duinker, P.N. 1989. Wildlife in forest management: from constraint to objective. pp. 133-144 in R.F. Calvert, B. Payandeh, M.F. Squires, W.D. Baker (co-chairs). Ontario Forest Research Committee Symposium Proceedings O-P-17 Forest investment: a critical look, Thunder Bay, Ontario, November 15-16 1988.
- Duinker, P.N. 1991. Lecture notes: forest management science I - 5650. Lakehead University, Thunder Bay, Ontario. 4 pp.
- Duinker, P.N. and G.L. Baskerville. 1986. A systematic approach to forecasting in environmental impact assessment. Journal of Environmental Management 23:271-290.
- ESRI. 1991. Understanding GIS: the ARC/INFO method. Environmental Systems Research Institute, Inc. Redlands, California. 347 pp.
- Farmer, A.H., M.J. Armbruster, J.W. Terrell and R.L. Schroeder. 1982. Habitat models for land-use planning: assumptions and strategies for development. 47th North American Wildlife Conference 47:47-56.
- Francis, G.R. and A.B. Stephenson. 1972. Marten ranges and food habits in Algonquin Provincial Park, Ontario. Report #91. Ontario Ministry of Natural Resources, Toronto, Ontario. 53 pp.

- Freund, J.E. and F.J. Williams. 1977. Elementary business statistics: the modern approach. Prentice-Hall, Toronto, Ontario. 560 pp.
- Greig, L.A., P.N. Duinker, C.H.R. Wedeles and P. Higgelke. 1991. Habitat supply analysis and modelling: state of the art and feasibility and implementation in Ontario. Report No. 91-403.2. Prepared for Ontario Ministry of Natural Resources. Environmental and Social Systems Analysts Ltd., Richmond Hill, Ontario. 81 pp.
- Hagmeir, E.M. 1956. Distribution of marten and fisher in North America. Canadian Field-Naturalist 70:149-168.
- Hansen, A.J., T.A. Spies, F.J. Swanson and J.L. Ohmann. 1991. Conserving biodiversity in managed forests. Bioscience 41:382-392. (*Cited in* Thompson and Welsh, 1993).
- Hargis, C.D. 1982. Winter habitat utilization and food habits of pine martens in Yosemite National Park. Technical Report No. 6. University of California, Berkeley, California. 59 pp.
- Hargis, C.D. and D.R. McCullough. 1984. Winter diet and habitat selection of marten in Yosemite national park. Journal of Wildlife Management 48:140-146.
- Hawley, V.D. and F.E. Newby. 1957. Marten home ranges and population fluctuations. Journal of Mammalogy 38:174-184.
- Holling, C.S. (editor). 1978. Adaptive environmental assessment and management. John Wiley & Sons, Toronto, Ontario. 377 pp.
- Jackson, G.L., G.D. Racey, J.G. McNicol and L.A. Godwin. 1991. Moose habitat interpretation in Ontario. Northwestern Ontario Forest Technology Development Unit Technical Report #52, Ontario Ministry of Natural Resources, Thunder Bay, Ontario. 74 pp.
- Johnson, L.B. 1990. Analyzing spatial and temporal phenomena using geographical information systems. Landscape Ecology 4:31-43.
- Kansas, J.L. and R.M. Raine. 1990. Habitat modelling in the wildlife sector. pp. 128-134 *in* B.J. Boughton, J.K. Samoil (editors), Forest Modeling Symposium. Forestry Canada, Edmonton, Alberta.

- Koehler, G.M. and M.G. Hornocker. 1977. Fire effects on marten habitat in the Selway-Bitterroot Wilderness. *Journal of Wildlife Management* 41:500-505.
- Koehler, G.M., W.R. Moore and A.R. Taylor. 1975. Preserving the pine marten: management guidelines for western forests. *Western Wildlands* 2:31-36.
- Laymon, S.A. and R.H. Barrett. 1986. Developing and testing habitat capability models: pitfalls and recommendations. pp. 87-91 *in* J. Verner, M.L. Morrison and C.J. Ralph (editors), *Wildlife 2000: Modelling Habitat Relationships of Terrestrial Vertebrates*
- Lensink, C.J. 1953. An investigation of the marten in interior Alaska. M.Sc. Thesis. University of Alaska, Fairbanks, Alaska. 89 pp.
- Levins, R. 1968. Evolution in changing environments - some theoretical explorations. Princeton University Press, Princeton, New Jersey. 120 pp.
- Lofroth, E.C. and J.D. Steventon. 1990. Managing for marten winter habitat in interior forests of British Columbia. pp. 67-75 *in* A. Chambers (editor), *Wildlife Forestry Symposium: a workshop on resource integration for wildlife and forest managers*. Forestry Canada, Prince George, British Columbia.
- Majone, G. and E.S. Quade (editors). 1980. Pitfalls of analysis. John Wiley & Sons, Toronto, Ontario. 213 pp.
- Major, J.T. 1979. Marten use of habitat in a commercially clear-cut forest during summer. M.A. Thesis. School of Wildlife Management, University of Maine at Orono, Orono, Maine. 31 pp.
- Marshall, W.H. 1951. Pine marten as a forest product. *Journal of Forestry* 49:899-905.
- Martelle, M. 1990. Potential responses of marten habitat carrying capacity effects to future timber harvests in a northern Ontario forest. Northwestern Ontario Forest Technology Development Unit Miscellaneous Report #06, Ontario Ministry of Natural Resources, Thunder Bay, Ontario. 80 pp.

- Martin, S.K. and R.H. Barrett. 1983. The importance of snags to pine marten habitat in the northern Sierra Nevada. pp. 114-116 *in* J.W. Davis, G.A. Goodwin and R.A. Ockenfils (editors), Symposium Proceedings, Snag Habitat Management. General Technical Report RM-99, USDA Forest Service, Flagstaff, Arizona.
- Masters, R.D. 1980. Daytime resting sites of two Adirondack pine martens. *Journal of Mammalogy* 61:157.
- Mech, L.D. and L.L. Rogers. 1977. Status, distribution, and movements of martens in northeastern Minnesota. Research Paper NC-143. USDA, Forest Service, 7 pp.
- Meslow, C.E., C. Maser and J. Verner. 1981. Old-growth forests as wildlife habitat. *Transactions: North American Wildlife and Natural Resources Conference* 62:329-335.
- Mitton, J.B. and M.G. Raphael. 1990. Genetic variation in the marten (*Martes americana*). *Journal of Mammalogy* 71:195-197.
- Moore, T.G.E. and C.G. Lockwood. 1990 The HSG wood-supply model: description and user's manual. Information Report PI-X-98. Petawawa National Forestry Institute, Chalk River, Ontario. 31 pp.
- More, G. 1978. Ecological aspects of food selection in pine marten (*Martes americana*). M.A. Thesis. Department of Zoology, University of Alberta, Edmonton, Alberta. 94 pp.
- Morrison, M.L., B.G. Marcot and R.W. Mannan. 1992. Wildlife habitat relationships: concepts and applications. University of Wisconsin Press, Madison, Wisconsin. 343 pp.
- NBDNRE. 1990. Forest land management in New Brunswick: Progress Report. Fish and Wildlife Branch, New Brunswick Department of Natural Resources and Energy, Fredericton, New Brunswick. 61 pp.
- OMNR. 1978. Forest Inventory Procedure for Ontario (3rd ed.). Ontario Ministry of Natural Resources, Toronto, Ontario. 31 pp.
- OMNR. 1988. Timber management guidelines for the provision of moose habitat. Ontario Ministry of Natural Resources, Toronto, Ontario. 33 pp.

- OMNR. 1992. Ontario forest products and timber resource analysis. Volume I. Ontario Ministry of Natural Resources, Sault Ste. Marie, Ontario. 201 pp.
- QOPC. 1988. Timber management plan for the Timmins Forest FMA #501800, 1988-1993. Quebec and Ontario Paper Company, South Porcupine, Ontario. 200 pp.
- QOPC. 1992. National round table on the environment and the economy: forest tour. Quebec and Ontario Paper Company, South Porcupine, Ontario. 27 pp.
- Quick, H.F. 1955. Food habits of marten (*Martes americana*) in northern British Columbia. *Canadian Field-Naturalist* 69:144-147.
- QUNO Corporation. 1993. Timber management plan for the Timmins Forest FMA #501800, 1993-1998. Quebec and Ontario Paper Corporation, South Porcupine, Ontario. 200 pp.
- Raine, R.M. 1981. Winter food habits, responses to snow cover and movements of fisher (*Martes pennanti*) and marten (*Martes americana*) in southeastern Manitoba. M.Sc. Thesis. University of Manitoba, Winnipeg, Manitoba. 144 pp.
- Raine, R.M. 1983. Winter habitat use and responses to snow cover of fisher (*Martes pennanti*) and marten (*Martes americana*) in southeastern Manitoba. *Canadian Journal of Zoology* 61:25-34.
- Raphael, M.G., L.F. Ruggiero and S.E. Henry. 1991. Habitat selection by marten in the Sierra Madre Range, Wyoming. p. 69 *in* Abstracts of Presentations: The Biology and Management of Martens and Fishers, University of Wyoming, Laramie, Wyoming. (Abstract).
- Ritter, A.F. 1985. Preliminary habitat suitability index model for marten in Maine. Maine Department of Inland Fisheries and Wildlife, Augusta, Maine. 21 pp.
- Schamberger, M.L. and L.J. O'Neil. 1988. Concepts and constraints of habitat-model testing. pp. 5-10 *in* J. Verner, M.L. Morrison and C.J. Ralph (editors), *Wildlife 2000: Modelling Habitat Relationships of Terrestrial Vertebrates*
- Schulz, T.T. and L.A. Joyce. 1992. A spatial application of a marten habitat model. *Wildlife Society Bulletin* 20:74-83.

- Seton, E.T. 1953. Lives of game animals, volume 2, part 2. Charles T. Branford Company, Boston, Massachusetts. 378 pp. (*Cited in Strickland and Douglas, 1987*).
- Simon, T.L. 1980. An ecological study of the marten in the Tahoe National Forest, California. M.Sc. Thesis. Department of Biology, California State University, Sacramento, California. 143 pp.
- Slough, B.G. 1989. Movements and habitat use by transplanted marten in the Yukon Territory. *Journal of Wildlife Management* 53:991-997.
- Snyder, J.E. and J.A. Bissonette. 1987. Marten use of clear-cuttings and residual forest stands in western Newfoundland. *Canadian Journal of Zoology* 65:169-174.
- Soutiere, E.C. 1979. Effects of timber harvesting on marten in Maine. *Journal of Wildlife Management* 43:850-860.
- Spencer, W.D. 1981. Pine marten habitat preferences at Sagehen Creek, California. M.Sc. Thesis. University of California, Berkeley, California. 121 pp.
- Spencer, W.D. 1987. Seasonal rest-site preferences of pine martens in the northern Sierra Nevada. *Journal of Wildlife Management* 51:616-621.
- Spencer, W.D., R.H. Barrett and W.J. Zielinski. 1983. Marten habitat preferences in northern Sierra Nevada. *Journal of Wildlife Management* 47:1181-1186.
- Starfield, A.M. and A.L. Bleloch. 1988. Building models for conservation and wildlife management. Macmillan, New York, New York. 253 pp.
- Steventon, J.D. 1979. Influence of timber harvesting upon winter habitat use by marten. M.A. Thesis. School of Wildlife Management, University of Maine at Orono, Orono, Maine. 24 pp.
- Steventon, J.D. and J.T. Major. 1982. Marten use of habitat in a commercially clear-cut forest. *Journal of Wildlife Management* 46:175-182.

- Storm, G.L. and W.M. Tzilkowski. 1982. Furbearer population dynamics: a local and regional management perspective. pp. 69-90 *in* G. C. Sanderson (editors), Symposium Proceedings, Midwest Furbearer Management. 43 rd Midwest Fish and Wildlife Conference, Wichita, Kansas.
- Strickland, M.A. and C.W. Douglas. 1987. Marten. pp. 530-546 *in* M. Novak, J.A. Baker, M.E. Obbard and B. Malloch (editors), Wild Furbearer Management and Conservation in North America. Ontario Ministry of Natural Resources, Toronto, Ontario.
- Suring, L.H., D.A. Anderson, E.J. Degayner, R.W. Flynn, M.L. Orme, R.E. Wood and E.L. Young. 1988. Habitat capability model for marten in southeast Alaska: winter habitat. Review Draft. USDA, Forest Service, Juneau, Alaska. 26 pp.
- Swartzman, G.L. and S.P. Kaluzny. 1987. Ecological simulation primer. Macmillan Publishing, New York, New York. 370 pp.
- Taylor, M.E. and N. Abrey. 1982. Marten (*Martes americana*) movements and habitat use in Algonquin Provincial Park, Ontario. Canadian Field-Naturalist 96:439-447.
- Thomas, J.W. 1979a. Preface. pp. IV-V *in* J.W. Thomas (editor), Wildlife habitats in managed forests - the Blue Mountains of Oregon and Washington. Handbook #553. United States Department of Agriculture, Washington, D.C. 512 pp. (*Cited in* Thomas, 1982).
- Thomas, J.W. 1979b. Wildlife habitats in managed forests: the Blue mountains of Oregon and Washington. U.S. Department of Agriculture and Forests, Portland, Oregon. 512 pp.
- Thomas, J.W. 1982. Needs for and approaches to wildlife habitat assessment. 47th North American Wildlife Conference 47:35-46.
- Thomasma, L.E. 1988. A test of the habitat suitability index model for the fisher (*Martes pennanti*) in the upper peninsula of Michigan. M.Sc. Thesis. Michigan Technological University, 23 pp.
- Thompson, I.D. 1986. Diet choice, hunting behaviour, activity patterns, and ecological energetics of marten in natural and logged areas. Ph.D. Dissertation. Queens University, Kingston, Ontario. 179 pp.

- Thompson, I.D. 1988. Habitat needs of furbearers in relation to logging in boreal Ontario. *Forestry Chronicle* 63:251-261.
- Thompson, I.D. 1991. Could marten become the spotted owl of eastern Canada? *Forestry Chronicle* 67:136-140.
- Thompson, I.D. 1993a. Marten populations in mature and post-logging boreal forest in Ontario. *Journal of Wildlife Management* (In press).
- Thompson, I.D. 1993b. Marten activity in mature and post-logging boreal forest in Ontario. *Journal of Wildlife Management* (In press).
- Thompson, I.D., I.J. Davidson, S. O'Donnell and F. Brazeau. 1989. Use of track transects to measure the relative occurrence of some boreal mammals in uncut forest and regeneration stands. *Canadian Journal of Zoology* 67:1816-1823.
- Thompson, I.D. and D.A. Welsh. 1993. Integrated resource management in boreal forest ecosystems - impediments and solutions. *Forestry Chronicle* 69:32-39.
- U.S. Fish and Wildlife Service. 1980. Habitat as a basis for environmental assessment. *Ecological Services Manual* 101. United States Department of the Interior, Fish and Wildlife Service, Division of Ecological Services. Government Printing Office, Washington, D.C. 32 pp. (*Cited in* Thomasma, 1988).
- U.S. Fish and Wildlife Service. 1981. Standards for the development of suitability index models. *Ecological Services Manual* 103. United States Department of the Interior, Fish and Wildlife Service, Division of Ecological Services. Government Printing Office, Washington, D.C. 68 pp. (*Cited in* Thomasma, 1988).
- Walters, C. 1986. *Adaptive management of renewable resources*. Macmillan Publishing Company, New York, New York. 374 pp.
- Walters, C.J. and C.S. Holling. 1990. Large-scale management experiments and learning by doing. *Ecology* 71:2060-2068.
- Watt, R. 1991. An analysis of FRI as a basic inventory for habitat supply modelling in Ontario. p.20 *in* Abstracts from Forest Planning: the leading edge. Ontario Forestry Research Committee, Toronto, Ontario. (Abstract).

- Wedeles, C.H.R., P.N. Duinker and M.J. Rose. 1991. Wildlife habitat management strategies: a comparison of approaches for integrating habitat management and forest management. Prepared for the Ontario Ministry of Natural Resources by ESSA Ltd., Richmond Hill, Ontario. 66 pp.
- Williams, J. 1987. Forest management and access: harvest allocation options and their impact on road expenditures (a simulation study). Volume 2, Science and Technology Series, Ontario Ministry of Natural Resources, Toronto, Ontario. 67 pp.
- Williams, R. 1993. Personal communication.
- Worthen, G.L. and D.L. Kilgore. 1981. Metabolic rate of pine marten in relation to air temperature. *Journal of Mammalogy* 62:624-628.
- Wynne, K.M. and J.A. Sherburne. 1984. Summer home range use by adult marten in northwestern Maine. *Canadian Journal of Zoology* 62:941-943.
- Young, R.K. and D.J. Veldman. 1972. *Introductory statistics for the behavioural sciences*. Holt, Rinehart and Winston. Toronto, Ontario. 559 pp.
- Zielinski, W.J. 1981. Food habits, activity patterns and ectoparasites of the pine marten at Sagehen Creek, California. M.Sc. Thesis. University of California, Berkeley, California. 121 pp.

APPENDICES

APPENDIX I

A COMPARISON OF EXISTING MARTEN HSI MODELS

	ALLEN (1987) UNITED STATES	MARTIN (1990) ONTARIO	BOMAN (1990) ALBERTA	STANG ET AL (1988) ALASKA	NEW BRUNSWICK DEPARTMENT OF NATURAL RESOURCES (1990)	WITTER (1993) WAHNE
HABITAT MAP VARIABLES	- X CANOPY CLOSURE - X CANOPY COVERED OF FR/SR/PLICE - SUCCESSIONAL STAGE - X GROUND COVERED BY DOWNFALL	- X STOCKING - COVER TYPES - DEVELOPMENT STAGE	- X SPRUCE/FIR COMPOSITION - TREE HEIGHT - X GROUND COVERED BY CWD (0.7-8 CM DIAMETER) - X CANOPY CLOSURE	- ROAD DENSITIES - STAND SIZE CLASSES (AGE) - HABITAT DESCRIPTION - ELEVATION - CLASSES OF VOLUME IN OLD GROWTH	- CROWN CLOSURE (MCH/DIV) - DEVELOPMENT STAGE - FOREST UNIT	- CANOPY CLOSURE - X SOFTWOOD BALSAM AREA - STAND SIZE CLASS - PREY INDEX (FROM TOLE HSA) - DEAD TREES AND SNAGS - DEN INDEX (STAND SIZE)
SUITABILITY INDEXES DERIVED FROM	- GROUPS OF HABITAT VARIABLES VS HABITAT SUITABILITY SI = $(V1+V2+V3+V4+V5)$	- HABITAT SUITABILITY MATRIX	- GROUPS OF HABITAT VARIABLES VS HABITAT SUITABILITY HS = $(S1+S2+S3+S4+S5)$	- HABITAT SUITABILITY MATRIX AND GRAPH	- GROUPS OF HABITAT VARIABLES VS HABITAT SUITABILITY	- GROUPS OF HABITAT VARIABLES VS HABITAT SUITABILITY
MODEL EQUATION	- SI = $(V1+V2+V3+V4+V5)$	- HABITAT SUITABILITY MATRIX	HS = $(S1+S2+S3+S4+S5)$	- MULTPLY APPROPRIATE HS VALUES TOGETHER FOR A SITE TO OBTAIN OVERALL INDEX VALUE	- EQUATION FOR IDEAL COVER AND FOOD COMPONENTS HSI PLOT = $(COVER + FOOD) / 4$	
RATING VARIABLES IN EQUATION (HS=0)	- < 25% CANOPY CLOSURE - SUCCESSIONAL STAGE (SPRUE-SETTLING)	- COVER TYPE (7%) - YOUNG DEVELOPMENT STAGE WITH STOCKING < 0.5	- CANOPY CLOSURE < 30% - TREE HEIGHT < 5m	- ELEVATION > 560 m - HABITAT = NONFOREST	- CANOPY CLOSURE < 25% - NON-FORREST PLOTS - PLOT CONTAINING > 3 EDGES - OF NON-FORREST	
MODEL OUTPUT	- SI = WINTER COVER VALUE (0-1)	- MAPS, GROUPS SHOWING CARRYING CAPACITY OF WANTEN OVER 25 YEARS	- HS = WINTER COVER VALUE (0-1)	- HS = WINTER COVER VALUE (0-1)	- HSI = (0-1) FOR FEMALE MARTEN IN WINTER	
SEASON OF MODEL	- WINTER	- NOT SEASONAL	- WINTER	- WINTER	- WINTER	
MINIMUM HABITAT AREA FOR MARTEN	- MINIMUM = 2.25 HAZ. < 2.55 HAZ. HS = 0	- NO MINIMUM SET	- MINIMUM = 15.0 HA	- NO MINIMUM SET	- NO MINIMUM SET	- MINIMUM = 4 HAZ
DENSITY ASSUMED BY MODEL	- NOT RELATED TO DENSITY	- HSI TRANSLATED DIRECTLY INTO CARRYING CAPACITIES	- HS 1.0 = 2.0/HAQ MARTEN (LINEAR RELATIONSHIP)	- HS 1.0 = 1.8/HAQ MARTEN	- HS 1.0 = 0.8 - 0.4 MARTEN	- NO DENSITY VALUES
MATHEMATICAL TOOLS REQUIRED (GIS)	- NONE	- FORMAN - GIS	- ATLAS - WOOD SUPPLY MODEL - GIS IN FUTURE	- NONE	- FORMAN11/FORMAN12 - GIS	- NONE
TEMPORAL/SPATIAL OUTPUT	- NEITHER (TEMPORAL ?)	- BOTH	- NOT SPATIAL/MAY BE RECALCULATED OVER TIME	- NEITHER	- BOTH	- SPATIAL
ASSUMPTIONS IN MODEL	- FOOD AVAILABILITY NOT LIMITING IF ADEQUATE COVER PRESENT	-	- ASSUME SUMMER HABITAT REQUIREMENTS ARE MET IF WINTER HABITAT IS PRESENT	- MODEL ASSUMES TO BE RELATED TO LONG-TERM CARRYING CAPACITY	- ASSUME A 1:1 LINEAR RELATIONSHIP BETWEEN HSI VALUE/CARRYING CAPACITY	
VERIFICATION DONE	- REVIEWED ONLY	- REVIEWED ONLY	- REVIEWED ONLY	- REVIEWED ONLY	- IN PROCESS OF TESTING FOR 1997 PLANNING	- REVIEWED BY BIOLOGISTS - NOT FIELD TESTED

APPENDIX II

A LITERATURE REVIEW OF MARTEN FOOD REQUIREMENTS,
HOME RANGE AND POPULATION SIZES, AND MANAGING FOR
TIMBER AND MARTEN

FOOD REQUIREMENTS

Considerable research into marten food requirements has been undertaken (see Table 1), including studies in: Alaska (Lensink *et al.*, 1955; Buskirk and MacDonald, 1984); Alberta (More, 1978); British Columbia (Cowan and MacKay, 1950; Quick, 1955; Nagorsen *et al.*, 1989); California (Spencer and Zielinski, 1983; Zielinski *et al.*, 1983; Hargis and McCullough, 1984); Idaho (Koehler *et al.*, 1975); Maine (Soutiere, 1979); Manitoba (Raine, 1987); Montana (Weckwerth and Hawley, 1962); Newfoundland (Bateman, 1986); Northwest Territories (Herman and Fuller, 1974; More, 1978; Douglass *et al.*, 1983); Ontario (Francis and Stephenson, 1972; Thompson, 1986); Wyoming (Murie, 1961); and the Yukon (Slough *et al.*, 1989).

Table 1. Food habits of marten. Source: Lofroth and Steventon, 1990.

Source (methods)	Small mammals (voles, shrews, mice)	Larger mammals	Ungulates	Birds	Reptiles/ Amphibians/ Fish	Insects	Plant parts
Buskirk & MacDonald (1984) (% volume of scat and colon contents)	71.0	13.2	2.3	4.9	0.4	-	5.7
Cowan & McKay (1950) (% of food in scats and stomach contents)	63.3	14.4	0.3	4.3		5.2	5.5
Francis & Stephenson (1972) (% of items in scats)	30.6-60.4	1.4-19.3	0.0-3.1	4.6-20.4	0.0-2.0	3.0-11.7	0.0-41.9
Hargis & McCullough (1984) (% volume of scats)	10.0-49.0	32.0-55.0	< 1	4.0-7.0	0.0-1.0	<1	7.0-11.0
Lensink <i>et al.</i> (1955) (% of items in scats and diges- tive tracts)	73.0	< 1	< 1	10.0			17.0
Slough <i>et al.</i> (1989) (% frequency in scats)	77.9	16.4	0.7	10.7		4.4	16.8
Zielinski <i>et al.</i> (1983) (% volume of scats)	35.0	39.6	1.2	5.3	0.1	2.9	2.0

Rabbit and Hare

Marten are known by the Cree name *wabachis* (meaning rabbit chaser), reflecting the fact that snowshoe hare can be an important prey item of marten (Strickland and Douglas, 1987). Cowan and MacKay (1950) suggested, however, that snowshoe hare are not necessarily an important item in the diet of marten. Thompson (1986), working in northern Ontario, found that hare when abundant are indeed important, providing as much as 85% of marten winter caloric intake. Comparisons between good and poor food years showed significantly more hare were preyed upon when abundant, and more hare taken in late winter compared to other seasons (Thompson, 1986).

Snowshoe hare are of increased importance to marten in the winter months and their use was noted in several winter studies (Marshall, 1946; Lensink *et al.*, 1955; Quick, 1955; Zielinski *et al.*, 1983; Thompson, 1986; Raine, 1987; Slough, 1989). Some studies were in areas of low hare populations, suggesting marten were actually seeking out hare. Bateman (1986) found hare to be the most important winter prey species in western Newfoundland, possibly because only one species of microtine was available in the area. Marten followed tracks and investigated resting areas of jack rabbit (*Lepus townsendi*) in Yosemite National Park (Hargis and McCullough, 1984). Quick (1955) found that one male marten exploited a localized hare population and had an 85.6% frequency of hare in its diet. Raine (1987) found marten having a high frequency of hare in their diet (58.9%). Marten tended to frequent coniferous ridges in all winter periods, as the snowshoe hare was often more susceptible to attack while resting in

the thick conifer regeneration on these ridges (Raine, 1983). An important difference between uncut and cutover areas is the greater encounter and prey-capture rates observed for marten in uncut forest (Thompson, 1993a).

Habitat Associations

The snowshoe hare exhibits tremendous population fluctuations which can influence habitat use. Snowshoe hare favour habitats of small black spruce thickets, alder at the edges of bogs, and areas of dense trembling aspen (*Populus tremuloides* Michx.) and white birch (*Betula papyrifera* Marsh.) (Keith, 1966; Wolff, 1980; Pietz and Tester, 1983). The overall preference for lowland and edge types probably reflects year-round availability of both cover and browse, suggesting these habitats are critical for snowshoe hare (Pietz and Tester, 1983). Vozech and Cumming (1960) found hare browsing more frequently in mixedwood forests than coniferous forests in winter. Conroy *et al.* (1979), working in lower Michigan, suggested that high densities of hare will not be found in areas farther than 200 to 400 m from cedar/fir cover, and high densities are less likely to be found in solidly canopied areas than in areas with high habitat interspersion. Gaps within uncut forest provide sufficient habitat to support hare at levels only slightly lower than those in cutovers (Thompson *et al.*, 1989). Apparently, a wide variety of forest types can be utilized if adequate cover is available (Carreker, 1985).

In New Brunswick, hare preferred spruce plantations 11 to 16 years old in both summer and winter (Parker, 1984). Winter habitat use was correlated with the use (food) of deciduous tree and shrub twigs ≤ 2 m high and the availability (cover) and use (food) of conifer twigs ≤ 2 m high (Parker, 1984). Monthey (1986) found greater use by hare of the 12 to 15

year old clearcut stage, likely due to the availability of dense, sapling cover. Within the commercially clearcut forest, Monthey (1986) determined that hare activity was greatest in areas with high juxtaposition of browse and cover, and least in large clearcuts with little sapling cover above the snow. Resource managers must consider that hare may not recolonize clearcuts until 6-7 years after cutting, and that it may take 20-25 years for hare densities to reach their highest levels (Litvaitis *et al.*, 1985).

Snowshoe hare have little difficulty surviving during the summer when cover is plentiful and grasses and shrubs are abundant. During winter, however, when snow covers low-growing plants, conditions become critical for hare as they must feed on shrubs and seedlings exposed above the snow surface (Koehler and Brittell, 1990). In Ontario, Vozech and Cumming (1960) found hare feeding on pin cherry (*Prunus pensylvanica*), mountain ash (*Sorbus americana*), mountain maple (*Acer spicatum* Lam.) and white birch in winter. Where snow depths reach 0.9-1.2 m, trees and shrubs must be 1.8-2.4 m tall (Wolfe *et al.*, 1982) and < 1.3 cm in diameter (Koehler, 1990).

Besides browse, hare need habitat that offers protection from predators and extreme cold (Koehler and Brittell, 1990). Dense softwood understories support hare densities greater than do hardwood stands because softwoods provide hare with superior cover from predators and climatic extremes (Litvaitis *et al.*, 1985). Hare may actually select habitat where security and thermal cover is abundant even if browse is limited (Monthey, 1986). Extremely dense stands (> 16200 stems/ha) may be of little use to hare if understorey cover and browse is sparse (Litvaitis *et al.*, 1985). Stands with 425-1195 stems/ha lack adequate thermal and security cover and would be of little use to hare (Koehler, 1990). As stands become older (greater than 20 to 30 years old) and stem density

declines, security cover and forage production diminish (Koheler, 1990). Snowshoe hare pellet counts in Nova Scotia spruce-fir forest showed that hare use is lower where trees are taller than 12 m and where canopies are denser than 60% (Orr and Dodds, 1982). Mature forests do not generally support snowshoe hare (Koehler, 1990), although overmature forests containing openings in the canopy with coniferous and deciduous regeneration do.

During the daytime no-snow seasons, snowshoe hare rest in simple, oval depressions (forms) in the ground litter (Trapp, 1962). In Minnesota, winter forms primarily occurred under snow-laden branches of black spruce, alder and tamarak (*Larix laricina* (Du Roi) K. Koch) (Pietz and Tester, 1983). Natural depressions in the snow around the bases of spruce trees are used less frequently (Trapp, 1962). Snowshoe hare were trapped by marten while resting in forms (Thompson, 1993a).

Rodents and Shrews

The majority of work on marten food requirements shows a preference for small mammals, especially red-backed voles and meadow voles (*Microtus pennsylvanicus*). Shrews (*Sorex* spp.), lemmings (*Lemmus* spp. and *Synaptomys* spp.) and deer mice (*Peromyscus maniculatus*) are preyed upon less frequently. Soutiere (1979) reported that in Maine, marten seldom prey upon deer mice. Nagorsen *et al.* (1989), however, found marten on the Pacific coast to be exploiting populations of deer mice in the winter, contrary to many studies. According to Bateman (1986), marten feed primarily on small mammals in winter.

Quick (1955) found red-backed voles to be the dominant prey species,

occurring with a frequency of 40% in marten scats. Slough (1989) found microtine rodents occurring in 82.3% of the summer scats and 59.5% of the winter scats, with red-backed voles being preferred over lemmings and deer mice. Expressed as percent occurrence, small mammals comprised about 78% and 66% of the diet in summers when prey were abundant and scarce, respectively (Thompson, 1986). Of these, red-backed voles, deer mice and other voles were most important. In winter, the proportion of small mammals declined slightly to about 71% when prey was abundant and 64% when prey was scarce (Thompson, 1987). Red-backed voles were the dominant prey item used by marten in Montana (Weckwerth and Hawley, 1962). Arvicolid rodents were the dominant prey item in south-central Alaska (Buskirk and MacDonald, 1984). Mean percentage frequency of occurrence of small mammals in marten scats was 88%, the highest in any North American study, with northern red-backed voles (*Clethrionomys rutilus*) constituting 53.8% of the total volume of arvicolids.

Buskirk and MacDonald (1984) noted that northern red-backed voles dominated the diet of marten when they and other arvicolids were generally scarce, while tundra voles (*Microtus oeconomus*) and meadow voles were the primary prey when arvicolids were abundant. Lensink *et al.* (1955), Weckwerth and Hawley (1962), Francis and Stephenson (1972), Soutiere (1979), and Douglass *et al.* (1983) also reported higher ratios of *Microtus* spp. to *Clethrionomys* spp. in marten scats than in trapline captures (Buskirk and MacDonald, 1984), demonstrating that marten appear to be selective predators. Hargis and McCullough (1984) observed *Microtus* spp. present in 53% of marten scats for one study period. Weckwerth and Hawley (1962) noted that the slight fluctuations in frequency of occurrence of small mammals in marten scats are more affiliated with high availability and consumption of other foods than with the fluctuations in abundance or

availability of the small mammals.

Zielinski *et al.* (1983) found that insectivores (shrews, and the broad-handed mole (*Scapanus latimanus*)) were eaten intermittently, primarily during summer. Slough *et al.* (1989) found the brown lemming (*Lemmus sibiricus*) to be consumed in a proportion greater than its relative abundance. Brown lemmings exhibited a clumped distribution in meadows, similar to meadow voles (Krebs and Wingate, 1976). This factor, or perhaps its association with a recognizable habitat, might contribute to energy-efficient foraging on the part of marten, and may account for the common use of this species in Alaska.

Habitat Associations

Red-backed voles are commonly associated with mature spruce/fir habitats, their lowest densities being in wet-meadow habitats. Raphael (1988) found voles with greater abundance in stands that had more herb and grass cover, on northerly slopes, and on sites with greater basal area of sub-alpine fir and greater log cover. Buskirk and MacDonald (1984) found red-backed voles to have a relatively even distribution across a wide range of habitat types. Gunderson (1959) found that red-backed voles preferred areas with stumps, rotting logs and roots in loose forest litter for cover and escape routes. Koehler *et al.* (1975) found mesic sites to support high red-backed and meadow vole populations, as these sites contain the dense succulent understorey vegetation required by voles for cover and food. Late-winter trapping indicated activity of red-backed voles around the bases of trees where snow depth was lowest (Ramirez and Hornocker, 1981). During midwinter, northern red-backed voles were found to aggregate in areas where the moss layer was significantly thicker (West, 1977). Deer mice tend to be more abundant on open xeric sites and meadows, and are

commonly associated with cutovers. Deer mice feed on insects, fruit and seeds which are associated with early seral stages.

HOME RANGE

Home-range size is one of the most commonly reported ecological attributes of marten (Buskirk and McDonald, 1989; see Table 2). Thompson (1986) found female ranges significantly smaller than those of males in uncut sites but not in logged areas. Female marten tend to remain in smaller areas than males and to confine their activities to one area throughout a season and from one year to the next (Francis and Stephenson, 1972).

Table 2. Mean home-range sizes of male and female marten in km². (N = number of animals studied). Source: Strickland and Douglas, 1987.

Source	Study Area	Technique	Males	
Females				
Archibald and Jessup (1984)	Yukon	telemetry and mark-recapture	6.2 N = 4	4.7 N = 4
Burnett (1981)	Montana	telemetry	2.9 N = 3	0.7 N = 2
Buskirk (1983)	Alaska	telemetry	6.6 N = 9	3.7 N = 3
Clark and Campbell (1977)	Wyoming	telemetry	2.0 N = 2	0.8 N = 1
Davis (1978)	Wisconsin	telemetry		7.7-8.2 N = 2
Francis and Stephenson (1972)	Ontario	mark-recapture	3.6 N = 4	1.1 N = 4
Hawley and Newby (1957)	Montana	mark-recapture	2.4 N = 6	0.7 N = 5
Mech and Rogers (1977)	Minnesota	telemetry	15.7 N = 3	4.3 N = 1
Raine (1982)	Manitoba	telemetry	8.1-9.6 N = 2	6.0-8.4 N = 1
Soutiere (1979)	Maine	mark-recapture	0.1-4.4 N = 81	0.1-2.3 N = 42
Steventon/Major (1982)	Maine	telemetry	8.2 N = 3	2.3 N = 1
Wynne and Sherbourne (1984)	Maine	telemetry	5.6 N = 3	2.9 N = 2

Between-site differences emphasize the need for identifying ecological factors that may explain variability in sizes of marten home ranges (Buskirk and McDonald, 1989). Hawley and Newby (1957) noted that certain portions of home ranges were used to a greater extent than other areas. Marshall (1942) found that marten in Montana and Idaho spent considerable time in a relatively small area when food was abundant, and concluded that food conditions may well govern ecological requirements of marten. According to Simon (1980), home range size and movements are closely related to food supply. Individuals may maintain a relatively fixed foraging area for a period of time and then shift to a completely new area. Steventon (1979) and de Vos (1952) found marten to hunt from one site for several days, move elsewhere, and then use the original site several days or weeks later.

Hawley and Newby (1957) found marten did exhibit territorial behaviour toward each other when they came in contact. Home ranges of marten overlapped to varying degrees in California, and some sites were used by two or even three individuals (Martin and Barrett, 1983) with temporal separation. It is believed that marten mark and maintain their territories with scent and droppings and avoid confrontation (Archibald and Jessup, 1984).

Francis and Stephenson (1972) suggested that immatures do not establish fixed ranges until they reach reproductive maturity at two years of age, and then only if vacant areas are available. They discovered that when a range became vacant it was quickly reoccupied by an adult. Hawley and Newby (1957) noted tolerance toward juvenile marten of either sex as juvenile home ranges were established without regard to home ranges of other marten. When a range becomes vacant, it is often absorbed into ranges of neighbouring marten (Hawley and Newby, 1957). Ranges that become

vacant during winter are unlikely to be filled until spring as marten are reluctant to leave established home ranges during winter (Quick, 1955). Archibald and Jessup (1984) suggested that familiarity with a home range during the rigours of winter is probably a prerequisite to overwintering success.

POPULATION DENSITIES AND DYNAMICS

Marten once displayed the classical pattern of cycles in abundance, with a mean phase of approximately 10 years (Cowan and MacKay, 1950). Some felt that this pattern may have followed cycles in abundance of key prey species. This pattern is no longer obvious today, due in part to the effects of trapping and habitat disturbance.

The combination of a two-year lag before producing any young, and a small litter size, means that marten populations are slow in building up or in recovering from over-utilization (Marshall, 1951). Population growth rates in a harvested population appear to be a function of trapping frequency and trapping intensity (Archibald and Jessup, 1984). Population pressures apparently result in greater vulnerability to stress for adult females (Hawley and Newby, 1955). When food is available and abundant in an area, more females survive and reproduction is high. In years when food is limited, females are more vulnerable to starvation due to their high energy demands, and reproduction is reduced (Hawley and Newby, 1957). Weckwerth and Hawley (1962) noted that changes in small-mammal densities were sufficient to affect the carrying capacity of marten on an area.

Marten population densities have been reported in the literature by a variety

of researchers (see Table 3). Soutiere (1979) found an average of 1.22 adult residents per km² in the undisturbed and partially harvested forest. Densities were lowest in the commercial clearcut forest with an average density of 0.4 resident adults per km² (Soutiere, 1979). A density of 0.4 will support only a minimum population level (Lofroth and Steventon, 1990). Strickland and Douglas (1987) noted that because many variables such as food abundance, habitat conditions and trapping pressure may influence both densities and sex ratios of the resident adults, it is difficult to compare studies conducted in different locations under different conditions.

Archibald and Jessup (1984) suggested that marten populations experienced two periods of dispersal, one for young-of-the-year marten, and one for over-wintering marten. The onset of dispersal of juvenile marten coincided with the onset of estrus (Archibald and Jessup, 1984) with over-wintering marten moving in spring. The composition of a marten population continually undergoes change through gain and loss of individuals (Hawley and Newby, 1957). Hawley and Newby (1957) discovered a large number (> 50%) of the marten in their study area were transients (< 1 week in study area).

Table 3. Marten population densities reported in the literature.

Source	Study Area	Density (Km ²)										
Archibald/Jessup (1984)	Yukon	0.4 (Spring) 0.6 (Fall)										
Bateman (1982)	Maritimes	1.0										
Francis/Stephenson (1972)	Algonquin Park	0.8-1.2 (Adults) 1.2-1.9 (Fall)										
Hawley/Newby (1957)	Montana	0.2-1.7										
Soutiere (1979)	Maine	1.2 (Adults) 2.2 2.1 0.4 (Clearcut)										
Thompson/Colgan (1987)	Ontario (1981-1984) (Uncut)	<table border="0"> <tr> <td>Spring</td> <td>Fall</td> </tr> <tr> <td>1.9- +0.6</td> <td>2.4- + 1.0</td> </tr> <tr> <td>1.5- +0.8</td> <td>1.7- +0.7</td> </tr> <tr> <td>0.7- +0.3</td> <td>0.8- +0.3</td> </tr> <tr> <td>0.4- +0.1</td> <td>0.8- +0.4</td> </tr> </table>	Spring	Fall	1.9- +0.6	2.4- + 1.0	1.5- +0.8	1.7- +0.7	0.7- +0.3	0.8- +0.3	0.4- +0.1	0.8- +0.4
Spring	Fall											
1.9- +0.6	2.4- + 1.0											
1.5- +0.8	1.7- +0.7											
0.7- +0.3	0.8- +0.3											
0.4- +0.1	0.8- +0.4											
Thompson (1993b) (In press)	Ontario	0.3 (10 yr cut) 0.2 (< 2yr cut)										

TIMBER HARVESTING AND FIRE: EFFECTS ON MARTEN, THEIR HABITAT AND FOOD BASE

Strong timber harvest pressure is present over much of the marten's current range, as those forest stands ideal for timber harvest are often ideal marten habitat. It has long been known that removal of mature and overmature forested habitats reduces marten populations (Yeager, 1950; de Vos, 1952). Expanding road networks associated with more intensive timber management practices may intensify trapping pressure in local areas by providing increased access for trappers, having a negative effect on local marten populations (Soukkala, 1983). Steventon and Major (1982) concluded that although individual marten may adapt behaviourally to unfavourable habitat and exploit seasonal resources, uncut or partially cut stands are important for winter survival.

Thompson and Welsh (1993) hypothesized that the use of riparian no-cut zones and travel corridors for wildlife may have unintended effects on several species. Marten use edge habitat for hunting and will attempt to live within reserves that they perceive as good habitat (Thompson and Welsh, 1993). Thompson and Welsh (1993) suspected that competition for limited food resources with other terrestrial predators will reduce the numbers of animals present, and that predation by larger species on the smaller predators will eliminate the latter. The assumption that leave blocks, travel corridors, and riparian zones can be used to maintain all wildlife species associated with mature forest is likely incorrect (Thompson

and Welsh, 1993), although this would depend on the size of the area remaining.

Clearcutting

Marten in Wyoming did not utilize harvested areas for at least one year after cutting (Clark and Campbell, 1977; Campbell, 1979). In eastern clearcuts, marten tracks were infrequent in the 0 to 15 year-old cuts (Soutiere, 1979). Data collected by Snyder and Bissonette (1987) suggests that 23 years after harvesting is still insufficient time for a clearcut to provide adequate marten habitat. Thompson (1986) found that marten densities were lower by 67-90% in logged areas up to 40 years after logging compared with uncut overmature sites. In the spruce/fir forests of northern Maine, Soutiere (1979) reported that an area with 50% clearcuts and 25% selection-cuts supported marten densities about one-third that of the undisturbed forest. Home range sizes were also found to be larger in the clearcut forest. Regenerating clearcuts were under-utilized by marten in northern Maine (Major, 1979).

Clearcuts may be under-used by marten for a variety of reasons. Work by Steventon and Major (1982) concluded that clearcuts were under-used by marten because of poor hunting conditions. Initially in a clearcut, there may be few places for both prey and marten to hide, making it difficult for marten to approach those areas in search of prey without being visible. Conversely, the dense growth that usually flourishes in clearcut openings in the summer may also hinder visual contact with prey and provide escape cover for prey species, thus reducing foraging efficiency for marten (Steventon and Major, 1982). Steventon and Major (1982) claimed that the structure of slash resulting from clearcutting may differ substantially

from that resulting from natural tree mortality in an uncut forest, and that the generally smaller-diameter material protruding out of the snow in clearcuts may not provide adequate access.

The avoidance of clearcuts is particularly pronounced during winter (Steventon and Major, 1982). Marten may avoid large open areas resulting from clearcuts because of the energy expenditure of obtaining prey beneath the snow. Although marten are physically capable of digging through snow, it may be energetically more costly than using natural crevices around tree trunks, rocks and protruding logs. Where snow cover is not a factor, open areas are sometimes used (Hargis and McCullough, 1984). Soutiere (1978) observed marten use of clearcuts when snow depth was low, but not when snow was deep. Koehler and Hornocker (1977) found open areas being used more frequently during a low-snowpack winter. Marten activity in stands with < 30% canopy cover is greatest when snow depth is < 30 cm (Koehler *et al.*, 1975).

Marten have been found to venture into areas without cover, including clearcuts, either for foraging or travelling to more desirable habitat (see Table 4). Several authors have reported the use of openings during summer (Marshall, 1951; Streeter and Braun, 1968; Koehler and Hornocker, 1977; Soutiere, 1979). In California during a light winter, marten use of sparse stands and open areas was not significantly less than the use of denser stands (Hargis, 1982).

Simon (1980) claimed that logged areas were only used if enough canopy and logging debris were present. In northern Maine, Major (1979) reported only 5 of 27 resting sites occurred in regenerating clearcuts. Soutiere (1979) found marten occasionally crossing 200 m wide openings, and although they were more direct in their travel than in uncut stands, they

still investigated protrusions through the snow. Marten trails in clearcuts were usually in a relatively straight line, from one residual stand to another (Snyder and Bissonette, 1987). Thompson (1986) also noticed marten foraging in a linear fashion. Thompson (1986) noted that travel speeds were significantly faster for marten in cutovers. Steventon (1979) concluded that males often crossed clearcuts 300-400 m wide and probably no cut in the study area acted as a barrier to them. Females, however, rarely crossed openings and it is likely that distances > 300 m would not be crossed (Steventon, 1979). Soutiere (1979) stated that males travelled in clearcuts more than females did.

Table 4. Distances travelled by marten into open areas in winter.

Source	Study area	Distance (type of opening)
Bateman (1986)	W. Newfl.	60 m (treeless)
Hargis and McCullough (1984)	Yosemite Nat. Park	≤ 50 m (meadow) (no resting/hunting) > 50 m (using cover/ scattered trees) 135 m (maximum)
Koehler and Hornocker (1977)	Idaho (1)	< 100 m (passed through/ no hunting)
Slough (1989)	Yukon	> 20 km into burns
Snyder and Bissonette (1987)	W. Newfl. (2)	20-600 m (clearcuts) 150 m average
Soutiere (1978, 1979)	Maine	< 200 m (clearcuts)
Spencer (1981)	California	< 10 m (meadows)
Steventon (1979)	Maine	300-400 m (clearcuts)
Steventon and Major (1982)	Maine	280 m (female) 1.7 km (male)

(1) Marten avoided bait placed 20 m within openings

(2) 87% of crossings < 250 m

Wildfire

Wildfire creates early successional stages and regenerates many shade-intolerant species in the forests of North America. Some researchers have suggested that forest openings are desirable or even necessary features of marten habitat in some landscapes (Spencer *et al.*, 1983; Buskirk and MacDonald, 1984). Koehler and Hornocker (1977) concluded that wildfire creates a mosaic of forest types and a diversity of cover and food types favourable to marten.

Very few studies have focused on marten use of burns, the exception being an intensive study of the Bear Creek burn in Alaska, by Magoun and Vernam (1986). Results from this study indicated that marten in Alaska are adapted to fire-driven ecosystems. Cover provided by dead, windthrown trees was considered to be a critical habitat feature, allowing some marten to live entirely within the burn (Magoun and Vernam, 1986). However, no den sites were located in the burn. Magoun and Vernam (1986) also suggested that natural mortality may be higher for marten living in the Bear Creek burn than for marten with at least part of their home range in unburned habitat. The majority of marten with home ranges partially or entirely within the Bear Creek burn were males.

INTEGRATED RESOURCE PLANNING: TO MAINTAIN OR INCREASE MARTEN HABITAT AND POPULATIONS

The potential impact of timber harvesting on marten populations largely depends upon the severity of the habitat disturbance. Although a large, homogeneous, mature forest may support more marten over a given area at

a moment in time, a diversity of forest communities may support more marten in the future (Koehler *et al.*, 1975). Wildlife research suggests that leaving residual stands, seed trees, buffers, clusters of trees and slash/logs may enable a remnant marten population to survive despite intense clearcutting (Major, 1979; Soutiere, 1979; Hargis and McCullough, 1984; Snyder, 1984; Snyder and Bissonette, 1987). Managing for minimum populations may, however, mean minimal or no opportunity for fur harvest (Lofroth and Steventon, 1990).

Silviculture

Silvicultural treatments can have a great influence on the suitability of a managed forest for marten habitat. They can also greatly influence the rate at which a managed stand may again become suitable habitat. Since marten depend largely on the structure and diversity of mature and overmature forests, one silvicultural goal could be to re-construct or mimic the structural features of mature and overmature forests in second-growth forests (Lofroth and Steventon, 1990). Many concepts and principles of silviculture suggest that creation of conditions mimicking old growth is feasible (Brown, 1985). Lofroth and Steventon (1990) believe that marten can make effective use of immature forests provided suitable habitat features are present.

Silvicultural planning for structural requirements of marten habitat must begin prior to stand harvest. Snags and CWD are important components of optimum habitat and should be retained in harvested areas where possible. Large logs, whether naturally occurring or cull logs from logging, were found to be extremely important as shelter for marten in all seasons,

especially in winter (Simon, 1980). Lofroth and Steventon (1990) recommended retaining average CWD volumes of at least 100 m³/ha of logs > 20 cm in diameter (based on Spencer *et al.*, 1983; Buskirk *et al.*, 1989; Lofroth, unpublished data). Spencer *et al.* (1983) recommended retaining 5 m²/ha basal area of snags.

The quality or quantity of CWD remaining on a site after timber harvest may not be limiting to marten use of the stand in the short term. What becomes important is the ability of the stand to provide structure as it grows and cover develops. Provided that adequate amounts of CWD have been maintained, the site will again become suitable marten habitat at a relatively young stage of development (Lofroth and Steventon, 1990). Groups of live trees should be left standing in clearcut areas if suitable snags are to be available for marten in the future. These trees will also be susceptible to blowdown, providing future CWD. It is imperative that provision be made for the creation of replacements through successive forest rotations (Lofroth and Steventon, 1990).

Silvicultural treatments that tend to "sterilize" a site should be avoided in areas where marten are managed (Lofroth and Steventon, 1990). Slash and logging residues, logs, and snags are necessary for marten populations to survive in clearcut landscapes (Simon, 1980). Eliminating slash and logging residue through broadcast burning, or piling and burning following timber harvest, may be detrimental to marten populations. Slash piles or windrows, if maintained within intensively managed forest stands, probably compensate in part for the decreased structural diversity in clearcut areas and even-aged monocultures by providing furbearers with shelter for prey and refuge sites (de Vos, 1952; Campbell, 1979; Steventon and Major, 1982; Allen, 1987). When snow is absent, open areas may furnish

abundant protective cover in the form of slash and low-growing vegetation (Hargis, 1982). Clark (1975) and Campbell (1979) found marten using slash piles for resting sites. Because most furbearers have relatively large home ranges, establishing only a few large slash piles per square kilometre may serve to enhance habitat value for these species in intensively managed forests (Allen, 1987). Scarifying, planting, and tending (even-aged management) will reduce site diversity, reduce prey numbers and result in lower marten densities in mature second-growth forests compared to uncut natural sites usually of fire origin (Thompson, 1988).

Spatial Requirements

Forest structure, along with the size and shape of various stands, their juxtaposition to other stands, and special habitat requirements, needs to be considered when predicting how various forest-management practices will affect resident marten populations (Simon, 1980). The type of cut, its size and shape, its influence on plant species composition, and its spatial relationship to other cutover areas and unharvested stands all may influence the ultimate habitat value for furbearers that depend on forested habitats (Allen, 1987). Simon (1980) found the habitat components of adjacent vegetation types to be important with regard to the amount of use an area received by marten. Heavily logged areas were only used when adjacent to dense stands of timber. Although the literature points to a lack of awareness about marten spatial needs, Bissonette *et al.* (1989) concluded that we can mimic the spatial arrangements of critical elements to provide for those needs under a high disturbance regime of cutting. A variety of researchers have produced recommendations on the spatial requirements of marten (see Table 5). Any attempts to assign habitat values to individual stands for furbearers such as lynx, fisher and marten

should consider the surrounding habitat conditions (Allen, 1987).

Table 5. Minimum spatial habitat requirements of marten.

Study	Minimum Habitat Requirements in a Clearcut Environment
Major (1979)	> 50% uncut habitat in a 10 km ² area
Major (1979)	> 250 ha habitat/female with < 20% cut
Soutiere (1979)	> 25% mature forest area in a clearcut forest
Snyder (1984)	> 15 ha mature habitat in clearcut areas
Bissonette (1989)	> 25 ha of mature habitat
Lofroth & Steventon (1990)	> 50% suitable habitat
Thompson & Harested (1991)	> 60-70% of a forest in mature age classes

A miscellany of resting sites scattered throughout the home range, each convenient to primary foraging patches, allows a marten to choose a resting site suitable to current conditions with a minimum of travel (Buskirk, 1984). Marten tracks in travelling mode invariably led to a den, suggesting that once they had finished hunting in winter, they travelled directly to a known place to rest (Thompson, 1986). The character, density, and distribution of logging debris could significantly affect the amount of marten use a site receives, as well as the number of martens present. Martens are unlikely to use snags, CWD and slash piles without the protection afforded from surrounding cover. The arrangement of snags and debris in relation to surrounding habitat has a significant influence on the potential use of these sites (Allen, 1987). The clustering of acceptable dens (Martin and Barrett, 1983), their state of deterioration, and proximity to (and amount of) overhead canopy cover may prove to be important in the management of marten habitat.

The question of how much habitat is enough can only be fairly addressed in the context of surrounding forest conditions (Harris, 1984). If only subtle

differences exist between the structure of the valued habitat and the structure of the surrounding habitat, the size of the valued habitat may actually be increased. According to Harris (1984), three factors determine the effective size of a valued habitat island: (1) actual size; (2) distance from similar habitat; and (3) degree of habitat difference of the intervening forest. The value of a patch of habitat is not only dependent upon its structural characteristics (its content), but also upon the landscape within which it occurs (its context) (Harris, 1984).

LANDSCAPE MANAGEMENT

The decline of marten populations and loss of their habitat in several eastern Canadian provinces is indicative of broad problems in natural resources management, an inability to regenerate forest ecosystems with their complex communities, and a lack of long-term, large-scale planning (Thompson and Harested, 1991). The dilemma facing the forest manager is how to orchestrate logging with marten habitat requirements (and the requirements of many other species) across the landscape (Bissonette *et al.*, 1989). The spatial and temporal scales of planning must be adjusted so that marten habitat can be managed properly (Thompson, 1991).

Forest landscapes, especially those with significant disturbance regimes (e.g. fire), are dynamically changing habitat mosaics, and any attempt to perpetuate overmature stands in localized areas will present difficult problems (Bissonette *et al.*, 1989). The occurrence and distribution of forest patches in a landscape are not static (Morrison *et al.*, 1992). Insect infestations, disease, wind-throw, fire and other mortality factors all contribute to tree loss causing structural changes in a forest landscape (Bissonette *et al.*, 1989). Likewise, the forces of vegetational succession are constantly at work and significant areas revert to regenerating forest (Bissonette *et al.*, 1989).

Focus has only recently turned to quantifying the proportions of marten habitat requirements in a spatial context. For the meantime, in areas where little old-growth forest remains, short-term objectives should be to maintain a large amount of these stands, with long-term objectives of developing the future potential for marten of surrounding young forests (Thompson and Harested, 1991).

Long-term forest management plans for areas where marten are important must demonstrate that forest types and age classes will exist in temporal and spatial arrangements appropriate for marten (Thompson and Harested, 1991). Habitat fragmentation may progress with little effect on a

population until the critical pathways of connectivity are disrupted. Then, a slight change near a critical threshold can have dramatic consequences on the persistence of the population (Turner and Gardner, 1991). The challenge is to orchestrate timber harvest and regeneration in such a manner as to allow for an economic harvest while providing for the continued existence of viable marten populations and populations of other species dependent on large expanses of mature and overmature forests (Bissonette *et al.*, 1989).

LITERATURE CITED

- Allen, A.W. 1987. The relationship between habitat and furbearers. pp. 164-179 *in* M. Novak, J. A. Baker, M. E. Obbard and B. Malloch (editors), *Wild Furbearer Management and Conservation in North America*. Ontario Ministry of Natural Resources, Toronto, Ontario.
- Archibald, W.R. and R.H. Jessup. 1984. Population dynamics of the pine marten (*Martes americana*) in the Yukon Territory. pp. 81-97 *in* R. Olsen, R. Hastings and F. Geddes (editors) *Northern Ecology and Resource Management: Memorial Essays Honouring Don Gill*. University of Alberta, Edmonton, Alberta.
- Bateman, M.C. 1982. Habitat use, winter food habits and home range size of marten in Southwest Brook, Newfoundland. *Canadian Wildlife Service, Sackville, New Brunswick*. 33 pp.
- Bateman, M.C. 1986. Winter habitat use, food habits and home range size of the marten (*Martes americana*) in western Newfoundland. *Canadian Field-Naturalist* 100:58-62.
- Bissonette, J.A., R.J. Fredrickson and B.J. Tucker. 1989. American marten: a case for landscape-level management. 54th North American Wildlife and Natural Resources Conference 54:89-101.
- Brown, E.R. (Technical Editor). 1985. Management of wildlife and fish habitats in forests of western Oregon and Washington. U.S. Department of Agriculture, Portland, Oregon. 332 pp.
- Burnett, G.W. 1981. Movements and habitat use of American marten in Glacier National Park, Montana. M.Sc. Thesis. University of Montana, Missoula, Montana. 130 pp.
- Buskirk, S.W. 1983. The ecology of marten in southcentral Alaska. Ph.D. Dissertation. University of Alaska, Fairbanks, Alaska. 131 pp.
- Buskirk, S.W. 1984. Seasonal use of resting sites by marten in south-central Alaska. *Journal of Wildlife Management* 48:950-953.

- Buskirk, S.W. and L.L. McDonald. 1989. Analysis of variability in home-range size of the American marten. *Journal of Wildlife Management* 53:997-1004.
- Buskirk, S.W., S.C. Forrest, M.G. Raphael and H.J. Harlow. 1989. Winter resting site ecology of marten in the central rocky mountains. *Journal of Wildlife Management* 53:191-196.
- Buskirk, S.W. and S.O. MacDonald. 1984. Seasonal food habits of marten in south-central Alaska. *Canadian Journal of Zoology* 62:944-950.
- Campbell, T.M. 1979. Short-term effects of timber harvests on pine marten ecology. M.Sc. Thesis. Department of Fish and Wildlife Biology, Colorado State University, Fort Collins, Colorado. 71 pp.
- Carreker, R.G. 1985. Habitat suitability index models: snowshoe hare. Biological Report 82(10.101). U.S. Fish and Wildlife Service, Fort Collins, Colorado. 21 pp.
- Clark, T.W. 1975. Analysis of pine-marten population organization and regulatory mechanisms in Jackson Hole, Wyoming. National Geographic Society Research Report 16:131-143.
- Clark, T.W. and T.M. Campbell. 1977. Short-term effects of timber harvests on pine marten behaviour and ecology. Idaho State University, Pocatello, Idaho. 60 pp.
- Conroy, M.J., L.W. Gysel and G.R. Dudderar. 1979. Habitat components of clear-cut areas for snowshoe hares in Michigan. *Journal of Wildlife Management* 43:680-690.
- Cowan, I.M. and R.H. MacKay. 1950. Food habits of the marten (*Martes americana*) in the rocky mountain region of Canada. *Canadian Field-Naturalist* 64:100-104.
- Davis, D.H. 1978. Reintroduction of the pine marten into the Nicolet National Forest County, Wisconsin. M.Sc. Thesis. University of Wisconsin, Stevens Point, Wisconsin. 64 pp.
- de Vos, A. 1952. Ecology and management of fisher and marten in Ontario. Ontario Department of Lands and Forests, Toronto, Ontario. 90 pp.
- Douglass, R.J., L.G. Fisher and M. Mair. 1983. Habitat selection and food

habits of marten (*Martes americana*) in the Northwest Territories. Canadian Field-Naturalist 97:71-74.

Francis, G.R. and A.B. Stephenson. 1972. Marten ranges and food habits in Algonquin Provincial Park, Ontario. Report #91. Ontario Ministry of Natural Resources, Toronto, Ontario. 53 pp.

Gunderson, H.L. 1959. Red-backed vole habitat studies in central Minnesota. Journal of Mammalogy 40:405-412.

Hargis, C.D. 1982. Winter habitat utilization and food habits of pine martens in Yosemite National Park. Technical Report No. 6. University of California, Berkeley, California. 59 pp.

Hargis, C.D. and D.R. McCullough. 1984. Winter diet and habitat selection of marten in Yosemite national park. Journal of Wildlife Management 48:140-146.

Harris, L.D. 1984. The fragmented forest. University of Chicago Press, Chicago, Illinois. 211 pp.

Hawley, V.D. and F.E. Newby. 1957. Marten home ranges and population fluctuations. Journal of Mammalogy 38:174-184.

Herman, T. and K. Fuller. 1974. Observations of the marten (*Martes americana*) in the Mackenzie District, Northwest Territories. Canadian Field-Naturalist 88:501-503.

Keith, L.B. 1966. Habitat vacancy during a snowshoe hare decline. Journal of Wildlife Management 30:828-832.

Koehler, G.M. 1990. Demographic and habitat characteristics of lynx and snowshoe hares in north-central Washington. Canadian Journal of Zoology 68:845-851.

Koehler, G.M. and J.D. Brittell. 1990. Managing spruce-fir habitat for lynx and snowshoe hares. Journal of Forestry 88:10-14.

Koehler, G.M. and M.G. Hornocker. 1977. Fire effects on marten habitat in the Selway-Bitterroot Wilderness. Journal of Wildlife Management 41:500-505.

Koehler, G.M., W.R. Moore and A.R. Taylor. 1975. Preserving the pine marten: management guidelines for western forests. Western Wildlands 2:31-36.

- Krebs, C.J. and I. Wingate. 1976. Small mammal communities of the Kluane Region, Yukon Territory. *The Canadian Field-Naturalist* 90:379-389.
- Lensink, C.J., R.O. Skoog and J.L. Buckley. 1955. Food habits of marten in interior Alaska and their significance. *Journal of Wildlife Management* 19:364-367.
- Litvaitis, J.A., J.A. Sherburne and J.A. Bissonette. 1985. Influence of understory characteristics on snowshoe hare habitat use and density. *Journal of Wildlife Management* 49:866-873.
- Lofroth, E.C. and J.D. Steventon. 1990. Managing for marten winter habitat in interior forests of British Columbia. pp. 67-75 *in* A. Chambers (editor), *Wildlife Forestry Symposium: a workshop on resource integration for wildlife and forest managers*. Forestry Canada, Prince George, British Columbia.
- Magoun, A.J. and D.J. Vernam. 1986. An evaluation of the Bear Creek burn as marten (*Martes americana*) habitat in interior Alaska: final report. Bureau of Land Management and Alaska Department of Fish and Game, Anchorage, Alaska. 58 pp.
- Major, J.T. 1979. Marten use of habitat in a commercially clear-cut forest during summer. M.A. Thesis. School of Wildlife Management, University of Maine at Orono, Orono, Maine. 31 pp.
- Marshall, W.H. 1942. The biology and management of the pine marten in Idaho. Ph.D. Dissertation. University of Michigan, Ann Arbor, Michigan. 107 pp.
- Marshall, W.H. 1946. Winter food habits of the pine marten in Montana. *Journal of Mammalogy* 27:83-84.
- Marshall, W.H. 1951. Pine marten as a forest product. *Journal of Forestry* 49:899-905.
- Martin, S.K. and R.H. Barrett. 1983. The importance of snags to pine marten habitat in the northern Sierra Nevada. pp. 114-116 *in* J.W. Davis, G.A. Goodwin and R.A. Ockenfils (editors), *Symposium Proceedings, Snag Habitat Management*. General Technical Report RM-99, USDA Forest Service, Flagstaff, Arizona.
- Monthey, R.W. 1986. Responses of snowshoe hares (*Lepus americanus*) to timber harvesting in northern Maine. *Canadian Field-Naturalist* 100:568-570.

- More, G. 1978. Ecological aspects of food selection in pine marten (*Martes americana*). M.A. Thesis. Department of Zoology, University of Alberta, Edmonton, Alberta. 94 pp.
- Murie, A. 1961. Some food habits of the marten. *Journal of Mammalogy* 42:516-521.
- Nagorsen, D.W., K.F. Morrison and J.E. Forsberg. 1989. Winter diet of Vancouver Island marten (*Martes americana*). *Canadian Journal of Zoology* 67:1394-1400.
- Orr, C.D. and D.G. Dodds. 1982. Snowshoe hare habitat preferences in Nova Scotia spruce-fir forests. *Wildlife Society Bulletin* 10:147-150.
- Parker, G.R. 1984. Use of spruce plantations by snowshoe hare in New Brunswick. *Forestry Chronicle* 60:162-166.
- Pietz, P.J. and J.R. Tester. 1983. Habitat selection by snowshoe hares in north central Minnesota. *Journal of Wildlife Management* 47:686-696.
- Quick, H.F. 1955. Food habits of marten (*Martes americana*) in northern British Columbia. *Canadian Field-Naturalist* 69:144-147.
- Raine, R.M. 1981. Winter food habits, responses to snow cover and movements of fisher (*Martes pennanti*) and marten (*Martes americana*) in southeastern Manitoba. M.Sc. Thesis. University of Manitoba, Winnipeg, Manitoba. 144 pp.
- Raine, R.M. 1983. Winter habitat use and responses to snow cover of fisher (*Martes pennanti*) and marten (*Martes americana*) in southeastern Manitoba. *Canadian Journal of Zoology* 61:25-34.
- Raine, R.M. 1987. Winter food habits and foraging behaviour of fishers (*Martes pennanti*) and martens (*Martes americana*) in southeastern Manitoba. *Canadian Journal of Zoology* 65:745-747.
- Ramirez, P. and M. Hornocker. 1981. Small mammal populations in different-aged clearcuts in northwestern Montana. *Journal of Mammalogy* 62:400-403.
- Raphael, M.G. 1988. Habitat associations of small mammals in a subalpine

forest, southeastern Wyoming. pp. 359-367 *in* R.C. Szaro, K.E. Severson and D.R. Patton (editors), Symposium Proceedings, Management of Amphibians, Reptiles and Small Mammals in North America. Technical Report RM-166, USDA, Forest Service, Flagstaff, Arizona.

Simon, T.L. 1980. An ecological study of the marten in the Tahoe National Forest, California. M.Sc. Thesis. Department of Biology, California State University, Sacramento, California. 143 pp.

Slough, B.G. 1989. Movements and habitat use by transplanted marten in the Yukon Territory. *Journal of Wildlife Management* 53:991-997.

Slough, B.G., W.R. Archibald, S.S. Beare and R.H. Jessup. 1989. Food habits of martens (*Martes americana*) in the south-central Yukon Territory. *Canadian Field-Naturalist* 103:18-22.

Snyder, J.E. 1984. Marten use of clear-cuts and residual forest stands in western Newfoundland. M.A. Thesis. School of Wildlife Management, University of Maine at Orono, Orono, Maine. 30 pp.

Snyder, J.E. and J.A. Bissonette. 1987. Marten use of clear-cuttings and residual forest stands in western Newfoundland. *Canadian Journal of Zoology* 65:169-174.

Soukkala, A.M. 1983. The effects of trapping on marten populations in Maine. M.Sc. Thesis. School of Wildlife Management, University of Maine, Orono, Maine. 41 pp.

Soutiere, E.C. 1978. The effects of timber harvesting on the marten. Ph.D. Dissertation. University of Maine, Orono, Maine. 87 pp.

Soutiere, E.C. 1979. Effects of timber harvesting on marten in Maine. *Journal of Wildlife Management* 43:850-860.

Spencer, W.D. 1981. Pine marten habitat preferences at Sagehen Creek, California. M.Sc. Thesis. University of California, Berkeley, California. 121 pp.

Spencer, W.D., R.H. Barrett and W.J. Zielinski. 1983. Marten habitat preferences in northern Sierra Nevada. *Journal of Wildlife Management* 47:1181-1186.

Spencer, W.D. and W.J. Zielinski. 1983. Predatory behaviour of pine

martens. *Journal of Mammalogy* 64:715-717.

Steventon, J.D. 1979. Influence of timber harvesting upon winter habitat use by marten. M.A. Thesis. School of Wildlife Management, University of Maine at Orono, Orono, Maine. 24 pp.

Steventon, J.D. and J.T. Major. 1982. Marten use of habitat in a commercially clear-cut forest. *Journal of Wildlife Management* 46:175-182.

Streeter, R.G. and C.E. Braun. 1968. Occurrence of pine marten (*Martes americana*) (Carnivora: Mustelidae) in Colorado alpine areas. *Southwestern Naturalist* 13:449-451.

Strickland, M.A. and C.W. Douglas. 1987. Marten. pp. 530-546 *in* M. Novak, J.A. Baker, M.E. Obbard and B. Malloch (editors), *Wild Furbearer Management and Conservation in North America*. Ontario Ministry of Natural Resources, Toronto, Ontario.

Thompson, I.D. 1986. Diet choice, hunting behaviour, activity patterns, and ecological energetics of marten in natural and logged areas. Ph.D. Dissertation. Queens University, Kingston, Ontario. 179 pp.

Thompson, I.D. and P.W. Colgan. 1987. Numerical responses of martens to a food shortage in northcentral Ontario. *Journal of Wildlife Management* 51:824-835.

Thompson, I.D. 1988. Habitat needs of furbearers in relation to logging in boreal Ontario. *Forestry Chronicle* 63:251-261.

Thompson, I.D. 1991. Could marten become the spotted owl of eastern Canada? *Forestry Chronicle* 67:136-140.

Thompson, I.D. and A.S. Harested. 1991. Effects of logging on marten with models for habitat management. p. 80 *in* *The Biology and Management of Martens and Fishers Symposium Abstracts May 29 to June 1 1991*. 89 pp. (Abstract).

Thompson, I.D. 1993a. Marten activity in mature and post-logging boreal forest in Ontario. *Journal of Wildlife Management* (In press).

Thompson, I.D. 1993b. Marten populations in mature and post-logging boreal forest in Ontario. *Journal of Wildlife Management* (In press).

- Thompson, I.D., I.J. Davidson, S. O'Donnell and F. Brazeau. 1989. Use of track transects to measure the relative occurrence of some boreal mammals in uncut forest and regeneration stands. *Canadian Journal of Zoology* 67:1816-1823.
- Thompson, I.D. and D.A. Welsh. 1993. Integrated resource management in boreal forest ecosystems - impediments and solutions. *Forestry Chronicle* 69:32-39.
- Trapp, G.R. 1962. Snowshoe hares in Alaska - home range ecology during an early population increase. M.Sc. Thesis. University of Alaska, Fairbanks, Alaska. 137 pp.
- Turner, M.G. and R.H. Gardner (editors). 1991. Quantitative methods in landscape ecology: the analysis and interpretation of landscape heterogeneity. Springer-Verlag, New York, New York. 536 pp.
- Weckwerth, R.P. and V.D. Hawley. 1962. Marten food habits and population fluctuations in Montana. *Journal of Wildlife Management* 26:55-74.
- West, S.D. 1977. Midwinter aggregation in the northern red-backed vole (*Clethrionomys rutilus*). *Canadian Journal of Zoology* 55:1404-1409.
- Wolfe, M.L., N.V. Debyle, C.S. Winchell and T.R. McCabe. 1982. Snowshoe hare cover relationships in northern Utah. *Journal of Wildlife Management* 46:662-670. (*Cited in* Koehler and Brittell, 1990).
- Wolff, J.O. 1980. The role of habitat patchiness in the population dynamics of snowshoe hares. *Ecological Monographs* 50:111-130.
- Wynne, K.M. and J.A. Sherburne. 1984. Summer home range use by adult marten in northwestern Maine. *Canadian Journal of Zoology* 62:941-943.
- Yeager, L.E. 1950. Implications of some harvest and habitat factors on pine marten management. *Transactions: 15th North American Wildlife Conference* 15:319-334.

Zielinski, W.J., W.D. Spencer and R.H. Barrett. 1983. Relationship between food habits and activity patterns of pine martens. *Journal of Mammalogy* 64:387-396.

APPENDIX III

OPERABILITY LIMITS AND THE TIMMINS FOREST NET MERCHANTABLE VOLUME (NMV) PURE SPECIES YIELD CURVES

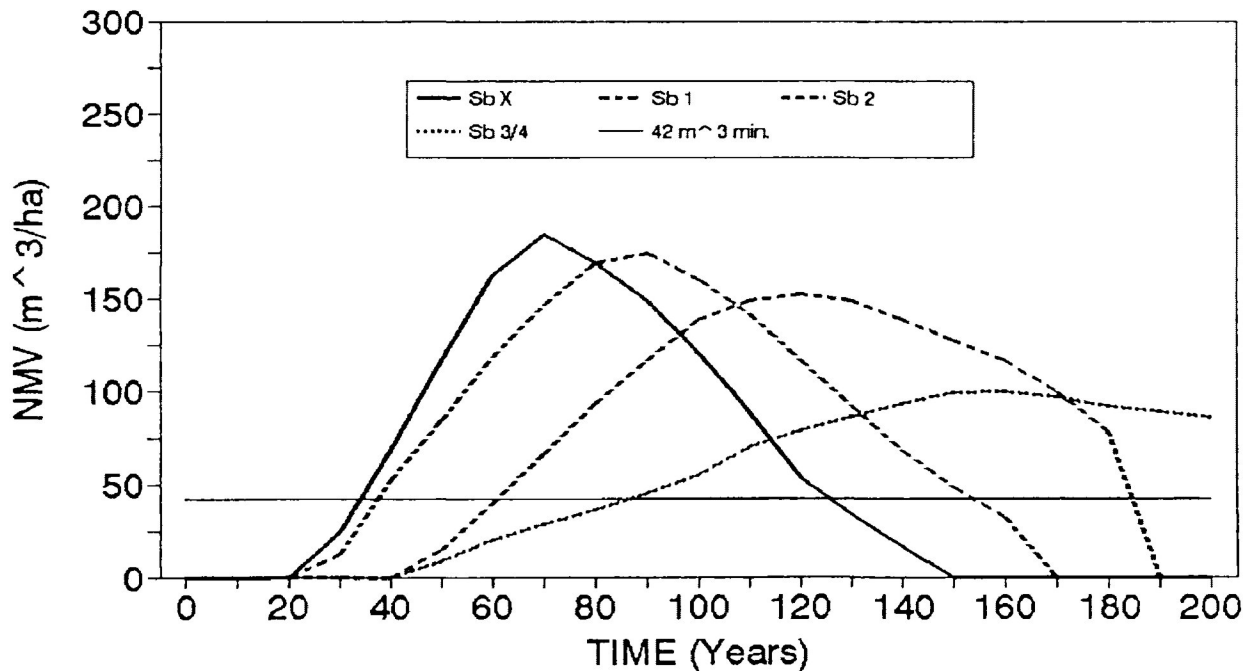
OPERABILITY LIMITS

Species/ Site Class	Age (Yrs) Minimum	Minimum Volume (m ³ /ha)
Sb/Sw X, 1, 2	80	42 *
Sb/Sw 3	100	42 *
Pj/all	60	50
Po X, 1, 2	60	90
Po 3	70	78

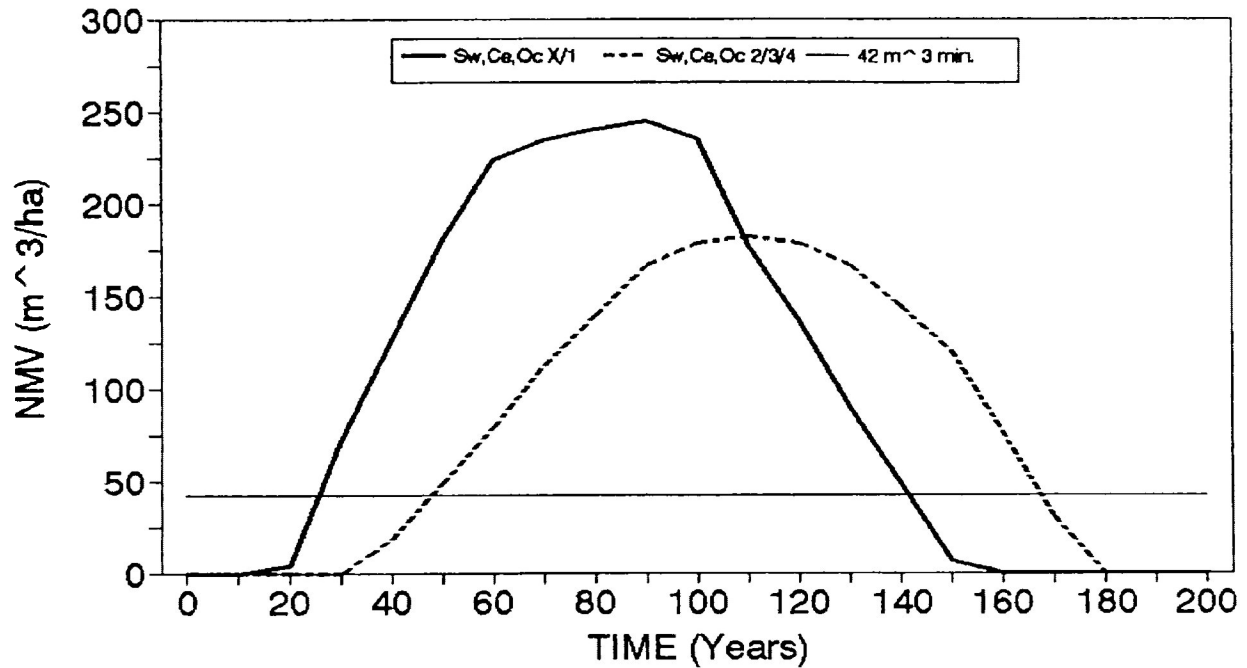
* This had to be increased to 51 m³/ha at 50 years into all runs to prevent an excess of balsam fir component in the spruce harvest.

BLACK SPRUCE YIELD CURVES

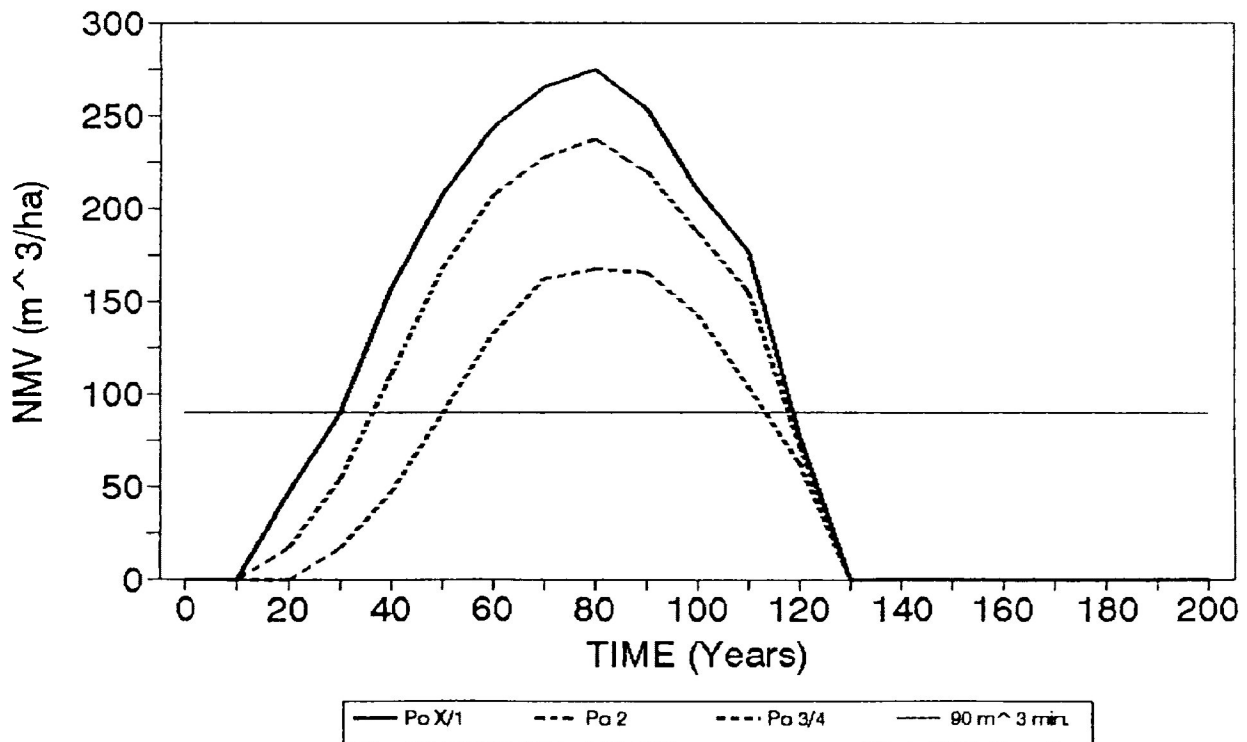
For Natural Stands



WHITE SPRUCE + Ce, Oc YIELD CURVES For Natural Stands

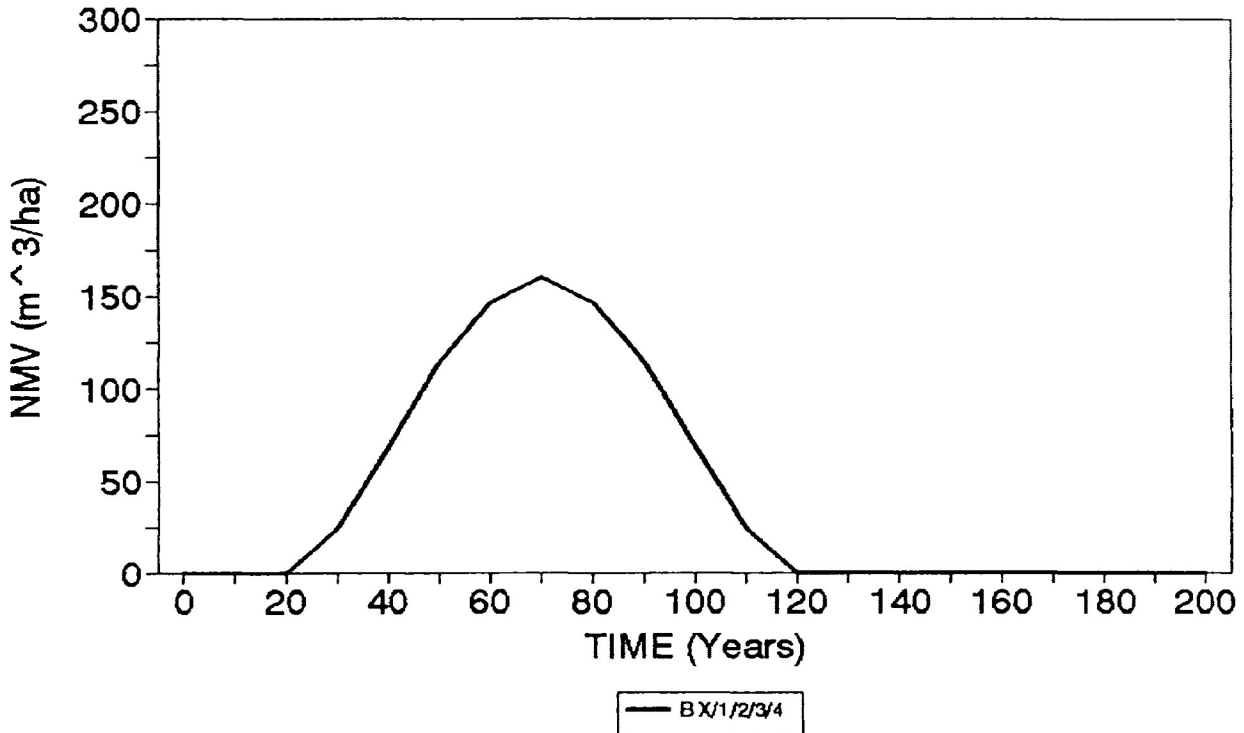


POPLAR YIELD CURVES For Natural Stands



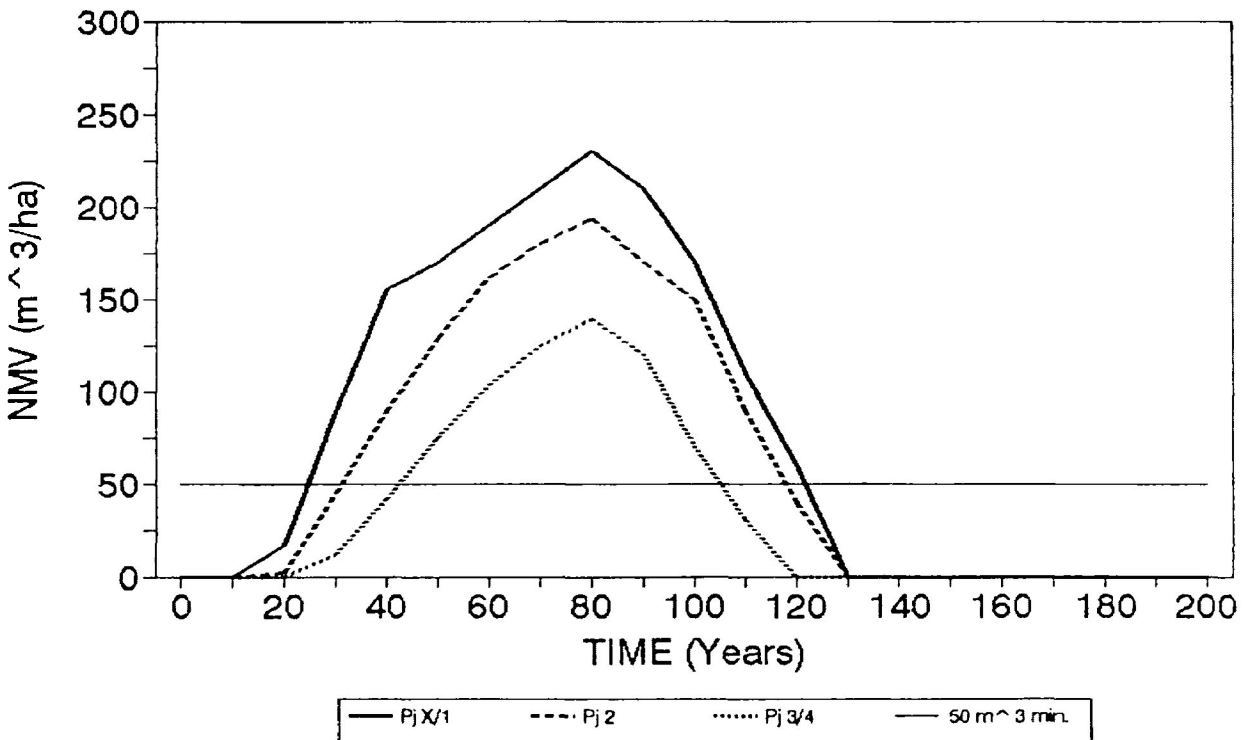
BALSAM FIR YIELD CURVES

For Natural Stands



JACK PINE YIELD CURVES

For Natural Stands



APPENDIX IV

STATE TABLE - SUCCESSIONAL AND SILVICULTURAL RULES USED TO
SIMULATE FOREST GROWTH IN HSG

LEGEND

Matching Rules

Spec	= Working group species of the stand
Site	= Site class of the stand
Age	= Age of the stand
Po	= The percentage of poplar within the stand
dstrb	= Disturbance code (either clearcut or none)
treatment	= The stand's silvicultural treatment

(matching and action rules are separated (SEPR) by a "/")

Action Rules

Sp1	= The first subcomponent species (also working group)
Site1	= Site class of Sp1
Age1	= Age of Sp1
Stk1	= Stocking of Sp1
Sp2	= Second subcomponent species
Site2	= Site class of Sp2
Age2	= Age of Sp2
Stk2	= Stocking of Sp2

where "*" = any value (wildcard)

Spec	Site	Age	Po	dstrb	treatment	SEPR	Sp1	Site1	Age1	Stk1	Sp2	Site2	Age2	Stk2
Sb	MX	*	*	clearcut	intensive	/	Sb	MX	0	0.8				
Sb	X	*	*	clearcut	intensive	/	Sb	MX	0	0.8				
Sb	X	*	=0	clearcut	basic	/	Sb	X	20	0.6	Sb	X	0	0.4
Sb	X	*	=0	clearcut	extensive	/	Sb	X	10	0.5	Po	X	0	0.3
							B	X	10	0.2				
Sb	X	*	>0<30	clearcut	basic	/	Sb	X	20	0.6	Po	1	0	0.4
Sb	X	*	>0<30	clearcut	extensive	/	Sb	1	10	0.5	Po	1	0	0.5
Sb	X	*	>30	clearcut	basic	/	Po	1	0	0.6	Sb	X	10	0.4
Sb	X	*	>30	clearcut	extensive	/	Po	1	0	0.6	Sb	X	10	0.4
Sb	X	>120	=0	none	natural	/	Sb	X	20	0.5				
Sb	X	>120	>0<30	none	natural	/	Po	1	15	0.7	Sb	X	20	0.3
Sb	X	>120	>30	none	natural	/	Po	1	15	0.8	Sb	X	10	0.2
Sb	M1	*	*	clearcut	intensive	/	Sb	M1	0	0.8				
Sb	1	*	*	clearcut	intensive	/	Sb	M1	0	0.8				
Sb	1	*	=0	clearcut	basic	/	Sb	1	20	0.5	Sb	1	0	0.3
							B	1	20	0.2				
Sb	1	*	=0	clearcut	extensive	/	Sb	1	10	0.5	Po	1	0	0.3
							B	1	10	0.2				
Sb	1	*	>0<30	clearcut	basic	/	Sb	1	20	0.6	Po	2	0	0.4
Sb	1	*	>0<30	clearcut	extensive	/	Po	2	0	0.8	Sb	1	10	0.2
Sb	1	*	>30	clearcut	basic	/	Po	1	0	0.6	Sb	1	20	0.4
Sb	1	*	>30	clearcut	extensive	/	Po	1	0	0.9	Sb	1	10	0.1
Sb	1	>140	=0	none	natural	/	Sb	1	20	1.0				
Sb	1	>140	>0<30	none	natural	/	Po	1	30	0.6	Sb	1	15	0.4
Sb	1	>140	>30	none	natural	/	Po	1	40	0.8	Sb	1	15	0.2
Sb	M2	*	*	clearcut	intensive	/	Sb	M2	0	0.8				
Sb	2	*	*	clearcut	intensive	/	Sb	M2	0	0.8				
Sb	2	*	=0	clearcut	basic	/	Sb	2	25	0.6	Sb	2	0	0.4
Sb	2	*	>0	clearcut	basic	/	Sb	2	20	0.6	Po	2	0	0.4
Sb	2	*	=0	clearcut	extensive	/	Sb	2	10	0.7	Po	2	0	0.3
Sb	2	*	>0	clearcut	extensive	/	Po	3	0	0.7	Sb	2	10	0.3
Sb	2	>160	=0	none	natural	/	Sb	2	30	1.0				
Sb	2	>160	>0	none	natural	/	Sb	2	25	0.7	Po	3	20	0.3
Sb	3	*	=0	clearcut	extensive	/	Sb	3	10	0.7	Po	3	0	0.3
Sb	3	*	>0	clearcut	extensive	/	Po	3	0	0.7	Sb	3	10	0.3
Sb	3	>170	*	none	natural	/	Sb	3	30	0.7				
Sb	4	>170	*	none	natural	/	Sb	4	30	0.5				

Sw	X	*	*	clearcut	intensive	/	Sw	X	0	0.8				
Sw	X	*	=0	clearcut	basic	/	Sw	X	20	0.8				
Sw	X	*	=0	clearcut	extensive	/	Sw	X	20	0.3				
Sw	X	*	>0&<30	clearcut	basic	/	Sw	X	20	0.5	Po	1	0	0.5
Sw	X	*	>0&<30	clearcut	extensive	/	Po	1	0	1.0				
Sw	X	*	>30	clearcut	basic	/	Po	1	0	0.6	Sw	X	20	0.4
Sw	X	*	>30	clearcut	extensive	/	Po	1	0	1.0				
Sw	X	>110	=0	none	natural	/	Sw	X	20	0.4				
Sw	X	>110	>0&<30	none	natural	/	Po	1	15	0.7	Sw	X	10	0.3
Sw	X	>110	>30	none	natural	/	Po	1	15	0.8	Sw	X	10	0.2
Sw	1	*	*	clearcut	intensive	/	Sw	1	0	0.8				
Sw	1	*	=0	clearcut	basic	/	Sw	1	0	0.8				
Sw	1	*	=0	clearcut	extensive	/	Sw	1	10	0.3				
Sw	1	*	>0&<30	clearcut	basic	/	Sw	1	0	0.6	Po	2	0	0.4
Sw	1	*	>0&<30	clearcut	extensive	/	Po	2	0	0.8	Sw	1	10	0.2
Sw	1	*	>30	clearcut	basic	/	Po	1	0	0.6	Sw	1	10	0.4
Sw	1	*	>30	clearcut	extensive	/	Po	1	0	0.9	Sw	1	10	0.1
Sw	1	>120	=0	none	natural	/	Sw	1	20	0.8				
Sw	1	>120	>0&<30	none	natural	/	Po	1	30	0.6	Sw	1	20	0.4
Sw	1	>120	>30	none	natural	/	Po	1	40	0.8	Sw	1	20	0.2
Sw	2	*	=0	clearcut	extensive	/	Sw	2	10	0.7				
Sw	2	*	=0	clearcut	basic	/	Sw	2	0	0.8				
Sw	2	*	=0	clearcut	intensive	/	Sw	2	0	1.0				
Sw	2	*	>0	clearcut	extensive	/	Po	3	0	0.7	Sw	2	0	0.3
Sw	2	*	>0	clearcut	basic	/	Sw	2	0	0.9				
Sw	2	*	>0	clearcut	intensive	/	Sw	2	0	1.0				
Sw	3	*	=0	clearcut	extensive	/	Sw	3	10	0.6				
Sw	3	*	>0	clearcut	extensive	/	Po	3	0	0.7	Sw	3	0	0.3
Sw	2	>160	=0	none	natural	/	Sw	2	30	1.0				
Sw	2	>160	>0	none	natural	/	Sw	2	25	0.7	Po	3	20	0.3
Sw	3	>160	*	none	natural	/	Sw	3	25	0.9				
Sw	4	>160	*	none	natural	/	Sw	4	25	0.8				
Po	X	*	*	clearcut	intensive	/	Sb	MX	0	0.8	Po	X	0	0.2
Po	1	*	*	clearcut	intensive	/	Sb	M1	0	0.7	Po	1	0	0.3
Po	X	*	*	clearcut	extensive	/	Po	X	0	1.0				
Po	1	*	*	clearcut	extensive	/	Po	1	0	1.0				
Po	2	*	*	clearcut	extensive	/	Po	2	0	1.0				
Po	3	*	*	clearcut	extensive	/	Po	3	0	1.0				

Po	X	>110	*	none	natural	/	Po	X	15	0.9	B	X	15	0.1
Po	1	>110	*	none	natural	/	Po	1	15	0.8	B	1	15	0.2
Po	2	>110	*	none	natural	/	Po	2	15	0.5	Sb	1	20	0.5
Po	3	>110	*	none	natural	/	Po	3	15	0.5	Sb	2	20	0.5
Po	4	>120	*	none	natural	/	Po	4	15	0.5	Sb	2	25	0.5
Bw	X	*	*	clearcut	extensive	/	Bw	X	0	0.7				
Bw	1	*	*	clearcut	extensive	/	Bw	1	0	0.7				
Bw	2	*	*	clearcut	extensive	/	Bw	2	0	0.7				
Bw	3	*	*	clearcut	extensive	/	Bw	3	0	0.7				
Bw	X	>150	*	none	natural	/	Bw	X	0	0.5	B	X	10	0.5
Bw	1	>150	*	none	natural	/	Bw	1	5	0.5	B	1	10	0.5
Bw	2	>140	*	none	natural	/	Bw	2	10	0.5	B	2	10	0.5
Bw	3	>130	*	none	natural	/	Bw	3	15	0.6	B	3	10	0.4
Bw	4	>130	*	none	natural	/	B	3	20	0.6	Bw	4	10	0.4
Pj	MX	*	*	clearcut	intensive	/	Pj	MX	0	1.0				
Pj	X	*	*	clearcut	intensive	/	Pj	MX	0	1.0				
Pj	M1	*	*	clearcut	intensive	/	Pj	M1	0	1.0				
Pj	1	*	*	clearcut	intensive	/	Pj	M1	0	1.0				
Pj	M2	*	*	clearcut	intensive	/	Pj	M2	0	1.0				
Pj	2	*	*	clearcut	intensive	/	Pj	M2	0	1.0				
Pj	X	*	*	clearcut	basic	/	Pj	X	0	0.8				
Pj	1	*	*	clearcut	basic	/	Pj	1	0	0.8				
Pj	2	*	*	clearcut	basic	/	Pj	2	0	0.8				
Pj	MX	*	*	clearcut	extensive	/	Pj	X	0	0.6	B	X	0	0.3
Pj	X	*	*	clearcut	extensive	/	Pj	X	0	0.6	B	X	0	0.3
Pj	M1	*	*	clearcut	extensive	/	Pj	1	0	0.6	B	1	0	0.2
Pj	1	*	*	clearcut	extensive	/	Pj	1	0	0.6	B	1	0	0.2
Pj	M2	*	*	clearcut	extensive	/	Pj	2	0	0.6	B	2	0	0.1
Pj	2	*	*	clearcut	extensive	/	Pj	2	0	0.6	B	2	0	0.1
Pj	3	*	*	clearcut	extensive	/	Pj	3	0	0.6				
Pj	X	>90	*	none	natural	/	Sb	X	30	0.8	B	X	15	0.2
Pj	1	>110	*	none	natural	/	Sb	1	30	0.8	B	1	15	0.2
Pj	2	>110	*	none	natural	/	Sb	2	30	0.8	B	2	15	0.2
Pj	3	>110	*	none	natural	/	Sb	3	30	0.8	B	3	15	0.2
Pj	4	>100	*	none	natural	/	Sb	4	35	0.8	B	4	20	0.2
Pw	X	>190	*	none	natural	/	Pw	X	35	0.5	B	X	30	0.5
Pw	1	>190	*	none	natural	/	Pw	1	35	0.5	B	1	30	0.5
Pw	2	>200	*	none	natural	/	B	2	35	0.5	Po	2	25	0.5

Pw	3	>200	*	none	natural	/	B	3	35	0.6	Po	3	25	0.4
Pw	4	>200	*	none	natural	/	B	4	35	0.7	Po	4	25	0.3
Pw	X	*	*	clearcut	extensive	/	Pw	X	35	0.5	B	X	30	0.5
Pw	1	*	*	clearcut	extensive	/	Pw	1	35	0.5	B	1	30	0.5
Pw	2	*	*	clearcut	extensive	/	B	2	35	0.5	Po	2	25	0.5
Pw	3	*	*	clearcut	extensive	/	B	3	35	0.6	Po	3	25	0.4
Pw	4	*	*	clearcut	extensive	/	B	4	35	0.7	Po	4	25	0.3
Pr	X	>200	*	none	natural	/	Pr	X	30	0.6	B	X	25	0.4
Pr	1	>200	*	none	natural	/	Pr	1	30	0.6	B	1	25	0.4
Pr	2	>200	*	none	natural	/	Pr	2	15	0.7	Sb	2	30	0.3
Pr	3	>200	*	none	natural	/	B	3	15	0.7	Sb	3	30	0.3
Pr	4	>200	*	none	natural	/	B	4	20	0.8	Sb	4	35	0.2
B	X	>80	*	none	natural	/	B	X	20	0.9	Sw	X	20	0.1
B	1	>80	*	none	natural	/	B	1	20	0.8	Sw	1	20	0.2
B	2	>80	*	none	natural	/	B	2	20	0.7	Sb	2	20	0.3
B	3	>80	*	none	natural	/	B	3	20	0.7	Sb	3	20	0.3
B	4	>90	*	none	natural	/	B	4	25	0.7	Sb	4	25	0.3
B	X	*	*	clearcut	intensive	/	Sw	X	0	0.9	Po	X	0	0.1
B	1	*	*	clearcut	intensive	/	Sb	1	0	0.7	Pj	1	0	0.3
B	2	*	*	clearcut	intensive	/	Sb	1	0	0.7	Pj	1	0	0.3
B	X	*	*	clearcut	extensive	/	Pj	X	0	0.8	Sb	X	0	0.1
B	1	*	*	clearcut	extensive	/	Pj	1	0	0.8	Sb	1	0	0.1
B	2	*	*	clearcut	extensive	/	Pj	2	0	0.8	Sb	2	0	0.1
B	3	*	*	clearcut	extensive	/	Pj	3	0	0.8	Sb	3	0	0.1
Ce	X	*	*	clearcut	extensive	/	Ce	X	10	0.7	Sb	X	10	0.1
Ce	1	*	*	clearcut	extensive	/	Ce	1	15	0.6	Sb	1	15	0.2
Ce	2	*	*	clearcut	extensive	/	Ce	2	20	0.5	Sb	2	20	0.3
Ce	3	*	*	clearcut	extensive	/	Ce	3	20	0.5	Sb	3	20	0.3
Ce	X	>130	*	none	natural	/	Ce	X	10	0.9	Sb	X	10	0.1
Ce	1	>140	*	none	natural	/	Ce	1	15	0.8	Sb	1	15	0.2
Ce	2	>150	*	none	natural	/	Ce	2	20	0.7	Sb	2	20	0.3
Ce	3	>160	*	none	natural	/	Ce	3	20	0.7	Sb	3	20	0.3
Ce	4	>170	*	none	natural	/	Ce	4	25	0.7	Sb	4	25	0.3
Oc	X	>130	*	none	natural	/	Oc	X	10	0.9	Sb	X	10	0.1
Oc	1	>140	*	none	natural	/	Oc	1	15	0.8	Sb	1	15	0.2
Oc	2	>150	*	none	natural	/	Oc	2	20	0.7	Sb	2	20	0.3
Oc	3	>160	*	none	natural	/	Oc	3	20	0.7	Sb	3	20	0.3
Oc	4	>170	*	none	natural	/	Oc	4	25	0.7	Sb	4	25	0.3

Oc	X	*	*	clearcut	extensive	/	Oc	X	10	0.9	Sb	X	10	0.1
Oc	1	*	*	clearcut	extensive	/	Oc	1	15	0.8	Sb	1	15	0.2
Oc	2	*	*	clearcut	extensive	/	Oc	2	20	0.7	Sb	2	20	0.3
Oc	3	*	*	clearcut	extensive	/	Oc	3	20	0.7	Sb	3	20	0.3
Oc	4	*	*	clearcut	extensive	/	Oc	4	25	0.7	Sb	4	25	0.3
Oh	X	>150	*	none	natural	/	Po	X	0	0.5	B	X	10	0.5
Oh	1	>150	*	none	natural	/	Po	1	5	0.5	B	1	10	0.5
Oh	2	>140	*	none	natural	/	Po	2	10	0.5	B	2	10	0.5
Oh	3	>130	*	none	natural	/	Po	3	15	0.6	B	3	10	0.4
Oh	4	>130	*	none	natural	/	B	3	20	0.6	Po	4	10	0.4
Oh	X	*	*	clearcut	extensive	/	Oh	X	0	1.0				
Oh	1	*	*	clearcut	extensive	/	Oh	1	0	1.0				
Oh	2	*	*	clearcut	extensive	/	Oh	2	0	1.0				
Oh	3	*	*	clearcut	extensive	/	Oh	3	0	1.0				

APPENDIX V

BASIC HSG ACTIVITY FILE

```
OUTPUT BASIC.sum
TITLE BASIC.act
DESC ** Timmins run with all Timmins curves.
DESC **
DESC ** Harvest rule in place is minimize volume loss.
DESC ** No access constraints in place.
DESC ** Eligibility file specifies no cutting in site class 4
DESC ** 100 year time period with 6 snapshot inventory files.
#
# Inventory file : MANDATORY.
INVENTORY /software/marten/data/timmins2.hsg
#
# Yield file(s) : MANDATORY.
# ** yield1.tab to yield13.tab : yield curves for timmins forest.
#
YIELD /software/marten/data/yield1.tab
YIELD /software/marten/data/yield2.tab
YIELD /software/marten/data/yield3.tab
YIELD /software/marten/data/yield4.tab
YIELD /software/marten/data/yield5.tab
YIELD /software/marten/data/yield6.tab
YIELD /software/marten/data/yield7.tab
YIELD /software/marten/data/yield8.tab
YIELD /software/marten/data/yield9.tab
YIELD /software/marten/data/yield10.tab
YIELD /software/marten/data/yield11.tab
YIELD /software/marten/data/yield12.tab
YIELD /software/marten/data/yield13.tab
#
#
# ** INDEX file: provides numeric codes for treatment/disturbance labels.
# ** Numeric codes are used in the stand inventory file.
#
```

```

INDEX /software/marten/data/index.dat
#
# State table : MANDATORY.
# ** State table : for Timmins data set.
#
STATES /software/marten/newdata/stateall.tab
#
# ** Constraints newinelig.tim
# all stands with site class 4,
# will not be eligible for harvest (ever).
#
#
CONSTRAINTS /software/marten/data/newinelig.tim
#
#
# ** TREATMENT file: prescribes treatment type by sp - site combo.
#
TREATMENTS /software/marten/newdata/treatpl.new
#
# ** BEGIN year: year at which to initialize stands and year to
# ** start simulation.
#
# Order file loads chart customization commands. Dictates the order
# in which categories will be displayed in charts when query posed.
#
ORDER /software/marten/data/category.dat
# alternative : /space/hsgdir/bin/order.hdr
#
SCHEDULE BASIC.sch
#
# Begin command : MANDATORY.
BEGIN 1993
#
# ** If (sum of sub-comp yields) LT OPMIN then
# ** all sub-comp yields become 0.
#
OPMIN 40
#
# ** SILVA : max area silviculture can be applied to - ha.
#
SILVA 770
#
# Simulation begins at year 1993.
#

```

```

# Step command : MANDATORY.
#
# Volumes are averaged from 84/85 to 90/91 from TMP
# m3 pine and spruce were lowered, poplar was increased
# wood-supply is sustainable
#
STEP 5 : Po = 30000,Pj = 36000,Sb/Sw = 57000 :
2-Po = 30000(90),2-Pj = 36000(50),2-Sb/Sw = 57000(42)
SNAPSHOT 1998.inv
#
STEP 5 : Po = 30000,Pj = 36000,Sb/Sw = 57000 :
2-Po = 30000(90),2-Pj = 36000(50),2-Sb/Sw = 57000(42)
#
STEP 5 : Po = 30000,Pj = 36000,Sb/Sw = 57000 :
2-Po = 30000(90),2-Pj = 36000(50),2-Sb/Sw = 57000(42)
#
STEP 5 : Po = 30000,Pj = 36000,Sb/Sw = 57000 :
2-Po = 30000(90),2-Pj = 36000(50),2-Sb/Sw = 57000(42)
SNAPSHOT 2013.inv
#
STEP 5 : Po = 30000,Pj = 36000,Sb/Sw = 57000 :
2-Po = 30000(90),2-Pj = 36000(50),2-Sb/Sw = 57000(42)
#
STEP 5 : Po = 30000,Pj = 36000,Sb/Sw = 57000 :
2-Po = 30000(90),2-Pj = 36000(50),2-Sb/Sw = 57000(42)
#
STEP 5 : Po = 30000,Pj = 36000,Sb/Sw = 57000 :
2-Po = 30000(90),2-Pj = 36000(50),2-Sb/Sw = 57000(42)
SNAPSHOT 2033.inv
#
STEP 5 : Po = 30000,Pj = 36000,Sb/Sw = 57000 :
2-Po = 30000(90),2-Pj = 36000(50),2-Sb/Sw = 57000(42)
#
STEP 5 : Po = 30000,Pj = 36000,Sb/Sw = 57000 :
2-Po = 30000(90),2-Pj = 36000(50),2-Sb/Sw = 57000(42)
#
STEP 5 : Po = 30000,Pj = 36000,Sb/Sw = 57000 :
2-Po = 30000(90),2-Pj = 36000(50),2-Sb/Sw = 57000(51)
#
STEP 5 : Po = 30000,Pj = 36000,Sb/Sw = 57000 :
2-Po = 30000(90),2-Pj = 36000(50),2-Sb/Sw = 57000(51)

```


SNAPSHOT 2053.inv

#

STEP 5 : $P_o = 30000, P_j = 36000, S_b/S_w = 57000$:

$2-P_o = 30000(90), 2-P_j = 36000(50), 2-S_b/S_w = 57000(51)$

#

STEP 5 : $P_o = 30000, P_j = 36000, S_b/S_w = 57000$:

$2-P_o = 30000(90), 2-P_j = 36000(50), 2-S_b/S_w = 57000(51)$

#

STEP 5 : $P_o = 30000, P_j = 36000, S_b/S_w = 57000$:

$2-P_o = 30000(90), 2-P_j = 36000(50), 2-S_b/S_w = 57000(51)$

#

STEP 5 : $P_o = 30000, P_j = 36000, S_b/S_w = 57000$:

$2-P_o = 30000(90), 2-P_j = 36000(50), 2-S_b/S_w = 57000(51)$

SNAPSHOT 2073.inv

#

STEP 5 : $P_o = 30000, P_j = 36000, S_b/S_w = 57000$:

$2-P_o = 30000(90), 2-P_j = 36000(50), 2-S_b/S_w = 57000(51)$

#

STEP 5 : $P_o = 30000, P_j = 36000, S_b/S_w = 57000$:

$2-P_o = 30000(90), 2-P_j = 36000(50), 2-S_b/S_w = 57000(51)$

#

STEP 5 : $P_o = 30000, P_j = 36000, S_b/S_w = 57000$:

$2-P_o = 30000(90), 2-P_j = 36000(50), 2-S_b/S_w = 57000(51)$

#

STEP 5 : $P_o = 30000, P_j = 36000, S_b/S_w = 57000$:

$2-P_o = 30000(90), 2-P_j = 36000(50), 2-S_b/S_w = 57000(51)$

SNAPSHOT 2093.inv

APPENDIX VI

SILVICULTURAL TREATMENT PRIORITY LISTS

Basic

Sw	X	intensive
Sb	MX	intensive
Sb	X	intensive
Pj	MX	intensive
Pj	X	intensive
Sw	1	basic
Sb	1	basic
Pj	M1	intensive
Pj	1	intensive
Sw	2	basic
Sb	2	basic
Pj	2	basic

Intensive

Sw	X	intensive
Sb	MX	intensive
Sb	X	intensive
Sw	1	intensive
Sb	M1	intensive
Sb	1	basic
Sw	2	intensive
Sb	2	basic
Pj	MX	intensive
Pj	X	intensive
Pj	M1	intensive
Pj	1	intensive
Pj	2	basic
B	X	intensive
B	1	intensive
B	2	intensive
Po	X	intensive
Po	1	intensive

APPENDIX VII

RELATIONSHIPS AND EQUATIONS FOR FOOD_HSI

FOOD EQUATIONS

Each stand is checked with these equations:

- 1) If Disturbance = Clearcut and
Treatment = Intensive then
 $FI = [S1]$
else
- 2) If Disturbance = Clearcut and
Treatment = Basic/Extensive then
 $FI = [S2 \times S3]^{1/2}$
else
- 3) If Disturbance = No Harvest (post break-up) and
Treatment = Natural Regeneration then
 $FI = [S4 \times S5]^{1/2}$
else
- 4) If EWG = SPRUCE or PINE then
 $Fli = [S6 \times S7]^{1/2}$
else
- 5) $Fli = 0.1$

HARVESTED STANDS (S1, S2, S3)

Intensive Silviculture (S1): These stands are scarified, planted to pine or spruce and chemically treated at least once. Cover is usually adequate in these areas beginning 10 years after stand initiation, but food species may not be. These areas are even aged and tend to grow quickly and become unsuitable to snowshoe hare in a relatively short time period. Any stands harvested prior to 1992 that have no record of disturbance or treatment are also checked with this curve.

Basic/Extensive Silviculture (S2, S3): These stands may be composed of a variety of species and can achieve high suitability for snowshoe hare at a young age. Both food and cover may be present on the sites and between 20 and 30 years after establishment these stand types provide ideal hare suitability, provided hardwood species account for 20 - 50 % of the stand composition.

POST BREAKUP STANDS (S4, S5)

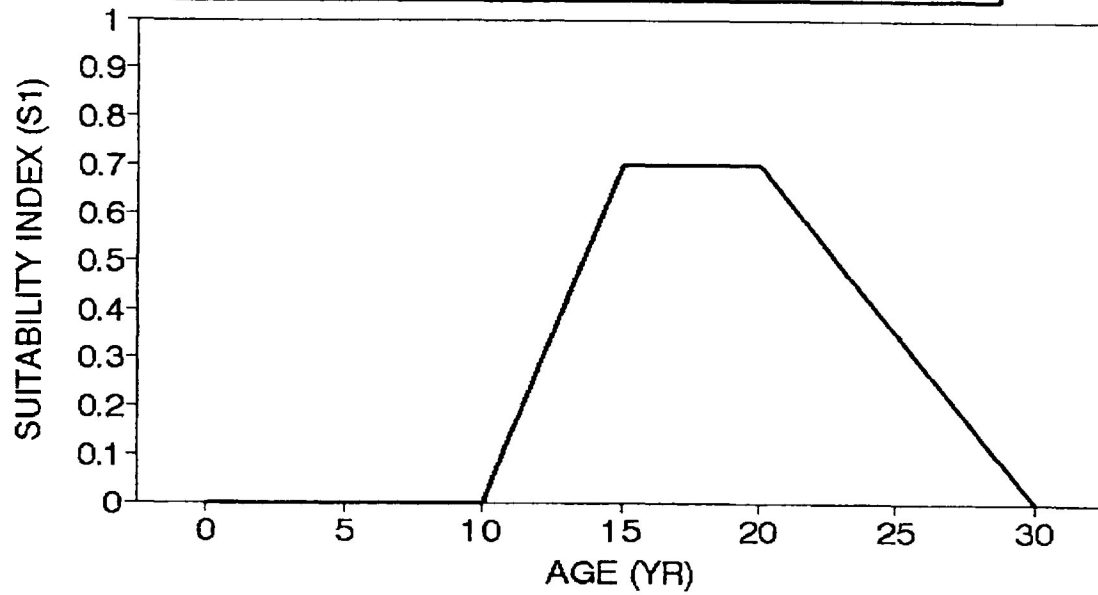
Stands remain suitable for snowshoe hare after breakup. A mixture of hardwood and coniferous species provide suitable food and cover. Little information exists regarding use of post breakup stands, although it is likely they decline in suitability before stands established from disturbance. From the time of breakup until 20 years old they provide ideal habitat.

EXISTING STANDS (S6, S7)

Overmature stands with a dominant component of spruce, pine, fir and cedar are assigned a habitat rating for snowshoe hare use of declining stands. Values are not assigned for overmature hardwood stands as these stands do not provide suitable cover to snowshoe hare.

AGE SUITABILITY

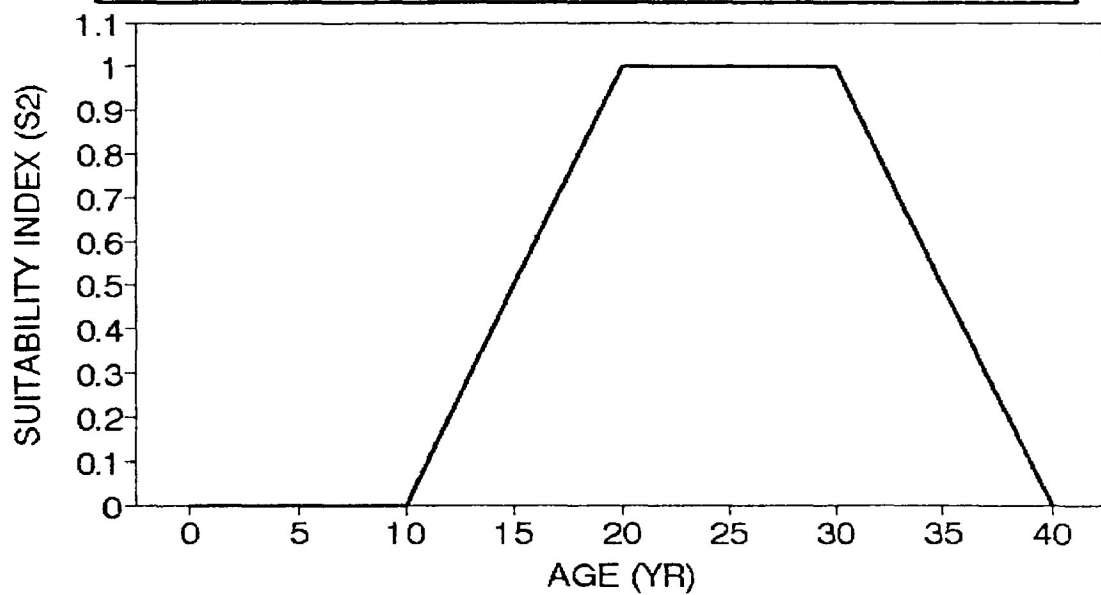
CLEARCUT - INTENSIVE SILVICULTURE



— ALL STAND TYPES

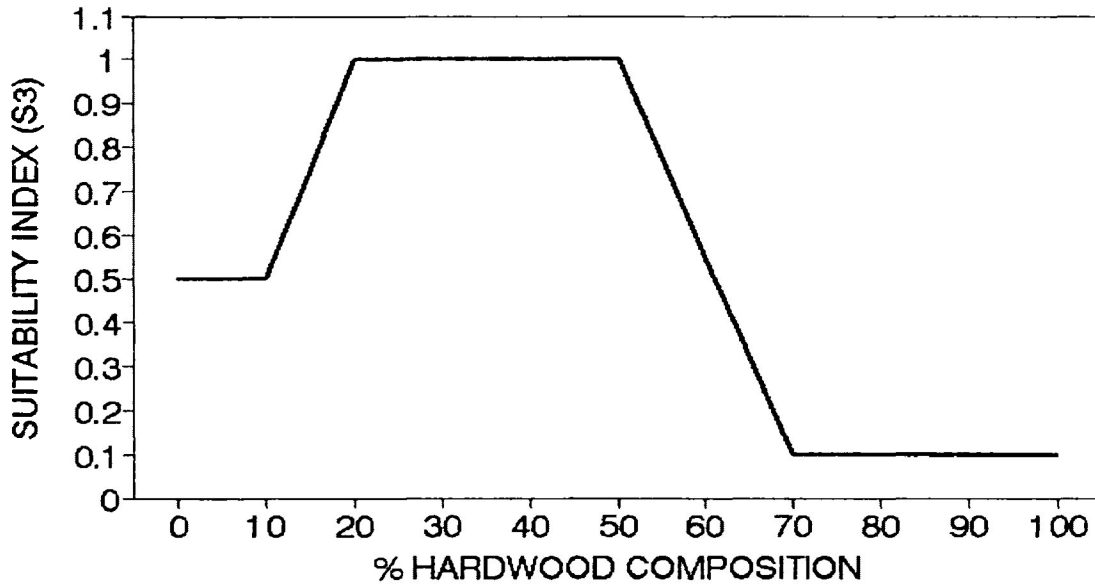
STAND AGE

CLEARCUT - BASIC/EXTENSIVE SILVICULTURE



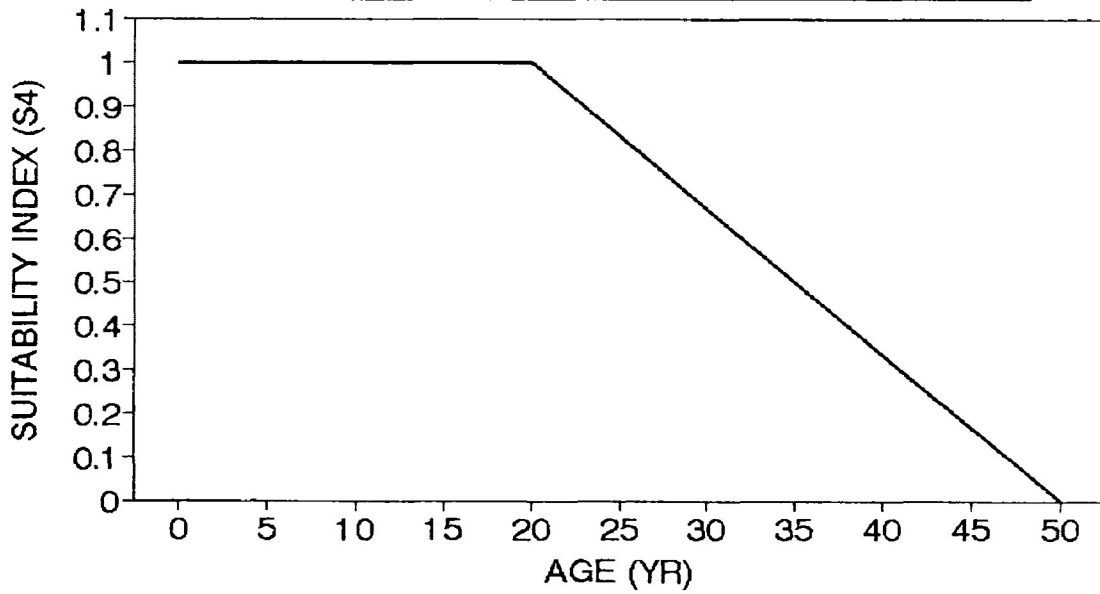
— ALL STAND TYPES

% HARDWOOD COMPOSITION
CLEARCUT - BASIC/EXTENSIVE SILVICULTURE



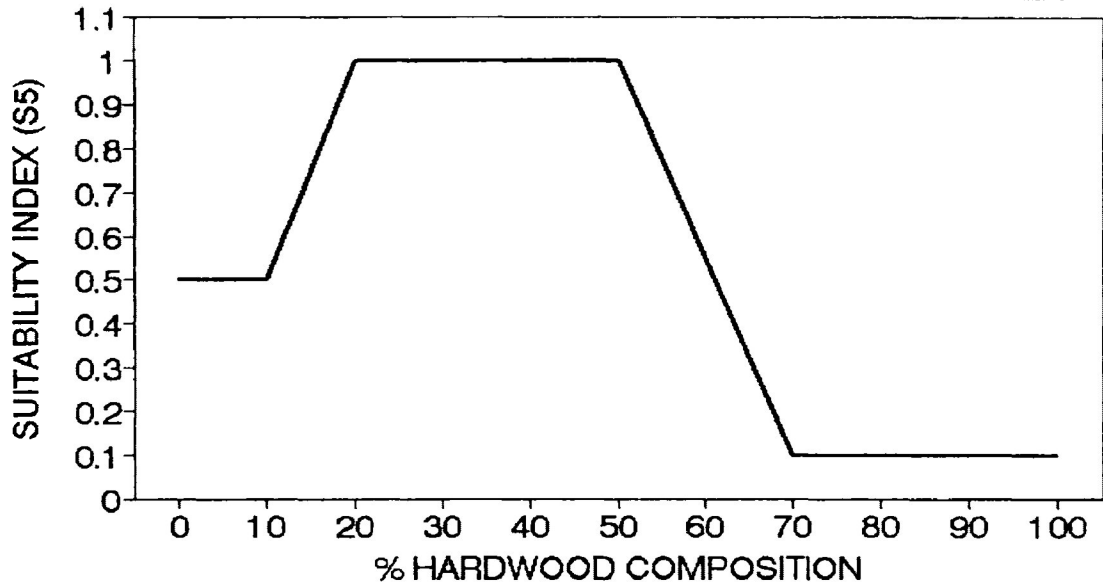
— ALL STAND TYPES

STAND AGE
NO HARVEST - NATURAL REGENERATION



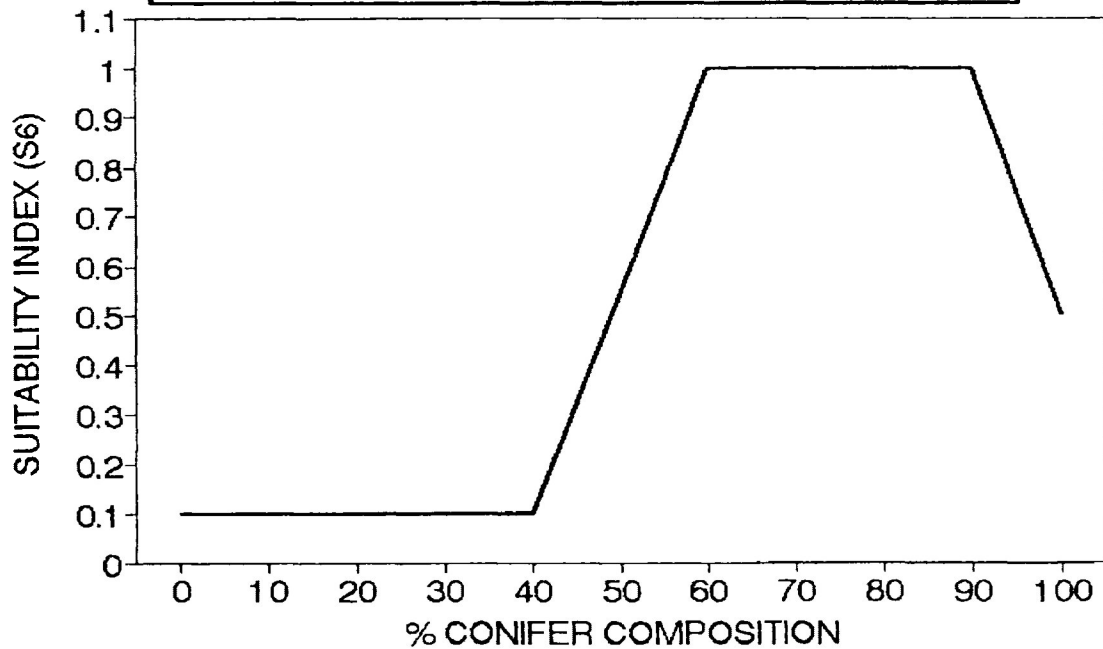
— ALL STAND TYPES

% HARDWOOD COMPOSITION NO HARVEST - NATURAL REGENERATION



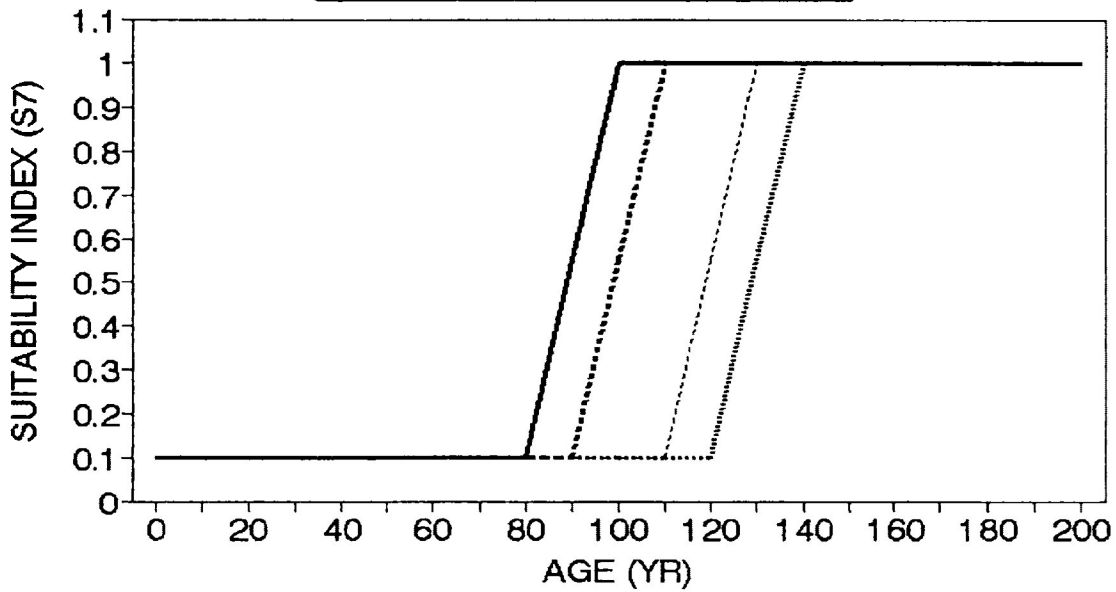
— ALL STAND TYPES

% CONIFER COMPOSITION



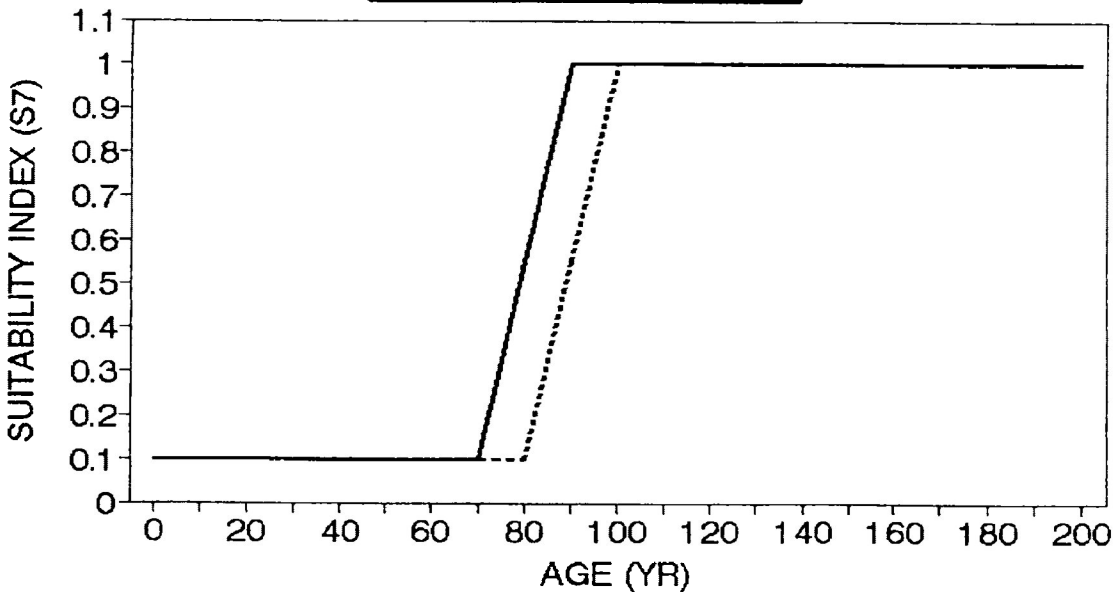
— ALL STAND TYPES

STAND AGE
WHITE SPRUCE STANDS



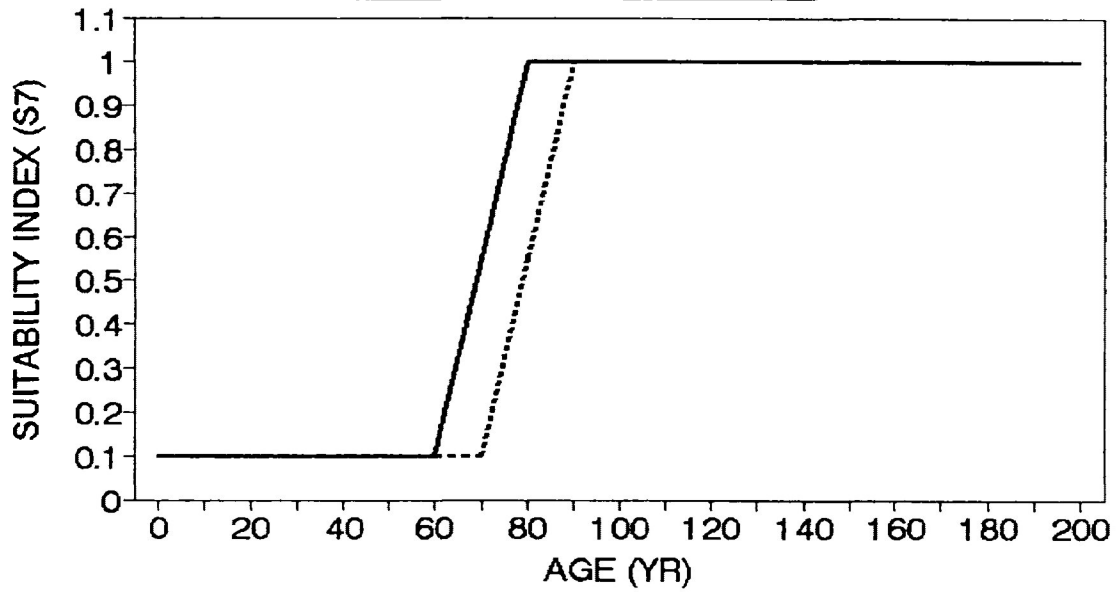
— Sw X Sw 1 - - - - Sw 2 ····· Sw 3/4

STAND AGE
JACK PINE STANDS



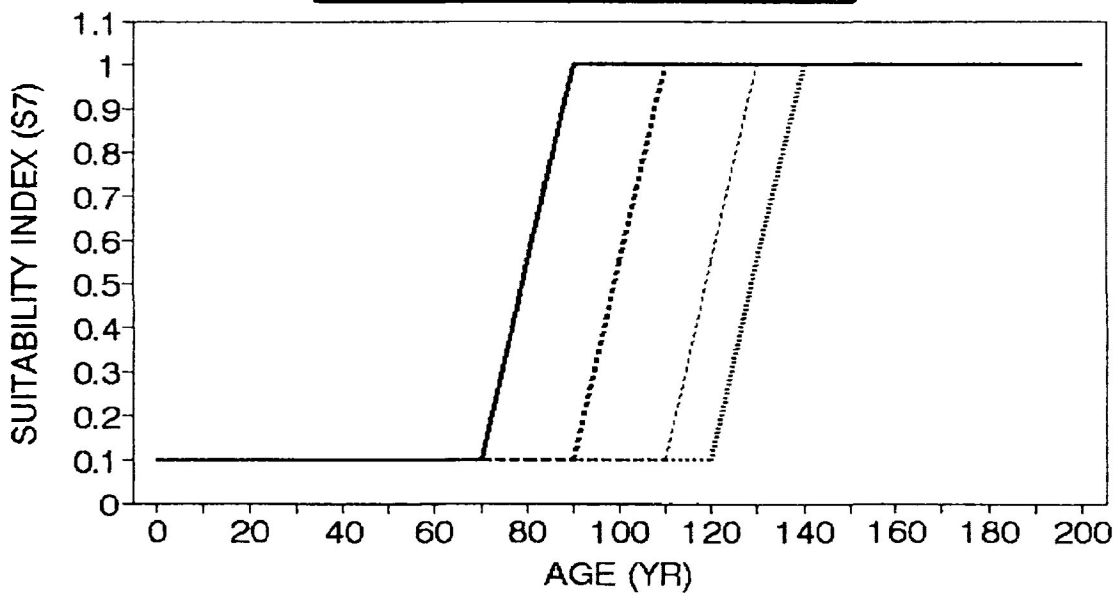
— Pj X Pj 1,2,3/4

STAND AGE
BALSAM FIR STANDS



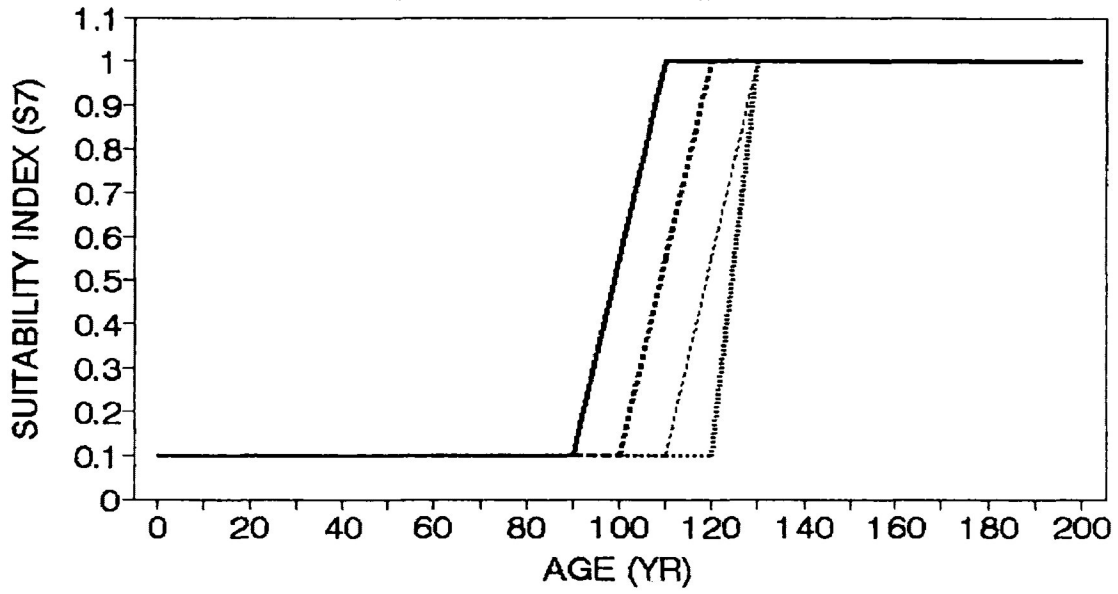
— B X,1,2,3 B 4

STAND AGE
BLACK SPRUCE STANDS



— SbX Sb1 - - - - - Sb2 - · - · - · Sb3,4

STAND AGE CEDAR STANDS



— Ce X Ce 1 - - - - Ce 2 ······ Ce 3/4