EFFECTS OF A RANGE OF BIOMASS REMOVALS ON LONG-TERM PRODUCTIVITY OF JACK PINE ECOSYSTEMS: ESTABLISHMENT REPORT

M.D. Tenhagen, J.K. Jeglum, S. Ran, and N.W. Foster

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ABSTRACT

The long-term loss of forest site productivity is a major concern to associated industries, governments, and the public at large. The establishment of a series of experimental and chronosequence sites, in a range of Plonski's site classes, in north cental Ontario jack pine ecosystems is documented. Baseline data collection methods including pre- and postharvest stand and site characteristics; tree, understorey, woody debris, and forest floor biomass sampling; and vegetation, seedbed, and natural regeneration assessments are presented. This framework will provide opportunities to study the effects of present day forest harvest and site preparation practices on long-term site productivity as well as on vegetation dynamics, succession, and biomass accretion in jack pine ecosystems.

RÉSUMÉ

La perte à long terme de productivité des terrains forestiers préoccupe beaucoup les industries forestières, les gouvernements et le public. On a documenté l'établissement d'un ensemble de stations expérimentales et de chronoséquences, selon un éventail de catégories de Plonski, dans les écosystèmes de pin gris du centre-nord de l'Ontario. La collecte des données de base a porté sur les caractéristiques du peuplement et du site avant et après la récolte et englobé l'échantillonnage de la biomasse des arbres, de la végétation en sous-étage, des débris ligneux et de la couverture morte, ainsi que des évaluations de la végétation, du lit de germination et de la régénération naturelle. Le cadre établi permettra d'étudier les effets des méthodes actuelles de récolte et de préparation des sites sur la productivité à long terme de ceux-ci et sur la dynamique de la végétation, la succession et l'accroissement de la biomasse dans les écosystèmes de pin gris.

PREFACE

ENFOR was established in 1978 as part of a federal interdepartmental initiative to develop renewable energy sources. It is a contract research and development (R&D) program aimed at generating sufficient knowledge and technology to realize a marked increase in the contribution of forest biomass to Canada's energy supply.

Administered by the Canadian Forest Service, the ENFOR program deals with biomass supply matters such as inventory, growth, harvesting, processing, transportation, environmental impacts, and socioeconomic impacts and constraints. The program normally provides total funding for contracted studies, the results of which become the property of the federal government and are freely available to the public.

A technical committee oversees the program and develops priorities, assesses proposals, and makes recommendations. Approved projects are then contracted out to the private sector. Although most project ideas are generated by the Canadian Forest Service personnel, proposals from outside sources are welcomed. These proposals should be submitted through the appropriate regional establishments or the Canadian Forest Service headquarters. Proposals are assessed in November of each year. The program operates on the basis of the fiscal year, from April 1 to March 31. On average, about $1 million is spent annually on ENFOR projects.

The program is coordinated by the Canadian Forest Service headquarters, but most projects are managed by one of the five Canadian Forest Service Centres. Scientists at these establishments initiate project proposals in response to regional and national priorities; they implement and manage approved projects; they carry out in-house R&D; and they prepare information reports. A scientific authority is assigned to each project to follow its progress and serve as the principal contact between the contractors and ENFOR program managers. The involvement of regional personnel provides the local perspective necessary to ensure the success of this national program.

Study results are either distributed as contractors' reports, or published in the Canadian Forest Service Information Report series or in technical journals. Comprehensive and detailed reports on the work are available and may be obtained on request from the addresses indicated.

For further information, write or telephone your nearest Canadian Forest Service regional centre or the ENFOR Secretariat at the Canadian Forest Service headquarters. To have your name added to the national mailing list, write to the ENFOR Secretariat.

ENFOR Secretariat
Canadian Forest Service
Natural Resources Canada
580 Booth Street
Ottawa, Ontario
K1A 0E4
(613)947-8997

Pacific Forestry Centre
Canadian Forest Service
Natural Resources Canada
506 West Burnside Road
Victoria, British Columbia
V8Z 1M5
(604)363-0600

Northern Forestry Centre
Canadian Forest Service
Natural Resources Canada
5320-122nd Street
Edmonton, Alberta
T6H 3S5
(403)435-7210

Great Lakes Forestry Centre
Canadian Forest Service
Natural Resources Canada
P.O. Box 490
1219 Queen Street East
Sault Ste. Marie, Ontario
P6A 5M7
(705)949-9461

Laurentian Forestry Centre
Canadian Forest Service
Natural Resources Canada
P.O. Box 3800
1055, rue du P.E.P.S.
Sainte-Foy, Quebec
G1V 4C7
(418)648-5850

Atlantic Forestry Centre
Canadian Forest Service
Natural Resources Canada
P.O. Box 4000
Fredericton, New Brunswick
E3B 5P7
(506)452-3500

Note: During the first 6 years of the ENFOR program, numerous projects were undertaken in the biomass conversion area. Efficiency and Alternative Energy Technology Branch, Natural Resources Canada, is now responsible for this topic. Information can be obtained from the Bioenergy Group, 580 Booth Street, Ottawa, Ontario, Canada K1A 0E4, (613)996-6226.

The ENFOR Program is funded by the federal Panel on Energy R&D (PERD).

ENFOR Priorities

The current priorities of the ENFOR program are:

1. Intensive Silviculture

To develop and test methods and systems for increasing forest biomass productivity.

2. Environmental Effects

To assess the environmental effects of intensified biomass production and harvesting for energy purposes.

3. Economics

To assess social, economic, technical, and institutional influences of and constraints to an increasing use of forest biomass for energy production.

4. Technology Transfer

To make the results of the program available to potential users in a readily accessible format.

PRÉFACE

Établi en 1978 dans le cadre d'une initiative fédérale interministérielle ayant pour but l'exploitation des sources d'énergie renouvelables, ENFOR est un programme de contrats de recherche et de développement (R.-D.) visant à accroître les connaissances et générer les techniques susceptibles de faire augmenter notablement l'apport de la biomasse forestière aux réserves énergétiques du Canada.

Administré par le Service canadien des forêts, le programme ENFOR porte sur les questions d'approvisionnement en biomasse : inventaire, croissance, récolte, traitement et transport des ressources, et répercussions sur l'environnement, effets socio-économiques et contraintes qui en découlent. Habituellement, le programme finance entièrement les études effectuées sous contrat; les résultats de ces études deviennent la propriété du gouvernement fédéral qui les met à la disposition du public.

Le programme relève d'un comité technique qui élabore les priorités, évalue les propositions et soumet ses recommandations. Les projets approuvés sont ensuite donnés sous contrat au secteur privé. Bien que le personnel du Service canadien des forêts conçoive la plupart des idées de projet, les propositions venant de l'extérieur sont accueillies avec plaisir. Elles doivent être soumises aux établissements régionaux ou à l'administration centrale de FC. L'évaluation de ces propositions se fait chaque année en novembre. Le programme fonctionne selon une année financière allant du 1er avril au 31 mars. En moyenne, on consacre à peu près un million de dollars par année aux projets ENFOR.

La coordination du programme relève de l'administration centrale du Service canadien des forêts, mais la plupart des projets sont administrés par l'un des cinq centres du Service canadien des forêts. Les scientifiques de ces établissements formulent des projets correspondant aux priorités régionales et nationales, administrent les projets approuvés, font des travaux de R.-D. et rédigent des rapports d'information. Chaque projet relève d'un responsable scientifique qui en suit l'évolution et sert de lien entre les entrepreneurs et les gestionnaires du programme ENFOR. La participation du personnel régional assure la perspective locale essentielle au succès de ce programme national.

Les résultats des études paraissent sous forme de rapport de l'entrepreneur, de rapport d'information du Service canadien des forêts ou encore dans des revues techniques. Des rapports complets et détaillés sur les travaux peuvent être obtenus sur demande à l'adresse indiquée.

Pour de plus amples renseignements, les intéressés sont priés d'écrire ou de téléphoner au centre régional du Service canadien des forêts le plus près ou au Secrétariat d'ENFOR, à l'administration centrale du Service canadien des forêts. Il suffit d'écrire au Secrétariat d'ENFOR pour être inscrit sur la liste d'envoi nationale.

Secrétariat ENFOR
Service canadien des forêts
Ressources naturelles Canada
580, rue Booth
Ottawa (Ontario)
K1A 0E4
(613)947-8997

Centre de foresterie du Pacifique
Service canadien des forêts
Ressources naturelles Canada
506 West Burnside Road
Victoria (Columbie-Britannique)
V8Z 1M5
(604)363-0600

Centre de foresterie du Nord
Service canadien des forêts
Ressources naturelles Canada
5320-122 Street
Edmonton (Alberta)
T6H 3S5
(403)435-7210

Centre de foresterie des Grands Lacs
Service canadien des forêts
Ressources naturelles Canada
C.P. 490
1219 Queen Street East
Sault Ste. Marie (Ontario)
P6A 5M7
(705)949-9461

Centre de foresterie des Laurentides
Service canadien des forêts
Ressources naturelles Canada
C.P. 3800
1055, rue du P.E.P.S
Sainte-Foy (Québec)
G1V 4C7
(418)648-5850

Centre de foresterie de l'Atlantique
Service canadien des forêts
Ressources naturelles Canada
C.P. 4000
Fredericton, (Nouveau-Brunswick)
E3B 5P7
(506)452-3500

Nota : Au cours des six premières années du programme ENFOR, le secteur de la conversion de la biomasse a fait l'objet de nombreux projets. La responsabilité de ce secteur relève maintenant de la Direction de l'efficacité énergétique et des énergies de remplacement, Ressources naturelles Canada, et pour obtenir des renseignements, il faut s'adresser au Groupe de la bioénergie, 580, rue Booth, Ottawa (Ontario), Canada K1A 0E4, (613)996-6226.

Le programme ENFOR est subventionné par le Groupe interministériel de recherche et de développement (GRDE).

Les priorités d'ENFOR

Voici les priorités courantes du programme ENFOR :

1. Sylviculture intensive

Mettre au point et expérimenter des méthodes et des techniques susceptibles d'améliorer la productivité de la biomasse forestière.

2. Effets sur l'environnement

Évaluer les effets sur l'environnement d'une production et d'une récolte intensives de la biomasse forestière à des fins énergétiques.

3. Facteurs économiques

Évaluer les influences sociales, économiques, techniques et institutionnelles d'une utilisation accrue de la biomasse forestière à des fins énergétiques ainsi que les contraintes imposées à une telle utilisation.

4. Transfert de technologie

Rendre disponibles aux utilisateurs éventuels les résultats du programme sous une forme qui sera facilement accessible.

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Cover photo: Log structure covering an exposed soil profile on the Well's Township self-guided interpretive trail. The trail was constructed to illustrate the research being done on the long-term productivity of jack pine ecosystems study. (M.D. Tenhagen)

INTRODUCTION

Public concern about the forest environment has never been greater. Within Ontario, this concern has been demonstrated by the Class Environmental Assessment (EA) of Timber Management, and by frequent news media coverage of such topics as old-growth forest preservation, clear-cutting, chemical use, biodiversity, and the loss of site productivity. To provide the scientific underpinning for forest management decisions that maintain the integrity, diversity, and long-term productivity of forest ecosystems, Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre, is currently pursuing research in several of these areas.

One of the critical concerns expressed in the EA (April 1994) was the impact of full-tree harvesting, in particular the removal of organic matter, on long-term site productivity. Impacts also result from nutrient removal associated with shorter rotations and from the removal of biomass from the site for energy use. In addition, some forestry practices, such as site preparation by blading or prescribed burning, may exacerbate the impacts of nutrient removal. So also will the compaction of soil by harvesting and site preparation equipment.

To address concerns about the loss of productivity owing to current forestry practices, a federal–provincial Sustainable Productivity Working Group has been established. The working group has focused principally on nutrient loss owing to biomass removal, but other influences on site productivity are also being considered. Emphasis is on poor sites with low nutrient reserves as these are suspected to be most susceptible to nutrient removal through full-tree harvesting. For jack pine (*Pinus banksiana* Lamb.) stands these include sites with coarse soils (sands and gravels), sites with a high content of coarse fragments, and sites with shallow soils over bedrock.

Jack pine is of major importance to the pulp and lumber industries in northern Ontario. Its fast-growing character and low requirement for site resources make jack pine a potential candidate species for fuelwood production. As jack pine is generally found in sites of low nutrient status (Chrosciewicz 1963, Bell 1991), its use as an energy source could lead to a depletion of nutrients, and degradation in stand productivity. Naturally occurring, normal to overstocked, juvenile, semimature or mature stands may be considered as a source of biomass for energy. Through intensive management (i.e., fertilization, tending treatments) and the use of thinnings (i.e., precommercial and commercial) the decrease in stand productivity over many rotations may be avoided.

From an operational point of view, jack pine is relatively easy to regenerate. Jack pine establishes best after planting in an exposed mineral soil medium (Eyre and Lebarron 1944, Benzie 1977, Rudolph 1983). This is commonly achieved by either passive or power disc-trenching, Bräcke mounding, or windrowing. Jack pine is also shade intolerant; therefore, herbicide (i.e., glyphosate, hexazinone) is usually applied to reduce competition. Jack pine can also maintain itself on very sandy or gravelly soils where other species can barely survive (Bell 1991). These silvicultural requirements, combined with rapid growth in the juvenile stage (Cayford and Bickerstaff 1968), make the regeneration of jack pine economically attractive, especially for low-profit fuelwood or energy production purposes. Additionally, many existing stands have originated from both natural seed sources (i.e., after wildfire) and artificial regeneration (i.e., direct seeding). Many of these stands are now overstocked and stand development could be enhanced by precommercial thinning.

Any harvesting/site preparation regime that removes biomass, and hence nutrients, has a potential to degrade site productivity. Of major concern is the impact of clear-cutting using full-tree harvesting, whereby the trees are skidded to the roadside, delimbed, and the slash piles are burned. This practice concentrates nutrients at roadside, and depletes forest sites. There is also a potential long-term degradation of site productivity. Radical site preparation by blading, which concentrates forest floor and slash into windrows and leaves wide strips of exposed mineral soil, has the potential for even greater site degradation. Long-term site productivity is also affected by changes in soil porosity, i.e., compaction due to the repeated passage of heavy harvesting equipment (Powers et al. 1990). A less productive site results in longer rotations and more land is needed to yield the same volume of wood.

The initial objectives of an ENFOR[1] project to support this work were:

1. To determine the feasibility of using jack pine as a fuelwood source by utilizing natural or direct seed origin stands of juvenile and midrotation ages.
2. To determine the effects of a range of biomass removals, related to main silvicultural options, on soil nutrient budgets, tree growth, and long-term productivity.

Through field observation of mortality and growth response of outplanted jack pine, environmental data, site and stand characterization, and analysis using a process model simulation approach, harvesting effects on site resource balance, nutrient budget, stand recovery, and long-term productivity will be determined. Additionally, data sets and results from previously conducted research will be combined with the findings of the present study. The approach will combine field experiments with

[1] ENFOR is the acronym for Energy from Forest Biomass, a program funded by the Interdepartmental Panel on Energy Research and Development (PERD).

modeling in order to extend specific knowledge gained, and information obtained from other work, to a predictive model of impacts of these activities on the long-term productivity of jack pine sites. This report will focus on the establishment of the field experiments.

Natural Resources Canada, Canadian Forest Service (CFS), Great Lakes Forestry Centre, in conjunction with the Ontario Ministry of Natural Resources (OMNR), Ontario Forest Research Institute (OFRI), and various cooperators (*see* Appendix A) initiated this project to study harvest/site preparation impacts as they applied to boreal forest ecosystems. Black spruce (*Picea mariana* [Mill.] B.S.P.) stands will be the focus of OFRI research; the CFS will examine jack pine stands. The present report, comprising the jack pine component, outlines the procedures and protocols used in the experimental design, site selection, establishment of experimental sites, biomass sampling, data collection and analysis, and detailed site and stand characteristics.

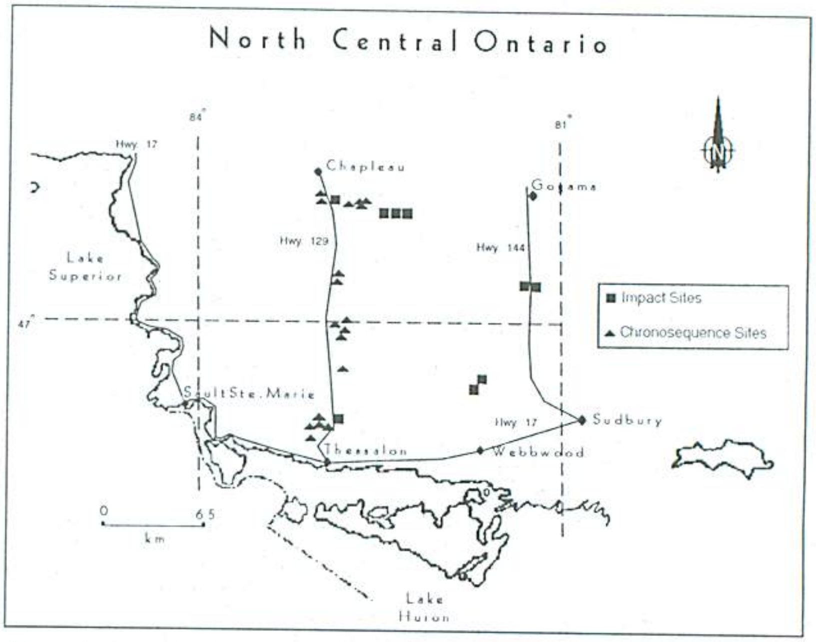

Figure 1. Location of experimental and chronosequence plots.

STUDY AREA

Located within the Algoma and Sudbury districts in northern Ontario, the study area lies between the towns of Chapleau and Gogama in the north and Webbwood and Thessalon along the north shore of Lake Huron in the south (*see* Fig. 1 for site locations). It extends across the Boreal Forest Region, Missinaibi/Cabonga Forest Section (B.7), into the Algoma (L.10) and Timagami (L.9) sections of the Great Lakes/St. Lawrence Forest Region (Rowe 1972) in the south. In this transect a steep thermal gradient is crossed, and it has been suggested that productivity for jack pine increases in the north–south direction (MacIver 1991).

METHODS

Site Selection

Jack pine on deep sandy or gravelly soils, mostly glaciofluvial outwash, were selected for study. However, some windworked soils were also chosen. One site (Eddy 2) on shallow soil over bedrock was included in the study.

The following site criteria were chosen: a minimum stand area of 10 hectares, stand stocking normal to overstocked, a slope less than 10 percent, pest and disease free, and a jack pine component > 60 percent.

Juvenile, semimature, and mature jack pine stands were considered to have a current age of 25 to 40 years, 41 to 65 years, and > 65 years, respectively.

Experimental Design

Chronosequence Study

In 1992, a chronosequence study was established to determine the biomass, soil, site, vegetation, and nutrient status for a range of immature stands. This would yield information regarding the accretion of biomass with age.

This study included a range of site classes (Site Class 1 to 3, Plonski 1974) and geographic locations on a north–south gradient from Chapleau to Thessalon, Ontario (Fig. 1). One stand each of juvenile and semimature ages for three climates x three site classes was sampled, giving a total of 18 stands. Precise descriptions of site locations may be found in MacMurray.[2]

Impacts Study

An impacts study was established in 1993 and 1994. The objectives of this study were to:

1. Determine the impacts of forest manipulations on jack pine sites of contrasting nutrient and climate regimes on i) soil nutrient supply, ii) key soil processes that determine site productivity, and iii) the recovery of nutrient cycling between vegetation and soil.

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[2] MacMurray, S.C. 1992. Sustainable productivity of jack pine: A report of the initial project proceedings. Sylva-Tech For. Serv., Sault Ste. Marie, Ontario. For. Can., Ontario Region, Sault Ste. Marie, ON. File Rep. 110 p.

2. Obtain long-term data on climate, soil, and vegetation, for experiments that manipulate key variables (water and nutrients) which limit forest productivity.
3. Document the mortality, vitality, and growth responses of jack pine outplantings to silvicultural treatments, vegetative competition, and the main gradients of climate and soil nutrient regime.
4. Demonstrate harvesting impacts on nutrient cycling to resource managers, forest scientists, environmentalists, and the public at large.

A set of nine mature stands was selected for this study. There were already two sites in Wells and Nimitz townships that had been monitored for some 20 years as part of previous nutrient cycling studies. Inclusion of these stands was essential, owing to the long-term database already collected and perspectives on changes over time. Three more sites were added to these from the Superior Forest Management Limits near Chapleau, and four more from the E.B. Eddy Forest Products Limits to the east. The sites covered a range of climatic and site conditions, although they did not uniformly fill the three climates x three site types matrix, owing to difficulties in locating Site Class 3 stands.

Establishment of the impacts study was intended to cover the main treatments and impacts encountered in forestry practices in jack pine. To do this the sites were subjected to several treatments representing different levels of biomass removal, as well as humus disturbance and compaction: namely, i) tree-length log, site preparation by power disc-trenching; ii) full-tree log, site prepare by disc-trenching; iii) full-tree log, blade off all organic down to mineral soil; and iv) same as iii, but followed by compaction. In addition, "controls" of standing timber and full-tree logging without any site preparation were included for comparisons. All sites were planted with jack pine seedlings so as to monitor the influence of treatments. Finally, blocks of red pine (*Pinus resinosa* Ait.) on conventional full-tree, disc-trenched sites were planted for growth comparisons. All nine impact sites have been characterized for biomass in all horizons of the stand for physical and chemical soil properties, and for vegetation and seedling substrates.

Site Locations

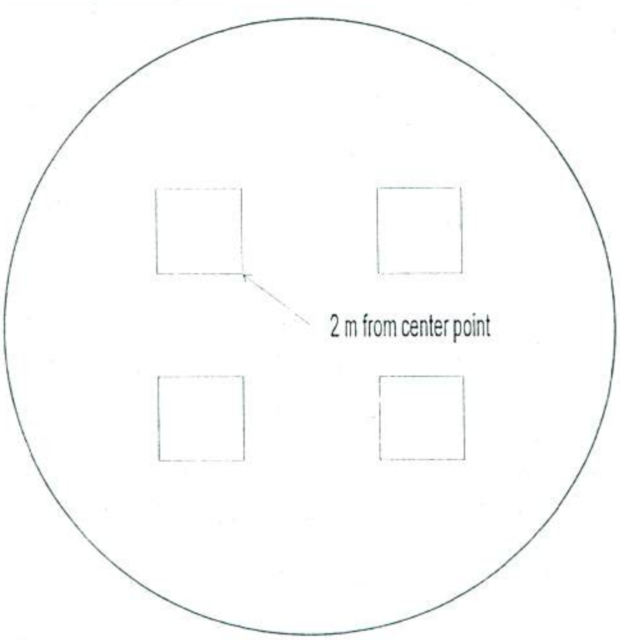
The chronosequence sites (nine juvenile and nine semimature) were established along the Chapleau/Thessalon corridor (Hwy. 129). Stands were subdivided into three replication areas roughly situated in the Nimitz Township–Sultan Road area in the north, Dean's Township in the central area, and in the Kirkwood Township in the south. Precise locations are detailed elsewhere.[3]

Mature experimental stands were dispersed throughout the study area, but these were located mainly on Highway 129 (Thessalon to Chapleau), Highway 144 (Sudbury to Gogama), Highway 667 (Sultan Road), and the Agnew Lake/Ramsey Road (north of Webbwood). Appendix B details the exact locations, and provides directions on how to reach the plots. Plot layouts are also included. One site, designated as Nimitz, is located approximately 28 kilometers south of Chapleau along Highway 129 in Nimitz Township. Another site, designated as Wells, is located approximately 26 kilometers north of Thessalon along Highway 129 in Wells Township. Three sites, designated as Superior 1, 2, and 3, are situated in Wakami Township approximately 50 kilometers southeast of Chapleau along Highway 667 (Sultan Road). Two sites, designated as Eddy 1 and 2, are located approximately 60 kilometers south of Gogama along Highway 144 in Paudash Township. Two sites, designated as Eddy 3 and 4, are situated in Monestime Township approximately 75 kilometers north of Webbwood along the Agnew Lake/Ramsey Road.

Field Measurements

Chronosequence Sites

Figure 2 illustrates the design for each of the chronosequence sites. Each of the 18 sites consists of two circular plots 11.28 m in diameter and at least 50 m apart. The area of these plots represents 99.93 m^2 or 1/100th of a hectare.



Circular plot diameter - 11.28 m (r = 5.64)
(Area = 1/100 ha)
Assessment quadrats - 2 m x 2 m

Figure 2. General design of chronosequence plots.

[3] Ibid.

Within each circular plot, four 2-m x 2-m assess-ment quadrats were placed equidistant from the center stake (2 m) for vegetation, regeneration, and seedbed assessments. These quadrats were permanently marked with steel pins at each of the four corners. Additionally, in each plot five healthy, dominant, permanent sample trees were selected, numbered, and tagged.

One of the plots in each site was treated with fertilizer. A mixture of urea (N = 435 kg/ha), triplesuperphosphate (P = 217 kg/ha), and muriate of potash (K = 167 kg/ha) was applied manually. The other plot in the site was not treated and can be considered as a control.

Foliage samples were collected from each of the five trees within each plot during the year before and for 2 years after fertilization.[4] Samples were analyzed individually for each tree; 100 needles were measured for length, oven-dried and weighed, and chemical analyses performed.

Mature Sites

The general design of plots within the sites is presented in Figure 3. Each site had a total of 15 plots (30 m x 30 m), of which three plots were placed in an uncut forest reserve. A total area of approximately 7 ha was required to accommodate a site. The plots were situated 20 m apart and an additional buffer of 50 m was usually left between the outer plot edges and the closest standing forest or road locations (*cf.* Mead et al. 1991). A 2-m x 2-m quadrat was placed in each corner, 4 m up and in from the corner stakes within each plot for floristic, vegetation structure, regeneration, and seedbed assessments.

There were four treatments replicated three times. The treatments were:

1. full-tree harvest with trenching;
2. tree-length harvest with trenching;
3. full-tree harvest with blading; and
4. full-tree harvest with blading and compacting.

Full-tree harvesting involved removing the entire tree, and then delimbing and detopping at roadside. In tree-length harvesting the branches and tops were removed at the cutting site and only the bole was removed to the roadside. In the Superior 1, 2, 3, and Nimitz sites, the feller buncher was situated in the plot but the trees were placed around and sometimes outside of the plot. The tops and slash were then redistributed manually within the plot. Eddy 1 was harvested using a feller buncher, but Eddy 2, 3, and 4 were hand cut and every attempt was made to correctly delimb within the tree-length plots.

Operational power trenching (TTS) was performed in all sites except for the one in Wells Township, where a passive trencher was used. Blading, or exposing the top of the Ae or B1 layers (all stumps and duff removed), was performed by using either D7 or D8 caterpillar bulldozers.

Compaction was first attempted by repeatedly passing over the plot with the bulldozers. Analysis of bulk density samples from the Wells Township site revealed a nonsignificant difference in the levels of compaction between the bladed and the bladed/compacted plots. Therefore, a CFS John Deere Model 401D narrow-tired front-end loader (industrial tractor), fully loaded in the front bucket and backhoe, was used by systematically, repeatedly passing over the plots—two passes over all areas, followed by another two passes at right angles. Subsequent analysis of bulk density samples revealed a significant

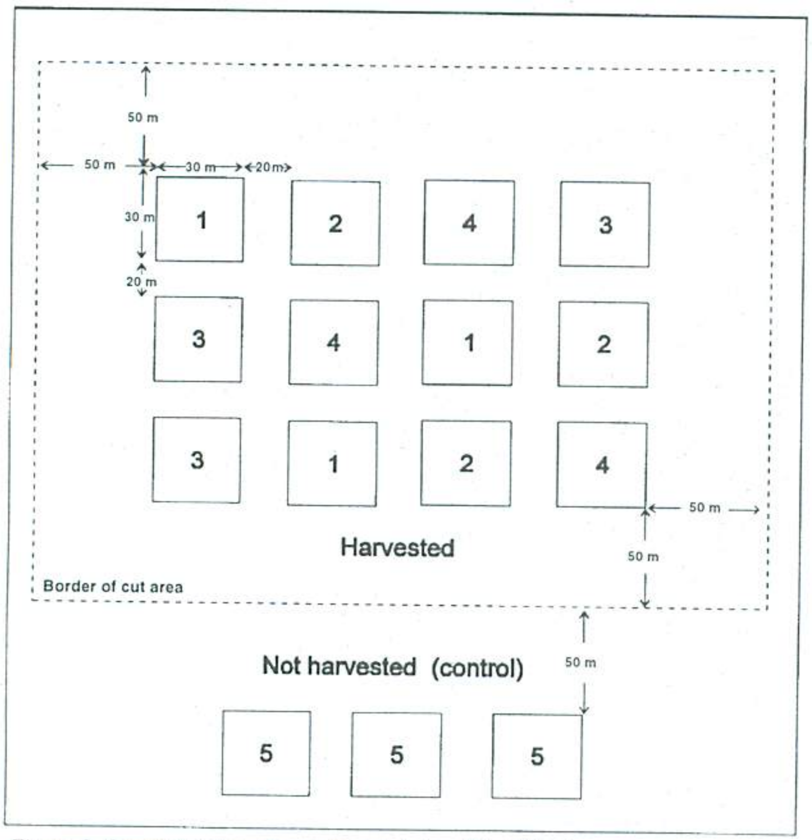


Figure 3. General design of experimental sites. The following treatments were randomly assigned: 1) full-tree harvest with disc-trenching, 2) tree-length harvest with disc-trenching, 3) full-tree harvest with blading, 4) full-tree harvest with blading and compaction, and 5) unharvested forest.

[4] Ibid.

compaction effect. Mechanical site preparation on six of the nine experimental sites was completed during 1993. Site preparation in the remaining three sites (Eddy 2, Superior 3, and Nimitz), and additional compaction (Superior 1, 2, 3, Nimitz Township, and Wells Township) were completed early in 1994.

In five sites, Superior 1, 2, and 3 and Eddy 3 and 4, an additional treatment (full-tree harvest/no site preparation) was added in three extra plots. This is the extreme end of the biomass removal gradient, where the least amount of disturbance and presumably the lowest level of accelerated decomposition of the forest floor occurred.

Due to application of only bulldozer compaction (not effective to compact soils) in the Eddy 1, 2, 3, and 4 sites, planting with 1.2-m spacing was substituted for the blading plus compacting condition. All other plots were planted at an operational spacing of 2 m. Another bladed plot, in addition to the three already bladed, was added to the Nimitz site. Therefore the total number of 30-m x 30-m plots numbered 124.

The treatments were designed to test the null hypotheses that: i) biomass removal has no influence on seedling establishment and growth, ii) compaction has no influence on seedling establishment and growth, and iii) spacing of seedlings does not influence tree form and stand development.

Baseline Data Collection: Experimental Sites

Tree biomass

Diameter at breast height (1.3 m) outside bark (DBHOB), and height were measured for all trees, alive and standing dead, for all species, equal to or greater than 2.54 cm in diameter in all plots. Canopy cover was estimated with a densiometer within all of the control plots. To obtain site indices, at least three dominant/ codominant trees were felled from the buffers of each stand. Total height, height of the crown (top of tree to lowest living branch), and length of the longest branch were measured. Discs were cut at 0, 1, and 1.3 m, and then at 2-m intervals for Tree Ring Increment Measurement (TRIM) analysis; the top 2.5 m of each tree was saved for further analysis of annual height growth.

Understory biomass

To determine existing pools of field layer biomass, twenty-four 1-m x 1-m plots (eight systematically located beside each control plot) from each site were clipped and separated by strata (species were categorized as creeping shrubs, low shrubs, herbs and graminoids, or tall shrubs), oven-dried, weighed, and analyzed for chemical and nutrient content. Biomass of the tree layers was determined using existing regression formulae developed in the literature for jack pine.[5]

Woody debris

To measure the amount of woody material in the form of twigs, branches, boles, etc., the ***line intersect fuel sampling method*** developed by Van Wagner (1968) and elaborated upon principally by Brown (1971) and Brown and Roussopoulis (1974) was employed. One, equilateral line triangle, 15 m on a side, was measured in the control and in all non-bladed treatment plots.

Forest floor

From two corners of each plot, near but not in the vegetation quadrat, 30-cm x 30-cm samples of the forest floor were collected. For each sample the depths of litter, fermentation, and humus layers on all four sides of the divot were measured and recorded. These samples were dried at 70° C for 48 hours; weighed; and analyzed for pH, chemical, and nutrient content. Divots were cut and measured from the other two corners and the center of the plot, but were not sampled. These samples will provide a basis for calculating the amount of biomass component in the forest floor, and will also furnish a possible indicator of site productivity.

Vegetation, seedbed, and regeneration

The abundance or presence of certain understory plants, and the changes that occur to each stratum after harvest and site preparation, may provide important indicators of productivity and elucidate succession and stand development after harvesting. All species of vascular plants, bryophytes, and lichens were given cover estimates in the pre- and postharvest (Year 1) conditions in the four 2-m x 2-m quadrats within each plot. Cover was estimated to the closest 1 percent, with the lowest value being 1 percent. Moss and lichen species that were known were given cover estimates only if they achieved at least 1 percent cover and were collected if they exceeded a cover value > 5 percent. All vascular plants were assessed, and those not known were collected for identification. Community vegetation structure was recorded by cover value for the individual stratum by life form within the quadrats. The matrix of vegetation structure used is included in Appendix C.

The amount and description of receptive seedbed in the quadrats were recorded using methods developed by Jeglum (1984). All tree species were assessed in each quadrat by recording their number, within height and diameter classes, up to a diameter at breast height (DBH) of 2.54 cm using the classes of Jeglum (1982).

[5] Ran, S.; Zakrewski, W.T.; Morrison, I.K.; Jeglum, J.K. Individual-tree dry matter estimation: Effect of age, site class and stand density. Can. Journal For. Res. (In review)

Soils

To sample the range of within-site variability, two soil pits from site locations as different as practicable were excavated in each site within the buffer zones. Detailed soil horizon descriptions using Forest Ecosystem Classification (FEC) Clay Belt 3e soil data cards were used for horizon structure and to determine moisture regime, drainage, textures, etc.. Bulk samples were taken from each horizon, Ah and down, for detailed pH, loss-on-ignition, and chemical and nutrient analyses. Bulk density samples were taken to determine soil porosity (compaction) from each corner of each plot, before and after site preparation. The depths sampled were 0–10 cm, 10–20 cm, and 20–30 cm. Four samples of each depth were combined to provide a mean bulk density (g/cm^3) for each depth for each plot. A 5.2-cm diameter corer was used in 1993; a 6.0-cm diameter corer was used in 1994.

Baseline Data Collection: Chronosequence Sites

Consistent and equivalent data from both the impact sites and the chronosequence sites were collected. Some procedures and methods used in the chronosequence sites were more representative because of the smaller plot size. Only differing methodologies are presented in the following sections.

Understory biomass

From each site, twenty-four 1-m x 1-m plots, systematically located between the two plots, were clipped and separated by strata for weight, and for chemical and nutrient analyses.

Woody debris

Similar methods were used as for the impact plots. Three 15-m lines, each crossing at the center point of the plot, were measured. Line 1 was established in a north–south direction. The other two lines were at 60° intervals to Line 1.

Forest floor

In the nonfertilized circular plot, five 30-cm x 30-cm samples of the litter, fermentation, and humus layers were taken from around the soil pit. The depths of each of the layers on all four sides of the divot were measured and recorded. These samples were dried, weighed, and analyzed for pH, and for chemical and nutrient content.

Soils

One soil pit was excavated in the nonfertilized circular plot in each site. Detailed soil horizon descriptions, bulk samples, and measures were taken as for the impact sites. Within each plot four bulk density samples were taken using a 6.0-cm corer, for 0–10 cm, 10–20 cm, and 20–30 cm depths within each plot so as to determine porosity (soil compaction).

Physical and Chemical Analysis

Mineral soils

Texture, Munsell soil color, and the presence of calcium carbonate were determined prior to preparation for chemical analysis. Mineral soil samples were air-dried and passed through a 2-mm sieve. The < 2 mm (fine earth) fraction was analyzed as follows: pH in 1:1 soil:water mix and in 0.01*M* $CaCl_2$, using a combination electrode pH meter; total nitrogen (N) by a semimicro Kjeldahl procedure, using a Tecator Kjeltec Auto 1030 Analyser; organic matter by loss-on-ignition (Kalra and Maynard 1991); carbon by wet oxidation (Walkley 1947); and total phosphorus (P), potassium (K), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), sodium (Na), and aluminum (Al) by inductively coupled argo plasma (ICAP) emission spectometry, using a Thermo Jarrel Ash Model 1100 ICAP emission spectrometer following HNO_3 digestion of forest floor material or $HClO_4$ digestion of mineral soil. In addition, available P was determined by ICAP after extraction with Bray and Kurtz No. 1 extractant; exchangeable K, Ca, Mg, SO_4^{2-}, Fe, Mn, Zn, Cu, Na, and Al were determined by ICAP, following extraction with unbuffered 1*M* NH_4Cl extractant; cation exchange capacity on the residual soil was determined by H+ displacement of NH_4+; and exchangeable NH_4+ and NO_3- were determined in 2*N* KCl extracts (Bremmer 1965) using the Tecator Analyser.

Organic materials

All plant materials (clipped biomass, foliar samples) and L, F, and H layers were dried at 70° C for 48 hours in a forced draught laboratory oven; weighed; and ground with a Standard Wylie Cutting Mill, sufficient to pass through a 0.2-mm sieve. Total nitrogen (N) was analyzed by a semimicro Kjeldahl procedure, using a Tecator Kjeltec Auto 1030 Analyser. Following HNO_3 microwave digestion, total P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Na, and Al were determined by ICAP emission spectometry, using a Thermo Jarrel Ash Model 1100 ICAP emission spectrometer.

Plantation Establishment and First-year Assessment

Prior to planting, a grid was formulated and planting spots were marked. Outplanting was performed in May/June of 1994. Over-wintered, containerized jack pine stock, grown from the appropriate seed provenance, was supplied by the industrial cooperators involved. Appendix D outlines the seed provenance and seedling stock specifications for each site. Spring sown containerized jack pine was planted in the Wells site due to the unavailability of over-wintered stock. Seedlings were planted at an operational spacing (for Ontario) of 2 m in the plots and also in the buffers. In the Eddy 1–4 sites, the bladed and compacted plots were planted at 1.2-m spacing. Compaction by D8 caterpillar bulldozers did not give significant compaction. Figure 4 illustrates the layout of the individual plots, and includes the planting grid and numbering sequence of the assessment seedlings. With 256 seedlings per plot (2-m spacing), and 676 seedlings per plot in the high density plots (1.2-m spacing), the approximate total number of seedlings planted within all of the treatment plots was (103 x 256) + (21 x 676) = 40 564. Planting crews were supplied by the cooperators, and supervisory assistance was provided by the CFS.

After planting, 12 400 assessment seedlings (25 per one-quarter plot, 100 per plot) were systematically pinned with numbered tags.

One-half of each of the treatment plots in the Nimitz and Wells sites were manually treated in 1995 with a herbicide (Vision© - glysophate), at a rate of 5 L of product per hectare, so as to release the seedlings from vegetative competition (Sutton 1958). It is possible that fertilization could be superimposed onto the experiment at a later date.

Subsamples of the jack pine planting stock were tested by the OMNR following 'seedling certification' criteria and methodology (Sampson et al. 1994). Appendix E summarizes the results of this seedling certification.

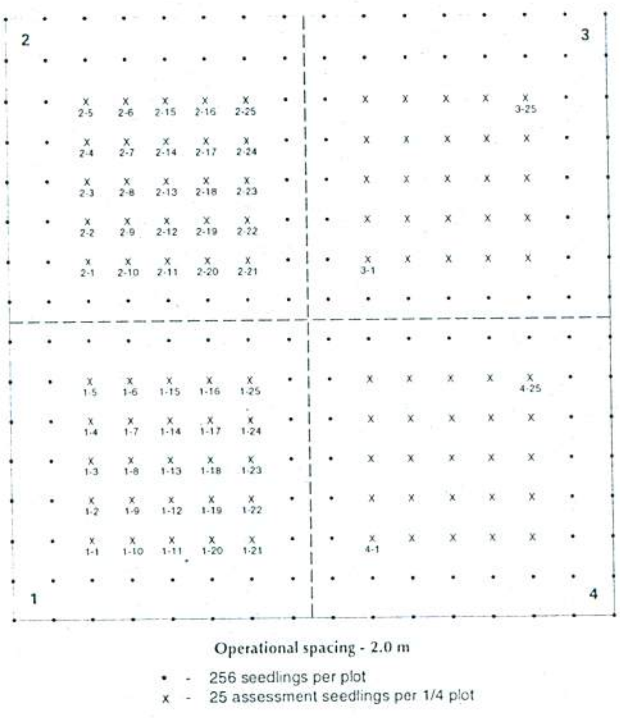


Figure 4. Outplanting grid and systematic numbering of assessment seedlings in the experimental 30-m x 30-m plots.

The first annual assessment was performed after hardening off in the fall of 1994. Measurements were recorded for total height and stem ground level diameter. Qualitative assessments of condition (vitality), type of damage, a measurement of the amount of influence of competition, and assessment of surface soil conditions were also performed. An assessment of condition and type of damage was performed in 1995. Appendix F contains the key for the first assessment.

Full assessments of mortality, vitality, and growth will take place in the third, fifth, and tenth years and should continue to chronicle development.

RESULTS

General Stand and Site Characteristics

Impact (Mature) Sites

A summary of general stand characteristics of the mature stands is presented in Table 1. There were three Site Class 1, five Site Class 2, and one Site Class 3 stands. Initially it was intended to have three stands of each site class. Eddy 2, a low Site Class 2, was a mixed site of shallow soil over bedrock plus a very moist lower slope that was at the base of the rock outcrop. Superior 3, intended as a Site Class 3, was in fact a very low Site Class 2.

The Superior and Eddy 4 sites are predominately jack pine with small proportions of black spruce. The Eddy 1, 2, and 3, and Wells sites, although dominated by jack pine, have higher proportions of white birch (*Betula papryifera* Marsh), balsam fir (*Abies balsamea* [L.] Mill.), white spruce (*Picea glauca* [Moench] Voss), and red pine. Trembling aspen (*Populus tremuloides* Michx.), balsam poplar (*Populus balsamifera* L.), and mountain maple (*Acer spicatum* Lam.) are also present.

Table 2 summarizes the site characteristics of the mature sites, which are mostly sandy and either glacial outwash or fluvial in origin. The sites are characterized by a range of textures from very fine sand (Eddy 1) to very coarse sand (Eddy 4) with a fair amount of gravel, pebbles, and cobbles in the poorer sites, and deeper fine sand to silty loam (Eddy 1) in the richer sites. The moisture regimes of the sites ranged from Fresh to Moderately Fresh, with some Moderately Dry.

Chronosequence Sites

A summary of general characteristics of the chronosequence stands is presented in Table 3. The juvenile stands in Plonski's Site Class 1 are generally purer to jack pine than are the semimature stands, although both have components of black spruce, white spruce, and white pine.

Table 1. General stand characteristics of the mature stands.[1]

Site	Site Class	Site Index	Stand comp.[2,3] (number of stems)	Age (yrs)	Mean DBH[2] (cm)	Mean height[3] (m)	Stems /ha.	Basal area (m^2/ha)	Vol.[4] (m^3/ha)	Stocking[5] (a)	Stocking[5] (b)
Eddy 1	1	19.3	$Pj_5Sb_3Bw_2$	92	24.2	22.6	581	26.6	253	1.0	0.7
Wells	1	18.3	$Pj_4Sb_4Pr_1$	57	19.0	19.3	703	19.9	172	0.7	0.7
Superior 1	1	17.9	Pj_7Sb_3	65	20.8	16.5	625	21.4	161	0.8	0.7
Nimitz	2	16.5	Pj_9Sb_1	68	18.4	18.2	1 140	30.3	248	0.9	1.3
Superior 2	2	16.5	Pj_{10}	75	20.7	17.9	814	27.4	221	1.1	0.8
Superior 3	2	15.9	Pj_9Sb_1	82	22.9	17	706	29.1	224	0.9	0.8
Eddy 4	2	15.2	Pj_{10}	71	19.2	15.9	818	23.7	172	0.9	0.8
Eddy 2	2	14.3	Pj_5Sb_5	97	18.4	15.5	1 003	26.7	190	0.8	1.2
Eddy 3	3	12.3	$Pj_6Fb_3Bw_1$	71	19.2	15.9	563	16.3	112	0.7	0.4

Notes: 1. All measures are based upon data collected from three representative plots (control) within each site, except for Wells, where all measures are based upon the 12 treatment plots.
2. Species composition is based upon number of stems, not canopy cover.
3. Pj = jack pine, Sb = black spruce, Bw = white birch, Pr = red pine, and Fb = balsam fir.
4. Volume calculations were performed using Honer et al.'s (1983) volume equations for jack pine.
5. Stocking for jack pine (a) is based upon basal area and Stocking (b) is based upon number of stems.

Table 4 summarizes the site characteristics of the immature sites, which are also glacial outwash or fluvial in origin. The sites are charaterized by a texture of fine to very coarse sand. The moisture regimes of the sites ranged from Moderately Dry to Moist.

ASSOCIATED STUDIES AND PUBLICATIONS

Studies using this establishment framework have been completed. Carbon reserve and carbon cycling responses to harvesting have been reported (Morrison et al. 1993). Carbon and nitrogen cycling within mid- and laterotation jack pine has also been reported (Foster et al. 1993). Continuing work in biomass/bioelements is also being reported.[6] In addition, these results are being utilized to develop sound management practices (Jeglum 1995).

ACKNOWLEDGMENTS

Initial work performed by S. MacMurray was invaluable in the incorporation of the chronosequence into the framework of the overall study. Help provided in the field by R. Schoepf, D. Bradley, E. Murtola, and G. Shuttleworth was greatly appreciated. The additional compaction, completed by B. Moffat, was essential and the authors gratefully acknowledge his assistance. Expertise in the outplanting and supervision of planting crews was supplied by T. Weldon.

[6] Ibid.

Table 2. General site characteristics in the mature stands.

Site	Operational group	Veg. type	Soil type	Forest humus form[1]	Depth of LFH[2] (cm)	Texture[3]	Moisture Regime	Drainage
Sup I pit 1	3	V4	Sandy S2	HF	4.0	fS to cS (90% to 5%)	Mod. Dry (0) to Mod. Fresh (1)	Rapid (2)
Sup I pit 2	3	V4	Sandy S4	HF	7.0	vcS	Very Fresh (3)	Very rapid (1)
Sup II pit 1	3	V4	Sandy S2	HF	5.0	mS to vcS	Mod. Dry (0)	Rapid (2)
Sup II pit 2	3	V4	Sandy S2	HF	4.0	vcS to mcS	Mod. Dry (0)	Rapid (2)
Sup III	3	V5	Sandy S2	F1	3.0	fS to vcS	Mod. Dry (0)	Very rapid (0)
Eddy I pit 1	3	V5	Fine Loamy–clayey S11	F	6.2	vfS	Moist (5)	Imperfect (5)
Eddy I pit 2	3	V5	Fine Loamy–clayey S11	HF	11.0	vfS	Very Moist (6)	Very poor (7)
Eddy II pit 1	3	V5	Fine Loamy–clayey	F	8.5	vfS	Mod. Moist (4)	Imperfect (5)
Eddy II pit 2	3	V5	Fine Loamy–clayey	F	7.0	vfS	Mod. Moist (4)	Imperfect (5)
Eddy III pit 1	3	V4	Sandy S2	HF	6.0	mS to cS	Mod. Dry (0)	Rapid (2)
Eddy III pit 2	3	V4	Sandy S2	HF	5.0	mS to C.S	Mod. Dry (0)	Rapid (2)
Eddy IV pit 1	3	V4	Sandy S2	HF	5.0	fS to mS	Mod. Dry (0) to Mod. Fresh (1)	Rapid (2)
Eddy IV pit 2	3	V4	Sandy S2	F	7.0	vcS	Mod. Dry (0)	Rapid (2)
Nimitz pit 1	3	V4	Sandy S2	HF	8.6	mLS	Mod. Dry (0)	Very rapid (1)
Nimitz pit 2	3	V4	Sandy S2	HF	8.6	mS	Mod. Dry (0)	Very rapid (1)
Wells pit 1	2	V2	Sandy S2	HF	6.3	cS	Mod. Dry (0)	Very rapid (1)
Wells pit 2	2	V2	Sandy S2	HF	6.3	cS	Mod. Dry (0)	Very rapid (1)

NOTES: 1. HF - HumiFIBRIMOR
F - FIBRIMOR

2. Depths of LFH averaged from sampled humus divots.
Nimitz - average LFH was derived from 240 humus divots.
Wells - average LFH was derived from 160 humus divots.

3. vfS - very fine Sand
fS. - fine Sand
mfS - medium Fine Sand
mS - medium Sand
mcS - medium coarse Sand
cS - coarse Sand
vcS - very coarse Sand
mLS - medium Loamy Sand

Table 3. General stand characteristics of the juvenile and intermediate stands.

Site designation[1,2]	Species comp.[3,4] (number of stems)	Age (yrs)	DBH (cm)	Height (m)	Stems /ha	Basal area (m^2/ha)	Vol.[5] (m^3/ha)	Stocking[6] (a)	Stocking[6] (b)
J1A - F[4]	Pj_{10}	37	19.9	16.7	1 000	31.1	236	1.1	0.5
J1A - UF[4]	Pj_8Sb_2	37	22.4	18.0	1 000	39.4	320	1.3	0.5
J1B - F	Pj_9Other (Ot.)$_1$	37	14.9	14.3	1 900	33.1	219	1.3	0.9
J1B - UF	$Pj_9Ot._1$	37	15.4	15.3	1 900	34.9	249	1.4	0.9
J1C - F	Pj_{10}	33	12.5	12.8	1 800	22.1	133	0.9	0.9
J1C - UF	Pj_{10}	33	14.0	12.5	1 800	27.7	162	1.1	0.9
J2A - F	$Pj_6Pw_3Sb_1$	36	20.1	16.1	1 100	34.9	257	1.3	0.4
J2A - UF	$Pj_3Sb_3Sw_3Pw_1$	36	28.3	20.1	800	50.3	449	2.2	0.3
J2B - F	Pj_{10}	36	12.5	14.0	2 800	34.4	223	1.5	1.0
J2B - UF	Pj_{10}	36	12.9	13.6	2 700	35.3	224	1.5	1.0
J2C - F	Pj_{10}	35	13.3	13.3	2 100	29.2	181	1.3	0.7
J2C - UF	Pj_{10}	35	15.0	13.9	1 300	23.0	148	1.0	0.5
J3A - F	$Pj_9Ot._1$	28	11.8	9.8	2 100	23.0	108	1.4	0.4
J3A - UF	Pj_8Sb_2	28	14.6	10.2	1 600	26.8	131	1.2	0.3
J3B - F	Pj_{10}	35	12.7	10.0	1 200	15.4	74	1.3	0.3
J3B - UF	Pj_6Sb_4	35	17.6	13.5	1 300	31.6	199	1.0	0.3
J3C - F	Pj_{10}	34	14.2	11.8	1 400	22.2	124	1.2	0.3
J3C - UF	Pj_{10}	34	14.2	12.2	2 200	34.8	200	1.9	0.6
M1A - F	$Pj_7Sw_2Ot._1$	50	28.8	17.2	600	39.0	305	1.4	0.5
M1A - UF	$Pj_5Sb_3Sw_2$	50	22.8	16.1	1 100	45.1	330	1.7	0.9
M1B - F	$Pj_8Sb_1Sw_1$	44	13.1	14.2	2 100	28.3	186	1.1	1.5
M1B - UF	Pj_9Sb_1	44	14.7	15.1	2 900	49.2	342	1.8	2.0
M1C -F	Pj_{10}	59	14.6	16.6	1 900	31.8	266	1.1	1.9
M1C - UF	Pj_{10}	59	15.8	16.5	2 500	49.0	368	1.8	0.6
M2A - F	$Pj_8Sb_1Sw_1$	51	17.8	16.2	1 000	24.8	184	0.9	0.7
M2A - UF	$Pj_6Sw_3Ot._1$	51	20.7	14.9	900	30.3	208	1.2	0.6
M2B - F	Pj_9Sb_1	48	14.4	14.4	1 800	29.3	195	1.1	1.1
M2B - UF	Pj_{10}	48	11.3	13.4	2 300	23.1	144	0.9	1.4
M2C - F	Pj_9Sb_1	64	18.0	17.6	1 300	33.1	263	1.3	1.1
M2C - UF	Pj_{10}	64	16.0	16.9	1 900	38.2	293	1.0	1.6
M3A - F	Pj_6Sb_4	48	11.5	10.4	2 600	27.0	134	1.3	1.2
M3A - UF	Pj_8Sb_2	48	12.9	13.6	2 400	31.4	199	1.5	1.1
M3B - F	$Pj_8Sb_1Sw_1$	44	16.7	16.5	1 500	32.9	247	1.5	0.6
M3B - UF	Pj_7Sb_3	44	16.2	16.2	1 400	28.9	216	1.5	0.6
M3C - F	Pj_8Sb_2	44	15.6	15.8	1 500	28.7	207	1.4	0.6
M3C - UF	Pj_7Sb_3	44	13.9	16.2	2 300	34.9	258	1.7	0.9

Notes:
1. J = juvenile, M = semimature; number denotes site class; A,B,C denotes replication.
2. F = fertilized treatment, UF = unfertilized treatment.
3. Species composition is based upon number of stems, not canopy cover.
4. Pj = jack pine, Sb = black spruce, Bw = white birch, Pr = red pine, and Fb = balsam fir.
5. Volume calculations were performed using Honer et al.'s (1983) volume equations for jack pine.
6. Stocking (a) is based upon basal area and Stocking (b) is based upon number of stems.

Table 4. General site characteristics of the juvenile and semimature stands.

Site	Operational group	Veg. type	Soil type	Forest humus form[1]	Depth of LFH (cm)	Texture[2]	Moisture Regime	Drainage
J1A	5	V7	Sandy S2/S3	HF	8.0	mS	Mod. Fresh (1)	Mod. Well (4)
J1B	2	V2	Sandy S2/S3	HF	7.0	mS	Mod. Dry (0)	Rapid (2)
J1C	5	V6	Sandy S2/S3	HF	9.0	mS	Mod. Dry (0)	Rapid (2)
J2A	3	V4	Sandy S2/S3	F	4.0	mfS	Fresh (2)	Mod. Well (4)
J2B	2	V2	Sandy S2/S3	HF	8.0	cS	Mod. Dry (0)	Rapid (2)
J2C	2	V2	Sandy S2/S3	HF	8.0	mS.	Mod. Dry (0)	Rapid (2)
J3A	2	V2	Fine Loamy–clayey S11	F	2.0	mfS	Moist (5)	Imperfect (5)
J3B	3	V4	Sandy S4	F	5.0	mcS	Very Fresh (3)	Mod. Well (4)
J3C	3	V2	Sandy S2/S3	HF	9.0	mS	Mod. Dry (0)	Rapid (2)
M1A	3	V3	Sandy S2/S3	HF	14.0	mS	Mod. Dry (0)	Rapid (2)
M1B	3	V4	Sandy S2/S3	HF	12.0	cS to vcS	Mod. Dry (0)	Rapid (2)
M1C	3	V3	Sandy S2/S3	HF	7.0	mcS	Mod. Dry (0)	Rapid (2)
M2A	2	V2	Sandy S4	HF	6.0	cS	Very Fresh (3)	Mod. Well (4)
M2B	3	V3	Sandy S2/S3	HF	9.0	cS to mS	Mod. Dry (0)	Rapid (2)
M2C	3	V3	Sandy S2/S3	HF	9.0	mS	Mod. Dry (0)	Rapid (2)
M3A	2	V2 S2	Sandy	H	11.0	vfS to vcS	Mod. Dry (0)	Very Rapid (1)
M3B	2	V2	Sandy S2/S3	HF	8.0	mS	Mod. Dry (0)	Rapid (2)
M3C	5	V7	Fine Loamy–clayey S11	HF	6.0	fS	Mod. Moist (4)	Imperfect (5)

NOTES: 1. HF- HumiFIBRIMOR
F - FIBRIMOR

2. vfS - very fine Sand
fS. - fine Sand
mfS - medium fine Sand
mS - medium Sand
mcS - medium coarse Sand
cS - coarse Sand
vcS - very coarse Sand
mLS - medium Loamy Sand
vfS - very fine Sand

LITERATURE CITED

Bell, F. W. 1991. Critical silvics of conifer crop species and selected competitive vegetation in northwestern Ontario. For. Can., Ont. Region, Sault Ste. Marie, ON. COFDRA Rep. 3310. 177 p.

Benzie, J.W. 1977. Managers handbook for jack pine in the north central states. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. Gen Tech. Rep. NC-32. 18 p.

Bremner, J.M. 1965. Inorganic forms of nitrogen. p. 1179–1237 *in* C.A. Black, ed. Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. Am. Soc. Agron., Madison, WI. Agron. No. 9.

Brown, J.K. 1971. A planar intersect method for sampling fuel volume and surface area. For. Sci. 17:96–102.

Brown, J.K.; Roussopolis, P.J. 1974. Eliminating biases in the planar intersect method for estimating volumes of small fuels. For. Sci. 20:250–256.

Cayford, J.H.; Bickerstaff, A. 1968. Man-made forests in Canada. Can. Dept. Fish. For., For. Br., Ottawa, ON. Publ. No. 1230. 63 p.

Chrosciewicz, Z. 1963. The effects of site on jack pine growth in northern Ontario. Dep. For., Ottawa, ON. Publ. No. 1015. 28 p.

Eyre, F.H.; Lebarron, R.K. 1944. Management of jack pine stands in the lake states. USDA, Washington, DC. Tech. Bull. No. 863. 66 p.

Foster, N.W.; Morrison, I.K.; Hazlett, P.W.; Hogan, G.D.; Salerno M.I. 1993. Carbon and nitrogen cycling within mid- and late-rotation jack pine. p. 355–375 *in* J.M. Kelly and W.W. McFee, eds. Carbon Forms and Functions in Forest Soils. Proc. Eighth North Amer. For. Soils Conf. May 1993, Gainesville, Florida. Soil Science Soc. of Amer., Madison, WI.

Honer, T.G.; Ker, M.F.; Alemdag, I.S. 1983. Metric timber tables for the commercial tree species of central and eastern Canada. Environment Canada, Maritime For. Res. Centre., Fredericton, NB. Inf. Rep. M-X-140. 139 p.

Jeglum, J.K. 1982. Stripcutting in shallow-soil upland black spruce near Nipigon, Ontario. IV. Regeneration in the first study area. Dep. Environ., Can. For. Serv., Sault Ste. Marie, ON. Inf. Rep. 0-X-337. 24 p.

Jeglum, J.K. 1984. Stripcutting in shallow-soil upland black spruce near Nipigon, Ontario. IV. Seedling-seedbed relationships. Dep. Environ., Can. For. Serv., Sault Ste. Marie, ON. Inf. Rep. O-X-359. 26 p.

Jeglum, J.K. 1994. Developing environmentally sound management practices for jack pine (*Pinus banksiana* Lamb.) in Ontario, p. 44–51 in Richardson, J., ed. Silviculture Tuned to Nature and Wood Energy Production. Proceedings of a workshop of the "Forest Energy Production" Activity, Task VIII, International Energy Agency, Bioenergy Agreement. April 24–28 1994, Geneva and Lausanne, Switzerland. Nat. Resour. Can., Canadian Forest Service, Ottawa, ON. 51 p.

Kalra, Y. P.; Maynard, D. G. 1991. Methods manual for forest soil and plant analysis. For. Can., Northwest Reg., North. For. Cent., Edmonton, AB. Inf. Rep. NOR-X-319. 116 p.

MacIver, D.C. 1991. Forest climates of Ontario: Part 2: GIS-generated atlas of Ontario. Environment Canada, Can. Climate Centre, Downsview, ON.

Mead, D.J.; Whyte, A.G.D.; Woollons, R.C.; Beets, P.N. 1991. Designing long-term experiments to study harvesting impacts. p. 107–124 *in* W.J. Dyck and C.A. Mees, eds. Long-term Field Trials to Assess Environmental Impacts of Harvesting. Proceedings IEA/BE T6/A6 Workshop. February 1990, Florida, IEA/BE T6/A6 Report No. 5. Forest Research Institute, Rotorua, New Zealand. FRI Bull. No. 161.

Morrison, I.K.; Foster, N.W.; Hazlett, P.W. 1993. Carbon reserves, carbon cycling, and harvesting effects in three mature forest types in Canada. New Zeal. J. Forest Sci. 23(3):403–412.

Plonski, W.L. 1974. Normal yield tables (metric) for major forest species of Ontario. Ont. Min. Nat. Resour., Div. For., Toronto, ON. 40 p.

Powers, R.F.; Alban, D.H.; Miller, R.E.; Tiarks, A.E.; Wells, C.G.; Avers, P.E.; Cline, R.G.; Loftus, N.S., Jr.; Fitzgerald, R.O. 1990. Sustaining site productivity in North American forests: Problems and prospects. p. 49–79 *in* S.P. Gessel, D.S. Lacate, G.F. Weetman and R.F. Powers, eds. Sustained Productivity of Forest Soils. Proceedings Seventh North American Forest Soils Conference. 24–28 July 1988, Vancouver, British Columbia. Univ. of British Columbia, Faculty of Forestry, Vancouver, BC. 594 p.

Rowe, J.S. 1972. Forest regions of Canada. Dep. Environ., Can. For. Serv., Ottawa, ON. Publ. No. 1300. 172 p.

Rudolph, T.D. 1983. Jack pine. p. 60–62 *in* R.M. Burns, tech. compiler. Silvicultural Systems for the Major Forest Types of the United States. USDA For. Serv., Washington, DC. Agric. Handb. No. 445. 191 p.

Sampson, P.H.; Colombo, S.J.; Templeton, C.W.G. 1994. The stock quality assessment program in Ontario. 1994. p. 66 *in* D.S. Maki, T.M. Mcdonough and T.L. Noland, eds. Making the Grade: An International Symposium on Planting Stock Performance and Quality Assessment. 11–15 September 1994, Sault Ste. Marie, Ontario. New Forests, Kluwer Academic Publishers, Dordrecht, Netherlands. 96 p.

Sutton, R.F. 1958. Chemical herbicides and their uses in the silviculture of forests of eastern Canada. Can. Dep. North. Aff. Nat. Resour., Ottawa, ON. For. Tech. Note No. 68. 54 p.

Van Wagner, C.E. 1968. The line intersect method in forest fuel sampling. For. Sci. 14:20–26.

Walkley, A. 1947. A critical examination of a rapid method for determining organic carbon in soils: Effects of variation in digestion conditions and of inorganic soil constituents. Soil Sci. 63:241–263.

APPENDIX A. List of cooperators. (In alphabetical order)

Forest Industry:

M. Stevens
A. Tremblay
R. Scyska
R. Steven

Superior Forest Management Ltd.,
10 Young Street, Chapleau. Ontario P0M 1K0.

B. Nicks
H. Pearce
D. Dedo

E.B. Eddy Forest Products Ltd.,
1 Station Road, Espanola, Ontario P5E 1R6.

Ontario Ministry of Natural Resources:

D. Pyke
E. Matthews
P. Payette
B. Guthrie
R. Hornsby

Ontario Ministry of Natural Resources,
Chapleau District,
190 Cherry Street, Chapleau, Ontario P0M 1K0

J. Stewart
B. Fox

Ontario Ministry of Natural Resources,
Blind River Office,
Box 190, 62 Queen Street, Blind River, Ontario P0R 1B0

B. Morris
A. Gordon

Ontario Forest Research Institute
1235 Queen St. East, Sault Ste. Marie, Ontario P6A 5N5

APPENDIX B. Site locations and directions.

Figures B1–B9 show the site layout and location of experimental plots.

Eddy 1.	District:	Gogama
	Township:	Paudash
	Stand No.:	328
	Licensee:	E.B. Eddy Forest Products
	Lat. and Long.	47° 16', 81° 47'

Follow Hwy. 144 south 29.8 km from the junction with Hwy. 560 (Sultan Industrial Road). Turn right (west) and follow the road 2.7 km. Take the road to the right and follow for approximately 0.3 km. The study area is on the right (west), approximately 50 m in from the road.

Eddy 2.	District:	Gogama
	Township:	Paudash
	Stand No.:	458
	Licensee:	E.B. Eddy Forest Products
	Lat. and Long.	47° 16', 81° 45'

Follow Hwy. 144 south 31.3 km from the junction with Hwy. 560 (Sultan Industrial Road). Turn left (east) and follow the road 2.5 km. Plots are on both sides of the road. The control plots, in two blocks, are a further 0.65 km down the road .

Eddy 3.	District:	Espanola
	Township:	Monestime
	Stand No.:	264
	Licensee:	E.B. Eddy Forest Products
	Lat. and Long.	46° 45', 82° 15'

From Hwy. 17 in Webbwood take the Agnew Lake turnoff. After several km look for the E.B. Eddy Camp 12 sign on the left and follow this road to the Mile 40 post. Turn left (west) and proceed 6.3 km; then bear left (west) at the fork in the road. The site is approximately 100 m from this fork. The study area is on both sides of the road. Alternatively, one could come from the north. Take the Sultan Industrial Road. (Hwy. 560) via Hwy. 129 and Hwy. 667 or from Hwy. 144 and then go south along the Ramsey Road. The road at the Mile 40 post would be about 90 km from the Sultan Industrial Road.

Eddy 4.	District:	Espanola
	Township:	Monestime
	Stand No.:	169
	Licensee:	E.B. Eddy Forest Products Ltd.
	Lat. and Long.	46° 46', 82° 15'

Follow the same directions as for Eddy 3, but when you reach the fork in the road go to the right (north) and follow for 1.15 km. The study area is on the right (north).

Superior 1.	District:	Chapleau
	Township:	Wakami
	Stand No.:	19
	Licensee:	Superior Forest Management Ltd.
	Lat. and Long.	47° 35', 82° 47'

Take Hwy. 667 from Hwy. 129 and travel east to the Wakami Dam Road. Go in approximately 0.7 km to the first road on the left (east). Follow this road until the first fork and bear left; then bear left again. The study area is on both sides of the road.

Superior 2.	District:	Chapleau
	Township:	Wakami
	Stand No.:	14
	Licensee:	Superior Forest Management Ltd.
	Lat. and Long.	47° 35', 82° 48'

Take Hwy. 667 from Hwy. 129 and travel east to the Wakami Dam Road. Go in approximately 0.5 km to the first road on the right (west). Follow this road approximately 0.5 km to a gravel pit on the top of an esker. The study area is on the right (north).

Superior 3.	District:	Chapleau
	Township:	Wakami
	Stand No.:	9
	Licensee:	Superior Forest Management Ltd.
	Lat. and Long.	47° 34', 82° 51'

Take Hwy. 667 from Hwy. 129 and travel about 2 km east of the Wakami Lake Provincial Park Road. Go in approximately 1.5 km to the first road on the right (south). Follow this road until the first fork (right) and follow this for approximately 1 km. The study area is on the north side of the road.

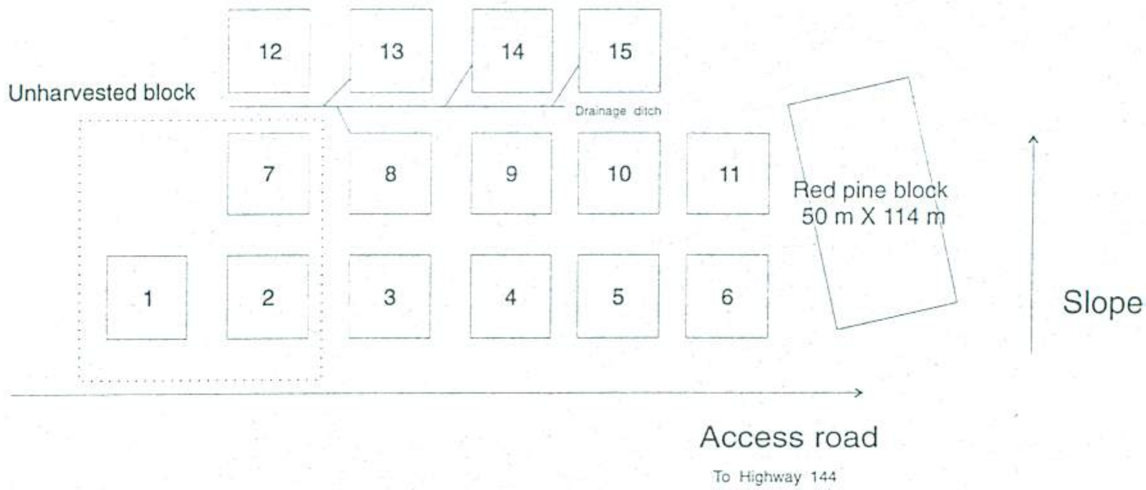
Nimitz.	District:	Chapleau
	Township:	Nimitz
	Stand No.:	83
	Licensee:	Superior Forest Management Ltd.
	Lat. and Long.	47° 38', 83° 15'

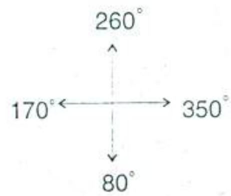
The site is located along the northeast side of Hwy. 129, approximately 4 km north of the junction with Hwy. 667 (Sultan Road).

Wells.	District:	Blind River
	Township:	Wells
	Stand No.:	131
	Licensee:	N/A
	Lat. and Long.	46° 25', 83° 22'

Follow Hwy. 129 north of Thessalon for 31 km to the third road past the large bridge over the Mississagi River. Follow this road for 2.3 km to the second bend in the road and then continue straight for approximately 50 m. The site is on the left (north) side of the road.

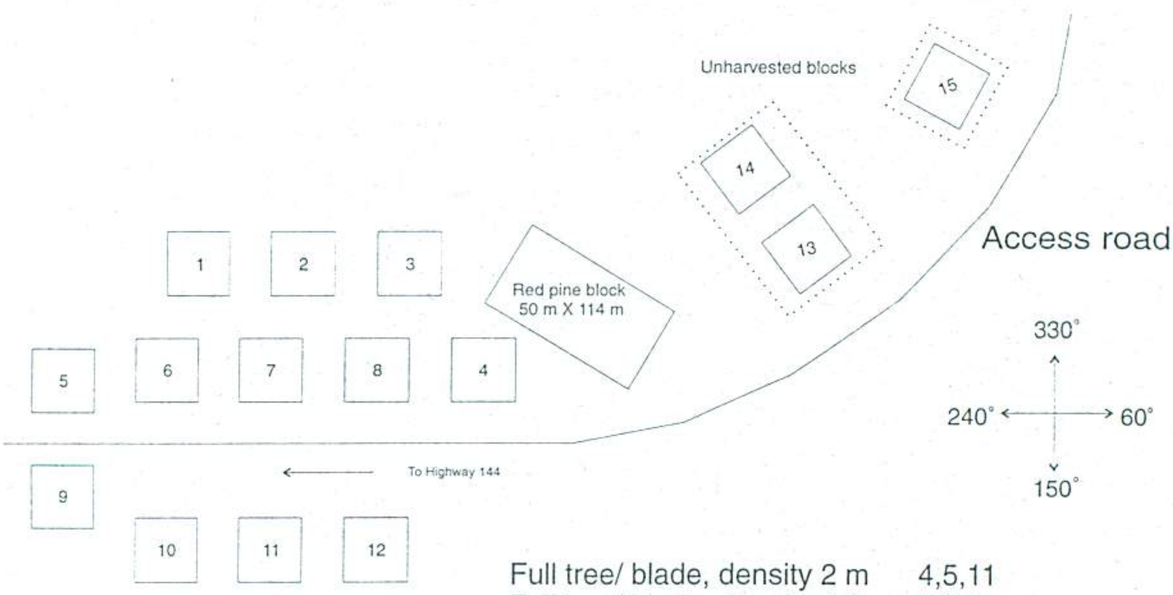
Eddy 1





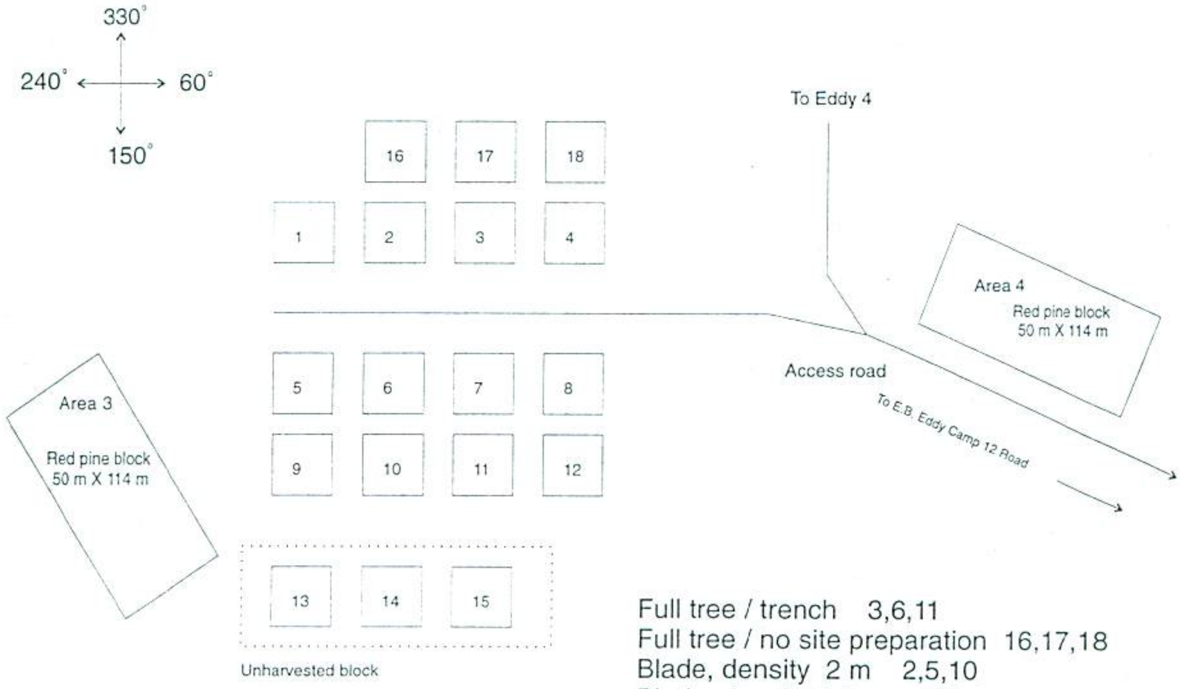
Full tree/ blade, density 2 m 3,8,15
Full tree/ blade, density 1.2 m 6,9,14
Tree length / trench 4,10,12
Full-tree / trench 5,11,13
Unharvested controls 1,2,7

Eddy 2



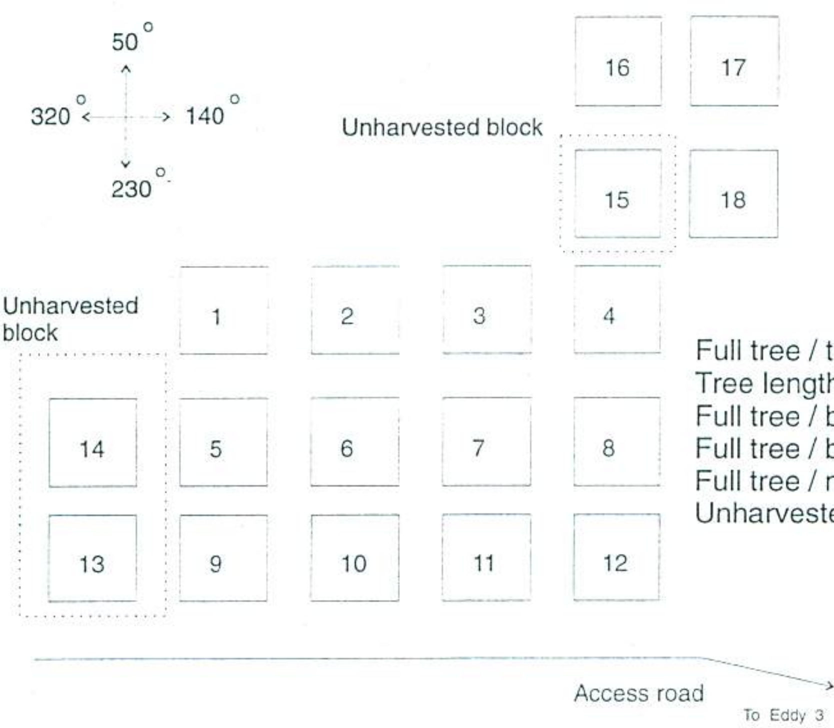
Full tree/ blade, density 2 m 4,5,11
Full tree/ blade, density 1.2 m 2,8,9
Tree length / trench 1,7,12
Full tree / trench 3, 6, 10
Unharvested controls 13,14,15

Eddy 3



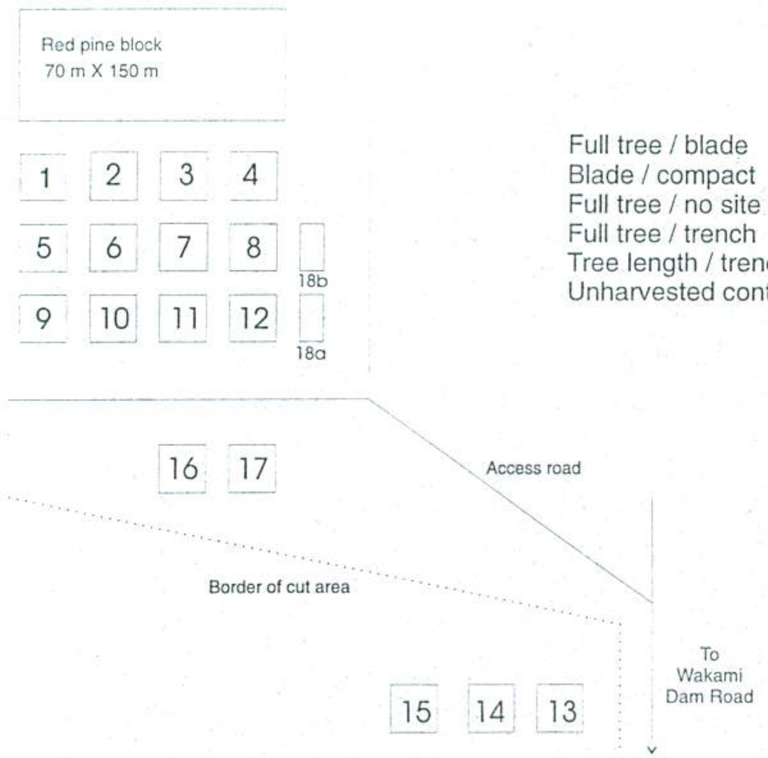
Full tree / trench 3,6,11
Full tree / no site preparation 16,17,18
Blade, density 2 m 2,5,10
Blade, density 1.2 m 4,8,9
Tree length / trench 1,7,12
Unharvested controls 13, 14, 15

Eddy 4

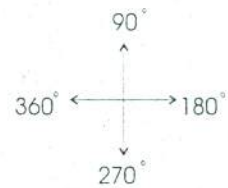


Full tree / trench 3,6,10
Tree length / trench 1,7,12
Full tree / blade, density 2 m 4,5,11
Full tree / blade, density 1.2 m 2,8,9
Full tree / no site preparation 16,17,18
Unharvested controls 13,14,15

Superior 1



Full tree / blade 4,5,11
Blade / compact 2,8,9
Full tree / no site preparation 16,17,18a,18b
Full tree / trench 3,6,10
Tree length / trench 1,7,12
Unharvested controls 13, 4,15



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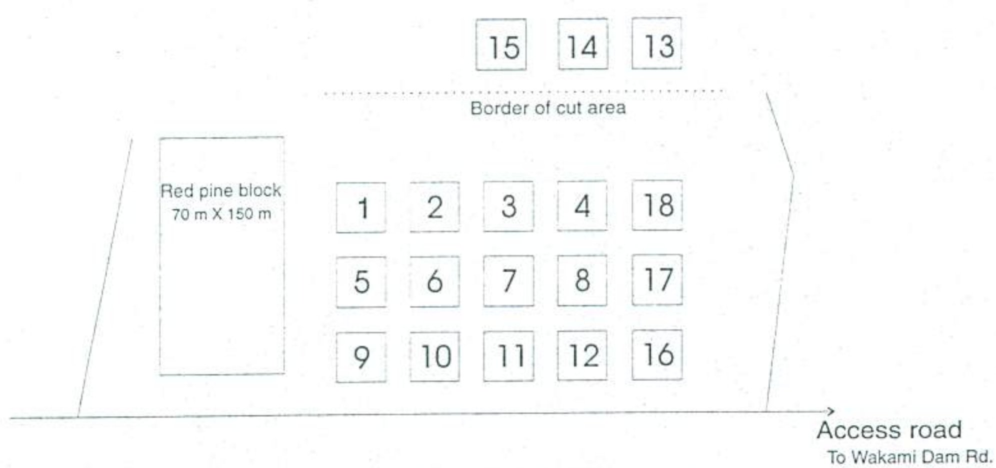
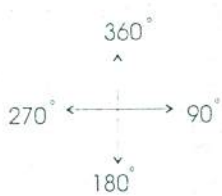
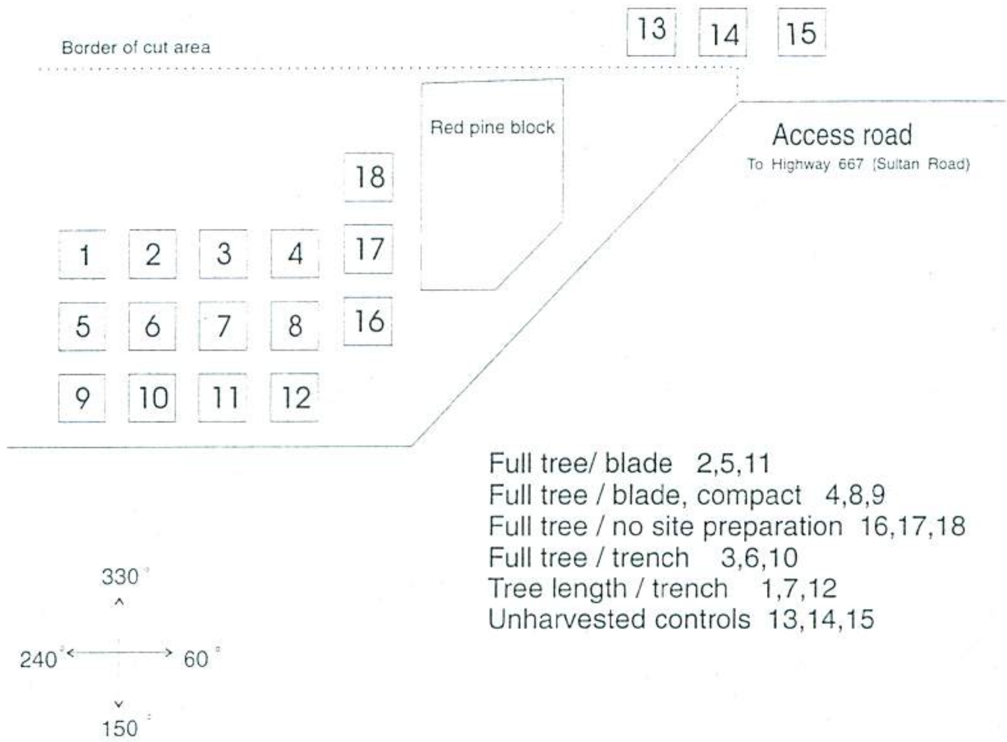




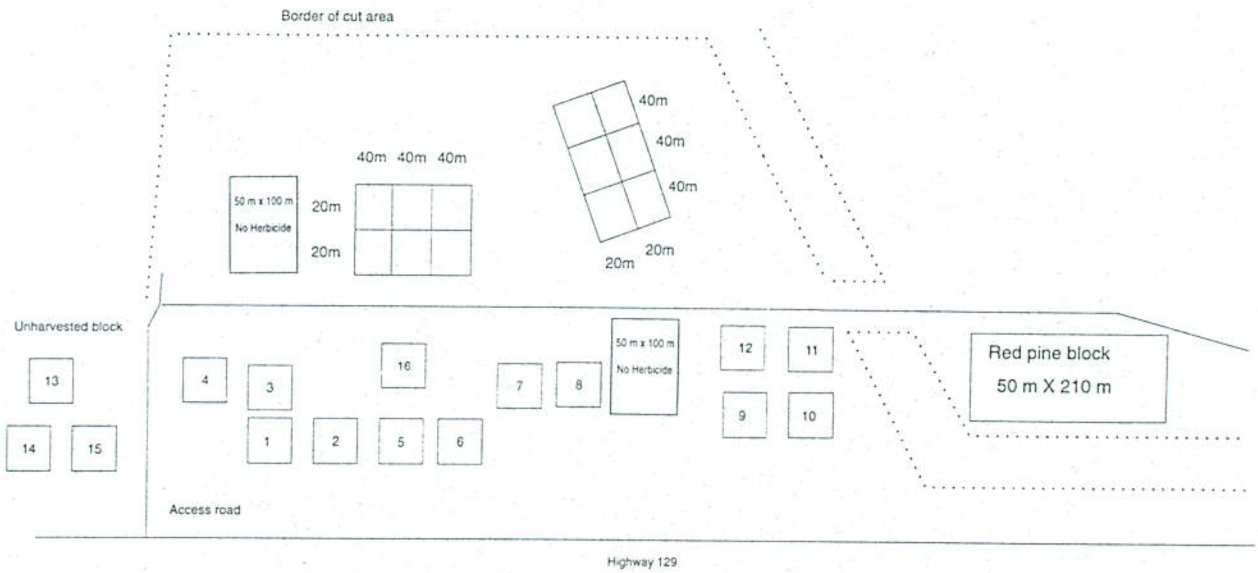
Full tree / blade 4,5,11
Full tree / blade, compact 2,8,9
Full tree / no site preparation 16,17,18
Full tree / trench 3,6,10
Tree length / trench 1,7,12
Unharvested controls 13, 14, 15

Superior 3

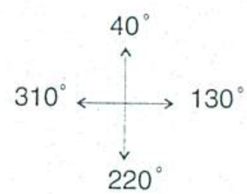


Full tree/ blade 2,5,11
Full tree / blade, compact 4,8,9
Full tree / no site preparation 16,17,18
Full tree / trench 3,6,10
Tree length / trench 1,7,12
Unharvested controls 13,14,15

Nimitz

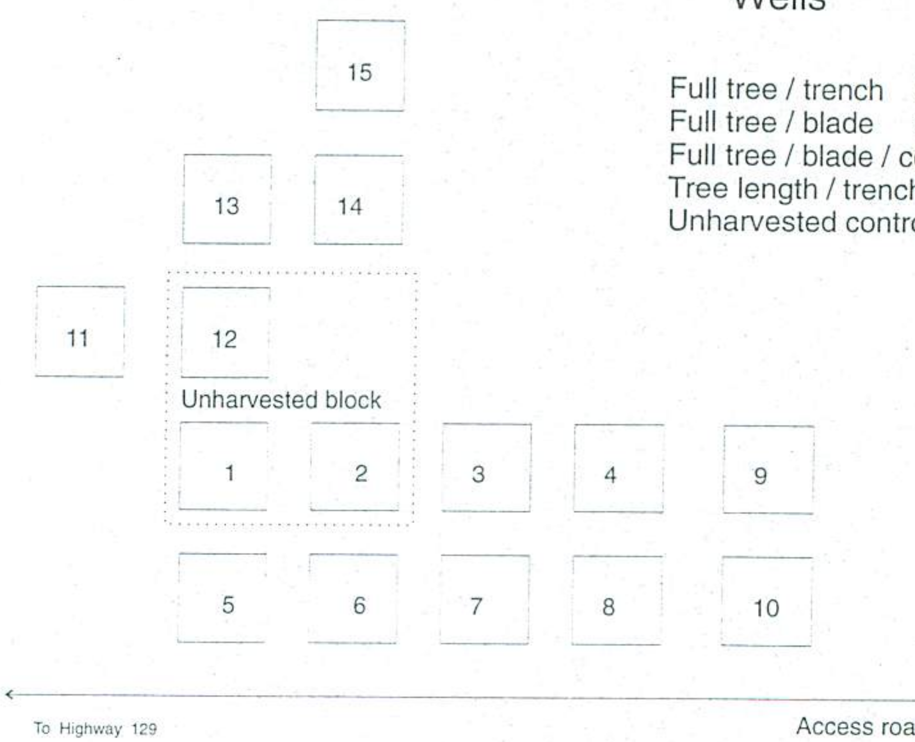


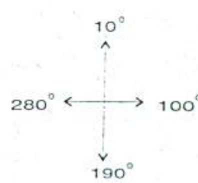
Full tree / trench 2,6,11
Tree length / trench 4,7,9
Full tree / blade 3,5,12,16
Full tree / blade / compact 1,8,10
Unharvested controls 13,14,15



Wells

Full tree / trench 6,11,14
Full tree / blade 3,5,15
Full tree / blade / compact 8,9,13
Tree length / trench 4,7,10
Unharvested controls 1,2,12





APPENDIX C. Vegetation structure matrix.

	B	C	S	H	G	L	M	Fea	Sph	Pio	Dic	Wat	Blit	Clit	Bare peat	Bare mineral	Woody material
> 10 m																	
5–10 m																	
1.5 m–5 m																	
50 cm–1.5 m																	
20–50 cm																	
0–20 cm																	

Key:

B = Broadleaf spp.
C = Conifer spp.
S = Shrubs
H = Herbs
G = Graminoids

L = Lichen
M = Mosses
Fea = Feathermosses
Pio = Pioneer mosses
Dic = *Dicranum* Spp.

Wat = Water
Blit = Broadleaf litter
Clit = Conifer litter

APPENDIX D. Seedling stock specifications.

Superior Forest Management Ltd.

Superior Sites 1, 2, 3, and Nimitz

Jack pine - overwintered 'Jiffy 140' container
Supplied by: Lafleur Garden Center
Timmins, Ontario

Seed source: 42-31-0-00
Seed year: 1981
Seed lot: 81/11/18

Mean height (mm)	106.5 ± 5.2	(4.9%)
Mean diameter (mm)	1.94 ± 0.06	(3.3%)
Mean ht./dia. ratio (_:1)	55.0 ± 3.0	(5.2%)

Assessment at age	15 weeks, 2 days
Trays sampled	10
Age at assessment	19 weeks, 5 days

Red pine - overwintered 'Panth 121' container
Supplied by: AquaNorth
Hwy. 17S, Wawa, Ontario

Seed source: 32-31-0-00
Seed year: 1991
Seed lot: 92/05/13 and 92/05/12 (seed lots were combined)

Mean height (mm)	74.5 ± 2.1	(2.9%)
Mean diameter (mm)	2.06 ± 0.06	(2.9%)
Mean ht./dia. ratio (_:1)	36.0 ± 1.0	(2.9%)

Assessment at age	16 weeks, 6 days
Trays sampled	20
Age at assessment	18 weeks, 6 days

E.B. Eddy Forest Products Ltd.

Eddy Sites 1–4

Jack pine - overwintered multipot container - mp 67
Supplied by: New North Greenhouses
Sault Ste. Marie, Ontario

Seed source: 42-42-0-02
Crop number: 9405

Mean height (mm)	11.4
Mean diameter (mm)	2.0
Mean ht./dia. ratio (_:1)	57:1

Red pine - Fall sown multipot container - mp 67
Supplied by: New North Greenhouses
Sault Ste. Marie, Ontario

Seed source: 42-44-0-00
Crop number: 9408

Mean height (mm)	12.2
Mean diameter (mm)	2.6
Mean ht./dia. ratio (_:1)	47:1

Wells Township

Jack pine - Spring sown multipot container - mp 67
Supplied by: New North Greenhouses
Sault Ste. Marie, Ontario

Seed source: 42-42-0-02
Crop number: 9405

Mean height (mm):	11.4
Mean diameter (mm)	2.0
Mean ht./dia. ratio (_:1)	57:1

APPENDIX E. Results of Stock Quality Assessment Program.

Five stock lots were delivered to the Ontario Forest Research Institute from planting operations for assessment in the Stock Quality Assessment Project as follows:

1 - Jack pine from Eddy 1 and 2
2 - Jack pine from Eddy 3 and 4
3 - Jack pine from Superior 1–3, Nimitz
4 - Jack pine from Wells
5 - Red pine from Eddy 1–4

Description of Assessment Tests

Visual examination involved assessment of seedling color, odor, foliage and root moisture, physical damage, presence of pathogens, and discoloration of the cambium, prior to the application of the other physiological tests.

Root growth potential (RPG) is used to determine the ability of the seedling to generate new roots under ideal conditions. RPG is often related to a stock lot's vigor and outplant performance. A sample of seedlings was potted and placed in a growth room. Following a period of growth, the soil was removed and the number of white root tips was counted and classified using a scale in which 0 means no new root tips were generated; 1 means some new root tips were generated, but all were less than 1 cm; 2 means one to three white roots were greater than 1 cm; 3 means four to ten white roots were greater than 1 cm; 4 means 11 to 30 white roots were greater than 1 cm; and 5 means more than 31 roots were greater than 1 cm. Bud activity and foliage condition were also observed at the conclusion of the test period.

Relative conductivity is used to determine the presence of cell damage in shoot tissues. Tissues are immersed in water without any other treatment after being received. Injured tissues release large amounts of cell electrolytes, which show up as increased electrical conductivity.

Chlorophyll florescence is a test that assesses the condition of the photosynthetic system. Seedlings are placed in the dark to stop photosynthesis, then placed in a sphere and illuminated with a narrow-band spectrum of light. The amount and pattern of light reflected (or fluoresced) back from the seedling is related to the photosynthetic activity of the seedling. Inactive (dead or dormant) seedlings produce unique patterns of florescence.

Results

A summary of test results is presented in Table E1. Foliage appeared healthy in Stock Lots 1 and 4. Needle tip browning was evident on all examined seedlings in Stock Lot 2 and on 40 percent of the seedlings in Stock Lot 3. In the red pine, Stock Lot 5, necrotic banding was evident on 40 percent of the seedlings. Subsequent analysis suggested damage was abiotic. Bud activity was evident in all five stock lots. Dissection of terminal buds and root cambium revealed no damage and root activity was present in all examined seedlings.

Table E1. Summary of seedling quality test results.

Stock lot	RPG	Relative conductivity	Chlorophyll florescence
Jack pine, Eddy 1 and 2	Excellent	Very good	Good
Jack pine, Eddy 3 and 4	Very good	Good	Excellent
Jack pine, Superior 1–3	Very good	Good	Excellent
Jack pine, Nimitz	Very good	Good	Excellent
Jack pine, Wells	Very good	Excellent	Very good
Red pine, Eddy 1–4	Good	Good	Good

APPENDIX F. Key for seedling assessment.

Area	Treatment	Plot number	Subplot number	Tree number	Initial height	Diameter	Condition	Damage	Soil
1 = Superior 1		01...18							
2 = Superior 2			1...4						
3 = Superior 3				1...25					
4 = Nimitz					0 to nearest cm				
5 = Eddy 1						0 to nearest mm			
6 = Eddy 2							0 = missing seedling		
7 = Eddy 3							1 = vigorous		
8 = Eddy 4							2 = healthy		
9 = Wells							3 = mediocre		
	1 = Blade/compact						4 = moribund		
	2 = Blade						5 = dead		
	3 = Full-tree log / no site preparation							0 = fire	
	4 = Full-tree log / trench							1 = drought	
	5 = Tree-length log / trench							2 = erosion	
	6 = Blade / 1.2 m spacing							3 = frost	
								4 = browsing	
								5 = insect	
								6 = mechanical	
								7 = competition	
								8 = water	
								9 = probably herbicide damage	
								10 = improper planting	
								11 = unknown	
									1 = mineral
									2 = mineral + humus
									3 = mineral + duff
									4 = duff
									5 = partial duff
									6 = wet peat / muck
									7 = water