LONG TERM PRODUCTIVITY OF BOREAL FOREST ECOSYSTEMS

ANNOTATED BIBLIOGRAPHY

Prepared for:

Natural Resources Canada,
Canadian Forest Service
Sault Ste. Marie, Ontario

Prepared by:

Geomatics International Inc. and Devlin Consulting Services

November 1994

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Report To:

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ABSTRACT

A federal-provincial working group has been established to coordinate research and information exchange on long-term productivity of boreal forest ecosystems. The Canadian Forest Service (CFS) section of Natural Resources Canada, is focusing its research activities on jack pine while the Ontario Ministry of Natural Resources Forestry Branch (OMNR) is concentrating on black spruce. Both organizations have agreed that nutrient poor and "sensitive sites" including shallow, and wet soils represent the greatest concern for sustainable forestry in the north. Field studies are in place to study long-term productivity. In the interim, a review of the literature and a survey of expert opinion were conducted to summarize the current understanding of long-term productivity in boreal ecosystems. The results of these interim processes are presented in separate publications.

This publication summarizes the compilation of an annotated bibliography of 379 references concerned with boreal ecology. The emphasis was on nutrient regimes and nutrient cycling in black spruce and jack pine ecosystems, but references relevant to the maintenance of long-term productivity in these systems were also included.

ACKNOWLEDGEMENTS

Numerous individuals were involved in providing background information, summaries of current forest management practices and technical support which have culminated in the current report. In particular, the study team members would like to recognize the following members of the Sustainable Productivity of Forest Ecosystems Technical Working Group for their support, advice, assistance and cooperation in this study: Dr. Nadaraja Balakrishnan, Dr. Neil Foster, Dr. Alan Gordon, Dr. John Jeglum, Mr. Dave Morris and Dr. Ian Morrison.

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The consulting study team was composed of members of Geomatics International Inc. (Dr. Mark E. Taylor, Donald N. Nixon) and Devlin Consulting Services (Ms. Maureen Kershaw). Assistance was also provided by Ms. Sheila Walsh (Sault Ste. Marie) and Mr. Angus Creighton (Sault Ste. Marie).

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DISCLAIMER

"The views, conclusions and recommendations are those of the authors and should not be construed as policy or endorsement by the Canadian Forest Service or the Ontario Ministry of Natural Resources."

1.0 INTRODUCTION

Forest ecosystems are regulated systems which maintain a certain homeostasis. Fluctuations in species composition occur in response to natural events such as fire, blowdown, insects, disease, and aging. Other changes result from human activities, particularly logging. Impacts are related to the size of area cut, post-logging treatments, planting, tending, thinning, and protection activities (pest and fire management). Other secondary effects may occur associated with the development of logging roads, modification of drainage patterns and landscape level impacts which modify hydrologic and nutrient cycles.

The boreal forest region consists of a variety of forest ecosystems which differ in terms of topographic expression, plant species composition and soil conditions. Soils range from the relatively nutrient-rich, deep, well-drained, fine-textured lacustrine silts and clays of former glacial Lake Agassiz to the frequently shallow, poorly- to well-drained, coarse-textured tills and outwash sands. Productivity of forest ecosystems varies with species composition, local climate, soil texture, drainage, soil depth and site history. Forest humus, ground cover and microclimatic conditions have a strong influence on nutrient cycling and associated tree growth within the boreal forest.

Harvesting methods on boreal forest sites can significantly influence long-term biological productivity and nutrient status through such physical site impacts as soil compaction, rutting, erosion (particularly on shallow soils and on steep topography), mixing of nutrient-rich soil surface horizons with nutrient-poor lower horizons (during site preparation activities), destruction and/or loss of surface organic matter and removal of nutrient-rich vegetation such as twigs and leaves (during harvesting or site preparation). Harvesting methods may also influence soil microflora and fauna, which in-turn may influence long-term soil/site productivity. Finally, timber harvesting and management activities can have influences on the infinite variety of life forms in boreal forests. For example, forestry operations influence the availability of nest sites for forest birds and the provision of browse for moose. Beaver affect riparian habitats through modification of succession and small mammals such as voles are important in the distribution of seeds, fungal spores and mycorrhizae. Forest management practices may remove suitable habitat for small but important components of boreal ecosystems.

Considerable research has focused on assessing the productivity of northern temperate and boreal ecosystems over the past 20 years. Results from this research have been summarized in refereed journals, unpublished government reports, in university theses, and in file reports. The focus of these papers may assist managers and scientists in evaluating where future gaps in information occur.

Public concern about the forest environment has never been greater. This was recently addressed in Ontario by the Class Environmental Assessment of Timber Management, and by frequent news media coverage of such topics as old-growth forest preservation, clearcutting, chemical use in forests, biodiversity and long-term productivity. The CFS and OMNR are pursuing research in these areas to provide a better understanding of the integrity and diversity of forests and to provide guidance towards managing forests for sustainable long-term productivity.

A review of the problem has indicated that the main issues and concerns about forest practices are associated with:

i) removal of nutrients contained in biomass from sites and the potential for reduction in long-term sustainable productivity;

ii) physical changes to the soil associated with the effects of heavy equipment on mineral and organic soils, particularly in compaction, soil mixing and modification of drainage patterns;

iii) impacts of clearcutting and how they compare to natural large scale disturbances such as wildfire;

iv) impacts of road building on erosion, stream water quality, and increased access by people for recreational activities;

v) potential losses of biodiversity associated with changes in species composition and forest structure;

vi) changes in patch size and age distributions for various ecosystem components;

vii) loss of old-growth forests and other critical habitats.

A major concern expressed during the Class Environmental Assessment (EA) hearings was the impact of full-tree harvesting, in which trees are skidded to the roadside, delimbed, and the slash piles burned or left. This practice concentrates nutrients at the roadside and depletes forest sites of nutrients with potential reductions in site productivity. Intensive site preparation by blading concentrates the remaining superficial forest floor materials into windrows leaving wide strips of exposed mineral soil, increasing the potential for site degradation. Other concerns about site degradation include impacts of soil compaction and prescribed burning.

A federal-provincial Working Group has been established to coordinate the investigation of the maintenance of long-term productivity of boreal ecosystems in relation to harvesting practices such as the full-tree method. The multiple working hypothesis approach suggests that a number of primary environmental factors could be responsible for reduction in productivity, e.g., low inherent nutrient regime, moisture regimes too dry or too wet, poor soil aeration, soil thermal regimes too warm or too cool, etc. The species that are emphasized by the Working Group are the conifers, jack pine and black spruce. Frequently these species occur on nutrient poor sites. These conifer dominated stands are showing shifts in composition following harvesting towards mixedwood and hardwood (Hearnden 1993) which are not preferred species for the forest industry. To avoid duplication of effort and to provide a focus for each agency, CFS is concentrating its research on jack pine while the OMNR is focusing on black spruce.

1.1 Project Objectives

The Project Objectives are derived from memoranda and meetings of the Sustainable Productivity of Forest Ecosystems Technical Working Group held over the last two years. The general objective is:

> "To facilitate federal and provincial cooperation in research on the sustainable productivity of forest ecosystems and to develop ecosystem management practices."

Within this overall objective there are a number of subsidiary themes:

i) providing coordination and linkages;
ii) information synthesis and needs analysis; and
iii) technology and information transfer.

A short summary of the scope of each of these subsidiary themes are presented below.

Coordination and Linkages

There are three general aims of this part of the program:

i) To coordinate research efforts and promote cooperation in the area of sustainable productivity of forest ecosystems. This is part of the activities designed to satisfy the information requirements which have been identified under the Ontario Sustainable Forestry Initiative, the Ontario Environmental Assessment Process and the CFS Strategic Plan.

ii) To develop experimental designs and protocols for studying forest ecosystems.

iii) To provide linkages with research programs on other aspects of forest ecology (e.g. wildlife) as well provide linkages with policy development.

Information Synthesis and Needs Analysis

Resource managers and field staff have limited access to, and limited time to keep up with the current literature. Concurrently they are being asked to manage within the broader forest ecosystems rather than the traditional stand-oriented management. Relative papers are increasingly published in journals other than the traditional forestry journals creating an increasing need for concise summaries of current literature and associated research results. The program will also facilitate opportunities for scientists and field staff to work together to address current and projected concerns that link forest practices to the maintenance of long-term productivity. The information and needs analysis objective has been subdivided into five tasks.

i) To provide an understanding of the structure and function of forest ecosystems.

ii) To fill information gaps for impacts of anthropogenic and natural disturbances.

ii) To synthesize information.

iii) To review current research in the context of provincial, national and international needs.

iv) To identify new directions and opportunities for research.

Technology and Information Transfer

There are always concerns with accurate information transfer and the lag time that commonly limits the adoption of new technologies and procedures. With the advent of environmental assessment procedures comes the increasing need for effective and efficient monitoring and response to any identified concerns. As such the following two tasks were identified as critical components of this program.

i) To develop cooperative approaches to the synthesis and marketing of research results and technologies to forest managers, environmental specialists and other clients.

ii) To assist in the development and monitoring of technology transfer output, client relationships and initiatives and mutual information exchange.

The Technical Committee consists of six scientists with active involvement in the area, being equally represented from OMNR and CFS. A steering committee consists of one director from OMNR and one from CFS to provide general management direction. Scientists from other organizations can be appointed to the Technical Committee for specific terms.

1.2 Approach

The following approaches have been initiated by both agencies:

i) ecosystem classification and dynamics;
ii) development of interim guidelines and indicators;
iii) ecosystem nutrient cycling and modelling;
iv) biomass removal experiments; and
v) studies of the ecophysiology of seedlings.

The Technical Working Committee is comprised of research scientists from the Canadian Forestry Service office in Sault Ste. Marie, Ontario and the Ontario Ministry of Natural Resources research offices in Sault Ste. Marie (Ontario Forest Research Institute) and Thunder Bay (Centre for Northern Forest Research Institute). Working group members are listed in the following table.

"Sustainable Productivity of Forest Ecosystems Technical Working Group"

	Canadian Forestry Service	Ontario Ministry of Natural Resources
Co-Chairs	Dr. John Jeglum Dr. Neil Foster Dr. Ian Morrison	Mr. Dave Morris Dr. Alan Gordon Dr. Nadarajah Balakrishnan

2.0 OBJECTIVES

The objectives of this study were to prepare an annotated bibliography of literature assessing long-term productivity in boreal jack pine and black spruce ecosystems and evaluating the impact of current harvesting practices on this productivity. It includes literature on nutrient cycling, site productivity, silvicultural operations, harvesting operations, seedling ecophysiology and wildlife population dynamics in harvested and non-harvested forests. The range of literature retrieved from the journals will contribute to identifying past and current research, minimizing future duplication of research effort and in identifying major gaps in the knowledge base with respect to long-term productivity in boreal ecosystems.

3.0 METHODS

The primary sources of bibliographic information included in this annotated bibliography were CD-ROM-based data bases held by the University of Toronto. These data bases include: Forestry Tree (TREECD) from 1939 to 1991; Biological Abstracts (CAB) from 1984 to 1991; Microlog, a data base containing federal and provincial research literature, for the period Jan. 1982 to Dec. 1992; and Dissertation Abstracts International (DAI) which contains bibliographic citations and abstracts for North American doctoral dissertations and some masters theses, from 1861 to June 1992. Each of these data bases were searched and relevant citations downloaded to disk. Disk files were then translated into Pro-Cite format using Biblio-Link to Silverplatter software and incorporated into a Pro-Cite data base. Pertinent articles were also selected from recent issues of the Canadian Journal of Forest Research (1991 to 1993) and The Forestry Chronicle (1990 to 1993). Abstracts are from the author's summaries.

In addition to the CD-ROM searches, existing bibliographies were reviewed. These bibliographies included: Whole-tree harvest - nutrient relationships: a bibliography (Kimmins et al. 1985); Growth and Yield of Northwestern Ontario Boreal (Coniferous) Forest Species: an annotated bibliography (Bell et al. 1989); The effects of forest management practices on nongame birds: an annotated bibliography (Nietfeld and Telfer 1990); and Petawawa National Forestry Institute (1987, 1989, 1991), Great Lakes Forest Research Centre/Forestry Centre (1991, 1992) and Northern Forest Research Centre (1976, 1988, 1991) bibliographies. A list of bibliographies, proceedings, symposia and books is provided in Appendix A.

Numerous citations were provided by researchers responding to the project questionnaire. Additional lists were provided by scientists in the CFS and the University of Toronto. Reference lists from relevant exhibits presented during the recently completed Class Environmental Assessment of Timber Management in Ontario were provided courtesy of the (OMNR).

In order to identify literature relating to recent research conducted at the university level, undergraduate and graduate theses were reviewed during visits to University of Toronto, Lakehead University and the University of Guelph. While many undergraduate theses are available, these are not readily available outside the academic institution for which they were written and they were not included in the citations. The peer review and quality of these publications varied. Those students who continue their forestry careers in research,will later publish reviewed and refereed papers on related subject material. Where authors published many papers on the same subject material, only the most recent papers were selected for inclusion in the bibliography. Progress reports were not included where refereed papers on the same subject material were available. While the general focus of this annotated bibliography is on boreal ecology, a few papers which are relevant to the principles of harvesting and nutrient loss from other forested ecosystems or which employed innovative methodology and analysis techniques are included.

The latest version of the bibliographic program, Pro-Cite 2.02 was used. This new version of Pro-Cite provides direct downloading to WordPerfect, thereby allowing for easy incorporation of bibliographic citations into text-based documents.

Biblio-Link to Silverplatter, a companion software program to Pro-Cite, was also utilized to translate CD-ROM-based data bases into Pro-Cite format.

The annotated bibliography is provided on a 3.5" low density diskette in the back pocket of this report. This diskette contains two compressed, self-extracting files, WORDPERF.EXE in WordPerfect 5.1 and PCITEBOR.EXE in Pro-Cite 2.02. In order to access either file, copy the desired file to a directory established on a computer hard drive. Make the newly created directory current and, at the prompt (>), type either wordperf or pcitebor, then the return key. The files will decompress themselves resulting in file sizes

of 503,823 bytes and 1,032,995 bytes for the WordPerfect file and the Pro-Cite files, respectively. Assuming the user has the appropriate software packages, keyword searches can be conducted utilizing the corresponding electronic files.

4.0 ANNOTATED BIBLIOGRAPHY

The following annotated bibliography contains a total of 390 bibliographic citations. The format of the citations follows that used by the Canadian Journal of Forest Research. Acronyms which appear in both the report and the bibliography are listed in Appendix B.

Many articles cover at least two and often three subject areas within this bibliography. Readers are encouraged to search the electronic data base provided either in Pro-Cite or WordPerfect for rapid access to bibliographic information on a particular subject area of interest. A list of key papers by major subject headings are listed by citation to provide an overview of the type of material included in this bibliography. A more detailed breakdown is provided in the index at the end of this report.

Nutrients

There are approximately 120 articles dealing with nutrients in northern forests of which approximately two thirds (i.e. 76) are directly related to the importance of nutrients in the productivity of these forests. These publications focused on nutrient poor sites, nutrient budgets, and nutrient management, fire effects on soil nutrients, clearcut effects, growth and yield comparisons for different silvicultural treatments, effects of full-tree harvesting, nutrient status of ground cover after harvesting and the effect of harvesting and fast growing species on nutrients. References on this subject include:

3, 4, 5, 6, 7, 28, 29, 35, 36, 37, 39, 54, 59, 73, 78, 96, 104, 108, 112, 113, 115, 123, 125, 126, 127, 128, 132, 134, 150, 152, 153, 154, 155, 156, 162, 168, 173, 175, 178, 180, 182, 188, 190, 192, 195, 199, 202, 204, 216, 217, 221, 224, 225, 229, 244, 246, 248, 250, 257, 260, 264, 268, 274, 283, 284, 285, 301, 310, 311, 314, 327, 329, 336, 338, 354, 355, 363, 364, 372, 377.

Silviculture

There are many references contained in this bibliography which discuss silvicultural strategies and their impacts on future site productivity. These references discuss traditional silvicultural subjects including direct seeding, the impacts of full-tree harvesting impacts on forest productivity and site quality, black spruce regeneration and site productivity responses to alternative silvicultural treatments. In addition some of the papers discuss the critical silvics of plant species which influence the effectiveness of silvicultural operations based on the timing of applications. Other papers focus on the influence of silvicultural operations on forest soil nutrient availability and nutrient cycling. A few focus on the timber management effects on wildlife populations. These papers include:

5, 9, 14, 17, 32, 38, 39, 41, 49, 55, 56, 67, 80, 83, 84, 87, 93, 94, 96, 117, 121, 135, 136, 144, 145, 148, 169, 170, 176, 180, 188, 205, 209, 226, 228, 233, 280, 284, 285, 315, 326, 338, 339, 353, 359, 360, 378, 379.

Silviculture - Harvesting

These records contain references to harvesting methods and their impact on long-term site productivity. They include discussion of fire effects on soil nutrients on clearcut full-tree harvesting sites, the biological and nutritional implications of harvesting, the impact of harvesting on soil compaction, water quality and yield and the impacts of harvesting on nutrient budgets.

3, 4, 16, 24, 25, 30, 35, 36, 37, 58, 59, 89, 104, 106, 107, 112, 123, 124, 131, 133, 136, 143, 152, 153, 154, 155, 156, 158, 161, 162, 173, 178, 182, 183, 192, 193, 199, 214, 220, 223, 224, 225, 230, 247, 248, 256, 257, 263, 264, 267, 274, 282, 283, 284, 287, 301, 309, 310, 312, 313, 318, 331, 335, 338, 341, 343, 348, 351, 363, 364, 365, 368, 375, 390.

Silviculture - Site Preparation

The following records concern site preparation methods and their impact on long-term site productivity. References include discussions of direct seeding, the impact of prescribed fire, comparisons of tree growth after different site preparation treatments, and the effects of site preparation methods on soil compaction, nutrient cycling, and non-game birds. It includes summaries of operational field trials.

5, 9, 10, 11, 33, 61, 63, 64, 70, 71, 77, 91, 98, 106, 124, 142, 146, 147, 206, 207, 243, 252, 253, 281, 283, 286, 302, 309, 323, 331, 337, 339, 343, 350, 351, 360, 384.

Silviculture - Tending

Five references focus on tending and its effects on the future forest. The papers discuss methods for determining the needs for stand tending, methods for site amelioration in fast growing tree plantations and the effect of monocultures on site productivity. The references include:

52, 138, 142, 231, 331.

Seedling Ecophysiology

There are approximately 27 citations dealing with seedling ecophysiology with many of them addressing the growth of seedlings rather than the physiological mechanisms involved. Subject material covered include mycorrhizae and seedling survival, soil compaction and its affect on seedling growth, species shifts associated with natural regeneration, morphological changes in response to competition and nutrient absorption during seedling establishment.

43, 44, 45, 48, 71, 79, 109, 123, 144, 165, 166, 170, 179, 194, 227, 228, 242, 244, 271, 273, 317, 325, 327, 336, 337, 357, 381.

Mycorrhizae

Mycorrhizae are known to influence the establishment and growth of jack pine and black spruce. Only eight references are included in this bibliography. Two papers address the inoculations of mycorrhizae on jack pine and black spruce. One paper discusses phosphorus concentrations and mycorrhizae development.

42, 43, 44, 45, 48, 194, 273, 280.

Nutrient Poor Sites

Nutrient poor sites are discussed specifically in six of the papers included in this bibliography. They address nutrient cycling, the effects of full-tree harvesting on site productivity and the characterization of site and stand conditions.

82, 94, 154, 268, 352, 376.

Wildlife

Eighteen general wildlife references are included in this bibliography. They include articles on the effect of fire on invertebrates, birds and animals, the impact of the use of Bacillus thuringienses (B.t.) and other insecticides on bird and mammal populations in jack pine plantation forests and changes in small mammal populations following clearcutting in black spruce forests. The linkages

between logging and wildlife ecology are discussed in both general terms and more specifically. For example, one scientist studied the influence of habitat diversity on the abundance and diversity of small mammals in jack pine forests.
The references that deal with wildlife in general include the following.

12, 21, 22, 27, 57, 69, 72, 76, 88, 135, 210, 215, 233, 331, 332, 334, 359, 366.

Mammals

Eleven papers are included which deal specifically with mammals, harvesting pattern and habitat diversity as well as the effects of fire and insecticides are covered. They include:

21, 22, 27, 90, 179, 230, 254, 262, 316, 333, 388.

Birds

This bibliography includes fifteen references to birds in the boreal forest ecosystem. These cover the effects of harvesting and fire on birds, insecticides (fenitrothion, matacil and b.t.), harvesting pattern on the fragmentation of habitat, and the effects of forest management on soil insects.

12, 21, 22, 24, 92, 211, 258, 281, 288, 316, 330, 365, 367, 386, 389.

Insects

Five key insect references were selected for inclusion in the bibliography. These cover the following broad topics: harvesting effects on insect populations, the effect of forest fragmentation and fire on insects populations and a review of methods for assessing insect populations. These include:

24, 83, 300, 316, 359.

Modelling

There are 27 articles on modelling in the boreal forest. These vary from modelling floristic composition following fires of different frequencies and intensities through to modelling the implications of intensive forest management and alternate silvicultural techniques on growth and yield. Others model the effect of harvesting on site productivity and nutrient pools. These papers include:

1, 30, 47, 54, 77, 89, 93, 94, 96, 99, 116, 119, 137, 157, 183, 184, 185, 186, 192, 226, 255, 270, 271, 300, 315, 334, 385.

Jack Pine

Publications that refer specifically to jack pine include the following. The subject material varies from the impact of different harvesting systems on the growth and yield of jack pine through to the assessment of current yields of jack pine.

1, 2, 7, 8, 16, 17, 20, 22, 34, 42, 43, 44, 45, 50, 55, 56, 61, 62, 63, 64, 65, 66, 84, 103, 117, 121, 134, 147, 149, 151, 164, 200, 201, 214, 216, 219, 227, 231, 235, 236, 242, 245, 246, 249, 254, 271, 272, 295, 302, 303, 304, 307, 308, 321, 322, 323, 324, 325, 327, 330, 342, 346, 347, 350, 354, 355, 356, 357, 358, 362, 376, 380, 381, 384, 390.

Black Spruce

Publications that refer specifically to black spruce include the following references. The subject material varies from the impact of different harvesting systems on the growth and yield of black spruce through to the assessment of current yields of black spruce.

8, 10, 11, 16, 17, 42, 43, 44, 45, 46, 48, 50, 51, 61, 74, 79, 81, 82, 97, 98, 104, 109, 110, 121, 125, 127, 129, 130, 137, 138, 142, 143, 145, 165, 166, 167, 168, 169, 170, 171, 176, 198, 205, 208, 209, 220, 227, 230, 238, 239, 240, 241, 242, 251, 255, 256, 265, 266, 267, 271, 285, 289, 291, 292, 293, 304, 305, 291, 322, 323, 324, 325, 327, 330, 336, 337, 338, 344, 345, 346, 352, 362, 373, 381, 382, 383.

A more detailed index to papers included in the bibliography follows the annotated references.

ANNOTATED BIBLIOGRAPHY

1. Abrams, M.D.; Dickmann, D.I. 1984. Floristic composition before and after prescribed fire on a jack pine clear-cut site in northern lower Michigan. Canadian Journal of Forest Research. 14(5):746–749.

Permanent frequency and cover plots were established and monitored for 3 years (1979-81) on an area clear felled in 1976 in order to characterize successional changes on burned and unburned blocks. Community data were also recorded from an adjacent mature jack pine stand. Vaccinium dominated (30% cover) the mature jack pine understorey, whereas at the time of burning, the clear-felled site (3 years old) was dominated (33% cover) by Carex pensylvanica. Two years after burning, burned blocks were significantly different from unburned blocks in terms of total cover, cover of grasses and sedges, and number of perennial forbs. Egler's initial floristic composition model was supported by the fact that every species in the mature jack pine understorey was present on either the unburned or burned clear-felled blocks.

2. Abrams, M.D.; Sprugel, D.G.; Dickmann, D.I. 1985. Multiple successional pathways on recently disturbed jack pine sites in Michigan. Forest Ecology and Management. 10(1/2):31–48.

Jack pine communities in northern lower Michigan recently disturbed by clear felling, deliberate burning, or wildfire were studied over three growing seasons, and were compared with undisturbed jack pine stands. Newly disturbed sites generally had more vascular plant species than mature forests. Many of these species did not persist, especially on burned sites, and species richness declined sharply in the second year after fire. In several cases annual and biennial species dominated first-year burns but were unimportant thereafter. Jack pine regeneration failed on all but one of the disturbed sites. Unburned clear-felled areas rapidly developed into Carex meadows, with few other species of any importance, as did some deliberately burned and wildfire sites. Other burned areas developed a stratified canopy of shrubs and early successional broadleaves, and were rich in species and high in cover.

3. Adams, P.W.; Boyle, J.R. 1980. Effects of fire on soil nutrients in clearcut and whole-tree harvest sites in central Michigan. Soil Science Society of America Journal. 44(4):847–850.

Surface mineral soil samples form adjacent northern red oak (*Quercus rubra* L.)-bigtooth aspen (*Populus grandidentata* Michx.) sites harvested by contrasting methods were evaluated for available Ca, Mg, K, P, and total N before and after a wildfire. Abundant slash from clearcutting contributed to significant and persistent increases in Ca, Mg, K, and N following fire. Sample data grouped by variations in estimated surface burn intensity revealed no significant differences, indicating that slash windrows did not appreciably localize nutrient increases. Minimal residues from whole-tree harvest released smaller quantities of Ca, Mg, and K, and total N exhibited no significant change. Significant increases in soil Ca, Mg, K, and P at both sites occurred within a month after burning. Five months after the fire, soil Ca, Mg, K, and P at both sites generally decreased, in some cases to prefire levels. Cation leaching losses from the surface soils, monitored by porous cup lysimeters at the 1 m depth, increased within 2 months after the fire, but losses appeared to stabilize within 5 months. Leaching losses of Ca were significantly greater in the clear cut site. Although short-term soil nutrient changes following fire were generally positive, the long-term effects on site quality remain in question due to the probable net loss of organic matter and nutrients through volatilization and accelerated leaching.

4. Adams, P.W.; Boyle, J.R. 1982. Soil fertility changes following clearcut and whole-tree harvesting and burning in central Michigan. Soil Science Society of America Journal. 16(3):638–640.

Soil fertility (available Ca, Mg, K, P, and total N) was evaluated at the time of and 1 and 5 years after clearcut and whole-tree harvest of adjacent oak-aspen forests. Surface mineral soil at both sites showed increased K and decreased N concentrations 1 year following harvest. A wildfire that burned both sites shortly thereafter generally increased the nutrient concentrations at each site, but smaller increases occurred at the whole-tree harvest site. Five years after cutting

(4 years after burning) soil Ca and P levels at both sites were higher than the concentrations at the time of harvest, while N and K were similar to original levels. Calcium and Mg concentrations at the clear-cut site were 88 and 75% higher that the levels at the whole-tree site 5 years after harvest. The increased soil fertility observed could provide a valuable nutrient supply to the succeeding forest stand, but net nutrient outputs through harvest and burning could also eventually reduce the already low productivity of these sites.

5. Adlard, P.G.; Johnson, J.A. 1983. Biomass estimation, nutrient cycling and organic matter relations in forest stands: annotated bibliography. Commonwealth Forestry Institute, Oxford, UK.

A working document prepared as part of the Overseas Development Administration Research Project R3738 (The effects of fast-growing tree crops on long-term site productivity). References are arranged in alphabetical order of author under the following headings: General ecosystem processes; Biomass data; Productivity; Energy fluxes; Nutrient cycling; Moisture relations; Organic matter relations; Productivity in relation to climate; Productivity and soils; Interactions, competition; Evidence of site change under forest crops; Effects of management on tree and stand growth; and Effects of management primarily on the soil. Each paper is also classified numerically by up to four subject codes out of a possible 80. An author index is provided. The reference collection is stored on floppy discs and is continually being updated.

6. Adlard, P.G.; Wright, S.F. 1987. The effects of fast growing tree crops on long term site productivity. Oxford Forestry Institute, Oxford, UK. 105 p.

An annotated bibliography intended to update an earlier compilation by Adlard, P.G.; Johnson, J.A. (1983). The references are listed in alphabetical order of authors under the following subject headings: Ecosystems (biomass data, productivity, nutrient cycling, moisture relations, organic matter relations); Climate; Topography; Soils; Vegetation (breeding, provenances); Interactions, competition etc.; Evidence of changes under forest crops; Effects of management on the stand; Effects of management on the soil; Methodology (measurement, analysis, field procedures); and Social aspects. An author index is provided.

7. Alban, D.H.; Perala, D.A.; Schlaegel, B.E. 1978. Biomass and nutrient distribution in aspen, pine and spruce stands on the same soil type in Minnesota. Canadian Journal of Forest Research. 8(3):290–299.

A study was made in adjacent 40-year-old stands of (a) *Pinus resinosa*, (b) *Pinus banksiana*, (c) *Picea glauca*, (d) *Populus tremuloides*/*Populus grandidentata* on a very fine sandy loam in north-central Minnesota. Total tree biomass was greatest for (a), followed by (d), (c), and (b). Nutrient weights per tree (N, P,K, Ca, Mg) were greatest in (d) followed usually by (c) (a) and (b). Particularly large proportions of the biomass and nutrients were found in the bark of (d) and foliage and branches of (c). Understorey biomass contributed less than 1.2% of total organic matter in the vegetation-soil complex, but contributed up to 5.0% of the nutrient. Exchangeable Ca in the surface soil was much less under stands of (d) and (c) than under (a) and (b). No significant soil differences between species were detected below 36 cm depth. Harvesting the entire aboveground portion of the tree would remove up to three times more nutrients from the site than would harvesting only the bole. From author's summary.

8. Alemdag, I.S. 1982. Aboveground dry matter of jack pine, black spruce, white spruce and balsam fir trees at two localities in Ontario. Forestry Chronicle. 58(1):26–30.

Standard equations for aboveground oven-dry mass of jack pine, black spruce, white spruce, and balsam fir were developed for the components and for the whole tree of single stems grown in natural stands in Ontario. The relationships between the component and stem wood oven-dry masses and those between the oven-dry and the green masses were determined. Distribution of oven-dry mass within the stem wood of merchantable trees was established.

Wood densities were calculated, and comparisons of stem wood oven-dry mass were made between the equations developed here and those found in other reports.

9. Anon. 1979. The whole-tree utilization project is completed. Norsk Skogindustri. 33(5):131–133.

A brief summary of the Norwegian project and the main conclusions contained in the final report. Raw materials included first thinnings in conifer stands, hardwoods from thinnings and final fellings, and less intensively, stumps and logging slash. Quantities involved, harvesting methods, storage of whole trees or whole-tree chips, measuring and quality evaluation of whole-tree chips, effect on the nutrient balance of forests, and uses were investigated. A list is appended of reports dealing with individual subordinate projects.

10. Archibald, D.J.; Baker, W.D.; Buse, L.J. 1988. Direct seeding black spruce in Northwestern Ontario. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Report #13. 30 p.

Black spruce is one of the most important commercial tree species in northwestern Ontario, existing on a wide variety of sites requiring different silvicultural prescriptions for successful stand establishment. An effective, inexpensive method is required to regenerate black spruce on these various sites after harvesting. This literature review covers the requirements for germination, establishment and growth of black spruce, examines where direct seeding is feasible, determines appropriate seedbed preparation, and reviews current seeding methods.

11. Archibald, D.J.; Baker, W.D. 1989. Prescribed burning for black spruce regeneration in Northwestern Ontario. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Report #14. 21 p.

Prescribed fire is a viable site preparation tool for regenerating black spruce (*Picea mariana* (Mill) B.S.P.) in northwestern Ontario; however its use for this purpose has been limited to date. Fire is usually not necessary on lowland sphagnum-rich sites as this moss type is an excellent seedbed for black spruce germination. On sphagnum sites, burning is only recommended for removal of slash for seedbed exposure. Light burning of sphagnum sites can be used to retard the growth of sphagnum. On lowland black spruce-feather moss sites, moderate to severe burning will reduce slash and litter accumulations and consume the feather mosses thereby creating receptive seedbeds. Prescribed burning on the black spruce-alder type can produce variable results. Consideration should be given to chemically treating alder sites with 2,4-D prior to burning. This will allow for a low to medium burn under lower indices to create a favourable seedbed. On the drier upland sites, moderate to severe burning is necessary to reduce the duff layer for natural or direct seeding, although some form of microsite protection from drying and extreme temperatures may be warranted. On upland, shallow black spruce-feather moss sites, a moderate burn should be considered, if slash reduction is the objective. Post-fire nutrient budgeting and vegetation regrowth are discussed.

12. Back, G.N. 1982. Impacts of management for ruffed grouse and pulpwood on nongame birds. Ph.D. thesis. University of Minnesota, Minneapolis, MN. 106 p.

Response of nongame birds to management for ruffed grouse and pulpwood was evaluated. Two bird species-habitat associations were based on presence and density of species in habitats of different ages. Changes in availability of foraging substrates and nest sites in regeneration following clearcutting were important factors determining species presence. Species richness and mean stem density were lower in mature forest areas than on commercial clearcuts. The current management program resulted in an increase in species richness, total avian density, and habitat diversity. However, a 40-year rotation would have a negative impact on cavity-nesting species, bark-foraging species, and raptors. Options for several levels of management for grouse, pulpwood, and nongame birds are provided. Removal of forest

canopy by clearcutting was expected to reduce bird species diversity (BSD). However, BSD values on clearcuts 2- to 5-years old were greater than BSD of mature forests. This unexpected result prompted an evaluation of the relationship between foliage height diversity (FHD) and BSD. The FHD-BSD relationship was found to have limited predictive capability. The FHD index does not include information about the presence of various life forms, distribution of foliage within each layer, or non-foliage avian resources. Other factors that can influence BSD independently of FHD also are not incorporated in the relationship. Application of the Shannon index to biological systems that include species of various trophic levels, territory sizes, and biomasses presents difficulties in interpretation. Standards need to be developed to make comparisons of BSD values meaningful.

13. Ballantyne, B.A.; Mitchell, M.H. 1989. Bibliography/Liste des publications 1986–1987. Forestry Canada, Petawawa National Forestry Institute, Chalk River, ON. Information Report PI-X-87E/F. 70 p.

This volume updates PI-X-70-E/F Bibliography/Liste des publications pour les années 1979–1985 by A.C. Yapa and M.H. Mitchell. It follows the same format and annotates all scientific and technical publications of the Petawawa National Forestry Institute for the period 1986 to 1987 inclusive. A species/key word index is provided.

14. Ballard, R.; Gessel, S.P., eds. 1983. IUFRO symposium on forest site and continuous productivity. 22–28 August 1982, Seattle, WA. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR. General Technical Report PNW-163. 406 p.

Some 52 papers are included in the proceedings under 4 headings: Determination and expression of forest productivity (6 papers); Factors that determine forest productivity (12); Effects of management on physical and chemical properties of soil and on yield (16); and Maintenance and improvement of forest productivity (17).

15. Bates, D.; Gillmeister, D., eds. 1986. Ontario Tree Improvement and Forest Biomass Institute publications 1980-1985: an annotated bibliography. Ontario Ministry of Natural Resources, [Toronto, ON]. Forest Research Report No. 114. 31 p.

This annotated bibliography covers research reports, papers and journal articles written by staff of the Ontario Tree Improvement and Forest Biomass Institute between 1980 and 1985. Book reviews are not included. Publications are listed alphabetically by first author, under the year of publication.

16. Bélanger, J.; Dumont, J.M.; Bélanger, G. 1984. Inventory of forest biomass left after logging. Forest Engineering Research Institute of Canada, Pointe Claire, PQ. Special Report SR-13. 135 p.

In 1979, four major forest types were the subject of a study intended to make an assessment of the residual forest biomass resulting from the use of various logging methods. Black spruce, jack pine, sugar maple and balsam fir types were selected for this study. Logging operations were carried out according to one of the following methods: tree-length, full-tree or shortwood. In Phase 1 of the project, sites were inventoried before logging using 0.04 ha sample plots. In Phase 2 the sample plots used in Phase 1 were relocated after logging in order to quantify the residues made up of tops, branches, green stems and dead stems. All residues found in the plot were weighed in their green condition and the moisture content of each category of residue was measured. The overall oven-dry weight included the weight of stumps (above- ground portion) as well as residual trees. The following are the oven-dry weights (t/ha): tree-length - black spruce stand (56.4), jack pine stand (50.7), sugar maple stand (77.2), balsam fir stand (81.2); full-tree - black spruce stand (25.8), jack pine stand (32.9), balsam fir stand (72.4); shortwood - black spruce stand (75.3). From authors summary.

17. Bell, F.W. 1991. Critical silvics of conifer crop species and selected competitive vegetation in northwestern Ontario. Forestry Canada, Ontario Region, Sault Ste. Marie, ON / Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. COFRDA Report 3310 / NWOFTDU Technical Report #19. 177 p.

The purpose of this project was to draw together practical information on the silvics of selected coniferous species in northwestern Ontario in a field guide that will aid forest managers in developing vegetation-management strategies. The project involved no original research; the information was compiled primarily from a review of relevant literature, incorporating selected soil/site data from the Northwestern Ontario Forest Ecosystem Classification (NWO FEC) database. The guide contains silvicultural and ecological information on five coniferous species (balsam fir, black spruce, white spruce, jack pine and red pine) and 23 woody and herbaceous potential competitor species (including trembling aspen, balsam poplar, white birch, beaked hazel and mountain maple). The field guide summarizes, for each species, information on identification and taxonomy, autecology in the context of the NWO FEC, phenology, and reproductive and growth habits. In addition, potential competitors are evaluated and discussed with respect to their competitive effects and mechanisms, their wildlife values, and their response to disturbance and silvicultural treatments, including their adaptation to the latter. The five conifers are also evaluated in terms of their response to competition and their ability to respond to release from different competing species. The guide does not provide specific prescriptions for the control of competing vegetation, but allows forest managers to develop site-specific vegetation management strategies on the basis of ecological and phenological criteria. Knowledge of the autecological characteristics of key competitive species will help to change the focus of vegetation management from corrective to preventative measures.

18. Bell, F.W.; Hanmore, C.J.; Willcocks, A.J. 1989. Growth and yield of northwestern Ontario boreal (coniferous) forest species: an annotated bibliography. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Report #31. 211 p.

Annotated bibliography for growth and yield of Northwestern Ontario boreal forests, concentrating on jack pine, lodgepole pine, red pine, black spruce, and white spruce. Articles pertaining to species related to Northwestern Ontario boreal conifers are also included. Of the 14 subject areas covered, the main emphasis was placed on growth and development, spacing, thinning, fertilization, and wood quality. Bibliographies are arranged in alphabetical order by author. Indices are given for author and key species and subject.

19. Bell, M.A.M.; Beckett, J.M.; Hubbard, W.F., compilers. 1974. Impact of harvesting on forest environments and resources: a review of the literature and evaluation of research needs. Canadian Forestry Service, Pacific Forest Research Centre, Victoria, BC. Technical Report No. 3. 141 p.

Summarizes the available literature relevant to British Columbia concerning the effects of harvesting and post- harvesting practices on the forest environment and resources, and points out significant gaps in present knowledge. In the review section the available information is grouped by harvesting practice so as to collate evidence on the effects of (a) felling and yarding, (b) log transport and related services, and (c) slash disposal, on a series of appropriate environmental features. In the summary section information on major effects of harvesting practices is further condensed under headings that cover components of the ecosystem, forest growth processes or other forest values, and areas for further research. The bibliography (62 pages of references) is arranged alphabetically by authors.

20. Bella, I.E. 1986. Spacing effects 20 years after planting three conifers in Manitoba. Canadian Forestry Service, Northern Forestry Centre, Edmonton, AB. Forest Management Note No. 39. 11 p.

Synopsis: A spacing study of three native conifers, jack pine (*Pinus banksiana* Lamb.), red pine (*Pinus resinosa* Ait.) and white spruce (*Picea glauca* (Moench) Voss) was established at Moodie, Manitoba, on flat, sandy, nutritionally poor soils with a fresh moisture regime. This note provides the latest growth information covering the first 20 years after planting.

Red pine had the largest average dbh in terms of both total stand and largest trees/ha. Jack pine was behind red pine by approximately 15 percent. White spruce dbh growth was less than half that of the pines. Crown width showed a gradual increase with spacing for all three conifers. Results suggest optimum spacing ranges between 1.8 and 2.4 metres for both pines in order to achieve rapid tree growth and high future timber yields. Spruce is not recommended for planting on similar sites.

21. Bendell, J.F. 1974. Effects of fire on birds and mammals. p. 73–138 *in* T.T. Kozlowski and C.E. Ahlgren, eds. Fire and Ecosystems. Academic Press, New York, NY.

A chapter which deals with the effects of fire on the life and environment of birds and mammals, and considers how species have evolved to live in a fire frequented environment. Topics covered include: 1) the immediate reactions to fire; 2) long-term effects of fire: a) local climate and microclimate, b) structure of vegetation, c) pattern of cover within a burn; 3) food; 4) species changes after fire; 5) changes in density and trend after fire; and 6) adaptations at the population level. Results from a review of research studies are used as available information. For birds, most breeding species stayed after a forest fire, a few species disappeared and a few new species moved in. The greatest loss was from foragers of the tree trunks and tree canopy, and the greatest gain was among those that fed on or near the ground. Most bird species remained at a steady density both on burned and unburned areas. As summarized in Nietfeld, M.T., and Telfer, E.S. (1991).

22. Bendell, J.F.; Naylor, B.J.; Szuba, K.J.; Innes, D.G.L.; James, R.D.; Smith, B.A. 1986. Jack pine plantations, outbreaks of jack pine budworm, birds and mammals, and impacts of *Bacillus thuringiensis* (B.t.), Matacil and Fenitrothion. p. 56–63 *in* Manitoba Natural Resources. Jack pine budworm: information exchange. Winnipeg, MB.

23. Benzie, J.W.; Little, S.; Sutton, R.F. 1973. Rehabilitation of forest land: the northeast and boreal region. Journal of Forestry. 71(3):154–158.

The Northeast and Boreal Region has more than 435 million acres of commercial forest land. About two-thirds are in Ontario, Quebec, and the four Maritime Provinces of Canada. Most of these forests could produce more valuable timber under intensive management. Such management would be most efficient on fertile lands suitable for mechanized harvesting. On some areas, conversion to species better adapted to the site may be an important part of rehabilitation, especially where present or previous forests have not produced much merchantable material.

24. Bird, G.A.; Chatarpaul, L. 1986. Effect of whole-tree and conventional forest harvest on soil microarthropods. Canadian Journal of Zoology. 64(9):1986–1993.

The effect of 2 kinds of harvesting on soil *Collembola* and *Acari* was investigated in a mixed forest in Ontario. Whole-tree and conventional harvesting reduced this microarthropod fauna to 56 and 68%, respectively, of that in an uncut plot. The total numbers of microarthropods and numbers of *Oribatei*, *Prostigmata* and *Mesostigmata* found on the uncut plot were significantly greater than on harvested plots. Slightly higher numbers of *Collembola* were recorded from the conventionally harvested than the uncut plot. *Oribatei*, *Prostigmata* and *Collembola* were more abundant on the conventional than the whole-tree harvest plot. Of the 2 harvesting methods, conventional had the lesser effect on soil microarthropods. Because the forest soil fauna is intimately involved in decomposition, nutrient cycling and soil formation, these findings suggest that long-term site productivity will be greater following conventional than whole-tree harvest.

25. Bird, G.A.; Rachar, D.B.; Chatarpaul, L. 1987. Increased skeletonization of leaf litter under snow following timber harvest. Ecology. 68(1):221–223.

Decomposition of plant material is mediated by both biotic and abiotic factors, e.g., microbial and soil faunal activity and the leaching of soluble compounds. During investigations into effects of whole-tree and conventional harvesting on site productivity, it appeared as if deciduous leaf litter was more decomposed (skeletonized) on harvested plots than on the uncut plot. Because the effect of harvesting on decomposition is poorly documented and because the rate of decomposition may affect site productivity, we designed a study to determine if the degree of skeletonization of hardwood leaf litter is indeed affected by timber harvest.

26. Blake, J.; Somers, G.; Ruark, G. 1991. Estimating limiting foliar biomass in conifer plantations from allometric relationships and self-thinning behavior. Forest Science. 37(1):296–307.

The ability of forest stands to sustain increasing amounts of foliage biomass is related positively to both above- ground woody biomass and to site productivity. An analysis was made of previously reported experimental data collected in even-aged tree populations undergoing self- thinning. The results of this analysis and a theoretical evaluation of physiological processes indicated that foliar biomass should achieve a nearly constant value for a given species and site. Average diameter-plant density relations for various conifers (*Pseudotsuga menziesii*, *Pinus taeda* and *P. radiata*), together with available foliage mass-stem diameter equations, were used to estimate the maximum amount of foliage which could be sustained. Sources of bias and effects due to changes in specific leaf area were evaluated. The maximum foliage biomass calculated in this manner was subject to positive bias, but estimates at low plant densities corresponded to values obtained empirically for mature stands growing under favourable environmental conditions. Estimates suggest that maximum sustainable foliage biomass increases slightly with decreasing plant density along the self- thinning line, in contrast to expectations. The magnitude of the increase depends on the relative value of the self- thinning exponent compared to the exponent of the allometric equation. Changes in light distribution in relation to crown architecture, particularly crown depth and foliage clustering, may account for this effect.

27. Boer, A.H. 1992. Transience of deer wintering areas. Canadian Journal of Forest Research. 22(9):1421–1423.

Fidelity of white-tailed deer (*Odocoileus virginianus*) to wintering areas was examined in west-central New Brunswick. Wintering areas were located and mapped during aerial surveys in 1975 and 1987-1989. Of 99 wintering areas identified in 1975, 42 were unoccupied 13 years later. Small wintering areas (<50 ha) were more likely to be unoccupied in the subsequent survey than larger ones (>100 ha). Forest cutting had a profound effect on transience of wintering areas. Small clearcuts within a wintering area increased the likelihood of deer use. Wintering areas that were completely clear-cut were likely to be abandoned.

28. Bormann, F.H.; Likens, G.E.; Siccama, T.G.; Pierce, R.S.; Eaton, J.S. 1974. The export of nutrients and recovery of stable conditions following deforestation at Hubbard Brook. Ecological Monographs. 44(3):255–277.

A further report on the effects of deforestation on a catchment in a northern hardwood forest in New England. In the first two years after clear felling the export of particulate matter in streams increased slightly, but in the third year increased rapidly to 38 t/km² per year (vs. 2.5 t/km² per year in a mature forest ecosystem). These increases are attributed to increased erodibility rather than increased stream-flow. On the other hand, the export of dissolved nutrients rose rapidly in the first two years and then declined. It is concluded that, immediately after disturbance to the ecosystem, the continued resistance to erosion, and the effects of natural plant species adapted to take advantage of the abundance of nutrients, enable the ecosystem to make a rapid recovery, thus minimizing the effects of erosion.

29. Bormann, F.H.; Likens, G.E.; Fisher, D.W.; Pierce, R.S. 1968. Nutrient loss accelerated by clear-cutting of a forest ecosystem. Science. 159(3817):882–884.

Gives graphs and tables showing the increased loss of N and cations in stream water draining from a clear-felled catchment, compared with values before felling and those for a comparable catchment where the vegetation was left undisturbed.

30. Bormann, F.H.; Likens, G.E. 1979. Pattern and process in a forested ecosystem. Springer-Verlag, New York. 253 p.

The second in a series of 3 volumes based on the Hubbard Brook ecosystem study, and subtitled 'Disturbance, development and the steady state'. An integrated view of the structure, functions and development of the northern hardwood [broadleaved] ecosystem is presented under the following headings, with an index: The northern hardwood forest: a model for ecosystem development; Energetics, biomass, hydrology, and biogeochemistry of the aggrading ecosystem; Reorganization: loss of biotic regulation; Development of vegetation after clear-cutting: species strategies and plant community dynamics; Reorganization: recovery of biotic regulation; Ecosystem development and the steady state; The steady state as a component of the landscape; and Forest harvest and landscape management.

31. Boross, P.A.; Mitchell, M.H. 1991. Bibliography: 1988-1990. Forestry Canada, Petawawa National Forestry Institute, Chalk River, ON. Information Report PI-X-106E/F. 125 p.

This is the third volume in the series of *Bibliography/Liste des publications*. It contains all the scientific and technical publications in the years of 1988, 1989, and 1990 in a similar format with annotations. A species/key word index is provided.

32. Bose, K.J.C. 1973. Thermodynamic study of plant growth in nature. Part II. Method of calculating productive capacity of site. Indian Forester. 99(9):543–550.

Describes the application of a simplified version of the equation derived earlier, modified by other simple equations to take account of environmental factors e.g. climate and soil moisture, and physiological characters of the plant community, in order to derive a formula for calculating site productivity. Theoretically derived estimates of productivity for forests of *Shorea robusta* agree well with empirical results.

33. Bosworth, B.; Studer, D. 1991. Comparisons of tree height growth on broadcast-burned, bulldozer-piled, and non-prepared sites 15 to 25 years after clearcut logging. p. 197–200 *in* A.E. Harvey and L.F. Neuenschwander, compilers. Proceedings: Management and Productivity of Western-Montane Forest Soils. 10–12 April 1990, Boise, Idaho. USDA Forest Service, Intermountain Research Station, Ogden, UT. General Technical Report INT-280.

Tree height growth was compared on clearcuts that were broadcast burned, bulldozer piled, or had no preparation for regeneration in the Bonners Ferry Ranger District, northern Idaho. Differences in heights and growth are related to treatment. Height growth on burned sites exceeded that on piled sites in 8 of 9 years. Questions arise as to effects on site productivity of piling. Reasons for differences include nutrients available to regeneration related to site preparation method, and compaction effects from piling.

34. Bowling, C.; Niznowski, G. 1991. Factors affecting jack pine cone and seed supply after harvesting in northwestern Ontario. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Report #63. 19 p.

Twenty-three cutovers formerly dominated by jack pine (*Pinus banksiana*) and harvested since 1985 were sampled in northwestern Ontario in 1989 for numbers and distribution of jack pine cones within 30 cm of ground level. Effects of stand age, harvesting season, harvesting method (full-tree vs. tree-length), and seedbed condition (with or without site

preparation) were evaluated. An equation was developed to estimate two-year jack pine seedling densities from post-harvest numbers of jack pine cones. In addition, minimum stocking standards were compiled from published data to relate numbers of cones in cutovers to stocking of two-year-old jack pine seedlings.

35. Boyle, J.R. 1976. A system for evaluating potential impacts of whole-tree harvesting on site quality. Tappi. 59(7):79–81.

Discusses the effects of removal of vegetation on site quality, including the loss of nutrients, increased incidence of solar radiation, reduced evapotranspiration, and reduced litter fall and also the secondary effects on fungal, insect and plant pathogens through change in sunlight, water, living plant material and residues. Repeated whole-tree harvesting could deplete available nutrient reserves below the amounts necessary for desirable tree growth. Nutrient-rich soils and longer crop rotations (50-70 years) may be less vulnerable. The need is emphasized for reliable nutrient budgets based on rates of input, transformation and output of essential elements. By way of illustration, data are included from Aspen/mixed hardwood stands already studied in north central Wisconsin.

36. Boyle, J.R.; Ek, A.R. 1972. An evaluation of some effects of bole and branch pulpwood harvesting on site macronutrients. Canadian Journal of Forest Research. 2(4):407–412.

The removal of major nutrients by conventional harvesting and by harvesting of boles plus all branches was evaluated in a stand of mixed hardwoods in north central Wisconsin. Results indicate that minimum soil reserves of N, P and Mg are 5-15 times and of K and Ca 1-3 times greater than the amounts removed by harvesting at the end of a 45-year rotation. Natural inputs will supplement these reserves over such rotations, but may not balance the nutrient drain over rotations that are much shorter.

37. Boyle, J.R.; Phillips, J.J.; Ek, A.R. 1973. 'Whole tree' harvesting: nutrient budget evaluation. Journal of Forestry. 71(12):760–762.

In harvesting a 40-year-old second-growth forest of Aspen/ mixed hardwoods in north-central Wisconsin, all above-ground parts of trees > 1-2 inches in diameter were removed from the site. N, P, K, and Ca were evaluated in the harvested crop, and in the soil of the site, and estimates were made of the natural input of these elements from precipitation, mineralization, and weathering. For a 30-year rotation on this site, it is suggested that supplies of N, P, and K are adequate, but that depletion of Ca may begin to limit tree growth after nine rotations.

38. Brand, D.G. 1991. Forest regeneration options in boreal forests. p. 245–254 *in* C.M. Simpson, ed. Proceedings of the Conference on Natural Regeneration Management. 27–28 March 1990, Hugh John Flemming Forestry Centre, Fredericton, NB. Forestry Canada, Maritimes Region, Fredericton, NB.

Various factors are discussed that must be considered prior to choosing a forest regeneration method in the boreal forest. The forests are typically adapted to regenerated following disturbance, and it is therefore important to first understand what controls natural regeneration. In many cases, unassisted natural regeneration is sufficient, but it can also be enhanced by forest management practices, such as partial canopy removal, site preparation or weed control. Artificial regeneration is used as a management tool when the species, density, distribution, or condition of natural regeneration is unsatisfactory. The criteria used to design a regeneration regime should include the choice of species, the minimum and maximum acceptable properly- distributed stand density, and a measure of minimum acceptable regeneration performance. The complexity of choosing among options favours the development of decision support tools such as expert systems that are able to encode knowledge and professional rules and link with secondary programs or geographic information systems. These tools will help silviculturalists define their criteria for choosing among regeneration systems and help in determining the best choice in a particular instance.

39. Brand, D.G.; Penner, M. 1990. Interactions between vegetation competition, nutrient availability, soil surface modification and the early growth of planted spruce. p. 25–33 *in* B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, eds. The silvics and ecology of boreal spruces: proceedings of the 11th IUFRO Northern Forest Silviculture and Management Working Party S1.05-12 Symposium. 12–17 August 1989, Central Newfoundland, Canada. Forestry Canada, Newfoundland and Labrador Region, St. John's, NF. Information Report N-X-271.

Data from three experimental plantations in the boreal, sub-boreal spruce, and Great Lakes-St. Lawrence forest regions were used to quantify the effects of site modification treatments on the early growth of three species of planted spruce (*Picea glauca*, *Picea mariana*, *Picea glauca* x *engelmannii*). Soil temperature was strongly controlled by characteristics of the soil surface, and scarification increased soil temperature by 3 to 7° C on the three sites. Soil moisture availability was reduced by either uncontrolled development of competing vegetation or scarification. Nutrient availability was increased by fertilization and brush control. These changes in environment caused changes in the ratio of foliar non-structural carbohydrates to nitrogen. Treatments that increased carbon assimilation relative to nitrogen uptake, such as scarification, widened this ratio, while treatments that increased nitrogen availability more than carbon, such as fertilization, reduced this ratio. Changes in the availability of one environmental factor, such as light, affected the efficiency of use of other factors such as nitrogen. Growth responded most to the control of competing vegetation on all three study sites. Use of scarification before planting also reduced the rate of development of competing vegetation and, through improvements in soil temperature, increased growth beyond the response expected from differences in non-crop competition alone. Fertilization was most effective at increasing tree growth when vegetation was controlled or the soil surface scarified. The spruce species studied showed 300 to 1500% increases in biomass across the range of treatments tested, indicating the opportunity for improvements in the success rate of spruce reforestation programs.

40. Brand, D.G.; Penner, M.E. 1991. Regeneration and growth of Canadian forests. p. 51–68 *in* D.G. Brand, ed. Canada's timber resources: proceedings of a conference held 3–5 June 1990 at the Victoria Conference Centre, Victoria, BC. Forestry Canada, Petawawa National Forestry Institute, Chalk River, ON. Information Report PI-X-101.

The Canadian forest is a heterogeneous landscape. Climate, physiography, and disturbance control the distribution and growth of forest types. Processes of forest regeneration and growth are linked to these basic factors in the natural forest, but they change or become uncertain in response to human intervention, particularly forest harvesting. Studies of forest regeneration indicate that some forest types regenerate successfully after harvesting, but others do not, leading to changes in the length of the regeneration period, species composition, or growth rate relative to natural forests. Although case studies have indicated that these changes are, in fact, occurring, little systematically collected data are available to quantify the degree of the changes being created in the Canadian forest by human intervention. Artificial regeneration has been used to counter these problems, but the inherently slow growth of Canada's boreal and subboreal forests limits the amount of investment that can be applied to forest management. Growth estimation is a necessary precursor to large-scale forest management decisions, but current techniques have been almost entirely based on measurements made in naturally established forests. This does not lead to accurate forecasting of the development of postharvest naturally or artificially regenerated forests. Recommendations are made that Canada needs to rethink its currently fragmented approaches to forest research, forest monitoring, and growth estimation. Only a concerted, coordinated approach will provide an adequate description of forest dynamics and prediction of future development of the forest resource.

41. Brown, H.G.; Loewenstein, H. 1978. Predicting site productivity of mixed conifer stands in northern Idaho from soil and topographic variables. Soil Science Society of America Journal. 42(6):967–971.

Characteristics of 32 soils and topographic variables were used to develop prediction equations for site index, height, and total stand volume. Soil and topographic variables explained 70% of the variation in site index; soil, age and topographic variables explained 94% of height variation and 86% of variation in total volume. Depth of volcanic ash, density, P content and altitude were important variables. Site index was negatively correlated with altitude, and positively correlated with

extractable Ca, exchange acidity, cation exchange capacity, organic matter, total N, soil to rock ratio of buried soils and clay of ash-derived soils. From authors' summary.

42. Browning, M.H.R.; Whitney, R.D. 1992. Field performance of black spruce and jack pine inoculated with selected species of ectomycorrhizal fungi. Canadian Journal of Forest Research. 22(12):1974–1982.

Seedlings of black spruce (*Picea mariana* (Mill.) B.S.P.) and jack pine (*Pinus banksiana* Lamb.) were inoculated with fragmented hyphae of one of five species of ectomycorrhizal fungi and outplanted on reforestation sites after 14 weeks of growth in the nursery. Black spruce were planted on a peatland site and a stony loam site; jack pine were planted on the same stony loam site and on a sandy site. Inoculation of both species with *Laccaria proxima* (Boud.) Maire resulted in significantly better shoot growth compared with uninoculated seedlings over a 2-year period on all sites. *Hebeloma cylindrosporum* Romagn. improved the height growth of black spruce on the peatland site and of jack pine on the stony loam site after 2 years. *Laccaria bicolor* (Maire) Orton also improved the height growth of jack pine on the stony loam after 2 years. Black spruce inoculated with *L. bicolor* were significantly smaller than uninoculated seedlings. Size differences present in black spruce at outplanting persisted for two growing seasons, whereas initial size did not predict the field performance of jack pine. Inoculation of black spruce with *L. proxima* resulted in higher foliar concentrations of K and Zn compared with uninoculated seedlings on the peatland site. Foliar concentrations of N, P, K, and Zn in jack pine inoculated with *L. proxima* were significantly higher than those of uninoculated seedlings at the stony loam site. All inoculated fungi (except *Pisolithus tinctorius* (Pers.) Coker & Couch, which did not form mycorrhizae) remained on the root systems for two growing seasons, but their presence declined sharply in the 2nd year. *Laccaria bicolor* was the most persistent mycobiont on root systems of both tree species. Colonization of black spruce by indigenous ectomycorrhizal fungi was faster on the stony loam site than on the peatland site. The diversity of wild ectomycorrhizae on the planted seedlings was higher on both the peatland and sand sites than on the stony loam site.

43. Browning, M.H.R.; Whitney, R.D. 1993. Infection of containerized jack pine and black spruce by *Laccaria* species and *Thelephora terrestris* and seedling survival and growth after outplanting. Canadian Journal of Forest Research. 23(2):330–333.

The standard container (Japanese paperpot) and soil mix used in Ontario did not prevent abundant (60 to 70% of short roots) ectomycorrhizal development by *Laccaria proxima* Boudier or *Laccaria bicolor* (Maire) Orton after inoculations on jack pine (*Pinus banksiana* Lamb.) and black spruce (*Picea mariana* (Mill.) B.S.P.) seedlings. Naturally occurring *Thelephora terrestris* Ehrh.:Fr., which caused similar proportions of short roots to become ectomycorrhizal on uninoculated control seedlings of both tree species, was apparently prevented from forming ectomycorrhizae on seedlings originally inoculated with *L. bicolor* and to a lesser extent those inoculated with *L. proxima*. Although it could not be proven statistically, it appeared that *L. proxima* mycorrhizae enhanced drought tolerance of jack pine seedlings to a greater extent than either *T. terrestris* or *L. bicolor*.

44. Browning, M.H.R.; Whitney, R.D. 1992. The influence of phosphorous concentration and frequency of fertilization on ectomycorrhizal development in containerized black spruce and jack pine seedlings. Canadian Journal of Forest Research. 22(9):1263–1270.

The growth response of jack pine (*Pinus banksiana* Lamb.) and black spruce (*Picea mariana* (Mill.) B.S.P.) seedlings was tested in growth chambers at two levels of P, with or without inoculation of the mycorrhizal fungus *Laccaria bicolor* (Maire) Orton and with weekly and thrice-weekly fertilizer application. While keeping N and K constant, an increase of P from 1.5 to 7.2 mg per seedling severely reduced formation of *L. bicolor* ectomycorrhizae on both jack pine and black spruce 17 weeks after inoculation. Inoculation of black spruce with *L. bicolor* was more successful (75%) than inoculation of jack pine (35%). Inoculated black spruce seedlings were 34% taller and 44% heavier than uninoculated controls, but only at the low P level; they were also 39% heavier and had more abundant *L. bicolor* ectomycorrhizae (180% of the weekly treatment) when fertilized thrice weekly than with weekly fertilization that supplied the same total nutrients. Dry weights

of jack pine inoculated with *L. bicolor* were 26 and 33% larger than those of uninoculated seedlings at high and low P levels, respectively. Fertilizing thrice weekly also produced 23% larger dry weights of jack pine, but fewer ectomycorrhizae were formed than with weekly fertilization (65% of the weekly value). The results indicate that inoculation of black spruce seedlings with *L. bicolor* will produce larger seedlings, but only where low P fertilizer is applied, preferably thrice weekly. Jack pine may benefit from artificial inoculation with *L. bicolor*, especially in a higher fertility growing medium.

45. Browning, M.H.R.; Whitney, R.D. 1991. Responses of jack pine and black spruce seedlings to inoculation with selected species of ectomycorrhizal fungi. Canadian Journal of Forest Research. 21(5):701–706.

Seedlings of jack pine (*Pinus banksiana* Lamb.) and black spruce (*Picea mariana* (Mill.) B.S.P.) were inoculated with liquid cultures of fragmented hyphae of 10 species of ectomycorrhizal fungi and grown in either aseptic culture tubes for 20 weeks or nonaseptic pots for 16 weeks. Seedlings in pots received more total nutrients and produced larger root systems than those in tubes. Four of the fungi produced higher levels of colonization associated with these larger root systems. Short-root density of black spruce was increased compared with that of uninoculated seedlings by inoculation with *Laccaria bicolor* (Maire) Orton, *Hebeloma cylindrosporum* Romagnési, or *Thelephora terrestris* Ehrh. ex Fr. Colonization of jack pine by *Rhizopogon rubescens* (Tul.) Tulasne, *L. biclor*, *H. cylindrosporum*, or *Pisolithus tinctorius* (Pers.) Coker & Couch resulted in greater short-root densities than in uninoculated controls. Inoculation of potted black spruce with *Laccaria proxima* Boudier resulted in larger shoot weights and those inoculated with *H. cylindrosporum* had smaller root weights than did uninoculated seedlings. Both fungi resulted in increased shoot/root dry-weight ratios in black spruce. In contrast with black spruce, seedling weights were not affected by inoculation of jack pine with the same fungal species. However, inoculation of jack pine with *R. rubescens* resulted in a significantly higher shoot/root dry-weight ratio.

46. Brumelis, G.; Carleton, T.J. 1988. The vegetation of postlogged black spruce lowlands in central Canada. I. Trees and tall shrubs. Canadian Journal of Forest Research. 18(11):1470–1478.

A total of 122 lowland stands in northeastern Ontario, dominated by *Picea mariana* before logging, were surveyed for the abundance of woody species to determine the extent of natural regeneration of *P. mariana*. Detailed information on soils, site characteristics, time since disturbance and the type of logging was included in the survey. Stands were aged 0-56 years since logging, and the carbon to nitrogen (C/N) ratios (used as an index of site nutrient regime) were 16.2-60.6. The average density of trees in logged stands was far less than in unlogged stands on comparable sites (3,050 vs. 42,000-342,000/ha). Among the logged stands, *P. mariana* density was highest in stands more than 20 years old and on sites with a C/N ratio greater than 40, whereas density was lowest in young stands on sites with a low C/N ratio. On sites with a C/N ratio between 25 and 35, *Abies balsamea* was the most important tree species, while broadleaved trees and shrubs dominated sites with a C/N ratio less than 25. In addition, broadleaved species, notably *Populus tremuloides*, *P. balsamifera* and *Betula papyrifera*, achieved greater annual height growth on the sites with a low C/N ratio than did *Picea mariana*. Large-scale mechanical logging began 20 years before the survey. The absence of young stands with a high C/N ratio in the soil indicates that mechanical wheel skidding caused a more drastic site conversion, through disruption of the surface peat, than occurred with the earlier horse skidding practices. Mechanical logging, therefore, places fast- growing species at a competitive advantage over *P. mariana* by creating microsites for broadleaved seedling establishment and promoting a nutrient-enhanced substrate. These results are discussed in relation to the postfire regeneration of *P. mariana* and the growth strategy of the species.

47. Burger, D. 1986. Physiography as an integral part of forest ecosystems. p. 43–48 *in* Y. Hanxi, W. Zhan, J.N.R. Jeffers and P.A. Ward, eds. The temperate forest ecosystem: proceedings of international symposium on Temperate Forest Ecosystem Management and Environmental Protection. 5-11 July 1986, Changbai Mountain Research Station, Antu, China. Institute of Terrestrial Ecology, Cumbria, UK. ITE Symposium no. 20.

Outline of the principles and relevance of a site classification system or model, in which selected physiographic features of soil and climate provide a framework for the vegetation/land relationships. Significant characteristics of this system are

forest succession in relation to physiography, feature continua, normality rather than average as a reference criterion in such continua, and the establishment of classes within continua by concurrent reference to vegetation. The selected features of local climate, soil moisture regime and soil nutrient regime are related to more easily recognizable features of the landscape. The classification comprises 4 inter-related levels, including climatic site or ecoregion based on differing relationships among tree species and position in the landscape, relevant geological material classes in the rooting zone of trees, and site condition comprising the more variable surface soil and ground vegetation.

48. Buschena, C.A.; Doudrick, R.L.; Anderson, N.A. 1992. Persistence of *Laccaria* spp. as ectomycorrhizal symbionts of container-grown black spruce. Canadian Journal of Forest Research. 22(12):1883–1887.

Picea mariana (Mill.) B.S.P. seedlings were grown in containers under three levels of N-P-K fertilization. They were inoculated with one of three levels of mycelial slurry of either an isolate of *Laccaria bicolor* (Maire) Orton or of *Laccaria longipes* G.M. Mueller. Seedlings were grown for 16 weeks in a glasshouse before planting on two different sites (organic and mineral soil) in northern Minnesota. Persistence of the two fungi was monitored over a 2.5-year period. Dikaryotic-monokaryotic pairings indicated that trees on the mineral soil site, inoculated with *L. bicolor*, remained colonized by that isolate for the entire test period. Controls and *L. longipes* treated seedlings on the same mineral soil site became colonized by indigenous isolates of *L. bicolor*. The half-strength fertilizer treatment produced significantly taller seedlings.

49. Buse, L.J. 1992. Critical silvics of bracken fern as related to vegetation management. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Note TN-16. 8 p.

This technical note is designed to assist resource managers in developing site-specific vegetation management strategies. It describes the bracken fern and its habitat, reproduction, growth and development, phenology, response to disturbance, effects on conifers, and uses by wildlife.

50. Buse, L.J. 1992. Effect of cold stratification on the germination and growth of jack pine and black spruce. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Report #67. 35 p.

In an effort to improve the cost effectiveness of forest operations, seeding is gaining favour as a method of regenerating forest lands. Low survival rates, especially for black spruce, and the enormous quantities of seed used in operational seeding have resulted in increased efforts to find practical methods of improving seed use efficiency and post seeding survival. Stratification is used to overcome the internal dormancy exhibited by the seeds of some species. This study evaluates the effect of seed stratification on the germination and growth of jack pine and black spruce in the field; determines if seeding can be extended later into the summer using stratified seed; and determines the effect of shelter vs. bare seeding on stratified seed. The report summarizes second and third year results of stratified seeding trial established north of Thunder Bay in 1989 and 1990. The trial included jack pine and black spruce; the use of shelter seed and bare seed; four stratification treatments in 1989 for 0, 7, 15, and 30 days and three stratification treatments in 1990 for 0, 7, and 15 days in 1990; and sowing dates in May, June, July, and August in 1989 and May, July and August in 1990.

51. Buse, L.J.; Baker, W.D. 1991. Black spruce site quality key for the northwestern region of Ontario. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Note TN-09. 3 p.

A key which allows field estimation of site quality for black spruce was developed for use in the northwestern region of Ontario. This note summarizes the development, limitations and applications of the key.

52. Buse, L.J.; Baker, W.D. 1991. Determining necessity and priority for tending in young spruce plantations in northwestern Ontario. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Note TN-08. 4 p.

Vegetation management directs more of the site's resources into usable forest products rather than just eliminating all competing plants. This note discusses the reasons for vegetation management and describes a systematic approach to using and applying a flow chart with spruce plantations.

53. Campagna, J.P., ed. 1987. Canadian Forest Tree Nursery Weed Control Workshop: proceedings. 20–22 July 1987, Sheraton Le St-Laurent, Longueuil, PQ. Pépinière forestière de Berthier, Berthier, PQ. 109 p.

Proceedings of the workshop, covering testing of oxyfluoren on bareroot and container seedling production, review of herbicide research in forest nurseries in the Prairies, Ontario, Québec and the Maritimes, and possible use of bioherbicides. The report of the general meeting is included, as well as details on the formation of the Canadian Forest Nursery Weed Management Association.

54. Carlisle, A.; Chatarpaul, L. 1984. Intensive forestry: some socioeconomic and environmental concerns. Canadian Forestry Service, Petawawa National Forestry Institute, Chalk River, ON. Information Report PI-X-43. 40 p.

This report outlines recent changes in society's demands upon forests, shifts in public attitudes towards the forest resource, and the increasing interaction and potential conflict between these policies, socio-economic issues, and environmental concerns. The increasing use of intensive forest management and utilization techniques, particularly the use of short rotations and whole tree harvesting, will make increasing demands on the soil. The distribution of nutrients in forests is described in relation to the individual components of nutrient flux. It is unwise to make general, simplistic statements about the effects of any harvesting technique. Such effects are specific to site, species, and element, and are influenced by many interacting factors which can be placed in perspective only by using holistic models. The assessment as to whether or not impacts are acceptable must be considered in the context of management objectives. In the future, environmental impact assessment should be an integral part of forest management plans. Long-term productivity cannot be attained by simply applying fertilizers to the forest soils. An understanding of physical and biological processes is the key to the development of methods for maintaining soil fertility. Forestry schools must place greater emphasis on soil science and research into forest processes to provide basic information needed to assess environmental effects. The report also discusses genetic and socio-economic impacts, and the suggestion is made that socio-economic rather than purely economic analyses be used in assessing forestry programs.

55. Cayford, J.H. 1966. Operational trials of regeneration methods for jack pine in southeastern Manitoba. Canada Dept. of Forestry, Ottawa, ON. Dept. of Forestry Publication No. 1165. 23 p.

In 1960 operational trials were begun in southeastern Manitoba to test clear cutting and clear cutting in strips, pre-logging mechanical seedbed preparation, and slash scattering, seeding and planting as methods for regenerating jack pine (*Pinus banksiana* Lamb.) stands. Thirty-two trials were established between 1960 and 1963 on a variety of sites. Ground preparation in conjunction with logging was unsuccessful in regenerating jack pine. However, supplementary scattering of cone-bearing slash over additional favourable seedbeds to improve upon that done during the logging resulted in an increase in stocking on most sites. Both seeding and planting resulted in successful stocking on all sites on which they were tried. Based on results and observations from this study, and results from other jack pine regeneration studies, silvicultural recommendations are presented for the six sites in the region that commonly support jack pine stands.

56. Cayford, J.H. 1971. The role of fire in the ecology and silviculture of jack pine. p. 221–244 *in* E.V. Komarek, chairman. Tall Timbers Fire Ecology Conference Number 10. 20–21 August 1970, University of New Brunswick, Fredericton, NB. Tall Timbers Research Station, Tallahassee, FL.

Reviews the extensive literature on the subject, including 11 unpublished reports.

57. Chambers, A., ed. 1990. Wildlife Forestry Symposium: a workshop on resource integration for wildlife and forest managers. 7–8 March 1990, Prince George, BC. Forestry Canada / BC Ministry of Forests, Victoria, BC. FRDA Report 160. 182 p.

This conference was conducted to identify factors limiting efforts to integrate the management of forests for both timber and wildlife. Papers presented at the symposium describe initiatives and provide current information on topics covering policy and administrative tactics, the nature of wildlife habitats and their inventory, recent advances in the synthesis and display of information, and a case history of successful integration in the East Kootenays. The workshop identified changes in policies and procedures that would remove factors presently limiting the efforts of field foresters and biologists to integrate the management of forests for timber and wildlife. A synthesis of the results is included.

58. Chatarpaul, L. 1987. Biological and nutritional implications of harvesting biomass: a central Ontario perspective. p. 139–145 *in* Z.Z. Stiasny, ed. Sixth Canadian Bioenergy R&D Seminar: proceedings of the seminar held at Richmond, British Columbia, Canada, 16–18 February 1987. Elsevier Applied Science, London, UK.

The effects of biomass (whole tree) harvest on various soil fertility processes were studied in a central Ontario mixed-wood forest. The biomass harvest yielded 43% more fibre than the conventional (stem only) harvest. However, the biomass harvest increased the export of N, P, K, Ca, and Mg from the site by 147% (214 kg/ha), 117% (22 kg/ha), 111% (98 kg/ha), 98% (294 kg/ha) and 96% (36 kg/ha), respectively. Biomass harvest also had a significant influence on other important processes including carbon and nitrogen cycling, soil microorganisms and invertebrates, nitrogen fixation, denitrification, and nitrification. Patterns of regeneration were also affected.

59. Chatarpaul, L.; Burgess, D.; Hendrickson, O.Q. 1984. A comparison of biomass and nutrients removed in whole tree harvesting and conventional (stem only) harvesting. p. 121–125 *in* S. Hasnain, ed. Fifth Canadian Bioenergy R&D Seminar. 26–28 March 1984, Westin Hotel, Ottawa, ON. Elsevier Applied Science, London, UK.

Nutrient contents (N, P, K, Ca, Mg) for branch, bark, and stem components of a number of major tree species growing at the Petawawa National Forestry Institute were estimated using regression analysis. An assessment of the impact of whole tree harvesting on site nutrient reserves was made by comparing biomass and nutrients in stems with those contained in entire trees.

60. Chatarpaul, L.; Carlisle, A. 1983. Nitrogen fixation: a biotechnological opportunity for canadian forestry. Forestry Chronicle. 59(5):249–259.

Intensive harvesting and forest management systems will increase nitrogen and organic matter losses from forest soils, and there will be a need to manage the soils using both fertilizers and nitrogen-fixing techniques to maintain site productivity. Legumes and non-legumes with nitrogen-fixing symbioses can fix up to 300 kg/ha/yr of nitrogen and provide soil organic matter, but poor soils will need fertilization to maintain the nitrogen-fixing process. There are many species and cultural techniques the forester can use, including green manuring and mixed stands, but carefully designed field trials are needed to solve cultural problems. In addition, there are many opportunities for genetic selection of both trees and shrubs and the bacteria (actinomycetes) involved. Before the systems can be used effectively the operational foresters will need to be better informed about the soil biota and the interaction with site and vegetation. The development

of nitrogen-fixing systems offers a biotechnological opportunity for Canadian foresters to increase tree yield while maintaining site productivity.

61. Chrosciewicz, Z. 1968. Drought conditions for burning raw humus on clear-cut jack pine sites in central Ontario. Forestry Chronicle. 44(5):30–31.

Further experiments on a *Pinus banksiana* mor on a fairly dry site and a *P. banksiana/Picea mariana* mor on a fresh site showed that the depths of residual raw humus after burning varied directly with the depth of the original raw humus before burning and inversely with the drought conditions under which the materials were burned. On this basis, humus-depth-reduction curves were developed to predict the outcome of burning over a range of drought conditions.

62. Chrosciewicz, Z. 1963. The effects of site on jack pine growth in northern Ontario. Canada Dept. of Forestry, Forestry Research Branch, Ottawa, ON. Dept of Forestry Publication No. 1015. 28 p.

Effects of soil moisture regime, soil texture, soil petrography, and regional macroclimate on height growth and diameter growth of dominant jack pine (*Pinus banksiana* Lamb.) trees were studied on various sites in Northern Ontario. Sampling was confined to pure or almost pure, fully stocked jack pine stands growing on deep, uniformly sorted, acid, podsolized, sandy soils. Generally, the height and diameter growth of dominant jack pine trees varied with the individual site factors and their combinations. With a few exceptions, the pattern of this variation was similar in both the height growth and the diameter growth.

63. Chrosciewicz, Z. 1967. Experimental burning for humus disposal on clear-cut jack pine sites in central Ontario. Canada Dept. of Forestry and Rural Development, Forestry Branch, Ottawa, ON. Dept. of Forestry Publication No. 1181. 23 p.

Previous experiments have shown that success in regenerating *Pinus banksiana* on well drained sites after clear felling, either by burning and subsequent sowing or by burning in the presence of seed-trees, depends primarily on the seedbed conditions produced. If a fire burns most of the raw humus, exposes the mineral soil in some places, and leaves only a very thin layer of organic residue, conditions are generally favourable. If, however, the fire destroys only the surface litter, and leaves behind a relatively thick layer of humus, conditions are often as unfavourable as before burning. The present report deals with experiments to ascertain the drought conditions necessary for adequate burning of humus of various types and depths, and to evaluate individual burns in terms of humus disposal in relation to factors involved (drought index, fire danger, humus type and depth, and major fuels present).

64. Chrosciewicz, Z. 1983. Jack pine regeneration following postcut burning and seeding in southeastern Manitoba. Canadian Forestry Service, Northern Forest Research Centre, Edmonton, AB. Information Report NOR-X-252. 10 p.

Pinus banksiana seed was broadcast sown in June 1970 at 1.24 kg/ha on 17 sandy sites, that had been clear-felled and then burned. After two growing seasons regeneration was unsatisfactory and the sites were resown with 0.62 kg/ ha. In mid-summer 1978, after height growth had ceased for the season, an assessment of regeneration found it to have failed on dry and fresh upland sites, but to be more than adequate on a moist lowland site, with 60% stocking on one plot and 76-94% on another four (10,873 to 29,807 seedlings/ha). It is suggested that differences in soil moisture were responsible for the mixed results.

65. Chrosciewicz, Z. 1990. Site conditions for jack pine seeding. Forestry Chronicle. 66(6):579–584.

There is a strong relationship between jack pine (*Pinus banksiana* Lamb.) regeneration and the combined site and seedbed conditions at the time of seeding. Both unfavourable and favourable seedbed characteristics, as well as available

seed sources, are reviewed by groups of sites, and then optional uses of major seedbed and seeding treatments are discussed in terms of practical considerations. Site groups with regeneration potential ranging from high to low are also indicated.

66. Clark, A. 1984. Ground seeding requirements for jack pine regeneration. p. 87–92 *in* C.R. Smith and G. Brown, cochairmen. Jack Pine Symposium. 18–20 October 1983, Timmins, ON. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. COJFRC Symposium Proceedings O-P-12.

The recent increase in direct seeding in the province of Ontario and its importance in the regeneration program are presented. The developmental process of direct seeding in the Kenora District, culminating with the current level of technology, is reviewed. Seedbed requirements are reviewed as a prerequisite for the successful establishment of jack pine (*Pinus banksiana* Lamb.). The relation between equipment performance and seeding success, and the future of direct seeding, are discussed.

67. Clausen, J.C.; Mace, A.C., Jr. 1972. Accumulation and snowmelt on north-south versus east-west oriented clearcut strips. Minnesota Forestry Research Notes No. 34. 4 p.

N.-S. or E.-W. strips 50 feet wide, alternating with uncut strips 16 feet wide, were felled in a *Pinus resinosa* stand, aged 90-100 years, in Minnesota. The N.-S. strips accumulated more snow but snow melted faster than on E.-W. strips in the first year after felling. Snow-melt was faster on strips near the centre of the strip-felled area than on border strips adjoining the intact stand. It is recommended that E.-W. strips of width 1-2 times the tree height should be felled, leaving uncut strips of equal width, in order to delay snow-melt and reduce flood peaks.

68. Cofer, W.R., III; Levine, J.S.; Winstead, E.L.; Stocks, B.J. 1991. New estimates of nitrous oxide emissions from biomass burning. Nature. 349(6311):689–691.

Atmospheric nitrous oxide is important because of its role in stratospheric ozone destruction and because it is a greenhouse gas. Measurements indicate that nitrous oxide is increasing in the atmosphere at a rate of ~0.2%/year. Fossil-fuel combustion and biomass burning have been considered to be significant global sources of nitrous oxide, but the recent discovery of an artefact producing increased levels of nitrous oxide in combustion gas sample collected and stored in grab bottles before chemical analysis has resulted in the downgrading of fossil-fuel combustion and the questioning of biomass burning as important sources of nitrous oxide. As almost all reported analyses of nitrous oxide produced from biomass burning have involved essentially the same collection and analysis protocols as used in fossil-fuel studies, this source of nitrous oxide must also be re-examined. The paper reports and compares measurements of nitrous oxide made over a large prescribed fire using a near real-time *in situ* measurement technique with measurements of nitrous oxide from simultaneously collected grab-bottle samples. The results from 27 small laboratory biomass test fires were used to help clarify the validity of earlier assessments. It is concluded that biomass burning contributes ~7% of atmospheric nitrous oxide, as opposed to earlier estimates of several times this value.

69. Conner, R.N. 1979. Minimum standards and forest wildlife management. Wildlife Society Bulletin. 7:293–296.

I recommend that managers provide habitat as close as possible to the optimum for each important habitat variable for threatened and endangered species. For example, the mean age of loblolly pine with newly completed red-cockaded woodpecker cavities is 80.6 years. Based on this I suggest that in loblolly stands managed for this endangered species, the rotation age be set between 85 and 90 years or higher (depending on the range of trees necessary) to provide the optimum age range of suitable nest trees. By providing optimum quality trees for woodpeckers, or the optimum requirements of special habitat factors for other sensitive species, we may achieve the goal of multiple use without any gradual, negative effect on species we wish to preserve. In managing multiple-use areas for desired species that are not

endangered, threatened, or sensitive, I suggest that we may be able to provide habitat in the range between a species mean and 1 standard deviation below the mean for important habitat factors without serious detrimental effects on the species.

70. Corbett, P.M., compiler. 1989. Aspects of site preparation biology and practice: proceedings of a workshop. 27–28 September 1988, Fort Frances, ON. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Workshop Report No. 2. 101 p.

Proceedings of a workshop/conference on site preparation, covering the program in Ontario, effects on nutrient cycling, cold soils, long-term effects in northern Europe, comparison of Bracke scalp profiles and seeding mechanisms, fourth year results of pneumatic seeder trials, a description of the Gaspardo seeding unit for disc trenchers, site preparation for sawlogs, and research conducted at the Forest Engineering Research Institute of Canada.

71. Corns, I.G.W. 1988. Compaction by forestry equipment and effects on coniferous seedling growth on four soils in the Alberta foothills. Canadian Journal of Forest Research. 18(1):75–84.

Soils developed on 4 parent materials (glaciolacustrine clay, clay loam till, coarse fluvial and loamy eolian) were examined to determine residual effects on soil bulk density of summer logging and mechanical site preparation during the previous 24 years. Compaction was evident on all soils except those of the Summit association which were predominantly Brunisolic Gray Luvisols developed on Tertiary cobbly fluvial deposits. Compaction was greatest on soils of the Marlboro association which were Brunisolic Gray Luvisols developed on clay loam till. Bulk density took up to 21 years to recover to values in undisturbed forest. In laboratory studies, lodgepole pine and white spruce seedlings were grown on the four soils compacted to bulk densities representing field conditions immediately after logging and site preparation, 5-10 years after disturbance and in the undisturbed forest. In most cases, seedling growth decreased with increases in bulk density.

72. Coulombe, R.; Lemay, A.B. 1982. Evaluation of potential interactions between forest biomass production and Canadian wildlife. Le Groupe Dryade, Québec, PQ. ENFOR project P-170. 262 p.

This report presents an overview of existing knowledge of interactions between maximum forest biomass production and wildlife in Canada. The management concept implies the construction of more access roads to remaining untouched forests, the cutting of these mature and overmature stands (including the removal of all forest residues), intensive management of second-growth forests and techniques required to produce maximum volumes on a short-rotation basis (biomass farming). Wildlife has been analyzed considering rare, threatened, endangered, recreational species and animals that are likely damaging trees. All the information contained in this report comes from available literature and unpublished information gathered in each province of Canada.

73. Covington, W.W. 1981. Changes in forest floor organic matter and nutrient content following clear cutting in northern hardwoods. Ecology. 62(1):41–48.

Forest floor samples were taken in 1974 from 14 broadleaved stands in New Hampshire 3-200 years after clear felling. Organic matter declined by 30.7 t/ha, more than 50%, in the first 15 years after felling, and increased in the next 50 years by 28.0 t/ha to approach within 5% of an asymptote of 56 t/ha by 64 years. Woody litter fall was simulated using the program JABOWA, which predicted a maximum rate of increase by 10-20 years, levelling off by 30-50 years. During the first 15 years, the forest floor is a major source of nutrients, releasing a net amount of approximately 800 kg/ha of N. After 15 years it becomes a sink for nutrients as organic matter and nutrients accumulate.

74. Cowles, S. 1982. Preliminary results investigating the effect of lichen ground cover on the growth of black spruce. Naturaliste canadien. 109(3):573–581.

A study was made over 4 years on some 300 trees at a site in Quebec with a lichen mat dominated by *Cladina stellaris*. Treatments included various combinations of lichen removal, application of lichen extract, overlays of white or clear polythene and fertilizer application with N and/or P. Lichen mat edge habitats contained the greatest proportion of established seedlings; bare ground around windthrown trees was also a favoured area. Lichen extracts slightly decreased branch tip elongation in mature trees, but growth was decreased by lichen removal. Fertilizer application was more effective on lichen-covered plots. Branch growth on polythene-covered bare plots was similar to that on lichen-covered plots.

75. Côté, S.; Bélanger, L. 1991. Variations de la régénération préétablie dans les sapinières boréales en fonction de leurs caractéristiques écologiques. Canadian Journal of Forest Research. 21(12):1779–1795.

The renewal of boreal fir stands after harvesting is related to the abundance of fir advanced regeneration. The objective of this study was to compare the advanced regeneration in 45-year-old balsam fir stands of second growth to determine if ecological site conditions could explain some regeneration problems noted in the balsam fir-white birch ecoclimatic domain. Seven ecological phases were studied; these are among the most common in the Laurentians north of Québec. On the basis of fir seedling densities (2 years old and more), three groups could be distinguished using a cluster analysis method for grouping means. Dry balsam fir-herb-and-moss type on well drained tills formed a first group characterized with very high seedling densities (> 60,000 seedlings/ha). A second group, characterized with high seedling densities (25,000 to 40,0000 seedlings/ha), was constituted of three phases with an important moss cover: the mesic balsam fir-moss- and-herb type on moderately well drained tills; the humid balsam fir-moss-and-herb type on imperfectly drained till with seepage; and the humid balsam fir-moss type on imperfectly drained tills. A third group, with low seedling densities (< 15,000 seedlings/ha), included three phases recognized by their important herb cover associated with a less abundant moss cover: the dry balsam fir-herb type on well drained till; the mesic balsam fir-white birch-herb type on moderately well drained till; and the mesic rich balsam fir-herb type on moderately well drained tills with seepage. Low densities of fir advanced regeneration seemed to be related to the abundance of leaf litter on the forest floor that could hinder fir regeneration. Insufficient natural coniferous regeneration can be anticipated in this last group if harvesting follows the 45-year rotation currently used now in Quebec.

76. Crawford, H.S. 1984. Wildlife habitat management and changing forest practices in the northeast. Northern Journal of Applied Forestry. 1(1):12–14.

A discussion, in which it is concluded that in even-aged stands in the northeastern USA, the best opportunities for increasing wildlife habitat values are on the intermediate sites. This may be impractical on the best sites because high timber management costs preclude the loss of wood products to favour wildlife. Wildlife habitat can be enhanced on low-quality sites but inherent site productivity will limit gains. Gains in wildlife habitat value must be quantified to help offset losses in timber values.

77. Cromer, R.N. 1984. Site amelioration for fast-growing plantations. p. 181–195 *in* D.C. Grey, A.P.G. Schonau and C.J. Schutz, eds. Symposium on site and productivity of fast growing plantations. 30 April–11 May 1984, Pretoria and Pietermaritzburg, South Africa. Vol. 1. South African Forest Research Institute, Pretoria, South Africa.

Factors which influence the growth rate of planted seedlings include solar energy, water availability, nutrient supply and soil physical properties. Site preparation and amelioration treatments modify the effect of these factors and thus can alter the rate at which carbon dioxide is assimilated by seedlings. Data from experiments which have examined the effect of these factors on growth and photosynthesis under controlled conditions are reviewed and compared with results from field experiments. Replies to a questionnaire sent to forest managers provided information on current site preparation

methods employed by growers. The type and intensity of ameliorative treatments were related to site conditions but also tended to reflect the availability of research information and the relative costs of labour, equipment and chemicals (fertilizers, herbicides). Research currently underway will provide better basic information about the mechanisms by which these factors influence growth. This information can be used in simple mechanistic models of tree growth following planting to assist forest managers in making sound financial decisions regarding ameliorative treatments.

78. Curlin, J.W. 1968. Nutrient cycling as a factor in site productivity and forest fertilization. p. 313–325 *in* C.T. Youngberg and C.B. Davey, eds. Tree growth and forest soils: proceedings of the 3rd North American Forest Soils Conference. August 1968, North Carolina State University, Raleigh, NC. Oregon State University Press, Corvalis, OR.

Synopsis: Results of several long-term fertilization experiments have shown contrasting patterns in slope, shape, and the period of the growth response function. For this paper, the literature is reviewed selectively with the intent of comparing the behavior and movement of the macro-nutrients N, P, K and Ca from trees through the biotic phase of the nutrient cycle. For simplicity, the nutrient cycle has been discussed only in terms of single tree values and relative transfer rates within the biotic phase.

79. Czapowskyj, M.M.; Rourke, R.V.; Grant, W.J. 1986. Growth and nutrient status of black spruce seedlings as affected by water table depth. USDA Forest Service, Northeastern Forest Experiment Station, Radnor, PA. Research Paper NE-RP-591. 9 p.

A greenhouse experiment was conducted to study the effects of soil water level on growth, biomass accretion, and inorganic element uptake by black spruce. One-year-old containerized seedlings were grown for 3 years at three water table depths. All trees survived for the duration of the study confirming that black spruce has a certain degree of survival tolerance to high water tables. However, tree height, diameter growth, and biomass production significantly increased as the depth to water table increased. The foliar levels of N, P, K, Mg, Fe, Zn, and B increased and those of Cu and Mn decreased with the increasing depth to the water table. For ash and Ca, differences were significant but did not follow a consistent trend. In shoots, the level of N, Ca, and Mg increased and those of ash, K, Fe, Cu, B, Al, and Mn decreased with the increasing depth to the water table. The level of P was not affected by the water table. In roots, the level of N and Ca increased and the level of ash, Mn, Fe, Al, and Cu decreased with increasing depth to the water table. The level of P, Mg, and Zn was significantly different but did not follow any trend. Foliar concentrations of ash, Ca, Na, Mn, Fe, Zn, Cu, Al, and B increased and concentrations of N, P, K, and Mg decreased with increasing foliage age. In shoots, ash, Ca, Al, Fe, and Zn increased and N, P, K, Mg, and B decreased with the increasing tree and shoot age. In roots, Fe, Mn, Na, and Al increased and N, P, and Cu decreased with the increasing tree age.

80. Czarnowski, M.S. 1971. Investigations of the potential productive capacity of forest sites as a function of soil, climate, and ecological properties of tree species. Acta Universitatis Wratislaviensis, Wroclaw No. 134:127–151.

Presents detailed proposals on sample plots, data to be collected, tree species to be observed etc. for the purpose of estimating the potential productivity of biomass by standardized methods under a plan sponsored by the IUFRO Working Group on the Ecological Evaluation of Site Productivity in connection with the International Biological Programme.

81. Damman, A.W.H. 1971. Effect of vegetation changes on the fertility of a Newfoundland forest site. Ecological Monographs. 41(3):253–270.

Describes a study on the nature and extent of changes in fertility under *Kalmia angustifolia* heathland and *Picea mariana* and *Abies balsamea* forests, all of which had originated 65 years previously, after fire in climax *A. balsamea*. The heathland had the greatest accumulation of raw humus and the greatest accumulation of major nutrients therein; the *A. balsamea* forest showed the highest annual return of organic matter and nutrients to the soil. No reliable comparison

could be made between the *P. mariana* and *A. balsamea* ecosystems, but the data do not indicate any obvious changes in fertility other than a greater immobilization of nutrients in the raw humus under *P. mariana*.

82. Damman, A.W.H. 1967. The forest vegetation of western Newfoundland and site degradation associated with vegetation change. Ph.D. thesis. University of Michigan. 382 p.

Studies on site degradation were made on well drained sandy soils, poor in nutrients, on which the *Pleurozium*/ Balsam Fir type forms the climax forest, and on black spruce forest and *Kalmia* heath, which occupy these sites after fire. The stands were compared as regards chemical composition of organic horizons, rate of mineralization of nutrients in litter and humus, available nutrients in mineral soil, and the annual supply of organic and mineral matter to the soil by litter fall, root mortality and the moss carpet; changes in chemical composition of needles with age were also studied. Results suggest that one generation of black spruce is unlikely to degrade sites in Newfoundland.

83. Daubenmire, R. 1976. The use of vegetation in assessing the productivity of forest lands. Botanical Review. 42(2):115–143.
A review of world literature, with emphasis on the basic principles in the use of vegetation types as indicators of forest site productivity in extratropical regions, viz. that: (1) vegetation reflects the sum of the environmental effects important to plants; (2) species with the highest competitive powers are the best indicators; (3) forests consist of superimposed groups of plants ('unions' - usually layers or storeys) which occur in different combinations over the landscape; (4) each 'union' is sensitive to certain special features of the environment; (5) many characters of the vegetation have potential significance as ecological indicators; and (6) types of environment ('habitat types') are the most basic ecological units of landscapes. Examples are given of the practical value of vegetation indicators for predicting tree growth, appropriate silvicultural treatment, susceptibility to insect and fungus attacks, and value for wildlife.

84. Davison, R.W. 1984. Jack pine management in the boreal forest of Ontario: North Central Region. p. 169–172 *in* C.R. Smith and G. Brown, cochairmen. Jack Pine Symposium. 18–20 October 1983, Timmins, ON. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. COJFRC Symposium Proceedings O-P-12.

Current management practices in the boreal jack pine (*Pinus banksiana* Lamb.) forest of the North Central Region [Ontario] are discussed in terms of management planning and silvicultural treatments. The success rates of silvicultural treatments are given and problems within the Region are discussed. Recommendations based on a survey of foresters from each district in the Region are made for regeneration treatments.

85. Dendwick, F.M.; Stevenson, G.R.; Rentz, C.L.; Gorman, J.R., compilers. 1980. Forest research bibliography, 1968–1975, with 1976–1979 supplement (Supplement complied by F.M. Dendwick and R.M. Waldron). Canadian Forestry Service, Northern Forest Research Centre, Edmonton, AB. Information Report NOR-X-152. 83 p.

This bibliography lists forest research literature produced in the prairie and northern regions of Canada from 1968 to 1979. Before 1970 research was carried out at Forest Research Laboratories in Winnipeg and Calgary which administered the Manitoba-Saskatchewan and Alberta-Yukon-Northwest Territories Regions, respectively. These two laboratories merged in 1970 to form the Northern Forest Research Centre, located in Edmonton. Since this bibliography lists literature dating back to 1968, it includes not only Northern Forest Research publications, but also those from the former Manitoba-Saskatchewan and Alberta-Yukon-Northwest Territories Regions in the last two years of their existence.

86. Dickerson, B.P. 1976. Soil compaction after tree-length skidding in northern Mississippi. Soil Science Society of America Journal. 40(6):965–966.

A rubber-tired skidder was used to construct 20 skid trails uphill on slopes of 9-35% in a mature pine-hardwood stand on loamy soils. After standardized skidding of hardwood logs in Feb. 1967, soil samples to 5 cm depth were taken annually until 1972 from (a) wheel ruts and (b) the area compacted by logs (log-disturbed soil) between the wheel ruts. Soil bulk density increased and pore space and percolation rates decreased after skidding: the effects were greater for (a) than (b). Regression analysis suggested that the bulk density of soils from (a) would take approximately 12 years to return to normal, and from (b) approximately 8 years. Even after 5 years the bulk density of soils from (a) would adversely affect pine establishment, and it is suggested that discing may be necessary after tree-length skidding.

87. Donald, D.G.M. 1987. Silviculture and yield. South African Forestry Journal. 141:45–52.

Paper presented at the IUFRO Symposium on Site and Productivity of Fast Growing Plantations, South Africa, May 1984. A brief discussion of factors increasing yields and/or reducing costs (tree breeding, site preparation, fertilizer use, weed control, better silviculture and more enlightened management) and those reducing yields and/or increasing costs (pests and diseases, invasive weeds, many aspects of harvesting, a reduction in the genetic base of plantations and ineffective management). Research to broaden the utilization of forestry land through the introduction of agroforestry concepts is recommended.

88. Dubé, D.E., compiler. 1978. Fire ecology in resource management: workshop proceedings, 6–7 December 1977. Canadian Forestry Service, Northern Forest Research Centre, Edmonton, AB. Information Report NOR-X-210. 111 p.

Twenty-seven papers are included; 21 are noticed here: Anderson, H.A. Annual burning and vegetation in the aspen parkland of east central Alberta; Alexander, M.E. Reconstructing the fire history of Pukaskwa National Park [Ontario]; Scotter, G.W. Fire and caribou in northern Canada; Quintilio, D. Fire behaviour in natural forest stands; Tande, G.F. Management implications of historic fire periodicity in relation to changing climate (based on forest fire history of the Athabasca River valley around Jasper townsite, Alberta); Dube, D.E. Prescribed fire on Henry House Prairie, Jasper National Park [Alberta]; Methven, I.R. Fire research at the Petawawa Forest Experiment Station [Ontario]: the integration of fire behaviour and forest ecology for management purposes; Schweger, C. Use of lake sediments for reconstructing prehistoric fire records; Miller, M. Perspectives for fire management in Alberta provincial parks and wilderness areas; Chrosciewicz, Z. Silvicultural uses of fire in midwestern Canada; Carroll, S. The role of fire in the jack pine-lichen woodlands of the Athabasca Plains Region [Alberta] of Canada; Markham, B.J. Activities of the Alberta Fish and Wildlife Division in the use of fire for habitat management; Richardson, C.J. Brush and regrowth control on pasture on crown lands in Alberta; Vance, D.L. A lightning detection system for rapid detection of lightning-caused fires; Edgecombe, A.H. Spring fuel hazard reduction in northwestern Alberta; Skrenek, J.M. The Cameron-Caribou [Alberta] fire control plan; Kourtz, P.H. An application of LANDSAT digital technology to forest fire fuel type mapping; Muraro, S.J. The use of prescribed fire in the management of lodgepole pine [in British Columbia]; Gray, H. Slash hazard assessments in Alberta; McQueen, J. N.W.T. priority zones for forest fire suppression; Eastman, D. Prescribed burning for wildlife habitat management in British Columbia.

89. Dyck, W.J.; Messina, M.G.; Hunter, I.R. 1986. Predicting the nutritional consequences of forest harvesting on site productivity. A review by the managing agent of IEA/FE Project CPC-10. Sveriges Lantbruksuniversitet, Institutionen for Ekologi och Miljovard. Report No. 26:9–27.

Empirical and computer simulation methods to predict the nutritional consequences of forest harvesting on site productivity are reviewed, and gaps in scientific knowledge that limit the ability to predict these consequences are presented and discussed.

90. Eastman, D.S. 1978. Habitat selection and use in winter by moose in sub-boreal forests of north-central British Columbia, and relationships to forestry. Ph.D. thesis. University of British Columbia, Vancouver, BC. 554 leaves.

A study of winter habitats and their selection by moose was conducted in the sub-boreal spruce biogeoclimatic zone in north-central British Columbia, from May 1971 to August 1973. Wintering moose used partial cutovers and burns more than coniferous forests; deciduous forests and recent clear cuts were used the least. Winter use increased from near zero after removal of the forest, to a peak sometime between 10 and 25 years later, then declined to low levels during 25 and 90 years, and then apparently stabilized in the mature forest stage at slightly higher levels. Moose began concentrating on winter ranges at least by mid- November, reached a peak in November-January, and declined steadily thereafter. Moose had catholic diets but ate primarily deciduous browse for most of the year. Diet varied according to season and habitat. Preferred species typically were least common. Moose moved into winter ranges before snow depths were limiting, but moved into forested habitats in mid-winter when snow depths approached 80 cm. Snow depths and densities varied between habitats. Compared to adjacent open areas, forest stands had higher relative humidity, less wind, more moderate temperatures and approximately 50% of the snow depth. The transition zone from open forest climates appeared to be less than 50 m. The relationship between carrying capacity, habitat selection and home range are discussed.

91. Endean, F.; Johnstone, W.D. 1974. Prescribed fire and regeneration on clearcut spruce fir sites in the foothills of Alberta. Canadian Forestry Service, Northern Forest Research Centre, Edmonton, AB. Information Report NOR-X-126. 33 p.

Reports that the *Picea/Abies* forests of the Alberta foothills are often characterized by deep accumulations of organic matter on the soil surface, and cold soil temperatures, both of which make reforestation difficult and result in a general deterioration in site productivity; and describes experiments to test prescribed burning as a means of seedbed preparation and site amelioration on representative clear-felled *Picea/Abies* areas. Results showed that, in general, prescribed burning did not produce a satisfactory reduction in the organic layers, or a large increase in soil temperature, on the sites tested. Increases in seedling establishment, survival, and growth on the burned sites were probably the result of slight reductions in the depth of the organic layer, minor increases in soil temperature, and marked improvements in the efficiency of the planting crews. Results also suggest that the process of site deterioration has not been reversed by the burning treatments applied.

92. Erskine, A.J. 1977. Birds in boreal Canada. Canadian Wildlife Service, Ottawa, ON. CWS Report Series No. 41. 73 p.

Birds of the boreal regions of Canada were studied over an 8-year period to assemble baseline data on the composition and density of bird communities in various habitat types. These data, with other material from a variety of sources, now permit an overall review of the boreal avifauna, its composition, evolution and prospects for survival. All boreal conifer forests share the same community of birds, with some additions or subtractions, whereas much greater differences are found in comparison with conifer habitats of other, nearby regions to the south, where such communities do not form the vegetational climax. The boreal avifauna of Canada includes species with their centres of abundance within this region, and also elements from adjoining regions, particularly the deciduous and transition forest regions to the southeast. Distribution patterns of closely related species pairs and of subspecies within a species indicate the main faunal breaks within the boreal forest avifauna to be along the lines of the Canadian Rockies and between Lake Superior and Hudson Bay; other important breaks along the British Columbia Coast Range and across south-central British Columbia form the southwestern borders of the boreal region as here understood. Few species are confined to boreal conifer forests, and these mostly are of holarctic families, genera, or species. The rest are either of other habitats, or else tolerant of a variety of forest types, particularly the broad-leafed forests of eastern North America in which many families originated. More than 80% or all bird species breeding in or to the north of the boreal forest region winter further to the south. Of the migrant land birds, roughly half the species winter south of 30° N, in tropical or subtropical regions. The impact of man on boreal birds has been less than in most biomes long settled by man. Extraction of mineral resources has created deserts locally, but as yet nowhere on a scale such as to threaten bird species' existence. Agriculture has also been of minor significance. Trends towards shorter turnover cycles in forestry could threaten mature and particularly old-growth forests, but transportation costs are likely to limit such effects to the more accessible regions. Hydro-electric developments destroy the often fertile riparian communities, though here, too, most of the species involved are widespread and/or

tolerant of a variety of habitats. Toxic chemicals threaten a number of raptorial or fish-eating birds which receive high concentrations of these poisons through extended food chains. As summarized in Nietfeld, M.T., and Telfer, E.S. (1991).

93. Evans, J. 1984. Measurement and prediction of changes in site productivity. p. 441–456 *in* D.C. Grey, A.P.G. Schonau and C.J. Schutz, eds. Symposium on site and productivity of fast growing plantations. 30 April–11 May 1984, Pretoria and Pietermaritzburg, South Africa. Vol. 1. South African Forest Research Institute, Pretoria, South Africa.

Plantation forestry is rapidly expanding. Most crops are still first rotation but their level of productivity is usually assumed for subsequent rotations. Few data exist which compare accurately yield differences between rotations, but where comparison has been made some disturbingly high declines in yield have been reported. Measuring yield changes between rotations is difficult owing to: i) poor yield data for former crop; ii) the necessity to compare rotations on different sites; iii) unrecorded or uncontrollable changes between rotations in silviculture, genetics or environment, notably climate. Ways to reduce these constraints include replication of sites and measurements, use of stem analysis, and careful pairing of stands. There is no substitute for keeping accurate yield data from permanent sample plots re- established on the same site in each rotation. Measuring site change is often arbitrary in choice of parameters whose correlation with tree growth may neither be clear nor causal. A major problem is natural variation in site factors both spatially and temporally. Regular measurements can indicate the gross changes within an ecosystem consequent upon plantation forestry, but replicated experiments specifically to examine the effect of rotation are needed. Predicting productivity change cannot be done accurately. Modelling ecosystem dynamics may improve accuracy of prediction and indicate direction of change, e.g. net nutrient loss, but converting this information into scale of yield change is at present uncertain.

94. Feller, M.C.; Kimmins, J.P.; Scoullar, K.A. 1983. FORCYTE 10: calibration data and simulation of potential long-term effects of intensive forest management on site productivity, economic performance, and energy benefit/cost ratio. p. 179–200 *in* R. Ballard and S.P Gessel, eds. IUFRO symposium on forest site and continuous productivity. 22–28 August 1982, Seattle, WA. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR. General Technical Report PNW-163.

FORCYTE (FORest nutrient Cycling and Yield Trend Evaluator) is a computer simulation model of forest plant biomass production, litterfall, and decomposition, complete with nutrient cycling, nutrient limitation on growth, and a variety of management interventions. The model is a computerized approach to the estimation of the effects of varying thinning and fertilizer regimes, utilization level, and rotation length on site nutrient budgets, stand productivity, and the economic performance and energy efficiency of management. The model has evolved over 5 years to its present version FORCYTE-10, which is briefly described. Accompanying the development of FORCYTE, there has been a series of field research projects. Detailed biomass and biogeochemical descriptions of age sequences of Douglas-fir stands on both good and poor sites have been prepared for purposes of model calibration and testing. The present report summarizes some of the results of the FORCYTE-10 field studies on Vancouver Island, British Columbia, and presents some examples of the use of the model when calibrated with these data.

95. Fernandez, I.J.; Struchtemeyer, R.A. 1985. Chemical characteristics of soils under spruce fir forests in eastern Maine. Canadian Journal of Soil Science. 65(1):61–69.

Soils supporting even-aged spruce-fir stands in eastern Maine are highly acid, soil pH often being a useful indicator of potential tree growth. In this investigation at 22 spruce-fir sites, the relationship between soil chemical properties and site productivity was examined. Each major soil horizon exhibited a distinctly different chemical environment. Spruce-fir site productivity was significantly correlated with B horizon organic-P, O horizon pH, and the total organic matter content of the mineral soil horizons. Soil pH increased with depth in the profile, ranging from a mean value of 3.13 in the O horizon (i.e. F + H) to 4.91 in the C horizon. Significant correlations were exhibited between pH and exchangeable Ca, exchangeable Al, and extractable Al throughout the profile. Fractionation of P in the B horizons demonstrated that occluded-P was the most concentrated of the fractions measured, with the order of relative abundance for the P fractions

being occluded-P > Al-P > organic-P > Fe-P > Ca- P > extractable-P. Sampling of soils for evaluating the potential for forest growth in this region must be carried out by horizons, as these differ markedly in those variables shown to influence tree growth.

96. Field, D.; Gordon, A.G.; Grier, C.C.; Havas, P.; Kitazawa, Y.; Murphy, C.E.; Reed, K.L.; Schutt, T.; Tamm, C.O. 1973. Seasonal model of the coniferous ecosystem. p. 306–312 *in* D.E. Reichle, R.V. O'Neill and J.S. Olson, compilers, L. Kern, ed. Modeling forest ecosystems: report of the International Woodlands Workshop, International Biological Program/Productivity of Terrestrial Ecosystems Section. 14–26 August 1972, Oak Ridge TN. Oak Ridge National Laboratory, Oak Ridge, TN.

This model of typical coniferous ecosystems is defined by biomass compartments and flows. Photosynthetic rate, dependent on stand environment feeds photosynthate pools which are used to provide dry matter for growth of overstorey canopy and ground vegetation. After biomass is accumulated, the flows to other compartments are functions of biomass in donor compartments, stand environment and phenological state. Litterfall varies seasonally according to a given pattern, while decomposition is a function of litter quantity, temperature and moisture stress. The functional model is programmed into an existing differential equation solving package. This model serves to elucidate the seasonal function of coniferous forest ecosystems and may aid directly or indirectly in the understanding of traumatic events such as the removal of nutrients through harvesting.

97. Fleming, R.L.; Crossfield, R.M. 1983. Strip cutting in shallow soil upland black spruce near Nipigon, Ontario. III. Windfall and mortality in the leave strips: preliminary results. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. Information Report O–X–354. 27 p.

A total of 74 leave strips was sampled and results are presented of volume losses in relation to strip characteristics. The most important factors affecting windfall and mortality were leave time (i.e. period until leave strip is felled), strip edge:area ratio, stand density and site index. To minimize losses, large, wide residual strips should be established in relatively dense stands on sites of poor to moderate productivity.

98. Fleming, R.L.; Mossa, D.S.; Burns, T.R. 1987. Scarification trials for direct seeding on upland black spruce sites in northwestern Ontario. Canadian Forestry Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON. Information Report O–X–385. 69 p.

Seven operational or prototype scarifiers were tested on upland sandy tills (with < 40 cm of organic matter over mineral soil) which before clear-felling had supported black spruce (*Picea mariana*) or black spruce/jack pine (*Pinus banksiana*) stands. Relations between site conditions, productivity and seedbed production were investigated for each one. None of the machines consistently met the target requirements in producing black spruce seedbed for subsequent aerial sowing but the best results were obtained with a substantially modified Cazes and Heppner (C&H) plough. Intensive treatment with implements such as disc trenchers, which provide continuous tillage but do not create large windrows, offer potential for improved seedbed distribution. Soils and topographic conditions generally had a greater effect on seedbed exposure than on machine productivity.

99. Ford, E.D. 1971. The potential production of forest crops. p. 172–186 *in* P.F. Wareign and J.P. Cooper, eds. Potential crop production: a case study. Heinemann Educational Books, London, UK.

A theoretical discussion of the features required in a model that would permit an economic evaluation of how a specified production objective might be reached with a particular forest crop. Topics discussed include site (productivity) classification and its limitations, and crop structure, crop nutrition and the interaction between them.

100. Forestry Canada, Ontario Region. 1991. 1990 bibliography. Sault Ste. Marie, ON. Information Report O–X–416. 12 p.

The 1990 bibliography of Great Lakes Forestry Centre Publications lists all publications issued in 1990 as well as any previous publications that did not appear in previous bibliographies. Included as main entries are all journal papers, Information Reports, Joint Reports, Miscellaneous Reports, contributions to symposium proceedings, leaflets, booklets, Survey Bulletins and articles in the Forestry Newsletter. A subject index, based largely on keywords obtained from the titles of the publications, follows the main entries. Information and Miscellaneous reports are listed in a separate appendix.

101. Forestry Canada, Ontario Region. 1992. 1991 bibliography. Sault Ste. Marie, ON. Information Report O–X–424. 14 p.

The 1991 bibliography of Great Lakes Forestry Centre Publications lists all publications issued in 1991 as well as any previous publications that did not appear in previous bibliographies. Included as main entries are all journal papers, Information Reports, Joint Reports, Miscellaneous Reports, contributions to symposium proceedings, leaflets, booklets, Survey Bulletins and articles in the Forestry Newsletter. A subject index, based largely on keywords obtained from the titles of the publications, follows the main entries. Information and Miscellaneous reports, as well as Technical Notes and COFRDA Reports, are listed in a separate appendix and an index based on keywords extracted from the titles of the papers is included.

102. Foster, D.R. 1984. Phytosociological description of the forest vegetation of southeastern Labrador. Canadian Journal of Botany. 62(5):899–906.

A floristic analysis of the forest vegetation of southeastern Labrador was conducted using the phytosociological methods of Braun-Blanquet. A phytosociological table was constructed with the FORTRAN program TWINSPAN, which produces hierarchical classifications by two-way indicator species analysis. 88 relevés incorporating 77 species are grouped into five major assemblages: birch; fir-spruce-feather moss; spruce- fir; spruce-*Pleurozium*; and spruce-*Sphagnum fuscum* communities. The five communities, as arranged from birch to spruce-*Sphagnum fuscum*, display decreasing trends in productivity, site quality and richness of vascular flora, and increasing prominence of oligotrophic species, primarily cryptogams and ericaceous shrubs. Black spruce and balsam fir comprise more than 95% of the forest canopy in this region, whereas paper birch is restricted to moist and well-drained slopes, and white spruce, aspen and balsam poplar are rare. Factors suggested as responsible for the limited productivity and depauperate vascular flora of the forests in this region include semipermanently frozen soil, short growing season, nutrient-deficient mineral substratum and intensive root competition in the poorly aerated soil. The low incidence of fire in this maritime climate is responsible for the old and uneven age structure of the conifer forests and the development of a thick bryophyte cover and deep organic humus that limit stand productivity.

103. Foster, N.W. 1979. The importance of chemical reactions and microbial activity in immobilizing urea nitrogen in jack pine humus. Ph.D. thesis. University of Guelph, Guelph, ON. 128 p.

This thesis is an investigation of the reactions of urea and its hydrolysis products (NH_4^+, NH_3) in humus from a jack pine (*Pinus banksiana* Lamb.) forest. The hypothesis is proposed that chemical reactions, initiated by urea additions to soil, significantly contribute to fertilizer -N immobilization in humus horizons. Chemical transformations of urea and microbial response to urea were studied in incubation studies involving fertilizer labelled with 15N, sterilization and control of soil moisture and temperature, and in a 15N tracer study under jack pine forest conditions. There was sufficient urease to rapidly hydrolyze urea to NH_4^+ in jack pine humus when moisture was not limiting. Conversion of fertilizer NH_4^+ to organic -N significantly reduced N availability in humus. Ninety-six days after 200 kg urea -N (5.32 atom % 15N)/ha was applied to soil in a jack pine forest *in situ*, approximately 50 kg/ha, or 25% of the fertilizer -N applied was immobilized as organic -N in the L and F horizons. High evaporation associated with rapid drying of surface humus of jack pine soils undoubtedly contributed to fertilizer -N losses by NH_3 volatilization. Approximately 35% of a urea addition equivalent to

200 kg N/ha was volatilized from soil incubated but open to the atmosphere for 24 days. As NH3 volatilization occurs only at soil pH above 7, pH values observed after urea addition indicated that N loss could probably be reduced by applying urea at rates lower than 150 kg N/ha. Chemical and microbial immobilization of fertilizer -N could also be reduced by keeping the rate of urea application low.

104. Foster, N.W.; Morrison, I.K. 1987. Alternate strip clearcutting in upland black spruce. IV. Projected nutrient removals associated with harvesting. Forestry Chronicle. 63(6):451–456.

Nutrient removals associated with conventional, full-tree, and whole-tree harvesting on 100-year rotations in an upland boreal black spruce stand in northern Ontario were estimated. Conventional (stems only) logging would remove 219 kg/ha of Ca, 62 of N, 36 of K, 18 of Mg and 9 of P from the site. Increased utilization of phytomass during full-tree harvesting, in comparison with conventional logging, could result in as much as a 400% increase in N removal and a 60% increase in Ca removal. Estimates of projected N and K removals by full-tree harvesting may be conservative, relative to those in other black spruce stands because of the low foliar mass of this forest. The forest floor contained 51% to 72% of the soil's reserves of nutrients, except for P, within the effective rooting zone. Post-harvesting site preparation methods should be restricted to those that
ensure that forest floor nutrient reserves are retained on site.

105. Foster, N.W.; Morrison, I.K. 1976. Distribution and cycling of nutrients in a natural *Pinus banksiana* ecosystem. Ecology. 57(1):110–120.

Data on dry matter and N, P, K, Ca, and Mg contents and movements in soil and ground vegetation in a 30-year-old natural *Pinus banksiana* Lamb. stand in northern Ontario are presented, together with previously published aboveground data. Dry matter and N, P, K, Ca, and Mg contents of trees were 90,700; 165; 14; 82; 112; and 18 kg/ha, respectively - less than in many *Pinus* spp. of comparable age in other parts of the world. A comparison with nutrient contents in younger (20 years) and older (65 years) stands on the same site indicated that most nutrient accumulation in vegetation takes place in the first decades of stand development. Annual nutrient uptake by all vegetation was 32 kg N, 2 kg P, 18 kg K, 21 kg Ca, and 3 kg Mg per hectare. Between 71% and 89% of the elements taken up annually by trees were returned to the soil by litterfall and leaf wash. There was a buildup of forest floor organic matter with stand age and N, P, and Mg accumulated in this material faster than the other elements. Soil reserves of plant-available or mineralizable nutrients were maintained by nutrient replenishment from precipitation and vegetation-soil nutrient cycling. Thus, we conclude that removal of elements from the ecosystem by logging or burning should not result in significant impoverishment of this site.

106. Foster, N.W.; Morrison, I.K. 1989. Effects of site preparation and full tree logging on nutrient cycling. p. 28–46 *in* P.M. Corbett, compiler. 1989. Aspects of site preparation biology and practice: proceedings of a workshop. 27–28 September 1988, Fort Frances, ON. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Workshop Report No. 2.

Theoretical estimates of nutrient removals from jack pine, black spruce, and aspen forests during tree harvesting and site preparation were determined for sites representative of the boreal forest of Ontario. Nutrient removals by conventional (stems-only) and full tree harvesting, for a range of sites, and N displacement based on the most severe site disturbance that might be produced by shear- piling, ploughing and prescribed burning, on two selected sites, were assessed on the basis of published information on site nutrient capitals. Average gains of 20 to 50% in phytomass recovery were achieved by full tree logging, at the expense of > 100% increases in removal of N, P, K, and Mg from jack pine and aspen sites and up to 175% increases in nutrient extraction from black spruce sites. Nitrogen displacement form boreal sites as a result of shear-piling may be as much as 750 to 835 kg N/ha; equal to 10 times that associated with bolewood harvesting of jack pine and 6 times that in the case of black spruce. An additional displacement of 150 to 250 kg N/ha from the rooting zone might result if deep ploughing were done on windrowed sites. Even if actual nutrient displacement is

somewhat less than predicted, the magnitude of the potential removal raises concern about the possibility that shear-pile treatments and deep ploughing could reduce site productivity on many boreal sites.

107. Foster, N.W.; Morrison, I.K. 1982. Nutrient recycling with respect to whole-tree harvesting in natural stands. p. 60–65 *in* D. Robertson, proceedings coordinator. The Sixth International FPRS Industrial Wood Energy Forum '82: proceedings. 8–10 March 1982, Washington, DC. Vol. 1. Kendall/Hunt Publishing, Dubuque, IA.

Increased utilization of biomass during forest harvesting results in greater removal of plant nutrients from the forest site. Nutrient removal associated with conventional (stem-only), full-tree and whole-tree harvesting is compared using a semimature boreal forest as a case study. The effect of different degrees of utilization on potential future forest productivity is examined. Specifically, stand above and below-ground biomass and nitrogen contents were calculated by regression analysis and component nutrient contents from a representative sample of trees. The nitrogen and carbon content of the soil and the cycle of these nutrients from the standing forest are quantified. The response of the stand to different levels of nitrogen fertilizer is also determined. The above is used to show that nitrogen plays a key role in determining the productivity of this forest. Infertile pine sites should be managed with an aim to conserving nitrogen and carbon reserves. The cost of replacing nutrients removed in harvesting must be considered in any forest management strategy.

108. Foster, N.W.; Morrison, I.K. 1983. Soil fertility, fertilization, and growth of Canadian forests. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. Information Report O–X–353. 21 p.

Fertilizer test plots have provided the best evidence for assessing soil nutrient-supplying ability in relation to tree demand. Results from experiments in adult forest across Canada and the adjacent United States support the hypothesis that lack of N generally limits growth of some coniferous species, especially on drier sites. Responses to P and K are reported only occasionally; e.g., red pine (*Pinus resinosa* Ait.) on outwash sands abandoned from agriculture, produced 25 to 80 m^3/ha of extra wood over 5 to 10 years after fertilization with K. With many species additional growth is realized when P and/or K are added with N, but generally response is not significantly greater than with N alone. The addition of urea (224 kg N/ ha) to natural stands produced, on average, an additional 15.6 m^3/ha of wood over 4 years with douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and 8.5 m^3/ha over 5 years with jack pine (*Pinus banksiana* Lamb.). In douglas-fir and jack pine forest, inverse relationships between site index and response to N have been found, the greatest growth increase being on poorer sites. Average 5- year responses were less with balsam fir (*Abies balsamea* (L.) Mill.), red spruce (*Picea rubens* Sarg.), white spruce (*Picea glauca* (Moench) Voss), and black spruce (*Picea mariana* (Mill.) B.S.P.). The use of foliar diagnosis and soil chemical analyses to determine which forests respond to fertilization is discussed.

109. Fraser, J.W., ed. 1975. Black spruce symposium. 23–25 September 1975, Thunder Bay, ON. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. COJFRC Symposium Proceedings O-P-4. 297 p.

Comprises 20 papers (and summaries of discussions on the papers) presented at a symposium sponsored by the Ontario Ministry of Natural Resources and the Great Lakes Forest Research Centre, held at Thunder Bay, Ontario 23-25 Sept. 1975. Papers are: Black spruce - the Cinderella species and the story of Canadian forestry (K.W. Hearnden); Ontario stocking standards for black spruce (F.C. Robinson); Results of 40 years of stocked quadrat surveys in the clay belt (V.I. Sleep); Establishment and early development of black spruce (K.A. Armson); Growth and economic analyses of a forest drainage experiment in northern Ontario (B. Payandeh); Tree planting and stock quality - a view from the forest (R.D. Fry); Standards in the production and planting of black spruce (K.H. Reese); Production of black spruce nursery stock in the boreal forest region (A. Wynia); Effects of seed origin and their utilization through silviculture and tree breeding (E.K. Morgenstern); Black spruce seeding experiments in the central plateau section B.8, Manitouwadge, Ontario (D.A. Winston); Direct seeding black spruce - is it feasible? (J.W. Fraser); Should we manage black spruce? (D.E. Ketcheson); Continuous planting of seedling black spruce (K.M. McClain); Ecosystem management of black spruce on shallow sites in the Lake Nipigon-Beardmore area (G.T. Marek); Modified harvest cutting in the Thunder Bay district (J.M. Auld);

Operational problems of modified cut harvesting (T.H. Peacock); Classification of swamp for forestry purposes (J.K. Jeglum); The role of layerings in black spruce forests on peatlands in the Clay Belt of Northern Ontario (W. Stanek); Peatland black spruce seed production and dispersal in northeastern Ontario (V.F. Haavisto); and Practical aspects of regeneration on Ontario's clay belt peatlands (K. Virgo).

110. Fraser, J.W.; Haavisto, V.F.; Jeglum, J.K.; Dai, T.S.; Smith, D.W. 1976. Black spruce regeneration on strip cuts and clearcuts in the Nipigon and Cochrane areas of Ontario. Canadian Forestry Service, Great Lakes Forest Research Centre. Sault Ste. Marie, ON. Information Report O–X–246. 33 p.

Describes a study begun in 1973 to evaluate the relative merits of clear-felling and strip-felling in promoting the regeneration of *Picea mariana* in the Nipigon and Cochrane areas of Ontario. Regeneration was sampled on 162 plots that had been felled between 1962 and 1972. Data were subjected to analysis of variance and were classified according to provincial stocking standards. In general strip-felled areas were better stocked with *P. mariana* and had a lower % of failures than clear-felled areas. Regeneration was better on peatland than on upland site types. Differences in regeneration on clear- and strip- felled areas of different age classes could not be clearly related to age alone. The experimental status of strip- felling, the need to reconsider provincial stocking standards, and the need for better regeneration surveys by site type are discussed.

111. Freedman, B. 1981. Intensive forest harvest: a review of nutrient budget considerations. Canadian Forestry Service, Maritimes Forest Research Centre, Fredericton, NB. Information Report M-X-121. 78 p.

A review of the literature, with particular reference to harvesting biomass for energy. Relevant data is summarized in 21 tables.

112. Freedman, B.; Duinker, P.N.; Morash, R. 1986. Biomass and nutrients in Nova Scotian forests, and implications of intensive harvesting for future site productivity. Forest Ecology and Management. 15(2):103–127.

Among four conifer and four broadleaved stands, average potential whole-tree (above-ground) harvest removals of biomass, N, P, K, Ca, and Mg were 136,000, 310, 38, 144, 360 and 39 kg/ha, respectively. These represented average increases over bole-only harvesting of 50%, 170%, 200%, 160%, 100%, and 120% respectively. Thus, a moderate increase in potential biomass yield via the whole-tree harvest, was obtained at the expense of much larger increases in removals of major nutrients. On average, the whole-tree contents of biomass and nutrients were smaller than quantities present in the forest floor plus mineral soil. For biomass, the whole-tree averaged 35% of the organic matter of the forest floor plus mineral soil, 6% of total N, 4% of total P, 1% of total K, 29% of total Ca, and 0.5% of total Mg. Only Ca comparisons indicated a short-term impoverishment of site nutrient capital by whole-tree harvesting. It is concluded that one or several whole-tree harvests of these natural stands, if done on rotations > 50 yr would be unlikely to result in important depletions of site nutrient capital.

113. Freedman, B.; Morash, R.; Hanson, A.J. 1981. Biomass and nutrient removals by conventional and whole-tree clear-cutting of a red spruce balsam fir stand in central Nova Scotia. Canadian Journal of Forest Research. 11(2):249–257.

Data are presented for 0.5-ha blocks of an all-aged *Picea rubens/Abies balsamea* stand in central Nova Scotia, Canada. The biomass yield from the conventional clear-cut plot was 105,200 kg dry wt./ha, and the removals of N, P, K, Ca and Mg were 98.2, 16.3, 91.7, 180.9 and 17.0 kg/ha respectively. Biomass removals from the whole-tree clear- cut plot were 152,500 kg dry wt./ha, and the removals of N, P, K, Ca and Mg were 239.1, 35.2, 132.6, 336.5 and 36.9 kg/ha respectively. These removals of N, P, K, Ca and Mg from the whole-tree harvested plot, expressed as percentages of the quantities of these nutrients in the 'total' pool within the exploitable soil horizons, were 5.0, 2.8, 1.0, 5.9 and 2.1%

respectively. However, when these removals were expressed relative to the quantities in the 'available' soil pools, they were much larger, i.e. 500, 34, 184, 306 and 95% for N, P, K, Ca and Mg respectively. From authors' summary.

114. Fuller, R.D.; Driscoll, C.T.; Lawrence, G.D.; Nodvin, S.C. 1987. Processes regulating sulphate flux after whole-tree harvesting. Nature. 325(6106):707–710.

Terrestrial processes that regulate transfer of strong- acid anions (for example SO4-2, NO-3,Cl-) play an important role in determining the acid-base status of surface waters. Anthropogenic perturbations of forested watersheds can alter these processes, resulting in changes of surface-water chemistry. Much controversy has arisen over the relative importance of acidic deposition, natural processes of soil acidification and the effects of changes in land use on the acidification of surface waters. Forest clearcutting represents a useful experimental tool to evaluate the effects of changes in strong-acid loading on biogeochemical processes controlling SO4-2 retention and release. Here we report that after the whole-tree harvesting of an experimental watershed at the Hubbard Brook Experimental Forest in the White Mountains of New Hampshire, USA, increased mineralization and nitrification led to substantial NO-3 loss, acidification of soil solutions and increased soil adsorption of SO4-2. As a consequence, solution concentrations and streamwater efflux of SO4-2 declined. Substantial increases in streamwater concentrations of H+ and potentially toxic inorganic Al+ after removal of biomass also occurred. A similar disruption of the soil N cycle observed in areas of forest decline suggests that decreased vegetation uptake of N may adversely affect surface water quality in acid-sensitive regions.

115. Gagnon, D.; Lafond, A.; Amiot, L.P. 1958. Mineral nutrient content of some forest plant leaves and of the humus layer as related to site quality. Canadian Journal of Botany. 36(2):209–220.

Nutrient content of the humus and foliage of the lesser vegetation of forest sites (herbs, dwarf shrubs and mosses) was investigated on 11 site types and 4 site classes in the N.E. coniferous region of Canada. Nutrient content of the leaf material showed no differences within a given species that could be related to site class, whereas that of the A horizon was closely related to site productivity, indicating that the differential accumulation of nutrients in the cells of these plants depends on the inherent properties of the species rather than on the amount of available nutrients in the humus on which they grow.

116. Gale, M.R. 1987. A forest productivity index model based on soil and root distributional characteristics. Ph.D. thesis. University of Minnesota, Minneapolis, MN. 171 p.

A soil productivity index model, originally developed for agronomic crops, was modified and verified for forested sites. The model is based on the premise that limiting soil and site characteristics affect a species' optimum vertical root distribution and thus its aboveground productivity. Mineral soil characteristics, in addition to topographic and climatic characteristics, are used in the model to calculate a productivity index (PI) for a site. Each soil horizon characteristic is weighted by its importance to a species' optimum proportional root distribution. To define a species optimum vertical root distribution, measurements of root biomass, number, diameter, and length by soil depth were assembled from 19 published papers, yielding a total of 123 vertical root distributions. A non-linear function, $Y = 1 - \beta^d$, where Y is the cumulative root fraction from soil surface to depth d in centimetres, was used as a response variable to test whether significant differences in ß existed among species from different tolerance classes. Early-successional or intolerant species had a significantly greater proportion of roots occurring deeper than did late-successional or tolerant species. Optimum vertical root distribution for use in the PI model was set as the most frequently observed vertical distribution and delineated by a species tolerance class (intolerant, midtolerant, and tolerant). The PI model was verified on datasets for five species (white spruce, red pine, trembling aspen, jack pine, and red maple). Information on below- and aboveground biomass production was provided with the white spruce dataset. Estimates of PI for individual horizons were highly correlated with actual measurements of white spruce vertical root distributions. This index was also significantly correlated with aboveground white spruce biomass and mean annual increment. Estimates of PI, however, were more closely related to below- and aboveground stand biomass in younger as compared to older stands. For the red pine,

trembling aspen, jack pine, and red maple datasets, PI explained significant amounts of variation in site index, volume or biomass, and mean annual increment. Comparable results for the white spruce, red pine, and jack pine datasets were observed when PI and site index were added separately into a Schumacher-type equation predicting volume or biomass and mean annual increment with age.

117. Galloway, R.L. 1984. Jack pine regeneration in the Northern Region. p. 173–176 *in* C.R. Smith and G. Brown, cochairmen. Jack Pine Symposium. 18–20 October 1983, Timmins, ON. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. COJFRC Symposium Proceedings O-P-12.

The economic importance and regeneration of jack pine (*Pinus banksiana* Lamb.) in the Northern Region, as well as site types and the silviculture system are discussed. Summaries of the type, quantity and success rates of silviculture treatments and problems within the Region are given.

118. Gessel, S.P., ed. 1986. Forest site and productivity. Martinus Nijhoff Publishers, Dordrecht, Netherlands. 270 p.

A collection of papers presented at the IUFRO World Congress held in Kyoto, Japan, Sep. 1981 to the special meeting sponsored by IUFRO Site Group S1.02. The papers are in 3 sections: Site and land classification [pp. 3- 99], 8 papers covering topics including land classification in conifer plantations and in Japan, Brazil and Poland, peatland drainage and water conservation; Nutrient cycling and site productivity [pp. 103-159], 6 papers including nutrition in short-rotation and radiata pine plantations, effects of management practices on productivity in South Africa, stem phloem analysis and use of X-ray densitometry to measure growth of *Gmelina arborea*; and Fertilization and site growth response [pp. 163-260], 8 papers including effects of fertilizers in Sweden, Yugoslavia, N. Germany, Finland, Japan and Poland. An index is included.

119. Getter, J.R.; Tom, C.H. 1977. Forest site index mapping and yield model inputs to determine potential site productivity. Resource Inventory Notes. No. BLM 7:1–10.

A prototype computerized system was designed to combine remote sensing data for a range of variables including altitude, vegetation type and density, slope, aspect and insolation. Potential productivity of 2.5-acre plots could be classified broadly as high, medium or low. The method provides an inexpensive means of obtaining information for land management planning.

120. Gimbarzevsky, P. 1964. The significance of landforms in the evaluation of forest land. Pulp and Paper Magazine of Canada. 65(7):WR302–WR317.

Describes the method of interpreting aerial photos used by North Western Pulp & Power Ltd. to evaluate and map > 2 million ha. of forest land in W. Canada. It involves first classifying and mapping the land into 9 broad land forms (alluvial, organic, aeolian, compacted glacial till, glacial till, glacio-fluvial outwash, roughly stratified deposits, lake deposits, and exposed bedrock) from 1:40, 000 photos, and then a detailed classification of these broad units into 5 site-productivity classes from 1:15,840 photos.

121. Goelz, J.C.G. 1984. Upland boreal forest northwest of Thunder Bay, Ontario: ecology and applications to silviculture. M.Sc. thesis. Lakehead University, Thunder Bay, ON. 169 leaves.

Multivariate phytosociological methods were used to investigate the ecology of upland boreal forest stands. The ecological information was used to derive silvicultural recommendations. The boreal forest stands did not form tight associations. Species were distributed individualistically; most species have broad, overlapping, environmental tolerances. Most of the

variability among stands was attributed to the environment and to species precedence on a site. Geomorphology and moisture regime were related to community composition. *Pinus banksiana* dominates sandy glaciofluvial deposits. *Picea mariana* achieves moderate abundance on glaciofluvial deposits which are moister due to finer soils or to topographic position. *Picea mariana* may also dominate shallow moraines. Deeper moraines were dominated by mixedwoods composed of all species common to uplands in the study area. Succession is of minimal importance; other factors override successional trends. While plant communities are related to landforms, the landforms are much more discrete than the plant communities. Therefore, landforms were used to derive silvicultural recommendations. Land types were identified by combining or dividing simple geomorphological features. The seven land types were associated with trends of community composition and of productivity. Silvicultural recommendations were derived for each of these land types. These recommendations were primarily determined by potential hardwood competition and productivity.

122. Goldsmith, F.B. 1980. An evaluation of a forest resource: a case study from Nova Scotia. Journal of Environmental Management. 10(1):83–100.

An extensive tract of forest, occupying over 4 million ha and 84% of the province of Nova Scotia, is examined in terms of past structure and species composition, history of logging and burning and current harvesting practices. It is suggested that the resource base has deteriorated in terms of height, girth, species composition, increase of fire barrens, nutrient depletion, and shortages of merchantable timber. Current proposals for whole-tree harvesting on short rotations are likely to further deplete the already nutrient-deficient soils in some parts of the province. From author's summary. The author's suggestion of site-quality deterioration is criticised in correspondence from L. Strand which is published together with the author's reply in this journal (1980) 11(3):285–287.

123. Gordon, A.G. 1982. The consequences of full-tree logging and biomass harvesting relative to maintaining forest ecosystem stability. *in* Ontario Professional Foresters Association. Papers presented at the 1982 Annual Meeting. 29 January 1982, Sault Ste. Marie, ON.

Describes the nutrient cycle, and factors affecting the availability of nutrients for seedling growth. Boreal upland mixedwood sites have much greater resilience than do black spruce stands. How and what is harvested will have substantial effects on subsequent rotation cycles.

124. Gordon, A.G. 1981. Impacts of harvesting on nutrient cycling in the boreal mixedwood forest. p. 121–140 *in* R.D. Whitney and K.M. McClain, cochairmen. Boreal Mixedwood Symposium. 16–18 September 1980, Thunder Bay, ON. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. COJFRC Symposium Proceedings O-P-9.

Biomass, productivity and nutrient cycling are demonstrated for typical boreal mixedwoods and the consequences of full-tree logging and biomass harvesting are considered. Data for other boreal stands such as black spruce indicate that dry outwash sand plains and organic soils may not sustain full-tree logging. In contrast, the budgets, while liberal, of average boreal mixedwoods indicate that full-tree logging can probably be sustained. This is more likely if slash is left. Phosphorous, however, may still become limiting. The consequences of site preparation methods are discussed.

125. Gordon, A.G. 1983. Nutrient cycling dynamics in differing spruce and mixedwood ecosystems in Ontario and the effects of nutrient removals through harvesting. p. 97–118 *in* R.W. Wein, R.R. Riewe and I.R. Methven, eds. Resources and dynamics of the boreal zone: proceedings of a conference held at Thunder Bay, Ontario, August, 1982. Association of Canadian Universities for Northern Studies, Ottawa, ON.

Nutrient cycling dynamics and productivity of fully-stocked black spruce (*Abies balsamea*) on two principal landtypes, peat and moist outwash sand, are elucidated and compared with those of two boreal mixedwood ecosystems consisting of white spruce (*Picea glauca*), white birch (*Betula papyrifera*) and trembling aspen (*Populus tremuloides*) of moderate and

high productivity. Comparisons are also made with north temperate red spruce ecosystems. Mass budgets indicate that almost half of the total organic pools above- and below-ground are in the standing crops. When these are compared to their respective total organic and mineral soil mass reserves, only that of black spruce on peat is still nearly as great as reserves. Such sites could become vulnerable under full-tree harvesting. The effects of full-tree harvesting on the nutrient pools of these sites are shown. While simple budgets do not predict replacement times, data from nutrient cycles will. Differences in residence times for nitrogen in red and black spruce ecosystems explain the more rapid reappearance of black spruce ecosystems on the outwash sand site after fire. Replacement times also provide estimates of the real tolerances to perturbations such as harvesting. Calculated at steady state input, they are relatively short, 20 years or less for the richer upland mixedwood sites and longer for black and red spruce sites. However on acidic tills, outwash sands and peat, replacement times for potassium can extend from 30 to 45 years. Upland mixedwood sites have greater resilience than black spruce stands on outwash or peat.

126. Gordon, A.G. 1975. Productivity and nutrient cycling by site in spruce forest ecosystems. p. 119–126 *in* T.W.M. Camercon and L.W. Billingsley, eds. Energy flow -its biological dimensions: a summary of the IBP in Canada 1964–1974. Royal Society of Canada, Ottawa, ON.

Canada's contribution to the International Biological Program involved detailed studies of productivity and related processes in several ecosystems. This paper presents initial data for the determination of static pools and seasonal process fluxes for the Canadian IBP forest ecosystem site. Above-ground biomass of the spruce forest was greatest on moist and diminished through fresh, then wet sites and was least on dry sites. Seasonal variation of foliar nutrient concentrations of red, white and black spruce compared across a moisture regime catena of fresh, moist and wet sites, indicated that highest concentrations of nitrogen were maintained by white spruce and lowest by red spruce. Foliar phosphorus concentrations of black spruce on wet sites were a third greater than those for red spruce, which were a third greater than white spruce; and potassium concentrations in red spruce were generally equivalent to, or greater than the other species. Data also indicated the pattern of internal cycling in spruce is far more conservative than that known for Douglas fir.

127. Gordon, A.G. 1979. Productivity and nutrient cycling in natural forests. p. 34–49 *in* Canadian Committee for the Unesco Program on Man and the Biosphere (MAB). Report of the Biomass Strategy Consultation, February 26–28 1979, Ottawa, Canada. Canada/MAB Committee, [Ottawa, ON].

Biomass, productivity and nutrient cycling - bioelement stores and fluxes, are comparatively presented for four red spruce forest ecosystems on a moisture catena of dry, fresh, moist and wet sites, and three black spruce ecosystems on moist sites but with mineral and organic substrates, and differing ages. Biomass and productivity are greatest in the red spruce moist and fresh sites and least on the red spruce dry and wet sites. Black spruce on moist outwash sand (Site Class 1) is intermediate. Structure and functioning of these ecosystems are explained in terms of nutrient cycling, input, uptake, retention and residence times. The effects of crop removal are demonstrated in terms of loss from reserves (nutrient pools) and replacement times. Constraints to full-tree harvesting whether for traditional products or feedstock for energy production from sites on the vast Canadian shield are outlined.

128. Gordon, A.G. 1981. Woodlands data set. p. 576–579 *in* D.E. Reichle, ed. Dynamic properties of forest ecosystems. Cambridge University Press. Cambridge, UK. International Biological Programme 23.

These data sets are part of a matrix of contributions of 116 international forest research sites from around the world associated with designated projects of the International Biological Program. They were collected into the Woodlands Data Set to facilitate comparisons involving a large number of diverse woodland ecosystems and specifically to address productivity. The present contribution represents data for four spruce forest ecosystems representing a soil moisture catena of dry, fresh, moist and wet sites in Ontario Site Region 5E. Principal species are red, black and white spruce, balsam fir, eastern hemlock, red maple and yellow birch. Data includes many variables such as growing season, mean

annual and growing season temperature and precipitation etc., standard stand mensurational data, compartment biomass and increment for all components eg. overstorey leaves, flowers, fruits, branches, bark etc., understorey the same, living and dead roots, standing crop above and below ground, leaf area indices, productivity above and below ground etc. and major fluxes such as litterfall.

129. Gordon, A.M.; Morrow, L.D. 1979. Growth of young plantation black spruce (*Picea mariana* (Mill.) B.S.P.) in the Lake Nipigon - Beardmore area. Ontario Ministry of Natural Resources, Nipigon, ON.

This study is an attempt to document the growth of upland black spruce (*Picea mariana* (Mill.) B.S.P.) plantations in the Lake Nipigon area which may be of interest to forest managers in plantation work in the northern part of Ontario. These plantations are well on their way to providing an acceptable yield of coniferous fibre on shorter rotation - a true black spruce forest.

130. Gordon, A.M.; Simpson, J.A. 1991. Growth of young plantation black spruce (*Picea mariana* (Mill.) B.S.P.) in Nipigon District, Ontario. Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Report #66. 10 p.

While plantation forestry has been practised in Ontario for several decades, it is only recently that data has been collected on the growth and structure of these plantations. Early reports on the growth of black spruce plantations near Beardmore, Ontario in Nipigon District documented a generally lower stem density and considerably increased diameter and height growth. This report provides additional mensurational data collected on ten plots at each black spruce plantation near Limestone Lake and Tyrol Lake.

131. Gordon, A.M.; Van Cleve, K. 1983. Seasonal patterns of nitrogen mineralization following harvesting in the white spruce forests of interior Alaska. p. 119–130 *in* R.W. Wein, R.R. Riewe and I.R. Methven, eds. Resources and dynamics of the boreal zone: proceedings of a conference held at Thunder Bay, Ontario, August, 1982. Association of Canadian Universities for Northern Studies, Ottawa, ON.

The effects of commercial timber harvesting upon nitrogen transformations were evaluated for the forest floor and mineral soils of mature white spruce (*Picea glauca*) forest sites in interior Alaska. Analyses of forest floor incubated *in situ* in mature forest and two recently harvested areas of different ages indicated an ammonium- dominated soil system for the unharvested area. Maximum NH4-N mineralization rates (300 μg N/100g dry soil/day) were found in mid-summer and generally declined with the onset of fall. In the harvested areas, rates of NH4-N accumulation were almost invariably lower than in the uncut area, a consequence of elevated levels of nitrification. Shortly after harvesting, NO3-N concentrations were extremely high. Thereafter, they declined to levels slightly higher than in the mature forest. Nitrification was strongly enhanced by harvesting, and regular patterns within season were evident. For the youngest clearcut, the combined processes of ammonification and nitrification only occasionally supplied more nitrogen to the site on a daily basis than was supplied to the mature forest site. For the oldest clearcut, the supply from the combined mechanisms was variable and depended on the time since clearcutting.

132. Gosz, J.R. 1984. Biological factors influencing nutrient supply in forest soils. p. 119–146 *in* G.D. Bowen and E.K.S. Nambiar, eds. Nutrition of plantation forests. Academic Press, London, UK.

The influence of biological factors on nutrient supply is complex and there are many ways of organizing a discussion of them. I have chosen to categorize the factors by various structural and functional properties on the premise that these would relate more easily to management practices. Pure stands will be discussed primarily; however, they will be contrasted with mixed stands, natural and artificial. Succession also will be addressed to emphasize further the importance of species change on nutrient availability. The organization of material into structural and functional properties

affecting nutrient availability is intended to reveal how different forests and forest conditions affect the biological processes controlling nutrient availability. Understanding these processes is the key to managing them.

133. Goulding, K.W.T.; Stevens, P.A. 1988. Potassium reserves in a forested, acid upland soil and the effect on them of clear-felling versus whole-tree harvesting. Soil Use and Management. 4(2):45–51.

The effect of conventional clear-felling (CF) and whole- tree harvesting (WTH) of Sitka spruce (*Picea sitchensis*) on the local ecosystem and on future productivity were studied. Sub-samples from horizons Ah, E and B+C were analyzed for exchangeable and short- and long-term reserves of K using Ca-resin and strong acid extraction procedures. The flux of K through the soil profile after both CF and WTH resulted in a small increase in exchangeable K throughout the profile after both treatments, but in a loss of short-term reserves from the Ah horizons of both and an overall loss of these after WTH. The nutrient flux down-slope through the Ah horizon could result in differential nutrient deficiency in future. The data suggest that exchangeable and short-term reserves of K will support about two further cycles of conifers, with either CF or WTH, but that long-term reserves are likely to be released quickly enough to meet the needs of such a slow-growing crop; these would support about 30 cycles. Other nutrients, such as Ca or P, may prove to be more limiting than K.

134. Green, D.C.; Grigal, D.F. 1980. Nutrient accumulations in jack pine stands on deep and shallow soils over bedrock. Forest Science. 26(2):325–333.

Nutrient concentrations and distribution were studied in jack pine stands on soils developed in shallow till (less than 30 cm) over 3 different bedrocks (granite, greenstone, and gabbro) and on soils developed in deep till (more than 1 m) in Minnesota. Plant nutrient concentration varied among rock types, with plants on shallow soils over granite having low Ca and Mg and plants on shallow soils over gabbro having low P. Stands were separated into the following components: soil forest floor, ground vegetation, tall shrubs, and overstorey stems and crowns. The distribution of nutrient mass paralleled the biomass of stand components: stands on deep soils had more nutrients in every component, except ground vegetation, than did stands on shallow soils, and had more total nutrient mass; on shallow soils a larger proportion of total ecosystem nutrients was in the vegetation than on deeper soils. Removal of nutrients by timber harvesting may, therefore, have more effect on nutrient status of stands growing on shallow soils than on deep soils. From authors' summary.

135. Greig, L.A.; Euler, D.; McNamee, P.J.; Rose, M.J.; Meisner, J.D.; Wedeles, C.H.R. 1991. An investigation into the effects of timber management on wildlife. A report prepared for Ontario Ministry of Natural Resources by ESSA Environmental and Social Systems Analysts Ltd. Report No. 91-401.4.

This report describes a plan of study into the effects of timber management on wildlife in Ontario. The study plan has been developed through the collaborative effort of technical experts with expertise in forest management/ silviculture, wildlife biology and ecology, community ecology, botany, landscape ecology and land classification. The formal objectives under which the study plan has been developed are to provide the Ministry of Natural Resources with an improved understanding of: i) the effects of timber management on wildlife other than moose and deer; and ii) the effectiveness of timber management guidelines in modifying those effects. Section 2 of the report sets out a number of questions about the potential effects of timber management. Section 3 focuses primarily on work to investigate the effects of timber management on wildlife that arise from effects on habitats, and on wildlife species which may be especially sensitive to disturbance. A major thrust of the proposed research involves developing an integrated-hierarchial system for landscape (habitat) classification.

136. Groot, A. 1987. Silvicultural consequences of forest harvesting on peatlands: site damage and slash conditions. Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON. Information Report O–X–384. 20 p.

The degree of site damage that occurs during forest harvesting on peatlands is influenced by site type and harvesting method. On peatland sites, susceptibility to damage during the frost-free season increased from the *Ledum* (OG 11) to *Alnus* herb-poor (OG 12) to the *Alnus* herb-rich (OG 13) operational groups. Correspondingly, susceptibility to damage increases with alder cover. On transitional peatlands, the conifer-herb/moss-rich group (OG 9) is more susceptible to damage than the feathermoss *sphagnum* group (OG 8). In the *Alnus* herb-poor operational group, harvesting in the summer with narrow-tired skidders is more damaging than harvesting with wide-tired skidders. Winter harvesting produces the least amount of damage, but damage can occur during portions of the winter when frost has not penetrated deeply into the ground and snow cover is not deep. Full-tree harvesting in the summer with wide- tired skidders leaves less deep slash than tree-length harvesting with narrow-tired skidders. Site damage can likely be reduced by careful planning of harvesting operations, operator training, and modification of equipment and harvesting technique. [Designation of Operational Groups was based on the Clay Belt Forest Ecosystem Classification].

137. Groot, A. 1984. Stand and site conditions associated with abundance of black spruce advance growth in the northern clay section of Ontario. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. Information Report O–X–358. 15 p.

Black spruce (*Picea mariana* [Mill.] B.S.P.) advance growth is most abundant in wet, poor site types -- the CHAMAEDAPHNE, LEDUM, FEATHERMOSS-SPHAGNUM, ALNUS-HERB POOR, FEATHERMOSS-COARSE SOIL, FEATHERMOSS-FINE SOIL, AND ALNUS-HERB RICH operational groups of the Forest Ecosystem Classification. Within operation groups and vegetation types there is considerable variation in advance growth stocking. Stand basal area explains a considerable portion of the variation in advance growth stocking, and when combined with other variables in regression models, can be used to describe forest types in which black spruce advance growth is abundant. The annual height growth of advance growth under a canopy is slow, averaging 2.3 cm. Harvesting methods that help to preserve advance growth, and levels of advance growth required in the forest before cutting, is discussed.

138. Haavisto, V.F.; Jeglum, J.K.; Groot, A. 1988. Management practices - black spruce ecosystem. p. 195–202 *in* D.D. Hook, et al., eds. The ecology and management of wetlands. Volume 2: Management, use and value of wetlands. Croom Helm, Beckenham, UK.

In the Canadian Province of Ontario, 40% of productive forest land occurs on peat substrate where *Picea mariana* is the primary species. Distribution, ecology and site types are discussed for *P. mariana*. Its management in order to maintain productivity is reviewed in terms of general perspectives, harvesting, regeneration, site amelioration (drainage) and tending.

139. Hagglund, B. 1981. Evaluation of forest site productivity. [Review article]. Forestry Abstracts. 42(11):515–527.

The aim of this article is to give a review of recent research work on evaluation of forest site productivity. The paper is limited to methods of site evaluation which reflect natural productivity and are intended for use in forestry practice. Thus, for example methods for judging the suitability of fertilizing a certain site are not included. The review does not completely cover all literature in the field of site evaluation. The main emphasis is on literature published later than 1973. The publications cited are examples of trends and ideas, chosen fairly subjectively and without aiming to be comprehensive. Because of translation difficulties, European and American literature is over-represented among the references, while for example Russian and Japanese literature is under-represented.

140. Hakkila, P.; Kalaja, H.; Salakari, M.; Valonen, P. 1977. Whole-tree harvesting in the early thinning of pine. Folia Forestalia. 333. 58 p.

141. Hallet, R.D.; Murray, T.S. 1980. Recent developments and current practices in forestation in Canada. Canadian Forestry Service, Maritimes Forest Research Centre, Fredericton, NB. Information Report M-X-116. 22 p.

Developments and current practices in forestation in Canada are outlined. In 1968 it was projected that 200,000 ha would be forested annually; it is now evident, with the expansion of forestation programs, that this will be surpassed. At the Canadian Forest Regeneration Conference (1977) it was recognized that forest renewal was inadequate and several needs and deficiencies in forestation were highlighted. New policies and programs are being implemented in most Provinces to effectively deal with forest renewal problems. One potential problem relates to the use of herbicides for protection of these forests.

142. Hambly, E.S.L. 1980. Growth of young black and white spruce in Northern Ontario. Ontario Ministry of Natural Resources, Forest Management Sect., Toronto, ON. 53 p.

The Ontario Ministry of Natural Resources let a contract to obtain height growth data for young, "free-to-grow" black spruce (*Picea mariana* (Mill.) B.S.P.) and white spruce (*Picea glauca* (Moench) Voss) regenerated artificially and naturally (strip cut) in northern Ontario. Graphs of total height and current annual height increment over age for all non-suppressed trees from "free-to-grow" plots are presented by soil texture, soil drainage, site region, stock type and season of planting. Visual differences in height growth are evident only when the data are grouped by soil texture (planted black spruce) and site region (planted black and white spruce). Fitted growth curves (total height/age and current annual height growth/age) show that planted black spruce (upland site) grow at a slightly faster rate than planted white spruce (upland sites). Both planted spruces have superior growth to natural black spruce (lowland sites). Current annual height increment for planted spruce levels off at age 15 years to an average 41 cm/year for black spruce and 32 cm/year for white spruce. Natural black spruce exhibits an almost static current annual height increment regardless of age (10-15 cm/year). Comments are made to the effect that the "free-to-grow" status of juvenile spruce stands can be achieved and maintained only with proper site preparation techniques and stand tending programs.

143. Harvey, B.D.; Bergeron, Y. 1989. Site patterns of natural regeneration following clear-cutting in northwestern Quebec. Canadian Journal of Forest Research. 19(11):1458–1469.

Pre- and post-harvest regeneration levels were compared for *Abies balsamea*/*Betula papyrifera*/*Picea* (*P. glauca* and *P. mariana*) forests in an area of the southern clay belt of NW Quebec for the interval 1979-80 to 1986-87. Results revealed abundant advance coniferous regeneration (mean 65,000 stems/ha), almost entirely of *A. balsamea* prior to harvest. The survey following mechanical and manual whole- tree harvesting suggested a 92% reduction in coniferous regeneration and a shift to a mixed or broadleaf (*B. papyrifera*/*Populus tremuloides*/*P. balsamifera*)/'shrub tree' (*Alnus rugosa*/*Acer spicatum*/*Prunus pensylvanica*/ *Salix* spp.)-dominated regeneration. Some 90% of conifer seedlings collected after harvest were pre-established. Destruction of advance regeneration was generally greater on fine-textured soils. Hierarchic cluster analysis of ecological types based on conifer, broadleaf and 'shrub tree' regeneration data, revealed nine groups that could serve as a basis for operational silvicultural decision making. In general: *Salix* spp. and *Alnus rugosa* are the major competitors on poorly drained sites; *Betula* sp., *Acer spicatum* and *Prunus pensylvanica* dominate on thin organic deposits and coarse deposits; and *Populus tremuloides* and *Acer spicatum* dominate on fine-textured deposits. An understanding of physical site factors can therefore provide useful information for harvest and silvicultural planning.

144. Hatcher, R.J. 1960. Development of balsam fir following a clear-cut in Quebec. Dept. of Northern Affairs and National Resources, Forestry Branch, Ottawa, ON. Technical Note No. 87. 21 p.

A study of stand development was begun in 1948 on an area of 5 miles^2, clear felled for fir and spruce pulpwood between 1941 and 1944, in section B.1 of the Boreal Forest Region in Quebec. At the time of felling, 70% of the forest was classified as virgin and uneven-aged, 25% was of fire origin 80 years old, and 5% was of blow-down origin. Most of the firs were between 60 and 90 years but the spruce were older, averaging approximately 100 years and ranging from 50

to 200. The forest contained 1,900-3, 000 cu. ft./acre of spruce and fir, and 20-600 cu: ft. of white birch. The 10-chain grid of semi-permanent 1/10 acre line plots was remeasured in 1958, when a study was also made of the origin and height growth of the fir. The forest recovered well from felling and now comprises fully stocked sapling stands, predominantly fir with much reduced quantities of white birch and white and black spruce. It is unlikely that spruce will again form a proportion of the stand equal to that before felling. Fir reproduced by accumulating regeneration for many years under a crown canopy that prevented normal growth until the parent stand was clear felled; between 78 and 90% was < 2 feet tall at the time of felling. These small seedlings grew well after overcoming heavy competition from raspberry, the growth of individuals being related to their growing space and available light. Study of the origin of the forest suggests that regeneration might be adequate after clear felling 50- to 60-year-old stands. Valuable information would be forthcoming from studies made to determine the state of advance growth in 40- to 60-year-old stands and its development after clear felling. From author's summary.

145. Hatcher, R.J. 1963. A study of black spruce forests in Northern Quebec. Dept. of Forestry, Forestry Research Branch, Ottawa, ON. Dept. of Forestry Publication No. 1018. 37 p.

A study of stand development was begun in 1950 in pure *Picea mariana* and mixed *P. mariana/abies balsamea* stands. The study area of 5 miles^2 contains uneven-aged stands of unknown origin and even-aged stands of fire origin. The plots established in 1950 were remeasured in 1961, when additional age studies were made to determine the origin and age structure of the forest. The data are set out in tables and graphs and discussed at length. A pattern of spruce establishment after fire, characterized by an initial time lag followed by peak years of establishment, was found for the 1896 fire-origin stands; this is the fourth burned area in Quebec to exhibit the same pattern. An uneven aged element recently entered the forest in the form of layers and seedlings filling openings that resulted from either low initial stocking or the death of birch. The results suggest that studies should be undertaken to determine: (1) the development of *P. mariana* layers and their value in forming stands; (2) the duration of *P. mariana* seed viability in cones on fire-killed trees, and (3) the pattern of seedling establishment after fire. From author's summary.

146. Hedin, I.B. 1989. Inverted humus mounds: follow-up field assessments. Forest Engineering Research Institute of Canada, Victoria BC. FERIC Special Report SR-58. 12 p.

As part of the Forest Resource Development Agreement, a series of site-preparation trials was established on 4 sites. One of the treatment options on these sites is the formation of inverted humus mounds, created by the Sinkkila HMF scarifier, the MOF-developed mounder (Ministry mounder), and the Bräcke mounder. Field assessment of the mounds produced consisted of measurements and classification in the fall 1986, remeasurement to document settling over the winter prior to planting in the spring 1987, and classification of soil cores taken adjacent to the planting positions in spring 1988. The report includes the results from the last two phases.

147. Heikurinen, J. 1984. Review of the jack pine regeneration program in the Northeastern Region. p. 177–184 *in* C.R. Smith and G. Brown, cochairmen. Jack Pine Symposium. 18–20 October 1983, Timmins, ON. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. COJFRC Symposium Proceedings O-P-12.

Jack pine (*Pinus banksiana* Lamb.), which is economically the most important boreal species in the Northeastern Region [of Ontario], accounts for 19% of the total annual cut, 77% of which is in the boreal transition forest. Major changes in regeneration systems, begun in 1977, have increased the level of planting from 1.4 million to 2.1 million seedlings annually with substantial improvements in survival rates. Site preparation methods, equipment and standards are described briefly. Past and current problems, with suggested improvements, are discussed.

148. Heikurinen, J.K.; Kershaw, H.M. 1986. Forest soils as a management framework: The application. p. 104–111 *in* G.M. Wickware and W.C. Stevens, cochairmen. Site Classification in Relation to Forest Management. 27–29 August 1985,

Sault Ste. Marie, ON. Canadian Forestry Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON. COJFRC Symposium Proceedings O-P-14.

The application of forest soil inventories in silvicultural planning and decision making is discussed in terms of policy, strategy and implementation. The use of such inventories in combination with site- and species- specific yield tables as a tool for setting forest production targets is demonstrated briefly. A soil-forest inventory overlay process is suggested for formulating management plan prescriptions. The use of site- and soil- related field data needed for implementing a rationalized silvicultural program is advocated, and sample data are discussed.

149. Hellum, A.K.; Zahner, R. 1966. The frond size of bracken fern on forested outwash sand in northern lower Michigan. Proceedings of the Soil Science Society of America. 30(4):520–524.

Reports a study of the value of *Pteridium aquilinum* as a site indicator. The length of the bracken frond and the density of frond stocking are strongly influenced by soil profile development and overstorey cover-type, as measured on 70 sites. Under *Populus grandidentata* and *P. tremuloides* or *Pinus banksiana*, bracken growth increases with increasing soil podzolization. On fully developed podzols, bracken growth is better under *P. grandidentata* and *P. tremuloides* than under *Pinus banksiana*, and both these types provide for better bracken growth than do stands of *Quercus rubra* and *Q. velutina* on open areas. On weakly podzolized soils, bracken growth is poor under all overstoreys, and the frond size is not affected by cover. The soil effect is attributable to enrichment of the B horizon with increased podzolization. The forest cover effect was correlated with time of emergence of bracken and protection of emerging fronds from spring frosts. It is concluded that bracken frond size and stocking can be used as an indicator of potential site productivity for forest land, only on sites already well stocked with Aspen or Pine, and here the trees themselves offer a better indicator.

150. Helvey, J.D.; Tiedemann, A.R.; Anderson, T.D. 1985. Plant nutrient losses by soil erosion and mass movement after wildfire. Journal of Soil and Water Conservation. 40(1):168–173.

Annual sediment yields increased as much as 180 times above pre-fire levels after wildfire destroyed all vegetation on three forested watersheds in the Entiat Experimental Forest in the eastern Cascade Range of Washington. Sediment was transported in debris torrents, in suspension, and as bedload. Suspended sediment concentration correlated well with turbidity. Total N losses by erosion processes increased from a pre-fire average of 0.004 kg/ha/yr to 0.16 kg/ha/yr. Available P losses increased from 0.001 kg/ha/yr before the fire to 0.014 kg/ha/yr. The combined erosion loss of Ca, Mg, K, and Na increased from an average of 1.98 kg/ha/yr before the fire to 54.3 kg/ha/yr. Greatest nutrient losses occurred with mass soil movements (debris torrents). Material deposited in alluvial fans represented losses of 13.5 kg/ha of total N, 3.4 kg/ha available P, and 3,850 kg/ha of Ca, Mg, K, and Na combined. An unmeasured but certainly large quantity of soil and rock entered the river during the debris flows. Nutrient losses on eroded soil, although greater than solution losses, were insignificant to site productivity and stability compared with the physical effects of channel scouring associated with greater runoff, higher peak flows, and debris torrents following fire.

151. Hendrickson, O.Q. 1990. Asymbiotic nitrogen fixation and soil metabolism in three Ontario forests. Soil Biology and Biochemistry. 22(7):967–971.

Field and laboratory incubations were used to assess nitrogenase (acetylene reduction) activity, nitrogen mineralization, and respiration in three mature forests in the northern hardwoods - boreal transition zone of eastern North America. A 66-year-old jack pine (*Pinus banksiana* Lamb.) forest had 45.4 t/ha of forest floor, ca 33% more than older mixedwood and hardwood forests in the same vicinity. Jack pine forest floor was more acid, mineralized only one-third as much N and half as much C during laboratory incubations, had little or no nitrogenase activity on eight sampling dates during the growing season, and contained 40- to 70-fold lower numbers of nitrogen-fixing bacteria. Low nutrient turnover in older jack pine stands may result in buildup of surface organic horizons and declining tree growth. At the moister hardwood site, temperature variations largely accounted for seasonal trends in acetylene reduction; activity at the drier mixedwood

site increased following rainfall events. Although asymbiotic nitrogen fixation in surface soils is a small N input (<1 kg/ha/yr) compared to precipitation in these more productive northern forests, it may stimulate litter decay and N dynamics.

152. Hendrickson, O.Q. 1988. Biomass and nutrients in regenerating woody vegetation following whole-tree and conventional harvest in a northern mixed forest. Canadian Journal of Forest Research. 18(11):1427–1436.

Biomass and nutrient contents of regenerating woody plants and litterfall were measured after a northern mixed conifer-hardwood forest was harvested by conventional and whole-tree methods. Before harvest, the central Ontario study site was occupied by a 95-year-old pine (*Pinus resinosa*, *P. strobus*) and aspen (*Populus tremuloides*, *P. grandidentata*) stand growing on gently rolling, gravel- free outwash sands. Four years after harvest, aspen abundance increased 100-fold in both harvested areas, with higher densities after whole-tree harvest (WTH) (4.1 stems/m^2) than after conventional harvest (CH) (2.7 stems/ m^2). No self-thinning of aspen occurred between 2 and 4 years after harvest. Total aboveground woody biomass accumulated at 2.0 t/ha/yr in the WTH area with 1.5 t/ha/ yr in the CH area; the preharvest rate was 2.0 t/ha/yr. Peak autumn litter production occurred earlier in the harvested areas than in an adjacent uncut area. Cycling of N and K in litterfall returned to preharvest rates after 4 years. Cycling of Ca in litterfall was lower after WTH than after CH. Vegetation uptake of N and K (litterfall plus woody biomass) in the harvested areas in year 4 exceeded the preharvest value. Increased N accumulation in woody biomass (3.0 kg/ha/yr before harvest, 10.6 kg/ha/ yr after WTH) would place a relatively greater demand on forest floor N pools in the WTH than in the CH area owing to lack of N input in logging slash. Although WTH did not reduce initial rates of biomass production, *Populus* spp. had lower concentrations of N, Ca, and Mg in the WTH area than in the CH area. There may be a danger that WTH on less fertile sites in the region will produce dense, unproductive aspen stands with low rates of self-thinning.

153. Hendrickson, O.Q. 1986. Invasion of clear-cuttings by the actinorhizal plant *Comptonia peregrina*. Canadian Journal of Forest Research. 16(4):872–874.

Three years after harvesting a mixed conifer-hardwood forest in Ontario, the density of sweet fern (*Comptonia peregrina* [L.] Coult.) was far greater on a whole-tree harvest site (logging slash removed) than on an adjacent conventional harvest site (logging slash present). These differences were related to the degree of site disturbance, particularly forest floor removal. Nodule fixation rates also appeared to reflect the degree of disturbance, being highest in plants growing along a logging road where the sandy nitrogen-poor mineral soil was exposed, and exceptionally low on the conventional harvest site (0.67 µmol ethylene/per dry weight/ha). Overall, acetylene reduction activity showed a significant negative correlation (r=-0.77, $p<0.001$) with total N.

154. Hendrickson, O.Q.; Burgess, D.M.; Chatarpaul, L. 1987. Biomass and nutrients in Great Lakes–St. Lawrence forest species: implications for whole-tree and conventional harvest. Canadian Journal of Forest Research. 17(3):210-218.

In studies in a mixed conifer/broadleaved stand at Petawawa National Forestry Institute, Ontario, plots were established from which all aboveground parts of woody plants > 1.3 m tall were removed (whole-tree harvest) or on which stems < 9 cm d.b.h. were left standing and crowns were left on site after felling larger trees (conventional harvest). Dry weight of living and dead material, and nutrient contents were determined for *Pinus strobus*, *P. resinosa*, *Picea glauca*, *Abies balsamea*, *Populus tremuloides*, *Betula papyrifera* and *Acer rubrum*. Tables show stand composition and the biomass, and content and concentration of N, P, K, Ca and Mg in wood and bark, separately for stems and large branches and combined for small branches (plus foliage for conifers). Conventional harvest yielded 138,000 kg/ha. Whole-tree harvest yielded an additional 52,000 kg/ha (38%) and increased N removal by 191 kg/ha (132%). There were clear differences between species in nutrient accumulation. Among the dominants, *P. strobus* and *P. resinosa* produced the greatest amounts of biomass per unit of nutrient. Cation concentrations were high in *P. tremuloides*, but its demand for N was moderate. Shade-tolerant understorey species retained relatively large amounts of nutrients in larger diameter portions of stems and branches. Larger diameter materials, however, had lower elemental concentrations, except for Ca. A

conventional harvest often leaves small diameter stems of species (*Abies balsamea* and *Acer rubrum*) that accumulate large amounts of nutrients and that may be poorly adapted to low throughfall cation inputs and high light intensity following canopy removal. Whole-tree harvesting on these nutrient-poor sites may lead to establishment of stands of *Populus* spp. of low productivity.

155. Hendrickson, O.Q.; Chatarpaul, L.; Robinson, J.B. 1985. Effects of two methods of timber harvesting on microbial processes in forest soil. Soil Science Society of America Journal. 49(3):739–746.

Microbial populations and activities in a mature, mixed conifer and hardwood stand were compared with those in similar adjacent stands harvested by conventional (CH) and whole-tree (WTH) methods. Samples of forest soil (sandy, mixed, frigid Typic Haplorthods) were collected monthly during the first season after harvesting. The NH4+-N production, measured over the course of 21-day laboratory incubations, declined in the forest floor of the WTH plot, but increased significantly in mineral soil in both harvested areas. Less than 10% of the NH4+-N produced was nitrified. Nitrifier and denitrifier populations did not increase during the first year following harvesting, and no significant changes in nitrification activity were noted. Forest floor respiration (measured as CO2 evolved in laboratory incubations) was significantly reduced on both harvested plots relative to the intact stand. Litter bag experiments indicated a reduction in nutrients (N, P, K, Mg) available for decomposer organisms on the WTH plot, and a corresponding reduction in litter decay rates. These effects correspond to reductions in forest floor moisture, water-holding capacity, and organic matter content after harvesting. In the 0 to 5-cm mineral soil depth, total bacteria increased on the CH plot but not in the WTH plot. Despite reduced forest floor moisture and nutrient availability, sprouting of trembling aspen (*Populus tremuloides* Michx.) on the whole tree-harvested area was vigorous.

156. Hendrickson, O.Q.; Chatarpaul, L.; Burgess, D. 1989. Nutrient cycling following whole-tree and conventional harvest in northern mixed forest. Canadian Journal of Forest Research. 19(6):725-735.

Soil and water chemistry and soil-respiration activity were studied in a mixed conifer and hardwood forest and in adjacent whole-tree harvest (WTH) and conventional harvest (CH) areas dominated by hardwood sprouts. Compared with the uncut mature forest, forest floor contents of N were lower in the WTH area 3 years after harvest; Ca and Mg were higher in the CH area, probably owing to inputs in logging slash. Mineral soil Ca and pH were higher in the harvested areas than in the uncut area. During the 2nd year after harvest, cation concentrations in forest floor leachate varied in the order WTH > CH > uncut area, but differences largely disappeared the next year. Soil water NO3 concentrations were slightly elevated in the CH area, but only 1.6 kg N/ha/yr leached below the rooting zone. Bulk precipitation K and Mg concentrations were lower in the WTH area than in the CH area owing to the loss of canopy leaching from the residual stand. Slightly higher amounts of cations were found in the snowpack under the mature canopy. Midwinter rains caused movement of NO3 and H within the snowpack. Despite the higher soil-respiration rates in the harvested areas, no differences in soil organic matter pools were observed relative to the uncut area; harvest-related inputs of slash, decaying roots, and stumps may have offset respiratory carbon losses. Current high nutrient demands of rapidly growing sprouts in the WTH area greatly exceed nutrient inputs in bulk precipitation; this may lead to future growth declines.

157. Hendrickson, O.Q.; Robinson, J.B. 1984. Effect of roots and litter on mineralization processes in forest soil. Plant and Soil. 80(3):391–405.

Leaf litter breakdown and fine root production, including exudation, are two major influences upon carbon and nitrogen mineralization rates in forest soil. Sieving and root removal experiments were used to examine their effects. Although carbon mineralization rates declined in smaller particle size fractions of forest litter, this trend largely disappeared when results were calculated on an ash-free basis. Nitrogen mineralization, by contrast, was greatest in smaller fractions. Much of the variation in carbon mineralization rates appeared to be associated with fine roots. A rapid initial exponential decay phase note in laboratory respiration studies was probably associated with the disappearance of available carbon in the form of root exudates and/or microorganisms dependent on them. Clear-cutting caused a marked reduction in the size

of available carbon pools, reflecting decreased root exudation and rhizosphere activity. A model of mineralization is proposed which represents the available and humified carbon pools.

158. Hendrickson, O.Q.; Robinson, J.B.; Rachar, D.B. 1984. Effects of two harvesting methods on biological and chemical properties of forest soil. p. 115–119 *in* S. Hasnain, ed. Fifth Canadian Bioenergy R&D Seminar. 26–28 March 1984, Westin Hotel, Ottawa, ON. Elsevier Applied Science, London, UK.

Monthly sampling was used to compare soil properties on uncut and harvested areas in a mixed conifer-hardwood stand of the southern Canadian Shield. Whole-tree harvesting reduced mineralizable N by nearly 50% compared to either conventional harvest or uncut plots. It also intensified drying of surface horizons, loss of soil water-holding capacity, and mixing of forest floor material with mineral soil. Reduced laboratory respiration rates, and increased pH and ammonium-N, were found in soil from both harvested plots.

159. Hendrickson, O.Q;, Robinson, J.B.; Chatarpaul, L. 1982. The microbiology of forest soils: a literature review. Canadian Forestry Service, Petawawa National Forestry Institute, Chalk River, ON. Information Report PI-X-19. 75 p.

This report discusses the activities of two major groups of forest soil microorganisms, bacteria and fungi. Special attention is paid to their participation in the decay of major forest litter substrates, including leaves, branches, and roots. The influence of bacteria and fungi in symbiotic associations with woody plant roots, upon the cycles of carbon and nitrogen, is described. The impacts of certain forest management alternatives are assessed in terms of the creation or elimination of suitable environments for the activity of soil microorganisms.

160. Hills, S.C.; Morris, D.M. 1992. The function of seed banks in northern forest ecosystems: a literature review. Ontario Ministry of Natural Resources, Ontario Forest Research Institute, Sault Ste. Marie, ON. Forest Research Information Paper No. 107. 25 p.

The phenomenon of seeds remaining dormant within the soil is well known and documented. Detailed information on the role of such "seed banks" in northern Ontario, however, is extremely limited. Research is required to determine the species and abundance of seeds in the soil across a range of forest types, as well as to determine the function of the seed bank in post-disturbance vegetation dynamics. Comparison tables of seed density and diversity are presented for the boreal and deciduous forest types and the research that has been conducted is discussed. This review includes detailed discussions of: (1) seed bank dynamics, (2) physiology of seeds in a seed bank, (3) boreal and deciduous forest seed banks, (4) seed bank dynamics and succession, and (5) recommendations for initiating a seed bank study in northern Ontario. Understanding the seed bank and its related processes will increase our knowledge of post-disturbance vegetation patterns and allow for more accurate predictions of the response of natural vegetation following a disturbance. In addition, an improved decision-making process for the recolonization of sites, vegetation management, and vegetation control will result.

161. Hornbeck, J.W.; Martin, C.W.; Smith, C.T. 1986. Protecting forest streams during whole tree harvesting. Northern Journal of Applied Forestry. 3(3):97–100.

Soil disturbance and changes in stream turbidity, temperature and chemistry are described following whole- tree harvesting operations in Maine, New Hampshire and Connecticut. Changes in stream quality can be expected after whole-tree logging. Suggestions are made for keeping the changes within acceptable limits.

162. Hornbeck, J.W.; Smith, C.T.; Martin, C.W.; Tritton, L.M.; Pierce, R.S. 1990. Effects of intensive harvesting on nutrient capitals of three forest types in New England. Forest Ecology and Management. 30(1–4):55–64.

Effects of whole-tree clear-felling are being studied in three major forest types in the northeastern United States: a spruce-fir forest in central Maine, a northern broadleaf forest in New Hampshire, and a central broadleaf forest in Connecticut. At each site, total and extractable nutrient capitals, inputs and outputs of nutrient ions in precipitation and streamflow, nutrient removals in harvested products, and nutrient accumulation in regrowth were sampled. Depending upon location, combined losses of nutrients in harvested products and increased leaching to streams were in the ranges of 374-558 kg/ha for Ca, 135- 253 kg/ha for K, 50-65 kg/ha for Mg, 248-379 kg/ha for N, and 19-54 kg/ha for P. Opportunities for replacing these losses over the next rotation are best for N. Data on inputs in precipitation versus outputs in streamflow indicate that, once effects of harvest subside, most N in precipitation will stay within the forest. By contrast, Ca shows a net output of 8-15 kg/ha per year from uncut watersheds, and the added leaching losses due to harvest may have a serious effect on Ca capital. This is especially the case for the Connecticut site, where total site capital for Ca is only about 4000 kg/ha.

163. Host, G.E.; Pregitzer, K.S.; Ramm, C.W.; Lusch, D.P.; Cleland, D.T. 1988. Variation in overstory biomass among glacial landforms and ecological land units in northwestern Lower Michigan. Canadian Journal of Forest Research. 18(6):659–668.

Spatial variation in overstorey biomass and mean annual biomass increment (MABI) of upland forests of the Manistee National Forest was studied for landform (scale 1:250,000- 1:1,000,000) and ecological land units (1:10,000-1:80, 000). Ecological land units (ecosystems) were defined by ground flora, soil and physiography. Biomass estimates were based on allometric regression equations developed in the Lake States area. Analyses of covariance were used to study the patterns of total biomass and biomass increment among landforms and among ecosystems; stand age was used as the covariate. Overstorey biomass ranged from 105 t/ha (MABI 1.5 t/ha) on glacial outwash landforms to 208 t/ha (MABI 3.2 t/ha) on morainal landforms. Landform and ecosystem accounted for 37% and 60% of the total variation in biomass, respectively. Overstorey biomass in ecosystems ranged from 85 t/ha (MABI 1.3 t/ha) for oak-dominated (*Quercus alba, Q. velutina*) forests on xeric sandy outwash sediments to 249 t/ha (MABI 3.6 t/ha) for sugar maple/red oak (*Acer saccharum/Q. rubra*) forests on mesic moraines. Variation in biomass was strongly related to variation in species composition and soil moisture availability. A relatively strong association was found between ground flora and productivity. It is concluded that mapping ecological land units gives a relatively high degree of spatial resolution in the quantification of site productivity.

164. Janas, P.S.; Brand, D.G. 1988. Comparative growth and development of planted and natural stands of jack pine. Forestry Chronicle. 64(4):320–328.

This study compares growth, yield and stem quality differences at age 21 between plantations spaced at 2.13 x 2.13 m (2,204 stems/ha) and 4.27 x 4.27 m (548 stems/ha), and a nearby natural jack pine stand of identical age (initial density of 29 800 stems/ha). Merchantable volume/ ha was greatest at the 2.13 m spacing, followed by the less dense plantation and natural stand. Total volume/ha (trees >1.3 m height) was also greatest in the 2.13 m plantation, followed by the natural stand and the 4.27 m plantation. Individual tree mean merchantable volumes decreased with increasing density. Height growth decreased in both the natural stand and the 4.27 m plantation relative to the 2.13 m plantation. Stem quality of the natural stand was markedly better than in both plantations. A comparison of an older natural stand and a plantation in the same area suggests that superiority of tree form of denser natural stands will continue through to rotation. High mortality in the natural stand was largely the result of snow and ice damage which caused patchy and irregular stocking. These results imply that widely spaced plantations of unimproved jack pine will produce large individual tree sizes, but at the expense of quality.

165. Jeglum, J.K. 1987. Alternate strip clearcutting in upland black spruce. II. Factors affecting regeneration in first-cut strips. Forestry Chronicle. 63(6):439–445.

In a two-cut, alternate strip clearcutting system in upland black spruce, the main factors influencing black spruce regeneration in the first-cut strips were strip width, natural seeding period, amount of receptive seedbed and topographic position. In the three study areas, 80 m strips yielded over 60% stocking and over 7,500 seedlings per hectare with a 4-year natural seeding period. Narrower strips 40 m and 20 m wide showed increasing levels of reproduction. Four years of natural seeding gave better natural regeneration than two years. Seedling density and frequency in quadrats were correlated with the amount of receptive seedbed. Regeneration was more abundant on drainageways and lower slopes, and less abundant on upper slope and crest sites. For successful regeneration under similar climatic and physiographic conditions, strip widths should be no more than 80 m, and leave times no less than 3 years. It is essential to scarify the upland mineral soil sites, but scarification of lowland sites is not recommended, especially where there is abundant Sphagnum.

166. Jeglum, J.K. 1981. Black spruce seedling growth and nutrition on Sphagnum and feather moss peats from a northern Ontario peatland. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. Information Report O–X–326. 20 p.

Seeds were sown in controlled greenhouse conditions on moss peat samples collected in the field. Seedling growth was measured 5½ months after germination. Best growth (measured as crown length) was on feather moss (*Pleurozium schreberi*) with poorer results on *S. magellanicum*, *S. angustifolium* and *S. fuscum* (in decreasing order). Crown length was significantly and positively correlated with groundwater pH and Ca concentration of the collection site and with N, P and K content of the peat; it was negatively correlated with loss on ignition and cation exchange capacity of the peat. Crown length was also significantly and positively correlated with foliar N concentration and negatively with foliar Ca and Mg. Silvicultural implications of the results are discussed. From author's summary.

167. Jeglum, J.K. 1983. Changes in tree species composition in naturally regenerating strip clearcuts in shallow-soil upland black spruce. p. 180–193 *in* R.W. Wein, R.R. Riewe and I.R. Methven, eds. Resources and dynamics of the boreal zone: proceedings of a conference held at Thunder Bay, Ontario, August, 1982. Association of Canadian Universities for Northern Studies, Ottawa, ON.

A long-term study of regeneration in alternate strip clearcuts in shallow-soil upland black spruce (*Picea mariana* (Mill.) B.S.P.) near Nipigon, Ontario, has revealed shifts in tree species composition. The original forest was dominated by black spruce and had minor tree size components of jack pine (*Pinus banksiana* Lamb.), balsam fir (*Abies balsamea* (L.) Mill.), trembling aspen (*Populus tremuloides* Michx.) and white birch (*Betula papyrifera* Marsh.). The regenerating first cut strips are a mix of black spruce-white birch-trembling aspen, and the proportion of hardwood to conifer is about 50:50. Scarification increased the level of regeneration in the upland site positions for all species except balsam fir. In lower slopes and peaty drainageways, black spruce regenerated slightly better in nonscarified strips. Regeneration of black spruce increased from 51 to 65% between two and four years of natural seeding. Comparisons of these results with regeneration in clearcuts on the limits of American Can Canada Inc. indicate that strip cutting provides much more regeneration of both conifers and hardwoods. Shallow-soil sites should be classified and managed on the basis of at least two subtypes - fragile nonplantable, and plantable. The manager should make explicit plans as to how he intends to manage hardwoods in cutover upland black spruce forests.

168. Jeglum, J.K. 1974. Relative influence of moisture aeration and nutrients on vegetation and black spruce growth in northern Ontario. Canadian Journal of Forest Research. 4(1):114–126.

Results of a principal-component analysis suggest that in the *Picea mariana* forests of N. Ontario the nutrient regime (a) is more important to variation in vegetation than the moisture/aeration regime (b). Correlations between site index and habitat measures suggest that (b) influences tree growth more than (a). For particular components of variation in vegetation and for segments of the total data, the relative influence of the two gradients varies. On *P. mariana* peatlands, (a) and (b) together explain a large proportion of the variation in minor vegetation and tree growth.

169. Jeglum, J.K. 1980. Strip cutting in shallow soil upland black spruce near Nipigon, Ontario. I. Study establishment and site conditions. Canadian Forestry Service, Great Lakes Forest Research Centre. Information Report O-X-315. 73 p.

A study commenced in 1974 in forests over 100 years old on fragile upland sites. Data on site and soil conditions and preharvest stand composition, structure and condition are given for a regeneration study of strip fellings 20, 40 and 80 m wide by 180 m long.

170. Jeglum, J.K. 1984. Strip cutting in shallow soil upland black spruce near Nipigon, Ontario. IV. Seedling–seedbed relationships. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. Information Report O–X–359. 26 p.

Seedbed materials and the conditions influencing regeneration from natural seeding of black spruce were studied before felling and for 1, 3 or 5 years after strip felling and scarification. An index for receptive seedbeds is developed. The relationships between vegetation changes, soil disturbance, topography of the seedbed and the numbers of seedlings is discussed.

171. Jeglum, J.K.; Kennington, D.J. 1993. Strip clearcutting in black spruce: a guide for the practicing forester. Forestry Canada, Ontario Region, Great Lakes Forestry Centre, Sault Ste. Marie, ON. 102 p.

This manual provides a summary of the current state-of- the-art of strip clearcutting in Ontario. It emphasizes the management of black spruce and covers the range of soils and sites from dry, shallow-soil uplands to lowlands with moist mineral or organic soils. It also suggests some modifications of the system that, although not tested, may warrant operational trials for further fine-tuning. The manual is organized into six main parts to describe the main features of the stripcutting system. Part I provides the background for and status of natural regeneration in Ontario. Part II presents a description of strip clearcutting and small-area clearcutting. Part III outlines the silvics of black spruce, presents the major requirements for achieving successful natural regeneration by seed, and details the site conditions under which strip clearcutting can be applied, mainly for black spruce but also including some other forest types in which the technique has been or can be applied. Part IV, the main body of the manual, provides details on how to stripcut. Part V, on economics, environment and other values, discusses several important considerations that will influence the decision on whether to use strip clearcutting. Part VI summarizes the advantages and disadvantages of strip clearcutting, and is followed by a comprehensive bibliography of selected literature on strip clearcutting.

172. Johnson, C.E.; Johnson, A.H.; Siccama, T.G. 1991. Whole-tree clear-cutting effects on exchangeable cations and soil acidity. Soil Science Society of America Journal. 55(2):502–508.

Short-term (3-year) effects of logging on soil pH, exchangeable cations, and cation-exchange capacity (CEC) were determined. Soils were sampled before and after whole-tree harvesting of a northern hardwood forest at the Hubbard Brook Experimental Forest, New Hampshire, USA. Cation-exchange capacity decreased by 23% in the Oa horizon and 24% in the E horizon but increased by 67% in the Bh horizon and 34% in the Bs1 horizon. Overall, the number of exchange sites in the solum did not change appreciably with harvesting (202 vs. 206 kmolc/ha). In the Oa, E, and Bh horizons, there was a decrease in the ratio of exchangeable base cations (Ca, Mg, and K) to exchangeable Al and H. As a result, base saturation decreased from 49 to 39% in the Oa, from 22 to 17% in the E, and from 14 to 11% in the Bh horizon. Soil pH decreased by 0.11, 0.32, and 0.24 pH units in the Oa, E, and Bh horizons, respectively. The acidification of the E and Bh horizons was probably the result of increased production of H through nitrification and mobilization of Al from the forest floor and mineral soil, while mixing of mineral soil into the forest floor largely explains the changes in the chemistry of the Oa horizon. At Hubbard Brook, accelerated leaching losses of nutrient cations following clear-cutting were not the result of depletion of exchangeable cation pools.

173. Johnson, D.W. 1983. The effects of harvesting intensity on nutrient depletion in forests. p. 157–166 *in* R. Ballard and S.P Gessel, eds. IUFRO symposium on forest site and continuous productivity. 22–28 August 1982, Seattle, WA. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR. General Technical Report PNW-163.

The effect of harvesting on nutrient removal from a given site is relatively easy to evaluate. The amount of nutrient varies with amount of biomass harvested, species, and age. Broad generalization about any of these factors must be viewed with caution, however, because exceptions as well as unknowns may be significant. The importance of nutrient removal during harvesting to nutrient status and productivity of the ecosystem is difficult to assess, because the availability of nutrients to trees will be determined by a number of unpredictable factors, including atmospheric inputs, soil weathering, leaching, and microbial mineralization-immobilization (the latter being especially important for N). Thus, while many investigators have, through a nutrient budget evaluation, forecast problems with supplies of Ca and few researchers forecast problems with supplies of N because of intensive harvesting, the effects of harvesting on the availability of nutrients to the regenerating forest remains unknown and constitutes a significant research need.

174. Johnson, J.D. 1985. Backlog treatment as a means of reducing costs of delivered wood in northern Ontario. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. Miscellaneous Report No. 25. 17 p.

Future average costs of delivered wood were calculated as a function of hauling distance and site productivity (merchantable vol./ha). These estimates were used to quantify the present value of the expected savings or losses on delivered wood that are associated with the treatment of backlog sites (productive sites that were disturbed by natural or artificial processes, were not treated after these disturbances and are not satisfactorily stocked). The marginal value is the expected future cost savings or losses associated with backlog treatment. Sensitivity analysis showed that this approach is very sensitive to the discount rate used and to the investment period.

175. Johnson, J.E.; Smith, D.W.; Stuart, W.B. 1985. Nutrient returns from field-drying of logging residue. Journal of Environmental Quality. 14(3):360–363.

The extent to which additional nutrient removals from the site occur as a result of removing logging residue for fuel was investigated. Nutrient returns from field-dried logging residue from four red maple (*Acer rubrum*) and chestnut oak (*Quercus prinus*) trees felled and skidded into a 2-ha clearcut area were determined. Twig and leaf samples were collected immediately after cutting and after 2, 4, 8, and 16 weeks of field-drying. Declines in both P and K concentrations in the leaves and twigs were noted over the drying period. When nutrient returns were computed on a kg/ha basis the following returns were observed after 16 weeks of drying: N, P, K, Ca, and Mg were 37, 2, 34, 20, and 2 kg/ha, respectively. These amounts are similar to those cycled annually in litter- fall in Appalachian mixed oak stands, which indicates that from a nutrient conservation standpoint, summer logging followed by field-drying may be comparable to winter (leaf-off) logging in these stands.

176. Johnston, W.F. 1971. Management guide for the black spruce type in the Lake States. USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN. Research Paper No. NC-64. 12 p.

Summarizes information on the ecology, silviculture (including broadcast-burning techniques), and yield of stands dominated by *Picea mariana*, with a key to their silvicultural management under various conditions.

177. Jones, R.K.; Pierpoint, G.; Wickware, G.M.; Jeglum, J.K.; Arnup, R.W.; Bowles, J.M. 1983. Field guide to forest ecosystem classification for the clay belt, site region 3e. Ontario Ministry of Natural Resources, Toronto, ON. 123 p.

A looseleaf handbook. The classification is developed in 2 stages. First, a given stand is classified into 1 of 23 vegetation types using key plant indicator species (illustrated). Then, the stand is assigned to 1 of 14 ecosystem types (operational groups) using soil texture, soil moisture regime and thickness of organic cap. The operational groups are described on 14 fact sheets, showing forest and soil in profile with notes on expected vegetation cover composition, forest humus form and soil characteristics. Also given are supplementary keys to soil texture, drainage, pore pattern and moisture regime, degree of decomposition of organic soils, forest humus types and soil horizon descriptions.

178. Kaminski, E. 1988. Forest exploitation and protection of the forest environment. Sylwan. 132(10):1–8.

A review of the effects of timber harvesting covering: removal of biomass and associated nutrients from the forest ecosystem; damage to soils and soil erosion; damage to remaining trees; and pollution by combustion gases from machinery and other substances (chainsaw lubricants etc.). Data are included on nutrient removal (P, K, and Ca) through harvesting on different general forest types (Scots pine [*Pinus sylvestris*] forest, other coniferous forest, and broadleaved forest), and on the load bearing capacity of different soil textural types.

179. Kennedy, A.J.; Penner, D.F.; Green, J.E. 1989. Small rodent populations and conifer seedling damage on a reclaimed area in west central Alberta. Forestry Chronicle. 65(4):271–275.

Small rodent populations and conifer seedling survival were monitored on a reclaimed area in west central Alberta from September 1979 to September 1985. Although several species of crictid rodents and shrews were captured during the live-trapping program, only meadow voles (*Microtus pennsylvanicus*) and deer mice (*Peromyscus maniculates*) occurred in sufficient number to monitor annual changes in abundance. Meadow voles increased rapidly on the reclaimed area from 1979-1981, remained at high numbers until 1984, then declined sharply in 1985. Deer mice increased to moderate numbers from 1979-1981 and declined gradually until 1983. By 1984-1985, very few deer mice were present. Two species of conifer seedlings, lodgepole pine (*Pinus contorta*) and white spruce (*Picea glauca*) were planted on the reclaimed area in 1979 and 1980. Numbers of seedlings killed or damaged by small rodents, primarily by girdling, increased sharply in 1981 and remained at high levels through to 1984. Significant correlations between the percentage of the annual mortality of seedlings attributed to small rodents or the percentage of live seedlings damaged by small rodents, and the abundance of meadow voles the previous winter, indicate that the amount of mortality and damage to seedlings in this reclamation area is in part determined by the overwintering abundance of meadow voles. This is in direct agreement with conclusions from similar studies in other areas of North America and Europe.

180. Khanna, P.H.; Ulrich, B. 1984. Soil characteristics influencing nutrient supply in forest soils. p. 79–117 *in* G.D. Bowen and E.K.S. Nambiar. Nutrition of plantation forests. Academic Press, London.

This chapter deals with the chemical characteristics of forest soils, with emphasis on those under plantations, with the intention of providing a basis for understanding the nutrient-supplying capacity of soils in relation to nutrient demands by plantation trees. Changes in soil chemical characteristics as a consequence of management practices, including the introduction of exotic tree species in plantations, are considered in relation to buffering systems operating in different soils. A theory on the stability of forest ecosystems based on nutrient dynamics is presented. Based on these theoretical considerations, silvicultural practices for a sound management of plantations are discussed.

181. Kiil, A.D.; Chrosciewicz, Z. 1970. Prescribed fire: its place in reforestation. Forestry Chronicle. 46(6):448–451.

Forest fires have played an important role in determining the type and composition of forest ecosystems in the temperate region of North America. The close association between fires and forest ecosystems has helped the resource manager to interpret the significance of fire in reforestation, which in turn has induced him to use burning for this specific purpose.

Until very recently, however, most of the burns in Canada have been carried out primarily for slash-fire-hazard reduction. Considerations in the planning and use of prescribed fire for hazard reduction and reforestation are inextricably linked and sometimes complementary. In addition to protection and reforestation objectives, prescribed burning should find wide application in the management of wildlife habitats and watersheds. Recommendations are made to assist resource managers and the public in appreciating more fully the present and potential role of fire in the forest ecosystems.

182. Kimmins, J.P. 1977. Evaluation of the consequences for future tree productivity of the loss of nutrients in whole-tree harvesting. Forest Ecology and Management. 1(2):169–183.

Data are presented on the range of increase in nutrient removals in harvested materials that would result from a change from conventional to whole-tree harvesting. The effects of such changes are discussed in relation to rotation length, utilization and rate of nutrient replacement.

183. Kimmins, J.P. 1986. Predicting the consequences of intensive forest harvesting on long-term productivity: the need for a hybrid model such as FORCYTE-11. p.31–84 *in* G.I. Agren, ed. Predicting consequences of intensive forest harvesting on long-term productivity: proceedings form the IEA/FE Project CPC-10 workshop. 24–31 May 1986, Jadraas, Sweden. Swedish University of Agricultural Sciences, Uppsala, Sweden.

In this paper, the history of forest yield and production studies is reviewed briefly, and attention is drawn to the critical importance of understanding fine root dynamics if we wish to estimated total net primary production (NPP) rather than yield or above-ground NPP. Methods of predicting future NPP and/or yield, and some important philosophical considerations thereof, are discussed, and an ecosystem simulation model of forest production, FORCYTE-11, is briefly described.

184. Kimmins, J.P.; Binkley, D.; Chatarpaul, L.; de Catanzaro, J. 1985. Whole-tree harvest - nutrient relationships: a bibliography/Exploitation des arbres entiers - rapport des éléments nutritifs: étude bibliographique. Canadian Forestry Service, Petawawa National Forestry Institute, Chalk River, ON. Information Report PI-X-60E/F. 377 p.

A bibliography on nutrient cycling in temperate forests was completed as part of the ENFOR program of the Canadian Forestry Service. This program had the goal of incorporating nutrient cycling aspects into forest utilization plans. The first step in this project was the development of the FORCYTE (FORest Nutrient CYcling Trend Evaluator) simulation model of forest productivity and nutrient cycling. Two major sources (Forestry Abstracts and Biological Abstracts) were used for entries between 1975 and 1981. Older references were obtained from key articles in each area. The entries were organized by four subject categories: nutrient cycling, biomass, nutrient content of biomass, and computer simulation models.

185. Kimmins, J.P.; Scoullar, K. 1981. FORCYTE: a computer simulation approach to evaluating the effect of whole tree harvesting on the nutrient budget in northwest forests. p. 266–273 *in* S.P. Gessel, R.M. Kenady and W.A. Atkinson, eds. Proceedings, Forest Fertilization Conference. 25–27 September 1979, Alderbrook Inn, Union, WA. University of Washington, Seattle, WA.

A brief description is given of FORCYTE, an interactive simulation model designed to examine, on a site-specific basis, the long-term effects on nutrient budgets and productivity of various intensive forest management and harvesting practices. There is an input-data file that provides the necessary site and species information and enables the user to dictate various regeneration, spacing, thinning, fertilization, and harvesting options. The model is a hybrid between a process model and an empirical model. It is being designed for use with inventory-type data that can be obtained in one year of research, from the literature, or both.

186. Kimmins, J.P.; Scoullar, K.A.; Comeau, P.G.; Kurz, W.A.; Apps, M.J.; Chatarpaul, L. 1988. FORCYTE-11: an example of the hybrid simulation approach to predicting the consequences for production, yield, economics, soil fertility, nutrient and organic matter reserves, and energy efficiency of alternate crop production systems. p. 305–314 *in* A.R. Ek, S.R. Shifley and T.E. Burk, eds. Forest growth modelling and prediction: proceedings of the IUFRO conference. 23–27 August 1987, Minneapolis, MN. Vol. 1. USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN. General Technical Report NC-120.

The eleventh version of the FORCYTE series of models is a flexible, ecosystem-level modelling framework capable of simulating most aspects of single or mixed-species even- aged forest or agroforestry crop production systems. FORCYTE-11 simulates both nutrient cycling and nutrient feedback on growth, and within-canopy light intensity profiles and the effects of shading on the production efficiency of foliage. The hybrid approach to yield prediction is explained and discussed as an example of the model's capabilities. Future development of FORCYTE will include an explicit treatment of moisture as a limiting factor, and improvements in the resolution of events that occur in the early years of stand establishment to make the model more useful as a vegetation management research tool.

187. Kinloch, D.; Mayhead, G.J. 1967. Is there a place for ground vegetation assessments in site productivity predictions? p. 246–260 *in* 14th Congress, International Union of Forestry Research Organisations. 1967, Munich. Pt. II, Sect. 21. IUFRO, Munich.

Outlines recent work on site assessment based on soil and physiographic factors and on the relationship between dry weight of ground vegetation, stand parameters, and relative light intensity, and describes work in progress by Mayhead on the value of ground vegetation data in quantitative site assessment and on the merits of principal component analysis (p.c.a.) in this context. An account is given of an assessment, based on species frequency and vigour, of ground vegetation under Sitka Spruce in Gwydyr Forest, N. Wales. Correlation and regression analyses show that Mnium sp. and Oxalis sp. are possible site indicators. Promising trials are reported of p.c.a. using (a) standard R-analysis (a National Elliott 803 computer programme) and (b) Orloci's Q-analysis techniques (using two programmes available at the University College of North Wales, Bangor). Two diagrams of an ordination of the ground vegetation using (b) are given, showing clear trends of increasing site productivity. Less definite patterns were obtained by superimposing soil nutrient extract data on the diagrams, but altitude gave a definite separation of stands above and below 600 ft.

188. Klock, G.O. 1983. The productivity resilience of forest soils. p. 81–86 *in* R. Ballard and S.P Gessel, eds. IUFRO symposium on forest site and continuous productivity. 22–28 August 1982, Seattle, WA. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR. General Technical Report PNW-163.

A concept is presented by which the sensitivity of soils to silvicultural activities can be described. Soils can be classified into one of five productivity resilience zones based on the intrinsic properties of the soil. The value and utility of such a classification in helping forest land managers to recognize soil factors limiting productivity and the sensitivity of soil productivity to major forest management activities is discussed.

189. Klock, G.O. 1982. Some soil erosion effects on forest soil productivity. American Society of Agronomy Special Publication. 45:53–66.

A bioassay technique is suggested and its use demonstrated to evaluate potential erosion effects on forest site productivity. Although the bioassay technique does not provide a soil loss tolerance T-value for productivity, it does show some forest soils may be less sensitive to nutrient loss through erosion.

190. Knight, D.H. 1991. Pine forests: a comparative overview of ecosystem structure and function. p. 121–135 *in* N. Nakagoshi and F.B. Golley, eds. Coniferous forest ecology, from an international perspective. SPB Academic Publishing, The Hague, The Netherlands.

Forest with pines (*Pinus* spp.) as the dominant or co- dominant tree exist throughout the northern hemisphere and are now widely planted south of the equator as well. Occurring over a broad range of climatic conditions, the forest are remarkably similar in structure even though net primary productivity and tree adaptations are quite different. Some species are adapted to water stress and cold temperatures; others are not. Most species, if not all, appear to be tolerant of nutrient deficiencies, and all are affected by periodic fires or insect epidemics. Survival under conditions of limited nutrient availability is facilitated by the evergreen leaves (though with different species having different leaf longevities), an ability to retranslocate nitrogen from senescing leaves back into twigs, and ectomycorrhizae. Plant uptake and microbial immobilization lead to an accumulation of N inputs, which occur primarily through wet and dry deposition rather than microbial fixation. As with other forest ecosystems, a large portion (often >50%) of the photosynthate is allocated to roots, fine roots in particular. Following disturbances, more photosynthesis occurs in the herbaceous understorey vegetation and there is the potential for nitrogen leaching during periods of deep water drainage. However, forest productivity should be sustainable if human-caused disturbances are not continuous, if ecosystem structure (with substantial detrital biomass) can be restored, and if soil erosion is not accelerated.

191. Kojima, S.; Pregitzer, K.S.; Barnes, B.V.; Spies, T.A.; Spooner, V.; Kadeba, O.; Aduayi, E.A. 1983. Determination and expression of forest productivity (Chapter). *in* R. Ballard and S.P Gessel, eds. IUFRO symposium on forest site and continuous productivity. 22–28 August 1982, Seattle, WA. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR. General Technical Report PNW-163.

Some 6 papers were presented including: Kojima, S. Forested plant associations of the lower northern subalpine regions of Alberta and their productivity relationships (pp. 13-30); Pregitzer, K.S., Barnes, B.V., Spies, T.A., Spooner, V. Ecological forest site classification and mapping in the McCormick Experimental Forest, Upper Michigan (pp. 36-45); Kadeba, O., Aduayi, E.A. Biomass production in *Pinus caribaea* L. of different ages in the savanna zone of Nigeria (pp.53-57).

192. Krapfenbauer, A.; Buchleitner, E. 1981. Timber harvest, biomass production and removal of nutrients: nutrient balance of a spruce stand. Centralblatt fur das Gesamte Forstwesen. 98(4):193–223.

A biomass and nutrient inventory was made on 4 different Norway spruce stands aged 63, 52, 45 and 10 yr in Lower Austria. Linear regression equations and an allometric equation were used to calculate the relations between DBH, height, stem volume and volume of parts of the tree, and also to calculate the distribution of N, P, K, Ca and Mg. Using these results and a yield table, a model was established for a stand with site index 10 and a 100 yr rotation. Biomass yield and nutrient removal were calculated for 4 schedules of intermediate fellings and final cuttings: (a) timber without bark, (b) timber with bark, (c) whole-tree harvesting and (d) whole-tree harvesting without needles, with thinnings at 25 and 55 years old. The ratio of total nutrient removal in the 4 schedules was respectively 1:2:6:3, for a relative biomass yield of 1:1.1:1.6:1.4. Measures are discussed to prevent deterioration in site productivity caused by removal of the forest biomass.

193. Kreutzer, K. 1979. Ecological problems of full tree harvesting. Forstwissenschaftliches Centralblatt. 98(6):298–308.

Estimated removal (per rotation and per year) of biomass and N, P, K, Ca and Mg is tabulated for model stands of Norway spruce and Scots pine, each of two site classes, under 4 different harvesting systems, viz. removal of stemwood: without bark; with bark; with bark and 50% of the slash; and with bark and 100% of the slash. The lost nutrients may be replaced by fertilizing, but the loss of humus is less easily remedied and may reduce the future productivity of poor sites.

194. Kropp, B.R.; Langlois, C.G. 1990. Ectomycorrhizae in reforestation. Canadian Journal of Forest Research. 20(4):438–451.

In view of the possible applications of ectomycorrhizae to forestry, this paper discusses the important functions of ectomycorrhizae, the conditions affecting their formation, and methods for the production and application of inoculum. A rationale for selecting the appropriate ectomycorrhizal fungi and considerations in selecting sites where ectomycorrhizal seedlings should be planted are presented. Suggestions are also made on encouraging the use of ectomycorrhizal technology. A cost-benefit analysis of inoculation is done.

195. Kubin, E. 1977. The effect of clear cutting upon the nutrient status of a spruce forest in northern Finland (64 deg 28'N). Acta Forestalia Fennica. No. 155. 40 p.

The distribution of phytomass and major nutrients (N, P, K, Ca, Mg, Fe and Mn) between merchantable stemwood and various components of residue was determined from a 137- year-old *Picea abies* stand felled in winter 1973-74. Harvested stemwood was estimated to account for 46% of the total and 58% of the aerial phytomass. Needles and bark contained the greatest amount of nutrients; 32% of the total N and 26% of the total P was in the needles. About one-fifth of the nutrients in the tree phytomass were removed with the stemwood. Harvesting whole trees (without stumps and roots) would have increased this proportion to 84%.

196. Lafond, A. 1956. Le rendement de quelques types de tremble sur la Côte Nord. [Abstract] Annales de l'ACFAS. 22:54.

A study based on > 450 sample plots and > 800 stem analyses indicated that in 3 forest types examined, differences in the structure and composition of the vegetation corresponded to differences in yield of conifers or Aspen, though total site productivity and site class were the same.

197. Larsen, J.A. 1980. The boreal ecosystem. Academic Press, New York, NY. Physiology Ecology Series. 500 p.

A textbook for students and research scientists, summarizing the available knowledge on quantitative plant ecology in the boreal forests of N. America, but with extensive reference to the boreal regions of Europe and Asia. After a note on nomenclature, there are 11 chapters: 1. Introduction: boreal ecology and ecosystems analysis; 2. History of the boreal vegetation (with sections on the northern and southern boreal borders and forest-tundra communities); 3. Climate of the boreal forest; 4. The boreal soils subsystem; 5. Boreal communities and ecosystems: the broad view (the major part of the book giving overall descriptions of different boreal communities); 6. Relationships of Canadian boreal plant communities (experimental results are given from vegetational continuum analyses of understorey associations in 4 forest types (black spruce; aspen, *Populus tremuloides*; jack pine; and mixed - primarily balsam fir and white spruce)); 7. Boreal communities and ecosystems: local variation; 8. Nutrient cycling and productivity; 9. The trophic pyramid: animal populations; 10. Boreal ecology and the forest economy (resources and management); and 11. Epilogue. There are 8 appendices (Analysis of boreal soils; Broad geographical species relationships; Community composition; Frequency of occurrence of lichens; Species frequently in black spruce communities; Species in boreal forest literature; and Special definitions) and subject and species indexes.

198. Lavigne, M.B.; Donnelly, J.G.; van Nostrand, R.S. 1987. A spacing trial in a precommercially thinned stand of black spruce at North Pond: stemwood production during the first five years after thinning. Canadian Forestry Service, Newfoundland Forestry Centre, St. John's NF. Information Report N-X-262. 16 p.

Stemwood production rates for the 5 years immediately after thinning were compared among plots in a young black spruce (*Picea mariana*) stand in Newfoundland. The plots had 4 spacings: 1.15 (unthinned), 1.8, 2.4 and 3.0 m. Production rates per hectare were inversely related to spacing, but production rates per tree increased with increasing spacing. Fertilization with 200 kg N/ha increased periodic stemwood production rates when done in conjunction with thinning. Rates of stemwood production per hectare were positively correlated with foliar weight per hectare, but rates

of stemwood production per kg of foliage were negatively correlated with canopy foliar weight. Increases in stemwood production per kg of foliage were due in part to a reduction in stem surface area per unit of foliar weight and not solely to the increased availability of light, mineral nutrients and water produced by thinning. The rate at which stem surface area per unit foliar weight increased was reduced by thinning and by fertilization. The effect of thinning is likely to be the most enduring and will have the greatest effect on final yields.

199. Leaf, A.L., chairman. 1979. Impact of intensive harvesting on forest nutrient cycling. 13–16 August 1979, State University of New York, Syracuse, NY. State University of New York, College of Environmental Science and Forestry, Syracuse, NY. 421 p.

The Symposium, "Impact of Intensive Harvesting on Forest Nutrient Cycling", held August 13-16, 1979 at Syracuse, New York, is the result of mutual interests expressed by the State University of New York College of Environmental Science and Forestry (SUNY ESF), the USDA Forest Service, Northeast Forest Experiment Station, and the USDOE, Fuels from Biomass Systems Branch. The concern with accelerated nutrient and organic removals is of great practical significance for the continued productivity of forested lands. Soil nutrient losses through intensive harvesting must be balanced by inputs if the soil resource is to remain unchanged, thus inputs from the atmosphere, biological activity, and mineral weathering must balance potential losses by leaching and erosion, as well as intensive harvesting. The impact of intensive harvesting, e.g., whole tree harvesting, on the soil nutrient status is a broad subject involving aspects of forestry, biology, soil science, etc. Much of the current literature shows a decided lack of multidisciplinary efforts. For instance, some biologists have worked within their own areas and have not understood problems associated with timber harvesting. Also, many foresters charged with managing lands for total tree harvest have not sufficiently understood aspects of tree growth and development, soil fertility, etc.

200. LeBlanc, P.A.; Towill, W.D. 1989. Can jack pine site productivity in north central Ontario be predicted using multiple regression soil-site equations? Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Report #33. 14 p.

Examination of the application of Schmidt and Carmean's (1988) multiple regression equations describing jack pine soil-site relationships for the Thunder Bay District and the B.8 Central Plateau and B.11 English River forest sections. Soils and jack pine site index data from 84 forest ecosystem classification plots located on various site conditions across the B.8 and B.11 forest sections were used to test the hypothesis that these soil-site relationships could be applied across north central Ontario.

201. LeBlanc, P.A.; Towill, W.D. 1989. Can we use the northern prime land classification to identify the productivity of jack pine site in north central Ontario? Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Report #34. 21 p.

In 1985, the Northern Region developed a classification and key for assigning various soil-site conditions to relative site productivity classes. This key was developed using selected soil site variables considered to be critical in influencing individual tree and stand growth. This investigation tested the accuracy of the Northern region prime land key in predicting jack pine site productivity in north central Ontario. An extensive data base consisting of 84 plots established by the forest ecosystem classification, and 99 plots from Schmidt's soil-site study for jack pine in the north central region was used. Site productivity was described using site index (height of dominant trees at breast height age of 50 years).

202. Lederle, K.A.; Mroz, G.D. 1991. Nutrient status of bracken (*Pteridium aquilinum*) following whole-tree harvesting in Upper Michigan. Forest Ecology and Management. 40(1/2):119–130.

Mineral nutrient status and biomass production of bracken, *Pteridium aquilinum* (L.) Kuhn., fronds and rhizomes were quantified immediately following a whole-tree harvest in Upper Michigan. Multiple sampling occurred between full leaf

expansion and senescence to monitor mineral translocation from the fronds to the rhizomes, as well as differences in bracken mineral content between harvested and unharvested control sites. Bracken rhizomes on the harvested site had significantly higher concentrations of phosphorus, potassium and magnesium than the control site. Frond biomass production was lower on the harvested site, while rhizome biomass production showed no differences between sites. Rhizome P contents were significantly higher on the harvested site. Translocation of mineral elements from the fronds to the rhizomes during senescence was monitored. Nitrogen, P, and K were readily translocated, while Mg and calcium were not. The larger amounts of nutrients present in the rhizomes on the harvested site suggest increased nutrient uptake, and therefore, nutrient conservation by bracken may occur on a harvested site.

203. Leroy, D.A. 1991. Northern Forestry Centre publications, 1987–90. Forestry Canada, Northern Forestry Centre, Edmonton, AB. Information Report NOR-X-321. 30 p.

Scientific, technical, and interpretive publications written by staff of the Northern Forestry Centre during 1987-90 are listed alphabetically by author. A subject index is provided for the main entries. In addition, there is an appendix listing reports prepared under the federal- provincial forestry development agreements for Alberta, Saskatchewan, and Manitoba.

204. Likens, G.E.; Bormann, F.H.; Johnson, N.M.; Fisher, D.W.; Pierce, R.S. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed ecosystem. Ecological Monographs. 40(1):23–47.

The annual stream-flow from a catchment in this northern hardwood forest experimentally clear-felled in 1965 and kept free of regrowth for two years by periodic application of herbicides was 39% and 28% greater in the first and second years respectively than would have been expected if the forest had not been felled. Large increases in concentration in the water of all major ions except NH4 SO4 and HCO3, were observed approximately 5 months after felling. The concentration of nitrate (41 and 56 times greater, during the first and second years respectively, than in stream water in undisturbed forest) has exceeded almost continuously the maximum concentration recommended for drinking water. Sulphate was the only major ion in stream water that decreased in concentration after the forest was felled; an inverse relationship between sulphate and nitrate concentrations in the water was observed in both undisturbed and felled forest. The greatly increased export of dissolved nutrients from the felled area was attributable to an alteration of the N cycle within the ecosystem. The stream from the felled catchment increased in acidity (from pH 5.1 to 4.3), became warmer in both summer and winter, fluctuated markedly (by 3-4° C) in daytime temperature in summer, increased approximately 6 times in electrical conductivity, and supported a dense growth of algae. Its output of particulate matter rose by approximately 4 times, although there was little increase in turbidity. The increase in recent years in the mean concentration of nitrate in the precipitation failing on the catchment may to some extent reflect a general increase in air pollution.

205. Linteau, A. 1955. Forest site classification of the northeastern coniferous section, boreal forest region, Quebec. Dept. of Northern Affairs and National Resources, Forestry Branch, Ottawa, ON. Bulletin No. 118. 85 p.

Forest site types were found to fall into 6 broad groups: herb and fern, herb and moss, moss, moss and dwarf shrub, peat moss and dwarf shrub, and lichen and dwarf shrub. These groups and individual types have definite structural characters that can be observed repeatedly over the whole area, and are associated with forests of definite composition and productivity. The main site types are described for their vegetational characteristics and soil conditions, with suggestions for the silvicultural management of the forest stands. Life forms of plants in each site type and in each group or association as a whole indicate that these types grow in different phytoclimatic or ecoclimatic conditions. Except for the most mesophytic communities (the herb and fern group) the general characteristics of the climax forest are its partnership with the feather mosses on moist sites and with peat mosses on humid to wet ones. In the latter case, black spruce is the exclusive species, whereas in the former it is co-dominant with balsam fir, and in the most mesophytic conditions it is almost excluded to give way to balsam fir, white spruce and white birch. This gradation in sociological structure is duplicated on the plane of site productivity: height of trees shows a gradual increase, starting from the wet

and proceeding towards the moist habitats. Site quality in the various site types is further reflected in rapid turnover of organic matter and site productivity is directly associated with the level of fertility of the humus layer. Significant correlation coefficients have been obtained between level of N, Ca, P, K, Mg, and site quality. From author's summary.

206. Lotan, J.E.; Alexander, M.E.; Arno, S.F.; French, R.E.; Langdon, O.G.; Loomis, R.M.; Norum, R.A.; Rothermel, R.C.; Schmidt, W.C.; Van Wagtendonk, J. 1981. Effects of fire on flora: a state of knowledge review. USDA Forest Service, Washington, DC. General Technical Report WO-16. 71 p.

One of a series of reports, prepared for a National Fire Effects Workshop held April 10–14, 1978 in Denver, Colorado. After an introduction, the effects of fire are described on 3 major forest types, on non-forest areas, and on the forest soil environment.

207. Lousier, J.D.; Still, G.W., eds. 1988. Degradation of forested land: forest soils at risk. Proceedings of the 10th BC soil science workshop. February 1986. British Columbia Ministry of Forests, Victoria, BC. Land Management Report 56. 331 p.

Proceedings from the Workshop, covering the causes of forest soil degradation, including timber harvesting, roads, and forest site preparation; soil disturbance, degradation and productivity in relation to broadcast burning and mass wasting impacts; predicting and controlling such degradation in both B.C. and the U.S. Pacific Northwest; rehabilitation; economics and rehabilitation; and research needs. A list of participants and manuscript reviewers is also included.

208. Lowry, G.L. 1975. Black spruce site quality as related to soil and other site conditions. Soil Science Society of America Proceedings. 39(1):125–131.

Site studies were made in 125 *Picea mariana* stands in eastern Canada. Regional differences in site index are apparently related to gross climatic factors, particularly sunshine. In general, site index was most closely related to soil moisture and nutrients, i.e. site index was greater on freely drained mesic mineral soils with little accumulation of humus, and N and P limited tree growth over a broad range of soil conditions. Few of the factors studied appear to have value for predicting site index, but many were suitable for broad site classification. For extensive mapping of site productivity, it is proposed that the classification should be based primarily on land form, soils and geology, and secondarily on soil moisture and nutrients.

209. Lowry, G.L. 1972. Forest soil/site studies V. Black spruce productivity as related to soil and other site factors. Pulp and Paper Research Institute of Canada, Pointe Claire, PQ. Woodlands Report No. WR/44. 49 p.

The final report in the series. The data from earlier reports are summarized, and the final results of the soil and site studies are given. The dependence of productivity of *Picea mariana* on three major factors, viz. site quality, stand basal area and stand age, is clearly indicated. Studies of site factors in relation to site index show that regional differences in site index are apparently related primarily to gross climatic factors, e.g. amounts of sunshine in June and July, and mean temperature and rainfall in July. Site index is most closely associated with soil moisture and soil nutrients (of which N seems to be the most limiting). For assessing the nutrient status of *P. mariana*, foliar analysis is apparently more reliable than soil analysis. The site/ productivity relations observed suggest that the yield of many *P. mariana*, sites might be improved by silvicultural treatment to achieve full stocking, by application of fertilizers, and by swamp drainage.

210. Luman, I.D.; Neitro, W.A. 1980. Preservation of mature forest stages to provide wildlife habitat diversity. Transactions of the forty-fifth North American Wildlife and Natural Resources Conference. Wildlife Management Institute, Washington, DC. 45:271–277.

The management of forests for timber production, if done properly, can benefit most wildlife species. The proposal is to structure the timber management program to provide for naturally self-sustaining populations of all native wildlife species. The key to achieve this goal is vegetative diversification. It is proposed, therefore, to manage forest lands so that all vegetative successional stages are adequately represented over time. This proposal would counter the current decline of older seral stands by allotting or planning for a portion of all forest lands to remain in the mid-age and old growth seral stages in perpetuity. A model would be developed for each forest management area to achieve this objective over time. A lesser portion of all forest lands in any one planning area would be maintained in mid-age and old growth seral stages for the benefit of secretive, sensitive and wide- ranging species such as northern spotted owl, pine marten, fisher, and mountain lion. A larger portion of each management area would be in mid-aged and old growth seral stages, averaging 80 acres (32 ha) or more per tract which would be maintained at intervals of approximately one mile if possible. As summarized in Nietfeld, M.T., and Telfer, E.S. (1991).

211. MacClintock, L.; Whitcomb, R.F.; Whitcomb, B.L. 1977. Island biogeography and "habitat islands" of eastern forests. II. Evidence for the value of corridors and minimization of isolation in preservation of biotic diversity. American Birds. 31(1):6–16.

Censuses of four plots and supplemental observations in forests surrounding the plots suggest that most of the forest interior bird species characteristic of the region [Maryland, USA] are able to breed in forest fragments as small as 35 acres. However, this is apparently only possible if the fragment is "subsidized" by a nearby major forest system. The results emphasize the requirement for preserves of large size and confirm the importance of minimal isolation and corridors connecting fragmented forest tracts for preservation of maximum biotic diversity. As summarized in Nietfeld, M.T., and Telfer, E.S. (1991).

212. Mace, A.C., Jr. 1971. Recovery of forest soils from compaction by rubber-tired skidders. Minnesota Forestry Research Notes. No. 226. 4 p.

In continued work, soil bulk density was determined one year after logging. Compaction at a depth of 0-2 in was still significant on plots under both logging systems. There was some evidence of recovery in the 2- to 4-in layer of soils on plots where tree-length logging had been done. Recovery on plots with full-tree logging was slower, probably owing to the greater initial compaction, and a lower intensity of soil freezing.

213. Mace, A.C., Jr. 1970. Soil compaction due to tree length and full tree skidding with rubber-tired skidders. Minnesota Forestry Research Notes. No. 214. 4 p.

Clear-strip thinnings 16 feet wide, radiating from a central collecting area, were made in a 90- to 100-year- old stand of *Pinus resinosa*. Tree-length logging (a) was carried out on one half, and full-tree logging (b) on the other half of the strips. The bulk density of the sandy soil was significantly increased - by 5% for (a), and 11% for (b). Further studies are needed to evaluate the long- term effects of the two logging methods.

214. Mace, A.C., Jr.; Williams, T.; Tappeiner, J.C. II. 1971. Effect of winter harvesting methods on soil bulk density and infiltration rates. Minnesota Forestry Research Notes. No. 228. 4 p.

Measurements of the area of disturbed soil, and of the bulk density of the soil and infiltration rates on disturbed areas, were made in June after whole-tree or whole-stem logging by wheeled skidder in late winter in a *Pinus banksiana*/*P. resinosa* stand in Minnesota. The area of disturbed soil (47%) was approximately 30% less than after summer logging, mainly owing to smaller areas of severe and medium disturbance. Differences in the degree of soil compaction between logging systems (whole-tree or whole-stem) and seasons were of minor importance.

215. MacInnes, C.D.; Voigt, D.R. 1986. Wildlife reaction to forest sites. p. 121–131 *in* G.M. Wickware and W.C. Stevens, cochairmen. Site Classification in Relation to Forest Management. 27–29 August 1985, Sault Ste. Marie, ON. Canadian Forestry Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON. COJFRC Symposium Proceedings O-P-14.

Forest site is an integrative concept. Management of sites is frequently based on correlations, when causes and effects are too complex to unravel. The authors examine some major factors that influence feeding by larger herbivores. Because there are important interactions among animals, their food plants, site characteristics and other factors, management is dependant on correlations. Wildlife managers therefore face the same array of problems as forest site managers, and should use similar tactics in response. Integrated management will work best when similar approaches are taken.

216. MacLean, D.A.; Wein, R.W. 1978. Litter production and forest floor nutrient dynamics in pine and hardwood stands of New Brunswick, Canada. Holarctic Ecology. 1(1):1–15.

Biomass and nutrient transfer of overstorey and understorey litter fall were studied over a 2-yr period in 4 jack pine and 4 mixed broadleaf (*Acer rubrum/Betula papyrifera/Prunus pensylvanica/Populus tremula*) stands, 16-57 and 7-29 years old, respectively. The relative amounts of nutrients in the litter fall decreased in the order N, K, Ca, P=Mg in both types of stand. The return of mineral nutrients to the soil was generally twice as high in the broadleaved forest as in the pine forest, for stands of similar age. The understorey contribution to the litter fall usually contained a nutrient mass similar to or greater than that in the tree layer contribution. From authors' summary.

217. MacLean, D.A.; Woodley, S.J.; Weber, M.G.; Wein, R.W. 1983. Fire nutrient cycling. p. 111–132 *in* R.W. Wein and D.A. Maclean, eds. The role of fire in northern circumpolar ecosystems. John Wiley and Sons, Chichester, UK. SCOPE 18.

Patterns of undisturbed nutrient cycling in northern ecosystems and the impact of fire on nutrient cycling are reviewed and discussed. The various effects of fire on ecosystem nutrient cycling may be broadly subdivided into: (1) nutrient redistribution during fire, and (2) changes in post-fire nutrient cycling. Effects during fire include the loss of nutrients (especially nitrogen) from ecosystems through volatilization, loss of particulate matter in smoke and convection action, transfer of mineral elements to the ash layer, and heating of biomass (often above lethal levels) and the upper soil layers. Post-fire changes include the 'pulse' addition of nutrients in the ash layer immediately after the fire, possible increased leaching from the soil profile, overland flow or erosional transfers of nutrients, increased soil pH, lowered albedo from the fire-darkened surface, increased active layer depth, and warmer soil profiles which affect microorganisms and decomposition processes. The magnitude of these effects is discussed in the light of our present knowledge. Needs for future research are proposed.

218. Mader, D.L. 1976. Soil-site productivity for natural stands of white pine in Massachusetts. Soil Science Society of America Journal. 40(1):112–115.

Presents the results of a 10-year study of the growth and yield of *Pinus strobus* in relation to soil and site characteristics in Massachusetts, begun in 1959, as part of a study already noticed. Stepwise multiple regression predictions from topographic variables alone were poor, but the addition of soil physical and chemical variables (particularly texture, drainage, moisture, organic matter, and pH of lower horizons) improved the prediction. It is concluded that the equations derived for site index, total height, and volume p.a.i. are of potential value for practical application.

219. Magnussen, S.; Smith, V.G.; Yeatman, C.W. 1985. Tree size, biomass, and volume growth of twelve 34-year-old Ontario jack pine provenances. Canadian Journal of Forest Research. 15(6):1129–1136.

Tree size and aboveground biomass in twelve 34-year-old Ontario jack pine (*Pinus banksiana* Lamb.) provenances growing at Petawawa National Forestry Institute (Chalk River, Ontario) was negatively correlated with latitude of origin. The best provenance exceeded the local provenance in tree height and diameter by approximately 10%. The pattern of geographical variation was stable over time, making feasible general and sound predictions of provenance growth based on juvenile performance. Persistent differences among some geographically close provenances indicated the potential for genetic improvement by selecting the best populations within site regions. The results demonstrated have important implications for jack pine breeding and improvement strategies at the provenance level. The provenance averages of aboveground ovendry weight per tree ranged from 44 to 79 kg. The aboveground tree biomass was distributed as follows in seven analyzed provenances: stem wood, 78%; stem bark, 8%; branch wood, 8%; needles, 5%; cones, 1%. Variation in average stemwood mass among provenances was less than the variation in average stem volume because of a strong negative correlation on a single tree basis between stem volume and stem wood density. The mean annual volume and biomass accretion per hectare in the best provenances averaged 10 m3 and 4 t, respectively. Total stem volume production per hectare varied exponentially with tree height. Mean annual stem volume increment of the best provenances exceeded that of the slowest growing provenances by 22-40%.

220. Mahendrappa, M.K. 1986. Potential acidification of black spruce (*Picea mariana* (Mill.) B.S.P.) sites due to intensive harvesting. Institutionen for Ekologi och Miljovard, Sveriges Lantbruksuniversitet. Rapport No. 26:165–171.

Using data for intensively harvested black spruce stands from a province-wide survey of biomass and nutrient inventory in New Brunswick, Canada, it is shown that the degree of acidification is affected by site class and tree species. Indiscriminate, intensive harvesting cannot therefore be recommended. Conservation of nutrients in the foliage and slash can moderate site acidification.

221. Mahendrappa, M.K.; Foster, N.W.; Weetman, G.F.; Krause, H.H. 1986. Nutrient cycling and availability in forest soils. Canadian Journal of Soil Science. 66(4):547–572.

Nutrient availability in different forest soils must be known before increased wood production can be sustained either by adding supplemental nutrients or by judicious silvicultural operations to optimize the linkage between the variable nutrient requirements of forest crops. This is complicated by the variable availability of nutrients on forest sites during crop development. Forest crops unlike agricultural crops have long rotation periods which make it difficult to apply agricultural methods of estimating potentially available nutrients directly to forest soils. Presented in this review are (i) various approaches used in forestry to estimate the nutrient supplying potential of different sites, (ii) factors affecting nutrient availability, and (iii) evidence to suggest that nutrient cycling processes in forest ecosystems are important factors affecting tree growth. It is suggested that data from chemical analyses of soil samples collected at specific times and sites should be used with caution for both practical decision making and simulation modelling purposes.

222. Mahendrappa, M.K.; Kingston, D.G.O. 1980. Nutrient cycling studies at the Arcadia Forest Experiment Station: establishment and soil characteristics. Canadian Forestry Service, Maritimes Forest Research Centre, Fredericton, NB. Information Report M-X-113. 117 p.

A description of the physical and chemical characteristics of the soils in plots established to study nutrient cycling in 3 broadleaved and 6 coniferous stands in New Brunswick. Thickness and weight of organic horizons, and the quantity of nutrient reserves in both organic and inorganic horizons are given.

223. Maliondo, S.M. 1988. Possible effects of intensive harvesting on continuous productivity of forest lands. Forestry Canada, Maritimes Region, Fredericton, NB. Information Report M-X-171. 26 p.

Intensive (whole-tree) harvesting of natural forest stands is widespread in the Maritime provinces. In some cases, the goal of whole-tree harvesting is to increase usable biomass, but often foliage and branch components are discarded at the landing site. This report examines the possible effects of whole-tree harvesting on long-term site productivity, particularly on soil fertility. Such effects might include large losses of nutrients in harvested components, long-term decrease in soil organic matter, loss of soil nutrients, including base cations, and the potential for increased soil acidification. The first part of this report evaluates published data collected from different parts of the world concerning potential decline in soil fertility resulting from the loss of organic matter and base cations caused by different harvesting methods. Biomass and the amount of base cations that would be removed both by conventional and whole-tree harvesting are calculated. Some published data from different stands in New Brunswick and Nova Scotia were used in the second part of this report to examine the effect of species and site quality on base cation losses and the potential increase in soil acidification which would result from whole-tree harvesting. Practising whole-tree harvesting would result in an additional gain in biomass of 55-103% and 29-74% for site classes and species comparisons, respectively. The corresponding increase in base cation losses would vary from 209-283% and 82-283% for site classes and species comparisons. The consequences of high base cation losses, especially from the infertile acid soils of this region, on long-term site productivity are discussed. The role of foliage and branch components in nutrient cycling processes in natural forest stands is stressed. It is concluded that the effects of whole-tree harvesting on site productivity will vary with species and site quality, but that long-term site studies, including nutrient cycling studies, will be needed to quantify such effects.

224. Maliondo, S.M.; Mahendrappa, M.K.; van Raalte, G.D. 1990. Distribution of biomass and nutrients in some New Brunswick forest stands: possible implications of whole-tree harvesting. Forestry Canada, Maritimes Region, Fredericton, NB. Information Report M-X-170E/F. 40 p.

The potential impacts of whole-tree harvesting, increasingly practised in the Maritimes region, on long- term site productivity were investigated in New Brunswick and the findings are reported here. A total of 25 stands, representing eight commercially important species, was characterized in terms of biomass and nutrients in the above-ground portions of the forest stands and the chemistry of the organic and mineral horizons under each stand. Stands were selected so that the sites were representative of different productivity classes in New Brunswick. Using the data on biomass and nutrients in the different components of forest stands, the additional quantities of biomass and nutrients removed from sites through whole-tree harvesting were calculated. Species differed with respect to biomass and nutrient contents. The effect of site quality on biomass and nutrient content differed with species, but differences in age and stand density, and their possible interactions, confounded the site effect in some species. The effect of whole-tree harvesting on site productivity is discussed, emphasizing possible losses in soil fertility and the potential for increased soil acidification. The need for more site-specific information is stressed.

225. Mann, L.K.; Johnson, D.W.; West, D.C.; Cole, D.W.; Hornbeck, J.W.; Martin, C.W.; Riekerk, H.; Smith, C.T.; Swank, W.T.; Tritton, L.M.; Van Lear, D.H. 1988. Effects of whole-tree and stem-only clearcutting on postharvest hydrologic losses, nutrient capital, and regrowth. Forest Science. 34(2):412–428.

Nutrient removal by sawlog or pulpwood harvest (SAW) and whole-tree harvesting (WTH) was determined for 11 forest stands located throughout the USA. Data from this study combined with previously published nutrient budgets indicated potential net losses of Ca and K at most sites without harvest and net losses of N, P, K and Ca with either harvest method. Total stem biomass and nutrients were significantly correlated with total above-stump biomass, providing a means for estimating nutrient removals with SAW and WTH in commercial forests. Limited data from harvested stands indicated greater regrowth biomass with SAW than with WTH on some sites. Hydrologic losses of N, K and Ca generally increased immediately after harvest, but returned to values for control areas within 3 years and are therefore considered minor in relation to harvest removals. Ca and K are possible exceptions. The large difference in amounts of nutrients left on site in logging slash after SAW compared with WTH did not result in major differences in leaching or runoff.

226. Marcot, B.G.; McNay, R.S.; Page, R.E. 1988. Use of microcomputers for planning and managing silviculture–habitat relationships. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR. General Technical Report PNW-GTR-228. 19 p.

Microcomputers aid in monitoring, modelling, and decision support for integrating objectives of silviculture and wildlife habitat management. Spreadsheets, data bases, statistics, and graphics programs are described for use in monitoring. Stand growth models, modelling languages, area and geobased information systems, and optimization models are discussed for use in modelling. Decision aids and expert systems for decision support are examined. Advantages of microcomputers include availability, transportability, and usability. Disadvantages include the building of unvalidated models, lack of software standards, and need for updating data bases. A case example is presented of an expert system that evaluates regional priorities for managing habitat for black-tailed deer in coastal British Columbia.

227. Margolis, H.A.; Brand, D.G. 1990. Biochemical response of planted black spruce and jack pine seedling to silvicultural treatment. p. 163 *in* B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, eds. The silvics and ecology of boreal spruces: proceedings of the 11th IUFRO Northern Forest Silviculture and Management Working Party S1.05-12 Symposium. 12–17 August 1989, Central Newfoundland, Canada. Forestry Canada, Newfoundland and Labrador Region, St. John's, NF. Information Report N-X-271.

A large study was undertaken in 1986 with the objective of understanding how planted seedling of two conifer species (black spruce and jack pine) would respond to changes in environmental conditions produced by some common silvicultural treatments. A brief report points out the differences found in the biochemical response of these two species to environmental manipulations.

228. Margolis, H.A.; Brand, D.G. 1990. An ecophysiological basis for understanding plantation establishment. Canadian Journal of Forest Research. 20(4):375–390.

Forest plantations in the early stages of establishment are considered as hierarchical biological systems, and some implications for the design of research projects and the education of regeneration foresters and scientists are discussed. Since less than optimum environmental conditions convey stress to seedlings, seedlings will in turn exhibit a strain response at either the biochemical, physiological, or morphological level. Environmental conditions in a clear-cut are contrasted with other regeneration niches, and implications for the performance of different plantation species are discussed. The important physiological and biochemical limitations on the absorption of water, nitrogen, and carbon by seedlings during their establishment phase are described. Methods of quantifying stress at the plantation site, including simple ways to separate seedling growth into its different physiological components, are shown. An example of an eastern white pine (*Pinus strobus* L.) plantation grown under different levels of soil temperature, fertilization, and brush control is presented to illustrate the concepts. An approach to silvicultural research is proposed that determines the effects of silvicultural treatment on the seedling environment and then relates these environmental conditions to seedling biochemistry, physiology, and growth.

229. Marion, G.M. 1979. Biomass and nutrient removal in long rotation stands. p. 98–110 *in* A.L. Leaf, chairman. Impact of intensive harvesting on forest nutrient cycling. 13–16 August 1979, State University of New York, Syracuse, NY. State University of New York, College of Environmental Science and Forestry, Syracuse, NY.

Data from a literature survey showed that biomass production in the mature forest is highest in the tropical forest, intermediate in the temperate forest, and lowest in the boreal forest. Nutrient concentrations fall in the order: tropical >> boreal > temperate broadleaf > temperate coniferous; nutrient efficiencies (biomass/ nutrient content) fall in the reverse order: temperate coniferous > temperate broadleaf > boreal >> tropical. The moderately high biomass productivity, high nutrient efficiency, and high proportion of the biomass in the stem make the temperate coniferous forest most suitable for intensive management. Whole-tree removal or thinning can increase harvested biomass by similar amounts over long

rotations (30%-90%); however, nutrient removal will be substantially higher in whole-tree harvests than in thinning harvests.

230. Martell, A.M.; Radvanyi, A. 1977. Changes in small mammal populations after clearcutting of northern Ontario black spruce forest. Canadian Field-Naturalist. 91(1):41–46.

Changes in small mammal populations on upland black spruce (*Picea mariana*) clearcuts near Manitouwadge, Ontario, were monitored between 1973 and 1975 by live-trapping. Additional clearcuts and uncut stands were sampled by dead-trapping in September 1975. The September density of mice and voles was similar during the first, second, and third year after clearcutting (13.0/ha, 11.6/ha, and 10.0/ ha, respectively). Red-backed voles (*Clethrionomys gapperi*), likely common in uncut stands but increased on clearcuts until they predominated in the small mammal community by the end of the second harvest, and then declined markedly to rare status. Conversely, deer mice (*Peromyscus maniculatus*) likely were scarce in uncut stands but increased on clearcuts until they predominated in the small mammal community by the end of the second summer after cutting. For less common species clearcut and uncut stands were compared. Meadow voles (*Microtus pennsylvanicus*) were more common on clearcuts than in uncut stands while the converse was true for rock voles (*Microtus chrotorrhinus*). Bog lemmings (*Synaptomys cooperi*) were taken only in uncut stands while heather voles (*Phenacomys intermedius*) and least chipmunks (*Eutamias minimus*) were captured only on clearcuts. Clearcutting of upland black spruce forest produced a dramatic change in the composition of the small mammal community but may have caused little change in density.

231. Martell, D.L.; Fullerton, J.M. 1988. Decision analysis for jack pine management. Canadian Journal of Forest Research. 18(4):444–452.

This paper demonstrates how decision analysis techniques can be used to develop a planning methodology that foresters can use to resolve regeneration and tending decision-making problems associated with the management of jack pine (*Pinus banksiana* Lamb.) cutovers on sand flats in the Boreal Forest region of the province of Ontario. The use of the technique is illustrated by applying it to a hypothetical jack pine sand flat cutover that is representative of such sites.

232. Maser, C.; Trappe, J.M., technical eds. 1984. The seen and unseen world of the fallen tree. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR. General Technical Report PNW-164. 56 p.

Large fallen trees in various stages of decay contribute much-needed diversity to terrestrial and aquatic habitats in unmanaged old-growth Douglas fir forests. When most biological activity in soil is limited by low moisture availability in summer, the interface between soil and a fallen tree offers a relatively cool, moist habitat for small animals and substrate for microbial and root activity. Increased utilization and management can deprive future stands of large fallen trees and smaller woody debris. Visible and invisible stages in the decay of fallen trees are discussed to encourage awareness of the losses in habitat diversity and long-term site productivity that may result from increased removal of woody debris from streams and forests in the name of economic progress.

233. Mathisen, J.E. 1988. Integrating wildlife habitat objectives with silvicultural prescriptions. p. 23–27 *in* T.W. Hoekstra and J. Capp, compilers. Integrating forest management for wildlife and fish. USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN. General Technical Report NC-122.

Land managers need methods to assess, measure and predict the affects on wildlife of vegetation change resulting from silvicultural prescriptions. A data base was developed to relate vertebrates on the Chippewa National Forest [in Minnesota] to their habitats and special requirements, providing a simple method comparing alternative land use proposals in terms of species.

234. McBride, R.A.; Gordon, A.M.; Shrive, S.C. 1990. Estimating forest soil quality from terrain measurements of apparent electrical conductivity. Soil Science Society of America Journal. 54(1):290–293.

A portable, non-contacting electromagnetic induction meter was employed to measure the apparent electrical conductivity (ECa) of nonsaline, medium- and coarse- textured forest soils on Manitoulin Island, Ontario. In simple linear regressions, bulk soil ECa was strongly correlated with ECe (saturated-extract electrical conductivity), as well as exchangeable Ca, exchangeable Mg, and cation exchange capacity. Within the limited study area, these soil characteristics were thought to be major determinants of forest soil quality for red oak (*Quercus rubra*) production. Multiple stepwise regression showed that variations in exchangeable Ca and total Kjeldahl N concentrations accounted for a large proportion of the variation in ECa meter response (R^2 = 0.871). The potential of this geophysical terrain measurement method as an integrator of edaphic properties important in forest site productivity is discussed.

235. McCullough, D.G.; Kulman, H.M. 1991. Effects of nitrogen fertilization on young jack pine (*Pinus banksiana*) and on its suitability as a host for jack pine budworm (*Choristoneura pinus pinus*) (Lepidoptera: Tortricidae). Canadian Journal of Forest Research. 21(10):1447–1458.

Effects of nitrogen fertilization on growth, foliar nitrogen concentration and monoterpenes were determined on 7- to 11-year old jack pine (*Pinus banksiana* Lamb.) on two sites in northwestern Wisconsin. One site established after wildfire; the other after clear-cutting. Jack pine budworm (*Choristoneura pinus pinus* Free.) larvae were caged on fertilized and unfertilized trees on each site. Relations among foliar nitrogen, monoterpenes, larval survival, and adult budworm weight were examined. Foliar nitrogen concentration, needle weight, shoot and diameter growth, and monoterpene production were lower on wildfire site trees than on clear-cut trees, and were significantly increased on both sites by fertilization. Fertilization increased production of staminate cones on the wildfire site. Height growth differed between sites but was unaffected by fertilization. Contrary to expectations based on the resource availability theory, foliar nitrogen and monoterpene levels were positively related. Survival of jack pine budworm larvae was greater on clear-cut than on wildfire site trees, but was not significantly affected by fertilization. Larvae on low-nitrogen trees on the wildfire site clipped more foliage than those on the clear-cut site, suggesting compensatory feeding. Adult female weight was higher for larvae on wildfire than clear-cut site trees. Two monoterpene compounds and site- related differences were the best predictors of adult female weight based on regression.

236. McRae, D.J. 1979. Prescribed burning in jack pine logging slash: a [literature] review. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. Information Report O–X–289. 57 p.

Includes sections on: uses of prescribed burning; environmental effects; ecological effects; prescribed burn planning; fire behaviour; and economics. Geographical and subject indices are given to a numbered list of references.

237. Methven, I.R.; Van Wagner, C.E.; Stocks, B.J. 1975. The vegetation on four burned areas in northwestern Ontario. Canadian Forestry Service, Petawawa Forest Experiment Station, Chalk River, ON. Information Report PS-X-60. 10 p.

Describes a pilot study of four burned areas in northwestern Ontario, intended to test a proposed method of sampling vegetation in the boreal forest at various intervals after fire, and investigate the role and consequences of fire in this type of forest. Data were also collected to facilitate prediction of the development of vegetation after fire of known intensity, in the various forest types of the boreal region. The results suggested that, in most cases, the same dominant tree species returned immediately after fire; this implies that cycling by fire rather than succession is the basic mechanism in this forest. Further work necessary to complete the study is described.

238. Morin, H.; Gagnon, R. 1991. Comparative growth and yield of layer- and seed-origin black spruce (*Picea mariana*) stands in Quebec. Canadian Journal of Forest Research. 22(4):465–473.

Stem analysis was used to compare the height, diameter at breast height, and volume growth of seven merchantable black spruce (*Picea mariana* (Mill.) B.S.P.) stands regenerated after harvesting from advance growth of layer origin with the growth of three merchantable black spruce stands regenerated after fire from seed. The year of harvesting in the second-growth stands was precisely determined using synchronous growth release after logging, scars left by the logging operation, and historical records. The year of the fires in seed-origin stands was determined using fire scars and historical records. Fire- origin stands showed typical even-aged structure, and logged, second-growth stands showed an uneven-aged structure associated with an asymmetric curve. When compared with seed-origin stands, layer-origin stands showed a significantly greater total height 30 years after the stand origin because of the initial height of the layers. However, annual height increments were similar between the two origin types at 30 years. The mean diameter increment at 30 years was significantly higher in the second-growth stands. The mean annual specific volume increment values for the entire period of growth were slightly higher for the fire-origin stands. Layers that were small at the time of logging (<1 m) had a higher specific volume increment after logging compared with the medium (1-2 m) and tall layers (>2 m). There was a significant negative correlation between the height, diameter, and age of the layers at the time of logging and both the mean specific volume increment and the mean annual height increment 30 years after logging. In the second-growth stands, the number of merchantable trees and volume increment increased gradually because of the uneven structure of the stands. In contrast, in the seed-origin stands, the trees attained merchantable size at around 30 years after the fire, and the merchantable volume rose rapidly after this. The layer-origin populations had a significant advantage over the seed-origin populations because of the initial height and diameter of the layers at the time of logging. All seven layer-origin stands achieved, or were predicted to achieve, higher merchantable volumes than the seed-origin stands at 40 years. Our results indicate that the second-growth stands growing on mesic sites have the potential to produce merchantable forests comparable to the yield tables available for black spruce provided that the number of stems per hectare is adequate.

239. Morin, H.; Gagnon, R.; Frisque, G. 1991. Évolution de la régénération, dans deux vieilles coupes par bandes, dans des peuplements d'épinette noire au Québec. Canadian Journal of Forest Research. 21(11):1660–1667.

The distribution and growth in height of two black spruce populations were studied in two areas that had been strip cut, one in 1968-1969 in the Nicauba Experimental Forest and the other in 1954 around Lake Massie. By careful sampling of trees, advance growth could be differentiated from post-established regeneration; to a certain extent, spruce originating from seed could also be distinguished from trees that grew by layering. Stem analysis was used to compare the juvenile growth of advanced and post- established regenerated black spruce to that of trees in the residual strips. The stocking and the density are high for black spruce 18-20 years after logging, regardless of their origin (seed, layering, advance growth, or post- established regeneration): more than 80% and over 18,000 stems/ha, respectively. The yield for seedlings is not uniform from strip to strip; it is significant in some and negligible in others. Thirty-four years after strip-cutting the area around Lake Massie, the stocking of black spruce is also over 80% and the density is greater than 22,000 stems/ha, but these trees originated almost exclusively by layering. In the Nicauba Experimental Forest, seedlings established themselves very rapidly after strip-cutting. Overall, over a 20-year period, the juvenile rate of growth in height of the dominant advance growth (mainly layers) in the two areas is comparable to that of the dominant trees in the residual strips of Nicauba; it is almost double the rate observed in dominant post-established regenerated black spruce in the Nicauba area.

240. Morin, H.; Gagnon, R. 1991. Structure et croissance de peuplements d'épinette noire issus de régénération préétablie, une quarantaine d'années après coupe au Lac Saint-Jean, Québec. Forestry Chronicle. 67(3):275–283.

Age, height and diameter distribution as well as height and diameter growth were studied in ten mesic black spruce stands originating from advance growth, forty years after cutting. All sampled stands showed a negative exponential type age structure. The majority of the trees were cut in the 1930's or 1940's. The sampled trees were generally distributed among numerous height and diameter classes. According to stem analysis, the ten sampled stands can be separated into two distinct groups based on their height growth performance, following the drainage pattern. Mean annual height

and diameter increments were comparable to those described in yield tables for natural black spruce stands. Sites with adequate stocking and density should thus give good volumes. Stands of advance growth origin have the advantage of possessing some trees with a certain height immediately after the cutting. However, they are generally highly variable in diameter and height classes which can be an inconvenience in wood processing.

241. Morris, D.M. 1988. Evaluation of morphological and physiological response variables of four-year old black spruce seedlings to perennial competition. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Report #23.

The overall objective of this paper was to highlight terms used in competition dynamics and evaluate those variables commonly used to describe plantation response and competition. The example presented was part of a 3-year project funded by COFRDA entitled "Growth response of young plantations to vegetative competition". From preliminary regression analyses, it was determined that simple morphological attributes (i.e., total height, CAI, crown dimensions) did not reliably respond to changing competition levels at an early stage of plantation development. Using destructive sampling techniques, additional physiological variables which determine variations in nutrient status, root development, plant structure, and allocation of resources were also tested for their sensitivity to increasing competition stress. The use of relative versus absolute growth response variables was also discussed. A single independent variable was used for the evaluation of the response variables. An adjusted percent open sky, obtained from fisheye photographs, proved to be the most reliable estimator of incident radiation received by each sampled seedling. Although foresters commonly use either total height or current height increment as response variables when examining plantation performance, the results from this study demonstrate that these are not reliable for four-year old black spruce plantations. Overall, the most consistent response variable was the square root of total seedling weight. The coefficients of correlation for the six plantations studied averaged 0.797. It seems apparent that, although minimal morphological changes could be detected, the physiological development of the seedlings responded significantly to changes in competitive stress during early plantation development. Unfortunately, the forester must be able to make rapid decisions concerning release treatments for his/her plantations. This constraint negates the use of destructive sampling techniques, which are costly and time consuming, Therefore, a simpler measurement which has a high correlation to total seeding weight would be beneficial. To date, a good relationship exists between root collar diameter and total seedling weight. However, this direct relationship is not consistent for all areas studied. Analysis is ongoing to develop a comprehensive competition index which utilizes easily measured variables.

242. Morris, D.M.; MacDonald, G.B.; McClain, K.M. 1990. Evaluation of morphological attributes as response variables to perennial competition for 4-year-old black spruce and jack pine seedlings. Canadian Journal of Forest Research. 20(11):1696–1703.

The sensitivity of seedling morphological attributes to changing competition levels was evaluated on 4-year-old black spruce (*Picea mariana*) and jack pine (*Pinus banksiana*) seedlings in plantations in Northcentral Ontario to determine the most appropriate response variables to be used in the assessment of early plantation performance. A total of 720 seedlings (360 per species, from 6 plantations each) were sampled from 1987 to 1989, covering a range of planting stock types, soil textures and levels of competition from shrubs and trees developing from root suckers after clear felling on these boreal mixed conifer/broadleaved sites. A competition index, derived from hemispherical photographs, provided an estimate of incident radiation received by each seedling sampled. Seedling stem volume at time of planting was used as a covariate in the regression analyses. Stratification by plantation was done to account for variations in site quality. The results demonstrated that total height or current height increment were not reliable for quantifying individual seedling response to interspecific competition for 4-year-old black spruce or jack pine plantations. Overall, the most consistent response variable was total seedling dry weight. Coefficients of determination ranged from 0.116 to 0.534 for black spruce and from 0.601 to 0.810 for jack pine across the range of sites and stock types. If it is inappropriate to determine total seedling dry weight, root collar diameter would be the best substitute. Correlation coefficients between these two variables were 0.897 for black spruce and 0.912 for jack pine.

243. Morris, D.M.; Rose, M.K.; MacDonald, G.B. 1988. Stand structure, species composition, and growth of the boreal mixedwood forest in northern Ontario: a comparison of natural stands and plantations. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Report #22. 21 p.

The objective of this paper was to provide awareness to others about the complexities of the boreal mixedwood forest in Northern Ontario. As we enter a new era of increasingly intensive forest management on mixedwood sites, it is essential that the forest manager gain a better understanding of stand dynamics. This understanding includes forest development in terms of growth, changes in species composition, and stand structure. The data presented here were part of a long term study which is currently attempting to model forest growth and development of mixedwood stands. Both mensurational measurements and stem analysis were carried out in eight circular plots (1/8 of a ha in size) in the North Central Region. Four plots were located in natural stands (ranging from 45 years to 85 years) with the other four in spruce plantations (ranging from 15 years to 25 years). An additional source of mensurational data detailing early development of natural stands was obtained from a discussion paper presented by N.F. Lyon in 1974 at the Sixth Annual Lakehead Forest Association Symposium entitled "The Future Forest". A series of figures compared the changes over time in species composition, stand structure, and growth rate for natural stands and plantations on typical mixedwood sites. This comparison identified a number of important differences in stand development which are important in the management of these stands. A positive note to current harvesting and mechanical site preparation methods is the virtual lack of advanced balsam fir regeneration present in plantations. Mature balsam fir is particularly susceptible to spruce budworm damage and eventual mortality. Therefore, as these plantations develop, the risk of spruce budworm infestation and subsequent wildfires may be reduced, while at the same time containing a greater proportion of the desired crop species. On the negative side, it was illustrated that these plantations have more intensive competition both within and between species, resulting in the greater mortality rates and lower relative height growth rates. The spruce volume increment becomes a significant portion of the overall stand volume at age 15- 20 years. Reduction of this lag-time could significantly decrease the rotation age of the crop species.

244. Morrison, I.K. 1969. The absorption of nutrients by roots of coniferous seedlings in relation to root characteristics and soil conditions. Ph.D. thesis. University of Toronto, Toronto, ON.

A method was developed for the rapid estimation of tree seedling root area, utilizing a photoelectric device measuring silhouette area convertible to total area by multiplying by π. The method combined rapidity with high degrees of accuracy and precision. At the same time it was non-contaminating and non-injurious so that following measurement the seedlings could be replanted. The uptake of N, P, K, Ca and Mg by seedlings of jack pine and white spruce was studied in relation to root area. Root growth and nutrient uptake were considered cumulative processes, such that total salt accumulation, the sum of increments of uptake, could be related to total root area, the sum of increments of growth in root area. A high correlation was noted between total growth and root area. It was shown that the complete nutrient uptake of the seedlings could be accounted for by reserves of elements within very short distances of the root surfaces. The amounts absorbed varied with availability, ion mobility and a plant factor. The fact that the thickness of this shell of soil did not vary appreciably with time may be taken as evidence that uptake is related to root extension in an overall sense. There were noticeable between-species differences in tissue concentrations, in uptake per unit root area, and in the distances from the root surfaces from which the various nutrients were removed. White spruce absorbed relatively more rapidly than did jack pine. Any involvement of an absorption exchange mechanism was discounted in that the root cation exchange capacities of the two species, whether based on weight or area, were similar. It was suggested that the plant factor involved differences in rates of active transport. The relative importance of the various factors was discussed in relation to the overall environment-plant system.

245. Morrison, I.K. 1973. Distribution of elements in aerial components of several natural jack pine stands in northern Ontario. Canadian Journal of Forest Research. 3(2):170–179.

Reports further studies in stands of *Pinus banksiana* already described in which the contents of N, P, K, Ca and Mg were estimated from analyses of the aerial parts in conjunction with dry-matter data from the earlier study. Regression

equations were calculated, and good correlations were found between the logarithms of the content of elements and d.b.h. The equations were used in association with individual plot stand tables to give the total weight per ha of each element in the aerial parts of each stand. Converted to normal stocking, the contents of all elements increased with increasing stand age. In 65- year-old stands, over half of the above-ground N and P occurred in crowns rather than stems; the proportions of above-ground K, Ca and Mg were higher in the stems than in the crowns.

246. Morrison, I.K. 1974. Dry matter and element content of roots of several natural stands of *Pinus banksiana* Lamb. in northern Ontario. Canadian Journal of Forest Research. 4(1):61–64.

In a further study on the content of dry matter and N, P, K, Ca and Mg in 30- to 35-year-old stands of *P. banksiana* in N. Ontario, the root systems of eight trees were excavated, weighed and chemically analysed. Dry-matter and nutrient content per ha were estimated by the regression/ stand-table method. On an area basis, root weight of *P. banksiana* was lower, for stands of comparable age, than that of other species located elsewhere. In *P. banksiana*, also, a smaller proportion of the total plant was contained in the root.

247. Morrison, I.K. 1980. Full-tree harvesting: disadvantages from the forester's viewpoint. Pulp and Paper Canada. 81(10):49, 51-52, 54.

As forest management in eastern Canada reaches the limit of allowable cut, productivity of the forest as a whole must be preserved to maintain allowable cut levels. More intensive harvesting and/or utilization options, such as whole-tree and complete-tree [including roots] harvesting, hold promise for increasing volume yield. However, increased yield through more intensive harvesting must be counterbalanced by loss of future forest productivity associated with a combination of inadequate regeneration, site downgrading through excessive removal of organic matter or nutrients, and outright site loss. The forester is seen as the key person in preserving site productivity values. Prepared by IPC.

248. Morrison, I.K.; Foster, N.W. 1979. Biomass and element removal by complete-tree harvesting of medium rotation forest stands. p. 111–129 *in* A.L. Leaf, chairman. Impact of intensive harvesting on forest nutrient cycling. 13–16 August 1979, State University of New York, Syracuse, NY. State University of New York, College of Environmental Science and Forestry, Syracuse, NY.

Various estimates of the magnitude of standing biomass and the element content of medium rotation forest stands are available. Good methods exist whereby estimates can be made of other stands. With reference to mineral elements, however, "magnitude" has meaning chiefly in relation to size of reserves and rates of recovery processes. Forest biogeochemical processes are complex. In view of the variation of species, stocking, age of rotation, locality, and nutritional aspects of site, evaluations of impact are best made on a case-specific basis. Substantial information is available on certain aspects of forest chemistry. However, at present it appears that neither an adequate framework nor enough specific information is available to permit conclusive statements to be made on the effect of complete-tree harvesting on future productivity of sites under medium rotation forest, on the basis of analysis of mineral cycles.

249. Morrison, I.K.; Foster, N.W. 1990. On fertilizing semimature jack pine stands in the boreal forest of Central Canada. p. 416–431 *in* S.P. Gessel, D.S. Lacate, G.F. Weetman and R.F. Powers, eds. Sustained productivity of forest soils: 7th North American Forest Soils Conference. 24–28 July 1988, University of British Columbia, Vancouver, BC. U.B.C., Vancouver, BC.

Between 1964 and 1982, 20 forest fertilization field experiments were conducted by Forestry Canada in natural, semimature jack pine (*Pinus banksiana* Lamb.) stands on upland sites in northern Ontario. The objective of this program was to investigate the possible use of mineral fertilizers to counter wood shortages projected for the region's pulp and paper industry. Ten-year responses are reported for experiments that tested different sources of nitrogen (N), the rate

of application of urea, the timing of application, and the effects of fertilization in combination with thinning. In general, jack pine stands responded positively to mineral fertilizers, particularly N, with volume gains of up to 20 m3/ha over 10 years. Various other studies were conducted to develop a fuller understanding of forest nutrition. Nitrogen was found to play a key role in determining the productivity of the stands examined. The availability of added N was moderately short-lived (approximately 1 year) because of rapid volatilization of urea from the soil as NH3 and incorporation of N into organic pools in the vegetation and soil. Prolonged effects of urea fertilizer on tree growth are due primarily to recycling (transformation) of N absorbed into trees during the early part of the response period, rather than to continued release of fertilizer-N from the soil.

250. Morrison, I.K.; Wickware, G.M. 1990. Conservative soil management for intensively managed conifer plantations. p. 233–236 *in* E.N. Hogan, ed. Proceedings of the Seventh Canadian Bioenergy R&D Seminar. 24–26 April 1989, Skyline Hotel, Ottawa, ON. CANMET, [Ottawa, ON].

In response to increasing demands for wood fiber, Canadian foresters have been actively seeking to increase tree growth rates by developing and implementing more intensive soil management practices. At the same time as there is increased demand for biomass for traditional products, there are prospects that even greater quantities could be removed for the production of energy. This raises questions concerning the drain of nutrients from some sites in harvested products; this drain may be of sufficient magnitude to lead to diminished future site productivity. Jack pine is a principal tree species of northern Ontario and is commonly associated with coarse, glaciofluvial sands of low fertility. Fertilizer trials in unmanaged or extensively managed stands have shown that growth in such situations is commonly limited by a lack of N with, in some instances, secondary deficiencies of P or K, as well. This suggests that, under more intensive harvesting regimes, deficiencies of nutrients could occur in future crops. In our study, we examined the nutrition of young jack pine plantations. In particular, we studied tree foliage for indications of nutrient deficiencies.

251. Munson, A.D.; Timmer, V.R. 1991. Site-specific growth and nutrition of planted *Picea mariana* in the Ontario clay belt. V. Humus nitrogen availability. Canadian Journal of Forest Research. 21(8):1194–1199.

The relationship between forest humus chemistry and net N mineralization in three boreal ecosystems was investigated by measuring N release in samples during an 8-week aerobic laboratory incubation. Nitrogen mineralization was significantly greater in the upland Feathermoss humus, intermediate in the Ledum humus, and lowest in Alnus - Herb poor substrate, although the differences between the last two lowland sites were not significant. Correlations of net mineralizable N at 8 weeks with humus chemistry variables were weak, although initial N release was correlated with total N. Field-fertilized (urea) and control substrates from the three ecosystems were similarly incubated to observe effects of N addition on mineralization and humus chemistry. Substrates were sampled 16 months after fertilization, and net N mineralization during incubation was most enhanced in Alnus humus and least affected in Feathermoss humus. Response was most strongly related to positive changes in humus total N. Growth response of outplanted, unfertilized seedlings was not correlated with N mineralization in the incubation, but was highly correlated with humus total N and N:P ratio, in both the 1st and 2nd years after outplanting.

252. Murray, M., ed. 1984. Forest classification at high latitudes as an aid to regeneration. Proceedings of a Fifth International Workshop. 15–17 August 1983, University of Alaska, Fairbanks, AK. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR. General Technical Report PNW-177. 56 p.

Contains 7 papers given at the workshop held in Aug. 1983 sponsored by the School of Agriculture and Land Resources, University of Alaska in cooperation with the Alaska Division of Forestry and the Alaska State Society of American Foresters: Packee, E.C. An ecological approach to forest management [pp. 5-15]; Pfister, R.D. Development and use of an ecological classification system [pp. 16- 19]; Draper, D.A., Hamilton, E.H. The importance of predictive models of forest succession to silvicultural management [pp. 20-24]; Viereck, L.A., Dyrness, C.T., Cleve, K. van. Potential use of the Alaska vegetation system as an indicator of forest site productivity in interior Alaska [pp. 25-34]; Zasada, J.C. Site

classification and regeneration practices on floodplain sites in interior Alaska [pp. 35-39]; Corns, I.G.W., Annas, R.M. Ecological classification of Alberta forests and its application for forest management [pp. 40-52]; and Stahl, P.H. How to choose site preparation methods based on site classification [pp. 53-56].

253. Murray, M.; Van Veldhuizen, R.M., eds. 1980. Forest regeneration at high latitudes: proceedings of an international workshop. 15–17 November 1979, Fairbanks, AK. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR. General Technical Report PNW-107. 52 p.

The proceedings of a workshop held in sponsored by the School of Agriculture and Land Resources Management, University of Alaska, the Bureau of Land Management, and the Division of Forest, Land and Water Management, Alaska Department of Natural Resources. There are 9 papers: Braathe, P. Developing a program for research and applied management related to forest regeneration - with special reference to Norway [pp. 5-6]; Weetman, G.F. The importance of raw humus accumulation in boreal forest management [pp. 7-9]; van Cleve, K.; Dyrness, T.; Viereck, L. Nutrient cycling in interior Alaska flood plains and its relationship to regeneration and subsequent forest development [pp. 11-18]; Gardner, A.C. Regeneration problems and options for white spruce on river floodplains in the Yukon Territory [pp. 19-24]; Zasada, J. Some considerations in the natural regeneration of white spruce in interior Alaska [pp. 25-29]; Kerr, C. Alaska regeneration: state policy and problems [pp. 31-34]; Remrod, J. Experiences and practices relating to forest regeneration in northern Sweden [pp. 35-41]; Putkisto, K. Site preparation techniques for reforestation in Finland [pp.43-48]; and Chrosciewicz, Z. Some practical methods for securing adequate postcut forest reproduction in Canada [pp. 49-52].

254. Naylor, B.J.; Bendell, J.F. 1983. Influence of habitat diversity on the abundance and diversity of small mammals in jack pine forests in Ontario. p. 295–307 *in* R.W. Wein, R.R. Riewe and I.R. Methven, eds. Resources and dynamics of the boreal zone: proceedings of a conference held at Thunder Bay, Ontario, August, 1982. Association of Canadian Universities for Northern Studies, Ottawa, ON.

Rodent and shrew populations were studied in pure and mixed jack pine forests in northcentral Ontario to determine how habitat diversity influenced the abundance and diversity of small mammals. Mixed forests were floristically more diverse and physiognomically more complex. Mixed forests contained a greater diversity of small mammals, but approximately the same total abundance as pure pine forests. Similar overall density resulted from a greater individual abundance of species in pure pine forests. Within forest types, changes in forest diversity with age apparently influenced rodent, but not shrew, diversity and abundance. The heather vole and masked shrew accounted for 71% of the total captures. Small mammals can be classified into three groups related to their apparent abundance in homogeneous, heterogeneous, or neither habitat type. Diversity and abundance of small mammals may influence their role in insect control, damage to forest regeneration, and nutrient cycling. Future research should quantify the value of small mammals to forest yield as predators of forest insects and as agents of accelerated nutrient cycling.

255. Newton, P.F.; Smith, V.G. 1991. Volume growth relationships within mixed black-spruce/balsam-fir stands. Forest Ecology and Management. 40(1-2):131–136.

Data from 58 semi-permanent sample plots (0.081 ha) in mixed black spruce (*Picea mariana*)/balsam fir (*Abies balsamea*) stands within central insular Newfoundland were used with linear regression models to describe the relation between relative volume growth of black spruce and balsam fir, and species-specific site occupancy variables. Tests of hypotheses concerning the significance of the site-occupancy variables were used to determine if species-specific effects existed. Results indicated that black-spruce relative growth was significantly affected only by black spruce, whereas balsam-fir relative growth was significantly affected by both black spruce and balsam fir. These results are consistent with the hypothesis that a one-sided dominance/suppression interspecific competitive relation exists between black spruce and balsam fir within mixed stands.

256. Nicolson, J.A. 1988. Alternate strip clearcutting in upland black spruce. V. The impact of harvesting on the quality of water flowing from small basins in shallow-soil boreal ecosystems. Forestry Chronicle. 64(1):52–58.

Streams flowing from 6 small basins (100-450 ha), dominated or originally dominated by *Picea mariana*, were monitored from 1978 to 1984 near Lake Nipigon, Ontario. Three basins were left unfelled and 3 were harvested, one by patch felling, one by clear felling and one by strip felling (in 1977, 1979 and 1981). Comparisons between samples from harvested and unfelled basins showed that water yield, specific conductance, alkalinity, Ca, Mg, K, Na, and HCO3 concentration were generally significantly greater in harvested basins. Nitrate N concentrations were generally smaller in harvested basins. Other differences in water chemistry were not significant.

257. Nicolson, J.A.; Foster, N.W.; Morrison, I.K. 1982. Forest harvesting effects on water quality and nutrient status in the boreal forest. p. 71–89 *in* National Research Council of Canada. Proceedings of the Canadian Hydrology Symposium '82: hydrological processes of forested areas. 14-15 June 1982, Fredericton, NB. Ottawa, ON.

Water samples were taken weekly from April to Oct. in 2 undisturbed catchments of jack pine/black spruce and in catchments clear felled 1, 3 and 4 years previously in NW Ontario. Results indicated that concentrations of N, P, Cl, K, and SO4 in runoff increased following clear felling but returned to pre-felling concentrations after 2 years. However, because runoff per unit area was increased by up to 98% by clear felling, total losses of N, Ca, Mg, P, Na, SO4 and Cl were much greater on clear-felled sites, reaching a maximum after 4 years. Using additional data from a previous study, it was estimated that losses from the tree and soil nutrient pool by crop removal using conventional shortwood harvesting may reach 35% of N and 20% of P.

258. Nietfeld, M.T.; Telfer, E.S. 1990. The effects of forest management practices on nongame birds: an annotated bibliography. Canadian Wildlife Service, Western and Northern Region, Edmonton, AB. Technical Report Series No. 112. 300 p.

This annotated bibliography contains over 700 references which deal with: (1) effects, direct and indirect, of forest management practices on nongame forest birds, covering such topics as logging, cut types, rotation periods, thinning, site preparation, plantations, pesticides, herbicides, burning and regeneration; (2) forest bird-habitat relationships in both natural and sites disturbed by forestry operations or other practices which would produce similar situations; (3) factors affecting species diversity and biogeography distributions; (4) the role of birds in the forest ecosystem; and (5) management and conservation considerations for nongame forest birds and some related techniques. The emphasis was placed on migratory songbirds in the boreal forest area. However, since few studies have investigated the effects of forestry practices on this category of birds in the boreal region, information was included for a variety of habitat types from all over North America, and a few from other regions. It was hoped that the findings and management considerations in these papers would provide useful information, and that some of the trends observed could be applied to the boreal region.

259. Nohrstedt, H.O. 1985. Nonsymbiotic nitrogen fixation in the topsoil of some forest stands in central Sweden. Canadian Journal of Forest Research. 15(4):715–722.

Topsoil nitrogenase activity was measured by the acetylene reduction method in 20 forest stands 40 to 120 years old and including coniferous and deciduous types. The purpose of the investigation was to examine N2 fixation by free- living heterotrophic micro-organisms in the topsoil (including ground vegetation and litter). The relations between nitrogenase activity and site productivity, stand composition, and soil properties were examined. Based on 3 samplings during the growing season, a considerable difference in activity was found to occur between the stands. The highest yearly mean activity for a stand was 200 X the lowest value. The activity was positively and significantly correlated with site productivity. The effect of stand composition on the activity in the forest floor was studied on 5 sites. The activity was similar under spruce (*Picea abies*) and pine (*Pinus sylvestris*), higher under spruce than beech (*Fagus sylvatica*), and

much higher under birch (*Betula pendula*) than spruce when compared two by two on identical parent material. The activity under birch was mainly concentrated in the birch leaf litter. Evaluating the influence of soil properties by regression analysis revealed a strong positive correlation between activity and pH. Soil acidity alone explained 85% of the variation in yearly mean activity among the 15 coniferous stands. The conversion factor between acetylene reduction and 15N2 fixation was determined for the 5 soils with highest nitrogenase activity and ranged from 1.6 to 5.6. N2 fixation down to a depth of 6 cm during the growing season was estimated as 0.4-1.4 kg/ha at 6 sites.

260. Norton, S.A.; Young, H.E. 1976. Forest biomass utilization and nutrient budgets. p. 55–73 *in* XVIth International Congress of IUFRO. 22 June 1976, Oslo, Norway. University of Maine, College of Life Sciences and Agriculture, Orono, ME.

Estimates of biomass and nutrient budgets are presented for sustained yield in a spruce/fir forest, harvested according to merchantable bole or complete-tree concepts, in a 40-yr rotation. Input in precipitation of the six nutrients evaluated was thought to be adequate when harvesting was limited to the merchantable bole; if the complete tree was harvested N, S, P and K became deficient.

261. Nykvist, N.; Rosén, K. 1985. Effects of clear-felling and slash removal on the acidity of northern coniferous soils. Forest Ecology and Management. 11(3):157–169.

Measurements of pH were carried out at two experimental sites in Sweden before and after clear-felling. At eleven sites, pH, cation-exchange capacity, base saturation and exchangeable hydrogen ions were compared in clear-felled areas where slash was left and removed, respectively. It is shown that pH increases significantly after clear- felling. The increase is larger than can be explained by the release of basic cations in connection with decomposition of slash and humus. The increase in pH is less in a clear-felled area when the slash is removed than when it is left. There is a decrease in exchangeable Ca+2, Mg+2 and Mn+2 and an increase in H+ and Al+3. There is a decrease in base saturation of about 80%.

262. Ontario Ministry of Natural Resources, Wildlife Branch. 1988. Timber management guidelines for the provision of moose habitat. Toronto, ON. 33 p.

The purpose of these guidelines is to assist forest and wildlife managers in planning timber management activities. In many circumstances, the practice of good timber management is consistent with good wildlife habitat management. The guidelines include general requirements and specific suggestions for providing habitat, although it is impossible to foresee every conceivable situation the manager might encounter. Moose range in Ontario encompasses a wide variety of physiographic site conditions. It extends from the western boundary of Ontario to the eastern border, and south to the edge of the Precambrian Shield. Habitat management for moose in northwestern Ontario may be substantially different from habitat management in eastern Ontario due to the diversity of site, climatic factors and other environmental conditions across the Province. Prescriptions for management vary. These guidelines provide the principles for moose habitat management which local managers can adapt to meet needs within their own district or region.

263. Outcalt, K.W.; White, E.H. 1981. Phytosociological changes in understory vegetation following timber harvest in northern Minnesota. Canadian Journal of Forest Research. 11(1):175–183.

Areas of 0.8 ha within an *Abies balsamea/Betula papyrifera* stand were subjected to: (a) full-tree logging with protective snow cover (winter 1974-75); (b) tree-length logging as (a), followed by prescribed burning in July 1975; (c) full-tree logging without snow cover in spring 1975. Occurrence and density of 54 spp. of woody and herbaceous understorey plants is tabulated for each treatment and a control site for 2 seasons after logging. New species invaded (a) and (c); changes in (b) were due primarily to the disappearance of species in burned-out areas. However, understorey production

increased on all sites, and by the end of the 2nd season above-ground biomass was (a) 3,847, (c) 4,516, and (b) 2,604 kg/ha, compared with 942 kg/ha for the uncut control.

264. Outcalt, K.W.; White, E.H. 1981. Understory biomass and nutrients 2 years after timber harvest in northern Minnesota. Canadian Journal of Forest Research. 11(2):305–308.

Adjacent areas within a 60-year-old *Abies balsamea/Betula papyrifera* stand in N. Minnesota, USA, were clear-cut by whole-tree logging or tree-length logging followed by prescribed burning. Two years after harvest, understorey biomass and nutrients were sampled on these sites and on an adjoining uncut control. All logged sites had significantly more total aboveground understorey biomass than the control. However, biomass of woody species on the tree-length logged burn area did not differ from the control site. Because of the greater biomass on harvested sites, nutrient accumulations (N, P, K, Ca, Mg) by the understorey were greater, with about 75% of these extra nutrients in herbs and shrubs. Although the quantity of nutrients in the understorey is less than that removed with the overstorey, it is important in maintaining the nutritional integrity of the system because it serves as a sink for available nutrients. From authors' summary.

265. Page, G. 1976. Quantitative evaluation of site potential for spruce and fir in Newfoundland. Forest Science. 22(2):131–143.

This paper examines relationships between site index of black spruce (*Picea mariana* (Mill.) B.S.P.) and balsam fir (*Abies balsamea* (L.) Mill.) and soil and topographic characteristics in two areas of Newfoundland. One hundred three quantitative variables were examined on 300 sample plots by multiple regression and principal component analysis. Equations, accounting for at least 60% of observed variation, were derived for predicting site index from soil and topographic characteristics. Soil moisture was most important, with soil nutrient status being of less, and topography of least, importance. Principal component analysis did not exceed multiple regression analysis in predictive ability, but was valuable in aiding biological interpretation of regression.

266. Paquin, R.; Doucet, R. 1992. Croissance en hauteur à long terme de la régénération préétablie dans des pessières noires boréales régénérées par marcottage, au Québec. Canadian Journal of Forest Research. 22(4):613–621.

Height-growth patterns of black spruce (*Picea mariana* [Mill.] B.S.P) in the boreal forest were studied in layer- origin stands released by clear-cutting in the first half of this century. Most stems responded to release brought about by clear-cutting of the main stand. Initially, small stems responded more rapidly and more strongly, but their height-growth rate culminated between 20 and 30 years following release, the same period when height-growth rate culminated for the taller, older stems. After the culmination period, growth rates were independent of height at the time of release. Consequently, the taller stems at time of release were able to maintain their dominant position. Height growth over the recent years indicates that this position could be maintained in the years to come, and even indefinitely. It seems that second-growth black spruce stands behave like even-aged stands despite their uneven-aged structure. Consequently, years since release and stem height are more accurate measures of stem effective age than total age. Moreover, the taller stems in the understorey, which are usually considerably older, should be considered to be as valuable as smaller regeneration when a stand is cut.

267. Paquin, R.; Doucet, R. 1992. Productivité de pessières noires boréales régénérées par marcottage à la suite de vieilles coupes totales au Québec. Canadian Journal of Forest Research. 22(4):601–612.

Five black spruce (*Picea mariana* [Mill.] B.S.P) stands originating from clear-cutting between 1924 and 1941 in the Baie-Comeau area of Quebec were studied to determine post-harvest growth. The analysis revealed that most stems originated from layers released by clear-cutting of the main stand. Present stem height is closely related to height at the time of release: stems that were taller at release are now generally dominant or codominant in the main canopy and tend

to contribute more to merchantable stand volume. Volume production of these stands is comparable to that of better sites of normal yield tables for black spruce. This means that black spruce layers occupying the understorey, including stems a few meters high, can lead to the establishment of productive stands when released by clear-cutting of the main stand. Despite the relatively advanced age of stems, decay does not seem to be more prevalent in these stands than in stands originating from seed, whose total age would be equivalent to release age of the stands studied.

268. Paré, D. 1990. Dynamics of nutrient cycling on post harvested white spruce sites in interior Alaska. Ph.D. thesis. University of Alaska, Fairbanks, AK. 196 p.

Various field and laboratory methods were used to characterize nutrient cycling on two mature white spruce sites, one recently harvested site and three 14-year-old harvested white spruce sites colonized by different plant communities and presenting different intensity of soil disturbance. Study sites were chosen on upland south facing sites and presented conditions of reduced environmental variability. Soil analysis showed no changes in pools of soil nutrient unless the forest floor was removed. On the other hand, some differences in the dynamics of nutrients were seen: (1) sites where the forest floor was removed showed low N mineralization rates; (2) N mineralization rates appeared faster in the surface soil of the recently harvested site than in mature white spruce sites; (3) the surface soil of sites regenerating to aspen showed the highest N mineralization rates of all 14-year-old sites. Field soil temperature, and field soil moisture content as well as N and lignin concentrations of the forest floor could not explain the differences in N mineralization rates between sites. This suggests that species colonization may influence N dynamics and that N cycling rate on regenerating sites is controlled by a small pool of rapidly cycling N. The determination of nutrient uptake and return by vegetation growing in the field indicated that nutrient cycling was much faster in 14-year-old aspen stands than on any other regenerating or mature site. The measurement of element availability with ion exchange resin bags indicated an increased leaching of nitrate, phosphate and sulfate at springtime, the second summer following harvesting. Poor correlations were obtained between conventional soil testing and ion exchange resin bag determinations. Comparisons between field and laboratory nutrient availability indices indicated that sites colonized by sprouting aspen exhibited the highest N cycling rates seen in this study. This observation makes aspen an interesting species to consider for mixed species management strategies.

269. Pastor, J.; Naiman, R.J. 1992. Selective foraging and ecosystem processes in boreal forests. American Naturalist. 139(4):690–705.

We suggest that selective foraging alters feedbacks between plants and decomposers and between plants and herbivores. Plant tissue chemistry is an important link between herbivores and decomposers. Plants that produce easily decomposable litter are also heavily browsed, because the same chemical properties that determine litter decay also determine digestibility. This trait links theories of food webs and nutrient cycles by posing a role of herbivores as functional switches determining both plant community composition and the array of litters returned to the soil. This role appears to be particularly strong in boreal forests, where nutrient availability is low and limits productivity and determines successional pathways, where effects of herbivores are strong and long lasting, and where the same plant traits that determine herbivore preference and response to browsing also determine interactions with soil nutrient availability. Such feedbacks cause the effects of herbivores on ecosystems to persist even after the herbivores are no longer present.

270. Payandeh, B. 1988. Preliminary yield functions and tables for spruce fir stands of northwestern Ontario. Canadian Forestry Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON. Information Report O–X–389. 11 p.

Linear and nonlinear regression models were used to estimate the growth and yield of the conifer component and the total stand (and by subtraction the broadleaf component) using data from 193 semipermanent plots in the spruce-fir type. Conifers (*Picea glauca*, *P. mariana* and *Abies balsamea*) form at least 60% of the stand volume, with *Betula papyrifera*, *Populus balsamifera* and *P. tremuloides* forming the rest. In general high and natural variability of the stands resulted in yield equations with low precision. Nonlinear models were more flexible and adaptable to natural growth processes

than linear models, although the latter gave a better fit. Tables show the effects of site productivity on yield components, mean annual increment and the age at which mean annual increment culminates.

271. Payandeh, B.; Sutton, R.F. 1989. Modeling early plantation performance: identification of critical factors. Scandinavian Journal of Forest Research. 4(1):75–86.

Four-year data (1973-77) on spring outplanted black spruce (*Picea mariana*), white spruce (*Picea glauca*) and jack pine (*Pinus banksiana*) in Ontario, Canada, (described more fully in an earlier paper) were subjected to stepwise multiple linear regression analysis with mixed models containing both continuous and categorical variables. Several treatments had been imposed on two provenances of seedlings of each species, including machine- and hand- planting in furrows or hand-planting on untreated ground, and heavy, light, or no NPK fertilizer application immediately after planting. Furrow depth, initial height, verticality, and direction of lean of each newly planted tree, and first- to fourth-year survival, growth, and condition were recorded. For each species, survival and total height equations are tabulated to show the proportion of variability explained by qualitative variables (site and stock factors), planting stock characters, and plantation age. Age accounted for 13-92% of the total variability in survival and growth. Planting without site preparation and heavy fertilizing were both significantly detrimental to survival and growth, but light fertilizing was sometimes beneficial. Provenance had little or no influence on results.

272. Perala, D.A.; Alban, D.H. 1982. Biomass, nutrient distribution and litterfall in *Populus*, *Pinus* and *Picea* stands on two different soils in Minnesota. Plant and Soil. 64(2):177–192.

Pole-sized stands of (1) *Populus tremuloides*, (2) *Picea glauca*, (3) *Pinus resinosa* and (4) *Pinus banksiana* on very fine sandy loam and loamy sand. Species ranking in above- ground biomass (3 more than 1 more than 2 more than 4) and above-ground tree nutrients (1 more than 2 more than 3 more than 4) were the same on both soils. Particularly large proportions of biomass and nutrients were found in aspen bark and spruce foliage and branches; harvesting entire above-ground trees would remove up to 3 times more nutrients than harvesting the bole alone.

273. Perry, D.A.; Rose, S.L. 1983. Soil biology and forest productivity: opportunities and constraints. p. 229–238 *in* R. Ballard and S.P Gessel, eds. IUFRO symposium on forest site and continuous productivity. 22–28 August 1982, Seattle, WA. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR. General Technical Report PNW-163.

Various soil microbes may have a positive influence on tree growth. Effects of mycorrhizae are numerous and well known. Other microorganisms play a role in higher plant defense against pathogens. Site disturbance, such as clearcutting and slash burning, had profound, sometimes persistent, effects on the soil microbial community. Mycorrhizal formation may be decreased in disturbed soils, though this does not always happen. Burning results in a dramatic increase in the numbers of bacteria relative to fungi, and also alters species composition within the bacterial community. These changes can result in increased pathogenicity to tree seedlings.

274. Pierce, R.S.; Hornbeck, J.W.; Martin, C.W.; Tritton, L.M.; Smith, C.T.; Federer, C.A.; Yawney, H.W. 1993. Whole-tree clearcutting in New England: manager's guide to impacts on soils, streams, and regeneration. USDA Forest Service, Northeastern Forest Experiment Station, Radnor, PA. General Technical Report NE-172. 23 p.

Intensively harvested forests in New England have shifted partially from conventional stem-only clearcutting using chainsaws and skidders to whole-tree clearcutting using harvesting machines. We have studied the impacts of whole-tree clearcutting on soil, water, and revegetation in spruce-fir, northern hardwood, and central hardwood forest types. This report summarizes the relevance of our findings to forest management and suggests various management considerations,

guidelines, and further readings. The intended audience consists of practicing foresters, land managers, environmental protection agencies and organizations, and the general public.

275. Plexman, C.A. 1988. 1988 supplement to the bibliography of Great Lakes Forestry Centre publications. Forestry Canada, Great Lakes Forestry Centre, Sault Ste. Marie, ON. 20 p.

276. Plexman, C.A. 1989. 1989 supplement to the bibliography of Great Lakes Forestry Centre publications. Forestry Canada, Great Lakes Forestry Centre, Sault Ste. Marie, ON. 48 p.

277. Plexman, C.A. 1978. Bibliography of Great Lakes Forest Research Centre publications 1965–1977. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. Information Report O–X–279. 108 p.

278. Plexman, C.A. 1982. Bibliography of Great Lakes Forest Research Centre publications 1978–1982. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. Information Report O–X–345. 94 p.

279. Plexman, C.A. 1987. Bibliography of Great Lakes Forestry Centre publications 1983–1987. Canadian Forestry Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON. Information Report O–X–388. 95 p.

280. Pritchett, W.L. 1979. Properties and management of forest soils. John Wiley & Sons, New York, NY. 500 p.

A book for advanced students and practising foresters providing current information on the fundamental properties and processes of forest soils, with particular reference to the application of soil science to silviculture. Special attention is given to recent advances in intensive management of soils of short- rotation plantations, and to the effect of such practices on the environment. The first part of the book (Properties and dynamic processes) has 13 chapters: Introduction; Forest soils and vegetation development; Soils associated with major forest biomes; The forest floor; Forest soil biology; Chemical properties of forest soils; Physical properties of forest soils; Soil water: measurement and movements; Forest soils and the hydrological cycle; Soil and roots; Mycorrhizae: forms and functions; Nutrient cycling in forest ecosystems; Soil properties and site productivity. The second part has 10 chapters: Classification of forest lands; Soils and silviculture; Management of nursery and seed orchard soils; Management of problem soils; Diagnosis and correction of nutrient deficiencies; Fertilizer materials and their reactions in forest soils; Operational techniques in forest fertilization; Secondary and off-site effects of chemical use in forests; Effects of fire on soils and site; Intensive management and long-term soil productivity.

281. Probst, J.R. 1988. Kirtland's warbler breeding biology and habitat management. p. 28–35 *in* T.W. Hoekstra and J. Capp, compilers. Integrating forest management for wildlife and fish. USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN. General Technical Report NC-122.

The Kirtland's warbler is an early succession, area sensitive species seldom found in stands smaller than 30 to 40 ha. This warbler occupies dense jack pine stands where trees are from 6 to 23 years old and from 1.7 to 5.0 m high growing on poor, sandy soils. Typically, it has been found in areas regenerated naturally by serotinous cones resulting from wildfires. In the past two decades, however, Kirtland's warblers have been found in naturally regenerated, unburned jack pine and in densely stocked pine plantations. Stands are managed on a 50 year rotation and clustered into discrete management areas. Extensive dispersal to find suitable habitat reduces breeding opportunities. Currently, about 15% of the males abandon territories, and about 15% of resident males do not find mates. Clustering stands into management units and staggering the schedule of stand regeneration should minimize biogeographic dispersal problems. Because

Kirtland's warblers colonize patches of taller, dense jack pine before they occupy habitat with shorter or less dense trees, the period of Kirtland's warbler occupancy in a management area can be extended by several methods such as varying tree spacing in a plantation. Researchers and managers have developed a variety of harvest options, site preparation methods, and pine regeneration alternatives for providing suitable Kirtland's warbler habitat. Several options do not require the use of prescribed fire. These management alternatives must not only provide suitable tree stocking and spacing for the Kirtland's warbler but also accommodate their spatial and temporal needs such as the size, chronology, and age diversity of stands.

282. Racey, G.D.; Reynolds, R. 1989. An examination of cutting patterns proposed in the Guidelines for the Protection of Tourism Values. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Note TN-05. 8 p.

This document looks at several modified cutting patterns and relates the harvest and site features to the practicality of using these patterns for the protection of aesthetic values. In addition, it lists many examples of modified cutting patterns in Northwestern Ontario which will encourage managers to become familiar with various cutting patterns and their effectiveness.

283. Raison, R.J. 1984. Potential adverse effects of forest operations on the fertility of soils supporting fast growing plantations. p. 457–472 *in* D.C. Grey, A.P.G. Schonau and C.J. Schutz, eds. Symposium on site and productivity of fast growing plantations. 30 April–11 May 1984, Pretoria and Pietermaritzburg, South Africa. Vol. 1. South African Forest Research Institute, Pretoria, South Africa.

Intensive forest practices which result in high rated of biomass (and nutrient) export and frequent marked disturbance of the site during soil preparation and harvesting have the potential to adversely affect soil fertility and hence the productivity of subsequent tree crops. With use of short rotations and a high degree of utilization of biomass, both the rate of nutrient removal in biomass and the nutrient cost (weight of nutrient per unit of harvested biomass) can be increased by up to five fold; nutrient cost is very high for young trees (e.g. thinnings) and where crown components are harvested. In addition to direct removal of nutrients in biomass, major losses can also result from soil erosion, leaching and transfer to the atmosphere in fires. These indirect losses by erosion and atmospheric transfer are less predictable than those associated with biomass harvest, but can be quantitatively more important. Site disturbance can also result in soil compaction, loss of organic matter and undesirable redistribution of soil (e.g. into windrows); all of which may have adverse effects on the environment of tree roots and the ability of the soil to store and supply water and nutrients. It is difficult to assess quantitatively the effects of intensive forest practices on subsequent site-productivity. Most judgements are either qualitative, relying on established principles (e.g. depletion of soil organic matter is undesirable), or simplistic (e.g. consideration of gross nutrient balance, or comparison of average rates of nutrient output and input). Despite these limitations, sufficient information exists to enable identification of high risk situations, and to rank management options in terms of their likely effects. Progress towards more quantitative (modelled) assessments is hampered by inadequate understanding of factors controlling rates of nutrient supply and uptake in soils.

284. Ranger, J.; Bonneau, M. 1986. Predictable effects of intensifying production and harvesting on the fertility of forest soils. Part 2. The effects of silviculture. Revue forestière française. 38(2):105–123.

A discussion of the effects on nutrient removal of different tree species, rotation length and the amount of the biomass produced that is harvested. For every combination of these factors an assessment can be made of the input/output nutrient balance of the rotation. It appears that a change to shorter rotations leads to a deficit of all the major elements in most forest soils.

285. Ray, P.N. 1985. An approach to evaluating site productivity response for black spruce (*Picea mariana* (Mill) B.S.P.) of the Ontario clay belt. Ph.D. thesis. University of Toronto, Toronto, ON.

Traditional site evaluation methods may not reflect possible improvements in the inherent productive capacity of site. This study aimed at improving conventional methods by developing techniques which can predict potential growth response to silvicultural practices. Fertilization treatment was adopted as a representative site manipulation technique and a standard application was tested on diverse natural stands of black spruce in the Ontario Clay Belt. The stand reaction to treatment was measured in terms of: (1) nutrient concentration, (2) nutrient content, and (3) dry weight of fall-sampled current foliage. A short term foliar nutrient index was derived to predict potential treatment response and was termed Productivity Response Index (PRI). PRI was subsequently tested for correlation with traditional measures of site which included site indices, pretreatment chemical properties of soil, foliar nutrient composition, plant indicator systems, and stand mensurational parameters. Regression and discriminant analysis were used to predict PRI and classify the response potential of sites. Foliar response varied over the range of site conditions encountered. Instances of deficiency, luxury consumption and antagonism were detected in a comparative foliar diagnosis, and nitrogen (N) was diagnosed as the major limiting nutrient constraining growth. The relative response in foliar N content was adopted as PRI since it represented the uptake of N committed to growth. In general, PRI correlated poorly with all pretreatment variables except untreated current foliar N content and a specific nutrient-related gradient of a Forest Ecosystem Classification scheme. Discriminant analysis identified site populations of responsive and nonresponsive stands more efficiently compared to conventional regression approaches (83 vs 59% correct classification). A quadratic discriminant model was developed using the 8 variables: dry weight and N content of current foliage, mineralizable NH4-N and organic carbon (C) of forest floor, C/N ratio and N content of intensive rooting zone, current volume and basal area of sample stands. The study showed that traditional site-index methods were not precise for predicting stand response to silvicultural treatment. A multivariate approach using stand, foliar and soil properties proved to be effective in classifying potential responsiveness to site manipulation.

286. Rennie, P.J. 1988. Annotated bibliography of openly available published reports, 1950 to 1987 written by Peter J. Rennie. Canadian Forestry Service, Ottawa, ON. 74 p.

The reports are listed chronologically and cover research on nutrition and site-preparation problems on poor soils in the UK during 1947-56 and research on forest nutrition, site classification, site productivity and air pollution in Canada since 1958.

287. Richardson, R.; Henderson, B. 1993. Harvesting systems and their environmental impacts: a summary of current knowledge and research needs. Prepared by FERIC for Forestry Canada. Contract #: 4Y050-91-1065.

This report provides information on the types of harvesting systems used in Canada. It also reviews the literature on the environmental impacts of harvesting on soils, the timber resource, water, fish and wildlife habitat, and social aspects. Eight matrices providing an assessment of the amount of publications found dealing with particular combinations of systems and environmental topics in both clearcut and partial cut applications are given. Recommendations on areas requiring further research are formulated.

288. Robbins, C.S. 1979. Effect of forest fragmentation on bird populations. p. 198–212 *in* R.M. DeGraaf and K.E. Evans, compilers. Management of north central and northeastern forests for nongame birds: workshop proceedings. 23–25 January 1979, Minneapolis, MN. USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN. General Technical Report NC-51.

Many of the insectivorous songbird species that winter in the tropics are dependent on large unbroken tracts of forest during the breeding seasons. These species are disappearing from localities where forests are becoming fragmented. By long-range planning, managers can prevent local extinctions of these area-sensitive birds through use of such

techniques as management in large units, retention of connecting corridors, and prevention of excessive isolation of forest fragments. Edge conditions can be provided, where appropriate to meet the needs of upland game species.

289. Robinson, F.C. 1987. Alternate strip clearcutting in upland black spruce. I. An introduction. Forestry Chronicle. 63(6):435–438.

This paper in the introduction to a workshop on the subject of alternate strip clearcutting in upland black spruce. The workshop, held on 24 and 25 June 1986, represents a 10-year review of the project that includes studies of economics, regeneration, environmental impacts, and planning and implementation. A historical background of the project and a list of papers are given. A set of general recommendations, arising from deliberations and discussions by workshop participants, is presented.

290. Romberger, J.A.; Mikola P., eds. 1964. International Review of Forestry Research. Vol. 1. Academic Press, New York. 404 p.

The first volume of this series of literature reviews, edited by J.A. Romberger and P. Mikola contains: History of the international science of forestry with special consideration of Central Europe (K. Mantel) [discussing developments in research, literature and training in Germany and France]; Improvement of forest growth on poorly drained peat soils (L. Heikurainen); Determination of nutrient requirements of forest stands (C.O. Tamm) [includes methods and a critical evaluation of results]; Evaluation of forest site productivity (C.W. Ralston); Anatomy, chemistry, and physiology of bark (L.M. Srivastava) [chiefly on the bark of old stems]; Physiological processes in forest tree seeds during maturation, storage, and germination (K.I. Hatano and S. Asakawa) [including recent advances in seed testing]; and Harmonious control of forest insects (A.D. Voute) ['harmonious control' is a newly coined term to cover the integration of all types of control, including prophylactic, silvicultural and other nontoxic measures].

291. Ruel, J.C. 1992. Abondance de la régénération 5 ans après la coupe à blanc mécanisée de peuplements d'épinette noire (*Picea mariana*). Canadian Journal of Forest Research. 22(11):1630–1638.

Regeneration was studied 5 years after harvesting on 128 permanent blocks located before logging in black spruce (*Picea mariana* (Mill.) B.S.P.) stands. Regeneration after 5 years was related to the abundance of advance growth, mainly black spruce layers. Regeneration also differed with the harvesting system used. Best results were obtained with the use of feller-forwarders while tree- length harvesting gave the lowest softwood stockings. Regional climax and soil texture also had an effect, mostly by modifying the advance growth abundance. The better softwood stocking observed in thick humus and in the black spruce-moss climax zone was related to higher precutting regeneration levels. The regeneration problems observed on coarse textured soils were also associated with initial differences in the amount of advance growth. The duration of spruce budworm (*Choristoneura fumiferana* (Clem.)) infestations seemed to have an impact on the regeneration of the stands studied. Hardwoods regeneration, mostly white birch (*Betula papyrifera* (Marsh.)), became established after logging or after defoliation by the spruce budworm. Their abundance was also dependent on regional climax and soil texture.

292. Ruel, J.C. 1989. Mortalité du bois laissé sur pied à la suite d'une coupe par bandes dans trois régions du Québec. Forestry Chronicle. 65(2):107–113.

This paper presents the results of a three-year study of mortality in black spruce leave strips. The effects of various stand and strip layout characteristics are considered and recommendations made for reducing blowdown are also provided. Mortality over the three years was highest in the Abitibi region of Quebec (20.2% of initial stand volume) and lowest in the Lac-Saint-Jean area (8.8% of initial stand volume). The Maurice region was intermediate (17.4% of initial stand volumes). Most of the mortality occurred during the second year. In the Abitibi region, losses tended to increase in the

leave strips when stand height was higher than 17 m and when leave strips were oriented SE to NW. In the Maurice region, mortality increased with stand height and initial volume. In the Lac-Saint-Jean area, losses also increased with stand height but mortality remained relatively low.

293. Ruel, J.C. 1989. Régénération des interbandes dans un système de coupe par bandes de peuplements d'épinette noire. Forestry Chronicle. 65(5):372–376.

A study on the regeneration of leave strips in an alternate strip clearcutting system was conducted in black spruce stands (*Picea mariana* [Mill.] B.S.P.) in Abitibi in northwestern Quebec. The study consists of 49 leave strips scheduled for harvesting and 24 adjacent first-cut strips. Winter harvesting gave the best results while a prescription aiming at preserving advance growth did not result in any gain. Site moisture regime and harvesting system had no effect on advance growth destruction. Regeneration on first-cut strips was not significantly affected by the cutting of the leave strip.

294. Samoil, J.K.; Turtle, G.B. 1988. Northern Forestry Centre publications, 1980–86. Canadian Forestry Service, Northern Forestry Centre, Edmonton, AB. Information Report NOR-X-297. 36 p.

Scientific, technical, and interpretive publications written by staff of the Northern Forestry Centre or published by the Centre during 1980-86 are listed alphabetically by author. A subject index is provided for the main entries. In addition, there is an appendix listing reports prepared under the federal-provincial forestry development agreements for Alberta, Saskatchewan, and Manitoba.

295. Schmidt, M.G.; Carmean, W.H. 1987. Jack pine site quality in relation to soil and topography in north central Ontario. Canadian Journal of Forest Research. 18(3):297–305.

Site index for jack pine (*Pinus banksiana* Lamb.) was determined by stem analyses using dominant and codominant trees on each of 99 site plots located in mature, well- stocked, even-aged jack pine stands. Plots located on four major glacial soil groups showed a wide range of site index within each soil group. Separate multiple regression analyses showed that site index was significantly related to different soil and topographic features for each soil group: a) morainal soils shallow to bedrock, R^2=0.83; b) deep morainal soils, R^2=0.65; c) outwashed glacial sands, R^2=0.65; and d) glacial lacustrine soils, R^2=0.75. The results indicate that site quality for jack pine on each of these four general soil groups is related to soil features associated with the quantity and quality of soil most favorable for root development. Results are illustrated by trend graphs, and site index prediction tables are given for each of the four soil groups.

296. Scott, C.T.; Voorhis, N.G. 1986. Northeastern forest survey site index equations and site productivity classes. Northern Journal of Applied Forestry. 3(4):144–148.

Polymorphic site index equations for 19 species in northeastern USA are presented for use in determining site productivity class. The equations were developed from existing site index tables and equations. A listing is given of the BASIC program for computing site index and age to b.h.

297. Scotter, G.W. 1963. Effects of forest fires on soil properties in Northern Saskatchewan. Forestry Chronicle. 39(4):412–421.

The effects of forest fires on some physical and chemical soil properties in the Black Lake region were determined on four burned-over areas, and results were compared with corresponding mature forested areas. Formerly, two of the burns supported jack pine forests and the other two black spruce forests. Temperatures at the 1-inch and 3-inch depths in the burned-over soils averaged 10.5 and 9.7° F. respectively, higher than soil temperatures under mature forests. Water

infiltration rates, compared at one location only, were not impaired. Erosion after fire was slight. Total exchange capacity decreased on three of the four burns. Exchangeable H was reduced and available P increased on all four burns, while exchangeable Ca increased on three of them. No conclusions could be reached for alterations in total N, exchangeable Mg, K, and Na. On all the burned-over areas, acidity decreased at 1-inch and 3-inch depths. Forest fires influence both chemical and physical soil properties on the winter range of barren-ground caribou in northern Saskatchewan. These alterations may be important in changing the habitat to one less favourable for the germination and growth of preferred food plants. From author's summary.

298. Shetron, S.G.; Sturos, J.A.; Padley, E.; Trettin, C. 1988. Forest soil compaction: effect of multiple passes and loadings on wheel track surface soil bulk density. Northern Journal of Applied Forestry. 5(2):120–123.

The change in wheel track surface soil bulk densities was determined after a mechanized thinning in a northern red oak [*Quercus rubra*] stand in Washburn, Wisconsin, USA. Mean bulk density values of the 0 to 5 cm surface of the wheel tracks immediately after felling, bunching, and skidding were: 0.80 g/cm3 on the high use areas; 0.77 g/ cm3 on the low use areas; and 0.42 g/cm3 in the undisturbed areas. No significant differences in surface soil bulk densities were found between several loading treatments using a four-wheel drive articulated forwarder. This suggests that initial passes of the equipment produced most of the disturbance. No significant recovery in wheel track soil bulk densities occurred during the year following harvest, regardless of treatment.

299. Shoulders, E.; Wittwer, R.F. 1979. Fertilizing for high fiber yields in intensively managed plantations. p. 343–359 *in* A.L. Leaf, chairman. Impact of intensive harvesting on forest nutrient cycling. 13–16 August 1979, State University of New York, Syracuse, NY. State University of New York, College of Environmental Science and Forestry, Syracuse, NY.

About 300 kg of N, 45 kg of P, 200 kg of K, 50 kg of Mg, and up to 600 kg of Ca per ha per decade can be removed in trees managed for maximum fiber production. Such removals will eventually deplete reserves of even the most fertile sites. Because trees are inefficient in recovering fertilizer, applications of up to 700 kg of N, 150 kg of P, and 440 kg of K per ha in 10 years may be required to maintain site productivity. Additional research is needed to develop specific fertilizer prescriptions.

300. Shugart, H.H.; Leemans, R.; Bonan, G.B., eds. 1992. A systems analysis of the global boreal forest. Cambridge University Press, Cambridge, UK. 565 p.

The boreal forests of the world, occupying some 15 million square kilometres over North America and Eurasia, are a major source of softwood timber and are expected to play a significant role in the response of vegetation to global climate change. This book, developed by an international panel of ecologists, provides a synthesis of the important patterns and processes that occur in boreal forests and reviews the principal mechanisms that control the forests' pattern in space and time. The effects of low temperatures, soil ice, insects, plant competition, wild- fires and climatic change on boreal forests are discussed as a basis for the development of the first global scale computer model of the dynamical change of a biome, able to project the change of the boreal forest over timescales of decades to millennia, and over the global extent of this forest.

301. Silkworth, D.R.; Grigal, D.F. 1982. Determining and evaluating nutrient losses following whole tree harvesting of aspen. Soil Science Society of America Journal. 46(3):626–631.

Nutrient loss following whole-tree harvesting of aspen (*Populus tremuloides* Michx.) was assessed on coarse-loamy Typic Fragiochrepts in northeastern Minnesota. A methodology was used that could be applied to other systems to roughly estimate the impact of harvesting on nutrient capital. Ceramic cups collected soil solution through the frost-free season at 130 cm on sites harvested 1, 2, and 5 years before and on undisturbed sites (total = 24). Nutrients in vegetation, soil, and forest floor were also determined. An evapotranspiration model predicted the flux of water moving through the soil.

Soil solution concentrations peaked in midsummer. Nitrogen concentrations in solution were below detection limits, and P concentrations were not related to harvesting. Potassium in soil solution decreased, and Ca and Mg increased on harvested sites compared to undisturbed sites. After adjusting for leaching flux, only Ca showed a statistically significant loss associated with harvest in the first 5 years after the harvest (60 kg/ha). Over a 60- year rotation, precipitation and normal weathering will replace N, P, and K lost by product removal and deep leaching, will replace about one-half the Mg, but will not replace Ca. Because of their initial abundance in the soil, Ca and Mg will probably not become nutritionally deficient, but their loss may lead to accelerated soil acidification and associated secondary effects.

302. Sims, H.P. 1976. The effect of prescribed burning on some physical soil properties of jack pine sites in southeastern Manitoba. Canadian Journal of Forest Research. 6(1):58–68.

Three clear-felled sites, with sandy soils and a shallow organic layer, that formerly supported *Pinus banksiana*, were subjected to three prescribed burns under various conditions. The average temperatures ranged from less than 52° C at 5-cm depth to 300° C at the mineral soil/humus interface. The most severe burn increased the weight of organic horizons by 7% owing to deposition of fuel residues (slash), while the least severe burn caused a 31% reduction in the weight of the organic mantle. During a 30-day rain-free period, soils at 3.8 and 7.6 cm under burned seedbeds reached permanent wilting point after 9 and 23 days, respectively, whereas soils at similar depths in an adjacent scarified area remained above permanent wilting point throughout the 30 days. 'High-hazard' prescribed burning may cause regeneration failures.

303. Sims, H.P. 1975. Temperature and moisture conditions on a plowed jack pine strip cut in southeastern Manitoba. Canadian Journal of Forest Research. 5(4):541–545.

Soil moisture, maximum surface temperatures and duration of critical temperatures for *Pinus banksiana* seedlings were measured across a scarified E.-W. strip on a dry site. Temperatures were significantly less severe on the southern third of the strip, and usually more favourable on the S. side and in the trough of the ploughed furrows. Soil moisture remained within the available range (1/3-15 atm) at depths of 3.8 and 7.6 cm under undisturbed and trough seedbeds throughout the growing season. Results indicate that moisture deficiency and temperatures lethal to germinants exist on all seedbeds of this site in weather normally to be expected in the area. The site is considered to be more suitable for planting than for direct sowing, and the more uniform moisture under the trough of the furrows suggests that this position is most favourable for planting.

304. Sims, R.A.; Kershaw, H.M.; Wickware, G.M. 1990. The autecology of major tree species in the North Central Region of Ontario. Forestry Canada, Ontario Region, Sault Ste, Marie ON / Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. COFRDA Report 3302 / NWOFTDU Technical Report 48. 126 p.

This report provides information on the autecology of twelve commercial tree species occurring in the North Central (NC) Region of Ontario. It is intended to provide forest and resource managers working in the NC Region with summarized ecological information for the following common forest trees: balsam fir (*Abies balsamea*), white spruce (*Picea glauca*), black spruce (*Picea mariana*), tamarack/ eastern larch (*Larix laricina*), jack pine (*Pinus banksiana*), red pine (*Pinus resinosa*), white pine (*Pinus strobus*), eastern white cedar (*Thuja occidentalis*), balsam poplar (*Populus balsamifera*), trembling aspen (*Populus tremuloides*), white birch/paper birch (*Betula papyrifera*), and black ash (*Fraxinus nigra*). Based on the Northwestern Ontario Forest Ecosystem Classification's extensive databases, vegetation, soil, and site conditions associated with each species are summarized for the NC Region. Common autecological properties that relate to each species' survival, establishment, reproduction, and growth are briefly described.

305. Sims, R.A.; Towill, W.D. 1988. Alternate strip clearcutting in upland black spruce. VIII. Shallow-soil ecosystems and their classification. Forestry Chronicle. 64(1):70–75.

Current definitions for shallow soils are briefly described and silvicultural practices in use are summarized. Research on a forest ecosystem classification for N. central Canada, started in 1983, is discussed, in which 9 shallow soil types on boulder pavement or bedrock are recognized. These are differentiated mainly on the basis of depth to rock contact, thickness of surface organic material and the texture of the primary mineral soil particles.

306. Sims, R.A.; Uhlig, P. 1992. The current status of forest site classification in Ontario. Forestry Chronicle. 68(1):64–77.

Forest sites are diagnostic forest-landscape ecosystem units that resource managers must deal with during the planning and implementation stages of management. Forest sites are the basic building blocks for undertaking integrated resource management which weighs wildlife, recreation, environmental impact and various other concerns along with timber harvesting. Consequently, accurate and practical systems for classifying and mapping forest sites are becoming increasingly necessary to organize, communicate and use existing and new management knowledge and experience effectively. Over the past four decades in Ontario, a number of studies and resource surveys have provided important background information of forest sites. Many have considered, to varying extents, the integrative roles of vegetation, soil-site, landform and general climate on forests and forest land. Generally, the emphasis has been on description and classification, with results generating a better understanding of how various forests in different areas develop, both qualitatively and quantitatively, in relation to soil-site or other features of the basic land resource. Some of these studies and surveys have been instrumental in advancing the definitions and understanding of forested ecosystems. Others have provided new information on site dynamics, interrelationships and functions, or have contributed to the science (and art) of site evaluation and classification. This paper briefly summarizes the current status of forest site classification in Ontario. Over time, the role of forest site classification has evolved in response to new technologies and information, and to new emphases and values in resource management. In general, site classification has become increasingly integrative and quantitative. Some of the important future challenges facing forest site classification in Ontario are briefly discussed.

307. Smith, C.R. 1984. Precommercial thinning in jack pine with particular reference to experiments in northeastern Ontario. p. 122–130 *in* C.R. Smith and G. Brown, cochairmen. Jack Pine Symposium. 18–20 October 1983, Timmins, ON. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. COJFRC Symposium Proceedings O-P-12.

The growth response of jack pine (*Pinus banksiana* Lamb.) to precommercial thinning is discussed. Special reference is made to the height and diameter response of individual trees in three different stands in northeastern Ontario thinned at ages 9, 22 and 33 years, respectively. Height response was not positive, but trees in all three age classes responded positively in terms of diameter growth. Because of lower treatment costs in the younger stands and a period of unproductive growth associated with older, over-dense stands, thinning is best done in stands that are between 10 and 15 years of age.

308. Smith, C.R.; Brown, G., cochairmen. 1984. Jack Pine Symposium. 18–20 October 1983, Timmins, ON. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. COJFRC Symposium Proceedings O-P-12. 195 p.

Discusses the state-of-the-art of jack pine management in Ontario and presents findings of recent research into the species. Papers also cover seed collection and various aspects of plantation management.

309. Smith, C.R.; Ryans, M.; Leblanc, J.D. 1985. Evaluation of the effect of tree-length and full-tree harvesting on the performance of three scarifiers. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. Joint Report No.6 / FERIC Special Report SR-26. 38 p.

A TTS-35 disc trencher, Leno 77 patch scarifier and Bräcke 2-row cultivator were evaluated in a jack pine stand in northeastern Ontario to determine the effects of tree- length and full-tree harvesting on their productivity and site preparation quality. Single passes on the areas logged by the full-tree method were compared with double passes on the areas logged by the tree-length method. Double coverage reduced overall productivity, but the dense slash associated with tree-length logging did not appear to influence the manoeuvrability of the three machines. Operator experience, power of the prime mover, treatment pattern, hitch type and terrain obstacles other than slash had greater effects on productivity than slash. However, the amount and type of slash on sites logged by tree-length methods clearly limited site preparation in terms of production of planting spots and receptive seedbed. None of the machines could cope satisfactorily with slash (< 1 year old) from tree-length logging.

310. Smith, C.T.; Hornbeck, J.W.; Martin, C.W.; Turcotte, D.E. 1987. Impact of intensive harvesting on the spruce-fir ecosystem: relationship to soil drainage class. p. 41–50 *in* T.M. Williams and C.A. Gresham, eds. Predicting consequences of intensive forest harvesting on long-term productivity by site classification. Proceedings of a workshop held at Hobcaw Barony, Georgetown, SC, October 2–9, 1987.

The impacts of whole-tree clearcutting on nutrient cycling and site productivity have been studied in the red spruce–balsam fir type of northern Maine using the paired watershed approach. Whole-tree clearcutting removed about 90 percent of the above-ground nutrients. These removals were much larger than the stream-water losses that occurred in the first three years after harvest. Site classification by soil drainage class was important for understanding the impacts of the harvest. The nutrient losses associated with nitrate leaching after harvest were greatest on the moderately-well drained soils, and negligible on the wetter soils of the Chesuncook catena. Mechanical harvesting equipment caused greater disturbance on the somewhat-poorly and poorly drained soils than the moderately-well drained soils. Severe mechanical disturbance can reduce the productivity of the next rotation on this catena when it results in deep ruts on the wetter soils, which were often filled with water, and because of the low nitrogen content of the exposed subsoils on scarified areas.

311. Smith, C.T., Jr. 1984. Intensive harvesting residue management alternatives and nutrient cycling in the spruce fir (*Picea rubens* Sarg. *Abies balsamea* (L.) Mill.) type: the Weymouth Point study. College of Forest Resources, University of Maine, Orono, ME. CFRU Progress Report No. 26. 42 p.

The report summarizes studies of soil profiles, nutrients in litter and mineral soil, soil solution chemistry and biomass of red spruce and balsam fir before harvesting. The area was harvested in summer 1981 with feller- forwarders or with a feller-buncher and grapple skidder. Residues were removed totally, or spread across plots with or without chipping. Dry weight of residues and soil disturbance were determined after harvesting.

312. Smith, C.T., Jr. 1985. Literature review and approaches to studying the impacts of forest harvesting and residue management practices on forest nutrient cycles. College of Forest Resources, University of Maine, Orono, ME. CFRU Information Report 13. 34 p.

This paper summarizes the literature that provided background information for the Weymouth Point Study. The study was initiated by the Cooperative Forestry Research Unit (College of Forest Resources, University of Maine at Orono), the US Forest Service, Forestry Sciences Laboratory, Durham, NH, and Great Northern Paper, Millinocket, ME, to determine whether whole-tree harvesting stands of red spruce (*Picea rubens* Sarg.) and balsam fir (*Abies balsamea* (L.) Mill.) on glacial till soils of north-central Maine might reduce site fertility.

312. Smith, C.T., Jr.; McCormack, M.L., Jr.; Hornbeck, J.W.; Martin, C.W. 1986. Nutrient and biomass removals from a red spruce–balsam fir whole-tree harvest. Canadian Journal of Forest Research. 16(2):381–388.

Mechanized, whole-tree harvesting was performed on a catchment area on Weymouth Point, Maine, dominated by *Picea rubens* and *Abies balsamea*. The harvest removal and redistribution of biomass, N, P, Ca, Mg and K were estimated. Regression equations were developed to estimate the nutrient contents and DM of the aboveground components of the tree species. Unit area estimates were made of exchangeable and total nutrients contained in the forest floor and glacial till above a hardpan. The harvest removed 90% of the biomass, 91% of the N, P, K and Ca and 90% of the Mg in the above-stump portions of the forest. These removals were 2- to 4-times the amounts of nutrients that would have been removed by a stem-only harvest, while increasing biomass removal by 1.4 times. The nutrients removed by the harvest were 0.1-5% of the total soil reserves.

314. Smith, D.W. 1970. Concentrations of soil nutrients before and after fire. Canadian Journal of Soil Science. 50(1):17–29.

Gives details of changes in soil organic matter, pH, and soluble salts in the 15 months after a severe fire in *Pinus banksiana* barren lands in northern Ontario. The organic matter in the L-H horizons was reduced to 9-21% of its original value. Large amounts of nutrients from the L- H horizons and the top 0-2 cm of mineral soil were either redistributed in the mineral soil or removed by leaching. Leaching of Na, P, and Ca was greatest in the first 3 months after the fire.

315. Sollins, P.; Means, J.E.; Ballard, R. 1983. Predicting long-term effects of silvicultural practices on forest site productivity. p. 201–211 *in* R. Ballard and S.P Gessel, eds. IUFRO symposium on forest site and continuous productivity. 22–28 August 1982, Seattle, WA. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR. General Technical Report PNW-163.

A system is described for predicting long-term consequences of silvicultural practices, especially those that may decrease long-term forest productivity. The system requires: (1) conceptual models that incorporate current understanding of interactions among ecosystem processes; (2) process studies that, guided by the conceptual models, allow the establishment of equations for the transfer of materials and energy among ecosystem components and refinement of the conceptual models; (3) a management-oriented simulation model, developed from the conceptual model, used to predict long-term consequences of silvicultural practices; and (4) validation studies that test those predictions. Conceptual models must account for interactions among processes as well as for all material flow. Process studies should clarify the relations between processes and their controlling factors; operational trials should duplicate silvicultural practices to determine their effectiveness. In general, process studies should be replicated at each site, operational trials across many sites. Experimental treatments selected for process studies need not adhere to standard silvicultural practice. Development of a management-oriented simulation model must be a high priority. FORCYTE, developed by J.P. Kimmins and K.A. Scoullar, may offer the best starting point for foresters and researchers in the Pacific Northwest. Operational trials should validate the simulation model rather that merely provide information for specific sites, species, and treatments.

316. Spires, S.; Bendell, J.F. 1983. Early postfire effects of some invertebrates, small mammals and birds in north-central Ontario. p. 308–318 *in* R.W. Wein, R.R. Riewe and I.R. Methven, eds. Resources and dynamics of the boreal zone: proceedings of a conference held at Thunder Bay, Ontario, August, 1982. Association of Canadian Universities for Northern Studies, Ottawa, ON.
Animals were trapped or observed in burned and adjacent unburned forest during the first five weeks following and intense 380 ha ground and canopy fire in May 1981. The following general trends were found. Herbivores (e.g., Gapper's red-backed vole, snowshoe hare) were captured or observed in lower numbers in burned than in unburned forest. Granivores such as deer mouse and white-throated sparrow were captured or observed in high numbers in both forests. Aerial insectivores (e.g., common nighthawk), ground insectivores (e.g., American robin, a tiger beetle) and bole insectivores (woodpeckers) were captured or observed in higher numbers in burned than in unburned forest. Foliage insectivores (mainly wood warblers) were observed in lower numbers in burned than in unburned forest. There were some exceptions to the above trends, for example the ground insectivorous masked shrew was captured in lower numbers in

burned than in unburned forest. These exceptions may relate to requirements of the species involved for cover or moisture. .

317. Stathers, R.J. 1989. Summer frost in young forest plantations. Forestry Canada, Victoria, BC. FRDA Report 073. 24 p.

Frost during the active growing season was observed to be a major cause of conifer seedling mortality and reduced plantation performance in research trials and operational plantings throughout the southern and central interior of B.C. This report describes the physical principles governing the causes and occurrence of frost and the effects of frost on conifer seedlings, identifies frost- prone sites, and presents techniques for avoiding or preventing frost problems in young plantations.

318. Sterba, H. 1988. Increment losses by full-tree harvesting in Norway spruce (*Picea abies*). Forest Ecology and Management. 24(4):283–292.

In three experiments in Austria, pre-commercial thinning was carried out in three different ways. After felling, trees were: immediately removed; removed one growing season later, so as to leave the needles in the stand; or left in the stand. Three years after establishment of the experiments, basal area increment was 12% greater where felled trees were left in the stand than in the other treatments. Since in one experiment nutrient supply of nitrogen and phosphorous was increased significantly where felled trees were left in the stand, it is concluded that increment differences between the treatments can be interpreted as the fertilizing effect of slash when left in the stand.

319. Stocks, B.J.; Elliott, R.G.; Walker, J.D., cochairmen. 1985. Forest fire management symposium. 15–18 September 1984, Sault Ste. Marie, ON. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. COJFRC Symposium Proceedings O-P-13. 125 p.

A collection of 16 papers discussing the effects of wildfires and controlled burning on wildlife, recreation, forest management and wood supply, mostly with reference to Ontario.

320. Stone, E.L., ed. 1984. Forest soils and treatment impacts. Proceedings, Sixth North American Forest Soils Conference. 19–23 June 1983, The University of Tennessee, Knoxville, TN. University of Tennessee, Department of Forestry, Wildlife and Fisheries, Knoxville, TN. 454 p.

The Sixth North America Forest Soils Conference was held June 19-23, 1983 at The University of Tennessee, Knoxville. The present volume consists of revised and sometimes expanded drafts of papers presented at the Conference, together with brief abstracts of the poster session papers. The twenty five years since the first of these Conferences have seen a marked intensification of forest management in several parts of Canada and the United States, with a consequent growth of interest in means of maintaining or increasing productivity. About half of the papers and several abstracts treat that interest. An additional group of papers and abstracts is concerned with the reaction of soils to acid precipitation, especially its sulfate component, as an inadvertent global treatment. Its potential effects, like those of soil compaction, drainage, and fertilizers applied to highly deficient soils, seem to warrant use of the term "impact" in the title of this Volume. A third group, not always clearly separated from the first in content, treats advances in assessing the productive capacity of forest soils and their probable responses.

321. Stone, E.L. 1952. Magnesium deficiency of some northeastern pines. Paper presented before Division V-A. Soil Science Society of America. 6 December 1952, Cincinnati, OH.

Magnesium deficiency of *Pinus resinosa*, *P. strobus* and *P. banksiana* was studied in young forest plantations on light textured soils bordering the western and southwestern margins of the Adirondack province of New York. The most conspicuous symptom of deficiency was a bright yellow discolouration of the tips of the current season's needles, appearing in the fall and affecting the upper part of the tree most strongly. When the deficiency was severe the chlorosis was followed by death of the needle tips or premature loss of foliage. Gross reductions in shoot growth and needle length occurred only under extreme deficiency or when lack of magnesium was accompanied by potassium deficiency. In *P. resinosa* the appearance of deficiency symptoms was usually associated with magnesium contents less than 0.16% of the oven dry weight of mature first year foliage; with less than about 0.13% symptoms were severe. Fertilization with magnesium sulfate at rates of 20 to 50 lbs. Mg per acre eliminated or reduced the symptoms after a lapse of at least a year. Fertilization of deficient trees with magnesium sulfate resulted in increased height growth over a period of at least three years. In two instances this increase was shown to be additive to that due to potassium, without evidence of significant interaction.

322. St-Pierre, H.; Gagnon, R.; Bellefleur, P. 1992. Régégération après feu de l'épinette noire (*Picea mariana*) et du pin gris (*Pinus banksiana*) dans la forêt boréale, Québec. Canadian Journal of Forest Research. 22(4):474–481.

Age structure analysis was performed in black spruce (*Picea mariana* [Mill.] B.S.P) and jack pine (*Pinus banksiana* Lamb.) stands following fire (*i*) to determine if there is a time lag between black spruce and jack pine establishment and (*ii*) to compare the composition of the regeneration with regard to the original stand. The study was conducted in an area burnt in 1983, 100 km northwest of Lake Saint-Jean, Quebec. Five years after fire, the age structure of the regeneration shows an early establishment of jack pine and black spruce, with more than 95% of the seedlings established during the first three growing seasons after fire (excluding the year of fire). The age structures were similar in mature stands and in the regeneration for the jack pine while they differed for black spruce. Errors in age determination due to suppression of adult trees sampled or other causes could explain the difference in the establishment pattern of young and mature black spruces. Compared with the mature stand, the postfire regeneration had an increased proportion of jack pine. The study concludes that both species can regenerate shortly after fire, but in somewhat varying proportions.

323. Sutton, R.F. 1991. Mounding site preparation for jack pine and black spruce in boreal Ontario: five-year results. Forestry Canada, Ontario Region, Sault Ste. Marie, ON. COFRDA Report No. 3311. 42 p.

Eleven plantations of each of jack pine (*Pinus banksiana* Lamb.) and black spruce (*Picea mariana* [Mill.] B.S.P.) were established with bareroot stock during a 3-year period beginning in 1980 on sites appropriate for those species between latitudes 48°27' and 50°22'N and longitudes 85°10' and 92°03'W. Site preparation provided five kinds of microsite for planting: (a) untreated, (b) Brăcke patch shoulder, (c) Brăcke patch bottom, (d) mound of mineral soil on the Brăcke patch shoulder, and (e) mound of mineral soil on the minimound of material scuffed out of the Brăcke patch. On each site, four 30-tree plots per microsite were planted. Five trees per plot were excavated 30 days after outplanting for purposes reported elsewhere. Root growth capacity was determined on subsamples of planting stock; performance in a low-stress (nursery) test planting was determined in other subsamples. Performance data were collected for 5 years. Several evaluations were conducted: height after five growing seasons; relative growth rate (height, years 1 through 5); stem diameter after five growing seasons; stem volume after five growing seasons; relative growth rate (volume, years 1 through 5); and two performance indices that combined survival and growth. The evaluations showed that, though both species performed well on mounded microsites, performance was equally good after outplanting on the shoulder of the standard Brăcke patch.

324. Sutton, R.F. 1979. Plantation establishment in the boreal forest: nutrient redistribution during mechanized planting. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. Information Report O–X–303. 19 p.

Two provenances each of 2+0 jack pine, 3+0 black spruce and 3+0 white spruce were hand-planted in 5 positions across the line taken a few days earlier by a bulldozer and planting machine on an Ontario jack pine cutover. Soil volumes and nutrients were about 30% less within 5 and 10 cm of the root collars of trees in the line of mechanical planting. Survival to 7 years was independent of species and provenance but significantly poorer in the undisturbed area to either side of the planting line. Species was the most important factor affecting height increment (jack pine grew fastest and white spruce slowest); provenance was significant only in the early stages. Height at 4 and 7 years was significantly greater in undisturbed areas and least along the line of planting. The best combination of survival and growth occurred in trees planted in the disturbed areas to either side of the planting line.

325. Sutton, R.F. 1987. Root growth capacity and field performance of jack pine and black spruce in boreal stand establishment in Ontario. Canadian Journal of Forest Research. 17(8):794–804.

Data on survival, height increment, stem diameter and condition were collected 1, 2, 3 and 5 years after planting seedlings at 2 sites in spring 1980-82. Seedlings were planted on 5 microsites, viz. unscarified, upper slope and bottom of Bräcke patches and 2 kinds of mound. Root growth capacity (RGC) was determined at each time of planting. Nursery test plantings in low-stress conditions confirmed the viability of planting stock. Of 4 components of RGC examined for correlation with field performance, mean number of new roots < 1 cm long, mean number of new roots > 1 cm long (a) and mean aggregate length of roots > 1 cm long (b) were sporadically and inconsistently correlated, while mean length of roots > 1 cm, derived from (a) and (b), was strongly correlated with survival after 3 years in both species.

326. Sutton, R.F. 1992. White spruce (*Picea glauca* [Moench] Voss): stagnating boreal old-field plantations unresponsive to fertilization and weed control. Forestry Chronicle. 68(2):249–258.

Two stagnant teenaged but pre-thicket plantations of white spruce (*Picea glauca* [Moench] Voss) on old-field sites in the Ontario Clay Belt were studied near Cochrane (49°04'N 81°02'W). Three herbicide x four fertilization treatments were applied, with four independently randomized replications at each site. Weed control (heavy, moderate and none) was with glyphosate, pronamide or nothing, respectively. Ammonium nitrate was broadcast in the first year at 0.0, 55.9, 112.0 and 167.9 kg/ha. Plots were 15 m x 15 m, surrounded by 2 m buffer zones. Performance data on individually identified trees were gathered over a 6- year period in the second decade after planting. Mortality of spruce continued throughout the study and was influenced significantly ($P = 0.01$) by tree size and by treatment. Mortality increased significantly in treatments that included glyphosate. However, treatments did not significantly ($P = 0.05$) affect any measured growth parameter. No treatment was silviculturally consequential. Stressed spruce were able to respond only sluggishly to weed control and/or fertilization.

327. Swan, H.S.D. 1960. The mineral nutrition of Canadian pulpwood species. 1. The influence of nitrogen, phosphorus, potassium and magnesium deficiencies on the growth and development of white spruce, black spruce, jack pine and western hemlock seedlings grown in a controlled environment. Pulp and Paper Research Institute of Canada, Montreal, PQ. Woodland Research Index. No. 116. 66 p.

More or less clearly defined visible deficiency symptoms were induced and photographed in colour [photographs included as an appendix]. Fifteen weeks after the sowing, some of the seedlings were weighed and analysed (results tabulated). The data show the nutrient composition and dry weights of the seedlings to be highly dependent on the nutrient concentrations in the feed solutions, and help to determine the concentrations of these elements within the seedling that indicate deficient, optimum and excess supply.

328. Swank, W.T.; Waide, J.B.; Swanson, F.J.; Triska, F.J.; Cromack, K., Jr.; Cummins, K.W. 1980. Section III: watershed and stream ecosystems. p. 137–198 *in* R.H. Waring, ed. Forests: fresh perspectives from ecosystem analysis. Oregon State University Press, Corvallis, OR.

Four chapters discussing the effects of logs, leaves, soil, sediment, water and minerals moving through forests and into stream ecosystems. Swank, W.T., Waide, J.B. Interpretation of nutrient cycling research in a management context: evaluating potential effects of alternative management strategies on site productivity [p. 137–158]; Swanson, F.J. Geomorphology and ecosystems [p. 159–170]; Triska, F.J., Cromack, K., Jr. The role of wood debris in forests and streams [p. 171–190]; and Cummins, K.W. The multiple linkages of forests to streams [p. 191–198].

329. Switzer, G.L.; Nelson, L.E.; Hinesley, L.E. 1981. Effects of utilization on nutrient regimes and site productivity. p. 91–102 *in* C.W. McMillin, ed. Complete tree utilization of southern pine: proceedings of a symposium, New Orleans, Louisiana, April 1978. Forest Products Research Society, Madison, WI.

The nutrient removals imposed on forest sites by various degrees of utilization and the ability of soils to sustain the utilization depends principally on the degree of disruption and the promptness of recovery of the system's nutrient cycles rather than on the removal of nutrients associated with increased utilization of the phytomass. These conclusions are reached after a consideration of the accumulation and distribution of nutrients in the compartments and components of forest stands and the annual nutrient requirements to develop and sustain forest stands. Ability to sustain nutrient removal and disruption and recovery of nutrient cycles associated with increased utilization also depend on the inherent characteristics of the soils and sites.

330. Szuba, K.J., and Bendell, J.F. 1983. Population densities and habitats of spruce grouse in Ontario. p. 199–213 *in* R.W. Wein, R.R. Riewe and I.R. Methven, eds. Resources and dynamics of the boreal zone: proceedings of a conference held at Thunder Bay, Ontario, August, 1982. Association of Canadian Universities for Northern Studies, Ottawa, ON.

We studied the association between population density and habitat of spruce grouse (*Canachites canadensis*) in 13 even-aged forests of jack pine (*Pinus banksiana*) and eight black spruce (*Picea mariana*) in the boreal forest region of north-central Ontario. The number of grouse observed per hour of search with dogs (grouse/h) was used to estimate grouse populations since it was strongly related (R^2=0.968) to total counts of banded grouse in six intensively worked forests. The highest densities of spruce grouse (0.50 to 0.80 grouse/ha), greater than any recorded elsewhere in North America, occurred in young (11 to 21 years) pine plantations. Similar forests have not been studied outside Ontario. Older plantations (28 to 62 years) were not as productive. However, one (46 years) contained a high population. Populations were generally lower in spruce forests, possibly because of differences in the herb layer and in microclimate. In jack pine, mean stand height was correlated with population density ($r=-0.745$, $P<0.05$). However, canopy height alone was not a good indicator of the level of spruce grouse populations, since four forests of comparable height differed in grouse/h. These differences appeared to be related to the extent of the coniferous understorey. In some cases differences in trees/ha were also apparent. A new variable, foliage area index (FAI), was used to represent the total amount of forest cover provided by the canopy and understorey. FAI was significantly correlated with population density in jack pine forests ($r=0.867$, $P<0.01$). Spruce grouse may be good indicators of the effect of forestry practices on wildlife, since they occur in a wide range of population densities and appear to respond to differences in habitat. Implications of the results to forest management are discussed.

331. Telfer, E.S. 1976. The impact of forest management on wildlife in the northern and eastern forests of Canada. p. 613–630 *in* XVI IUFRO World Congress: proceedings. Div. 1. 1976, Oslo, Norway. Norwegian IUFRO Congress Committee, Ås, Norway.

Regions discussed are the Boreal, Great Lakes-St. Lawrence and Acadian Forest Regions. Prevailing methods of harvesting, site preparation, regeneration, tending and protection of stands are discussed by major groups of cover-types within the region. Clear felling is the greatest problem in the Boreal Forest Region. Other problems are habitat loss in mature forests, truncating natural succession by eliminating mature forest habitat with dead trees. Boreal Forest regeneration often involves site preparation which destroys remaining trees. Truncation of early, forage producing,

successional stages may result from artificial regeneration. In the southeastern forests the principal impact on wildlife stems from attempts to control insects, particularly outbreaks of spruce budworm. In all regions regeneration increases the coniferous monoculture compare to a mixed original forest. Fire suppression has been increasingly effective with mixed impacts on wildlife.

332. Telfer, E.S. 1974. Logging as a factor in wildlife ecology in the boreal forest. Forestry Chronicle. 50(5):186–190.

Extensive stands of boreal forest in the late successional stages provide suitable habitat for some birds and for caribou but are unsuitable for many other species. Deer, moose, beaver, ruffed grouse and many other birds and mammals require the greater food production during the period of early regrowth following fire or logging. Wildlife species also require some dense, closed forest for shelter, therefore a diversity of forest types and age classes within their home ranges at all times of year is most beneficial. Logging can be used as a tool to provide diversity but much more research on boreal forest ecology is required to provide the basis for multiple-use management.

333. Thompson, I.D.; Colgan, P.W. 1987. Effects of logging on home range characteristics and hunting activity of marten (*Martes americana*) in Ontario. *in* XVIII Congress, I.V.G.B., Krakow.

A major impact on marten (*Martes americana*) habitat in Canada is timber harvesting. Attributes of home range and hunting activity of marten were compared in uncut and logged forest stands in north central Ontario. Home ranges in logged areas were significantly larger than in uncut areas for both sexes. Male and female ranges in logged sites were the same size while in uncut areas they differed significantly, with males having larger ranges. The number of core areas was similar for all animals but those in logged sites were located significantly further apart than in uncut areas. Marten in logged areas travelled faster than those from uncut sites and spent a significantly greater proportion of time above mean speed, except in core areas where speed was the same as in uncut habitats. Marten in both types of site deposited scent at the same rate. Marten were found to hunt logged and uncut areas in a similar manner. This suggests that despite habitat and prey changes owing to logging, animals are unable to adapt by altering their hunting methods. Curtailing of trapping in logged areas may permit facilitation of behaviors.

334. Thompson, I.D.; Welsh, D.A. 1993. Integrated resource management in boreal forest ecosystems - impediments and solutions. Forestry Chronicle. 69(1):32–39.

The goals of integrated resource management in boreal forests are sustainable production of commercial forest products and conservation of biodiversity. An appropriate approach to achievement of both goals is through maintenance of ecosystem types at the landscape level. Conservation of wildlife (defined as all organisms) through holistic ecosystem management is a relatively new discipline in Canada. Ecosystem management causes certain problems for agencies attempting to pursue these goals resulting from: poor autecological knowledge, conflict of habitat requirements with timber harvesting goals, legacy of past forest management, lack of management regimes, and few techniques that are applicable at the ecosystem level. Steps toward a more integrated approach to forest resource management include: recognition of institutional short- comings, development of predictive models using a common language for foresters and wildlife managers, re-tooling with GIS technology and decision support systems, and development of habitat models to be used within landscape- scale management plans.

335. Tiarks, A.E.; Kimble, M.S.; Elliot-Smith, M.L. 1991. The first location of a national, long-term forest soil productivity study: methods of compaction and residue removal. p. 431–442 *in* S.S. Coleman and D.G. Neary, eds. Proceedings of the Sixth Biennial Southern Silvicultural Research Conference. 30 October–1 November 1990, Memphis, TN. Vol. 1. USDA Forest Service, Southeastern Forest Experiment Station, Asheville, NC. General Technical Report SE-70.

To ensure that Forest Service management practices do not reduce long-term soil productivity, a network of coordinated, long-term experiments is being established across the United States. The national study plan calls for three levels of compaction (none, moderate, and severe) and three levels of organic matter removal (bole only, total tree, and total aboveground biomass). In this paper, the establishment of the first of these installations in central Louisiana is discussed. A loader was used to reach in and lift logs off the uncompacted plots instead of equipment entering the plots during harvest. Moderately compacted plots were rolled by a pneumatic-tired compactor loaded to 2.34 Mg/m, while a 4.22 Mg/m load was used for the severely compacted plots. After treatment, the bulk densities of the 0-10 cm depth were 1.47, 1.54, and 1.60 g/cm3 for the none, moderate, and severe levels, respectively. The densities at the 10- 20 cm depth were 1.61, 1.63, and 1.69 g/cm3, while the treatments had no effect at the 20-30 cm depth. Of the 98 Mg/ha aboveground biomass on the plots, the bole-only removal left 23% of the biomass while the total tree harvest left 6%. Biomass contained about 155, 17, 63, 100, and 25 kg/ha of N, P, K, Ca, and Mg, respectively. The concentration of nutrients was higher in the foliage and understorey components of the stand, so proportionately more nutrients were removed as the harvest intensity increased.

336. Timmer, V.R.; Armstrong, G.; Miller, B.D. 1991. Steady-state nutrient preconditioning and early outplanting performance of containerized black spruce seedlings. Canadian Journal of Forest Research. 21(5):585–594.

Conventional fertilization of black spruce (*Picea mariana* (Mill.) B.S.P.) container stock usually does not conform to steady-state nutrient conditions and may limit outplanting performance. Steady-state nutrient preconditioning of seedlings, characterized by maintaining stable tissue nutrient (N, P, and K) concentrations during the exponential growth phase, was induced by an exponentially based fertilization regime that compensated for low nutrient reserves in germinating seeds. By the end of the greenhouse rotation, this regime reduced the shoot/ root ratio of the trees, but fell short of increasing seedling growth and nutrient status when compared with seedlings conventionally fertilized with equivalent amounts of nutrients. However, first-season height growth and shoot biomass of trees outplanted on different surface soils in pot bioassays were significantly improved by steady-state nutrient preconditioning and were accompanied by increased plant nutrient uptake, particularly N at the half-dose level and P at the full-dose level. Outplanting performance was higher on an upland site type, although relative response was greater on nutrient-poorer, lowland substrates. The preconditioning response from exponentially based fertilization was attributed to lower shoot/root mass ratio and more effective nutritional adaptation of the seedlings in the field environment. Under steady-state nutrient culture, seedling nutrient uptake conforms more closely with stable nutrient supply in nature, since expanding root systems exploit new soil volumes exponentially. Field performance of exponentially fertilized seedlings may be further enhanced when combined with balanced nutrient loading in the greenhouse phase.

337. Timmer, V.R.; Munson, A.D. 1991. Site-specific growth and nutrition on planted *Picea mariana* in the Ontario clay belt. IV. Nitrogen loading response. Canadian Journal of Forest Research. 21(7):1058–1065.

Black spruce (*Picea mariana* (Mill.) B.S.P.) containerized seedlings were raised at high fertilizer regimes, i.e., "nutrient loaded," during greenhouse culture to assess whether increased preplant nutrient reserves improved site-specific outplanting performance. Growing media electrical conductivity levels during the greenhouse phase ranged between 0.9-1.2 and 0.3-0.6 dS/m for loaded and nonloaded seedlings, respectively. Although similar in total biomass and P and K content at rotation end, the loaded seedlings contained 78% more N than the nonloaded seedlings, demonstrating induced luxury consumption of N from loading. After overwintering, the seedlings were planted on intact potted surface soils from three ecological site types (upland Feathermoss, lowland Alnus, and lowland Ledum) of contrasting fertility. In the first growing season, N loading significantly increased height growth and dry matter production on all substrates; relative response was higher on the more N-deficient lowland sites. Plant nutrients were markedly diluted after establishment, except for N of nonloaded seedlings. The loading response was closely associated with the buildup of preplant N, which served as a critical nutrient source for internal retranslocation to new growth. Loading stimulated not only N uptake after outplanting, but also uptake of other nutrients presumably because of the expanded root system with this treatment. Balanced nutrient loading offers a cost-effective alternative to field fertilization by promoting outplanting

performance of container stock, and by avoiding competition response and operational constraints often associated with on-site fertilization.

338. Timmer, V.R.; Savinsky, H.M.; Marek, G.T. 1983. Impact of intensive harvesting on nutrient budgets of boreal forest stands. p. 131–147 *in* R.W. Wein, R.R. Riewe and I.R. Methven, eds. Resources and dynamics of the boreal zone: proceedings of a conference held at Thunder Bay, Ontario, August, 1982. Association of Canadian Universities for Northern Studies, Ottawa, ON.

The effect of intensive logging systems on future forest productivity was assessed on four contrasting stand conditions in the Nipigon area: a young coniferous (*Abies balsamea*) stand, a young deciduous (*Populus tremuloides* - *Betula papyrifera*) stand, and two 120 year old *Picea mariana* stands, one established on deep mineral soils, the other on shallow soils restricted by bedrock. Parts of these stands were harvested using a whole-tree chipping process. The uncut portion of the stands was sampled to determine biomass and nutrient exports associated with intensive (whole-tree) logging and conventional (stem only) harvesting. Although biomass removal increased 56- 116% with full tree utilization, corresponding nutrient removals from these sites increased 83-224%. Higher nutrient losses reflected large differences in elemental concentrations between stems and foliage. Nutrient content of the stands varied with age and species. Nutrient exports at harvest were compared with the existing nutrient reserves of the forest floor and mineral soil, and with the quantities of nutrients returned as logging residue. Assuming steady state nutrient cycling, results indicated that nutrient losses from conventional harvesting were relatively modest with regard to soil nutrient supplies. However, on three out of the four sites studied, intensive logging methods would lead to deficiencies in P, K or Ca in the succeeding rotation. Forests on deeper soils, managed at long rotations were less susceptible to nutrient depletion than short rotation stands established on shallow soils. Silvicultural strategies minimizing potential nutrient loss from intensified harvesting are discussed.

339. Titus, B.D.; Lavigne, M.B.; Newton, P.F.; Meades, W.J., eds. 1990. The silvics and ecology of boreal spruces: proceedings of the 11th IUFRO Northern Forest Silviculture and Management Working Party S1.05-12 Symposium. 12–17 August 1989, Central Newfoundland, Canada. Forestry Canada, Newfoundland and Labrador Region, St. John's, NF. Information Report N-X-271. 197 p.

The 11th Meeting and Symposium of the IUFRO Northern Forest Silviculture and Management Working Party (S1.05-12) met in Gander and Grand Falls, Central Newfoundland, Canada, on 12-17 August 1989. Over 70 delegates from 5 circumpolar countries met to discuss the Symposium theme, "The Silvics and Ecology of Boreal Spruces", through formal presentations and field trips. Seventeen scientific papers were presented during the four paper session: Site Preparation for the Establishment of Boreal Spruces, the Ecology of Boreal Spruces, the Genetics of Boreal Spruces, and the Natural Regeneration of Boreal Spruces. Eleven posters were presented. A Summary Paper was given at the end by an invited scientist. In addition, five papers were presented by representatives of the local forestry sector to introduce delegates to the forest resources and industry in Newfoundland and central Labrador. Visits to a range of sites in central Newfoundland provided a forum for discussion of local black spruce silviculture and management problems and opportunities. Three Post- Symposium tours to Labrador, Western Newfoundland, and Nova Scotia were held.

340. Towill, W.D.; Barauskas, A.; Johnston, R. 1988. A pre-cut survey method incorporating the Northwestern Ontario Forest Ecosystem Classification. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Report 02.

This paper presents a pre-cut survey technique which uses the Northwestern Ontario Forest ecosystem classification for describing the soil, site and stand conditions of allocated stands. The forest ecosystem classification system permits classification and description of 38 vegetation types, 12 deep and 9 shallow soil types. The sampling intensity is consistent with mapping at a scale of 1:15,840 - 1:20,000 and is considered a level 2 forest land survey. The survey technique comprises 5 basic steps each of which addresses a unique aspect of the information gathering approach.

341. Turcotte, D.E.; Smith, C.T.; Federer, C.A. 1991. Soil disturbance following whole-tree harvesting in north central Maine. Northern Journal of Applied Forestry. 8(2):68–72.

Mechanical whole-tree harvesting can reduce site productivity if it results in excessive soil disturbance, which may both kill advanced regeneration and reduce the potential of the soil to support tree growth. Large feller-forwarders with wide, high flotation tires were designed to reduce soil disturbance, but they can cause excessive amounts of site disturbance if harvesting is conducted when soils are wet. The spatial distribution and severity of soil disturbance were determined on line transects after a spring whole-tree clear cut in northern Maine on the silt loams of the Chesuncock catena. Exposed mineral soil and deep wheel ruts occurred more frequently on somewhat poorly (37% of surface area) and poorly (42%) drained soil than on moderately well-drained soil (19%). This amount of site disturbance seems excessive and could reduce future site productivity due to removal of organic horizons and destruction of advanced conifer regeneration. Harvesting with large feller-forwarders on the poorly and some-what poorly drained silt loam soils of this region should be discouraged in the spring and possibly during other periods of high soil water tables.

342. Urie, D.H. 1971. Estimated groundwater yield following strip cutting in pine plantations. Water Resources Research. 7(6):1497–1510.

Ground water recharge balances were determined under 40- acre blocks of a jack pine (*Pinus banksiana* Lamb.) plantation in northwestern lower Michigan during the 4 years following the removal of 50% of the trees in clear- cut strips. Analyses were made by graphical interpretation of diurnal fluctuations and by use of finite difference equations. In the numerical method, weekly water table elevation measurements over each 40-acre block were used to determine water table convexity, which was then linearly related to the groundwater inflow-outflow balance. Results from both methods of analysis showed the effect of strip cutting as increased groundwater yields. Estimates of water yield by the two methods differed primarily as a result of poor estimates of net evaporative loss from the saturated zone using the graphical method. Three other tests of cutting effects on groundwater recharge supported the budget estimates of treatment effect. Approximately 3 inches per year of additional water was produced as a result of the strip cut during the first 4 years after cutting. The numerical analysis showed that the amount of treatment effect decreased rapidly over this period.

343. Utzig, G.F.; Walmsley, M.E. 1988. Evaluation of soil degradation as a factor affecting forest productivity in British Columbia. A problem analysis. Phase I. Canadian Forestry Service, Victoria, BC. FRDA Report No. 025. 122 p.

An analysis of the causes, nature and extent of soil degradation, and the potential resultant losses in productivity. Ground skidding has the greatest potential to cause soil degradation during harvesting, and windrowing and blade scarification are considered the most harmful site preparation methods. Total area of degraded soils resulting from all forestry activity in 1976-85/86 was over 400,000 ha, and over 49,000 ha for the year 1985/ 86. Potential reduction in productivity over the period is estimated at 400,000 m3/yr and is increasing by 50,000 m3/ yr. Rehabilitation costs range from $500 to $5,000/ha and seldom returns the site to original productivity, whereas costs for prevention/reduction of degradation are estimated at $250-$1,800/ha through alternative harvesting methods and 0-$200/ha for improved pre-harvest planning. Significant reductions in degradation can be achieved without significant cost, and prevention is both more effective and cheaper than rehabilitation.

344. Vallé, G.; Lowry, G.L. 1970. Forest soil-site studies. II. The use of forest vegetation for evaluating site fertility of black spruce. Pulp and Paper Research Institute of Canada, Pointe Claire, PQ. Woodlands Paper No. 16. 32 p.

Data are presented from 125 *Picea mariana* stands located from Newfoundland to western Ontario. The vegetation is described by strata and as a whole. Two major vegetation regions, that can be termed 'Atlantic' and 'continental' and lie

east and west of the 65th meridian respectively, are identified. The diversity of the vascular species increases from east to west, the variation being apparently related to the major soil formations and climatic conditions. It is clearly shown that plant species native to *P. mariana* stands can be used to estimate site fertility with reasonable accuracy; both (a) traditional discrete vegetational site types and (b) multiple regression equations can be employed for this purpose, (b) giving the greater precision. In trials with (b), both individual species and species-groups were used, the latter giving more precise results; separate equations were developed for ground observation and aerial-photo interpretation. Although dominance of species and species- groups could be more accurately measured by quadrat measurement than by visual estimate, site-index precision was not sufficiently improved to justify the former. The advantages of the multiple regression technique used (ease of application, lack of subjectivity, and sufficient accuracy) are stressed.

345. Van Cleve, K.; Viereck, L.A.; Dyrness, C.T. 1983. Dynamics of a black spruce ecosystem in comparison to other forest types: a multi-disciplinary study in interior Alaska. p. 148–166 *in* R.W. Wein, R.R. Riewe and I.R. Methven, eds. Resources and dynamics of the boreal zone: proceedings of a conference held at Thunder Bay, Ontario, August, 1982. Association of Canadian Universities for Northern Studies, Ottawa, ON.

For the past several years, the University of Alaska and the Institute of Northern Forestry have conducted a multi-disciplinary study of a black spruce ecosystem in interior Alaska. The black spruce type, widespread in interior Alaska, is the most fire-prone forest type. Black spruce ecosystems are also the most nutrient limited and least productive forest type, especially in the late stages of succession. The central hypothesis of this study is that ecosystem differences in productivity and degree of nutrient limitation are controlled mainly by soil and forest floor temperature. A corollary hypothesis is that in the black spruce ecosystem, which is characterized by low productivity and slow nutrient cycling, fire acts as a rapid decomposer and is essential to replenish depleted available nutrient pools. In order to test these and other hypotheses a number of semi-intensive sites were studied for comparison with the black spruce permafrost-dominated intensive site. These semi-intensive sites represent a complete spectrum from the coldest sites to the warmest and driest sites that support tree growth in interior Alaska. The sites were also selected to represent both successional and mature stands.

346. Van Damme, L.; Buse, L.; Warrington, S. 1988. The effect of microsite compaction on direct seeding success of jack pine and black spruce in northwestern Ontario. KBM Forestry Consultants, Thunder Bay, ON. 36 p.

The effects of microsite soil compaction on direct seeding were tested in conjunction with Brăcke scarification. The compaction effect was achieved by manually tamping the seed spot with a wooden pallet with either a flat surface or a surface with pyramidal indentations. It was anticipated that compaction might decrease the number of seeds required to establish seedlings and extend the sowing season for jack pine and black spruce in Northwestern Ontario. Compaction increased the number of scalps stocked with jack pine by 30% after the first growing season but had no effect on black spruce. The experimental sowing rate of five seeds per scalp may have been insufficient to detect black spruce treatment responses on the dry mineral soil seed spots. No differences were found between pre-sowing and post-sowing compaction treatments for jack pine. However, compaction with a pyramidal surface improved stocking slightly over compaction with a flat surface, especially for the latest sowing date. Compaction with a pyramidal surface doubled the percent stocked scalps over conventional sowing for the latest sowing date. Compaction may allow an extension of the jack pine sowing season from late June into early July. Still, early spring sowing provided the best overall results for both species. Although no site location by compaction treatment interaction was detected, site strongly influenced emergence and survival. It was discovered that the site with moisture levels conducive to establishment for both species in the first growing season were subject to significant seedling mortality from frost heaving and drowning by the end of the second season. The study also showed that establishment of black spruce on upland sites, which may have had a significant black spruce component prior to harvesting, is problematic.

347. Van Damme, L.; McKee, K. 1990. The extent and nature of seeded jack pine clumping following disturbance in northwestern Ontario. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Report 58. 42 p.

Exploratory investigation of clumping in juvenile jack pine, comparing the structure of artificially established stands with the structure of natural (fire established) stands. The report provides a definition of clumping of jack pine in units that can be readily recognized and measured in the field; a measure of the prevalence of the clumping condition and its relationship to stand origin and age; and a comparison of the growth and development of free growing to clumped trees. The study area included most of the commercial and accessible parts of the boreal forest region in Northwestern Ontario. Thirty-one stands, from 2-20 years old, were sampled, representing hand seeded with shelter cones, hand seeded with no shelter cones, Brăcke spot seeding, scarification of slash, aerial seeding, and wildfire. The seeding methods were compared for total density, density of clumps, ratio of clumped seedlings to total seedlings and a measure of non-random spatial distribution.

348. Van Hook, R.I.; Johnson, D.W.; West, D.C.; Mann, L.K. 1982. Environmental effects of harvesting forests for energy. Forest Ecology and Management. 4(1):79–94.

A brief review of the direct (nutrient removal, soil disturbance and compaction, regeneration of new stands, exposure of soil and litter, and fire hazard/air pollution) and indirect (erosion, leaching, and wildlife habitat) effects of harvesting forests to meet demands on wood for energy in the USA.

349. van Kesteren, A.R. 1992. An application of ecosite mapping to assess land sensitivity to forest harvesting in the Corner Brook Lake Watershed, western Newfoundland. Forestry Canada, Newfoundland and Labrador Region, St. John's NF.. Information Report N-X-280. 55 p.

The Corner Brook Lake watershed in western Newfoundland is the source of municipal and industrial water supplies for the city of Corner Brook. Forestry Canada was requested to provide assistance to a monitoring committee to facilitate in the planning and operations for industrial timber harvesting in the watershed. A land sensitivity assessment of the watershed was undertaken through an application of ecosite mapping concepts common to current Canadian ecological land classification practice. Ecosites were delineated as homogeneous pedologic, geomorphologic and hydrologic land units using conventional air photo interpretation. Additionally, a simple provisional water yield assessment based on ecosite ranking was undertaken to address water supply concerns. Ecosite mapping of the watershed area, approximately 90 km^2, was produced at an operational scale of 1:12,500. Maps were digitized and entered into a GIS to aid in application to the data base. Mapping and analysis resulted in the following percentage of land sensitivity levels for the watershed: none - 18.63%; low - 1.26%; moderate - 31.53%; and high - 39.33%.

350. Vassov, R.; Baker, W.D. 1988. Pre-commercial thinning of jack pine. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Report 12. 25 p.

Jack pine is one of the most important commercial species in northwestern Ontario. Much of the jack pine regeneration effort following harvesting or fire has been site preparation followed by direct seeding. Natural seeding also follows fire from serotinous cones. This review synthesizes the current literature on pre- commercial thinning of jack pine for growth response, method of thinning, wood quality, end product and economic considerations. In addition, major gaps in knowledge are identified and possible future areas for research and development are suggested.

351. Walsh, S.A.; Krishka, C.S. 1991. Early stand development after harvesting on selected sites in northwestern Ontario. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Report 64. 33 p.

Tree species often revegetate harvested forest sites but desirable conifer trees may not be the first to assume dominance. This study was designed to provide descriptions of vegetation communities that develop on a range of newly harvested sites across the North Central Region of northwestern Ontario. Relationships between these post- harvest vegetation communities and pre-harvest site classification units were also investigated. Sampling was conducted on 40 cutovers to cover a range of pre-harvest stand conditions. Each sampled cutover was classified to a Northwestern Ontario forest ecosystem classification treatment unit. All sites had been harvested within five years of sampling, most had been mechanically site prepared, but none had been chemically treated.

352. Walsh, S.A.; Wickware, G.M. 1991. Stand and site conditions associated with the occurrence and distribution of black spruce advance growth in north central Ontario. Forestry Canada, Ontario Region, Sault Ste. Marie ON / Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. COFRDA Report 3309 / NWOFTDU Technical Report #24. 37 p.

In many mature and overmature stands of black spruce (*Picea mariana* [Mill] B.S.P.) in Ontario, advance growth originating from layers or seed could contribute significantly to the restocking of the area, if the young trees can be preserved from damage during the harvesting operation. This project examined the occurrence and distribution of black spruce advance growth in relation to the vegetation types and soil conditions that occur in the North Central Region of Ontario. The survey was carried out within the framework of the Forest Ecosystem Classification for Northwestern Ontario (NWO FEC). Within the stands examined, 96% of all black spruce advance growth originated from layers. However, the survey showed that stocking levels of advance growth are generally low and very variable. The highest stocking levels were found in stands dominated by black spruce on wet, organic lowland and nutrient-poor upland site types. Only in the unmerchantable black spruce lowland type (NWO FEC Vegetation Type 38) did stocking levels exceed 40%. Upland mixedwood stands with a diverse and abundant herb and shrub component supported only limited amounts of black spruce advance growth. In general, the study showed that black spruce advance growth is best regarded as a supplementary stocking source rather than as a primary form of regeneration.

353. Wambach, R.F. 1969. Compatibility of mechanization with silviculture. Journal of Forestry. 67(2):104–108.

Argues that silvicultural systems should be changed wherever an economic gain can be derived from mechanization. This view is supported by evidence (including previously unpublished work in the Lake States) that stand density influences volume production relatively little, whereas site productivity has a large influence. It is concluded that forest managers should concentrate on pure plantations, preferably on productive sites, with either row thinning or a wide initial spacing.

354. Weber, M.G. 1987. Decomposition, litter fall, and forest floor nutrient dynamics in relation to fire in eastern Ontario jack pine ecosystems. Canadian Journal of Forest Research. 17(12):1496–1506.

Decomposition, litterfall, and nutrient organic matter turnover rates were determined in five eastern Ontario jack pine (*Pinus banksiana* Lamb.) stands having various burning histories, including wildfire. The stands included a 65-year-old age-class, two stands within this age-class were treated with nonlethal understorey fires in 1962 and 1963, a 21-year-old age-class, and an 8-year-old age-class created by experimental burning plots within the 21-year- old age-class. Overstorey and understorey litter decomposition was assessed separately using the litterbag (1 mm mesh size) technique over a 2-year period. Overstorey litter weight loss did not vary among stands and understorey litter lost significantly more weight ($P<0.05$) in the older age-classes compared with the younger stands. Litterbag nutrient dynamics between overstorey and understorey were significantly different ($P<0.05$) for P, K, and Ca in all stands. Magnesium and N dynamics were the same in both litter types on all treatments, as was Fe, except in the 65-year-old stand where significantly more Fe was accumulated in understorey litter ($P<0.04$) at the end of the litterbag exposure period. Three-year averages of annual litter ranged from 119 kg/ha/yr in the 8-year-old age-class to 4,182 kg/ha/yr in the older stands. Nutrient inputs through litterfall reflect the developmental stage occupied by the younger stands along a

continuum leading to equilibrium conditions of the 65-year-old age-class. Forest floor nutrients and organic matter residence times (or annual fractional turnover) were longest (least amount cycled) in the 8- year-old stand (57.6 years for organic matter), indicating harsh environmental controls over nutrient dynamics. Recovery for the 21-year-old age-class to turnover rates approaching equilibrium conditions (10-year residence time for organic matter) was rapid, demonstrating ecosystem stability in its interaction with fire. Detrimental effects on ecosystem processes can be expected if a stand- replacing fire recurs during early stages of jack pine ecosystem development.

355. Weber, M.G. 1988. Fire and ecosystem dynamics in eastern canadian *Pinus banksiana* forests. p. 93–105 *in* J.T.A. Verhoeven, ed. Vegetation structure in relation to carbon and nutrient economy: production, decomposition and atmospheric interception. SPB Academic Publishing, The Hague, The Netherlands.

Jack pine (*Pinus banksiana*) is an economically important Canadian tree species and its autecology is inextricably linked to fire. It would disappear as a natural component of the boreal forest landscape were it not for the periodic occurrence of fire. By examining a series of experimental prescribed burns, as well as wildfires, the dynamic interaction of jack pine ecosystems with fire is quantified. During the regeneration step, high frontal fire intensities of around 17,000 kW/m are required to produce seedling numbers of 30,000 to 50,000/ha which are considered adequate for establishing the next generation of crop trees. Seedling height was also a function of frontal fire intensity with best growth performance exhibited by those sites exposed to the greatest fire intensity. Functional ecosystem attributes, such as soil respiration (carbon dioxide evolution), decomposition (assessed by using litterbags), litterfall, and nutrient and organic matter turnover rates were also measured. All lines of evidence pointed to jack pine ecosystem stability in its interaction with fire, i.e., periodic fires resulted in only temporary deviation from steady state conditions. Exceptions to this pattern were observed when fire reoccurred within 15 years of stand establishment or when forest floor layers were mechanically disturbed in mature stands.

356. Weber, M.G. 1990. Selected ecosystem processes in a *Pinus resinosa* Ait forest in relation to other fire-affected eastern North American forest ecosystems. p. 137–156 *in* J.G. Goldammer and M.J. Jenkins, eds. Fire in ecosystems dynamics: mediterranean and northern perspectives. 3rd International Symposium on Fires Ecology. May 1989, Freiburg University, Freiburg, Germany. SPB Academic Publishing, The Hague, The Netherlands.

Litterfall, decomposition, organic matter turnover, and forest soil respiration (carbon dioxide evolution) in a mature (75-year-old) eastern Ontario red pine (*Pinus resinosa* Ait.) ecosystem were compared with similar eastern North American fire-affected forest types. Litterfall patterns were shown to be vary seasonally as well as from year to year. Annual littermass inputs varied from a high of 5,300 kg/ha to a low of 2,400 kg/ha during the three-year observation period. Nutrient inputs through litterfall followed mass input patterns. Understorey litter decomposed more readily than overstorey litter (needles) probably because of the higher nutrient content in understorey material, pointing to the importance of the understorey in overall nutrient cycling processes. Organic matter turnover rates, or residence time, were between 19 and 16 years for the three red pine stands studied. This represents intermediate values between rapid rates such as 2 to 3 years for south central Wisconsin forests and relatively slow rates such as 43 years for jack pine (*Pinus banksiana* Lamb.) ecosystems in northern New Brunswick. Strong climatic control over ecosystem processes, as well as substrate quality, is implicated in the observed variability among forest types. It is apparent that climatic controls will assume added importance in studies of ecosystem structure and function in light of anticipated global greenhouse warming. Soil respiration was measured *in situ* with soda lime and shown to be very similar to levels observed in adjacent jack pine forests. Seasonal respiration means in red and jack pine forests with various fire histories were around 4,300 mg CO_2/m^2/day. In comparison, local fire-origin aspestands had soil respiration rates in excess of 5,000 mg CO_2/m^2/ day, reflecting better nutritional status of the aspen site. Temperature appeared to be the overriding controlling factor in determining substrate respiration patterns. Soil moisture content and rainfall proved to be poor predictors of respiration activities in this study.

357. Weber, M.G., Hummel, M., and Van Wagner, C.E. 1987. Selected parameters of fire behaviour and *Pinus banksiana* Lamb. regeneration in eastern Ontario. Forestry Chronicle. 63(5):340–346.

Fire behaviour variables were quantified in eastern Ontario jack pine (*Pinus banksiana* Lamb.) ecosystems and used to interpret observed fire impacts and effects. A series of seven fires, ranging in frontal fire intensity from 70 to 17,000 kW/m, were documented. Forest floor moisture content prior to burning was negatively correlated with weight of forest floor consumed per unit area (R^2=0.97) and per cent mineral soil bared (R^2=0.95). Frontal fire intensity was positively correlated with per cent tree mortality (R^2=0.98) and mean height (R^2=0.76). Frontal fire intensities of 17 kW/m resulted in seedling numbers of 30,000 to over 50,000/ha considered to be more than adequate for establishing the next generation of crop trees. Jack pine mean seedling height, 13 to 16 years after fire, was also positively correlated with frontal fire intensity (R^2=0.82), ranging from 0.5 to 3.8 m on lowest and highest intensity burns, respectively. Similar relationships were found when seedling height was regressed against per cent tree mortality (R^2=0.62) and forest floor consumption (R^2=0.79). Results are discussed in terms of ecological requirements of the species, particularly during the regeneration phase, and it is concluded that quantification of fire behaviour is mandatory if burning conditions are to be understood and/ or duplicated by the land manager for the attainment of a given forest management objective.

358. Weber, M.G.; Methven, I.R.; Van Wagner, C.E. 1985. The effect of forest floor manipulation on nitrogen status and tree growth in an eastern Ontario jack pine ecosystem. Canadian Journal of Forest Research. 15(2):313–318.

Four forest floor manipulation treatments were applied to an eastern Ontario jack pine (*Pinus banksiana* Lamb.) ecosystem. These included a one-time complete removal of the forest floor to mineral soil; annual removal of the total forest floor to mineral soil; one-time removal of the forest floor, ashing of the material, and broadcast spreading of the ash onto exposed mineral soil; and, an untreated control. Eight years after treatment, radial tree growth on the treated plots showed a 30% reduction compared with the untreated plot. Annual removal of the forest floor caused most severe nitrogen depletion in jack pine foliage, forest floor, and mineral soil. Effects of one-time removal and burning treatments were less severe, but significant. Any interference with the normal buildup of the forest floor during stand development should be avoided if site quality is to be maintained for tree growth.

359. Weber, M.G.; Taylor, S.W. 1992. The use of prescribed fire in the management of Canada's forested lands. Forestry Chronicle. 68(3):324–334.

Present uses of prescribed fire in Canada are reviewed. Fire has been a natural component in many forested North American landscapes for millennia, making it an obvious choice as an effective forest management tool. It can be used in harmony with known fire adaptations of ecosystems to be managed. Prescribed fire uses are separated into six categories: (1) hazard reduction which evolved into (2) silviculture (including fire use for site preparation, managing competing vegetation, stand conversion, and stand rehabilitation) (3) wildlife habitat enhancement (4) range burning (5) insect and disease control (6) conservation of natural ecosystems. Some historic developments of prescribed fire use are presented including area burned under prescription by province and territory. Prescribed fire emerges as a cost effective practice that is ecologically compatible with many forest, wildlife, and park management objectives. Its continued use in the management of Canadian forests seems to be assured, as long as it is constantly developed and adapted to the changing needs and priorities of the general public.

360. Weetman, G.F. 1989. Boreal forest pre-harvest silviculture prescriptions: Problems, issues and solutions. Forestry Chronicle. 65(2):85–88.

An attempt is made to outline briefly the biological, administrative and economic realities that influence the preparation of cutover regeneration prescriptions for virgin, boreal forests in Canada. Overmature public forests close to the economic margin, under a system of industrial licences, and often with unknown stand dynamics, present very difficult problems in preparing feasible regeneration prescriptions. For rich white spruce and mixedwood types we currently lack biologically

successful prescriptions except at great expense. The problems associated with these old forests will persist for several decades; our track record in regeneration has not been good for some types. Public and professional awareness of the problems have escalated recently, often triggered by reductions in allowable cuts and tightening of regulatory controls.

361. Weetman, G.F., et al. 1987. Interprovincial forest fertilization program 1968–1983: standardized fertilizer installations in 81 unmanaged middle-aged stands in seven provinces. Final report: results of ten-year growth remeasurements. Canadian Forestry Service, Forest Science Directorate, Ottawa, ON. Information Report DPC-X-21. 53 p.

The Interprovincial Forest Fertilization Program comprises 81 standardized experiments established by the provincial forest services of New Brunswick, Quebec, Ontario, Manitoba, and Alberta, and by the Canadian Forestry Service in the provinces of Nova Scotia and Saskatchewan. Seventy-three experiments were remeasured after 10 growing seasons. The field trials were designed to test the effect of nitrogen when applied as urea at the rates of 112 and 224 kg/ha, and the effects of combined nitrogen, phosphorus, and/or potassium additions on the growth of pole-size and semimature conifer stands. In the combination treatments, nitrogen was applied at the high rate, phosphorus as triple super phosphate at the rate of 112 kg/ha, and potassium as potassium chloride, also at the rate of 112 kg/ha. This final report contains the 10- year response data, with sections of the 5-year report included to present a more complete picture.

362. Weetman, G.F.; Algar, D. 1983. Low-site class black spruce and jack pine nutrient removals after full-tree and tree-length logging. Canadian Journal of Forest Research. 13(6):1030–1036.

An old, merchantable black spruce stand growing on a Lithic Humo-Ferric Podzol overlying a granite bedrock, and a younger but merchantable jack pine stand growing on a Ferro-Humic Podzol overlying a deep coarse sand near Baie Comeau, Quebec, were analysed for stand biomass and macronutrient contents of both stand and soil. The magnitude of the depletions of macronutrients from the site, in full-tree and tree-length methods of logging, were compared with their available and total quantities in the soil. The range of values from the literature for nutrient inputs are presented and discussed in relation to logging losses. The results suggest that full-tree logging in the dry jack pine stand could cause a severe loss of potentially mineralizable N supply, and some loss of Ca, but there were no deficiencies in P, K and Mg. It is suggested that full-tree logging should be avoided on such sites.

363. Weetman, G.F.; Webber, B. 1972. The influence of wood harvesting on the nutrient status of two spruce stands. Canadian Journal of Forest Research. 2(3):351–369.

Calculations are presented on the quantities of N, P, K, Mg and Ca in the soil and above-ground portions of two spruce-pulpwood stands on sites of average fertility in northern and southern Quebec. The magnitude of the depletions of these nutrients from the site, in full-tree and tree-length methods of logging, are compared with the available and total quantities of them in the soil. The ranges of values, from the literature, for the input of these nutrients in dust and precipitation, and the losses in leaching, are presented and discussed in relation to the logging losses. It is concluded that on both sites it is unlikely that full-tree logging will result in any reduction in growth, due to nutrient removal, during the second rotation of trees. However, nutrient depletion due to full-tree logging, particularly with respect to Ca, K and N, may require correction by means of fertilizers in forest ecosystems of marginal fertility. These are usually either dry sites with low reserves of organic matter and low exchange capacity or wet sites with excessive accumulations of organic matter. The need for further detailed studies of the nutrient cycle in different forest ecosystems is stressed. An all-aged stand of balsam fir (*Abies balsamea* (L.) Mill.) and red spruce (*Picea rubens* Sarg.) and a 65-year-old upland black spruce (*Picea mariana* (Mill.) B.S.P.) stand of fire origin were selected as study areas for this project.

364. Wells, C.G.; Jorgensen, J.R. 1979. Effect of intensive harvesting on nutrient supply and sustained productivity. p. 212–230 *in* A.L. Leaf, chairman. Impact of intensive harvesting on forest nutrient cycling. 13–16 August 1979, State

University of New York, Syracuse, NY. State University of New York, College of Environmental Science and Forestry, Syracuse, NY.

There is a general concern that increased removal of biomass and nutrients with intensive harvest will cause a decline in soil nutrients and forest productivity. Nutrient cycling studies indicate that normal stem harvest removes or causes nutrient losses from the forest ecosystem at rates compatible with nutrient inputs. Harvesting on short rotations and biomass harvesting, however, place demands upon the soil that may exceed the natural supplying capability of the system. The quantitative aspects of the biological, chemical, and physical processes in the soil are not sufficiently known to predict the long-term effect of intensive harvest on the soil or on forest productivity. Soil fertility and forest productivity can be monitored using fertilizer prescription technology and alternatives such as fertilization and adjustment of rotation length, and harvesting intensity can be applied to meet the production objectives within the nutritional limitations of the system. Soil nutrient supply and productivity in forests change relatively slowly; therefore, biomass harvesting practices can be selected from rotation to rotation without serious risk of decline in soil productivity.

365. Welsh, D.A. 1981. Impact on bird populations of harvesting the boreal mixedwood forest. p. 155–167 *in* R.D. Whitney and K.M McClain, cochairmen. Boreal Mixedwood Symposium. 16–18 September 1980, Thunder Bay, ON. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. COJFRC Symposium Proceedings O-P-9.

The boreal mixedwood forest has a rich breeding bird community of 150 species. Most are migrants and many winter in the tropics. Density and richness are controlled principally by factors not directly affected by selective cutting. Harvesting results in dramatic bird species shifts, some of which may be irreversible.

366. Welsh, D.A. 1988. Meeting the habitat needs of non-game forest wildlife. Forestry Chronicle. 64(3):262–266.

This paper deals with: (1) what is non-game wildlife; (2) who is responsible for non-game wildlife; (3) non-game wildlife-forestry interactions; and (4) the problems of trying to develop management plans for non-game wildlife.

367. Welsh, D.A.; Fillman, D.R. 1980. The impact of forest cutting on boreal bird populations. American Birds. 34:84–94.

Each year almost one half million acres of the boreal forest of Ontario are cut. As part of its Migratory Birds Programme, the Ontario Region of the Canadian Wildlife Service is studying the effects of forest harvesting practices on migratory bird populations. The paper describes 22 forest regions of various composition and ages, and those bird species associated with each area.

368. White, E.H.; Harvey Alan E. 1979. Modification of intensive management practices to protect forest nutrient cycles. p. 264–278 *in* A.L. Leaf, chairman. Impact of intensive harvesting on forest nutrient cycling. 13–16 August 1979, State University of New York, Syracuse, NY. State University of New York, College of Environmental Science and Forestry, Syracuse, NY.

Suggestions for modifying intensive management practices to maintain adequate site productivity range from no harvesting on extremely critical sites to rehabilitation efforts on seriously damaged sites. Options that forest managers have in maintaining site productivity include implementation of practices to prevent site deterioration and initiation of corrective practices on previously abused sites.

369. United States Department of Agriculture, Forest Service. 1972. Fire in the environment: symposium proceedings. 1–5 May 1972, Denver, CO. Washington, DC. 151 p.

A collection of papers, including: History of fire in North America (G.F. White); Fire as an ecological factor in boreal forest ecosystems of Canada (G.W. Scotter); The significance of forest fires in Mexico (J. Vasquez Soto); Perspective on fire and ecosystems in the United States (W.H. Hendrickson); Forests and the purposes of man (R.A. Rappaport); Man in the forest ecosystem (D.N. Radcliffe); The impact of fire on forest values and services other than wood production (C.A. Connaughton); Public attitudes toward fire (A.D. Hall); Forces shaping public opinion toward fire and environment (H.R. Glascock, Jr.); Economic tradeoffs in fire management (J.A. Zivnuska); Use of fire in Canadian forests (J.H.G. Smith and R.C. Henderson); Fire and the environment (J.P. Johnston); Fire in the Australian environment (W.J.B. Crane); Alternatives to conflagration through the use of prescribed burning and other means (D.C. Campbell); Prescribed burning as an alternative to conflagrations: the air pollution potential (J.L. Murphy); Forest fire control background (J. Verduzco Gutierrez); Modern technology for fire control (P.H. Kourtz); Cooperative forest and environmental protection in Oregon (J.E. Corlett); Forest and streamflow experiment at Wagon Wheel Gap, Colorado, 1909-1926 (W.A. Garstka); and Studies on bushfire smoke (N.K. King, D.A. MacArthur, D.R. Packham, R.J. Taylor, and R.G. Vines).

370. Whitney, R.D.; McClain, K.M., cochairmen. 1981. Boreal Mixedwood Symposium. 16–18 September 1980, Thunder Bay, ON. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. COJFRC Symposium Proceedings O-P-9. 278 p.

Boreal mixedwood management deals with five major Ontario species and covers a broad range of subject areas; hence, it was obvious that not all facets of the topic could be covered in a three-day symposium. Six general areas that had not been discussed in depth in previous symposia of this series were therefore selected for broad coverage. Twenty-four papers were presented and a conscious attempt was made to introduce the ecosystem concept and to include management purposes other than fibre utilization (e.g., wildlife). The discussion which followed the papers was recorded and paraphrased and is presented at the end of each section.

371. Whittaker, R.H.; Bormann, F.H.; Likens, G.E.; Siccama, T.G. 1974. The Hubbard Brook ecosystem study: forest biomass and production. Ecological Monographs. 44(2):233–254.

Reports further results from this long-term biogeochemical and ecological study in New Hampshire. The Brookhaven system of forest dimension analysis was applied to 93 sample trees of the dominant species: *Acer saccharum*, *Betula alleghaniensis*, *Fagus grandifolia*, *Picea rubens* and *Acer spicatum*. In general, basal area, height, age, volume, above-ground biomass, volume increment, above- ground net primary productivity and leaf-area ratio decreased with increasing altitude. Estimated mean climax biomass (above ground) for the catchment area was approximately 350 t/ha. Biomass of the root systems was 18-21% of above-ground biomass. Net ecosystem productivity declined from 435 g/m^2 per year in 1956-60 to 290 g/m^2 per year in 1961-65. Possible reasons for this decline are discussed and it is concluded that the period 1956-60 was more nearly normal for the forest.

372. Whittaker, R.H.; Likens, G.E.; Bormann, F.H.; Eaton, J.S.; Siccama, T.G. 1979. The Hubbard Brook ecosystem study: forest nutrient cycling and element behavior. Ecology. 60(1):203–220.

Data from dimension analysis of forest biomass and production are combined with analyses of plant tissues, soil, and precipitation to describe nutrient cycling in a cool-temperate deciduous forest on a podzol. Mean concentrations of nutrient elements measured (N, P, S, Ca, K, Mg, Mn, Na, Fe, Zn, Cu) in tissues are relatively low, and nutrient stocks in vegetation are low compared with other forests because of the low concentrations and the relative youth of the forest (cut in 1909-17). The largest fractions of nutrients in aboveground net primary production (NPP) go into leaves - 58-78% of all nutrients except Na (45%) - although leaves are only 40% of aboveground NPP. Net community (woody) growth included ≈30% of aboveground NPP, but smaller fractions of nutrients (7% of N and K to 21% of Ca and 28% of Na). Nitrogen, P, and some other elements are retracted from dying leaves; but concentrations of Ca, Mn, and Na increase from living to dead leaves, branches, and stem wood. Return to the soil from aboveground is primarily by leaching for K and Na but by litterfall for other elements. "Throughflow" is defined as nutrient uptake needed beyond that in NPP to

provide for both leaching and increase in dead tissues before they fall. For Na, throughflow exceeds uptake into NPP; but negative throughflows for N and P reflect conservation of these elements. Belowground plant nutrient stocks are 0.25 to 0.5x and belowground uptake rates into NPP are 0.1 to 0.2x aboveground values for most elements, but belowground values are higher for N, P, Na, and Fe. Significant amounts of some elements, especially S, Ca, K, and Na, are excluded from roots as part of the total, above- and belowground throughflow. Behaviours of nutrient elements can be characterized by ratios expressing concentration into leaves vs. woody tissues and relative leachability and throughflow vs. conservation. Relative turnover rates compare litterfall plus leaching with aboveground stocks or with nutrient contents of NPP. Turnover rates increase in the sequence: N and P; Ca: Mg, K, Fe, and Mn; S; and Na. Means and coefficients of variation of foliage nutrient concentrations express some differences between ecosystems. Comparing different ecosystems, coefficients of variation are low for N and P, intermediate for Ca, K, Mg, and Al, and high for Si, Mn, Fe, Cl, and Na. Differences in these and other expressions of element behaviour can be interpreted on the basis of function in plants.

373. Whynot, T.W.; Penner, M. 1990. Growth and yield of black spruce ecosystems in the Ontario clay belt: Implications for forest management. Forestry Canada, Petawawa National Forestry Institute, Chalk River, ON. Information Report PI-X-99. 81 p.

Fifty years of permanent sample plot growth information from the Clay Belt Region of Northern Ontario were analyzed. Operational groups (OG's) defined by the Forest Ecosystem Classification (FEC) system for the Clay Belt were compared on the basis of productivity (black spruce (*Picea mariana* [Mill.] B.S.P.) site index at age 50) and grouped into broad productivity classes. An alternate approach, comparing the OG's on the basis of their site index curve shape, did not appear to be an improvement over the first study method and was not pursued. The advantages of using the FEC system for forest productivity studies are that it is an objective classification scheme and is used for silvicultural decision making. The disadvantage is that the system is not based on forest productivity and may not be the best classification for growth and yield predictions. Local black spruce volume tables and stand volume curves were developed based on these classes. Productivity Class I volumes peaked earlier and declined at a younger age than other classes and preliminary results indicate volume decline is strongly related to black spruce top height. Mixed stands generally produced slightly more volume than pure black spruce stands on similar sites. A comparison of cut-origin versus fire-origin stands revealed that post-harvest stands have substantially lower black spruce but higher balsam fir (*Abies balsamea* [L.] Mill.) volumes, indicating that volume curves developed for old growth stands are not suitable for cut stands. Examination of two noncommercially thinned old growth stands at age 80 (approximately 40 years after treatment) revealed no measurable benefit from thinning.

374. Wickware, G.M.; Stevens, W.C., cochairmen. 1986. Site Classification in Relation to Forest Management. 27–29 August 1985, Sault Ste. Marie, ON. Canadian Forestry Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON. COJFRC Symposium Proceedings O-P-14. 142 p.

Seventeen papers are presented that discuss approaches to site classification in Ontario, regional site classification in other areas, and site productivity and the economics of site evaluation.

375. Wiensczyk, A. 1992. A brief review of the issues surrounding full tree harvesting. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Note TN-13. 12 p.

Full tree harvesting, in which the entire above-ground portion of the tree is taken to the roadside with branches and foliage removed and the bole is taken to the mill has increased in use in northwestern Ontario as timber harvests have converted to a more mechanized, less labour intensive method of harvesting. This note summarizes the information on the potential effects of full tree harvesting on site fertility and long term site productivity.

376. Wilde, S.A.; Iyer, J.G.; Tanzer, C.; Trautmann, W.L.; Watterston, K.G. 1964. Growth of jack pine (*Pinus banksiana* Lamb.) plantations in relation to fertility of non-phreatic sandy soils. Soil Science. 98(3):162–169.

This paper reports results obtained with plantations of jack pine (*Pinus banksiana* Lamb.), the least-exacting native conifer, which was usually assigned to the reforestation of the poorest soils. In spite of the low requirements of this tree for moisture and nutrients, it has proved to be a highly sensitive indicator of the soil productive capacity; its growth was found to be very strongly correlated with physical and chemical soil productivity factors.

377. Will, G.M. 1984. Monocultures and site productivity. p. 473–487 *in* D.C. Grey, A.P.G. Schonau and C.J. Schutz, eds. Symposium on site and productivity of fast growing plantations. 30 April–11 May 1984, Pretoria and Pietermaritzburg, South Africa. Vol. 1. South African Forest Research Institute, Pretoria, South Africa.

Fast-growing monoculture plantations are tending to become the norm in many countries. Frequently there have been dire predictions about resulting hazards to forest site productivity but available evidence does not support the often extravagant and emotional warnings that have been given. Original assessments of monocultures in Europe failed to recognise management practices, such as litter raking, as major factors in decreased site productivity. Soil acidification and podzolisation, processes that become extreme in some natural forests, are not major influences in plantations of many fast-growing species. Productivity can be sustained in these monocultures if appropriate management practices are adopted, e.g., (1) nutrient conservation (no litter raking, no injudicious slash burning, erosion control, etc.), (2) fertilizer replacement of nutrients removed in harvested material, and (3) control of competition by weeds - particularly for soil moisture. "Second-rotation decline" in radiata pine forests in Australia has been overcome by such sound management practices; in their absence productivity will inevitably decline because, like many forms of agriculture, fast-growing forest plantations are an intensive form of land use in which sustained productivity requires sound management. .

378. Willcocks, A.J.; Baker, W.D.; Sumi, L.; Carmean, W., compilers/editors. 1990. Tools for site specific silviculture in northwestern Ontario: proceedings of a workshop. 19–20 April 1989, Thunder Bay, ON. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Workshop Report No. 3. 283 p.

This workshop began with a discussion on site productivity and forest ecosystem classification. Speakers outlined the many types of silvicultural tools that could be applied to achieve silvicultural objectives. The workshop concluded with how some agencies applied silvicultural principles to their forests. Presently, foresters base most of their silvicultural choice on qualitative reasons, rather than quantitative. Silviculture is a means to achieve forest management objectives or needs of the forest owner. Before we apply silvicultural techniques, these needs must be determined and matched with the appropriate silvicultural treatments.

379. Willcocks, A.J.; Bell, F.W.; Williams, J.; Duinker, P.N. 1990. A crop-planning process for northern Ontario forests. Ontario Ministry of Natural Resources, Northwestern Ontario Forest Technology Development Unit, Thunder Bay, ON. Technical Report #30. 159 p.

Crop planning in forestry consists of determining the most suitable management options from a wide array of alternative courses of action so that the objectives for a forest can be attained at the least cost. This report introduces and demonstrates the potential of a practical crop-planning process which allows the forest manager to develop silvicultural and forest-management strategies responsive to forest objectives. The report begins with an overview of the crop planning process and its major components, then illustrates the use of the process in some simple examples.

380. Winston, D.A.; Morrison, I.K.; Foster, N.W. 1977. Nitrogen and herbicide treatments in semimature jack pine forest, Chapleau, Ontario: fifth-year results. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. Information Report O–X–266. 9 p.

In May 1970, a 3 x 4 factorial experiment, replicated three times, was established to determine the effects of killing ground vegetation by herbicides, in combination with nitrogen fertilization, on the growth of 45-year-old jack pine (*Pinus banksiana* Lamb.). Two herbicides, singly and in combination, paraquat and simazine were applied to ground vegetation in 0.8 ha square plots. Nitrogen fertilizer treatments using urea at 0, 168, and 336 kg N/ ha were applied. After 5 years the response variables, mean DBH increment, basal area increment, percent basal area growth, total volume increment, and merchantable volume increment were estimated. Herbicide was associated with increased growth of jack pine in only one instance: a combination of paraquat and simazine increased mean DBH increment. Nutrient tie-up by ground vegetation does not appear to be an important limiting factor in jack pine tree nutrition.

381. Wood, J.E.; Dominy, S.W.J. 1985. Black spruce, white spruce, and jack pine outplantings in boreal Ontario: bare-root vs. paperpot stock and spring vs. summer planting. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. Information Report O–X–368. 83 p.

This report presents five-year results of a study to evaluate the comparative field performance of spring- and summer-planted Japanese paperpot, transplant and/or seedling stock. From 1974 to 1981, 18 experimental plantations were established on a range of typical boreal forest sites in Ontario. Included in the experiments were one or more of the following species: black spruce (*Picea mariana* (Mill.) B.S.P.), white spruce (*Picea glauca* (Moench) Voss), and jack pine (*Pinus banksiana* Lamb.). Several trends were evident in most of the experiments. Spring-planted spruce transplants were superior to spring- planted paperpot and seedling stock. Black spruce paperpots planted in July generally had higher survival and were in better condition than was July-planted bare- root stock. Summer-planted white spruce paperpot and rising transplant stock demonstrated equivalent performance. The spring-planted jack pine paperpots frequently achieved survival and growth rates similar to those of spring-planted seedlings and substantially higher than those of July-planted rising seedlings. It appears that paperpot stock of the three species examined may be planted until the end of July provided that good care is taken of stock during transportation and handling.

382. Wood, J.E.; Jeglum, J.K. 1984. Black spruce regeneration trials near Nipigon, Ontario: planting versus seeding, lowlands versus uplands, clearcut versus strip cut. Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. Information Report O–X–361. 19 p.

This report presents fifth-year survival, stocking, and height growth results from a black spruce (*Picea mariana* [Mill.] B.S.P.) regeneration trial near Nipigon, Ontario. Two stock types (bare-root stock and Japanese paperpots) and two seeding treatments (bare seed and sheltered seed) were studied on upland seedbeds (feather moss and mineral soil) and lowland seedbeds (*Sphagnum* and dark peat) in a clearcut and in 20-m-wide, first cut strips. Planting either bare-root or container stock on upland mineral soil seedbeds yielded the best results in terms of survival and height growth. The best seeding option was spot seeding on mineral soil seedbeds in strip cuts. Feather moss (primarily *Pleurozium schreberi* [Brid.] Mitt.) was an extremely poor seedbed with less than 15% stocking after five years. On mineral soil seedbeds, seed shelters increased seedspot stocking by 32% on a clearcut and by 15% on strip cuts. Heavy vegetative competition on the lowlands in comparison with that on the uplands reduced height growth of planted trees. Graminoid competition and flooding on the dark peat seedbeds were heavier on strip cuts than on clearcuts, and consequently the performance of planted and seeded trees was poorer on the former.

383. Wood, J.E.; Raper, R. 1987. Alternate strip clearcutting in upland black spruce. III. Regeneration options for leave strips. Forestry Chronicle. 63(6):446–450.

In the alternate stripe clearcutting system, first-cut strips are regenerated by seed produced by black spruce (*Picea mariana* (Mill.) B.S.P.) in the forested leave strips. However, after the second cut, such a seed source is not available for regenerating the leave strips. Therefore, the forest manager must consider a number of alternative regeneration options. The selection of the most appropriate regeneration option is dependent upon several economic and biological criteria. These include future costs of delivered wood, site productivity, post- harvest site condition, future alternative sources of supply, and future demand for industrial wood. Regeneration options such as preservation of advance growth and direct seeding are recommended for sites on which the manager is concerned primarily with regenerating first cut strips and is willing to accept a lower level of stocking in leave strips. Planting, the most intensive option discussed, should be reserved for sites offering the highest potential return or greatest future cost savings. Direct seeding of jack pine (*Pinus banksiana* Lamb.) should be considered on the upland portions of this patterned site type. Mixing jack pine and black spruce is a suggested regeneration option if the site contains both upland and lowland topographic positions. Other seeding options include the use of semi-transparent plastic seed shelters. The manager might consider combining two or more of these options to meet management objectives.

384. Wood, J.E.; Sutton, R.F.; Weldon, T.P.; Rissanen, H. 1988. Jack pine establishment: effect of stock type, Bräcke scarification, mounding, and chemical site preparation. Three year results. Canadian Forestry Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON. Information Report O–X–393. 19 p.

A field experiment was begun in May 1984 to assess the performance of 2+0 bare rooted stock and FH408 Japanese paperpot stock of jack pine (*Pinus banksiana*) in relation to mechanical site preparation (Bräcke scarification) with and without both various kinds of mounding in June 1983 and chemical site preparation (spraying Roundup [glyphosate] in August 1983) on deep silt loam about 200 km N. of Sault Ste. Marie, Ontario. Assessments of survival and growth were made annually for 3 years. The paperpot stock after 3 seasons was larger than the bare rooted stock after 2 seasons. Paperpot stock benefited more than bare rooted stock from mechanical site preparation. Both stock types responded positively to mounding. Shape, volume and type of mound had little effect on survival or growth. There were consistent indications that glyphosate spraying gave positive (although not significant) growth responses to both stock types.

385. Wright, H.L., ed. 1983. Planning, performance and evaluation of growth and yield studies. Commonwealth Forestry Institute, University of Oxford, Oxford, UK. Occasional Paper No. 20. 175 p.

A collection of 19 (Mensuration, Growth and Yield) held in Oxford from Sept. 16 to 22, 1979. Bruce, D. Where is the ground? Determination of ground level for d.b.h. measurements [pp. 1-3]; Christie, J.M., Edwards, P.N. Do future establishments of permanent sample plots in Britain need to follow past practice to meet the requirements of forest management? [pp. 4-9]; Edwards, P.N. Portable data terminals for data collection in the field [pp. 10-14]; Ferguson, I.S. Collecting growth data in Australia and New Zealand [pp. 15-24]; Ferguson, I.S. Growth functions for radiata pine plantations [pp. 25-45]; Gallagher, G.J., O'Brien, D. Sample plots and experiments in crop development studies in the Irish Republic [pp. 46-55]; Graaf, N.R. A caliper for use in tropical rainforest management [pp. 56-60]; Howell, R.S., Stickland, R.E. A stem analysis machine under development [pp. 61]; Liu, C.J. Stem profile analysis of *Liriodendron tulipifera* using spline approximation [pp. 62-73]; McEwen, A.D., Goulding, C.J. The permanent sample plot system of the New Zealand Forest Service [pp. 74-82]; Monserud, R.A., Ek, A.R. Comparison of two stand growth models for northern hardwoods in the Lake States, USA [pp. 83-89]; Rennolls, K., Tee, V. Estimation of the volume of a stand using a tariff procedure [pp. 91-99]; Rondeux, J. A flexible yield and management model for spruce [*Picea abies*] in the Belgian Ardennes [pp. 100-109]; Schneider, T.W., Alder, D. A stand growth model as a tool in studying management options for MAB-rainforest ecosystem projects and for temperate forests [UNESCO's Man and the Biosphere programme] [pp. 110-119]; Schonau, A.P.G. Application of a factorial design to a thinning experiment in *Eucalyptus grandis*, with intermediate results [in the Natal Midlands, South Africa] [pp. 120-139]; Singh, S.P. Data collection in tropical forests [in India] [pp. 140-148]: Solomon, D.S., Seegrist, D.W. Growth and yield analysis of thin uneven-aged spruce and fir stands in Maine [pp. 149-156]; Young, H.E., Ribe, J.H. Quantifying forest science with biomass. Part one: site productivity [pp. 157-165]; and Young, H.E., Hoppe, J.C. Quantifying forest science with biomass. Part two: conifer thinning studies [pp. 166-175].

386. Yahner, R.H.; Scott, D.P. 1988. Effects of forest fragmentation on depredation of artificial nests. Journal of Wildlife Management. 52(1):158–161.

Depredation on artificial ground and arboreal (1.5 m above ground) nests was studied in mature (uncut) forest stands on a ruffed grouse management area in central Pennsylvania from May to August 1986. Predation was evaluated in mature stands with zero, 25, and 50% zones of the surrounding forest fragmented by clearcutting. Nest depredation was highest in the 50% zone and least in the zero percent zone; more arboreal nests than ground nests were disturbed. American crows were major predators on nests in the 50% zone, and crows and blue jays caused most nest disturbances in the 25% zone. Our results suggest that fragmentation of surrounding forest stands may negatively impact avian nesting success, especially when the principal nest predators are corvids. Predation in fragmented forests may have a greater effect on nesting success of birds nesting above ground than those nesting at ground level.

387. Yapa, A.C.; Mitchell, M.H. 1987. Bibliography/Liste des publications pour les années 1979–1985. Canadian Forestry Service, Petawawa National Forestry Institute, Chalk River, ON. Information Report PI-X-70E/F. 150 p.

This volume is the first in a series planned for publications of the Petawawa National Forestry Institute (PNFI). The starting point of 1979 was chosen as it was the year during which PNFI was formed, amalgamating three research facilities of the Canadian Forestry Service - the Forest Management Institute, the Petawawa Forest Experiment Station, and the Forest Fire Research Institute. This publication is intended to be a comprehensive annotated bibliography. All publications of professionals working out of PNFI, for the period 1979- 1985 inclusive, are listed in alphabetical order. Contract reports of projects administered by PNFI staff are also included, if these were/are generally available in the scientific literature. A species/key word index is provided.

388. Yeager, L.E. 1950. Implications of some harvest and habitat factors in pine marten management. Transactions of the 15th North American Wildlife Conference. 15:319–334.

Marten are a significant economic resource in North America but timber harvest, fire, and forest diseases are making inroads on marten range. A discussion of implications of land use is presented.

389. Zarnowitz, J.E.; Manuwal, D.A. 1985. The effects of forest management on cavity-nesting birds in northwestern Washington. Journal of Wildlife Management. 49(1):255–263.

Population characteristics and nest-site preferences of 11 species of cavity-nesting birds were studied in the Olympic National Forest (ONF) of northwestern Washington in the spring and summer of 1979-1980. We characterized breeding populations in four different forest successional stages where either high or low densities of snags occurred. Species richness (N=13 vs. N=9), densities ($P<0.01$), and diversities ($p<0.01$) of cavity-nesting birds increased with increasing snag densities. Active cavity- nests were five times more numerous on the 1980 plots (Snag Plots) than the 1979 plots (Clean Plots). Snag densities on the Snag Plots varied from 13.8/ha in a clear-cut to 97.1/ha in a 25-50 year old second-growth stand. Clean Plots contained from 0.5 snags/ha in a clear- cut to 37.3 in old-growth. Hairy woodpeckers, a primary cavity-nester, selected western hemlock snags for nest sites. In contrast, broken-topped Douglas-fir snags were preferred by secondary cavity-nesters. The average diameter at breast height (DBH) for active nest trees was substantially greater than the mean DBH for sampled snags in the ONF. Snags appear to be a limiting factor for breeding cavity-nesting bird populations. We discuss management recommendations for cavity-nesting birds in the ONF.

390. Zundel, P. 1986. The economics of integrated, full-tree harvesting and central processing in jack pine: final report. Forest Engineering Research Institute of Canada, Pointe Claire, PQ. Special Report SR-37. 82 p.

This report presents the results of an analysis examining the economic worth associated with investing in forest harvesting systems designed to recover energy biomass in conjunction with conventional products such as tree lengths or logs. This report also summarizes the findings of five field experiments designed to provide estimates of the energy biomass recovered by the feller-forwarder and cut-and-skid harvesting methods, to test experimental methods and to quantify the merchantable volume loading of standard highway-legal trailers loaded with full trees rather than tree lengths. ENFOR project P-322.

APPENDIX A: BIBLIOGRAPHIES, PROCEEDINGS, SYMPOSIA, BOOKS

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APPENDIX B: ACRONYMS APPEARING IN REPORT AND/OR BIBLIOGRAPHY

BSD - Bird Species Diversity
CFS - Canadian Forest Service
CNFER - Centre for Northern Forest Ecosystem Research
COFRDA - Canada-Ontario Forest Resource Development Agreement
COJFRC - Canada-Ontario Joint Forestry Research Committee
CTH - Conventional Tree Harvest
DBH - Diameter at Breast Height
FEC - Forest Ecosystem Classification
FERIC - Forest Engineering Research Institute of Canada
FHD - Foliage Height Diversity
FRDA - Canada-British Columbia Forest Resource Development Agreement
FORCYTE - FORest Nutrient CYcling Trend Evaluator
FTH - Full Tree Harvest (tree's bole and branches removed, stump and roots left on-site)
GIS - Geographic Information System
IRM - Integrated Resource Management
IUFRO - International Union of Forest Research Organizations
JABOWA - an individual tree growth model developed by JAnak, BOtkin and WAllace
NEST - Northeastern Region Science and Technology Development Unit
NODA - Northern Ontario Development Agreement
NWOFTDU - Northwestern Ontario Forest Technology Development Unit
OFRI - Ontario Forest Research Institute
OMNR - Ontario Ministry of Natural Resources
SIP - Site Preparation
SIVE - Stress Induced Volatile Emissions
TRIM - Tree Ring Increment Measurement
TWINSPAN - TWo-way INdicator SPecies ANalysis
USDA - United States Department of Agriculture
WTH - Whole Tree Harvest (entire tree removed, including stump and roots)