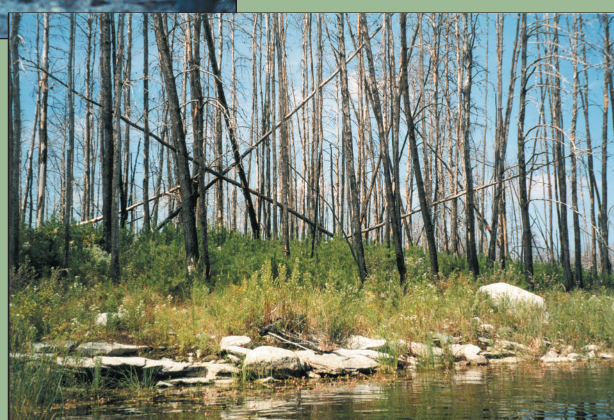
Ecological Effects of Forest Fires in the Boreal and Great Lakes - St. Lawrence Forest Regions of Ontario:

A Partially Annotated Bibliography

T.J. Lynham, M.E. Alexander, D.M. Morris, and J.L. Kantor

Information Report Number: GLC-X-6



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Ontario

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Published by:
Natural Resources Canada
Canadian Forest Service
Great Lakes Forestry Centre
Information Report Number: GLC-X-6

Catalogue No. Fo29-51/6-2002E
ISBN 0-662-32586-9 ISSN 2562-0738 (online)

National Library of Canada cataloguing in publication data
Main entry under title :

Ecological effects of forest fires in the boreal and Great Lakes – St. Lawrence forest regions of Ontario : a partially annotated bibliography

(Information report ; GLC-X-6)
Includes preliminary material in French.
ISBN 0-662-32586-9 ISSN 2562-0738 (online)
Cat. no. Fo29-51/6-2002E

1. Fire ecology – Ontario — Bibliography
2. Forest fires – Environmental aspects – Ontario – Bibliogaphy.
3. Forest fires – Environmental aspects – Great Lakes Region – Bibliography.
4. Forest fires – Environmental aspects – Saint-Lawrence River Region —Bibliography.
5. Forest fires – Environmental aspects – Bibliography.
6. Fire ecology – Bibliography.

I. Lynham, T.J.
II. Great Lakes Forestry Centre.
III. Series: Information report (Great Lakes Forestry Centre) ; GLC-X-6.

Z5322.F57E25 2002 016.6349'618 C2002-980292-X

Copies of this publication may be obtained free of charge from:

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PRINTED IN CANADA IMPRIMÉ AU CANADA

Printed on recyled paper

Cover design by Mark J. Primavera

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1.0 INTRODUCTION

This report is an annotated bibliography on the ecological effects of fire on fauna, flora, soil, water, and microclimate in the Boreal and Great Lakes - St. Lawrence Forest Regions of Ontario and adjacent areas (i.e., eastern Manitoba, northern Minnesota, Isle Royale in Michigan, and western Quebec). It includes published literature as well as important unpublished reports. In some cases, author's abstracts, summaries, conclusions, or selected passages were excerpted. Many reports, especially reports before 1980, were annotated to be included in the bibliography.

The focus of this bibliography is on fire effects in natural forest stands. Fire impact in cut-over stands (McRae *et al.* 2001) is not covered, nor are the biological and silvicultural effects of broadcast slash burning (e.g., McRae 1979). The report is patterned after Schrige and Penderis (1978) in which a specific geographical area is covered. It is intended to be a handy reference for Ontario land managers, researchers, educators, and university students. It includes several references on fire effects that came from Drysdale *et al.* (1974). His report originated from a joint Canada-Ontario research committee and was the first recorded attempt to pull together references on fire effects in Ontario.

Historical Fire Incidence

The annotated portion of this bibliography does not include references related to the historical incidence of fire in Ontario. A comprehensive review on this subject was conducted by Alexander (1980). An atlas of fires greater than 200 ha, that date back to 1926, was produced by Donnelly and Harrington (1978).

Several reports have examined historical fires in conjunction with specific parts of the boreal forest in Ontario. Johnston and Sharpe (1923) produced a forest survey report that included fires in northeastern Ontario. Forest age distributions and rates of disturbance in northwestern Ontario were examined by Suffling *et al.* (1982). Simkin (1965) reported on specific fires related to woodland caribou in the Hudson Bay Limits. In the Great Lakes - St. Lawrence Forest Region, Brunskill and Schindler (1971) studied fire history in western Ontario and Battson (1983) examined it in northeastern Ontario. Other papers (Table 1) examined average fire rotation periods in various forest zones.

Table 1. Fire rotation periods in Ontario and adjacent areas.

Fire Rotation (yr)	Forest Region	Location	Reference
8-45	GLSL	Itasca State Park, MN	Clark (1990)
22	GLSL	Itasca State Park, MN	Frissell (1973)
20-30	Boreal	Sachigo Hills, ON	Lynham and Stocks (1991)
60-70	GLSL	Boundary Waters, MN	Swain (1973)
70-80	GLSL	Barron Township, ON	Cwynar (1977, 1978)
78	GLSL	Quetico Provincial Park, ON	Woods and Day (1977)
60-100	Boreal	Northwest Lake, ON	Pilmanis (1994)
100	GLSL	Boundary Waters, MN	Heinselman (1973)

The Ecological Role of Fire

The subject of fire ecology and effects across the boreal forest has been covered in several review papers (e.g., Lutz 1960; Kayll 1968; Scotter 1972; Rowe and Scotter 1973; Heinselman 1981a, b), symposium proceedings (e.g., Slaughter *et al*. 1971; Anon. 1979; Hoefs and Russell 1980; Wein and MacLean 1983) and monographs (e.g., Lutz 1956; Scotter 1964; Kelsall *et al*. 1977; Viereck and Schandelmeier 1980). Reviews on fire ecology in the Great Lakes - St. Lawrence Forest Region include Heinselman (1981a, b) and Wright and Bailey (1982).

The ecological significance of fire was summarized in an unpublished paper by Van Wagner (1981). He pointed out that fire is one of the three primary physical factors, along with climate and soil, that have shaped the Canadian forest. In its natural state, most of the forest is dependent on periodic fire for its long-term stability. In this role, fire acts as a recycling agent. He suggested that fire is neither "good" nor "bad". The real degradation of forest or site by fire is usually associated with repeated fires at abnormally short intervals or fires resulting from human activities such as logging. On the average, in otherwise undisturbed forests, the post-fire stands are similar and equal in quality to the pre-fire stands (Van Wagner 1981).

Wright and Heinselman (1973) briefly summarized the effects of fire as an ecosystem process with several summary points. They stated that fire influences the physical-chemical environment, regulates dry matter accumulation, controls plant species and communities, determines wildlife habitat patterns and populations, controls forest insects, parasites and fungi, and controls major ecosystem processes and characteristics.

Alexander and Euler (1981) reviewed the ecological role of fire in the uncut boreal mixedwood forests of Ontario by drawing upon literature from across North America. The authors used the summary points from Wright and Heinselman (1973) to organize their review paper. They completed their review by adding sections on management implications and needs and opportunities for future research. Additional selected examples of the ecological role of fire in the boreal and Great Lakes - St. Lawrence forest regions include: Ellis (1911), Candy (1939), Hustich (1957), Horton and Brown (1960), deVos (1962), Cumming (1972), Heinselman (1975), Foster and Morrison (1976), Day (1982), Klein (1982), and Cayford and McRae (1983).

In the first half of the twentieth century, the emphasis on the ecological effects of fire was on forest regeneration. Hosie (1953) summarized some of this work across Ontario from 1918-1951. Gradually research interests expanded to include fire effects on soils, animals and lower plants (e.g., shrubs, herbs, graminoids, mosses, lichens and ferns). Through the Quetico-Superior Wilderness Research Center, Ahlgren (1970, 1973, 1978) conducted ecological research and summarized three decades of ecological investigations. Nearby, in Isle Royale National Park, Krefting (1974) reported on moose distributions on the island and the role of fire in producing moose habitat. Meanwhile the Canadian Forest Service (Van Wagner 1979) produced an annotated bibliography of fire research on the Petawawa National Forest which included important work related to red pine and white pine. The USDA Forest Service and the University of Minnesota initiated a 5-year study (Ohmann and Grigal 1979) that examined plant, tree and soil changes following the Little Sioux Fire of 1971. Two decades later, Slaughter (1994) reported on a follow-up study of the site. Lotan *et al*. (1981) produced a joint USA/Canada review on the effects of fire on flora.

The Ontario Ministry of Natural Resources (OMNR) studied fire effects in Quetico Provincial Park (Woods and Day 1975, 1977; Woods 1978). The results of these OMNR studies were instrumental in developing fire management guidelines for the Park in 1998 (Parks Ontario 1998). Meanwhile, Schindler *et al*. (1980) played the role of opportunists in monitoring the effects of fire on two boreal watersheds in northwestern Ontario. They had been monitoring two watersheds for four years when a severe windstorm caused a massive blowdown in 1973. The windstorm was followed by a natural wildfire in 1974. They were in the unique situation of having extensive pre-burn data on water yields and nutrient levels for an area that burned. Their data led them to conclude that, under fire return intervals that are not unusually short, there are no nutrient or water related changes that support fire suppression. They argued that when human life or property are not threatened, then wildfires should be allowed to burn naturally in the boreal forest.

Future Direction

Land managers require models that will allow them to make predictions about fire effects based on fire behavior just as those same managers use fire weather information to predict fire behavior. A national fire effects model is required for land management in Canada. Development of such a model is complicated by the fact that post-fire recovery is not just determined by the characteristics of a fire but also by the weather and land use conditions that follow the fire. For example, a long term drought can result in the failure of regeneration for some plant species. Also natural seed production cycles are not only controlled by fire events but may also be affected by weather conditions and population cycles of both insects and small mammals. Nonetheless, the future for studying the ecological effects of fire lies in relating these effects to fire behavior as suggested by Lotan *et al*. (1981) and Alexander (1982).

The last two decades of fire management have brought managers to a new realization regarding the ecological role of fire in Canadian forest ecosystems. “Periods of extreme short-term fire weather, in combination with a recognition of both the ecological desirability of natural fire and the economic impossibility of controlling all fires, have resulted in the realisation that forest fires in Canada are a problem that cannot, and should not, be eliminated.” (Stocks *et al*. 2001).

1.0 INTRODUCTION

Le présent rapport est une bibliographie annotée sur les effets écologiques du feu sur la faune, la flore, le sol, l’eau et le microclimat dans la portion ontarienne de la région forestière boréale et la région forestière des Grands Lacs et du Saint-Laurent (GLSL) et dans les régions adjacentes (à savoir, l’est du Manitoba, le nord du Minnesota, l’Isle-Royale au Michigan et l’ouest du Québec). Il fait état de documents publiés ainsi que d’importants rapports inédits. Dans certains cas, il présente le résumé du ou des auteurs, un sommaire, les conclusions ou des extraits de certains passages. Nombre de rapports, notamment ceux antérieurs à 1980, ont été annotés et inclus à la bibliographie.

La présente bibliographie porte sur les effets du feu dans les peuplements forestiers naturels. Elle ne traite pas des incidences du feu dans les peuplements coupés à blanc (M^cRae *et collab.* 2001) ni des répercussions biologiques et sylvicoles du brûlage extensif des rémanents (p. ex., M^cRae, 1979). Elle est présentée sur le modèle du rapport de Schrige et Penderis (1978), soit par secteur géographique précis. Elle se veut un outil de référence pratique à l'usage des responsables de la gestion du territoire, des chercheurs, des éducateurs et des étudiants universitaires de l'Ontario. Elle fait notamment référence à plusieurs documents sur les effets du feu tirés de Drysdale *et collab.* (1974). Ce dernier rapport a été préparé par un comité conjoint de recherche Canada-Ontario et était la première compilation officielle de documents de référence sur les effets du feu en Ontario.

Incidences historiques du feu

La partie annotée de la présente bibliographie ne comprend pas de documents de référence concernant les incidences historiques du feu en Ontario. Alexander (1980) a effectué un examen détaillé de cet aspect. Donnelly et Harrington (1978) ont préparé un atlas des incendies de forêt d'une superficie de plus de 200 hectares depuis 1926.

Plusieurs rapports ont examiné l'historique des incendies de forêt dans des régions précises de la forêt boréale en Ontario. Johnston et Sharpe (1923) ont préparé un rapport d'inventaire forestier qui faisait état des superficies balayées par le feu dans le nord-est de la province. Suffling *et collab.* (1982) ont examiné la répartition des classes d'âge et les régimes de perturbation dans le nord-ouest de l'Ontario. Simkin (1965) a rédigé un rapport traitant des incendies de forêt et du caribou des bois sur le territoire de la baie d'Hudson. Dans la région forestière des Grands Lacs et du Saint-Laurent, Brunskill et Schindler (1971) ont étudié l'historique des feux dans l'ouest de l'Ontario et Battson (1983) s'est concentré sur le nord-est de la province. D'autres auteurs (tableau 1) ont étudié l'intervalle moyen des feux dans diverses zones forestières.

Tableau 1. Intervalles des feux en Ontario et dans les régions adjacentes.

Intervalle des feux (années)	Région forestière	Emplacement	Document de référence
8-45	GLSL	Itasca State Park (Minnesota)	Clark (1990)
22	GLSL	Itasca State Park (Minnesota)	Frissell (1973)
20-30	boréale	Mont Sachigo (Ont.)	Lynham and Stocks (1991)
60-70	GLSL	Boundary Waters (Minnesota)	Swain (1973)
70-80	GLSL	Canton de Barron (Ontario)	Cwynar (1977, 1978)
78	GLSL	Parc provincial de Quetico (Ont.)	Woods and Day (1977)
60-100	boréale	Lac Northwest (Ontario)	Pilmanis (1994)
100	GLSL	Boundary Waters (Minnesota)	Heinselman (1973)

<u>Le rôle écologique du feu</u>

L'écologie et les effets du feu en forêt boréale ont été les thèmes de plusieurs documents de synthèse (p. ex., Lutz, 1960; Kayll, 1968; Scotter, 1972; Rowe and Scotter, 1973; Heinselman, 1981a, b), de symposiums (p. ex., Slaughter *et collab.*, 1971; Anon., 1979; Hoefs and Russell, 1980; Wein and MacLean, 1983) et de monographies (p. ex., Lutz, 1956; Scotter, 1964; Kelsall *et collab.*, 1977; Viereck and Schandelmeier, 1980). Heinselman (1981a, b) et Wright et Bailey (1982) ont notamment examiné l'écologie du feu dans la région forestière des Grands Lacs et du Saint-Laurent.

Van Wagner (1981) a résumé dans un rapport inédit l'importance écologique du feu. Il soulignait que le feu est l'un des trois principaux facteurs physiques qui, avec le climat et les sols, ont modelé la forêt canadienne. La stabilité à long terme de la majeure partie des forêts à l'état naturel est tributaire d'incendies périodiques. À ce titre, le feu sert d'agent de « renouvellement ». Selon Van Wagner, le feu n'était ni « bon » ni « mauvais ». La détérioration véritable d'une forêt ou d'une station par le feu est habituellement associée à une succession d'incendies à des intervalles anormalement courts ou à des feux causés par des activités humaines comme l'exploitation forestière. En général, les peuplements établis après feu et les peuplements présents avant le feu étaient similaires et de même qualité dans les forêts par ailleurs non perturbées (Van Wagner, 1981).

Wright et Heinselman (1973) ont brièvement résumé les effets du feu comme un processus écosystémique comportant plusieurs aspects essentiels. Selon eux, le feu influe sur le milieu physico-chimique, régit l'accumulation de matière sèche, équilibre les espèces et les communautés végétales, gouverne les modes de répartition de l'habitat et les populations d'espèces sauvages, réprime les insectes, les parasites et les champignons pathogènes des arbres et régit les principaux processus et caractéristiques de l'écosystème.

Alexander et Euler (1981) ont puisé dans la documentation nord-américaine pour examiner le rôle écologique du feu dans les forêts mixtes boréales non exploitées de l'Ontario. Ils ont utilisé les aspects essentiels définis par Wright et Heinselman (1973) pour structurer leur document de synthèse. Ils ont complété leur examen en ajoutant des sections sur les incidences de l'aménagement et sur les besoins en matière de recherches futures et les possibilités à exploiter. Parmi les autres documents sur le rôle écologique du feu dans la région forestière boréale et dans la région forestière des Grands Lacs et du Saint-Laurent, mentionnons les suivants : Ellis (1911), Candy (1939), Hustich (1957), Horton et Brown (1960), deVos (1962), Cumming (1972), Heinselman (1975), Foster et Morrison (1976), Day (1982), Klein (1982) ainsi que Cayford et M^c^Rae (1983).

Durant la première moitié du XX^e^ siècle, la régénération des forêts était le point de mire de la recherche sur les effets écologiques du feu. Hosie (1953) a résumé certains des travaux menés de 1918 à 1951 en Ontario. La portée des recherches s'est peu à peu élargie pour inclure les effets du feu sur les sols, la faune et la végétation plus basse (comme les arbustes, les plantes herbacées, les graminoïdes, les mousses, les lichens et les fougères). Par l'entremise du Quetico-Superior Wilderness Research Center, Ahlgren (1970, 1973, 1978) a effectué des recherches en écologie et a dressé un bilan de trois décennies d'études écologiques. Non loin de là, dans le parc national de l'Isle-Royale, Krefting (1974) a rédigé un rapport sur la répartition de l'orignal dans l'île et sur le rôle du feu dans le façonnement de l'habitat de cette espèce. Pendant ce temps, le Service canadien des forêts (Van Wagner 1979) a préparé une bibliographie annotée de la recherche sur les incendies menée dans la forêt expérimentale de Petawawa qui comportait d'importants travaux sur le pin rouge et le pin blanc. Le Service des forêts des États-Unis et l'Université du Minnesota ont entrepris une étude quinquennale (Ohmann and Grigal, 1979) des modifications de la végétation, de la couverture arborescente et du sol à la suite de l'incendie de Little Sioux de 1971. Deux décennies plus tard, Slaughter (1994) publiait un rapport sur les résultats d'une étude de suivi menée à cet endroit. Lotan *et collab.* (1981) ont préparé un examen conjoint É-U./Canada des effets du feu sur la flore.

Le ministère des Richesses naturelles de l'Ontario (MRNO) a étudié les effets du feu dans le parc provincial de Quetico (Woods and Day, 1975, 1977; Woods, 1978). Les résultats de ces études du MRNO ont contribué à l'élaboration de lignes directrices sur la gestion des incendies dans le parc en 1998 (Parcs Ontario, 1998). Pendant ce temps, Schindler *et collab.* (1980) ont profité de l'occasion qui s'offrait à eux pour surveiller les effets du feu dans deux bassins versants de la forêt boréale dans le nord-ouest de l'Ontario. Ils surveillaient ces deux bassins depuis quatre ans lorsqu'une violente tempête de vent a déraciné et brisé les arbres sur une vaste superficie en 1973. Cette tempête a été suivie d'un incendie de forêt d'origine naturelle en 1974. Ils ont eu une chance unique : ils disposaient de données détaillées, compilées avant l'incendie, sur l'apport d'eau et les teneurs en éléments nutritifs d'un territoire qui avait été balayé pat le feu. Leurs données leur ont permis de conclure qu'aucun changement des teneurs en éléments nutritifs ou de l'apport d'eau ne justifiait des activités de suppression des incendies lorsque l'intervalle des feux n'était pas anormalement court. À leur avis, il fallait laisser brûler librement les incendies en forêt boréale lorsqu'aucune vie humaine ou bien n'était menacé.

Orientation future

Les responsables de la gestion des terres utilisent déjà l'information sur les conditions propices aux incendies pour prévoir le comportement des incendies et ont besoin de modèles qui leur permettront de prévoir les effets du feu à partir du comportement des incendies. Il faut élaborer un modèle national des effets du feu pour gérer les terres au Canada. Le rétablissement après feu est fonction non seulement des caractéristiques d'un incendie, mais également des conditions météorologiques et de l'utilisation ultérieure des terres, des facteurs qui viennent compliquer l'élaboration d'un tel modèle. Ainsi, une sécheresse prolongée peut entraîner l'échec de la régénération de certaines espèces végétales. De plus, les cycles naturels de production de semences sont non seulement régis par les incendies qui surviennent, mais peuvent également être affectés par les conditions météorologiques et les cycles de population des insectes et des petits mammifères. Néanmoins, la voie à suivre pour étudier les effets écologiques du feu est d'établir des liens entre ces effets et le comportement des incendies, comme l'ont suggéré Lotan *et collab.* (1981) et Alexander (1982).

Deux décennies de gestion des incendies de forêt ont permis aux gestionnaires de faire une constatation au sujet du rôle écologique du feu dans les écosystèmes forestiers canadiens. « De courtes périodes de conditions extrêmement propices aux incendies, conjuguées au fait qu'il a été reconnu que les incendies d'origine naturelle sont écologiquement souhaitables et que la maîtrise de tous les incendies est économiquement impossible, ont permis de se rendre compte que les incendies de forêt au Canada constituent un problème qui ne peut ni de doit être éliminé. » (Stocks *et collab.*, 2001).

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2.0 FIRE AND THE BOREAL FOREST REGION

2.1 Influence of fire on soil: physical and chemical properties

Armson, K.A. 1968. The effects of forest fires on the physical and chemical properties of soils in northwestern Ontario. Extr. from Rep. For. Res. Glendon Hall Fac. For. Univ. Toronto, Toronto, Ont.

During the summer of 1968, an extensive survey was made of burnt and unburnt soils in northwestern Ontario. It was found that fires, although consuming part of the surface organic layers, only rarely exposed the mineral soil to any extent, and then only when two consecutive fires occurred within 20 years. Chemically, the general effect of fire was to increase the pH of the upper horizons (Ae) from 4.3 to 5.2, and this effect lasted for 10 years. The content of available P was also higher. In general, no measurable surface erosion was observed. Regeneration after fire was variable, but *Pinus banksiana* predominated.

Armson, K.A. 1969. Report on fire damage appraisal study. Unpublished report; on file with Aviation and Fire Management Centre, Ont. Min. Nat. Res., Sault Ste. Marie, Ont. 16 p. + Appendix.

During the summer of 1968 an extensive survey was made of burned and unburned soils in the Sioux Lookout District of Northern Ontario. This study was undertaken at the request and with the support of the Forest Protection Branch, Ontario Department of Lands and Forests. In particular, the effects of fires on physical and chemical properties of the soils, erosion rates or hazards subsequent to fires, and forest regeneration and growth were studied in detail. Of the soils examined (61 locations) 77 percent were sands or sandy loam with orthic or minimal podzol profiles. Of the remaining 13 percent - fine textured soils such as clays and clay loams - the majority of profiles were grey-wooded. It was found that the fires, although consuming a part of the surface soil organic layers, only rarely exposed the mineral soil to any extent. A sequence of two fires during a 1-20 year period was the only one in which such drastic removal of organic layers was likely to occur. Chemically, the general effect of a fire was to increase the pH values of the upper organic and inorganic layers (Ae) from 4.3 to 5.2 and this effect lasted for at least 10 years following the fire. Available phosphorus levels were also higher. In general no measurable surface erosion was observed. Regeneration after fire was variable, but generally, jack pine (*Pinus banksiana* Lamb.) predominated. Only when a second fire occurred within 20 years of the first was there evidence of a greatly reduced stocking to pine and black spruce (*Picea mariana* Mill. (BSP)).

Comments: see (Armson 1977) in Appendix B and Armson *et al*. (1973) below.

Armson, K.A.; Taylor, J.M.; Astley, E. 1973. The effects of fire on organic layers of spodosols in the boreal forests of Ontario. Agron. Abstr. 1973: 137.

A field study was made of soils in northwestern Ontario which had been subject to natural fire, but not disturbance by man such as logging. At 65 locations, categorized as to age class and frequency of occurrence of fires, soil descriptions were made, particularly of the 0 horizons. Mean thicknesses of 0 horizons were 14 cm in areas that had not been burned within the past 50 years. In areas that had been burned either once or twice within the past 50 years 0 horizons ranged from 2 to 8 cm. Occurrence of fire resulted in increase in pH values in both 0 and A2 horizons from 4.4 to 6.0. These higher values persisted for at least 60 years following the fire. No measurable surface erosion was observed.

Bradbury, J.P.; Tarapchak, S.J.; Waddington, J.C.B.; Wright, R.F. 1975. The impact of a forest fire on a wilderness lake in northeastern Minnesota. Verh. Int. Verein. Limnol. 19:875-883.

The Little Sioux fire, a spring fire, may not be typical of fires that burn during the late summer and fall. Fall fires might cause larger nutrient losses because more of the forest floor material is likely to be consumed and revegetation does not begin until the following spring. Fire is a natural part of coniferous forest ecosystems, and the results of this study indicate that nutrient losses after fire may be minimal. The removal of nutrients by logging, on the other hand, can seriously deplete the available nutrient capital of the forest and transport it to lakes and rivers. Since the annual inputs of nutrients by weathering and atmospheric precipitation are small, many years are required to restore forest losses while enriched aquatic environments may show undesirable limnological changes. By causing only minimal nutrient losses and therefore only slight increases in nutrient supply to lakes, fire plays a natural and restrained role in wilderness ecosystems.

Bunting, B.T. 1983. The effect of fire on humus profiles in Canadian boreal forests. p. 681-688 *in* Bullock, P.; Murphy, C.P. (eds.). Soil micromorphology. Volume 2. Soil genesis. A B Academic Publishers. Berkhamsted, Herts, UK.

The nature and extent of fire impact on boreal forest humus profiles is described. Recolonisation by moss, lichen and higher plants on sites of various age provide varied litters to supplement surviving humified material. New humus forms and modexi are dependent on intensity of past burns, partially-burned humus profiles showing more elaborate and varied components, intensely-burned profiles having many charred fragments of varied origin. The physical and chemical properties of the humus profiles of intensely-burned and partly-burned sites are significantly different, as are the proportions of skeletal, fibrous and plasmic materials.

Campbell, G.S.; Jungbauer, J.D., Jr.; Bristow, K.L.; Hungerford, R.D. 1995. Soil temperature and water content beneath a surface fire. Soil Sci. 159:363-374.

We report here the results of laboratory and computer simulations designed to supply information on soil temperatures under forest and range fires. Measurements of temperature and water content in a soil column that was heated strongly at the surface showed a consistent pattern of warming and drying. In initially wet soil, temperature rose to around 95° C and remained there until the water content of the soil at that depth dropped below about 0.02 $m^3 \cdot m^{-3}$. When the soil was initially dry, the temperature increased more rapidly, but even the moisture present in air-dry soil was sufficient to slow the rate of temperature rise when temperatures reached 90° C. A linked-transport model, which simultaneously computes changes in temperature and water content, simulated the main features of heat and water flow in a soil column heated to high temperature. There were no consistent deviations of measured from modeled temperatures, but the water content simulations consistently showed a greater buildup of moisture ahead of the heating front than did the measurements, and less drying of the soil in the heated layers when the initial soil water content was low. Soils from sand to clay, and with differing mineralogies, water contents, and bulk densities were used to compare measurements and simulations. The model performed well in all cases. Since the temperature simulations are reasonable, the model appears suitable for predicting fire effects in the field.

Chrosciewicz, Z. 1967. Experimental burning for humus disposal on clear-cut jack pine sites in central Ontario. Can. Dept. For. Rural Dev., For. Br., Dept. Publ. 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).

Dubreuil, M.A.; Moore, T.R. 1982. A laboratory study of postfire nutrient redistribution in subarctic spruce-lichen woodlands. Can. J. Bot. 60:2511-2517.

The redistribution of nutrients after fire was examined by igniting samples of spruce needles, birch leaves and lichen and leaching the ash through a soil column, under laboratory conditions. Nitrogen was lost from the tissue samples at temperatures above 200° C. Up to 40 kg/ha can be lost from the woodlands during a fire. Leaching of the plant tissue ignited at 500° C for 2 minutes removed about a third of the cations, as well as 10% of the phosphorus, but very little ammonium or nitrate. The cations were adsorbed by the organic and subsoil horizons, so that losses from the soil column were small (10-15 kg/ha). Ninety percent of the phosphorus removed from the ash and the organic horizons was absorbed by the subsoil horizons. The leachates of the lichen ash were acid and low in nutrients, promoting nutrient removal from, or redistribution within, the soil column. The nutrient flush from subarctic woodland fires is small compared with the flush from other ecosystems.

Filion, L. 1984. A relationship between dunes, fire and climate recorded in the Holocene deposits of Québec. Nature (UK) 309:543-546.

The Holocene chronology of sand dunes near the outer forest limit along the eastern Hudson Bay coast in Québec was established by carbon-14 (C-14) analysis of samples taken from 12 sites. Some 101 C-14 dates were produced from 86 organic horizons from dune palaeosols containing discrete non-mixed coniferous and shrub-species charcoal and from non-charred wood fragments found in dune blowouts. Aeolian phases were established from the dates and found to occur episodically over the last 5000 years, with 3 major episodes (one from 750 years BP to the present). The presence of many buried organic horizons suggests an alternation of stabilization (plant cover) and erosional stages, with the number of alternations decreasing progressively from the boreal forest to the arctic tundra zones, and dune landforms north of the forest limit being the result of more intense and longer aeolian periods. In all the study sites, the presence of buried charcoal suggested a close relation between fires and aeolian activity, fire incidence being especially conducive to erosion in sandy areas. The decreasing number of buried horizons from the boreal forest to the tundra implies a decreasing gradient in fire incidence. A detailed analysis of the regional chronologies showed that the greatest aeolian activity shifted south to north between 5000 and 3500 years BP - soon after the Hypsithermal in the boreal zone (4650 years BP) but about 1000 years later in the tundra zone, both these factors probably resulting in decreased fire incidence from the taiga to the tundra.

Green, D.G. 1989. Simulated effects of fire, dispersal and spatial pattern on competition within forest mosaics. Vegetatio 82:139-153.

Simulations representing tree locations on a rectangular grid (cellular automaton) imply that spatial patterns associated with fire, seed dispersal, and the distributions of plants and resources affect forest dynamics profoundly. Simulated fires ignited at random locations in a uniform environment create non-uniform habitats and lead to patches dominated by different vegetation types. Short-range seed dispersal promotes vegetation clumping; fires cause these clumps to coalesce into vegetation zones separated by sharp borders, especially across an environmental gradient. In simulation of competition within vegetation mosaics, tree populations with a competitive advantage still require the intervention of fire to eliminate rivals. Also, the availability of local seed sources enables established tree populations to exclude invaders, but fires can trigger sudden changes in the composition of such systems. In models of simple succession systems, ‘climax' vegetation tends to displace ‘pioneer' vegetation, even under harsh regimes.

Grigal, D.F.; McColl, J.G. 1975. Litter fall after wildfire in virgin forests of northeastern Minnesota. Can. J. For. Res. 5:655-665.

The Little Sioux Fire burned virgin forests in northeastern Minnesota on May 14-17, 1971. We monitored litter fall for 3 years after the fire in mixed conifer-deciduous forests both within and outside the fire boundaries. We separated four categories of litter: conifer needles, deciduous leaves, woody material, and miscellaneous material. Significantly more litter fell in the burned area during the 3 years (575 g/m^2) than in the unburned areas (350 g/m^2). Major differences were related to an increased fall of needles from conifers that had been killed by the fire and an increased fall of woody material from dead trees on the burn. Needles falling from these dead trees had significantly higher concentrations of N, P, and and lower concentrations of Ca than did needles falling in the unburned areas. No other litter components showed significant differences in concentrations of N, P, K, Ca and Mg between the burned and unburned areas for the 3 years of the study. By the 3rd year after the fire, less litter fell on the burn than on the unburned area, and the proportion of litter in all components except needles was similar in both areas.

Grigal, D.F.; McColl, J.G. 1977. Litter decomposition following forest fire in northeastern Minnesota. J. Appl. Ecol. 14:531-538.

Litter bags, containing aspen or aster leaf litter, were used to compare decomposition in areas that had burned and in adjacent unburned areas in forests in northeastern Minnesota. Bags were placed in the field in October 1971, 5 months after the fire, and again in October 1972 and October 1973. Bags were collected periodically until October 1974. There was no significant difference in the weight loss of litter bags between burned and unburned areas for bags placed on the same date. Differences in nutrient concentration of the litter were only statistically significant for bags placed in October 1971, but these differences were small. The order of net mobility from the decomposing leaves was K > Mg > Ca > P > N. Aster decomposed four times faster than did aspen, with a rate of $1.6\%\cdot wk^{-1}$ of original weight, compared to $0.4\%\cdot wk^{-1}$ for aspen.

Maclean, D.A.; Wein, R.W. 1980. Simulation of wildfire effects on the nitrogen cycle of a *Pinus banksiana* ecosystem in New Brunswick, Canada. Ecol. Model. 10:167-192.

A non-linear deterministic model of and nitrogen cycling in an even-aged, pure *Pinus banksiana* stand was developed to explore effects of fire intensity and frequency of burning on the long-term nitrogen cycle. Simulated results showed that successive fires of both light and severe intensities caused gradual depletion of the N accumulated in the vegetation layers and in the litter and soil pools, with the initially large soil organically-bound N pool showing a particularly sharp decline, and decreased the productivity of the simulated stand. A frequency of one fire per 20 years for five successive burns produced declines of N accumulated in the tree stratum of 50-75% (depending upon fire intensity) in comparison with the undisturbed system at a corresponding age, whereas a 100-year frequency produced decreases of 10-22%. Similarly, declines in litter layer N were 54-72% at a 40-year frequency, compared with 30-55% at a 100-year frequency. The simulated results suggested that both the stand age when burning occurred and the fire frequency were important, because distinctive patterns of accumulation and decline of N in ecosystem pools existed with increasing stand age.

McColl, J.G.; Grigal, D.F. 1975. Forest fire: effects on phosphorus movement to lakes. Science 188:1109-1111.

After a wildfire in the virgin forest of a lake-watershed region in northeastern Minnesota, the phosphorus concentration in the runoff was elevated for 2 years and decreased in the third year. However, there was no increase in the phosphorus concentrations of a lake and its input stream. This indicates that, under similar circumstances, controlled burning will not damage streams or lakes by elevating phosphorus levels.

McColl, J.G.; Grigal, D.F. 1977. Nutrient changes following a forest wildfire in Minnesota: effects in watersheds with differing soils. Oikos 28:105-112.

The concentrations of nutrient elements in water were monitored in the unburned watershed of Dogfish Lake and in the burned watersheds of Lamb and Meander Lakes for three years following the 1971 Little Sioux Wildfire in the Superior National Forest, northeastern Minnesota. Lamb Lake watershed contains fine-textured soils of glacial lacustrine origin, whereas the other two watersheds contain coarse-textured soils derived from glacial till or granite bedrock. Nutrient concentrations of various hydrologic components were determined largely by soil type rather than by the effect of fire. Nutrient concentrations of lake waters and input streams were unaffected by the fire, due to immobilization of nutrients in the soil and to uptake by prolific post-fire revegetation.

Moore, T.R. 1980. The nutrient status of subarctic woodland soils. Arct. Alp. Res. 12:147-160.

Five sites are examined near Schefferville, Québec; two sites represent mature open spruce-lichen woodlands and the remaining three sites are regenerating woodlands. The soils are acid and have very low amounts of available macro-nutrients (Ca, Mg, K, P, and N). The nutrient inputs into the soil through precipitation, spruce canopy drip and stemflow are low, as are the leaching losses from the soil. The spruce trees act as the major nutrient accumulators in the ecosystem and the soil around the trees shows increased nutrient availability. Although burning increases the pH and available nutrient status of the soil, this increase is short-lived (less than 5 years) and smaller than observed in other ecosystems. The soils remain oligotrophic.

Paré, D.; Bergeron, Y.; Camiré, C. 1993. Changes in the forest floor of Canadian southern boreal forest after disturbance. J. Veg. Sci. 4:811-818.

The concentrations and contents of organic matter and nutrients in organic deposits on the forest floor were estimated along a 231-year chronosequence following fire at the southern limit of the boreal forest in eastern Canada. The sampling design was stratified to take into account the variability related to the presence of the principal tree species as well as to the presence of large gaps created by a recent spruce budworm (*Choristoneura fumiferana*) outbreak. The forest floor showed a steady accumulation of organic matter and total nutrients with time-since-fire and a 50% decrease in the concentrations of available P and K, but not N (as determined by aerobic incubation). The increase in forest-floor weight was accompanied by an increased storage of available N, Ca and Mg. The availability of N and Ca was more strongly affected by tree species and gaps than by time-since-fire. A high N-availability was observed under *Betula papyrifera* and in gaps, while a high Ca-availability was found near *Populus tremuloides* and *Thuja occidentalis*. In old sites, the forest floor of gaps, created by a recent spruce budworm outbreak, had a necromass similar to that of a young forest, but the low concentrations of available P and K of an old forest.

Reeder, C.J.; Jurgensen, M.F. 1979. Fire-induced water repellency in forest soils of upper Michigan. Can. J. For. Res. 9:369-373.

Soils on 53 burned sites in the upper peninsula of Michigan were examined for fire-induced water repellency. The development of water repellency was found to be fire related with over 40% of the burned soils showing at least some water-repellent properties. Most water-repellent layers occurred in the upper 5 cm of mineral soil and were related to burn intensity. Laboratory burning experiments with 10 hardwood and conifer litters showed that white pine, red pine, and quaking aspen litter produced water repellency in underlying mineral soil. Repellency was also found on unburned sites, particularly under aspen. Water-repellent soils were widely distributed, but their nonwettable properties generally decreased rapidly over time. Fire-induced water repellency does not appear to present a major long-term management problem on most soils in this region. However, on certain burned sites, water repellency may influence seedling survival and subsequent stand establishment.

Rouse, W.R.; Kershaw, K.A. 1971. The effects of burning on the heat and water regimes of lichen-dominated subarctic surfaces. Arct. Alp. Res. 3:291-304.

Areas of ground lichen in the subarctic are particularly susceptible to fire either by man's activity or by natural causes. Experimental evidence from the Hudson Bay lowlands gathered in the summer of 1970 indicates that the burning of lichen has a pronounced effect on the ground water regime. Soil moisture measurements made in a mature lichen woodland with thinly spaced trees, and in areas of recent and older burning indicate that the soil moisture under the lichen-dominated surface was at least 40% greater than in either of the burned areas. This suggests that a mature lichen cover offers a high resistance to the evaporation of soil moisture. The nature of the evaporation regime was determined using the energy budget (Bowen Ratio) approach over each surface. These data were augmented by measurements of the moisture content of the lichen made at three levels within the canopy. The evidence indicates that lichen dominated surfaces act as an effective mulch in preventing evaporation from the subsurface zone whereas the burned areas which are able to evaporate more water into the atmosphere when moist, also develop a strong resistance to evaporation as the soil surface layers become drier. The role of ground lichen in the water budget of northern lands is significant because of its extensive cover and its destruction by fire must exert an important influence on the hydrologic and atmosphere water regimes.

Schindler, D.W.; Newbury, R.W.; Beaty, K.G.; Prokopowich, J.; Ruszcynski, T.; Dalton, J.A. 1980. Effects of a windstorm and forest fire on chemical losses from forested watersheds and on the quality of receiving streams. Can. J. Fish. Aquat. Sci. 37:328-334.

A severe windstorm followed by a high intensity forest fire caused significant increases in runoff and in nutrient losses in two boreal watersheds. The study took place in the Experimental Lakes Area of northwestern Ontario (Lat. 49°40' N, Long. 93°44' W). Nitrogen, phosphorous, and potassium were the nutrients that were measured. Monitoring of the watersheds started 4 years before the windstorm and the fire occurred one year after the blowdown. Water measurements in the two basins were 1.6 and 1.8 times the pre-disturbance means, the year after the burn. The chemical losses for nitrate in the two basins were 3.4 and 9 times the pre-impact means in the year after the burn. The authors judged that there is little likelihood that the losses in nutrients caused by the fire would negatively impact the regrowth of the forest. Also, the combined impacts of the windstorm and fire did not have adverse effects on the water that moved through the basins. They concluded that, under fire return intervals that are not unusually short, there are no nutrient or water related changes that support fire suppression. They argued that when human life or property are not threatened, then wildfires should be allowed to burn naturally in the boreal forest.

Smith, D.W. 1968. Surface fires in northern Ontario. Tall Timb. Fire Ecol. Conf. 8:41-54.

This paper deals with investigations which concentrated on certain aspects of the direct and indirect effects of surface fire on the soil in the jack pine barren community in northern Ontario. The research site was located in the Cochrane District and had been burned by a severe crown fire in 1916, however no fires had been recorded since that year. The experiment, started in 1964 and terminated in 1966, involved burning at controlled intensities and durations on three dates, early spring, summer and late fall. Soil sampling and sampling of the vegetation and surface litter were completed immediately before and after the application of the burning treatments. Results showed that the direct effects of burning at two levels of intensity of each of the three durations were restricted to the surface 2 cm of soil. Severity is one of the important factors determining the effects of surface burning on the soil of the sandplains areas in northern Ontario. Loss of nutrients from the surface was proportional to burning severity. Change in the vegetation community type and the depletion of surface soil fertility was slight when moderate burning was completed in early spring or late fall. In fact, the productivity of the wild blueberries, the most abundant component in the surface flora, was increased. [abstract adapted from report]

Smith, D.W. 1970. Concentrations of soil nutrients before and after fire. Can. J. Soil Sci. 50:17-29.

Large amounts of nutrients from the L-H horizons and 0-2 cm of mineral soil were either redistributed at mineral soil depths or removed by leaching within a 15-month period after severe fire in jack pine barren lands in northern Ontario. Losses and redistribution by leaching were attributed to the large decrease in amount of organic matter (79 to 91%) and a decrease in exchange capacity of the L-H horizons as a result of burning. Increased solubility of the nutrients deposited in ash contributed to their vulnerability to leaching. Leaching of sodium, potassium and calcium was greatest during the 3-month period after fire. Differential leaching resulted from the differing adsorption properties of the cations; more potassium was leached in comparison with calcium. Decreases in levels of extractable iron, aluminum and phosphorus may have been partly the result of their fixation in unavailable form, but leaching was responsible for 48% of the decrease in extractable phosphorus from the surface horizons over the 15-month period.

Stergas, R.L.; Adams, K.B. 1989. Jack pine barrens in northeastern New York: postfire macronutrient concentrations, heat content, and understory biomass. Can. J. For. Res. 19:904-910.

Macronutrient concentrations (N, P, K, Ca and Mg), ash, high heat, and ash-free high heat contents were determined for current-year jack pine (*Pinus banksiana* Lamb.), huckleberry (*Gaylussacia* *baccata* (Wang.) K. Koch.) and blueberry (*Vaccinium angustifolium* Ait.) foliage, and reindeer lichen (*Cladonia rangiferina* (L.) Web.) thallus, in four fire-regenerated jack pine (*Pinus banksiana* Lamb.) stands in northeastern New York aged 21, 29, 46 and 67 years. Macronutrient concentration and heat contents were usually lowest in lichen, but other species patterns differed with the variable. Overall, differences in macronutrient concentrations for each species in an age sequence were not significant. Comparisons of live aboveground understory biomass, macronutrient content, and heat content through the age sequence showed no significant differences, but the influence of stand age may have been masked by large spatial variability. If the wildfires that regenerated these jack pine stands caused serious nutrient losses, the adverse effects were no longer detectable with the methodology used in this study.

Veilleux, J.M. 1972. Effects of controlled burning on the physical and chemical properties of the humus layer. Memoire No. 9. Service de la Recherche, Ministre des Terres et Forets, Québec. 31 p.

An analysis of the effects, six years afterwards, of an experimental controlled-burning operation in boreal forest in the Laurentides Park (Québec) in 1963, showed that the treatment was certainly an effective and cheap method of reducing fire risk from slash accumulation but led to adverse changes in the properties of the humus horizon of the soil and retarded the establishment of new regeneration, thus increasing the likelihood of establishment of weed growth. Biological activity of the soil was apparently stimulated by burning and this led to faster mineralization of the soil and to losses of essential elements by leaching.

Visser, S. 1995. Ectomycorrhizal fungal succession in jack pine stands following wildfire. New Phytol. 129:389-401.

A study was conducted to determine if ectomycorrhizal fungi in an age sequence of jack pine (*Pinus banksiana* Lamb.) stands which had regenerated following wildfire disturbance followed a successional pattern. Ectomycorrhizal development and number of symbionts were assessed in the forest floor and 0-20 cm deep mineral soil in 6, 41, 65 and 122-year-old stands by conducting a macrofungal fruit body survey and examining pine root tips microscopically for mycorrhizal status and types of fungi forming the symbiosis. The majority of roots were located in the mineral soil with no substantial invasion of the forest floor except in the 122-year-old stand. Over 90% of the jack pine root tips were mycorrhizal and the majority of fruit bodies were produced by ectomycorrhizal species, regardless of stand age. There was no decrease in ectomycorrhizal colonization of roots with stand age. Both fruit body and root assessments revealed a distinct sequence of mycorrhizal fungi with stand age consisting of early-stage fungi [*Coltricia perennis* (L: Fr.) Murr., *Thelephora* spp., E-strain]; multi-stage fungi [*Suillus brevipes* (Pk.) Kuntze, *Inocybe* spp., *Cenococcum geophilum* Fr., *Mycelium radicis atrovirens* Melin] and late-stage fungi [*Cortinarius* spp., *Lactarius* spp., *Russula* spp., *Tricholoma* spp., *Hygrophorus* spp., *Hydnellum peckii* Banker, *Suillus tomentosus* (Kauff.) Sing., Snell & Dick, *Piloderma byssinum* (Karst.) Jul. and *Sarcodon scabrosus* (Fr.) Karst.]. Many of the basidiomycete species fruiting above ground were detected also on the roots below ground. Fruit bodies of 50 species of ectomycorrhizal fungi were recorded while 39 distinct mycorrhizal types were identified on the roots. There was a significant increase in mycorrhizal-species richness between the 6 and 41-year-old stands and this was primarily the result of partial replacement of *Suillus brevipes* on the 6-year-old trees by late-stage fungi in the older stands. Very few species present in the 6-year-old stand were completely replaced in the older stands; rather, the multi-stage species present in the young stand were joined by late-stage species in the mature stands. The species abundance distribution of fungi on the roots in the 6-year-old stand was best described by a geometric series which is typical of an early successional community while the distributions in the three oldest stands conformed to a lognormal series which is indicative of a stable, species rich community. Both the composition and structure of the ectomycorrhizal community had stabilized 41 years after wildfire.

Weber, M.G. 1987. Decomposition, litter fall, and forest floor nutrient dynamics in relation to fire in eastern Ontario jack pine ecosystems. Can. J. For. Res. 17:1496-1506.

Decomposition, litter fall and nutrient and 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 (stand No. 1), two stands within this age class that were treated with nonlethal understorey fires in 1962 and 1963 (stand Nos. 2 and 3, respectively), a 21-year-old age class (stand No. 4), and an 8-year-old age-class (stand No. 5) 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 (stands 1, 2, and 3) compared with the younger stands (stands 4 and 5). 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 fall ranged from 119 $kg \cdot ha^{-1} \cdot year^{-1}$ in the 8-year-old age-class to 4182 $kg \cdot ha^{-1} \cdot year^{-1}$ in the older stands. Nutrient inputs through litter fall 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 nutrient 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.

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* Goldammer, J.G.; Jenkins, M.J. (eds.). Fire in ecosystem dynamics. SPB Academic Publishing. The Hague, Netherlands.

Litterfall, decomposition, organic matter turnover, and forest soil respiration (CO_2 evolution) in a mature (75 years) eastern Ontario red pine (*Pinus resinosa*) ecosystem were compared with similar eastern North American fire-affected forest types. Litterfall patterns were shown to be variable seasonably as well as from year to year. Annual littermass inputs varied from a high of 5,300 $kg \cdot ha^{-1}$ to a low of 2,400 $kg \cdot ha^{-1}$ during the three year observation period. Nutrient inputs through litterfall followed mass input patterns. Understory litter decomposed more readily than overstory litter (needles) probably because of the higher nutrient content in understory material, pointing to the importance of the understory in overall nutrient cycling processes. Organic matter turnover rates, or residence time, were between 19 and 16 years for the three red pines 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 pine forests. Seasonal respiration means in red and jack pine forests with various fire histories were around 4,300 mg of $CO_2 \bullet m^{-2} \bullet d^{-1}$. In comparison, local fire-origin aspen stands had soil respiration rates in excess of 5,000 mg of $CO_2 \bullet m^{-2} \bullet d^{-1}$, reflecting better nutritional status of the aspen site. Temperature appeared to be the overriding controlling factor in determining substrate respiration activities in this study.

Wright, H.E., Jr. 1971. Aftermath of the fire: effects on plant growth and water quality. Naturalist 22 (4):4-7.

This article is a popularized account of the fire effects research program on the 1971 Little Sioux Fire in northeastern Minnesota dealing chiefly with the watershed aspects of nutrient cycling.

Comments: see Wright (1981) later in this section.

Wright, H.E., Jr. 1981. The role of fire in land/water interactions. p. 421-444 *in* Mooney, H.A.; Bonnicksen, T.M.; Christensen, N.L.; Lotan, J.E.; Reiners, W.A. (Tech. coordinators). Conf. Proc. Fire regimes and ecosystem properties (Dec. 11-15, 1978, Honolulu, Hawaii). USDA For. Serv., Washington, D.C. Gen. Tech. Rep. WO-26. 594 p.

This paper includes a review of two studies on the effects of fire on morphology, hydrology, water chemistry, and biological productivity of streams and lakes in the Great Lakes-St. Lawrence Forest Region. "The Little Sioux Fire in May 1971 in the largely virgin conifer forest of the Boundary Waters Canoe Area of northeastern Minnesota provided the opportunity to examine impacts of wildfire on ligotrophic lakes as well as on the forest itself. Because the fire was unanticipated, the watersheds had not been monitored, so the impacts were assessed by comparing a burned with an unburned watershed of similar size on the same kind of granitic terrain. Phosphorus released by the burning of living and dead biomass was largely absorbed on the clay components of the soil and then taken up by vigorous vegetative regrowth, which started immediately after the fire (Grigal and McColl 1975, McColl and Grigal 1977). Stream inflow to the lake in the burned area increased by 60% compared to that of the unburned area, and this increase accounted for about two-thirds of the 93% increase in phosphorus input to the lake from the burned watershed (Wright 1976) when expressed as phosphorus loading to the lake surface (mg/m^2). This increase is 38%, probably within the yearly variation for this forest/lake ecosystem, in which most of the phosphorus input comes ultimately from precipitation rather than from rock weathering. As was the case with the Entiat Fire in Washington, the loss of phosphorus from the watershed was small compared to the phosphorus capital of the forest/soil system. Analysis of the total phosphorus, phytoplankton biomass, and chlorophyll a concentrations made at generally biweekly intervals for 2 years after the fire showed no significant increase attributable to the fire, nor any differences in the composition of the phytoplankton (Bradbury *et al.* 1975). Of the cations, calcium export from the burned watershed increased 26% compared to the unburned, magnesium 29%, sodium 65%, and potassium 265%. Most of the cations were flushed out the lake outlet. Only potassium is important biologically in the lake, but it is already present in such a large quantity that it does not effect algal growth, and its increase after fire had no impact on the lake ecosystem. An even better test of the effects of forest fire on lakes was made possible by events in the Experimental Lakes Area in northwestern Ontario (Schindler *et al.* 1979). Here two watersheds monitored for 4 years were subject to a violent windstorm in 1973 and then a year later in 1974 by a summer wildfire, followed by drought with little vegetative regrowth and then by two major rainstorms. An adjacent monitored watershed was untouched by winds or fire, providing exceptional circumstances for assessing nutrient release after fire. Water yields from the blowdown (both during storms and during base flow) increased immediately, and they further increased after the fire, but in the third year the vigorous vegetative regrowth renewed the evapotranspiration losses from the forest, and the runoff decreased to normal levels."

2.2 Influence of fire on vegetation

2.2.1 Influence of fire on vegetation: crop tree regeneration and growth

Ahlgren, C.E. 1959. Some effects of fire on forest reproduction. J. For. 57:194-200.

The results of a six-year study on the effect of fire on the reproduction of various native tree species in northeastern Minnesota indicate that: (1) All species studied were capable of reproducing vigorously on burned-over land. However, the time of germination, optimum conditions for growth, and factors influencing reproduction varied among the species; (2) Fire not only aided in the dispersal of jack pine and black spruce seed, but also stimulated germination of jack pine; (3) By reducing the depth of the organic layer so that the seedling roots were able to reach mineral soil more quickly, fire improved seed bed conditions for jack pine and black spruce. These conditions also favored birch and aspen, especially on the more moist sites; (4) Poor reproduction was obtained where the fire did not reduce the organic matter and slash sufficiently; (5) The minerals present in the ash stimulated growth of a lush herbaceous cover. Usually, where not too dense, this provided shade and microclimatic condition favorable to young seedling growth; (6) There were some indications that the ash concentrations present on the soil surface inhibited the germination of black spruce. This inhibition, however, disappeared after one year; (7) Burning did not seriously reduce the concentration of mineral nutrients present in the soil, at least for five years after the fire.

Arseneault, D.; Sirois, L. 1990. Forme et croissance de l'épinette noire (*Picea mariana* (Mill.) B.S.P.) avant-feu et aprés-feu en toundra forestière (Québec subarctique). Nat. Can. (Que.) 117:1-8.

Black spruce (*Picea mariana* (Mill.) B.S.P.) populations regenerated before and after a 1955 fire in subarctic Québec were compared in order to assess the effect of two contrasting sets of environmental conditions on the growth form and the growth rate of regenerating spruce seedlings. The results indicate that postfire regenerated spruces have a higher mean radial growth rate than the spruces that have regenerated in the mature lichen woodland before the incidence of fire. However, the postfire spruces tend to have a more eroded growth form than the prefire spruces, as a consequence of the fire which has lowered the snow accumulating capacity of the site.

Belanger, L.; Allard, D.; Meek, P. 1993. Dynamique d'établissement d'un peuplememt bi-étagé de bouleau blanc et de sapin baumier en zone boréale. For. Chron. 69:173-177.

The age structure of a boreal two-storied stand formed by an upperstory of white birch (*Betula papyrifera* Marsh.) with an understory of balsam fir (*Abies balsamea* (L.) Mill.) was analyzed. The establishment of this 50-year-old stand followed a burn that ran through a cut-over area. The objective was to verify if the establishment of the fir understory followed the traditional successional model or the initial floristic composition model. The age structure analysis indicated an immediate and rapid establishment of white birch during a period of 6 years after the fire. Establishment of fir, however, was initiated only 16 years after the fire. Peak establishment was 33 years after the fire. Fir regeneration followed a cycle. The regeneration pattern was characterized by the absence of fir establishment the first 16 years after the fire, followed by sporadic fir regeneration the next 12 years, then by a 13-year period of abundant regeneration after which there was a complete halt to fir regeneration. So, in this case, the successional model was more fit to describe the dynamics of balsam fir. The absence of fir regeneration during the initial period after the fire could be explained by the absence of the nearby fir seed sources due to harvesting. However, the total absence of fir establishment during the last period is more difficult to explain. Seedbed evolution since the fire could possibly be in cause. This and other studies indicate that in the boreal balsam fir-white birch ecoclimatic domain vegetation dynamics after fire does not limit itself to one pathway. Stand regeneration after fire is significantly affected by local conditions.

Brown, G. 1984. Aerial seeding of wildfire areas in the Northwestern region. p. 93-101 *in* Smith, C.R.; Brown, G. (chairmen). Jack pine symposium (Oct. 18-20, 1983, Timmins, Ont.). Dept. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. 0-P-12. 195 p.

The development of a technique for sowing 23 wildfire areas in northwestern Ontario with jack pine and white clover is described. Results are presented of stocking densities after sowing operations on the wildfire sites and the relationship between intensity of wildfire and regeneration of jack pine is discussed.

Burton, D.H. 1949. The Gogama Fire of 1941. Ont. Dept. Lands For., Res. Div., Maple, Ont. Res. Pap. 10 p. & Map.

The Gogama Fire of May 1941 burned over an area of approximately 133,855 ha in 26 townships of northeastern Ontario. Of the total area burned, 34,869 ha were classed as mature coniferous according to a survey of 1927-1929. In addition to this, 33,221 ha were considered as mixed stands of various ages. A survey was carried out in 1948 to determine the present condition of the reproduction as to stocking and health. The areas for the purpose of this survey were divided among three main types based on the original stands before the fire: (1) Jack pine - pure jack pine sand flats with a low percentage (5%) of white birch; (2) mixed jack pine, poplar, birch, red and white pine - poplar and white birch comprise 50 to 60% of the species present and (3) spruce and black ash swamps. The regeneration in the `Jack Pine' was found to be almost pure jack pine. Generally speaking, areas either cut or uncut before the fire are adequately stocked to jack pine. It was felt that the uncut stands show a higher percentage of stocking than the stands cut prior to the fire. However, in some special cases the opposite of this was found to be true and it is possible the lapse of time between the fire and the cutting operations is a deciding factor. In some cases the regeneration was better in the cut stands where the operations had taken place the same year or shortly before the fire. Probably obstruction of the site due to brush growth is important. Also the degree to which the slash was burned would undoubtedly have some bearing. Throughout the entire burn not one white birch was found that was not from coppice growth. The percentage of this species in the stand today is much less than it was before the fire. Poplar was practically absent from the `Jack Pine' except in the vicinity of creeks or lakes, where the moisture conditions were good. Spruce and balsam were also absent. The seedlings present in 1948 were about seven years old and averaged approximately 0.6 m (2 feet) in height. Despite the results shown in the plot summaries, the impression gained in travelling these stands (Mixed type) that were uncut before the fire, is that they are not adequately stocked to any species. The areas cut before the fire appear to be adequately stocked to both jack pine and hardwoods.

Because this fire occurred in May and in all probability did not do very great damage to the underbrush, the killing of the trees undoubtedly released the underbrush and gave it a dominant position that appears to be hindering the establishment of tree seedlings. Jack pine being very intolerant will not come into these stands due to the shading by underbrush. However, the birch appears to be doing well in some places. Poplar is represented to a greater degree than in any other type. All species that are present appear to be healthy and thrifty. The areas in this type that held white and red pine are not reproducing to these species. It seems very unlikely that this species will be represented at all in the future stands. The spruce and black ash swamps were, for the most part, not damaged by the fire.

Candy, R.H. 1951. Reproduction on cutover and burned-over land in Canada. Can. Dept. Res. Dev., For. Br., For. Res. Div., Silv. Res. Note No. 92. 224 p.

This reproduction survey, carried out from 1946 to 1948 in important forest regions from the Atlantic to the Rocky Mountains, was based on a stocked quadrat system, using 1-milacre quadrats, plus an actual count of reproduction on every 20th quadrat. In all, 583,000 quadrats were examined and the data recorded directly on punched cards. The results of the survey are summarized in 3 sections: (1) the Maritime Provinces, Québec and the northeastern clay belt of Ontario; (2) Western Ontario, and (3) the Prairie Provinces. On areas disturbed by logging, reproduction on the basis of stocked quadrats and number per acre was fully stocked for all species and conifers (in western Ontario the stocking was not quite as good). On areas disturbed by logging and fire, reproduction on the basis of stocked quadrats and number per acre was moderately stocked for all species, but a failure for conifers. In addition to poor coniferous reproduction, a serious proportion of the more valuable original softwood and mixedwood types has been converted to intolerant hardwood sub-types. Fire following logging destroys not only well-established advance growth, but any remaining seed-trees. On areas disturbed by fire before logging, reproduction on the basis of stocked quadrats and numbers per acre ranges from well stocked to failure for all species and for conifers. Conditions are much less favourable on areas disturbed by fire than on areas disturbed by logging. There is a moderate amount of type conversion to intolerant hardwoods or jack pine. In general, reproduction following fire is considered unsatisfactory. It is considered that the most important fact obtained in the eastern part of Canada from this survey is the appalling damage done to future coniferous stands of timber by a fire following a logging operation.

Carleton, T.J. 1982. The pattern of invasion and establishment of *Picea mariana* (Mill.) BSP. into the subcanopy layers of *Pinus banksiana* Lamb. dominated stands. Can. J. For. Res. 12:973-984.

Stand age-structure analysis is used to determine whether establishment of *Picea mariana* (Mill.) BSP. in the subcanopy of *Pinus banksiana* Lamb. dominated stands takes the form of a gradual influx or a sudden event. Twenty-six *P. banksiana* dominated stands were investigated of which 15 contained *P. mariana* trees at moderate to high densities. Postfire ages ranged from 46 years to 132 years for the oldest *P. banksiana* cohort in each stand. The 26 stands were subjectively assigned to one of seven groups on the criterion of age-structure histogram appearance. A multivariate test of the hypothesis that such age-structure differences could be due to soil differences was not significant. Three patterns of *P. mariana* influx were indicated. (*i*) Gradual influx over a long time span in the oldest stands. (*ii*)

Contemporaneous postfire reestablishment of both *P. banksiana* and *P. mariana* on a site. (*iii*) Invasion of *P. mariana* cohorts following surface fire activity as evidenced by fire scar dates. Results from a *P. mariana* seedling survival experiment indicated that depth of burn is of critical importance for black spruce seedling establishment in these stands. However, circumstantial evidence suggests that *P. mariana* seed supply may also be limiting to establishment success. These observations are discussed briefly in relation to models of forest succession.

Cayford, J.H. 1963. Some factors influencing jack pine regeneration after fire in southeastern Manitoba. Can. Dept. For., For. Res. Br., Ottawa, Ont. Dept. For. Publ. 1016. 16 p.

In the fall of 1955 a forest fire burned approximately 12,000 acres of merchantable and young growth jack pine on the Sandilands Forest Reserve in southeastern Manitoba. A fact-finding observational study was carried out between 1956 and 1961 to determine the amount and distribution of natural jack pine regeneration occurring in various forest conditions following crown fire. At the same time, general information was obtained regarding some of the factors that appeared to have affected germination, survival and early growth. More than 99% of the seedlings resulted from germination in the spring of 1956. Mortality was most pronounced during hot dry periods that occurred during the summers of 1957 and 1961. Site was one of the most important of the factors that affected survival and early growth of jack pine. On moderately fresh and moist sites, initial stocking was excellent, mortality was low, and by 1961 well-stocked six-year old stands of regeneration were present. Initial stocking on dry sites was generally adequate; however, as a result of mortality most areas were under-stocked in 1961. Early height growth was best on moist sites and poorest on dry sites. Stand density at the time of fire had an effect on initial stocking on dry sites; best stocking occurred under the heaviest canopy. Germination and survival were somewhat related to aspect on the dry site, and in 1961 best stocking generally occurred on northerly and easterly aspects. Disking prior to the fire created favourable conditions for germination. [summary]

Chrosciewicz, Z. 1974. Evaluation of fire-produced seedbeds for jack pine regeneration in central Ontario. Can. J. For. Res. 4:455-457.

Burning and seeding were successfully used to regenerate jack pine after cutting in central Ontario. Two years after seeding, the depth of post-burn humus was measured under 2769 seedlings, of which 729 were dominant ones of known height. Generally, jack pine frequency distribution and heights of dominant jack pine were strongly affected by the depth of residual humus. The relationships were curvilinear and mostly inverse. They were subsequently used as guides in the evaluation of seedbeds.

Desponts, M.; Payette, S. 1992. Recent dynamics of jack pine at its northern distribution limit in northern Québec. Can. J. Bot. 70:1157-1167.

The northernmost jack pine (*Pinus banksiana* Lamb.) populations in northern Québec are located at the boreal forest-forest tundra boundary, along the Grande Rivière de la Baleine, where they colonize the sandy terraces affected by recurrent fires. The recent fire history in the study area, as deduced from fire scar and age structure data, spans a 216-year period from 1773 to 1988. Forest fires occurred on the sites at intervals averaging 40 to 80 years. The analysis of 19 coniferous stands (jack pine and black spruce (*Picea mariana* (Mill.) B.S.P.) indicated that forest communities younger than 67 years were open jack pine-*Cladina mitis* or jack pine-black spruce-*C. mitis* woodlands, while the oldest stands, more than 132 years old, were dominated by jack pine, black spruce, and *Cladina stellaris*. Stands less than 67-years-old had an age structure almost normally distributed and regeneration often occurred within less than 30 years after fire in both species, while most stands older than 132 years had a multiaged structure. In sites with a prolonged fire-free interval, jack pine was overgrown by black spruce. Spruce woodlands have developed on sites where the organic layer was relatively thick and continuous and they are the end result of the postfire successional process. However, at several sites both conifer species showed an ability to regenerate in prolonged absence of fire disturbance, particularly in open sites with exposed mineral substrates. At the regional scale, fire frequency during the last 200 years has been high enough to prevent pine exclusion at its range limit. The key requirement for the long-term maintenance of jack pine populations is that fires return at intervals shorter than the average life-span of individual trees. It is concluded that the northernmost jack pine populations are able to maintain and regenerate under present fire conditions.

Desponts, M.; Payette, S. 1993. The holocene dynamics of jack pine at its northern range limit in Québec. J. Ecol. 81:719-727.

The postglacial history of jack pine (*Pinus banksiana* Lamb.) at its northernmost limit in the upper boreal forest, along the Grande Rivière de la Baleine (northern Québec), was reconstructed by using radiocarbon-dated conifer macrofossils found in dune palaeosols. Black spruce (*Picea mariana* (Mill.) BSP.) was the first conifer species to colonize the area at 6000 BP, immediately after deglaciation. Jack pine first invaded the sandy terraces at 3050 BP, apparently at a low density. The species most likely survived for several centuries at this low density before experiencing a regional expansion between 2400 and 1750 BP. From the period of regional expansion of jack pine to the present, mixed and monospecific stands of jack pine and black spruce developed concurrently, indicating that both species responded positively to fire and climatic conditions. The regional expansion of jack pine was not followed by a northward spread of the species into the forest tundra. The formation and expansion of the forest tundra during the last 3000 years restricted jack pine to the boreal forest. A lower fire frequency with colder conditions in the forest tundra may have been responsible for the inability of jack pine to expand northwards.

Dorworth, C.E.; Buchan, P.E. 1972. *Scleroderris lagerbergii* Gremmen in the boreal forest of Ontario. Can. Dept. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Inf. Rep. 0-X-156. 9 p.

Scleroderris canker (*scleroderris lagerbergii*) has become an established disease in the boreal forest of northern Ontario. Infections in jack pine stands can be categorized as:

CASE I - outbreaks originating directly from infected nursery stock

CASE II - infections in mixed-age stands

CASE III - infections in young pure stands of jack pine.

CASE III describes a situation in which burns of many thousands of hectares have become infected at random points. Mortality is generally light in the faster-growing stock, becoming quite heavy in areas where seedlings are suppressed either by poor site or by dense stocking. Inspection of residual, old-growth trees that survived in strips and patches around and within the burn revealed no infections.

The most notable example of the CASE III situation is 95-130 km north of Pickle Lake in northwestern Ontario where large areas (800 km^2) were burned over in 1961. A detailed study of the Pickle Lake Area was made in the spring of 1971. To determine the extent of damage caused by *S. lagerbergii* and to establish a basis for later determination of spread; strips of 100 x 5 m were located in the regeneration areas and data recorded as to the degree of infection, tree height, and density of stocking. Two such strips were measured per site, the data averaged and listed in order of increasing stand density. An infection center is defined here as a clearly defined patch of dead and infected trees in which the original point of infection can be identified and infection of the surrounding trees clearly resulted from immediate local spread of the fungus.

The data indicate that percent mortality increases with increasing stand density. According to the authors, these data must be interpreted, in light of the actual field situation. Consequently, the estimate of the number of infection centers may be conservative, because two or more coalescing centers had to be counted as one if they could not be clearly separated. Similarly, as stand density increases, it is more difficult to separate trees killed and damaged by *S. lagerbergii* from those killed by overcrowding or other causes. Even the experienced observer must expect some degree of overlap in his data. Local spread (*i.e.*, immediate tree-to-tree spread within a stand) is accomplished largely by means of a sexual spores of the fungus that are disseminated by splashing rain. Thus, as stand density decreases, the chance that a rain-splashed spore will encounter susceptible tissues of an adjacent tree decreases, and the conidia are restricted largely to the trees on which they were produced.

As stand density decreases toward optimum, trees are inclined to be more vigorous than when overcrowded and to have better-developed lower branches. The fungus thus has less immediate access to the main stem: a tree is not ordinarily killed unless the main stem is invaded. Thus, where spacing favors growth and development of the lower branches, a predominance of nonlethal lower-branch infections can be expected at the expense of the lethal bole infections, and local spread of the fungus is impeded. As density of stocking increases, local spread occurs with greater facility and more infection centers are recorded.

The sexual spores of the fungus are formed in fruit bodies on dead infected tissues of the suspects. These spores are disseminated by wind rather than by splashing rain, and tree-to-tree spread can occur over greater distances. As is the case with the conidia, the total number of ascospores produced increases as the number of infected trees per unit area increases. The more densely stocked and heavily infected parts of a stand constitute the best sources of ascospore production and, consequently, represent the most serious threat to adjacent trees within the stand. If these wind-disseminated ascospores remain viable after an appreciable exposure in the atmosphere, then areas such as the Pickle Lake burn represent potential threats to adjacent forest regions and, indeed, to adjacent provinces. The questions of effective distance of inoculum dispersal by wind and of longevity of the spores when exposed to conditions in the atmosphere remain to be answered. Aerial spread of spores of *S. lagerbergii* over a distance of 15 km was noted near Sault Ste. Marie in 1970, and spores of certain other fungi remain viable after travelling several thousand kilometres through the atmosphere.

The greatest mortality in jack pine regeneration on the Pickle Lake burns occurred in stands so dense that stagnation would have been inevitable. Damage decreased as desirable stand characteristics became more prominent, especially where site and stand density permitted the most rapid growth. Many trees on the best sites will undoubtedly mature to form a crop, largely because infection did not occur until the trees had several years to become established and the most vigorous trees passed through their most susceptible stage of growth before infections became general in the area.

Dorworth, C.E.; Buchan, P.E. 1972. *Scleroderris lagerbergii* Gremmem in the boreal forest of Ontario. GLFC. Inf. Rep. O-X-156

The fungus Scleroderris lagerbergii Gremmen will undoubtedly exercise its full potential as a forest tree pathogen among the young jack pine (*Pinus divaricata* (Ait.) Dumont = *P. banksiana* Lamb.) stands of the Boreal Forest Region. Great numbers of juvenile pines are destroyed in parts of the Boreal Forest, the damage becoming increasingly severe as stand density increases. This situation is most notable in regeneration on areas cleared by fire or logging. Equally serious are those situations in which *S. lagerbergii* is endemic in the pine understory, being a potential source of infection for regeneration that appears after the area is logged, and a continuing source of inoculum to infect young pines in adjacent areas. (abstract)

Duchesne, S.; Sirois, L. 1995. Phase initiale de régénération après feu des populations conifériennes subarctiques. Can. J. For. Res. 25:307-318.

The objective of this study was to investigate the first stage of post-fire regeneration of black spruce and jack pine in a black spruce woodland and a jack pine forest burned over in 1989 in Radisson's region, in northern Québec. Emphasis was given to determine the optimal microsites for black spruce and jack pine regeneration. Our results show that the burned over jack pine forest offers better substrates for seedling germination than the burned over black spruce one. A total of 139 seedlings were observed in the jack pine forest, burned over humus was the preferred substrate for germination. Soil moisture content correlated with seed germination of both species. Soil temperatures at -5 cm and the soil surface influenced survival of black spruce seedlings in the jack pine forest.

Gagnon, R.; Morin, H.; St-Pierre, H. 1991. Natural seed regeneration of black spruce (*Picea mariana*) stands in the Québec boreal forest. p. 103-113 *in* Simpson, C.M. (ed.). Proceedings of the conference on natural regeneration management (March 27-28, 1990, Fredericton, N.B.). For. Can.-Mar. Reg., Fredericton, N.B. 261 p.

Natural fires are an important ecological factor in the boreal forest. After fire, black spruce behaves like jack pine. Our results show a prompt recolonisation of burned sites. The majority of new seedlings were established within three years after fire. These data differ from other works where a delay in recolonisation has been noted. For comparison purposes, a second project has been conducted in black spruce strip cutting to determine the establishment period of black spruce seedlings under a continuous seed supply. Quite surprisingly, the establishment period was similar to the natural burned site, showing a prompt and brief installation after cutting.

Gauthier, S.; Gagnon, J.; Bergeron, Y. 1993. Population age structure of *Pinus banksiana* at the southern edge of the Canadian boreal forest. J. Veg. Sci. 4:783-790.

To assess the effects of site type, forest initiation periods and fire regimes on the dynamics of *Pinus banksiana* (jack pine), the age structure of 69 populations of the species was analyzed. Two landscapes with different fire regimes were selected in the southern part of the Canadian boreal forest in Québec: the `mainland landscape' is characterized by a fire regime of large lethal fires, the `island landscape' is affected by a complex fire regime including lethal and non-lethal fires. Age structure was compared between forest initiation periods and site types (mesic mainland, xeric mainland and xeric island) using the Shannon regularity index. An even-aged population structure was found within the first 100 years following a lethal fire, while after that period the population structure becomes more uneven-aged. Under mesic conditions, populations tend to have an even-aged structure, under xeric conditions an uneven-aged structure. Natural openings present in xeric sites allow for recruitment in the absence of fire. This permits the self-maintenance of *Pinus banksiana*. Xeric island populations show more uneven-aged structures than xeric mainland populations. The occurrence of non-lethal fires on the islands creates uneven-aged structures. Further, the results suggest that the selection pressure of the island fire regime, favouring non-serotinous and mixed *P. banksiana* individuals, is one of the factors responsible for a higher recruitment in the absence of fire on islands than on the mainland.

Grafstrom, M.D.; Hansen, H.L. 1962. Post-fire regeneration study of the 1959 Badoura and 1960 Bemidji fires. Minn. For. Notes No. 116. 2 p.

To determine some of the ecological effects of wildfires in jack pine stands, a study of the 1959 Badoura fire and the 1960 Bemidji fire was undertaken in 1960. Pre- and post-fire stem counts were made to learn more about post-fire reproduction and how fire may be used as a silvicultural tool to encourage reproduction. Data taken for the two different fires indicated that regeneration of jack pine was much more successful following the Badoura fire. Two major differences, the smaller cone crop on the Bemidji trees and the fortuitous precipitation following the Badoura fire, probably accounted for this difference. Brush regrowth following the hottest burn intensities on both fire areas indicated that severe fire failed to kill the underground roots and rhizomes and actually stimulated an increased number of stems.

Hatcher, R.J. 1963. A study of black spruce forests in northern Québec. Can. Dept. For., For. Res. Br., Publ. 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 square miles 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. 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 Québec 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.

Hatcher, R.J. 1963. Jack pine cut-over and fire origin stands, Vermillion River, Québec. Progress report 1951 to 1961 (Project Q - 39). Can. Dept. For., For. Res. Br., Que. Dist. Mimeo. Rep. 63-Q-5, 11 p.

The Vermillion River Observation Area is one of fifteen 5-square-mile areas established in Québec between 1948 and 1954. The purpose of these areas is to study forest development after logging and/or fire. A one-percent systematic sample in the form of 66-foot square line plots was established in each area and remeasurements are at 10 year intervals. The first remeasurement of the plots in jack pine stands at Vermillion are reported herein. The remainder of the area is reported separately.

Herr, D.G.; Duchesne, L.C. 1995. Jack pine (*Pinus banksiana*) seedling emergence is affected by organic horizon removal, ashes, soil, water and shade. Water Air Soil Pollut. 82:147-154.

The effects of organic horizon removal, ashes, soil water, and shade on jack pine (*Pinus banksiana* Lamb.) seedling emergence were investigated. For this purpose soil monoliths were taken to the laboratory and received prescribed burning, leading to 100%, 75%, 50%, 25%, and 0% organic horizon removal. One half of each monolith contained ashes generated from burning whereas the other half was kept ash-free. Each half of every monolith was sown with jack pine seeds and the monoliths were then watered under four watering schedules (100%, 75%, 50%, and 25% of the regional average daily June rainfall) or shaded under four shading levels (100%, 75%, 50%, and 25% photosynthetically active radiation). Seedling emergence was most successful under high watering schedules, increased depth of burn, high shading, and without ashes. Ash had an inhibitory effect on seedling emergence.

Johnson, H.J. 1956. Some aspects of black spruce reproduction in the central boreal forest region of Manitoba. Can. Dept. North. Aff. Natl. Res., For. Br., For. Res. Div., Ottawa, Ont. S & M Mimeo Rep. 56-3. 15 p.

During the summer of 1954, a study was made of factors affecting black spruce reproduction on upland sites in the Central Boreal Forest Region. Disturbed and undisturbed stands were studied in an attempt to relate the abundance of reproduction to various environmental factors. Most well-stocked stands of upland black spruce are of fire origin. The amount of reproduction following a fire is usually dependent on its severity. Light ground fires may do little more than stimulate the growth of herbaceous vegetation, encourage aspen sucker growth, and destroy any existing advance growth. Very severe fires may destroy all seed on the trees and on the ground. Reproduction after severe fires may then be dependent on the amount of side-seeding from the edges of the burn. As black spruce seed is a "limited air traveler", the full stocking of such an area may be a very slow process. Fires which completely eradicate all minor vegetation and burn off most of the litter and humus but leave undamaged cones on the fire-killed trees, are usually the ones which will effect successful reproduction. Here most of the factors which normally impede germination and subsequent survival are at least temporarily inactive. If climatic conditions are favourable, the burn will usually restock satisfactorily. Studies in the Lake States have indicated that fires must be quite severe before the cones are destroyed. An area showing excellent reproduction, the result of a fire in 1941, was studied. It was fairly moist and considered to be a swamp-border type. The water table was within four inches of the surface at the time of observation, but the area may have been considerably drier before the burn. The mineral soil, a medium sand, showed signs of gleization at about one foot below the surface. Below the thin humus layer there was a layer of ash about a quarter of an inch in thickness, showing that immediately after the fire a layer of grey ash covered the area. A grey ash layer may be more conducive to regeneration than black humus or charcoal as the latter condition would result in higher ground surface temperatures which might be lethal to new seedlings. Minor vegetation after 13 years was not abundant. Herbs and shrubs (chiefly *Cornus canadensis* and *Ledum groenlandicum*) were scattered. Predominant ground-cover consisted of *Sphagnum* spp., *Calliergon schreberi*, and *Polytrichum juniperinum*. The area was between 90 and 100% stocked with black spruce seedlings, all of which had become established on mineral soil, ash, or thin humus. This reproduction dated from 1941 to 1950, the larger percentage being more than 10 years of age. Aspen and jack pine had also become established, the latter around the edges of the burn where the site was drier, and the former near the center of the burn where the site was more moist. Conditions following this burn were ideal for the regeneration of black spruce. Seed was available, competition from minor vegetation was eliminated, and a receptive seedbed was exposed. The results of this study have shown that black spruce reproduction is inadequate on all upland sites investigated with the exception of those which had been burned over. Certain burned-over stands regenerated adequately because competition from minor vegetation and the stand itself was reduced, a favourable seedbed was exposed, and abundance of seed was available.

Larsson, H.C. 1948. Forest regeneration survey on cut-over spruce and pine lands in the Midwestern and Western Regions, 1947. Ont. Dept. Lands For., Res. Div., Toronto, Ont. Res. Rep. No. 17. 39 p. + Tables.

A regeneration study, started in 1945, was continued in the summer of 1947 in the Midwestern Regions. The aim of the study was to determine the number and quality of tree species reproducing in the various sites and types on cut-over and burned forest land. Three widely separated areas, covering approximately 9 square miles, were examined. The study areas lay at approximately 49° N latitude. Elevation, frost free days, and annual precipitation varied considerably between areas. The soils were generally acidic and varied in texture from coarse gravels and sands to fine sand loams and clay silts. Three major forest types were encountered: (1) spruce-fir (confined to the slopes as mixed or pure stands and to a lesser extent in the flats and swamps), (2) spruce (found in flats and swamps) and, (3) pine (pure stands or associated with black spruce and trembling aspen on well drained sands and dry clay silts). The virgin stands appear to have originated by the interaction of fire, tree species and site. Cutting had removed 50 to 97% of the cover type from the stands. The bulk of coniferous reproduction in cut-over stands had become established prior to cutting. There was some natural seeding after cutting in stands occupying moist sands and sand loams. The succeeding forest in the cut-over lands will generally be different in composition to the virgin stands depending on site, stand age, amount and type of advanced reproduction, and mortality suffered by advanced reproduction during and after cutting. The spruce-fir associations will normally change to a fir-spruce type. The spruce type will generally form a spruce-fir or a fir-spruce association on the slopes and flats and a spruce type in the swamps. A spruce or a spruce-fir association will usually replace a jack pine cover type. Immature, dense, conifer stands are generally sparsely stocked with reproduction whereas the semi-open mature and over-mature stands are well to fully stocked with seedlings and advanced growth. The gravel, sands, sand loams and dry clay silts are better stocked to coniferous regeneration than are the moist clay silts which are usually understocked or a failure. The after effects of cutting, such as the desiccation of the humus layer through increased sunlight and wind action, the absence of seed trees, the presence of competitive underbrush and small seed eating animals all contribute to the failure of coniferous reproduction. Vigourous underbrush and herbaceous growth prevent reproduction on the moist and wet clay silts in both the uncut and cut-over stands. Regeneration was not affected by plant competition on the dry clay silts and sands as competitive underbrush was only sparsely represented on these sites. Fires in uncut conifer stands will normally reproduce to black spruce and jack pine depending on the composition of the cover type. Two burns occurring a few years apart in the same area will destroy all reproduction. Burns in cut-over stands are either poorly stocked with conifer or a complete failure. Fire control and cutting operations must be guided by sound silvicultural practices to ensure adequate regeneration of seedlings and advanced growth during and following cutting operations. [abstract adapted from summary]

LeBarron, R.K. 1939. The role of forest fires in the reproduction of black spruce. Proc. Minn. Acad. Sci. 7:10-14.

Black spruce is a dominant cover in northern Minnesota because it can tolerate wet-sites and peat soils, it can regenerate in shade, and it can act as a pioneer species. Black spruce also has a special adaptation to post-fire reseeding. The cones, which stay attached to the tree for many years and disseminate seed for at least 2 to 3 years, are borne in a dense cluster near the tip of the trees where they are not apt to be injured even by severe crown fires. Hence, after a forest fire when the trees have all been killed, a large amount of seed is still available. This special adaptation is discussed in more detail.

Lynham, T.J.; Curran, T.R. 1998. Vegetation recovery after wildfire in old-growth red and white pine. Can. For. Serv. Great Lakes For. Cen., Frontline Tech. Note No. 100.

In August 1995, an Ontario wildfire (FOR-141) burned 25,000 ha on the southeast side of Quetico Provincial Park (QPP). The area burned was about 5% of the total area of the Park. This fire was the largest, and most significant fire in QPP since July 1936 when six fires in the month of July burned more than 60,000 ha or about 13% of the Park area. The largest of theses fires burned 30,000 ha in the northwest corner of the park, which had been previously logged for red pine (*Pinus resinosa* Ait.) and white pine (*Pinus strobus* L.). In contrast, fire FOR 141 burned large stands of mature red and white pine that were 200-300 years old. Wildfires in red and white pine are not common in Ontario because so little of the forest type still remains. In October 1995, a reconnaissance of the fire was carried out to assess the potential for carrying out long term ecological monitoring. The main interest was in the recovery of red and white pine species. Based on the preliminary assessment, five vegetation and soil sample plots were established in several red and white pine stands in the summer of 1996. Four sample sites were located in stands that burned with a high intensity fire while one site was located in a stand that burned with a low intensity fire. In the stands that burned in the high intensity fire, a small number of red pine seedlings were present one year after the fire. White pine regeneration was rare, jack pine regeneration was increasing in pockets and balsam fir was, temporarily eliminated. In the area of the low intensity fire, a red pine/balsam fir/white pine stand appeared to be regenerating back to a similar mix of the same three tree species. Most of the parent pine trees were not killed by the fire. Although the balsam fir parent trees were killed, the crowns were not consumed and balsam fir seedlings were present in the new stand.

Maclean, D.W. 1960. Some aspects of the aspen-birch-spruce-fir type in Ontario. Can. Dept. For., For. Res. Div., Ottawa, Ont. Tech. Note 94. 24 p.

The aspen-birch-spruce-fir type consists of trembling aspen (Populus *tremuloides*), white birch (*Betula papyrifera*), black spruce (*Picea mariana*), white spruce (*P. glauca*), and balsam fir (*Abies balsamea*). One or more of those species may be absent from the mixture but neither softwood nor hardwood component represents more than 80% of the volume. Aspen-birch-spruce-fir is typically a fire type and most mixedwood stands in the area under consideration have originated after fires which have taken place since 1800. Fires create conditions favourable to reproducing black spruce, trembling aspen and white birch, sometimes favourable to white spruce, and unfavourable to balsam fir. Fires on mixedwood sites tend to maintain a high proportion of birch and aspen. These species reproduce prolifically by vegetative means and they produce seed in abundance. Aspen sprouts from the roots, and its root system is widespread. A few large trees can produce enough sprouts to reproduce an acre. Seeding plays a relatively minor part in the reproduction of aspen. Light spring fires in particular favour the development of aspen sprouts. White birch reproduces readily by stump sprouts or by seed, and burned-over areas are often characterized by clumps of white birch from sprouts and single stems from seedlings. Fire destroys much of the lesser vegetation, consumes some of the humus, and exposes patches of mineral soil, particularly near stumps. These changed seedbed conditions, together with the shade provided by the fire-killed trees, provide an ideal environment for the establishment of black spruce. Balsam fir is seldom abundant on burned areas owing to a scarcity of seed. There is some question as to the over-all effect of fire on the abundance of white spruce. Burning improves seedbed conditions but it may eliminate all possibilities of seed. Values derived from survey data provide an approximation of the difference between the coniferous components of stands which follow fires and those which develop after cutting. In fire stands, less than 60 years of age, spruce comprised 90% of the combined spruce and fir stems. On cut-over land, spruce made up only 16% of the spruce-fir reproduction. [abstract adapted from summary]

Millar, J.B. 1939. Spruce regeneration in northern Ontario. For. Chron. 15:93-96.

Forest fires have been very important in the development of our pulpwood stands. In a recent 2,000 square mile cruise of the Clay Belt of Ontario, it was estimated that 78% of the area had been burned in the last 120 years. There had been at least seven extensive fires since 1820. These fires have been beneficial, they have rejuvenated the pulpwood stands and today these burns carry our best stands of black spruce. The swamps, spruce flats, and merchantable muskegs which predominate in the Clay Belt region of Ontario invariably regenerate to spruce following a fire. Other species are noticeably absent. On the higher, well-drained areas, which are considerably less in extent, poplar, white birch, and white spruce are commonly found with it after the fire. If the previous stand contained no spruce, or if the previous stand was less than 40 years old, a fire does not produce spruce. The black spruce seed to regenerate burned areas comes from the tops of standing, fire-killed timber. The presence of black spruce in a burn is directly influenced by the drainage, age, and condition of the original stand. Following a fire, the reproduction will be: (1) On a cut-over area--no spruce, (2) In a young stand--no spruce, (3) On well-drained sites--spruce, both black and white, with poplar and birch, and (4) In poorly drained swamps and muskegs--black spruce exclusively. [abstract adapted from body of report]

Morin, H.; Gagnon, R. 1992. Comparative growth and yield of layer- and seed-origin black spruce (*Picea mariana*) stands in Québec. Can. J. For. Res. 22:465-473.

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. 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 for black spruce provided that the number of stems per hectare is adequate.

Nalder, I.A.; Merriam, H.G. 1995. Simulating carbon dynamics of the boreal forest in Pukaskwa National Park. Water Air and Soil Pollution 82:283-298.

The development of forests in Pukaskwa National Park, Ontario, Canada, was simulated over 150 years to investigate boreal carbon dynamics and to test the feasibility of simulating large tracts of heterogeneous boreal forest. Pukaskwa National Park, located on the north shore of Lake Superior, encompasses 1835 km^2 of the Superior Section of the boreal forest. We developed a patch model, called BOPAS (BOreal PAtch Simulator), to simulate the development of carbon pools as a function of environmental parameters. Using GIS techniques, we divided the park into patches defined by a unique combination of forest type, age, climatic variables, soil type and topography, then used a forest gap model to develop biomass-over-time relationships for each patch type. BOPAS uses these relationships to simulate the development of carbon pools for trees, moss and litter/humus. We report results for constant climate, but BOPAS can be easily adapted to changing climate scenarios. Good results were obtained for predictions of carbon storage in trees. The initial value was 3.61 kg C m^2, which agrees closely with literature values. With no disturbance, tree carbon increased to a maximum of 3.97 kg C m^2 at 30 years then slowly declined. Carbon storage was stabilized by introducing fire as a disturbance with a return interval of 100 years. Predicted forest floor carbon density, however, was much lower than expected, being less than half that of trees. It was anticipated to be substantially higher than tree carbon density based on a preliminary survey in the park and values reported in the literature. Published data, however, are very limited in coverage and give such a wide range of values that it was impossible to draw any firm conclusions about the validity of the model. BOPAS also showed that the forest floor carbon pool was relatively constant over the timescales of the simulation, but no published data were available to test this prediction. In summary, this work has demonstrated the feasibility of the BOPAS approach, but has high-lighted the necessity for more extensive data on forest floor carbon storage and dynamics.

Rouse, C. 1986. Fire effects in northeastern forests: aspen. USDA For. Serv., North Cent. For. Exp. Stn., St. Paul, Minn. Gen. Tech. Rep. NC-102. 8 p.

Fire has been a natural component of the aspen (*Populus tremuloides* Michx. and *Populus grandidentata* Michx.) ecosystem. In aspen stands, low intensity surface wildfires are most common. Severe fires may kill aerial portions of the tree, but leave the roots intact. Although root tissue is more susceptible to heat-induced mortality than above ground tissue, the insulating quality of the soil and the heat release characteristics of most fires allow roots to remain viable. The main fire adaptive trait of aspen, in fact, is its ability to sprout from roots. Aspen roots can range in depth from about 39 to 60 inches but most sprouts are produced from roots that are within 3 to 4 inches of the soil surface. Lateral roots of aspen may be 80 feet long enabling sprouts to occur at some distance from the parent. More commonly, however, new sprouts are within 30 feet of the parent. [expanded from original abstract]

Rouse, C. 1986. Fire effects in northeastern forests: jack pine. USDA For. Serv., North Cent. For. Exp. Stn., St. Paul, Minn. Gen. Tech. Rep. NC-106. 8 p.

The jack pine ecosystem has evolved through fire. Jack pine, although easily killed by fire, has developed serotinous cones that depend upon high heat to open and release the seeds. Without a fire to enable the cones to open, jack pine would be replaced by another species. Fire can also aid in regeneration by preparing an adequate seedbed and sanitizing the site. After the overstory is removed, competition from sedges can be severe enough to prevent jack pine from becoming established. Within two years of the removal of the canopy, sedges can fully occupy a site to the exclusion of almost all other vegetation, including jack pine. Fire can slow this process, but only if used before or immediately after removing the overstory. In addition to controlling competition, fire can also help protect jack pine from pests, namely damping-off, Scleroderris canker, and dwarf mistletoe. Newly created slash often encourages populations of *ips* beetle. This beetle can be checked by burning the slash. [expanded from original abstract]

St-Pierre, H.; Gagnon, R.; Bellefleur, P. 1992. Régénération après feu de l'épinette noire (*Picea mariana*) et du pin gris (*Pinus banksiana*) dans la forêt boréale, Québec. Can. J. For. Res. 22:474-481.

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, Québec. 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.

St-Pierre, H.; Gagnon, R. 1991. Distribution spatiale de la régénération après feu de l'épinette noire (*Picea mariana*) et du pin gris (*Pinus banksiana*) dans la forêt boréale, Réserve faunique Ashuapmushuan, Québec. Can. J. Bot. 69:717-721.

Post-fire spatial distribution of black spruce (*Picea mariana* (Mill.) B.S.P.) and jack pine (*Pinus banksiana* Lamb.) regeneration were studied in the Réserve faunique Ashuapmushuan, Québec. The main factors analyzed were (*i*) effects of organic matter thickness on growth and regeneration, (*ii*) spatial distribution and type of the regeneration, (*iii*) effects of burned stems on this distribution, and (*iv*) links between spatial distribution of the regeneration and the thickness of the post-fire residual organic matter. A strong correlation was observed between the presence of seedlings and the thickness of the post-fire residual organic matter. However, jack pine was much more efficient in getting established on microsites with thicker organic matter. Spatial distribution of the regeneration has a tendency to spread, following Blackman's dispersion coefficient, while adult individuals of the original population follow a more random pattern; this suggests that some seedling mortality, induced by seedling density, is to be expected. Regeneration shows a spatial link (point correlation coefficient) with trees of the original population, thus showing up the post-fire perpetuation of the individuals on the same microsites. Finally, the residual organic matter thickness on the ground seems without significant influence on the overall growth of jack pine and black spruce seedlings.

Sirois, L. 1993. Impact of fire on *Picea mariana* and *Pinus banksiana* seedlings in subarctic lichen woodlands. J. Veg. Sci. 4:795-802.

The demography of *Picea mariana* (black spruce) and *Pinus banksiana* (jack pine) seedlings was monitored through five censuses over 13 months in four different seed bed types after fire of four severity levels in lichen woodland. Most seeds germinated just before early frost in late summer 1990 or immediately after snow thaw in early spring 1991; the germination rate subsequently decreased. For both species, germination rate decreased along a gradient of fire severity. The proportion of *Pinus* seeds that produced a seedling surviving 13 months after sowing was 4.3% and 0.4% respectively in the intact lichen mat and in the mineral soil seed bed type. For *Picea* these values are 3.2% and 0.2% respectively. The low germination rate in a severely burned seed bed type appeared to be associated with the formation of a water-repellent crust at the soil surface following the fire. Seedlings were contagiously distributed and were more frequent in flat and hollow microsites, where there is probably more water available than on bumps or among pebbles. Properties of experimentally burned seed bed types may differ from those under natural fires where regeneration by seed generally occurs following dispersal. However, the high germination rate observed in the intact lichen mat suggests that scattered lichen woodland patches may respond to increased seed input by a higher frequency of seedling establishment.

Sirois, L. 1995. Initial phase of postfire forest regeneration in two lichen woodlands of northern Québec. Ecoscience 2:177-183.

A five-year postfire monitoring of forest floor regeneration, black spruce (*Picea mariana* [Mill.] BSP) and jack pine (*Pinus banksiana* Lamb.) seed dispersal, germination and seedling establishment was performed in a black spruce and in a jack pine lichen woodland of the upper boreal forest in northern Québec. The plant species present before the fire and able to resprout vegetatively were the fastest to regenerate. The slower regeneration of the spruce stand forest floor probably resulted from deeper combustion of the organic layer which killed most potentially meristematic organs of species which otherwise might have regenerated. The total seed dispersal over the five-year postfire monitoring period in the spruce stand reached 1,700,886/ha and 270,830/ha for black spruce and jack pine, respectively. In the pine stand, these values were in the same order: 216,011/ha and 298,883/ha. The spatial pattern of seed dispersal was generally contagious. The number of seeds dispersed decreased during the last trapping periods, suggesting that seed banks were becoming exhausted. Likewise, seed viability dropped markedly over time. These temporal patterns of seed dispersal and viability fit the predictions of Wilton's model. Despite a lower total seed input, jack pine established at a higher density than black spruce, particularly on charred organic seedbeds. Seedling establishment success observed in this study and elsewhere suggests that this parameter has been probably underestimated in simulation models of the dynamics of the northeastern Canadian lichen woodland.

Sirois, L.; Payette, S. 1989. Postfire black spruce establishment in subarctic and boreal Québec. Can. J. For. Res. 19:1571-1580.

Forest regeneration in areas burned during the 1950s in northern Québec was studied along topographic and climatic gradients, from the northern Boreal Forest to the northern Forest-Tundra. Regenerated plant communities were mostly dominated by *Cladina mitis* in well-drained uplands and by hygrophilous shrub species in moister lowlands. The age structure of 23 stands, as they were immediately before and about 30 years after the 1950s fires, was used to analyze the patterns of establishment and development of black spruce (*Picea mariana* (Mill.) B.S.P.) populations associated with fire disturbance. Postfire black spruce establishment was active during the first 20 years of vegetation recovery, then it decreased rapidly. Three older populations originating from 1936 and 1922 fires showed a rapid postfire tree establishment, whereas a long delay of recolonization was observed in the 1906 fire. Along the topographical gradient, postfire regeneration was more rapid in hill sites, whereas spruce recruitment was more abundant in lowland sites. Along a northward latitudinal gradient, prefire populations showed an increasing trend in age range, mean age, and mean age of youngest individuals. This gradient coincided also with an increasing fire rotation period from south to north. The proportion of stunted individuals in postfire populations was often more important than in prefire populations on the same sites, suggesting more rigorous growth conditions associated with forest removal. Because most black spruce seedling establishment is occurring during a short period in this area, it is suggested that stand density is determined by regeneration conditions, including seed input and seedbed quality, soon after the fire. Therefore, comparisons between prefire and 30-year-old postfire populations can be used as an index to evaluate fire impact on stand density.

Sirois, L.; Payette, S. 1991. Reduced postfire tree regeneration along a boreal forest-forest-tundra transect in northern Québec. Ecology 72:619-627.

The large 1950s fires that burned > 5500 km² of land across a south-to-north climatic gradient in northern Québec provide an opportunity to evaluate the role of fire in forest-tundra development on a demographic basis. The tree population density before and ≈ 30 years after fire was estimated by censusing trees in plots of 400 m² located in upland and lowland sites within four representative ecoregions of northern Québec. The analysis of tree recruitment before and after fire, in 410 randomly selected sites along a transect crossing the upper boreal forest and forest-tundra zones, indicated that wildfires induced substantial depletion of tree populations. Taken as a whole, fires have significantly reduced the density of black spruce populations in forest-tundra uplands, but not in the lowlands. A reduction in tree population density of ≥ 75% was observed in 22% of upper boreal forest sites, and 45% and 93% of sites located in the forest and shrub subzones, respectively, of the forest-tundra zone. Complete exclusion of tree populations by fire was observed in 43% of upland sites in the northern part of the transect, while complete removal was a rare event in the southern part. Sustained reduction of tree population density after several destructive fires appears as one of the main deforestation processes in the subarctic zone. This leads to the patchy distribution of forest stands and scattered tree populations typical of the forest-tundra biome. Comparisons with paleoecological data suggest that the impact of the 1950s fire contributed to the expansion of the forest tundra into the upper boreal forest. The ecological impact of these fires was probably similar to those fires responsible for development of the forest-tundra during the Holocene. It is suggested that the fire-climate interaction should be considered in order to predict the ecological impact of warming climate on high-latitude forest ecosystems.

Weber, M.G. 1988. Fire and ecosystem dynamics in eastern Canadian *Pinus banksiana* forests. p. 93-105 *in* Verboeven, J.T.A. (ed.). Vegetation structure in relation to carbon and nutrient economy. SPB Academic Publishing. The Hague, 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 was quantified. During the regeneration step high frontal fire intensities of around 17,000 $kW \cdot m^{-1}$ are required to produce seedling numbers of 30,000 to 50,000 ha^{-1} 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 greatest fire intensity. Functional ecosystem attributes, such as soil respiration (CO_2 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 returned within 15 years of stand establishment or when forest floor layers were mechanically disturbed in mature stands.

Weber, M.G.; Hummel, M.; Van Wagner, C.E. 1987. Selected parameters of fire behavior and *Pinus banksiana* Lamb. regeneration in eastern Ontario. For. Chron. 63:340-346.

Fire behavior 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 percent mineral soil bared (r^2 = 0.95). Frontal fire intensity was positively correlated with percent tree mortality (r^2 = 0.98) and mean height of char (r^2 = 0.76). Frontal fire intensities of 17,000 kW/m resulted in seedling numbers of 30,000 to 50,000 ha^{-1} 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 percent tree mortality (r^2 = 0.62) and forest floor consumption (r^2 = 0.79).

Yarranton, M.; Yarranton, G.A. 1975. Demography of a jack pine stand. Can. J. Bot. 53:310-314.

The demography of a jack pine, *Pinus banksiana*, stand established after a fire in 1915 was reconstructed by estimating the ages of dead trees. The survivorship curve is nonlinear and mortality rates rise linearly from 18 to 47 years after the fire and then decline. A balance between intensification of competition and increasing regularity of distribution of surviving trees may account for this. Causes of death appear to be drought stress and physical damage from ice storms.

2.2.2 Influence of fire on vegetation: community structure and biodiversity

Abrams, M.D.; Dickmann, D.I. 1982. Early revegetation of clearcut and burned jack pine sites in northern lower Michigan. Can. J. Bot. 60:946-954.

Revegetation of clearcut and (or) burned jack pine (*Pinus banksiana* Lamb.) sites in northern lower Michigan was characterized during the first 5 years following treatment. Burning promoted the establishment of a large variety of species not typical of unburned areas. A total of 89 species was recorded on burned sites, of which 40 were exclusive, compared with 51 species on unburned sites, of which only 2 species were exclusive. Burned sites consistently showed greater species richness compared with unburned sites of the same age. Low species diversity on the older unburned clearcuts (years 3 to 6) and certain burned sites was directly influenced by the dominance of the sedge *Carex* *pensylvanica*. The total domination of *Carex* (up to 86% relative cover) on many of these sites appears to be unique to northern lower Michigan. It is hypothesized that *Carex*, acting as an opportunistic species, monopolizes the space and soil resources liberated following disturbances and suppresses or excludes other species.

Abrams, M.D.; Dickmann, D.I. 1984. Floristic composition before and after prescribed fire on a jack pine clearcut site in northern lower Michigan. Can. J. For. Res. 14:746-749.

Permanent frequency and cover plots were established and monitored for 3 years on a recent jack pine (*Pinus banksiana* Lamb.) clearcut in northern lower Michigan to characterize vegetational 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 understory, whereas at the time of burning, the clearcut site (3 year old) was dominated (33% cover) by *Carex pensylvanica* Lamb. Two years after fire, 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 understory was present on either the unburned or burned clearcut blocks.

Abrams, M.D.; Sprugel, D.G.; Dickmann, D.I. 1985. Multiple successional pathways on recently disturbed jack pine sites in Michigan. For. Ecol. Manage. 10:31-48.

Jack pine communities in northern lower Michigan recently disturbed by clearcutting, deliberate burning, or wildfire were studied over three growing seasons, and were compared to 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 the second year after fire. In several cases annual and biennial species dominated first-year burns but were unimportant thereafter. Several pathways of early successional development were evident on the disturbed sites, which was facilitated by jack pine regeneration failure on all but one of the disturbed sites.

Ahlgren, C.E. 1958. The significance of the effect of forest fires on herb and shrub growth in northern Minnesota. Bull. Ecol. Soc. Amer. 39:79-80.

Field observations on the growth of herbs and shrubs and trees have been made on 1,300 acres of burned and unburned forest land in northern Minnesota. Chemical analyses of the soils were made on burns of different ages and intensities. In addition, greenhouse tests were made in which selected herbs were grown on these soils under controlled conditions. The possible significance of the observed alteration in herb and shrub growth on tree reproduction is discussed.

Ahlgren, C.E. 1959. Vegetational development following burning in the northern coniferous forest of Minnesota. Proc. Soc. Am. For. 21-22.

A long-range study was initiated eight years ago, in order to determine the ecological effects of fire in the Superior National Forest, northeastern Minnesota. Because of their microenvironment and soil conditions in which the tree seedlings develop, the herbs and shrubs were studied in detail in relation to tree reproduction and growth. The 1,000 acres included in the study were burned mostly by wildfire, but some areas were prescribed burned. Before burning the study areas consisted primarily of jack pine mixed with black spruce, quaking aspen, and paper birch. The distribution of plants on burned and unburned land was dependent on the type of reproduction - whether vegetative or by seed - the extent to which vegetative parts were heat tolerant, and the extent to which species were able to compete in the opening created by the fire. In areas where the fires were of sufficient intensity to reduce the organic layer and provide a compact, moist seedbed, the land was rapidly covered with a lush growth of herbs and shrubs, but primarily herbs. While a number of factors such as light, moisture, and temperature may have been involved, greenhouse experiments revealed that the fertilizing action of ash had a more direct influence. Good tree reproduction occurred on areas where fire had reduced the organic layer to a depth of 1 to 2 inches. Where the burn was light, leaving a 3-6 inch organic layer, young seedling mortality was high and little or no reproduction was established.

Ahlgren, C.E. 1960. Some effects of fire on reproduction and growth of vegetation in northeastern Minnesota. Ecology 41:431-445.

This paper is an interim report on a long-range study of the effects of wild and prescribed fires in northeastern Minnesota. Material dealing with forest tree reproduction applicable to forest management was published separately (Ahlgren 1959). This study was initiated eight years ago, in the Superior National Forest, Minnesota. Because of their importance in establishing the microenvironment and soil conditions in which the tree seedlings develop, the herbs and shrubs have been studied in detail in relation to tree reproduction and growth. The herbs and shrubs found on the study areas were divided into three major groups: (1) those found only on the unburned land, (2) those which appeared only on the burned land, and (3) those found on both burned and unburned land. In general, the distribution of plants on burned and unburned land is dependent on the type of reproduction - whether vegetative or by seed - the extent to which vegetative parts are heat tolerant, and the extent to which the species are able to compete in the opening created by the fire. Good tree reproduction occurred on areas where fire had reduced the organic layer to a depth of 1 to 2 inches. Results thus far indicate that if the conditions of good seedbed, necessary quantity of ash, and adequate seed source can be duplicated through prescribed burning, such burning could be used not only for the preparation of seedbed but also for natural seeding of jack pine, black spruce, and associated hardwoods in northeastern Minnesota.

Alexander, M.E.; Sando, R.W. 1989. Fire behavior and effects in aspen-northern hardwood stands. p. 263-274 *in* MacIver, D.C.; Auld, H.; Whitewood, R. (eds.). Proceedings of the 10th Conference on Fire and Forest Meteorology (August 17-21, 1989, Ottawa, Ont.). For. Can., Chalk River, Ont. 471 p.

Six experimental fires were carried out within pure trembling aspen (*Populus tremuloides*) and mixed deciduous stands in the U.S. Lake States region during both spring and late fall (*i.e.*, leafless stage). Available surface fuel loads averaged 2.5 t/ha. High to extreme burning conditions prevailed as determined by the Canadian Forest Fire Weather Index (FWI) System. Head fire spread rates varied from 1.5 to 8.8 m/min and were highly correlated with the Initial Spread Index component of the FWI system (r = 0.91). Frontal fire intensities ranged from 115 to 672 kW/m. Extensive mortality was observed in trees less than 7.6 cm in diameter at breast height (dbh) while overstory stems greater than 15 cm dbh were seldom affected. Most shrub species were readily top-killed by fire but quickly resprouted. The total number of woody understory stems (deciduous shrubs and small trees) often increased following the fires.

Auclair, A.N.D. 1985. Postfire regeneration of plant and soil organic pools in a *Picea mariana-Cladonia stellaris* ecosystem. Can. J. For. Res. 15:279-291.

Post-fire recovery of biomass and soil organic pools was measured in a sequence of 10 subarctic lichen woodlands in Québec aged from 0 to 140 years. Less than one-tenth of total live biomass combusted at the time of burning. Aboveground biomass combustion of species ranged from nil to over 90% depending on plant stature. Although no trees or lichen survived, shrub mortality (6%) was minor. Developmental phases similar to those in northern hardwood forest were apparent. Reorganization was dominated by shrubs over the first three decades. Aggradation resulted in a fourfold increase in total biomass; it was then followed by a 14% decrease occurring at transition (110-140 years postfire). Breakdown of the burnt lichen mat was rapid (1500 $kg \cdot ha^{-1}$) compared with the disintegration of dead wood. Of an initial 40,000 $kg \cdot ha^{-1}$ in dead boles and branches, 15,000 $kg \cdot ha^{-1}$ remained 110 years later. Little change in soil humus mass occurred during the fire and postfire. Total live and dead organic mass remained relatively constant over the 140 years of recovery. However, the live/dead ratio of organic mass showed a gradual but consistent increase.

Beasleigh, W.J.; Yarranton, G.A. 1974. Ecological strategy and tactics of *Equisetum sylvaticum* during a postfire succession. Can. J. Bot. 52:2299-2318.

The proportion of the total aerial dry weight of *Equisetum sylvaticum* devoted to spore producing and supporting structures does not change in the first 6 years of postfire succession: the ecological strategy remains constant. However, the stem and branch lengths of sterile shoots, their time of appearance, and the distribution of dry weight between sterile shoots do vary during the same period, indicating changes in ecological tactics. The tactical changes appear to be a response to increasing competition. Clones of *E. sylvaticum* survive repeated fires by means of the deeply buried rhizomes and are evidently very long-lived.

Bergeron, Y.; Charron, D. 1994. Postfire stand dynamics in a southern boreal forest (Québec): a dendroecological approach. Ecoscience 1:173-184.

Arboreal succession in the southern boreal forest of Québec was documented through a dendroecological analysis of a mid-successional stand originating from fire 75 years ago. The studied stand was located in the forest surrounding Lake Duparquet, south of Lake Abitibi in northwestern Québec. Tree composition and ecological characteristics were assessed in quadrats distributed systematically within the burnt area. One site was selected for a detailed dendroecological analysis as it was representative of the average composition found on moderately well-drained clay deposits. In a 20 m × 20 m quadrat, all living and dead tree stems (> 1 cm d.b.h.) were mapped and cut down. Cross sections collected at the root collar and at every metre were analyzed using standard dendrochronological techniques. While the prefire composition was characterized by an old (> 210 years) forest of *Thuja occidentalis* L. and *Abies balsamea* (L.) Mill., *Populus tremuloides* Michx. and *Betula papyrifera* Marsh. dominated the composition of the burnt area. These two species, originating most likely from suckering and sprouting, were recruited immediately after the fire while most of the *Picea glauca* (Moench) Voss and *Abies* regeneration was delayed for five years. Most *Populus* rapidly attained dominance while, with few exceptions, the other species were suppressed and occupied lower positions in the canopy. Differences in growth between *Populus* and *Betula* were accentuated by an important growth decrease in the mid-1950s, from which only *Populus* had fully recovered. Defoliation by the forest tent caterpillar caused hardwood growth decrease in the 1950s, as well as previous ones, while defoliation by the spruce budworm caused growth decreases and mortality in conifers around 1940 and from 1972 to 1987. *Picea* and *Abies* were regularly recruited since the fire and they formed an abundant understory cover. The recent recruitment of a few *Thuja* seedlings may be incidental or related to an increase in mosses with time since fire. Our results suggest that all species, except *Thuja*, can be abundant in the postfire cohort and that differences in diameter and height among species were explained by their respective growth and not by successive species invasion. This relatively regular stand development was, however, significantly influenced by episodes of insect defoliation. Mechanisms involved in subsequent stands development towards the mixed and coniferous compositions observed in older stands cannot be easily extrapolated from the present stand structure. Similar studies are therefore needed to explain these mechanisms in older stands.

Bergeron, Y.; Dansereau, P.R. 1993. Predicting the composition of Canadian southern boreal forest in different fire cycles. J. Veg. Sci. 4:827-832.

Post-fire succession was reconstructed for a sector located in the southern part of the Québec boreal forest. Forest composition for different periods since fire was evaluated using a stand initiation map together with ecological maps representing both site conditions and stand types. Nine fires covering at least 100 ha and representing a chronosequence of more than 230 years were used. Although a relatively clear successional pattern from deciduous to coniferous composition relating to time-since-fire was observed, *Pinus banksiana* stands showed an erratic distribution not related to succession but possibly to the pre-fire stand composition. A comparison with forest cover maps produced after a recent spruce budworm outbreak, showed that succession toward coniferous dominance appeared to be interrupted by spruce budworm (*Choristoneura fumiferana*) outbreaks which, by killing *Abies balsamea*, lead to a mixed deciduous forest composition. A simple empirical model based on a negative exponential distribution of age classes was developed to evaluate how changes in the fire cycle would affect the composition of the forest mosaic. The transition between deciduous dominance and coniferous dominance occurs in a fire cycle > 200 years. Although pure deciduous stands tend to disappear during long fire cycles, the proportion of mixed stands remains relatively constant. Prediction of the forest composition for longer fire cycles is complicated by the interaction between post-fire composition and stand vulnerability to spruce budworm outbreaks.

Bergeron, Y.; Dubuc, M. 1989. Succession in the southern part of the Canadian boreal forest. Vegetatio 79:51-63.

Forest succession following fire in a forest mosaic of northwestern Québec was studied using ordination and classification techniques to remove changes in forest composition related to abiotic conditions, and to study shifts in species composition in relation to time since the last fire (based on tree diameter distributions). Regardless of forest composition after fire, most stands showed convergence toward dominance of *Thuja occidentalis* and *Picea mariana* on xeric sites and dominance of *Abies balsamea* and *T. occidentalis* on more mesic sites. Stable communities of > 300 years occurred on xeric sites while on mesic sites directional succession still occurred after 224 years. Nearly all species involved in succession were present in the first 50 years following fire. Only *A. balsamea* and *T. occidentalis* increased significantly in frequency during succession. Following initial establishment, successional processes could generally be explained by species longevity and shade tolerance. Early successional species could be abundant in the canopy for more than 200 years while the rapid decrease of *P. glauca*, a late successional species, could be related to spruce budworm outbreaks. Considering the short fire rotation observed (about 150 years), a steady-state forest is unlikely to occur under natural conditions, though it may be possible if fire is controlled.

Books, D.J. 1972. Little Sioux Burn: year 2. Naturalist 23:2-7.

The Little Sioux fire occurred on May 14-17, 1971 in the Superior National Forest of northeastern Minnesota. The fire burned about 6000 ha, a large proportion of which was virgin forest. Revegetation following the fire was rapid; plants began to appear in a few weeks, and by the end of the first summer waist-high vegetation covered much of the burn. Herbs, shrubs, and tree sprouts of many species were present, but aspen sprouts provided the bulk of the new tree growth. Jack pine seedlings germinated prolifically in areas where good seed sources were available. Black spruce, balsam fir, white pine, and red pine seedlings were not in evidence the first year because the seeds of these species are not shed until fall. Paper birch, red maple, and red oak sprouts were present in varying numbers, depending on stand composition before the fire. At the end of the first growing season after the fire the number of jack pine seedlings was 39,910 per acre; at the end of the second growing season the number was 26,680. Mortality was generally higher for aspen than for jack pine between 1971 and 1972. Black spruce seedlings began to appear in some stands in 1972, and paper birch stems increased in some also. Three weeks after the fire redback voles, chipmunks, and deer mice were active even in the most severely burned parts of the forest. Small mammal numbers were the same on burned and unburned areas. [abstract adapted from body of report]

Books, D.J.; Heinselman, M.L.; Ohmann, L.F. 1971. Revegetation research on the Little Sioux burn. Naturalist 22(4):13-21

This article is a popularized account of the research studies on forest revegetation conducted by the USDA Forest Service's North Central Forest Experiment Station following the 1971 Little Sioux Fire in northeastern Minnesota.

Comments: see Ohmann and Grigal (1979) later in this section.

Carleton, T.J. 1982. The composition, diversity, and heterogeneity of some jack pine (*Pinus banksiana* Lamb.) stands in northeastern Ontario. Can. J. Bot. 60:2629-2636.

Understorey composition, diversity, and interquadrat heterogeneity are examined among a series of 23 jack pine (*Pinus banksiana* Lamb.) dominated stands in northeastern Ontario. Information on the soils, density, and age structure of the trees was available for each site studied. Composition in both vegetation and soils data sets was explored using detrended correspondence analysis (DCA), an efficient trend seeking ordination technique. Following a rotation to congruence of vegetation axes upon those for soil, variation in the soils data accounted for a maximum of 40-50% variance in the first two axes of the vegetation analysis. Examination of a residual ordination, after soil effects were removed, indicated a primary gradient related to both canopy type and frequency of disturbance by surface fire. Diversity measures, including richness and N2, showed no relationship to stand age, disturbance frequency, or canopy type. Some indefinite patterns appeared with bryophyte diversity. Interquadrat heterogeneity showed no relationship to stand age, canopy type, or disturbance regime as more than one source of spacial pattern was evident among the stands. These results are discussed in relation to the study of succession by indirect methods. (abstract)

Carleton, T.J.; Jones, R.K.; Pierpoint, G. 1985. The prediction of understory vegetation by environmental factors for the purpose of site classification in forestry: an example from northern Ontario using residual ordination analysis. J. For. Res. 15:1099-1108.

Problems arise in the use of understory vegetation as an indicator of site condition in that impermanent factors such as microclimate, succession, and chance may play significant roles in determining local composition. Residual ordination analysis is a method which facilitates quantification of the sources of variation in understory vegetation over a landscape. Here it is applied to survey data, representing 250 stands upon which the forest ecosystem classification program for the Clay Belt portion of northeastern Ontario is based, to test the premise that vegetation types will differentiate soil conditions for forestry purposes. Ordination of data by detrended correspondence analysis yielded a bivariate scatterplot which, through visual appraisal, seemed readily interpretable in terms of site-related nutrient and moisture gradients. Formal exploration, using canonical redundancy analysis, yielded the following predictive model: understory vegetation (detrended correspondence analysis axes 1 and 2) = soils (67%) + canopy (8%) + succession (1%) + error (24%). Extraction of residual ordinations confirmed this general model and demonstrated that although canopy and successional influences are minor in the data, they are significant. Because the nonsite-related, predictable components account for only 9% of the variation at most, the premise of the existing forest ecosystem classification system is judged to be sound insofar as the data upon which it is based adequately describes the range of commercial stand conditions normally encountered. The results are discussed in relation to vegetation survey design and the performance of residual ordination analysis on a large data set is assessed.

Carleton, T.J. 1994. Woody vegetation responses to fire versus clear-cutting logging: A comparative survey in the central Canadian boreal forest. Ecoscience 1:141-152.

The woody vegetation of 131 clear-cut, postlogged boreal forest stands in central Canada, previously dominated by *Picea mariana* (Mill.) BSP., is compared with 250 natural postfire stands from the same region. Each dataset represents a stand chronosequence on a range of substrate types. Correspondence analysis (CA) based ordination methods is used for structural and compositional comparison in order to address the question of the extent to which woody vegetation recovery and succession are similar between the two disturbance types. In addition, canonical CA is used as a general linear model strategy to examine unique and covariant influences on forest composition. The postlogged stand dataset had a much lower representation of conifer-dominated stands than the postfire dataset and a far greater proportion of stands dominated by poplars. Detrended and canonical CA on all 381 stands indicated a primary influence on stand composition due to site factors, but disturbance type and intensity, *i.e.* wildfires versus horse or mechanical hauling in postlogged stands, showed the strongest correlation of any single variable. Analyses of each dataset, separately, indicated similar predictability of vegetation composition from associated stand environmental and age data but regressions were weak (R^2~22%). Whereas skidding type and stand age were the most important correlates with the postlogged data, soil variables were the most prominent correlates with the postfire woody vegetation. In addition to *Abies balsamea* (L.) Mill. dominated woodland deriving from postfire succession, such forests also arose on a widespread basis in horse skidded, postlogged stands through the persistence of advanced growth seedlings. Mechanically skidded, postlogged stands show a wholesale conversion from conifer dominance, mostly *Picea mariana*, to dominance by *Populus*. It is concluded that both the qualitative nature and the intensity of boreal forest disturbance lead to different woody vegetation recovery patterns.

Carleton, T.J.; Maycock, P.F. 1978. Dynamics of the boreal forest south of James Bay. Can. J. Bot. 56:1157-1173.

Ordination models of approximate environmental and dynamic relationship between eight boreal tree species were constructed based upon principal components analysis and Kruskal's nonmetric multidimensional scaling. The assumptions inherent in these models are stated and discussed. The data consisted of 152 forest stands from the closed-crown boreal forest zone of Ontario and Québec south of James Bay. Sequential forest succession, as demonstrated by similar techniques for a section of the Wisconsin evergreen-hardwood forest, is not common in the region of boreal forest studied. However, for those species in common between this and the Wisconsin study, similar dynamic pathways are indicated despite differences in sample size and field technique. Tree species developmental pathways, as indicated by `succession vectors' on the ordination models are, for the most part, short and circular with the exception of *Abies balsamea* (balsam fir). This reflects the reestablishment of similar, relatively monospecific forest stands following catastrophic forest destruction by fire and (or) other agencies. Where catastrophe does not intervene, deciduous primary forest species may be succeeded by an understory of *A. balsamea* or by *Picea mariana* (black spruce). Equally, some forest stands of primary establishment may become decadent with little or no subsequent tree growth. These observations are discussed with respect to the general notion of forest succession.

Carleton, T.J.; Maycock, P.F. 1980. Vegetation of the boreal forests south of James Bay: non-centered component analysis of the vascular flora. Ecology 61:1199-1212.

Results from an extensive vegetation survey of 197 boreal forest stands, encompassing a full spectrum of succession and site types in the regions of Ontario and Québec south of James Bay, are reported. Non-centered principal component analysis plus varimax rotation (nodal component analysis) is applied to overstory and understory data in order to detect vegetational noda. The overstory data are inherently more structured (*i.e.*, contain more distinct subgroups) than those of the understory. An exception is seen with groups in which *Abies balsamea* plays a prominent role. These are interpreted as stages in various successions of which only one, a *Betula papyrifera* to *A. balsamea* sequence, represents the complete transition from one canopy dominant to another. The understory noda are summarized in terms of the compositional and environmental features of stands belonging to each nodum. Relationships among the understory noda are summarized in a multidimensional scaling ordination which is derived directly from similarity values (conjunction coefficients) representing the overlap between pairs of noda. Two major environmental gradients seem to affect understory composition. These are a site moisture-nutrient concentration gradient and a general fertility-productivity gradient. Canopy composition and understory vegetation are compared by nodal conjunction between the two analyses. Groups of noda, representing wet bog forests and also upland mesic forests, show moderate to good coincidence but beyond this little canopy specificity emerges. These results indicate that overstory-understory coincidence is due primarily to similar site requirements. Understory species' response to an overstory succession is examined. Many abundant herbs seem indifferent to dramatic canopy change. This observation and results from nodal component analysis are discussed with respect to forest fire.

Carleton, T.J.; Maycock, M.F. 1981. Understory-canopy affinities in boreal forest vegetation. Can. J. Bot. 59:1709-1716.

One hundred and ninety-seven boreal forest stands, in a region of Ontario and Québec south of James Bay, were examined. Tree species were summarized as relative density of each of five stem size classes. These data formed the basis for an exclusive polythetic divisive stand classification into 10 groups. Most of these groups were characterized by a single tree species. The affinity of each of 410 understory taxa was assessed with respect to each canopy stand group or natural combinations of groups. Only 121 understory taxa showed specificity to the canopy classes identified. This apparent lack of tight overstory-understory affinity is discussed in relation to site nutrient status and regeneration following forest fire.

Croskery, P.R.; Lee, P.F. 1981. Preliminary investigations of regeneration patterns following wildfire in the boreal forest of northwestern Ontario. Alces 17:229-256.

A vegetation survey was initiated to monitor the pattern of natural revegetation resulting from a 1976 forest fire in the Ignace area of Ontario. During the period 1976 to 1980, a total of 316 site inventories on burnt and non-burnt sites was conducted recording 88 different species in 32 sampling days. Ground cover vegetation on burnt-over areas reached the same density as that of non-burn areas in the third growing season following the fire. By the fifth year following the fire, shrub cover was re-established at an approximate height of 2 m and with a cover factor of 75% pre-burn conditions. No significant change in canopy cover on burnt-over areas was noted during the 5-year study. The greatest changes in species numbers occurred during the first 2 growing seasons. Two types of vegetational species changes were noted, annual succession and re-colonization. Each was identified during the first 3 growing seasons.

Degrandpre, L.; Gagnon, D.; Bergeron, Y. 1993. Changes in the understory of Canadian southern boreal forest after fire. J. Veg. Sci. 4:803-810.

We investigated changes in the composition and abundance of understory species after fire in the southern boreal forest around Lake Duparquet, Québec. Ten plots of 100 m^2 were sampled in each of eight sites varying in post-fire age from 26 to 230 years, with 20 1-m^2 quadrats in each of these 80 plots. Variation in the understory was described by DCA ordination and interpreted as a regeneration succession series. Thickness of the organic layers, stand age and canopy composition were all correlated with vegetational change. This change was not constant throughout succession; some old sites showed an increase in the diversity and abundance of certain pioneer species. This was partly related to openings in the canopy resulting from a major outbreak of spruce budworm, which affected sites dominated by *Abies balsamea*. The ordinations were performed on both the 100-m^2 plots and the 1-m^2 quadrats. Heterogeneity within sites was larger at the 1-m^2 scale and there was a great deal of overlap in the position of the quadrats in ordination space. At the smaller scale of analysis, stand age and thickness of the organic layers were not correlated with the changes observed in the understory.

Diotte, M.; Bergeron, Y. 1989. Fire and the distribution of *Juniperus communis* L. in the boreal forest of Québec, Canada. J. Biogeography 16:91-96.

The distribution of *Juniperus communis* L. in the boreal forest cannot be explained merely in terms of potential sites. In the Lake Duparquet area, in northwestern Québec, this species is restricted to islands of the lake, despite an abundance of apparently similar sites on surrounding mainland. In order to evaluate the ecological factors, both abiotic and historical, that could be responsible for this limited distribution, nineteen populations of *Juniperus communis* in the Lake Duparquet area were studied. A phytosociological analysis revealed that *Juniperus communis* can be found in three types of communities related to degree of opening of the vegetation cover. Individuals can reach an age of more than 170 years and, in many cases, have survived fires. The existence of a fire regime which permits a part of the population to survive, seems responsible for the maintenance of *Juniperus communis* on the islands of Lake Duparquet. Poor seed dispersal from existing stands, together with low percentage seed germination could explain why the favourable mainland habitat is not recolonized after large fires have destroyed the vegetation. We suggest that the restricted distribution of the species in the boreal forest is not linked to low availability of favourable habitat, but to an imbalance between the species regeneration potential and its elimination by fire.

Ehnes, J.W,; Shay, J.M. 1995. Natural recovery of logged and burned communities in the Lake Winnipeg East Forest Section, Manitoba. Joint Publ., Can. For. Serv., For. Bran., Man. Nat. Res. 138 p.

The objective of this study was to determine how well naturally regenerating plant communities in the southern part of the Canadian boreal forest recover from logging when compared with fire. Differences in species composition (species present and their abundances) were described for 13 and 37 year old communities on site types that included rock outcrops, shallow and moderately deep mineral soils and organic soils. Many of the species present at the time of fire or logging are known to regenerate shortly thereafter. We found that, by the time the communities were 13 years old, most species which performed better in one treatment did so in post-logging communities. This was expected based on the research of others and was attributed to the less destructive effect that logging generally has on plants when compared with fire. Pioneer mosses (*Polytrichum* spp.), *Epilobium angustifolium*, *Smilicana trifolia*, jack pine and black spruce were the only species which performed better in 13-year-old post-fire communities. An average of 12 common species was found across the four site types (14 in 37-year-old communities). The number of common species was higher in the 13-year-old post-logging communities found on outcrops and shallow mineral soils. By 37 years of age, most species performed better in post-fire communities. Reindeer lichens and several species of *Vaccinium* were the main exceptions. Logging resulted in different species being the most abundant. The extent to which grasses and other herbs performed better in 37-year-old post-fire communities (16 of 21 situations) was not expected and could not be explained. Logging may have had long term impacts on ecological processes which then led to differences in species composition by 37 years of age. The pattern of post-disturbance recovery supports this suggestion. That is, even though the species composition of communities was less affected by logging than fire, subsequent recovery appeared to be slower in post-logging communities. The well known difficulties which trees have regenerating in cutovers appears to also be true of some understorey species. Forest management planning should allow for the fact that post-logging recovery will be different from that after fire.

Frelich, L.E.; Reich, P.B. 1995. Spatial patterns and succession in a Minnesota southern-boreal forest. Ecol. Monogr. 65:325-346.

Succession was studied in a cold-temperate forest in the Boundary Waters Canoe Area Wilderness (BWCAW) of northeastern Minnesota. The 13 × 18 km study area comprises a complex forest mixture of jack (*Pinus banksiana*) and other pines, quaking aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), black spruce (*Picea mariana*), balsam fir (*Abies balsamea*), and white cedar (*Thuja occidentalis*) on thin soils over the Canadian Shield bedrock. The main objectives of this study were to examine the relationships between spatial patchiness, spatial scale, and canopy succession in the southern-boreal forest of the BWCAW, and to evaluate under what conditions successional direction may remain stable, converge, or diverge. Knowledge of the successional direction of old forests in the BWCAW that are undergoing demographic transition from even-aged to uneven-aged is important because the landscape now has many old stands as a result of reduced fire frequency. Rotation periods for fires have changed from ≈ 50-100 years in presettlement times to > 1000 years since 1910. Results show that the reduced fire frequency in recent years has changed the dominant successional pathways. When fire frequency was high, jack pine or aspen stands usually burned while still in the even-aged stage of development, and the new trees after the burn were the same species as before. Currently, many stands are undergoing demographic transition from even-aged stands of catastrophic fire origin to uneven-aged stands. This transition parallels a change in canopy composition from jack pine (occasionally red pine (*Pinus resinosa*)) or aspen to an old-growth multi-aged mixture of black spruce, balsam fir, paper birch, and white cedar. [original abstract modified, only information relevant to fire was retained]

Granström, A.; Schimmel, J. 1993. Heat effects on seeds and rhizomes of a selection of boreal forest plants and potential reaction to fire. Oecologia 94:307-313.

To analyze the potential reaction to fire-generated heat pulses, seeds of 12 species of plants and rhizomes of 3 species were exposed to elevated temperatures for 10 minutes. The tested material split into three groups with respect to heat tolerance: (1) the rhizomes, for which the lethal temperatures were in the range 55-59° C; (2) the seeds of most species tested, for which the lethal temperatures were in the range 65-75° C; (3) the seeds of two species of Leguminosae and three species of *Geranium* for which the lethal temperatures were around 100° C. For all 3 *Geranium* species and for one of the legume species, *Anthyllis vulneraria*, exposure temperatures above ca. 45° C resulted in dormancy release, and maximum germination occurred above 60-65° C. Speed of germination was little affected for most species, except after exposure to near-lethal temperatures, where it slowed down dramatically, although the seedlings emerging were healthy. We conclude that due to sharp temperature gradients in the soil during fire, differences in heat tolerance between species in most cases are not large enough to be a decisive factor in their post-fire colonising success. There are exceptions: the seeds of certain taxa that are impermeable to water in the dormant state, some of which have heat triggered germination.

Janke, R.A.; McKaig, D.; Raymond, R. 1978. Comparison of presettlement and modern upland boreal forests on Isle Royale National Park. For. Sci. 24:115-121.

The presettlement upland boreal forest type of Isle Royale National Park, as reconstructed from original survey notes of 1847-48, was compared with the forest as sampled in 1974. A drastic reduction in balsam fir (*Abies balsamea*) and an increase in white birch (*Betula papyrifera*) and aspen (*Populus tremuloides*) have occurred. These changes are attributed to the high frequency of man-caused fires since 1848. A reduction in tamarack (*Larix laricina*) is probably the result of an invasion of the larch sawfly. Thimbleberry (*Rubus parviflorus*) has replaced American yew (*Taxus canadensis*) as the prevailing understory shrub. Proliferation of thimbleberry probably followed fires in the late 1800's and the failure of the American yew to replace it is the result of heavy moose browsing on this highly palatable species.

Janke, R.A.; Lowther, J.L. 1980. Post-fire succession in the boreal forest type of Isle Royale National Park. p. 99-135 *in* Proc. Second Conf. Sci. Res. Natl. Parks (Nov. 26-30, 1979, San Francisco, Calif.), Vol. II. VSDI Natl. Park Serv., Washington, D.C.

Post-fire successional trends in tree species composition, forest inflammability, and ground cover species composition were studied by comparison of these parameters in approximately 200 forest stands of different age. Results indicate a shift in dominance from white birch and/or quaking aspen to white spruce and balsam fir. The inflammability of the forest is shown to increase with time. Vascular ground cover plants also undergo marked changes. Most species increase progressively with time, decrease progressively with time, or rise to a peak value at intermediate ages and decline again as maturity is approached.

Comments: The paper is available in microfiche form as Report NPS/ST-80-02-11 (2 of 3) from U.S. Department of Commerce, National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

Johnston, M.H.; Elliott, J.A. 1996. Impacts of logging and wildfire on an upland black spruce community in northwestern Ontario. Envir. Mon. Assess. 39:283-297.

Plant species composition and community structure were compared among four sites in an upland black spruce community in northwestern Ontario. One site had remained undisturbed since the 1930s and three had been disturbed by either logging, fire, or both logging and fire. Canonical correspondence ordination analyses indicated that herbaceous species composition and abundance differed among the disturbance types while differences in the shrub and tree strata were less pronounced. In the herb stratum *Pleurozium schreberi*, *Ptilium crista-castrensis* and *Dicranum polysetum* were in greatest abundance on the undisturbed forest site, while the wildfire and burned cutover sites were dominated by *Epilobium angustifolium* and *Polytrichum juniperinum.* The unburned harvested site was dominated by *Epilobium angustifolium*, *Cornus canadensis* and *Pleurozium schreberi*. Species richness was lower on the undisturbed site than on any of the disturbed sites while species diversity (H') and evenness (Hill's E5) were higher on the unburned harvested site than on the other sites. Results suggest that herb re-establishment is different among harvested and burned sites in upland black spruce communities and we hypothesize that differences in the characteristics of the disturbance were responsible, in particular, the impact of burning on nutrient availability. These differences need to be taken into account in determining the effects of these disturbances on biodiversity and long-term ecosystem management.

Kayll, A.J. 1968. The role of fire in the boreal forest of Canada. Can. For. Serv., Petawawa For. Exp. Stn., Inf. Rep. PS-X-7. 15 p.

Through a review of literature, the essential role of fire in the boreal forest as a natural regulatory agent of composition and succession is discussed in terms of plants, soils, and animals. In natural, long-term cycles, the incidence of lightning-started fires on a particular area may have been only once in one to three centuries, but fire nevertheless has always been an agent for destruction and renewal of boreal forest stands. It is suggested that fire's beneficial effects, *e.g.* nutrient cycling, removal of excessive mor humus, warming of soil surface, depression of permanent frost, provision of browse, etc. should be utilized in managing the forest's renewable resources. Research on physical, physiological, ecological extent of fire will supplement the meagre experience available for effective management of the boreal forest.

Kenkel, N.C. 1986. Structure and dynamics of jack pine stands near Elk Lake, Ontario: a multivariate approach. Can. J. Bot. 64:486-497.

Data on percentage cover and number, height and d.b.h. of each tree species in the canopy and the percentage cover of each species in the understory were collected in 180 sandy, upland, even-aged stands dominated by jack pine alone or with black spruce at the southern edge of the boreal forest. Cluster analysis led to the recognition of 10 vegetation types, each showing a unique combination of floristics, physiognomy and environmental components. Nonmetric multidimensional scaling of the stands suggested a vegetational continuum in response to overall moisture availability. A corresponding ordination of common species indicated the development of interspecific associations related to soil moisture conditions. It is suggested that the composition of upland jack pine forests is influenced by both deterministic factors (*e.g.* substrate and topographic conditions) and probabilistic factors related to fire and fire history.

Kershaw, K.A.; Rouse, W.R. 1971. Studies on lichen-dominated systems. I. The water relations of *Cladonia alpestris* in spruce-lichen woodland in northern Ontario. Can. J. Bot. 49:1389-1399.

The water relations of *Cladonia alpestris* in spruce-lichen woodland in northern Ontario is described. The rate of drying of the lichen canopy was measured by resistance grids inserted into the canopy and monitored during the drying cycle. The effects of dew were measured in a similar fashion and shown to form an insignificant proportion of the total annual metabolism of the lichen. The lichen mat showed a very high stratified resistance to water loss and the effective mulching properties produce a high level of water availability under the lichen mat. This was confirmed using neutron attenuation techniques and the significance of discussed in relation to the development of lichen woodland. The physiological response of the lichen to conditions of varying levels of saturation is also discussed. (abstract)

Kershaw, K.A. 1977. Studies on lichen-dominated systems. XX. An examination of some aspects of the northern boreal lichen woodlands in Canada. Can. J. Bot. 55:393-410.

The existence of two major types of lichen woodland in Canada, *Cladonia stellaris* woodland and *Stereocaulon paschale* woodland, is discussed in relation to their seral nature and their rarely developed theoretical climax type. Our own observations, coupled with previous descriptions from a wider area, suggest that *Stereocaulon paschale* woodland replaces *Cladonia stellaris* woodland in a more or less continuous zone from just west of Churchill across to Great Slave Lake, immediately north and south of latitude 60° N. Both woodland types are often typical of sandy soils (pH 6 or less) and almost always represent the final recovery phase after fire. Rarely, the lichen surface is replaced by a continuous moss cover as the spruce canopy closes. The lichen surface is thus dependent on the lack of competition from higher plants, the absence of which is characteristic of the climate of this northern boreal region. *Cladonia stellaris* woodland also occurs on palsas and peat plateaux where, again, lack of higher plant competition and a suitable pH exist. The recovery sequence after fire is a highly complex process and as yet only the following parameters have been categorized. In the early recovery phases, limited soil moisture and hence a reduced summer latent heat flux enhance the sensible heat flux. The surface conditions are analogous to those of a hot desert with very high surface temperatures and extremely large diurnal temperature fluctuations. The physiology of these initial moss and lichen colonizers presumably enables them to tolerate these harsh conditions. The establishment of a few spruce seedlings and the subsequent development of open lichen woodland modulates the harsh summer temperature regime and allows the further development of a vegetated surface. After humus accumulation, which acts as an effective mulch, summer soil moisture is elevated, enhancing the latent heat flux and correspondingly reducing sensible heat flux. This probably allows the full development of mature lichen woodland with its almost monospecific ground cover of either *Cladonia stellaris* or *Stereocaulon paschale*. Limited data suggest that the net photosynthetic responses of these two species is favoured by the relatively warm mesic conditions established by the open spruce canopy. Good accumulation of snow in the winter is probably also important for protection of the lichen surface from low temperatures. The open nature of mature lichen woodland is apparently maintained by an active inhibition of spruce seedling establishment by the lichen mat, although the mechanism is not entirely clear.

Kloet, S.P.V. 1994. The burning tolerance of *Vaccinium myrtilloides* Michaux. Can. J. Plant Sci. 74:577-579.

One hundred and twenty *Vaccinium myrtilloides* plants were subjected to various prescribed burning regimes. Equal numbers were burnt annually, biennially, triennially, or not at all. Plants burnt every year for 9 years had a survival rate equal to the control (no burning) or those plants burnt less frequently. Highest yields occurred in the third year of the prune-burn cycle. Clonal expansion was least for plants burnt every year and greatest for plants burnt every 3 years.

Lieffers, V.I.; Macdonald, S.E.; Hogg, E.H. 1993. Ecology of and control strategies for *Calamagrostis canadensis* in boreal forest sites. Can. J. For. Res. 23:2070-2077.

Calamagrostis canadensis (Michx.) Beauv. is a widely distributed rhizomatous grass that can seriously inhibit growth of white spruce (*Picea glauca* (Moench) Voss) seedlings in the boreal forests of North America. We review the dynamics of this grass during four successional stages: the colonization of disturbed sites; dominance of the site by the grass a few years after disturbance; gradual loss of dominance with overstory development; and maintenance of the grass at low levels in the understory of the mature forest. We also describe *C. canadensis* in relation to recruitment from clonal growth and seed, environmental conditions for growth, the effects of grass litter buildup on conifer seedling microclimate, and overall competitive abilities. Control strategies for *C. canadensis* are as follows. If the grass is found in nearly every square metre in the understory prior to logging, there will be rapid spread when the stand is clear-cut unless clones are killed using herbicides or a deep burn. Large spruce seedlings, planted on large soil scalps or mounds, coupled with release by way of herbicides or sheep grazing, may be necessary for plantation establishment under conditions of encroachment by *C. canadensis*. Alternatively, the shade provided by a partial canopy may inhibit the grass sufficiently to allow spruce seedlings to establish. If grass is not abundant in the understory, we recommend (*i*) minimizing forest floor disturbance to reduce sites for grass seedling colonization or (*ii*) a slash burn with the hope of encouraging colonization by herbaceous species that have less impact on conifer seedlings.

Lynham, T.J.; Wickware, G.M; Mason, J.A. 1998. Soil chemical changes and plant succession following experimental burning in immature jack pine. Can. J. Soil Sci. 78:93-104.

In 1975 and 1976, an experimental burning program was conducted in an immature stand of boreal jack pine (*Pinus banksiana* Lamb.) growing on level, granitic outwash sands in northern Ontario. Nine 0.4-ha plots were burned under a range of fire weather conditions and sampling was conducted to examine the effect of fire on soil chemical changes and revegetation. Results indicated that depth of burn (DOB) affected both soil chemical changes and plant succession on these pine sites. *Vaccinium angustifolium* Ait., *Oryzopsis* spp,. *Waldsteinia fragarioides* (Michx.) Tratt, *Salix* spp. and *Viola adunca* Sm. increased in cover at two levels of DOB but the increase was greatest at the lower DOB and decreased to pre-burn levels after 10 yr. *Comptonia peregrina* (L.) Coult., *Epilobium angustifolium* L., *Polytrichum commune* Hedw. and *Amelanchier sanguinea* (Pursh) DC. were not found in the pre-burn surveys but appeared after burning. Vegetation cover for these species was always higher at the deeper DOB but decreased almost to zero after 10 yr. Other species such as *Pleurozium schreberi* (Brid.) Mitt., *Linnaea borealis* L., *Corylus cornuta* Marsh., *Cladina rangiferina* (L.) Nyl. and *Aralia nudicaulis* L. were eliminated from the site and did not recover even after 10 yr. Soil pH increased 0.3 to 1.0 pH units in the organic and mineral soil layers. The rate of increase in pH was always steeper at the higher DOB and pH returned to pre-burn levels in the mineral soil layers after 10 yr. Immediately after burning, exchangeable Ca in the mineral soil layers doubled but 10 yr later, Ca returned to pre-burn levels. Phosphorus and K increased in the mineral soil, leveled off and were still elevated after 10 yr. Total Kjeldahl N was reduced by 50% in the organic soil while N in all mineral soils increased, and was still increasing after 10 yr. Except for immediate post-fire increases in pH, Ca and N, soil chemical changes were small or they rebounded to pre-burn levels 10 yr after burning. Therefore it is unlikely that these changes were the cause of the plant cover changes that persisted to 10 yr.

Lutz, H.J. 1959. Aboriginal man and white man as historical causes of fires in the boreal forest, with particular reference to Alaska. Yale University : School of Forestry Bulletin No. 65.

Lightning is certainly responsible for starting fires in the boreal forest but man, both aboriginal and white, seems to have a more important cause. It is the purpose of the writer to examine the uses to which man in the boreal forest has put fire and his role in forest burning. For this purpose the examination has been concentrated on the early historical period, prior to about 1915.

Methven, I.R.; Van Wagner, C.E.; Stocks, B.J. 1975. The vegetation on four burned areas in northwestern Ontario. Dept. Environ., Can. For. Serv., Chalk River, Ont. Inf. Rep. PS-X-60. 23 p.

As the initial step in a study of forest fire cycles in the boreal forest of northwestern Ontario, four burned areas of different ages were briefly examined. This report describes the present condition of the areas visited in terms of both forest cover and minor vegetation. Tentative hypotheses on the role of fire in this region of the boreal forest are put forward and several questions raised about the interactions among the main tree species. Apparently, in most cases the same dominant tree species return immediately after fire, implying that cycling by fire rather than succession is the basic mechanism in this forest. Proposed further work to complete this study is described and the hope expressed that similar studies will eventually be undertaken in other parts of Canada.

Morneau, C.; Payette, S. 1989. Postfire lichen-spruce woodland recovery at the limit of the boreal forest in northern Québec. Can. J. Bot. 67:2770-2782.

A 250-year postfire plant chronosequence in well-drained sites at the northern limit of the boreal forest in the Grande Rivière de la Baleine area, northern Québec, was reconstructed from nine sites associated with the development of the lichen-spruce woodland. Most species recorded along the chronosequence reinvaded burned sites within 15 years after fire, whereas important vegetational changes occurred during the first 100 years of postfire recovery, corresponding to full development of the *Cladina stellaris*-spruce woodland. No vascular plant species replacement was observed during succession, whereas by contrast a well-defined lichen-bryophyte sequence occurred along 5 successional stages. Species diversity (Shannon index) was low 4 years after fire, but it reached a maximum about 25 years after fire and then dropped and stabilized at a low value in old-growth woodlands dominated by black spruce (*Picea mariana* (Mill.) BSP) and *C. stellaris*. The active period of black spruce sexual regeneration spans about 20-25 years, with maximum regeneration occurring 5-14 years after fire. After this period, seed regeneration is mostly sporadic and sustained layering becomes fairly common at all sites. From 100 to 250 years after fire, no significant changes were observed in vegetation structure, floristic composition, species diversity, and spruce regeneration, suggesting that lichen woodlands are self-perpetuating in the absence of fire. In limiting spruce regeneration at the ground surface, the lichen cover seems to be the most important factor controlling the open structure of the lichen/spruce woodland.

Noble, M.G.; Deboer, L.K.; Johnson, K.L.; Coffin, B.A.; Fellows, L.G.; Christensen, N.A. 1977. Quantitative relationships among some *Pinus banksiana* - *Picea mariana* forests subjected to wildfire and postlogging treatments. Can. J. For. Res. 7:368-377.

Numerical classifications are used to compare vegetation and soil characteristics at virgin, logged, slash-burned, wildfire burned, and rock-raked sites in northeastern Minnesota and western Ontario. Virgin sites are dominated by *Pinus banksiana* Lamb. and *Picea mariana* (Mill.) BSP. and adjacent disturbed sites were previously dominated by these species. The vegetation of each study site is related to regional upland community types by discriminant and canonical analysis. A relationship between predisturbance and postdisturbance vegetation is indicated, regardless of the type of disturbance. Sites disturbed by logging or logging followed by slash burning are more similar to virgin sites than to wildfire or rock-raked sites, which are generally more similar to one another than to any of the other sites. The wildfire and rock-raked sites have undergone significant vegetation changes, but the difference in invader species indicates that the types of changes have not been the same. The number of invader species present is influenced by the type of disturbance experienced by a site. An important consequence of rock-raking is the movement of nutrients from timber producing areas to windrows.

Nordin, J.O.; Grigal, D.F. 1976. Vegetation, site, and fire relationships within the area of the Little Sioux fire, northeastern Minnesota. Can. J. For. Res. 6:78-85.

The relationships among various landscape features were examined in an area in northeastern Minnesota that burned in a forest fire in May 1971. Maps based on fire intensity, cover types in 1948 and 1970, soils, and topography were randomly sampled. A total of 34 comparisons were made between pairs of classifications based on the mapped characteristics. The closest relationship was between dominant vegetation in 1948 and that in 1970. Relationships between soil mapping units and slope position and between vegetation and soils were also relatively high. The vegetation-soil relationships were influenced by the close associations of lowland vegetation to lowland soils and of upland vegetation to upland soils. However, specific categories of upland vegetation were not well related to specific categories of upland soils. Fire intensity was most closely related to slope position. An 80% decrease in balsam-fir cover types occurred from 1948 to 1970. This decrease was accompanied by a nearly equal increase in aspen cover types. This balsam-fir to aspen cover type change is attributed to the spruce budworm epidemic, which occurred from the mid-1950's. Decreases in jack pine, red pine, and white pine cover types are attributed to commercial logging.

Ohmann, L.F.; Grigal, D.F. 1979. Early revegetation and nutrient dynamics following the 1971 Little Sioux forest fire in northeastern Minnesota. For. Sci. Monogr. No. 21. 80 p.

Three virgin plant communities dominated by *Pinus banksiana*, three by *Populus-Betula*, and one mixed community were studied over five growing seasons after burning in the 1971 Little Sioux fire. From 1971 through 1975 tree and tall shrub reproduction generally decreased in density and increased in biomass. Low shrub cover and biomass increased for three years and then leveled off as tree and tall shrub competition increased. Herb cover and biomass increased most rapidly through 1972 and then slowed substantially. By 1975 total net primary productivity averaged 850 g/m^2/year for all seven stands, and over 1,200 g/m^2/year in the broadleaf-dominated stands. The forest floor 01 horizon increased in mass through 1974, and then apparently stabilized at about 620 g/m^2. The 02 horizon averaged about 1,000 g/m^2 and was still increasing in 1975. By the 1975 growing season the total amount of nutrients in aboveground vegetation on burned plots ranged from 33% of the N to 65% of the K found in nearby unburned forest communities. By 1973 the nutrients in the above-ground vegetation and the 01 horizon of the forest floor were greater than the quantity estimated to have been mobilized by the fire. The vegetation was an effective sink for the released nutrients.

Ohmann, L.F.; Grigal, D.F. 1981. Contrasting vegetation responses following two forest fires in northeastern Minnesota. Am. Midl. Nat. 106:54-64.

Response of *Pinus banksiana* Lamb. forest communities during the first growing season following a spring fire (three communities) was contrasted with response following a summer fire (two communities) in northeastern Minnesota. Differences in both quantity and quality of vegetation were related to degree of destruction of the forest floor. The spring fire destroyed the litter layer, but left much of the cool, moist lower layers intact, protecting the plant reproductive structures within them. The summer fire consumed virtually all of the warmer, drier forest floor and most of the associated reproductive structures. Reproduction following the spring fire developed vegetatively and prolifically, while that following the summer fire developed primarily from seed and was less abundant. The summer fire also liberated more nutrients from the forest floor, as reflected by significantly greater plant nutrient concentrations in those communities burned in summer.

Ohmann, L.F.; Ream, R.R. 1971. Wilderness ecology: virgin plant communities of the Boundary Waters Canoe Area. USDA For. Serv., North Cent. For. Exp. Stn., St. Paul, Minn. Res. Pap. NC-63. 55 p.

Describes one non-forest and 11 forest communities, distinguished by analysis of data for 106 stands from a study already noticed. The stands were classified by a combination of agglomerative clustering and principal-components analysis of the frequency of each species. Communities damaged by *Choristoneura fumiferana* were frequent and were distinguished from the normal or slightly damaged forest type dominated by *Abies balsamea* and *Betula papyrifera* as the `budworm-damaged community'. An old, stable community dominated by *Thuja occidentalis* was identified on relatively cool, nutrient-rich elevated sites. The pattern of communities is discussed and is related largely to the periodicity of disturbance by fire. Continuing succession towards the *A. balsamea/B. papyrifera* type, with loss of the scenically interesting types dominated by *Pinus resinosa* and/or *P. strobus*, is probable unless some form of controlled burning is introduced.

Comments: Two semi-technical articles on the research reported in the above publication have been published: Ohmann, L.F.; Ream, R.R. 1969. Vegetation studies in the BWCA: a brief report on plant communities. Naturalist 20(1):20-29.; Grigal, D.F.; Ohmann, L.F. 1973. Upland plant communities of the Boundary Waters Canoe Area. Naturalist 24(4):16-20.

Paré, D.; Bergeron, Y. 1995. Above-ground biomass accumulation along a 230-year chronosequence in the southern portion of the Canadian boreal forest. J. Ecol. 83:1001-1007.

The above-ground biomass of trees in a southern boreal forest was assessed along a 231-year-old chronosequence following fire. The vertical distribution of crown width was also measured. As the forest develops, the canopy profiles changed from a single layer to a bimodal distribution before reverting to one layer of trees with low stature. The changes in the morphology of the canopy were largely due to changes in abundance of *Populus tremuloides* (Michx.), which reached a greater height than other species. The living above-ground biomass increased linearly to 17.3 kg·m^{-2} by 75 years after fire and then declined strongly to 7.7 kg·m^{-2} by year 197. A recent (10-year-old) spruce budworm (*Choristoneura fumiferana* Clem.) outbreak that affected old stands most severely contributed to the low biomass of old sites. A strong positive relationship between the proportion of *Populus tremuloides* and total above-ground biomass corrected for the spruce budworm effect, which remained significant throughout the chronosequence, suggested that a decreasing abundance of this species could also contribute to the biomass decline with age. In boreal forests, the decline in the amounts of living tree above-ground biomass that follows the aggradation phase has often been explained by decreasing soil nutrient availability. The present observations suggest that succession to species of different physiognomy and of increased susceptibility to disturbance could also contribute to this decline.

Ritchie, J.C. 1960. The vegetation of northern Manitoba. VI. The Lower Hayes River Region. Can. J. Bot. 38:769-788.

The vegetation of the Hudson Bay Lowlands of Canada is known only in the most superficial terms. This contribution provides descriptions of the chief cover types of a small portion of the Lowlands near the confluence of the Hayes and Nelson rivers. The area has a continental, subarctic climate. Postglacial marine inundation has deposited thick calcareous clays; the topography is flat. On the mineral substrata of alluvial and marine deposits the chief types of vegetation are salt marsh, shrub (dominated by *Salix* species), forests of *Populus balsamifera*, and forests of *Picea glauca*. They often form discrete zones in the order mentioned, and it is likely that this is a seral as well as spatial relationship. On the extensive peat substrata there are bog and fen types. In the former are distinguished two communities dominated by *Picea mariana*-one, termed lichen muskeg, with a ground layer of *Cladonia* and *Ledum*, and the other, moss muskeg, with *Pleurozium* and *Ledum groenlandicum* as ground layer dominants. Locally, areas of lichen muskeg have been destroyed by fire and are now occupied by willow communities. In four areas within the overall study area, the original lichen muskeg had been destroyed by fire and secondary vegetation was found to consist of a shrub layer dominated by *Salix planifolia* with a few individuals of *S. arbusculoides* and *Betula glandulosa*. The ground vegetation consists of the following species, in approximate order of relative abundance: *Calamagrostis canadensis*, *Deschampsia caespitosa* var. *littoralis*, *Achillea millefolium*, *Epilobium angustifolium*, *Erysimum cheiranthoides*, *Stellaria longipes*, *Carex vaginata*, and *Potentilla anserina*. In wet inland areas, moss muskeg and lichen muskeg communities are associated with palsa and string-bog features. On shallower peats, usually nearer the shores and rivers, fens predominate, with *Larix laricina* and *Betula glandulosa* as the dominant phanerophytes. All these types have been distinguished on vertical and aerial photographs, and their photographic characteristics are summarized. A detailed vegetation map illustrates their chronology. [additional information added]

Rowe, J.S.; Scotter, G.W. 1973. Fire in the boreal forest. Quat. Res. 3:444-464.

The boreal forest in North America owes much of its floristic and faunistic diversity to periodic fires ignited by lightning and by man since he appeared on the scene. The indirect evidences of burning in vegetation and soils, and recent direct observations of fires, are reviewed. Fire is shown to exert a significant effect on vegetational composition, on soil chemical properties and thermal regime, and on animal populations through the particular mosaic of habitats created. In turn, fire is itself influenced by the nature of geographic landscape ecosystems according to their surface forms, accumulations of organic materials, and susceptibility to drought. It is concluded that fire should be viewed as a normal ecological process in the boreal forest. A thorough understanding of its long-term role in terrestrial and aquatic ecosystems is needed.

Schaefer, J.A. 1993. Spatial patterns in taiga plant communities following fire. Can. J. Bot. 71:1568-1573.

The scales of spatial patterns of the vascular understorey were examined during postfire succession in the taiga of southeastern Manitoba. Patterns of individual species from analogous burned (5 years old) and old-growth (≥ 90 years old) communities were revealed using Paired Quadrat Variance; multispecies patterns were determined with Moran's *I* following ordination. The scales of single-species patterns were variable within communities and not significantly different between the two age classes. Similarly, multispecies patterns displayed no consistent differences in scale according to age of the community. The results fail to support the hypothesis that the scale of the spatial pattern in plant communities increases with stand age.

Scheiner, S.M.; Teeri, J.A. 1981. A 53-year record of forest succession following fire in northern lower Michigan. Mich. Bot. 20:1-14.

A 53-year record of forest succession following fire was analyzed for five experimentally or naturally burned plots in northern Michigan. After a fire the species diversity increased gradually for 25 years and remained level thereafter. This finding contrasts with studies which have found an early peak in species diversity with a subsequent decrease within the first 10 years of succession. Immediately following fire, *Populus grandidentata* became the dominant tree species. During the 53-year period *Acer rubrum* and *Pinus strobus* replaced *Populus grandidentata* in abundance. In contrast with other investigations, the importance of annual species did not decrease during the period of succession.

Scheiner, S.M.; Teeri, J.A. 1986. Microhabitat selection and the successional gradient of a forest grass. Can. J. Bot. 64:734-738.

Secondary forest succession involves large changes in the environment of the forest floor. Populations of *Danthonia spicata* occur in sites representing a 70-year span of succession following fire in the aspen-pine forests of northern lower Michigan. Five populations were studied from sites of ages 0, 26, 32, 44, and 69 years after fire. Four populations were in sites that were clearcut and burned; one population occurred on the site of a natural burn. Environmental measurements in the sites revealed large differences with respect to light, soil water, and soil nutrients. The authors investigated the extent to which microhabitat selection was responsible for the persistence of *D. spicata* across the 70-year successional gradient. On three sites the *D. spicata* populations were in locations with a higher mean light level than the mean value for the site. During a 3-week period of no rain the plants in the four experimental burn sites were observed to occur in locations with a lower mean soil water potential than the mean for the site. It appears that microhabitat selection significantly altered the successional gradient as experienced by these populations of *D. spicata*.

Shafi, M.I.; Yarranton, G.A. 1973a. Diversity, floristic richness, and species evenness during a secondary (post-fire) succession. Ecology 54:897-902.

Diversity, species richness, and species evenness were analyzed in 11 boreal forest areas that had been burned from 0 to 44 years previously. The values of the information measure of diversity, H′, and Hurlbert's probability of interspecific encounter, Δ_1, obtained here are highly correlated. Both show a long term declining successional trend, but exhibit relatively high values for the period 4 to 11 years after burning. Fluctuations in both appear to be attributable to variations in richness rather than evenness, supporting Pielou and Hurlbert's contentions that the two components of diversity should be analyzed separately. Δ_1 is preferred to H′ because, if used in conjunction with a knowledge of spatial heterogeneity, it can provide information about the levels of competition in a community. The results indicate a slight increase in the amount of intraspecific competition during the course of succession, contrary to what might be expected as the outcome of evolution. It is argued that the species present are adapted to the occurrence of frequent catastrophes, particularly fires, so that prevailing evolutionary pressures and their outcome differ from those in more stable environments.

Shafi, M.I.; Yarranton, G.A. 1973b. Vegetational heterogeneity during a secondary (postfire) succession. Can. J. Bot. 51:73-90.

Areas of boreal forest in the Clay Belt of northern Ontario, burned at a range of times from 0 to 57 years before the present, were examined. The range of vegetation present was sampled by means of a number of plots in each area. A simple test of heterogeneity, based on the number of significant correlations between species, was applied to the data from each area. Vegetation samples and species were each classified into non-exclusive groups, and the properties of the groups explored. Maturity weightings, based on the age of the site at which each species was first detected, were calculated for each sample. The results of analyses indicated the presence of four stages in the succession: (a) initial heterogeneity; (b) early phase; (c) heterogeneous phase; and (d) late phase. Initial heterogeneity, attributable to burning intensity, persists for a year, but is succeeded by a more homogeneous phase dominated by species which survive the fire in various ways. The heterogeneous phase is dominated by environmentally differentiated mosaic elements; it is succeeded by the late phase as a canopy develops and as ephermeral species, which colonized the disturbed area, disappear. The late phase is dominated by jack pine in sandy areas and by black spruce in peaty areas. There is evidence that the changes from one phase to the next are spatially heterogeneous because some sites mature more rapidly than others. The paths of succession at different sites within an area may differ, but there is convergence to one of the two main vegetation types in the late phase. The late phase types are differentiated at a much larger scale than the seral mosaic elements.

Sirois, L.; Bonan, G.B.; Shugart, H.H. 1994. Development of a simulation model of the forest tundra transition zone of northeastern Canada. Can. J. For. Res. 24:697-706.

A forest succession model has been adapted to simulate the dynamics of subarctic spruce-lichen woodland of northeastern Canada. Most adaptations concern the simulation of seed regeneration of subarctic forest communities growing on moderately to well drained sites. The yearly seed production in *Picea mariana* (Mill.) B.S.P. stands is controlled by temperature and stand structural characteristics. In addition to the seed input, the model considers the influence of seedbed properties on the establishment of seedlings. Overall, this model simulates the entire regeneration dynamics in a more realistic way than in most other gap models where successional processes are driven by resource constraints on tree growth. The model produces realistic predictions about the pattern of early post-fire age structure, and the biomass and density dynamics of black spruce populations. Simulations under a climate-warming scenario suggest that physiognomic change in subarctic spruce-lichen woodland would be more pronounced in areas subjected to moderately frequent forest fires than in those where the fire frequency is very low.

Stocks, B.J.; Alexander, M.E. 1980. Fire behaviour and effects research in northern Ontario: a field oriented program. p. 18-24 *in* Proc. Sixth Conf. Fire and For. Meteorol. (Apr. 22-24, Seattle, Wash.). Soc. Amer. For., Washington, D.C.

Fire behavior and the ecological effects of fire were studied on a combination of experimental fires and wildfires. A total of 23, 0.4 ha experimental fires ranging from low to high intensity were carried out in a mature jack pine stand near White River, Ontario and in an immature jack pine stand north of Sault Ste. Marie, Ontario. Two high intensity experimental fires were also conducted in spruce budworm-killed balsam fir north of Sault Ste. Marie. Permanent regeneration plots were established on 22 stands (13 jack pine and 9 black spruce) in northwestern Ontario that burned as wildfires between 1976 and 1979. Analysis between fire effects and fire behavior characteristics have not yet been undertaken but preliminary observations indicate that understory biomass and plant cover generally return to and exceed pre-fire levels within 2-3 years provided fire intensity is high enough to open up the canopy. With 100% surface fire coverage, coupled with a sufficient depth of burn, feather mosses and species with shallow rhizome systems such as creeping snowberry (*Gaultheria hispidula* [L.] Bigel.), trailing arbutus (*Epigea repens* L.), starflower (*Trientalis borealis* Raf.), and wood anemone (*Anemone quiquefolia* L.) are nearly eliminated. Typical fire species such as hair-cap moss (*Polytrichum commune* Hedw.), and fireweed *(Epilobium angustifolium* L.) are nearly universal.

Suffling, R. 1983. Stability and diversity in boreal and mixed temperate forests: A demographic approach. J. Environ. Manage. 17:359-371.

In landscapes routinely suffering catastrophic disturbance, a patch dynamics mosaic develops in which individual ecosystems can be characterized, in a Clementsian sense, by age, size, health, and productivity, without obviating an individualistic (Gleasonian) approach with ecosystems. For this "landscape demography", the age-class distribution (successional age polygon) proves a useful model, especially if the distribution is negative-exponential. Twenty-one age-class distributions were plotted from Ontario government forest resource inventory data representative of boreal and Great Lakes forest biomes. Eleven of 15 typical distributions indicated a negative exponential distribution, depending on the statistical criteria used, and six distributions were anomalous.

Suffling, R.; Lihou, C.; Morand, Y. 1988. Control of landscape diversity by catastrophic disturbance: a theory and case study of fire in a Canadian boreal forest. Environ. Manage. 12:73-78.

A landscape may be envisioned as a space partitioned by a number of ecosystem types, and so it conforms to a neo-Clementsian model of succession. A corollary is that intermediate disturbance rates should maximize landscape (beta) diversity. This was confirmed using eight boreal forest landscapes in northwestern Ontario, Canada, where intermediate rates of forest fire were associated with highest landscape diversity. Because current measures of evenness subsume a richness measure, it is not, as yet, feasible to assess the relative contributions of evenness and richness to biological diversity, and thus it was not possible to determine the roles of numbers of habitat types and relative amounts of habitat types in the above situation. Both theory and observations suggest that forest fire control in fire-prone landscapes increases landscape diversity, but that it is lowered by fire control on landscapes of intermediate to low diversity.

Viereck, L.A. 1983. The effects of fire in black spruce ecosystems of Alaska and northern Canada. p. 201-220 *in* Wein, R.W.; MacLean, D.A. (eds.). The role of fire in northern circumpolar ecosystems. John Wiley & Sons Ltd. Chichester, UK. 322 p.

Fire in the black spruce ecosystem of northern Canada and Alaska is characterized by large and frequent fires that usually kill the overstory trees and most, if not all, of the vegetation above-ground. Most species within the black spruce ecosystem show adaptations to fire, and black spruce stands are usually perpetuated by fire. Depending on the site, revegetation follows one of two primary patterns, although under some conditions there may be intervening stages of birch, aspen, or lodgepole pine. In general, the succession on dry sites develops as open lichen woodland with a nearly continuous cover of fruticose lichens. On moist sites, the development is that of a closed forest with a forest floor dominated by dense feathermosses and with a buildup of an organic mat. The final or climax vegetation that develops depends on site and climate and may vary from treeless bogs through feathermoss types to open lichen woodlands. In some areas, balsam fir replaces the black spruce. Fire reduces the organic layer on the forest floor and causes higher soil temperatures, an increase in available nutrients, and an increase in productivity for a period following the fire.

Zoladeski, C.A.; Maycock, P.F. 1990. Dynamics of the boreal forest in northwestern Ontario. Am. Midl. Nat. 124:289-300.

Histories of stand establishment and development in seven boreal forest types, dominated by *Picea mariana, Pinus banksiana, Populus tremuloides* and *Abies balsamea*, were analyzed. The initially established tree cohort in the stand appears to be the major determinant of compositional development. The short fire interval accounts for the preponderance of young communities and prevents deterioration of stands. Spruce budworm infestations are a possible factor in the perpetuation of *A. balsamea* forests.

Zoltai, S.C. 1975. Structure of subarctic forests on hummocky permafrost terrain in Northwestern Canada. Can. J. For. Res. 5:1-9.

Examination of 30 stands in sub-arctic woodlands showed that most were even-aged, having been established after fires. Most fires killed all trees in the stand, but in some instances some trees survived, indicating light fires. The rare occurrence of uneven-aged stands shows that fire is not necessary for the development of open spruce/lichen woodlands. Diameter growth is relatively rapid in the young, fire-originated stands, but slows down after about 100 years. Continuous heaving of the ground by frost action under the trees causes them to lean. In young fire-originated stands the trees generally grow upright, but most trees are leaning after the stands are > 100 years old.

2.3 Influence of fire on fauna: populations, habitat

Addison, R.B.,Williamson, J.C.; Saunders, B.P.; Fraser, D. 1980. Radio-tracking of moose in the boreal forest of northwestern Ontario. Can. Field-Nat. 94(3):269-276.

Movements of eight moose (*Alces alces*) equipped with radio-transmitter collars were followed by airplane flights at approximately weekly intervals between July 1972 and June 1973, in boreal forest of northwestern Ontario. Two adults and one yearling made migrations of 2-13 km linear distance between a mid- and late winter range, and a second range used at other times of the year. These animals occupied ranges of 2-12 square km in winter, and 6-90 square km in other seasons. Another adult used an area of 14 square km during the year, with adjacent winter and non-winter range. Two adults used acres of 10-14 square km, but winter tracking was incomplete. Two yearlings showed large movements, and one dispersed over a distance of 25 km. Most of the moose alternated between periods of wide-ranging movements and periods of localized movements. Most animals moved to conifer-dominated winter range in Dec. or Jan., near the time when snow-covered thickness increased rapidly to about 50 cm. (abstract).

Ahlgren, C.E. 1966. Small mammals and reforestation following prescribed burning. J. For. 64:614-618.

Changes in populations of small mammals were investigated on four jack pine (*Pinus banksiana*) tracts in northeastern Minnesota. One tract was left uncut, one was cut with slash evenly distributed, and two were cut and subjected to controlled burning. North American census trapping methods were used in July and October for three consecutive years. Populations of deer mice (*Peromyscus maniculatus*) were significantly higher on burned tracts than on unburned tracts the first and third post-fire years. This increase was related to the supply of seed released by burned jack pine and also other seed exposed in the upper layers of soil, as well as to cover conditions. Since burning created habitat and food conditions favorable to the increase of seed-eating mouse species they must be taken into consideration in regenerating burns.

Ahti, T.; Hepburn, R.L. 1967. Preliminary studies on woodland caribou range, especially lichen stands, in Ontario. Ont. Dept. Lands For., Res. Br., Toronto, Ont. Res. Rep. (Wild.) No. 74. 134 p.

In 1958 an extensive survey of northern Ontario was made with the purpose of describing and classifying the vegetation, and particularly the lichen resources, of this area as habitat for woodland caribou (*Rangifer tarandus caribou*). Survey methods consisted of random and systematic observations along 4800 miles of aerial transects, and intensive examination of 74 ground plots and 72 examples of arboreal lichen stands. Distribution and ecology of 38 of the most abundant macrolichens are discussed. The ecology and composition of typical lichen stands throughout the study area are outlined in relation to sub-strata, to their use as food for caribou, and to the distribution of vascular plants. On the basis of broad land types and availability of lichens, seven major divisions of the caribou range are proposed, and estimates are given for carrying capacity in each. It appears that present food supplies could support about six times as many caribou as now occupy the range, particularly north of 53° N latitude. Controlled burning is suggested as the best method of range management. Keys to 138 macrolichens of northern Ontario are included in this report.

Alexander, M.E.; Euler, D.L. 1981. Ecological role of fire in the uncut boreal mixedwood forest. p. 42-64 *in* Whitney, R.M.; McClain, K.M. (Cochairmen). Proc. Boreal Mixedwood Symposium (Sept. 16-18, 1980, Thunder Bay, Ont.). Dept. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. 0-P-9. 278 p.

Forest fires play a multiple role in the ecology of Ontario's boreal mixedwood forest: this forest is a fire-dependent ecosystem that would lose its character, vigor, and faunal and floral diversity in the absence of fire. The role of fire in land use of random and planned ignition prescribed fires, must be considered more fully. Fire ecology research needs and opportunities are suggested.

Armstrong, E. 1980. Forest Successional changes in the Chabbie Lake Burn Moose Brows Study Area, 1975-1979. Ont. Min. Nat. Resour., Cochrane District, Cochrane, Ont. Unpubl. Rep. 23 p.

In August and September 1975, about 320 ha of forest burned near Chabbie Lake (49°35'N, 79°46'W). The fire completely burned about 40 ha of a ridge, followed by a partial surface fire that burned unevenly, leaving burned and unburned patches. Chabbie Lake is in an area of low moose (*Alces alces*) density with low potential to support moose. The study area was established to monitor the progression of forest succession and changes in moose browse. The author established a sample line running through the burned ridge (complete burn), the partial burn, and an unburned (control) forest to compare the effect of the different levels of burning on moose browse. Willow was the only species present in the partial burn and the complete burn. Pin cherry, mountain ash, and white birch were found in the unburned, control area. Moose and snowshoe hare browse was highest in the complete burn. Even though the willow reproduction was relatively low on the burned areas, it provided added moose browse. Regeneration after fire, that advances toward willow, creates favourable conditions for moose.

Comments: see Stewart (1976) later in this section.

Bergstedt, B.; Niemi, G.J. 1974. A comparison of two breeding bird censuses following the Little Sioux Forest Fire. Loon 46:28-33.

Two breeding bird population studies were conducted in the 1971 Little Sioux burn of the Boundary Waters Canoe Area. Comparative results of the two study plots indicates no drastic change in population levels two years after the fire. Based on the research conducted in unburned communities previously cited, however, it is plausible to assume the population is not as high as it would be if the fire had never occurred. The species content of both plots was drastically changed from what would be expected in a normal aspen or jack pine stand. Once again these changes would be expected and attributed to the fires destruction of the predominant vegetation. The species changes would be considered temporary and indicative of the bird composition in a brush or seedling stage of plant succession. Weighing the pros and cons of forest fire as a means of revitalizing a mature, sterile forest is not the scope of this article; however, a minor discussion is necessary. It seems workable to assume fire as an agent to regenerate a forest ecosystem from an ornithological viewpoint as long as the fire does not occur during the breeding season. This general conclusion is very inconclusive because a great amount of data must be accumulated in relation to broader censusing programs of burned communities, more detailed vegetation analysis, and the alternative of harvesting the lumber by either clear cutting or selective logging. Needless to say, more research is badly needed on avian populations before and after forest fires. Equally so, more quantitative and qualitative research is needed throughout Minnesota. There is much data on types of birds nesting in Minnesota, migrating through Minnesota, and wintering in Minnesota; but, there is absolutely minimal data as to how many birds are nesting and in what types of habitats they are nesting. Why do we need more data on population levels? This can be answered in a large number of ways. What kind of habitats house the most species in diversity and numbers? What are some limiting factors affecting avian populations and individual species? What constitutes a good breeding season? These are some of the questions which remain unanswered. We the authors would like to find the answers to some of these questions. Possibly through individual motivation or local group sponsorship more breeding bird census plots could be established. [summary]

Buech, R.R.; Siderits, K.; Radtke, R.E.; Sheldon, H.L.; Elsing, D. 1977. Small mammal populations after a wildfire in northeastern Minnesota. USDA For. Serv., North Cent. For. Exp. Stn., St. Paul, Minn. Res. Pap. NC-151. 8 p.

Small mammals were studied shortly after a large wildfire in northeast Minnesota. An average of only 16% as many small mammals were in three forest communities that had burned than were in comparable unburned areas. The greatest reduction was for the red-backed vole. An analysis of population attributes suggests that deer mice immigrated to the burned area. Small mammal succession and their impact on reforestation is predicted.

Crête, M.; Drolet, B.; Huot, J.; Fortin, M.J.; Doucet, G.J. 1995. Chronoséquence après feu de la diversité de mammifères et d'oiseaux au nord de la forêt boréale québécoise. Can. J. For. Res. 25:1509-1518.

Diversity of passerine birds and mammals was estimated in well-drained areas located near the hydroelectric reservoir La Grande-3, where natural fire regime still prevails in the absence of forest exploitation. Forest stands were divided up into four post-fire stages: (*i*) recent burns (4 years old), (*ii*) shrubs (25 years old), (*iii*) young forests (50 years old), and (*iv*) mature forests ($\geq$ 71 years old). Richness and species diversity were highest in middle stages, in shrubs and young forests. The degree of opening seems to have affected more the composition of bird communities than stand age. Some bird species, typical of shrub stands, in particular white-crowned sparrow (*Zonotrichia leucophrys* Forster), Lincoln's sparrow (*Melospiza lincolnii* Audobon), and alder flycatcher (*Empidonax alnorum* Brewster), appeared after the falling of dead trees, $\approx$ 15 years after fire, and disappeared progressively as forests matured. Deer mice (*Peromyscus maniculatus* Wagner), moose (*Alces alces* L.), and black bears (*Ursus americanus* Pallas) were more common at the beginning of succession, whereas northern red-backed voles (*Clethrionomys gapperi* Vigors) and caribou (*Rangifer tarandus* L.) were typical of late stages. Mammal presence was mostly associated to their feeding requirements. Fire creates a mosaic of forest stands through periodic killing of trees in the north of the boreal forest, which contributes to maintain regional wildlife diversity; its suppression would reduce biodiversity.

Cringan, A.T. 1958. Influence of forest fires and fire protection on wildlife. For. Chron. 34:25-30.

In this paper I wish to review certain facets of the role of fire in the ecology of forest game, then go on to speculate about how forest fire protection may influence populations of forest wildlife. Before considering the effects of fire on game, it is necessary to remember that faunal succession exists, just as does plant succession. There is an optimum habitat for every species of animal, and this optimum is restricted to some particular stage of a certain plant succession. Three of Ontario's native species of grouse demonstrate this fact. The sharp-tailed grouse is found on abandoned farmlands, recent burns and cut-overs and open muskegs in western Ontario. It decreases, then usually disappears, as the forest canopy closes. The ruffed grouse appears during the sapling stage, sharing the habitat with the sharptail, and may experience optimum conditions during the early polewood stage. Subsequently it declines, although remaining in small numbers even in the climax. The spruce grouse appears during the polewood stage, at about the time the sharptail disappears. Its optimum habitat is the sub-climax and climax (after Grange, 1949). Deer, moose and caribou also illustrate this principle. High populations of deer and moose require large areas of young forest, interspersed with older stands. They are mammals of early successional stages. The woodland caribou almost always requires large areas of sub-climax or climax forest, and may be considered a climax species. [introduction]

Comments: This article is based to a large extent on the following reference: Cringan, A.T. 1957. Possible effects of forest fire on big game in the Sioux Lookout Forest protection District. p. 1-10 *in* Ont. Dept. Lands For. Fish and Wildl. Manage. Rep. 36.

deVos, A. 1952. Ecology and management of fisher and marten in Ontario. Ont. Dept. Lands and For., Toronto, Ont. Tech. Bul. (Wild. Ser. No. 1). 90 p.

REASONS FOR THE STUDY: Fisher, *Martes pennanti* (Erxleben), and marten, *Martes americana* (Turton), are two animals which were once important in the fur-economy of Ontario. In recent years they have decreased to such a low population level, that their economic role has become insignificant. In an attempt to protect these species from further depletion, a closed season was declared on marten in 1948 and on fisher in 1949. A study of the biology and problems involved in their management has been carried out in order to prepare a basis for a sound management program which would repopulate large areas of northern Ontario to such a level that they may be harvested.

SCOPE OF THE STUDY: The ecology of the fisher has been stressed more than that of the marten because the writer has relatively little to add to the recent studies of the latter species made by W. H. Marshall (1942) in North America, and of the closely related European and Asiatic forms by F. Schmidt (1943). As no monograph is available as yet on the biology of the fisher, a detailed account is given based on the findings of the author and available published material. Marten data for Ontario are included only when they extend those presented in other papers or when they are of value for comparison with information collected on the fisher.

SOURCES OF INFORMATION: Data concerning the two fur-bearers were collected by the following means:
(a) Field work in the Chapleau Forest District including studies of the animals and their environment.
(b) Museum and laboratory work consisting of the measurement and examination of carcasses and

pelts, and the study of food habits and parasites.

(c) Study of fur returns of the Department of Lands and Forests, the Dominion of Canada and the Hudson's Bay Company.

(d) Interviews with Department personnel and trappers.

(e) Review of the available literature.

TIME AND PLACE OF THE STUDY: The Study was conducted in Ontario from January 1948 to April 1952. During the winter of 1947-48, an exploratory trip was made through the Chapleau Game Preserve. During the years 1948, 1949,1950, and 1951 trips ranging in duration from one to three weeks were made to the Chapleau District in different seasons of the year. On these field trips attention was given to a study of the animals and their environment and to interviews with local residents.

Library work was done during the winter of 1949-50 in the library of the Royal Ontario Museum of Zoology in Toronto, and of 1950-51 in the library of the University of Wisconsin.

Laboratory work was carried out in the food research section of the Division of Mammalogy of the Royal Ontario Museum of Zoology, and also at the Ontario Research Foundation. (introduction)

Duchesne, L.C.; McAlpine, R.S. 1993. Using carabid beetles (Coleoptera: Carabidae) as a means to investigate the effect of forestry practices on soil diversity. For. Can, Chalk River, Ont. Tech. Rep. 16.

Carabid beetles were collected through pitfall trapping from undisturbed stands of jack pine (*Pinus banksiana* Lamb.) and compared with carabid beetles from clear-cut sites and sites that had been clear-cut and burned-over. A total of 28 species of carabids was collected in this experiment. Species diversity was highest in burned-over sites and lowest in clear-cut sites. Carabid assemblages were found unique to each of the three treatments. Carabids were divided into four groups according to site preference: (1) burned-over sites, (2) clear-cut sites, (3) undisturbed sites, and (4) all three sites in similar proportions. Clear-cutting by itself and clear-cutting along with prescribed burning showed a trend toward increasing average carabid catches as compared to average carabid catches from undisturbed sites.

Euler, D.L.; Snider, B.; Timmermann, H.R. 1976. Woodland caribou and plant communities on the Slate Islands, Lake Superior. Can. Field-Nat. 90:17-21.

During 3-14 June 1974 we investigated the winter distribution of woodland caribou (*Rangifer tarandus caribou*, Gemlin) on the Slate Islands. These caribou have two choices of habitat on the islands, either mature conifer forest with virtually no hardwoods present, or a mixedwood forest in relative early stages of succession. At least one large fire occurred in the early 20th century on Patterson Island; consequently much of the largest island's forests date from this period. A major unresolved question of woodland caribou ecology concerns their dependence on climax forest. Cringan (1957) concluded that woodland caribou are dependent on mature forest because they need the lichens associated with this type. His studies on the Slate Islands showed that lichen utilization was very heavy and that more lichens were associated with mature forest than with other types. Conditions of the caribou and plant communities of the Slate Islands may shed some evidence on this problem. A massive disturbance (burning) to the island ecosystems occurred at about the same time that caribou colonized the islands. They have maintained a viable population for about 67 years in an area that was primarily in early stages of vegetative succession. It is clear that extensive forest disturbance and continuing caribou populations were not mutually exclusive in this example. The first measurement of forest cover by Cringan (1956) indicated less than 15% of the islands' area was at or near the climax phase of succession. This measurement was some 40-45 years after caribou became established. In order for a population of at least 30-40 animals to exist at that time the habitat must have been reasonably adequate for the animals. Most of the islands' area is not climax forest at present, yet the caribou population appears to be relatively stable. These facts tend to support the hypothesis that woodland caribou, to survive, do not necessarily need a major portion of their range in climax forest. It is well known that woodland caribou are adapted to a diet of lichens...but it seems lichens may not be essential for their survival. Studies of caribou food habitats reveal that a wide variety of lichens, woody browse, and herbaceous plants are consumed... In this case, habitat management for woodland caribou may well consist of prescribed burning or logging to provide early successional plant communities over part of the range.

Euler, D.L. 1984. Forest fires: Nature's mandate for change. p. 11-19 *in* Stocks, B.J.; Elliott, R.G.; Walker, J.D. (Cochairmen). Proc. Forest Fire Management Symp. (Sept. 15-18, Sault Ste. Marie, Ont.). COJFRC Symp. Proc. O-P-13. 125 p.

Fire is portrayed as both a natural and an inescapable fact of life in North American forests and the adaptability of the forest environment to periodic fire is discussed. The effect of fire on wildlife habitat and patterns, and role of fire in regulating biotic productivity and maintaining ecosystem diversity and stability, are outlined in detail.

Fox, J.R. 1978. Forest fires and the snowshoe hare - Canada lynx cycle. Oecologia 31:349-374.

This paper shows on the basis of historical fire and lynx trapping records for Canada, including Ontario, and the Lake States that there is a reasonable coincidence between the Canada lynx cycle and wildfires. Fires set in motion plant succession, potentially leading to an increase in snowshoe hare areas. On the evidence presented, the author concludes that the snowshoe hare-Canada lynx cycle seems likely to be a forced oscillation rather than a predator-prey, parasite-host, or herbivore vegetation limited cycle.

Fritz, R.; Suffling, R.; Younger, T.A. 1993. Influence of fur trade, famine, and forest fires on moose and woodland caribou populations in Northwestern Ontario from 1786 to 1911. Environ. Manage. 17:477-489.

Hudson's Bay Company records were used to estimate the 1786-1911 annual number of moose (*Alces alces andersonii*) and caribou (*Rangifer tarandus caribou*) involved in trade by northern Ojibwa natives to the company post at Osnaburgh House (51°10'N, 90°15'W) in northwest Ontario, Canada.

The human population for the early 19th century, and the number and severity of human starvations from 1786 to 1911 were estimated. The extent of forest fires in the region around Osnaburgh was documented using a `fire-day' index computed from Hudson's Bay Company journals and using qualitative archival information. It is argued that the human population was too small to have caused the observed early 19th century moose and caribou population decline solely through predation. Likewise, severe early 19th century famines were caused by climatic factors rather than by declines in moose and caribou numbers. Habitat change caused by increased forest fires correlates with the observed decline of caribou, while moose increased and subsequently collapsed as winter shelter was destroyed. A burgeoning human population, sustained during winter food shortages on potatoes donated by the Hudson's Bay Company, then kept ungulate populations to low levels until the late 19th century. Only then did maturing forests and a new outbreak of fires provide renewed habitat for resurgences of, respectively, caribou and moose.

Hansen, H.L.; Krefting, L.W.; Kurmis, V. 1973. The forest of Isle Royale in relation to fire history and wildlife. Minn. Agric. Exp. Stn. Tech. Bull. No. 294. 43 p.

The present study had several objectives. The broad objective was to explore the unique advantages of a large wilderness island as a field laboratory for advancing the knowledge of forest ecosystems. Special reference was placed on forest succession, fire history, browse production, and the role of primary production as the homeostatic control of moose populations. Within this framework were several more specific goals: (1) to identify and describe major forest types according to tree, regeneration shrub, and herbaceous components and, (2) to associate primary and secondary successional trends in forest types with their consequences to populations of several wildlife species, especially moose. Two major lines of successional development on Isle Royale have been identified leading to the sugar maple-yellow birch and the paper birch-balsam fir-white spruce climax associations. Of these, the paper birch-balsam fir-white spruce climax, together with its preclimax successional stages, covers most of the island. They are of great significance as wildlife habitat, particularly for moose. Fire, the spruce budworm, and wind have initiated secondary successions that have greatly affected the nature and development of the vegetation and consequently its quality as animal habitat.

Holliday, N.J. 1984. Carabid beetles (Coleoptera: Carabidae) from a burned spruce forest (*Picea* spp.). Can. Ent. 116:919-922.

An intense forest fire destroyed a spruce (*Picea* spp.) stand in Agassiz Provincial Forest, Manitoba in May 1981. From 1 week following the fire, throughout the summer of 1981 and of 1982, carabid beetles were collected by pitfall trapping and standardized searches at weekly intervals. In all, 241 beetles of 24 species were collected. *Agonum obsoletum* Say and *A. quadripunctatum* De Geer were found; both species are known to be attracted to fires. *A. quadripunctatum* reproduced in the site in 1981 but there is no evidence that it did so in 1982. *A. obsoletum* was found in the study site only during the first 3 weeks after the fire. Evidence is presented to show that *Harpalus laticeps* LeConte is a characteristic species of forests after fire.

Holliday, N.J. 1991. Species responses of carabid beetles (Coleoptera: Carabidae) during post-fire regeneration of boreal forest. Can. Ent. 123:1369-1389.

Beginning 1 year after an intense forest fire in the Interlake region of Manitoba, carabid beetles were sampled by pitfall trapping in two burned sites and two unburned control sites. Before the fire, one burned site had been dominated by aspen, *Populus tremuloides* Michx., and the other by conifers (mostly *Picea* spp.). During the 11-year study, burned sites became dominated by aspen saplings. Three carabid species were caught significantly more frequently in burned sites than in control sites. Two of these, *Harpalus laticeps* LeConte and *H. egregius* Casey, invaded soon after the fire and were caught in the burned sites for several years after the fire. Seventeen species were caught significantly less often in burned than in control sites; catches of another 13 common species were not significantly affected by burning of the site. Burning influenced the seasonal patterns of catches of *Carabus taedatus* F. and *Pterostichus adstrictus* Eschscholtz; this was attributed to higher litter and soil temperatures in burned sites. Seasonal patterns of other common species were not markedly affected by burning. In burned sites, the incidence of brachyptery was independent of time, but the percentage of brachypterous species was significantly higher in the conifer than in the aspen site. Trends of brachyptery and size are those expected if early colonizers are super-tramp r-strategists and later invaders are K-strategists. Patterns of species occurrence during forest regeneration can be explained in terms of dispersal and competitive abilities, preference for physical attributes of the habitat, and responses to prey availability.

Holliday, N.J. 1992. The carabid fauna (Coleoptera: Carabidae) during postfire regeneration of boreal forest: properties and dynamics of species assemblages. Can. J. Zool. 70:440-452.

Following an intense forest fire, carabid beetles were sampled by pitfall trapping in a burned site that had been dominated before the fire by aspen, *Populus tremuloides*, in a second burned site that had been dominated by conifers (*Picea* spp.), and in matching unburned sites. In principal-components ordination, carabid species assemblages in burned sites were initially distinct, but at the end of the study were similar to those in the unburned aspen site. The assemblage in the burned aspen site approached its final position more rapidly than that in the burned conifer site. There were fewer individuals and fewer species in burned sites, but the logarithmic series $\propto$ and the evenness were unaffected by burning. Species gain and loss were used as indices of colonization and extinction rate, respectively. Species loss did not differ significantly between burned and unburned sites. In unburned sites, species gain was related to previous numbers of species caught in the way expected if gain was limited by the pool of potential colonist species. In burned sites, species gain was initially similar to that in unburned sites, but later gain was less than expected. Low species gain, coupled with ongoing species loss, was responsible for the small number of species caught in burned sites. It is suggested that domination of the burned sites by aspen saplings limited the establishment of arriving colonist species and so depressed species gain in the later stages of the study.

Irwin, L.L. 1975. Deer-moose relationships on a burn in northeastern Minnesota. J. Wildl. Manage. 39:653-662.

A study of habitat selection and distributions of white-tailed deer (*Odocoileus virginianus*) and moose (*Alces alces*) was conducted from July 1972 through December 1973 on a 5,920-ha burn that occurred in spring 1971 in northeastern Minnesota. Most use of coniferous stands within the burn by both moose and deer occurred in late fall and early spring, but they selected deciduous stands above all others ($P < 0.05$), especially in summer and fall. Moose and deer utilized aquatic communities from late May through June. Both species selected postburn communities that produced large amounts of preferred forage. Sites logged prior to the fire and openings along roads were attractive to deer. Association coefficients confirmed moose and deer utilized similar communities in summer and fall, but by December they occurred in similar communities by chance. Aerial and ground observations of animal groups indicated that moose and deer used the burn during summer and the periphery and unburned forest during winter. Coefficients of dietary overlap indicated relatively high overlap occurred during fall, when deer used browse plants more often. This study suggests the large burns, which produce large quantities of woody forage in boreal forests, allow moose populations to increase despite the presence of deer and the pathogenic nematode parasite *Parelaphostrongylus tenuis*.

Irwin, L.L. 1985. Foods of moose, *Alces alces*, and white-tailed deer, *Odocoileus virginianus*, on a burn in boreal forest. Can. Field-Nat. 99:240-245.

Foods habits were described for moose (*Alces alces*) and white-tailed deer (*Odocoileus virginianus*) two years after a wildfire in boreal forest in northeastern Minnesota. Terrestrial diets of moose were dominated by leaves and twigs of woody species, primarily willow (*Salix* spp.) and quaking aspen (*Populus tremuloides*). Deer used a broader variety of foods, but succulent terrestrial species preferred by deer were found in areas that had been logged prior to the fire. Moose appear better able to capitalize upon young forest stages following wildfires because woody plants are abundant and preferred by moose. Large herbivores may assume a more selective foraging strategy in the presence of high forage supplies, probably resulting in a higher quality diet.

Janke, R.A. 1979. Moose-forest-fire ecology in Isle Royale National Park. p. 1243-1251 *in* Proc. First Conf. Sci. Res. Natl. Parks (Nov. 9-12, 1976, New Orleans, La.), Vol.II. USDI Natl. Park Serv., Washington, D.C., Transactions and Proc. Ser. No. 5.

This study reported in this paper is one phase of a long-term research project on the ecology of the upland boreal forest type on Isle Royale National Park. Since fire and moose appear to be the two most important environmental influences affecting Isle Royale forests, the emphasis is on the relationships between moose, fire, and the forest ecosystem. As a result of moose browsing on Isle Royale for approximately the past 65 years, the upland boreal type forest has been dramatically altered. The density of trees has greatly declined, but the average tree diameter has increased. The density reduction is mostly attributable to the reduction in fir density caused by browsing on this species. This reduction has mostly affected the younger age classes of fir since the older trees were beyond reach of moose the time the latter arrived on Isle Royale. To a smaller extent the reduction in total tree density may be attributed to the near elimination of mountain ash trees by browsing. The increase in average tree diameter may be, in part, the direct effect of elimination of trees of smaller diameter. It may also be, in part, a result of increased growth rate due to thinning of the tree layer. The reduction in overall tree density and the increase in average tree diameter, together with a reduction in average shrub height in moose-browsed stands, have created forests which are more even-aged, open, and park-like as compared to pre-moose forests. This, in turn, may have reduced the susceptibility of the forest to crown fires, especially since there are fewer low conifers to bridge the gap between the ground, where most fires start, and the tree canopy. It is not obvious why low ground cover plants are more abundant in the browsed stands. This could possibly be due to increased light on the ground because of removal of lower branches of balsam fir and reduction of the shrub canopy. White birch, though a browse species, was relatively unaffected by moose browsing in the study areas. The succession studies indicated that this is the major pioneer species in the boreal forests of Isle Royale, and that in time it tends to be replaced by spruce and fir. By the time moose arrived, therefore, much of the birch may have been out of reach of moose in the study areas. This would be true for most of Isle Royale upland boreal type forests except for the areas burned in 1936. In the latter, moose have fed heavily on young birch and aspen for several decades after the fire. Despite this, birch survives today in the 1936 burn area as the major dominant in stands of relatively high density. A major trend in post-fire succession is the gradual replacement of broad-leaf deciduous tree species by conifers. Moose have modified the coniferous element by increasing the importance of white spruce at the expense of balsam fir. Other post-fire trends are an increase in the soil litter depth and an increased amount of wood covering the forest floor. The latter is undoubtedly due to an increase in the incidence of windthrow as the trees become larger and older. All of these trends tend to increase the inflammability of the forest as post-fire succession proceeds. At the time of this conference, only a part of the data collected in the field has been processed. We shall continue our search for post-fire successional trends among the 230 plots. Then, using data from these same plots, we will explore relationships between tree seedling establishment and the important environmental factors associated with post-fire succession. [discussion]

Keith, L.B.; Surrendi, D.C. 1972. Effects of fire on a snowshoe hare population. J. Wildl. Manage. 35:16-26.

This paper examines the demographic effects of a spring fire on a snowshoe hare (*Lepus americanus*) population in central Alberta. A major change in distribution of hares on the study area resulted from abandonment of severely burned sites. Reoccupation of the severe burn took place during the second summer following fire, as brushy cover redeveloped through sprouting. There was no evidence of fire-induced mortality. Sex ratios of both adult and juvenile cohorts were unaffected, but the proportion of juveniles on the study area was reduced markedly. Pregnancy rates were also lowered after the fire. The investigators believe that egress of young hares was principally responsible for the aberrant summer age ratios, and that such movements were probably a response to intensified social interaction resulting from the postfire concentration of population in remaining habitat.

Klein, D.R. 1982. Fire, lichens and caribou. J. Range. Manage. 35:390-395.

Continental populations of caribou (*Rangifer tarandus*) usually winter in the northern taiga. "Taiga" refers to the northern coniferous forests of Eurasia and North America and is synonymous in North America with the term "boreal forest". Fire is a natural feature of the ecology of the taiga but its effect on the winter range of caribou has been the subject of conflicting reports in the literature. Lichens, which are an important component of the diet of caribou in winter, are associated with late successional stages in the post fire sequence; therefore their loss when old growth forests burn has been considered detrimental to caribou. On the other hand, several authors have suggested that lichens are not essential for caribou in winter and therefore their loss through forest fires does not seriously affect caribou. Recent nutritional investigations with reindeer and caribou have demonstrated the importance of lichens in their winter diet. Botanical studies have shown that fires are essential for the long-term productivity of the boreal forest and they account for much of the habitat diversity that characterizes caribou winter range. Extremely old forest stands show reduced lichen productivity. I conclude that, when viewed on a short-term basis of 50 years or less, fire may destroy lichens and other forage, thus reducing the taiga's potential to support caribou. Over long-time periods, often of a century or more, fire appears essential for maintaining ecological diversity and forage production for caribou. [additional information added]

Krefting, L.W. 1974. Moose distribution and habitat selection in North Central North America. Nat. Can. (Que.) 101:81-100.

The moose (*Alces alces andersonii*) is mostly confined to the boreal forest where important habitats are produced in the early seral stages of plant succession. As forest succession advances, the quality of the habitats and populations decrease accordingly because at maturity the boreal forest shades out the understory browse, and the overstory trees grow beyond the reach of moose. Wildfire is the most important factor that has influenced moose distribution and habitat selection for at least several hundred years; historic fires that covered thousands of square kilometres created seral shrub stages needed by moose. Timber cutting is presently the most important factor improving moose habitat by creating vegetation in the seral stage. The spruce budworm (*Choristoneura fumiferana*) destroys the overhead canopy of balsam fir (*Abies balsamea*) and white spruce (*Picea glauca*), and removal of the overstory benefits moose by increasing the browse supply although budworms sometimes kill young balsams, an important source of winter browse. Therefore, moose habitats within the boreal forest are unstable, and natural population fluctuations occur. Natural fire apparently occurred enough in many parts of the boreal forest to prevent the forest from reaching maturity, but fire protection during the past half-century has reduced the amount of good moose habitat. Summer and winter home ranges for moose require different kinds of habitats. In winter, movements and habitat selection are influenced by the depth and quality of snow. As the winter advances, moose gradually move from the more open stands to denser cover; usually snow depths of 36 inches (90 cm) or more result in greater use of spruce-fir stands in late winter.

Krefting, L.W.; Ahlgren, C.E. 1974. Small mammals and vegetation changes after fire in a mixed conifer-hardwood forest. Ecology 55:1391-1398.

Following wild fire in northeastern Minnesota, small mammals were snap-trapped on two burned and one unburned area for three nights each fall from 1955 to 1967. The deer mouse (*Peromyscus maniculatus*) was the most abundant species on the two burns the first 7 years. Later the vegetation changes produced a habitat less attractive to the deer mouse, while the red-backed vole (*Clethrionomys gapperi*) increased. Numbers of meadow voles (*Microtus pennsylvanicus*), jumping mice (*Zapus hudsonius*), and cinereus shrews (*Sorex cinereus*) were low and erratic on all areas. Eastern chipmunks (*Tamias striatus*) were abundant most years on only one of the burns.

McCullough, D.G.; Kulman, H.M. 1991. Differences in foliage quality of young jack pine (*Pinus banksiana* Lamb.) on burned and clearcut sites: effects of jack pine budworm (*Choristoneura pinus pinus* Freeman). Oecologia 87:135-145.

The suitability of young jack pine (*P. banksiana*) as a host for jack pine budworm (*C. pinus pinus*) was examined on similarly-aged trees (7-11 years old) growing on two sites previously burned in wildfires and on two previously clear felled sites in northwestern Wisconsin in 1988. Nitrogen, monoterpene and moisture contents of foliage, and xylem water potential, were measured and related to larval survival and pupal weight of caged jack pine budworm larvae. Nitrogen, monoterpene, and needle moisture contents, and needle weight, were greater in trees growing on clear felled sites than on burned area trees. Survival of budworms to early and late instar, pupation, and adult eclosion was greater for larvae caged on clear felled-area trees than on burned-area trees. Female pupal weight differed between older (about 10 years old) and younger (about 8 years old) trees, but not between clear felled and burned areas. Mean female pupal weight was greatest on low-N trees, where larval survival was lowest. Foliar N was consistently included as a significant predictor in budworm survival regressions. Regressions indicated that larval survival and pupal weight may be associated with different tree- and foliage-related traits. The results suggest that long-lasting effects of previous forest disturbance may subsequently affect herbivorous insects such as jack pine budworm.

Naylor, B.J.; Bendell, J.F.; Spires, S. 1985. High density of heather voles, *Phenacomys intermedius*, in jack pine, *Pinus banksiana*, forest in Ontario. Canadian Field-Naturalist 99(4):494-497.

One-hundred and forty-six Heather Voles (*Phenacomys intermedius*) were collected in eight jack pine (*Pinus banksiana*) forests in northeastern Ontario in 5398 snap trap nights and 12 579 pitfall nights. Parallel lines of snap traps were the most efficient trapping method. Pitfalls captured a significantly greater proportion of young voles. Low densities and high proportions of juveniles suggested that disturbed and mixed forests acted as dispersal sinks. Monocultures exhibited higher densities of Heather Voles than previously reported. These forests may provide optimum habitat because they concentrate resources preferred by Heather Voles. Dense, relatively continuous understories of Ericaceous shrubs may provide food, protection from predators and conspecifics, or favourable microclimates.

Niemi, G.J. 1978. Breeding birds of burned and unburned areas in northern Minnesota. Loon 50:73-84.

The Little Sioux fire area and an unburned strip of forest surrounding the burn were visited 31 days during the June breeding season of 1973, 1974, and 1975. This corresponded to two, three, and four years following the May 1971 forest fire. All species encountered while I conducted a variety of activities in the burn and unburned area were classified into one of five commonness groups. This classification was based on the frequency and number of individuals of species registered on a daily basis. Since the Little Sioux area has undergone rapid vegetational changes, the commonness classification was divided into the years of coverage for this area. A total of 107 species were identified in the unburned area and 91 species in the burn area. There were 54 species decreases, 17 species increases and 42 species showing no apparent change in commonness following forest fire. Greatest bird species group reductions following fire were shown in waterbirds, flycatchers-swallows, and vireos and warblers. Woodpeckers were the only group that increased. Reasons for the apparent increases or decreases are discussed in terms of changes in habitat structure, conspicuousness of birds, or other species specific factors. Many species such as the Red-tailed Hawk, American Kestrel, Red-headed Woodpecker, House Wren, and Indigo Bunting would not occur in the Boundary Waters Canoe Area without forest disturbance such as forest fire. However, many pre-fire occupants do not occur or were reduced in the forest fire due to loss of proper habitat such as the Broadwinged Hawk, Yellow-bellied Sapsucker, Black-capped Chickadee, Red-eyed Vireo, most warblers, and Rose-breasted Grosbeak. General conclusions of the study indicate that: 1) birds especially the smaller passerines decrease following forest fire due to a reduction in habitat complexity which provided suitable niches, 2) there is a bias in censusing birds in open areas like burns due to the increased conspicuousness, 3) the changes following forest fire are temporary changes which are a part of the natural vegetation-wildlife cycle, 4) most changes in bird species commonness following forest fire result in an increase of species typically found south of the SNF and native breeding species are reduced in commonness, and 5) some species like the Least Flycatcher may show a strong affinity to territories occupied prior to alteration and extreme vegetational change such as those created by fire may not displace the species territory. [summary]

Ohmann, L.F.; Cushwa, C.T.; Lake, R.E.; Beer, J.R.; Brander, R.B. 1973. Wilderness ecology: the upland plant communities, woody browse production, and small mammals of two adjacent 33-year-old wildfire areas in northeastern Minnesota. USDA For. Serv., North Cent. For. Exp. Stn., St. Paul, Minn. Gen. Tech. Rep. NC-7. 30 p.

Woody browse production was measured and small mammals were snap-trapped in four upland community types (aspen, aspen-birch, jack pine-birch, jack pine) on two adjacent 33-year-old wildfire areas. These community types were identified through cluster and canonical analysis of species frequency of occurrence data from 33 sample stands located randomly over the two areas. Present vegetation differences appear to relate better to the type and condition of vegetation present before the fire than to measured environmental parameter differences found between the types. No difference in twig numbers were found between the burns for ten species studied. Only three of the ten browse species present in more than one community type showed differences in twig numbers among the types. Yields of the species groups, total shrub browse, and total seedling browse, differed among the types while total browse did not. Lack of a difference in total browse production is attributed to various species reaching peak yield in different community types, thus offsetting each other and maintaining an overall relatively stable level of production. Small mammals were snap-trapped for 5,326 trap-station days during summer 1969. Of 142 individuals captured, 103 were either *Peromyscus maniculatus gracilis* or *Clethrionomys gapperi*. Reproductive histories for these two species are discussed. An attempt was made to relate distributions of small mammals to vegetative community types. The sketchy evidence suggests a uniform distribution with no strong linkages to any of the four types. The latter are described in a companion paper. [abstract altered]

Peek, J.M. 1972. Adaptations to the burn: moose & deer studies. Naturalist 23:8-14.

Many species of wildlife are adapted to an environment subject to frequent burning. Large ungulates, wherever they occur, are frequently *major influents* upon the landscape. They are capable of altering vegetation pattern, usually through their foraging activities. Initial surveillance of the Little Sioux burn in northeastern Minnesota began in November 1971, one growing season after the fire. The objectives were: (1) to obtain data on moose and deer distributions; (2) to conduct a moose census; (3) to determine group sizes, and (4) to estimate the percentages of calves, yearlings, cows and bulls in the moose population. The census was completed in December 1971 and moose population was estimated at one moose per two square miles. This estimate is considerably lower than the 2-5 per square mile on high density moose range further east. However, the percentage of yearlings appears quite high on the burn (34%) when compared to the percentage (13%) further east. This implies that the fire had created shifts in distribution within the yearling segment of the moose population in the general area of the burn. Both white-tails and moose were feeding on vegetation on the burn within the month after the fire, and were using most of the area. Closer examination the second summer following the fire showed that each species preferred different feeding sites. There was very little potential competition for forage among the two species because of the browsing level differences. Forage preferences may be expected to change for both species as the vegetation matures, and competition may well eventually be observed. [abstract adapted from body of report]

Peek, J.M. 1974. Initial response of moose to forest fire in northeastern Minnesota. Am. Midl. Nat. 91:435-438.

Density of moose (*Alces alces*) in northeastern Minnesota increased from less than 0.5 per sq mile prior to a large fire to over 2 per sq mile two growing seasons following the fire. The increase was related to immigration, especially of yearlings, rather than to increased production and survival of calves.

Peterson, R.L. 1953. Studies of the food habits and the habitat of moose in Ontario. Royal Ont. Mus. Zool. Palaeontol., Toronto, Ont. Contrib. No. 36. 49 p.

In 1936 a small area was burned on the southwest portions of both St. Ignace and Simpson Islands, Ontario. A total of 55 browse plots were analyzed in these two areas (in 1947 and 1948). White birch is the outstanding species from the standpoint of both the amount available and amount eaten. Following in the order of amounts available were balsam fir, white spruce, willow, quaking aspen, red-berried elder, mountain ash and cherry. These two small burned areas were providing a significant proportion of the entire islands' available white birch, willow and quaking aspen. Utilization of these two burned areas seems to reach maxima in late fall and early spring. Since balsam fir is eaten only during the winter months, this undoubtedly affects the low amount indicated in the winter diet for these areas. There is little protective cover in these areas but they are sufficiently small that moose effectively utilized them by ranging out from nearby cover. There are in Ontario some extensive burned areas into which moose rarely venture. Preliminary investigations suggest that large burned-over tracts do not normally become heavily populated by moose until a balanced winter and summer habitat becomes available. Key factors under such circumstances seem to be (1) sufficient variety of foods for all seasons including, (2) aquatic vegetation in summer and (3) balsam fir in winter.

Comments: The above discussion also appears in: Peterson, R.L. 1955. North American moose. Univ. Toronto Press., Toronto, Ont. 280 p.

Probst, J.R.; Weinrich, J. 1993. Relating Kirtland's warbler population to changing landscape composition and structure. Lands. Ecol. 8:257-271.

The population of male Kirtland's warbler (*Dendroica kirtlandii*) in the breeding season has averaged 206 from 1971 to 1987. The Kirtland's warbler occupies dense jack pine (*Pinus banksiana*) barrens from 5 to 23 years old and from 1.4 to 5.0 m high, formerly of wildfire origin. In 1984, 73% of the males censused were found in habitat naturally regenerated from wildfire or prescribed burning. The rest were in plantations (11%) or in harvested, unburned jack pine stands stocked by natural regeneration (16%). Twenty-two percent (630 of 2,886) of the Kirtland's warbler males counted in the annual censuses from 1971 through 1984 were found in 26 stands that were unburned and naturally regenerated following harvest. From 1982 to 1987, suitable regenerating areas were barely sufficient to replace currently occupied maturing stands, so population growth was impeded. Ecosystems of suitable size and regeneration characteristics (wildfire and plantation) doubled in area by 1989. In response, the population of Kirtland's warblers increased from 167 to 398 males between 1987 and 1992, but they withdrew almost entirely from the unburned, unplanted barrens by 1989 when the area of more suitable regeneration types increased. Minimum (368 males) and maximum (542 males) population estimates for 1996 were calculated based on 1984 average density (1.9 males per 40 ha) and peak population in burns (2.8 males per 40 ha).

Raine, R.M. 1982. Ranges of juvenile Fisher, *Martes pennanti*, and Marten, *Martes americana*, in southeastern Manitoba. Canadian Field-Naturalist 96(4):431-438.

A radio-telemetry study of a resident population of Fisher and an invading population of Marten was conducted from August 1978 to August 1980, in the boreal forest of southeastern Manitoba. Two juvenile, female Fisher had winter ranges of 15.0 and 20.5 km^2, while other juvenile females and males dispersed from the study area after their release. One juvenile, male Marten had a range of 9.6 km^2 in early winter, while another wandered at random in late fall and early winter, but had a range of 8.1 km^2 by the following spring. A juvenile, female Marten had seasonal ranges varying from 6.0 to 8.4 km^2. A fire that swept through the study area in May 1980 perhaps caused one male Marten to disperse 61 km, while a female Marten did not alter her range during the two months that radio contact was maintained.

Richardson, R.J.; Holliday, N.J. 1982. Occurrence of carabid beetles (*Coleoptera*: *Carabidae*) in a boreal forest damaged by fire. Can. Ent. 114:509-514.

Fifteen months after an intense forest fire in Manitoba, the fauna of carabid beetles in burnt and unburnt sites was sampled using pitfall traps to detect the indirect effects of fire on carabids caused by habitat change. Traps were installed in burnt and unburnt sites in which the dominant tree species before the fire was either spruce (*Picea* spp.) or aspen (*Populus tremuloides*). The most commonly caught species was *Pterostichus pensylvanicus* which was captured more frequently in unburnt sites, but was not affected by dominant tree species; a similar pattern of distribution of captures was found for *Carabus taedatus*. *Harpalus laticeps* was captured only in burnt sites. *P. lucublandus* and *Dicaelus sculptilis upioides* were most commonly caught in the unburnt aspen site, while *Pterostichus adstrictus* was most commonly caught in the burnt spruce site.

Schaefer, J.A.; Pruitt, W.O., Jr. 1991. Fire and woodland caribou in Southeastern Manitoba Canada. Wildl. Monogr. 116:1-39.

The effects of fire on the Aikens Lake population of woodland caribou (*Rangifer tarandus caribou*) were studied over a 2-year period. Quantity, quality and accessibility of forages were determined in recently-burned (5-year-old) habitats and compared to those in intermediate (37 years) and old-growth (90-160 years) stands. These measures were correlated with patterns of habitat use by Aikens caribou over 2 winters. Forage productivity was determined by harvesting the current growth of vascular plants and standing crop of aboreal and terrestrial lichens. Quality of forage was inferred from the content of acid detergent fiber and published digestibility studies of *Rangifer*. Accessibility of forage was estimated from the Värriö Snow Index, including hardness and thickness of snow cover, and from the intersection frequency of windfallen trees. Principal components analysis revealed that original floristic distinctions between jack pine (*Pinus banksiana*) and mixed forest communities persisted after fire. Compared to old-growth stands (90 years), most burned upland habitats exhibited enhanced productivity of summer forages but a decline in quality and accessibility of winter forages. This deterioration of winter habitat for caribou resulted from the loss of lichens (*Cladina* spp.) in the predominant jack pine communities, the increase in both thickness and hardness of snow cover, and the accumulation of deadfalls. The oldest stands (160 years) showed the lowest forage productivity including lichens, but had the most favorable nival conditions. Caribou winter travel and feeding were significantly skewed towards use of lakes, old-growth uplands and bogs, and away from burned uplands. In both winters of study, Aikens caribou continued to exploit the remnant lichen supply in old-growth bogs and crown-burned habitats within the limits of the 5-year-old burn. In late winter, however, caribou shifted their activity entirely outside the recent burn in favour of stands ≥ 55 years old. The heightened accumulations of snow and deadfalls are implicated in this late-winter range abandonment. The winter range of the population, 5.5 years after fire, was mutually exclusive with its prefire range. Taiga in southeastern Manitoba is not suitable for woodland caribou in its recently-burned and intermediate stages (up to 50 years following fire). Yet fire may be necessary to maintain optimal, long-term lichen resources. Due to the remnant lichen supply in burned areas and the delay in the accumulation of windfallen trees, the short-term detriments of fire may not be fully realized until 5 years or more after burning. Woodland caribou adapt to these short-term effects by abandoning their range. Local fire history-in particular, proximity to alternative, lichen-rich stands-must be considered in the management of woodland caribou habitat.

Schindler, D.W.; Beaty, K.G.; Fee, E.J.; Cruikshank, D.R.; DeBruyn, E.R.; Findlay, D.L.; Linsey, G.A.; Shearer, J.A.; Stanton, M.P.; Turner, M.A. 1990. Effect of climatic warming on lakes of the central boreal forest. Science 250:967-970.

Twenty years of climatic, hydrologic, and ecologic records for the Experimental Lake Area of northwestern Ontario show that air and lake temperatures have increased by 2°C and the length of the ice free season has increased by 3 weeks. Higher than normal evaporation and lower than average precipitation have decreased rates of water renewal in lakes. Concentrations of most chemicals have increased in both lakes and streams because of decreased water renewal and forest fires in the catchments. In Lake 239, populations and diversity of phytoplankton also increased, but primary production showed no consistent trend. Increased wind velocities, increased transparency, increased exposure to wind of lakes in burned catchments caused thermoclines to deepen. As a result, summer habitats for cold stenothermic organisms like lake trout and opossum shrimp decreased. Our observations may provide a preview of the effects of increased greenhouse warming on boreal lakes.

Sims, H.P.; Buckner, C.H. 1973. The effect of clear cutting and burning of *Pinus banksiana* forests on the populations of small mammals in southeastern Manitoba. Am. Midl. Nat. 90:228-231.

Although the total population of small mammals was lower immediately after burning, the rapid reestablishment and large population (84% of total catch on burn areas) of *Peromyscus maniculatus bairdii* (Hoy and Kennicott) represent a hazard to direct seeding on jack pine sites in southeastern Manitoba.

Spires, S.; Bendell, J.F. 1983. Immediate effects of a forest fire on some invertebrates, small mammals and birds in north-central Ontario. p. 308-318 *in* Wein, R.W.; Riewe, R.R.; Methven, I.R. (eds.). Conf. Proc. Resources and dynamics of the boreal zone (August 1982, Thunder Bay, Ont.). Assoc. Can. Univers. North. Stud. 544 p.

Animals were trapped or observed in burned and adjacent unburned forest during the first five weeks following an 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 the deer mouse and white-throated sparrow were captured or observed in high numbers in both forest. 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.

Stenlund, M. 1971. Fire and wildlife. Naturalist 22(4):8-11.

This semi-technical article provides a few informal wildlife observations with respect to the 1971 Little Sioux Fire in northeastern Minnesota: "There are no confirmed reports of any direct wildlife losses. Ruffed grouse were heard drumming in unburned pockets of aspen within the "hot" burn area a week after the fire. Small mammal trap lines in the area three weeks after the fire showed red backed mice, chipmunks, and jumping mice were active even in the most severely burned parts. It is obvious that they merely found safety in the ground and rocks and reappeared after the fire had gone by."

Stewart, R. 1976. The establishment and description of the Chabbie Lake Burn moose browse study area (an interim report). Ont. Min. Nat. Res., Cochrane District, Cochrane, Ont. Unpl. Rep. 41 p.

During August and September 1975, approximately 800 acres of a mixed jack pine (*Pinus banksiana*) and black spruce (*Picea mariana*) forest stand located on a drumlinoid or esker ridge near Chabbie Lake (49° 35'N., 79° 46'W.) was destroyed by fire. In one portion of the burn a crown fire killed all above-ground vegetation. The rest of the area was only partially burned. Sections of this area were left unburned (31%) and in parts of the burned area some of the jack pine were only scorched. In mid September 1975 three grids, each of 20 permanent mille-acre vegetation sample plots, were laid out along the glacial ridge. The grids were located in a completely burned area, a partially burned area, and in an unburned section of the ridge. The latter grid served as a control. At each mille-acre plot location a permanent one-tenth acre moose pellet group plot was established to measure relative moose utilization rates. During mid October 1975 the extent and degree of the burn to the duff layer and vegetational cover on the sample plots were estimated. At each plot location general characteristics of the surrounding forest stand were noted as well. These data were used to establish the post-fire physical and vegetational characteristics of the completely burnt, partially burnt, and control sample areas. Structural diagrams representing the post-fire stands in each area were developed using Dansereau's universal system for recording vegetation. Sampling techniques are outlined for the 1976 spring assessment of browse regeneration and its over-winter use by moose. A modified Shafer twig-count technique will be used to assess browse yield and its degree of use by moose. Additional browse data will also be collected on the sample plots. Sampling will be conducted each spring until the effect of the burn on browse regeneration and the corresponding increase in over-winter use of the area by moose (if any) has been established.

Comments: see Armstrong (1980) earlier in this section.

2.4 Role of fire in forest management

Ahlgren, C.E. 1981. Seventeen-year changes in climatic elements following prescribed burning. For. Sci. 21:33-39.

Soil and air temperature, soil moisture, rainfall, and humidity were monitored after prescribed burning on a harvested, mature jack pine stand and on an adjacent, unburned and uncut forest in northeastern Minnesota. Greater temperature and humidity extremes and lower rainfall interception occurred on the burned area. Some differences between burned and unburned areas persisted for more than 17 postfire years. Early postfire herbaceous growth, later shrub development, and emergence of a sapling-sized jack pine and aspen forest all were associated with definite changes in postfire climatic conditions.

Aksamit, S.E.; Irking, F.D. 1983. Prescribed burning for lowland black spruce regeneration in northern Minnesota. Can. J. For. Res. 14:107-113.

Concern over the variability of black spruce (*Picea mariana* (Mill.) B.S.P.) regeneration on peatland in northern Minnesota following prescribed burning led to a cooperative study between the University of Minnesota and the Minnesota Department of Natural Resources. Twenty-seven black spruce cutovers on State lands that had been prescribed burned and either seeded or left to regenerate naturally were sampled. These were stratified into sphagnum--Labrador tea--leather-leaf (SPHG) sites (10), feather moss (FM) sites (9), and alder--graminoids--other tall shrubs (ALDR) sites (8). Results indicated that fire was not necessary to regenerate SPHG sites. FM sites required fire to modify unfavorable seedbeds and to reduce competition. Best results were obtained by burning when the upper layers of the peat were highly desiccated. ALDR sites occupied a wide range of ecological conditions which led to highly variable regeneration results. A larger sample size and possibly more carefully controlled study conditions are needed to fully understand ALDR site regeneration. Seedling results were uncertain for all sites.

Brown, G. 1983. Aerial seeding of wildfire areas in the Northeastern region. p. 93-101 *in* Smith, C.R.; Brown, G. (chairmen). Jack pine symposium (Oct. 18-20, 1983, Timmins, Ont.). Dept. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. 0-P-12. 195 p.

The development of a technique of seeding 23 wildfire areas is described and the available results are given. Some observations concerning wildfires are included.

Cayford, J.H.; McRae, D.J. 1983. The ecological role of fire in jack pine forests. p. 183-200 *in* Wein, R.W.; MacLean, D.A. (eds.). The role of fire in northern circumpolar ecosystems. John Wiley and Sons Ltd. Chichester, UK. 322 p.

Jack pine (*Pinus banksiana* Lamb.) is a species well adapted to fire in the boreal forest environment. Cone serotiny and an ability to survive harsh environmental conditions permits jack pine to regenerate successfully after fire. Indeed, without the periodic occurrence of fire the species would disappear from the boreal forest. Fire in the jack pine forest is a highly variable phenomenon; behaviour characteristics are dependent largely on the fuel characteristics of individual stands and on fire weather. Prescribed fire is being used successfully in the jack pine forest as an economical site-preparation tool for regenerating logged-over sites. It can aid in slash removal, seedbed preparation, hazard reduction, and competition reduction. Because of the vast complexity of the variables involved in the jack pine fire ecosystem, continued research in this field is warranted.

Chrosciewicz, Z. 1976. Burning for black spruce regeneration on a lowland cutover site in southeastern Manitoba. Can. J. For. Res. 6:179-186.

Two experimental burns were tested on a peaty, very moist, lowland site in southeastern Manitoba to improve seedbeds and black spruce (*Picea mariana*) regeneration after cutting. The operations were conducted under different degrees of desiccation in the upper peat materials so that light and moderate burns were obtained. Unmerchantable trees that were left standing at the time of cutting constituted the main seed source on each of the burns. After five growing seasons, black spruce stocking by 0.001-acre (4.047-m^2) quadrats was 94% on the moderate burn, 70% on the light burn, and 35% on the control. The numbers of seedlings associated with this stocking were 16 129, 3075, and 1898/acre (39 856, 7598, and 4690/ha), respectively. Various seedbed, regeneration, and plant-succession characteristics indicated beneficial effects of burning, and on this basis, future requirements for its postcut use on the black spruce lowlands are discussed.

Day, R.J.; Harvey, E.M. 1981. Forest dynamics in the boreal mixedwood. p. 29-41 *in* Whitney, R.M.; McClain, K.M. (Cochairmen). Proc. Boreal Mixedwood Symposium (Sept. 16-18, 1980, Thunder Bay, Ont.). Dept. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. 0-P-9. 278 p.

The mixedwood forest is defined as a successional mosaic of stratified mixed stands of disturbance (mainly wildfire) origin. With a fire rotation that rarely exceeds 75 ± 50 or at most 125 years, it is not possible for pioneer and successional stands to develop to the late-successional or climax forest stages. This is especially the case in boreal mixedwoods because the slower growing pioneers, black spruce and white spruce, are often suppressed initially by more vigorous pioneer species such as aspen, jack pine and white birch. As many of the pioneer species live 100-150 years or more, a boreal mixedwood forest usually develops into a stratified mixture with the following layers: Upper Layer-intolerant, fast growing, pioneer species (aspen, birch and jack pine); Middle Layer-moderately tolerant, suppressed, pioneer species (white spruce and black spruce); and the Lower Layer-tolerant, suppressed, successional species (balsam fir, hazel and mountain maple). As the upper layer becomes decadent, the middle layer is released, this process begins about 45 to 75 years after the initiating wildfire, and in time the middle layer assumes a dominant position over the lower layers. As both the spruces are long-lived and may dominate for 150 to 200 years on good sites, the lower layer usually does not assume dominance but remains an understory until the wildfire recycles the stand and initiates another patch in the mosaic. The exclusion of fire from the boreal mixedwood forests tends to minimize the pioneer phase and maximize the later successional phases.

Dupuis, M.M. 1994. Le feu: agent de contrôle des insectes. For. Chron. 70:468-472.

For millennia, fire and insects have played an important role in forested land evolution. Understanding the roles they play can be important in helping us not only to control them, but to use them as an ecological tool. As insects affect fire, fire may control insect pests. Controlled burning may provide excellent results, but allows a very slight margin for possible errors. Fire use as an insect management tool, requires a very precise and wide knowledge of weather conditions, fire intensity, insect's life cycle, available fuels, and type of ecosystem involved. Fire has been, and will always be, an important factor in equilibrium of some ecosystems. Since wild fire prevention campaigns and the emergence of insecticides, some forests have become excessively vulnerable to insect pests. Proper knowledge, and use of fire control, rather than immediate suppression of forest fires, would allow us to conserve various ecosystems in a healthy balance.

Euler, D.L. 1975. The economic impact of prescribed burning on moose hunting. J. Environ. Manage. 3:1-5.

The purpose of this paper is to provide a preliminary estimate of the benefits which accrue as a result of the favourable habitat created for moose (*Alces alces*) through prescribed burning. Three situations in eastern North America where moose have increased following fire are used to estimate the monetary benefits provided by the moose resource through hunting. The values range from $4.31 per acre per year for 32 years on Isle Royale to $0.11 per acre per year for 32 years in northwestern Ontario. These examples serve as guides to decision making only and the range of values should not be expected to apply everywhere.

Felton, G.C. 1965. Northern fire study of the Sioux Lookout District. Ont. Dept. Lands For., Sioux Lookout For. District, Sioux Lookout, Ont. Unpubl. Rep. 66 p.

The Sioux Lookout Forest Fire District is the largest and least accessible district in the province of Ontario. The fire district covers an area of over 75,000 square miles (48,000,000 acres), the major portion being remote, undeveloped timber land. The district is composed of the Ignace, Sioux Lookout, Red Lake and Pickle Lake Chief Ranger divisions. The two southern divisions, Sioux Lookout and Ignace, are well forested and because of the major industries operating in this area, give the district a sixth place ranking, on a province wide basis, for total volume of wood cut. In comparison, there are no large timber operations in the Red Lake division except in the southern portion and practically no operations at all in the Pickle Lake division. It is these two northern divisions with which this report is concerned. Since the two northern divisions are in general, accessible only by aircraft, have endless miles of continuous fuel, lie in a wide lightning belt, and are subjected to high winds, the occurrence of large fires is not uncommon. These large fires run into high suppression costs, especially if there is a prolonged campaign. In fact, well over half a million dollars was spent on actual fire suppression activities on fires in these two divisions during the 1961 fire season alone. A quick glance at the location of these northern fires makes one wonder if such effort and expense is actually worth the results obtained. The purpose of this report is to present information which will assist in the determination of the intensity of protection required in various portions of the district and the setting out of a firm policy regarding northern fires. [introduction]

Frissell, S.S. 1973. The importance of fire as a natural ecological factor in Itasca State Park, Minnesota. Quat. Res. 3:397-407.

During the period between 1650 and 1922 at least 32 fires occurred in Itasca State Park. Twenty-one of these fires were of major consequence. A fire occurred on the average of every 8.8 years with "major" fires every 10.3 years. Any specific location in the park was affected by fire about every 22 years. Individual burns varied in size from 850 acres to approximately 31,960 acres (99% of the park). Sixteen of the 21 "major" fires resulted in the regeneration of pine forests. Management programs involving intensive fire control have resulted in a serious departure from natural conditions.

Gauthier, S.; Leduc, A.; Bergeron, Y. 1996. Forest dynamics modelling under natural fire cycles: a tool to define natural mosaic diversity for forest management. Envir. Mon. Assess. 39:417-434.

In natural boreal forests, disturbances such as fire and variation in surficial deposits create a mosaic of forest stands with different species composition and age. At the landscape level, this variety of stands can be considered as the natural mosaic diversity. In this paper, we describe a model that can be used to estimate the natural diversity level of landscapes. We sampled 624 stands for tree species composition and surficial deposits in eight stand-age classes corresponding to eight fire episodes in the region of Lake Duparquet, Abitibi, Québec at the southern fringe of the Boreal Forest. For six surficial deposit types, stand composition data were used to define equations for vegetation changes with time for a chronosequence of 230 years for four forest types. Using Van Wagner's (1978) model of age class distribution of stands, the proportion of each forest type for several lengths of fire cycle were defined. Finally, for real landscapes (ecological districts) of the ecological region of the "Basses-Terres d'Amos", the proportion of forest types were weighted by the proportion of each surficial deposit type using ecological map information. Examples of the possible uses of the model for management purposes, such as biodiversity conservation and comparisons of different landscapes in terms of diversity and sensitivity to fire regime changes are discussed.

Gluck, M.; Rempel, R. 1996. Structural characteristics of post-wildfire and clearcut landscapes. Envir. Mon. Assess. 39:435-450.

A continuing discussion in the field of ecology and forest management concerns the implications of clearcutting as a functional replacement for wildfire in disturbance-driven ecosystems. At the landscape level, spatial pattern has been shown to influence many ecologically important processes. Satellite imagery allows the evaluation of structural patterns created by alternative forest management activities at broad scales. In northwestern Ontario, both clearcutting and wildfire have occurred over large contiguous areas. Spatial characteristics including composition, patch size, patch shape, and interspersion were calculated from classified Landsat Thematic Mapper (TM) data at two thematic scales and used to compare post-wildfire and clearcut landscapes. Patches in the clearcut landscape were found to be larger in size, and had a more irregular shape than those in the wildfire landscape. Differences in landscape structure were much more pronounced at broad scales than at fine thematic scales.

Gross, H.L. 1981. Other important diseases associated with the boreal mixedwood forest. p. 266-270 *in* Whitney, R.M.; McClain, K.M. (Cochairmen). Proc. Boreal Mixedwood Symposium (Sept. 16-18, 1980, Thunder Bay, Ont.). Dept. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. 0-P-9. 278 p.

"*Rhizina* root disease caused by *Rhizina undulata* Fr. is probably an important cause of conifer seedling mortality in recently burned areas. The disease seems to be restricted to fire sites, possible because the spores that cause infection are stimulated to germinate by heat (50° C). Last year our FIDS field technicians checked a selection of 25 natural or prescribed burn sites and detected Rhizina on five of the sites. Also, members of our fire research group at the Great Lakes Forestry Centre commonly find Rhizina fruiting in the burns they investigate. The fungus appears to be a weak parasite that can compete only where fire has more or less purged the area of competition. Both mortality and fruiting were investigated at several locations in British Columbia. Seedlings were killed in groups, and 10% seedling mortality was attributed to Rhizina root rot. After two years, impact was negligible. Reports from Europe indicate that the disease can spread into mature timber and cause stand openings. This has not been observed in Canada. Limited data for Ontario indicate that we probably have a problem similar to that of British Columbia. Following a site for two years after a burn probably can provide control. For Ontario we hope to provide data on the type of site likely to be inhabited by Rhizina."

Hansen, H.L.; Kurmis, V.; Ness, D.D. 1974. The ecology of upland forest communities and implications for management in Itasca State Park, Minnesota. Minn. Agric. Exp. Stn. Tech. Bull. No. 298. 43 p.

Reports some results of the Itasca Park Project, initiated in 1964 to study the ecological consequences of past use and protectionist management on the park and its forest vegetation. The area is described and historical aspects of the park forest, its contemporary ecological state and natural successional trends are discussed. Research on vegetation management is reported, and management implications of the study are considered. It is noted that elimination of fires from the park as a result of recent management practices has discouraged the establishment of *Pinus* spp.; has favoured the increase of more tolerant and aggressive hardwood trees and shrubs. The use of fire as an aid to management is being tested.

Harjula, A.M. 1984. Fire management in Quetico Provincial Park. Proc. p. 26-30 *in* Stocks, B.J.; Elliott, R.G.; Walker, J.D. (Cochairmen). Proc. Forest Fire Management Symp. (Sept. 15-18, Sault Ste. Marie, Ont.). COJFRC Symp. Proc. O-P-13. 125 p.

Fire is an important element in managing wilderness parks such as Quetico Provincial Park. An active fire management program should be initiated in order to perpetuate the ecosystem for which the park was established and to prevent the forest from becoming a decadent mix of hardwoods and fir.

Heinselman, M.L. 1971. The natural role of fire in northern conifer forests. p. 61-72 *in* Slaughter, C.W.; Barney, R.J.; Hansen, G.M. (eds.). Fire in the northern environment-a symposium. USDA For. Serv., Pacific Northwest For. Range Exp. Stn. Portland, OR. 275 p.

The primeval conifer forests of North America, with their associated deciduous components, were largely fire-dependent ecosystems. Fire was a key environmental factor in controlling succession, species composition, and age structure of these forests. An almost universal policy of fire exclusion over the last 50 years is superimposing a vegetation succession which is "unnatural" and is often undesirable in terms of resource management. For most forested areas, a fire policy is advocated which involves selective control of wildfires and managed, prescribed burning to duplicate the natural fire regime.

Hunter, M.L. 1993. Natural fire regimes as spatial models for managing boreal forests. Biol. Conserv. 65:115-120.

Because organisms have adapted to the natural disturbance regimes of forest ecosystems such as fires and windfalls, conservationists often suggest that timber harvesting systems be designed to imitate natural disturbance regimes. Using the crown fires that shape true boreal forest ecosystems as spatial models for harvesting would require very large clearcuts; in two studies, mean fire size was 12,710 ha (in Labrador) and 7,764 ha (in Québec). Most conservationists would be reluctant to advocate such large clearcuts and it is not easy to justify them from the perspectives of various ethical systems. A solution is proposed in which moderate-sized clearcuts would be clustered into portions of land areas bounded by water-bodies. Water-bounded areas have an average size of 770 ha in Labrador and 322 ha in Québec.

Johnson, E.A.; Miyanishi, K. 1995. The need for consideration of fire behavior and effects in prescribed burning. Rest. Ecol. 3:271-278.

Prescribed burns are increasingly being used in ecological restoration and vegetation management. Despite the accumulation of scientific information on fire behavior and fire effects, however, in many cases fires are prescribed without consideration of such information and often simply because of evidence of past fires. Rather than basing fire management plans on ideas of the historical "natural" occurrence of fire, we present the case for fire management being based on the fire effects desired. Effective fire management and development of proper fire prescriptions require an understanding of fire processes and heat transfer that explain fire behavior characteristics, as well as an understanding of how fire behavior is coupled to specific fire effects. We provide a basic introduction to these concepts and processes, which will help in understanding the importance of having a more technical understanding of fire. The discussion includes the processes of heat transfer and the relative role of various fuel variables in these processes, as well as the concepts of fire intensity, rate of spread, fuel consumption, duff consumption, fire frequency, and the ecological effects associated with variation in these characteristics of fire behavior.

Johnston, W.F. 1971. Broadcast burning slash favours black spruce reproduction on organic soil in Minnesota. For. Chron. 47:33-35.

Burning trials were made on clear-felled areas near Big Falls, north-central Minnesota, and regeneration of *Picea mariana* was sampled 2 to 6 years after burning. Methods used were: (1) broadcast burning of unpiled slash on large patches and wide strips during summer; and (2) progressive burning of piled slash on small patches and narrow strips during winter. Natural seeding was relied on except on the large patches, where ca. 100,000 seeds/acre were broadcast with a hand seeder. Regeneration of *P. mariana* was denser and better distributed on burned areas than on control plots, owing to the exposure of moist *Sphagnum* moss. It is suggested that (2) will give satisfactory regeneration only where *Sphagnum* spp. are abundant, since they remain moist after exposure; other mosses on burned areas dry out, giving a poor seedbed. With (1), adequate regeneration of *P. mariana* was obtained, dry moss species were consumed, and residual conifers were destroyed, thus eradicating *Arceuthobium pusillum*. The effect of the severity of the broadcast burn on the regeneration of *P. mariana* and competing vegetation is discussed. Results indicate that natural seeding of *P. mariana* in (1) should be adequate on strips 5 chains wide with a seed source on each side, or 4 chains wide with a seed source to the windward.

Martell, D.L. 1983. Fire impact management in the boreal forest region of Canada. p. 526-533 *in* Wein, R.W.; Riewe, R.R.; Methven, I.R. (eds.). Resources and dynamics of the boreal zone. Assoc. Can. Univers. North. Stud. 544 p.

Increasing awareness that fire is a natural component of boreal forest ecosystems and escalating suppression costs are fostering growing opposition to traditional fire exclusion policies. However, since many people live and work in the boreal forest region of Canada, threats to their social and economic well-being make fire managers understandably reluctant to alter their exclusion stance. The author advocates the adoption of fire impact management polices whereby decisions concerning the suppression of wildfires and the use of prescribed fire are based on sound social, economic and ecological principles, and discusses some of the practical problems associated with the development and implementation of such polices.

Martell, D.L. 1994. The impact of fire on timber supply in Ontario. For. Chron. 70:164-173.

Results are presented for an assessment of the impact of fire on timber supply in the province of Ontario. Historical fire report data are used to develop statistical summaries of fire regimes in terms of annual fire occurrence and area burned by administrative district and region. A simple hypothetical jack pine forest is used to illustrate how forest level timber harvest scheduling models can be employed to assess the timber supply implications of fire management regimes. Although fire may have had a significant detrimental impact on timber supply in some parts of the northwestern region during the 1976-1988 period, the effectiveness of Ontario's forest fire management system is such that timber supply in most districts has not been significantly diminished by fire. The results of our timber supply analysis, and the fact that fire management also benefits public safety and reduces property loss, suggest forest fire management is profitable in Ontario.

McRae, D.J. 1979. Prescribed burning in jack pine logging slash: a review. Dept. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Inf. Rep. O-X-289. 57 p.

An increase in the use of prescribed fire as a forest management tool is anticipated in Ontario where its use is viewed as a viable method of site preparation for regeneration purposes. Literature available on prescribed burning in the jack pine (*Pinus banksiana* Lamb.) logging slash fuel type is reviewed in order to assess the current state of knowledge. Topics of discussion include fuel hazard reduction, silvicultural, environmental and ecological effects, prescribed burn planning, economics, and fire behavior in jack pine logging slash. A serious lack of quantitative data on prescribed burning in jack pine logging slash was noted. Research required for a complete understanding of prescribed burning in this fuel type is outlined. An area and subject index shows the geographical location of, and subject area investigated by, individual studies reviewed in this report.

McRae, D.J. 1980. Preliminary fuel consumption guidelines for prescribed burning in Ontario slash fuel complexes. Dept. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Inf. Rep. O-X-316. 25 p.

This report provides interim fuel consumption guidelines for five common slash fuel complexes found in Ontario. Slash fuel consumption and depth of burn were found to be related to preburn fuel loadings, and to fire weather as expressed by the Buildup Index (BUI), a component code of the Canadian Forest Fire Weather Index (CFFWI). The use of these guidelines for prescribed burn planning is discussed.

McRae, D.J. 1986. Prescribed burning for stand conversion in budworm-killed balsam fir: an Ontario case history. For. Chron. 62:96-100.

Recent spruce budworm (*Choristoneura fumiferana* Clem.) infestations have resulted in widespread areas of balsam fir (*Abies balsamea* (L.) Mill.) mortality in Ontario, and there is growing interest in reestablishing these areas quickly as productive forests. One technique being used is prescribed fire after salvage and bulldozer tramping operation. A 445-ha prescribed burn was carried out under moderate fire danger conditions in northern Ontario. The site, which was covered by balsam fir fuel that had been killed by spruce budworm, was tramped to improve fire spread. Weather, fuel consumption, and fire effects are reported. The burn effectively reduced heavy surface fuel loading and consequently planting on the site was easier.

McRae, D.J. 1994. Prescribed fire converts spruce budworm-damaged forest. J. For. 92:38-40.

Recent spruce budworm infestations have been more frequent and widespread because of human intervention on the composition of the forest. In some regions, such as Ontario, balsam fir is not considered a good pulp species, especially when compared with spruce, and is not harvested. Such practices in combination with fire protection policies have created a higher density of balsam than might have occurred naturally. Stand condition, with a higher mature balsam content, is thus more conducive to budworm attack. In addition, balsam fir is a climax species that appears naturally in the absence of wildfires. The efficiency of modern fire suppression has allowed the shift toward balsam fir to occur unhindered. Because the budworm generally attacks mature to overmature balsam, young balsam fir seedlings in the understory tend to survive and replace the dead trees, thereby continuing the budworm cycle. Increased sunlight resulting from the dead overstory and subsequent increases in understory shrubs make establishment of other conifer species difficult, even if seed trees are present in the budworm-damaged forest. Therefore, re-establishment of a new forest must involve some form of site preparation. Prescribed fire is often used for site conversion because it reduces a substantial portion of the unmerchantable, woody residue left behind after a budworm infestation. [additional information from report added]

M^cRae, D.J. 1995. Prescribed burning on black spruce sites can assist regeneration efforts. Can For. Serv., Sault Ste. Marie, Ont. Frontline Tech. Note No. 37.

One of the alternatives available to Ontario forest managers for site preparation of harvested black spruce *(Picea mariana* (Mill.) B.S.P.) sites is prescribed burning. Prescribed fire lends itself well to a holistic approach to forest management, especially in fire-adapted ecosystems such as the black spruce forest community. Black spruce sites are often considered inappropriate to burn because of the preconception that they are too wet, but in fact many of these areas can burn quite well. Often, when prescribed fire is considered for these sites it is associated with burning a typically large boreal forest clear-cut, but good results have been achieved on smaller areas such as strip cuts. Proper ignition is required on these smaller burns to draw the fire so that trees in uncut strips are not damaged. One of the incentives for using prescribed fire is its low cost. Expenditures are less on larger burns because of economies of scale, but smaller burns (< 40 ha) can be economical if hand ignition is utilized instead of the more expensive aerial ignition required for large burns. On smaller burns, aerial ignition may be deemed better if sites are remote or if burning conditions warrant a mass-fire approach. Economy of scale can be achieved for smaller burns by conducting several the same day.

M^cRae, D.J. 1996. Use of forest ecosystem classification systems in fire management. Envir. Mon. Assess. 39:559-570.

Forest Ecosystem Classification (FEC) Systems have been used in the past mainly for forest management decision-making. FEC Systems can also serve an important role for decision-making in other disciplines, such as fire management for both wildfire suppression and prescribed burning operations. FEC Systems can provide an important means of identifying potential fuels that may be present on a forest site. This fuel information, in combination with current fire weather conditions, as determined by the Canadian Forest Fire Weather Index (FWI) System, can assist fire managers in determining potential fire behaviour if ignition should occur. FEC Systems provide a means of identifying the possible presence of a live understory vegetation component, a fuel layer that has been largely ignored in the past due to a lack of information. Dense understory vegetation can produce a very moist microclimate that can effectively hinder fire spread. The use of FEC Systems can help in setting priorities on which wildfires need to be attacked aggressively. For prescribed burning, FEC Systems can assist in achieving burn objectives better and more safely.

Niering, W.A. 1981. The role of fire management in altering ecosystems. p. 489-510 *in* Mooney, H.A.; Bonnicksen, T.M.; Christensen, N.L.; Lotan, J.E.; Reiners, W.A. (Tech. coordinators). Conf. Proc. Fire regimes and ecosystem properties (Dec. 11-15, 1978, Honolulu, Hawaii). USDA For. Serv., Washington, D.C. Gen. Tech. Rep. WO-26. 594 p.

Prescribed burning is extensively used in wildlife, forest, and range management, and in maintaining biotic diversity. Burning tends to increase food and/or favourable habitat conditions for many upland game and waterfowl species. Prescribed burning in forest management is used in site preparation, removal of competitive species, and fire hazard reduction. Fire is used in preserving biotic diversity in natural areas by stimulating natural fire frequencies and intensities. Favourable forage species are also maintained by integrated fire management regimes. In altering habitats with fire, a holistic view must be maintained to preserve ecosystem integrity.

Ontario Centre for Remote Sesnsing. 1975. The use of ERTS-1 imagery to delineate boundaries of recent burns and to estimate timber damage. Ont. Cent. Rem. Sens., Ont. Min. Nat. Res., Toronto, ON. 20 p. + appendices.

On the basis of the mapping of 1974 fires using ERTS-1 imagery, it would appear that this provides a rapid and economical means of delineating burned-over areas. It is possible that the boundary delineated on ERTS-1 imagery may not be completely precise in areas where a ground fire consumes ground vegetation without having an immediate effect on the tree cover, but where trees may eventually be affected by disturbance. In spite of this source of inaccuracy, the ERTS-1 imagery is believed to provide a useful approximation of the perimeter of recent burns. For areas surveyed by the Forest Resources Inventory, an estimate of the standing timber affected by fire can be readily made at a minimal cost. The accuracy of these estimates is almost exclusively dependent upon the accuracy of the FRI data. In addition to the burned-over area cited in the above example, the Ontario Centre for Remote Sensing (OCRS) has delineated the boundaries and calculated the areas of all the burned-over areas in Northwestern Ontario (approximately 1.5 million acres or 607,000 hectares), including burns north of the area where forest protection measures are applied. Remote sensing provides the only efficient means of delineating burned-over areas in the remote parts of the province. In future, maps could be compiled by the OCRS for the remote areas of the province. These maps will provide a record which will be of considerable value to ecologists investigating the ecosystems of the northern boreal regions of Ontario in the decades to come. [discussion]

Perala, D.A. 1974a. Prescribed burning in an aspen-mixed hardwood forest. Can. J. For. Res. 4:222-228.

The effects of (a) prescribed burning and (b) complete clear felling on *Populus tremuloides* and associated hardwoods and shrubs were compared for 8 years after commercial logging of a 60-year-old *P. tremuloides* stand in Minnesota. Lack of suitable weather prevented burning before the *P. tremuloides* suckers were 2 years old. All the original suckers were killed by fire, but new suckers were produced; these were more numerous but less vigorous (for reasons discussed). The results showed that (a) can be used effectively to control residual hardwood overstories detrimental to the growth and survival of suckers, where (b) (or some other means of removing the overstory) is not practicable. The long-term effect of fire on sucker growth of *P. tremuloides* is, however, unknown.

Burning should be done during the first dormant season after logging. Advice is given on the distribution of slash, and prescriptions for burning are suggested.

Perala, D.A. 1974b. Repeated prescribed burning in aspen. USDA For. Serv., North Cent. For. Exp. Stn., St. Paul, Minn. Res. Note NC-171. 4 p.

Describes the effects of felling a stand of *Populus tremuloides* and prescribed burning of the area in the spring 2 and 4 years after felling, and in the autumn 5 years after felling in order to clear the area for conifers. Repeated spring burning reduced the vigour of *P. tremuloides* suckers, but the low flammability, infrequent burning weather and prolific sprouting and seeding of shrubs and hardwoods made this an impractical method of clearing the site for conifers. Burning in the autumn stimulated the production of suckers by *P. tremuloides* and sprouting of other shrubs and hardwoods, as well as changing the species composition.

Perala, D.A. 1995. Quaking aspen productivity recovers after repeated prescribed fire. USDA For. Serv., North Cent. For. Exp. Stn., St. Paul, Minn. Res. Pap. NC-324. 11 p.

This report describes how a quaking aspen (*Populus tremuloides* Michx.) stand recovered after logging, and logging and burning. Aspen yield may be less after burning slash left by clearcutting, but this study shows that repeated burning may ameliorate growth. Ultimately, aspen yield is determined by conditions that control growth, stockability, and site index. Site index was diminished by the initial burn and did not recover regardless of ensuing history. The response to subsequent burning suggests mitigation of the factors controlling stockability, thought to be related to the water balance (Perala *et al*. 1994). The responsible mechanism is not apparent from these data. Tree growth may follow different trajectories accompanied by more-or-less complementary survival trajectories. Thus stands may eventually converge on the same yield, distributed over different numbers of trees. [abstract adapted from conclusions]

Prevost, M. 1994. Scalping and burning of *Kalmia angustifolia* (Ericaceae) litter - effects on *Picea mariana* establishment and ion leaching in a greenhouse experiment. For. Ecol. Manage. 63:199-218.

A greenhouse experiment was conducted to assess the effects of scalping and burning the *Kalmia* litter of an acidic peaty soil on (*i*) germination and early growth of black spruce, (*ii*) the nutrient status of the soil surface (0-5 cm), and (*iii*) nutrient leaching. Burning of the litter clearly increased concentrations of NH_4-N, NO_x-N and P in soil, proportionally to intensity. Burning also improved the availability of Ca and Mg, while scalping of the litter exposed a layer with lower K and Ca availability and a lower pH than the surface. For the 3 month growth period, as a percentage of water input, downward drainage totalled 71% in the control treatment, 62% in the partial burning of litter treatment and 50% in the complete burning treatment. It varied around 40% in the two scalping treatments, where evapotranspiration dominated the water balance. For all treatments, the first 6-8 weeks of watering were characterized by a decrease in the pH of leachate and by leaching of Ca, K, Mg and Na. In general, a smaller leachate volume was associated with higher pH and concentrations of Ca, Mg and Na. Hence, on a mass basis, nutrient leaching did not differ with treatment. Only 14%

of the seeds sown in the undisturbed *Kalmia* litter germinated, while 36-55% of the seeds germinated in other treatments. Any of the treatments had a significant effect on seedling growth which was very slow, probably because of low nutrient availability, allelopathy and competition from vigorous *Kalmia* resprouting. However, root growth was slightly reduced in the substrates where the *Kalmia* litter was left undisturbed.

Reinhardt, E.D.; Wright, A.H.; Jackson, D.H. 1992. Development and validation of a knowledge-based system to design fire prescriptions. AI Appl. 6:3-14.

In this study, we explored application of expert system methodology to design of fire prescriptions. Prescribed fire is used to manipulate forest ecosystems to accomplish a variety of resource management objectives. To develop prescriptions that successfully achieve these objectives, managers use information from a variety of sources, including results of scientific research and their own experience. We modeled the prescription development process as an expert system that uses rule-based inference and frame-based inheritance to integrate technical and heuristic information and interpret it for application. Site data and the manager's objectives for treating the site with prescribed fire are inputs to the expert system. The system develops and documents a fire prescription that describes ranges of acceptable fire effects, the desired fire treatment, and a range of conditions under which to burn to achieve the desired treatments and effects. The system was validated using data from research burns in a variety of forest types throughout the interior western United States.

Richards, N.R. 1984. Fire management in wilderness and nature reserves. p. 20-25 *in* Stocks, B.J.; Elliott, R.G.; Walker, J.D. (Cochairmen). Proc. Forest Fire Management Symp. (Sept. 15-18, Sault Ste. Marie, Ont.). COJFRC Symp. Proc. O-P-13. 125 p.

The beneficial role of fire, both natural and prescribed, in the management of park ecosystems is discussed in detail. Emphasis is given to parks classified as wilderness or nature reserve and the potential role of fire in these park types is outlined. Some ideas on implementing a fire management policy for all provincial parks are given.

Roseborough, J.D.; Post, L.J. 1984. Fire management and wildlife policy. p. 7-10 *in* Stocks, B.J.; Elliott, R.G.; Walker, J.D. (Cochairmen). Proc. Forest Fire Management Symp. (Sept. 15-18, Sault Ste. Marie, Ont.). COJFRC Symp. Proc. O-P-13. 125 p.

The occurrence or absence of wildfires, in conjunction with their frequency and intensity, profoundly influences wildlife abundance. The long-term absence of fire, and the resultant overmature forest, drastically reduce browse for moose and deer. Controlled burning simulates the effects of natural disturbances, and, if used appropriately on a relatively small scale, creates the interspersion of age classes that favor many wildlife species. We must balance the values to be protected from fire with the wildlife values to be derived from fire.

Sims, H.P. 1976. The effect of prescribed burning on some physical soil properties of jack pine sites in southeastern Manitoba. Can. J. For. Res. 6:58-68.

The effect of prescribed burning on physical soil properties of clear-cut areas originally supporting jack pine was studied in southeastern Manitoba. Average temperatures recorded during three burns ranged from < 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% because of deposition of fuel residues, while the least severe burn produced a 31% reduction in the weight of the organic mantle. Soils at 3.8 and 7.6 cm under burned seedbeds reached permanent wilting point at days 9 and 23 respectively during a 30-day rain-free period. Moisture contents at similar depths on an adjacent scarified area were significantly higher than on the burn, were much less variable, and remained above permanent wilting point for the duration of the 30-day period. Burning did not significantly affect percolation rate.

Stocks, B.J. 1987. Fire potential in the spruce budworm-damaged forests of Ontario. For. Chron. 63:8-14.

An experimental burning program was carried out in Ontario between 1978 and 1982 to document quantitatively fire behavior in balsam fir killed by spruce budworm. Forest fire potential in budworm killed balsam fir stands was shown to be significantly higher for a number of years following stand mortality. Crown breakage and windthrow, with resultant fuel complex rearrangement and increased surface fuel loads, peaked 5-8 years after mortality. Fire potential was greatest during this period, decreasing gradually as balsam fir surface fuels began to decompose and understory vegetation proliferated. Fires occurring prior to "green-up" in the spring behaved explosively with continuous crowning, high spread rates, and severe problems with downwind spot fires. Summer fires in this fuel type did not spread at all in the early years following mortality; however, sufficient woody surface fuel accumulation 4-5 years after mortality permitted summer fire spread.

Suffling, R. 1988. Catastrophic disturbance and landscape diversity: the implications of fire control and climate change in subarctic forests. p. 111-120 *in* Moss, M.R. (ed.). Landscape ecology and management. Polyscience Publications Inc., Montreal, Canada. 240 p.

Historical data for northwestern Ontario were used to determine relations between catastrophic (stand replacing) fires and landscape diversity in the boreal forest. Results showed that landscape diversity was greatest with intermediate amounts of fire disturbance. Any change of disturbance rate will reduce landscape diversity. The data showed gross variation in forest fires over time, with clusters of severe fire years and of quiescent years. It is suggested that an increase in numbers of fires will occur in response to climate warming. Fighting such fires in timber production areas is amply justified; in areas not prone to fires and of marginal forestry potential such fires should be allowed to burn to increase habitat diversity without harming forestry interests.

Suffling, R. 1991. Wildland fire management and landscape diversity in the boreal forest of northwestern Ontario during an era of climatic warming. p. 97-106 *in* Nodvin, S.C.; Waldrop, T.A. (eds.). Proc. Fire and the environment: ecological and cultural perspectives (March 20-24, 1990, Knoxville, Tenn.). Southeastern For. Exp. Stn., Asheville, NC. Gen. Tech. Rep. SE-69. 426 p.

A climatic gradient across northwestern Ontario induces a spacial gradient in fire incidence, with few fires in the northeastern part and many in the southwestern part. The resultant landscape mosaics exhibit maximum landscape (beta) diversity with intermediate disturbance frequency, as predicted by a theoretical model. This implies the results of suppression on landscape-scale habitat diversity differ qualitatively, depending on previous fire occurrence. Diversity is promoted by fire in fire-free areas, and suppressed by fire where fire occurs frequently. Fire occurrence has fluctuated wildly, however, over periods shorter and longer than the life span of forest trees and, with anticipated anthropogenic global climate warming, fire occurrence may depart from the norms of living memory. Thus the future lightning-fire regime cannot necessarily be regarded as an unmodified feature of the natural environment. Because temporal variation in fire frequency makes estimation of a "natural" fire frequency almost meaningless, wildland fire management polices should not be aimed at maintaining vegetation in a state that is representative of a particular historical time. Policy objectives can be set, however, to retain a minimum area of each ecosystem type, with the minimum defined by reference to historical variation.

Tashiro, C.; Clement, R.E.; Stocks, B.J.; Radke, L.F.; Cofer, W.R.; Ward, P.C. 1990. Preliminary report: dioxins and furans in prescribed burns. Chemosphere 20:1533-1536.

The Ontario Ministry of Environment (MOE) recently participated in a joint Canadian/U.S. program to monitor the behavior and environmental impact of prescribed fires. Air, soil and ash samples were collected at the burn sites and analyzed for chlorinated dibenzo-p-dioxins (CDD) and dibenzofurans (CDF). Preliminary results indicated that larger air sample volumes were required.

Tellier, R.; Ruel, J.C.; McAlpine, R.S. 1995. Effets de l'intensitè du brûlage dirigé et de la scarification sur la diversité des espèces végétales dans un peuplement de pin gris (*Pinus banksiana* Lamb.). Ecoscience 2:159-167.

Vegetation development was studied in a jack pine (*Pinus banksiana*) clear-cut one and two years after prescribed burning or scarification. Even if differences were found in species composition, most species present before treatment were also present afterward. However, variations in the abundance of those species were observed: a strong initial decrease in shrub and grass biomass was noted on the burned-over plots, whereas scarification affected only the grass biomass. On the second year, the influence of burning and scarification on plant biomass significantly decreased. Fire intensity correlated negatively with shrub biomass and positively with tall forbs biomass. Shannon's diversity index was calculated for each of the vegetation characteristics (percent cover, number of individuals, frequency and biomass). One year after treatment, prescribed burning and scarification affected all diversity indices except those based on the number of individuals. Richness and diversity indices based on percent cover and biomass were lower on the burned and scarified plots than on the clear-cut plots, while there were no differences between the indices based on frequency between burned and clear-cut plots. These effects were, however, negligible two years after treatment. No correlation was found between fire intensity and any of the diversity indices one year after treatment, but indices based on percent cover and number of individuals correlated with fire intensity the second year after treatment.

Van Wagner, C.E. 1970. Temperature gradients in duff and soil during prescribed fires. Dept. Fish. and For., Can. For. Serv., Bi-mon. Res. Note 26. 42 p.

Temperatures in duff and upper mineral soil during surface fires in pine stands were measured with strips of temperature-sensitive paint on mica strips. Where some duff remained, the gradients in maximum temperature was 125° F per 1/10 inch; in bared mineral soil it was 45° F per 1/10 inch. The 212° F level was at a depth of about 0.4 inch in duff, and 0.8 inch in bared soil. [abstract from Van Wagner 1979]

Ward, P.C.; Tithecott, A.G. 1993. The impact of fire management on the boreal landscape of Ontario. Ont. Min. Nat. Res., Aviation, Flood and Fire Management Branch Publication No. 305. Sault Ste. Marie, Ont. 12 p.

Traditionally, fire management objectives have been fairly simple. Fire poses a significant threat to structures, private property, and timber values, and standard responses have been to minimize these impacts by attempting to suppress all fires within the commercial forest at small sizes. However, as resource management objectives and values become more complex, the demands on the fire management program are becoming more complicated. If resource managers truly start managing resources from an ecological perspective and develop management objectives related to ecosystem structure and function, biodiversity, and the landscape, they need to start thinking about the impacts of both fire, and the absence of fire, on those objectives. One of the things managers will need to do better in the future is to forecast or model the impacts on the resources in the area, as well as the impacts on more difficult to measure qualities such as landscape and ecosystem diversity will need to be addressed. This analysis has demonstrated, that from a landscape perspective, the impacts of fire on the boreal forest now are radically different from the role fire played in the natural or pre-suppression fire regime. Fire management will continue to play an important role as resource managers start to look at tools and techniques to manage the landscape to meet diverse management objectives. Clearly, doing that may require a significant change in traditional attitudes about the role of fire in the forest, and the subsequent delivery of fire management.

Weber, M.G.; Taylor, S.W. 1992. The use of prescribed fire in the management of Canada's forested lands. For. Chron. 68:324-334.

Present uses of prescribed fire in Canada are reviewed. Fire has been a natural component of 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 (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.

3.0 FIRE AND THE GREAT LAKES - ST. LAWRENCE FOREST REGION

3.1 Influence of fire on soil: physical and chemical properties

Adams, P.W.; Boyle, J.R. 1980. Effects of fire on soil nutrients in clearcut and whole-tree harvest sites in Central Michigan. Soil Sci. Soc. Am. J. 44:847-850.

Surface-mineral soil samples from adjacent northern red oak (*Quercus rubra*)-bigtooth aspen (*Populus grandidentata*) 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, 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 through volatilization and accelerated leaching.

Adams, P.W.; Boyle, J.R. 1982. Soil fertility changes following clearcut and whole-tree harvesting and burning in central Michigan. Soil Sci. Soc. Am. J. 46:638-640.

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 concentration 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 K and N were similar to original levels. Calcium and Mg concentrations at the clearcut site were 88 and 75% higher than 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.

Alban, D.H. 1977. Influence on soil properties of prescribed burning under mature red pine. USDA For. Serv., North Cent. For. Exp. Stn., St. Paul, Minn. Res. Res. Pap. NC-139. 8 p.

Prescribed fires in a 90-year-old red pine (*Pinus resinosa* Ait.) stand in Minnesota reduced shrub (*Corylus cornuta* Marsh.) competition and the amount of organic matter and nutrients in the forest floor. These soil changes and the unaffected tree growth suggest that prescribed fires resulting in volatization of up to one half of the forest floor weight have had no affect on site productivity.

Clark, J.S. 1990. Twentieth-century climate change, fire suppression, and forest production and decomposition in northwestern Minnesota. Can. J. For. Res. 20:219-232.

Long-term fire, climate, and vegetation data were used together with simulation models to estimate the effects of 20th century climate change and fire suppression on fire regime and organic-matter accumulation in mixed-conifer stands of Itasca State Park, northwestern Minnesota. Spatial and temporal patterns of fire occurrence and forest composition over the last 150 years determined by stratigraphic charcoal, fire-scar, tree-ring, and pollen analyses in separate studies provide evidence for vegetation and fire relationships. Water balances constructed from temperature and precipitation data collected since 1840 were used to model fire probability and intensity of burn before fire suppression which began in 1910. Existing patterns of biomass accumulation in forest-floor, herb, shrub, and tree components were compared with fire history and topographic variability to provide a spatial perspective on fire effects. Simulation models used these relationships to estimate: (*i*) how accumulation of organic matter had changed through the past under the different fire regimes that prevailed on different topographic aspects, (*ii*) the changes brought about by fire suppression in 1910, and (*iii*) the fire regimes and their effects that would have prevailed since fire suppression with the warm-dry climate of the 20th century. Humus, litter, shrubs, and herb cover were less abundant and more variable spatially and temporally before fire suppression. Spatial variability in forest-floor organic matter, which resulted from different fire frequencies in different vegetation and topographic settings before fire suppression, was largely gone by 1920 as a result of fire suppression. Had fire suppression not been instituted in 1910, fire frequency would have increased by 20-40% in the 20th century because of warmer and drier conditions. Forest-floor organic matter would have been largely depleted by frequent and severe fires exposing mineral soils, particularly during the drought years of the 1930s. Herb biomass would have increased, shrubs would have been more variable, and tree seedling establishment would have been substantially altered. Time required for buildup of fuels limits the extent to which increased moisture deficits increase fire frequency.

Herr, D.G.; Duchesne, L.C.; Tellier, R.; McAlpine, R.S.; Peterson, R.L. 1994. Effect of prescribed burning on the ectomycorrhizal infectivity of a forest soil. Int. J. Wildl. Fire 4:95-102.

Ectomycorrhizae formation, seedling health index, and seedling survival were assessed for two-year-old nursery-grown seedlings of *Pinus resinosa* and *Pinus strobus* two months after planting in clear-cuts that had received prescribed burning under different fire intensities. Controls consisted of seedlings planted in unburned clear-cuts. Fire intensity positively correlated with percent ectomycorrhizal roots for *P. strobus* but not for *P. resinosa.* Seedling health index and survival were highest in burned-over sites as compared to control sites for both pine species. Fire intensity correlated with seedling health index for *P. strobus* but not for *P. resinosa*. Fire intensity correlated with seedling survival for both species. Colonization of seedlings by ectomycorrhizal fungi did not correlate with seedling health index or seedling survival. *P. resinosa* seedlings planted in burned-over sites had a smaller number of lateral roots per unit length primary/secondary roots compared to seedlings planted in control plots.

Mroz, G.D.; Jurgensen, M.F.; Harvey, A.E.; Larsen, M.J. 1980. Effects of fire on nitrogen in forest floor horizons. Soil Sci. Soc. Am. J. 44:395-400.

The effects of burning on nitrogen (N) losses and transformations in red pine (*Pinus resinosa* Ait.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), and Douglas-fir (*Pseudotsuga menziesii*)/western larch (*Larix occidentalis* Nutt.) forest floor were investigated. Organic horizon samples were burned at 400° C for 30 minutes in a top-heating oven to simulate field conditions. Measurements taken immediately after burning showed total and available N losses from the O_1 horizons but gains in total and available N in underlying layers. After burning, the litter was incubated for 5 weeks and analyzed for ammonium and nitrate concentrations and changes in acidity. Each forest floor type displayed varying patterns of ammonification, nitrification and immobilization of N. The N changes appeared related to the differing initial N contents of the organic material.

Schaetzl, R.J. 1994. Changes in O Horizon mass, thickness and carbon content following fire in northern hardwood forests. Vegetatio 115:41-50.

This study examines temporal changes in the thickness, mass, and organic carbon content of the O horizon (forest floor) of eight forested plots in northern Michigan, U.S.A.. Each plot had experienced a recent burn (prescribed or accidental); burn dates ranged from 1798 to 1980. The climax forest in this region is mixed *Pinus-Acer-Betula-Tsuga*, whereas the fire successional species are predominantly *Populus* spp. and *Betula papyrifera*. O horizon data were fit to logarithmic functions (chronofunctions) that depicted rapid accumulations of mass and thickness in the first years after the fire, followed by decreasing rates of increase after ≈ 100 years. Extension of the chronofunctions to ≈ 5000 years allowed for a theoretical examination of forest floor conditions, *e.g.*, steady state and time to steady state, after long periods without disturbance. The models predicted greater O horizon thicknesses and slightly lower mass for steady state conditions than have been reported for old-growth stands elsewhere. Steady state accumulations of litter in these mixed, temperate forests requires at least 200 and possibly > 1000 years, which is markedly longer than most other estimates. Although frequent disturbance by fire in these forests would likely preclude such values from being attained, these data provide theoretical maximum values for forest floor conditions in these ecosystems.

Smith, D.W.; Bowes, G.G. 1974. Loss of some elements in fly-ash during old-field burns in southern Ontario. Can. J. Soil Sci. 54:215-224.

In a series of 11 surface burns in old fields at two locations in southern Ontario the environmental factors having the greatest effect on fire severity were fuel moisture content, windspeed and fuel energy. Other environmental factors were of less significance. Changes in soil chemistry were restricted to the surface litter and were transitory. Changes at mineral soil depths may have gone undetected because of the highly buffered soils involved. As much as 30% of the loss of nutrients from the biomass during burning was recovered in downwind deposits of fly-ash adjacent to the burned areas. Recovery estimates are considered approximate and minimal but indicate the importance of nutrient losses in fly-ash during low temperature burns.

Van Wagner, C.E. 1972. Duff consumption by fire in eastern pine stands. Can. J. For. Res. 2:34-39.

Data are presented on the consumption of duff by fire on six plots in a jack pine (*Pinus banksiana* L.) stand and six plots in a red and white pine (*P. resinosa* Ait. and *P. strobus* L.) stand. The amount consumed was found to correlate well with the moisture content of the duff before fire, and with the Duff Moisture Code, a component of the Canadian Forest Fire Weather Index. A tentative theory to account for the amount of duff consumed is presented in terms of (a) downward heat transfer within the flaming front, and (b) the energy required to heat the duff to ignition temperature.

Weber, M.G. 1985. Forest soil respiration in eastern Ontario jack pine ecosystems. Can. J. For. Res. 15:1069-1073.

Forest soil respiration *in situ* was used as a comparative measure of the metabolic activity of substrate in eastern Ontario jack pine (*Pinus banksiana* Lamb.) ecosystems that had been exposed to various burning treatments, including wildfire. The five burning treatments consisted of a 1920 wildfire, experimental understorey burning (nonlethal to the overstorey) of this age-class in 1962 and 1963, a 1964 wildfire, and experimental burning of this age-class in 1977. Seasonal respiration trends were similar on all treatments. Carbon dioxide evolution increased in the spring (4000 $mg{\cdot}m^{-2}{\cdot}d^{-1}$) in response to ambient warming (5000 $mg{\cdot}m^{-2}{\cdot}d^{-1}$) and decreased in late fall as seasonal temperatures declined (4000 $mg{\cdot}m^{-2}{\cdot}d^{-1}$ in November). Precipitation and autumnal litter fall apparently acted as secondary modifiers of this general trend by affecting respectively substrate moisture content and nutrient quality, respectively. Highest metabolic activities were measured on the 1963 understorey burning treatment followed in decreasing order by the 1920 wildfire, the 1964 wildfire, the 1962 experimental understorey burn, and the 1977 burn of the 1964 age-class. Multiple comparisons of overall seasonal respiration means revealed lower rates ($P < 0.01$) on the latter two treatments compared with the 1963 treatment. Effects of understorey burning treatments on respiration activity appeared to depend on depth of burn and subsequent forest floor development. Stand-replacing fire, reoccurring during early stages of jack pine ecosystem development, significantly lowered metabolic activity of the site.

Weber, M.G.; Methven, I.R.; Van Wagner, C.E. 1984. The effect of forest floor manipulation on nitrogen status and tree growth in an eastern Ontario jack pine ecosystem. Can. J. For. Res. 15:313-318.

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 mineral, 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 treatment 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.

3.2 Influence of fire on vegetation

3.2.1 Influence of fire on vegetation: crop tree regeneration and growth

Ahlgren, C.E. 1976. Regeneration of red pine and white pine following wildfire and logging in northeastern Minnesota. J. For. 74:135-140.

The exacting silvical requirements for regenerating red pine and white pine in northeastern Minnesota are rarely met by natural disturbance including wildfire. Buildup of aspen to the point of takeover, incidence of white pine blister rust (*Cronartium ribicola*), and lack of abundant seed trees make impossible the re-creation of natural conditions which favored the establishment of these pines in the past. Data from seven areas--two burned, two logged, and three undisturbed--illustrate the point.

Anderson, H.W. 1958. Ecological investigation of a natural burn. Ont. Dept. Lands For., Dorset, Ont. File Rep. 41 p. + appendices. (unpublished; original on file with Ontario Tree Improvement and Forest Biomass Institute, Ont. Min. Nat. Res., Maple, Ont.).

The regeneration and understory vegetation development were quantitatively assessed for five years following a low-intensity surface fire (7.3 ha in size) in a mixedwood forest of Algonquin Provincial Park in May 1953. White pine (*Pinus strobus* L.) were approximately 90 years old and occupied 15-25% of the stand basal area. Although seedbed conditions for white pine created by the fire were not extremely favorable germination conditions were not unfavorable due to ample shading and moisture conditions. Aspen, red oak, red maple and white birch sprouts were profuse in places where the burn was superficial. White pine seedling development was very poor due to intense shading and high level of root competition. *Rubus parviflorus* was the only migrant species on the burn after five years. Rodent damage, local lack of seed dispersal, fungi and/or toxic elements may have limited the establishment of white pine on the burned area.

Anderson, H.W. 1983. Regenerating yellow birch with prescribed fire. p. 168-172 *in* America's Hardwood Forest - Opportunities Unlimited. Proc. Soc. Amer. For. 1982 Convention (Sept. 19-22, Cincinnati, Ohio). SAF Publ. 83-04. 352 p.

Yellow birch (*Betula alleghaniensis* Britt.) can be successfully regenerated by using suitable seedbed preparation techniques, including prescribed fire. Experimental fall burning of tolerant hardwood stands prior to harvesting under a group selection prescription resulted in a 90% reduction in hard maple (*Acer saccharum* Marsh.) advance growth stocking less than 1.5 m high. Subsequent yellow birch seedling stocking initially was as high as 250,000 stems per hectare, decreasing to 4000 stems > 2.5 cm DBH by age 15 years. Stocking was better on land which was disturbed by logging and at residual stocking densities of 10 $m^2 \cdot ha^{-1}$. Hard maple has not reoccupied the forest floor on burned sites even 20 years after treatment.

Burgess, D.M.; Methven, I.R. 1977. The historical interaction of fire, logging and pine: a case study at Chalk River, Ontario. Dept. of Fish. Environ., Can. For. Serv., Chalk River, Ont. Inf. Rep. PS-X-66. 18 p.

This report describes a study of the history and present composition of two adjacent pine stands near Chalk River, Ontario. One is a three-aged jack pine (*Pinus banksiana* Lamb.) stand, the other a red pine (*Pinus resinosa* Ait.) stand with scattered white pine (*Pinus strobus* L.). The soil is a fine lacustrine sand. The area was logged several times between 1837 and 1897 for both square timber and sawlogs. There were also numerous fires, including dated ones in 1914, 1882, and 1864 as well as several undated ones extending back about 300 years. The average fire interval over this time was about 37 years. The logging and fire history has resulted in variable stocking and good growth of jack pine trees, and excellent stocking and good growth of red pine trees. The tree regeneration beneath the canopy is almost entirely white pine, most of it growing well. This suggests that in this particular habitat, white pine does not require fire for its perpetuation, and would, in the absence of fire, eventually dominate the area. The results have implications for the management of the three pines on similar sites.

Clark, J.S. 1989. Ecological disturbance as a renewal process: theory and application to fire history. Oikos 56:17-30.

Failure time analysis and renewal theory were used to evaluate two assumptions implicit in most studies involving calculations of disturbance frequency. These calculations assume that the disturbance process is stationary (intervals between disturbances are drawn from the same distribution) and that the probability of disturbance does not change with time since the last disturbance. Quantitative methods are presented and applied to long-term fire occurrence data (fire scars on red pine (*Pinus resinosa*) trees and stratigraphic charcoal data) and climate data from northwestern Minnesota, U.S.A. Results show that past decade- and century-scale fluctuations in climate correspond to changes in the disturbance regime. Probability of fire occurrence increases with time since the last fire, albeit at different rates during the various climatic conditions that have prevailed over the last 750 years. These results suggest two reasons to question disturbance regimes calculated from spatial dispersion of events. Firstly, expected fire intervals derived as the inverse of spatial proportion of area disturbed requires a stationary process. The space/time analogy assumed by this method is highly inaccurate when the expected interval between disturbances changes over time. Secondly, because fire hazard is an increasing function of time since the last fire, the number of disturbances predicted to occur over short time intervals will be overestimated by the usual constant hazard assumption. Probability densities of events having age-specific probabilities that increase over time (*e.g.* fire, windthrow) exhibit modes at time > 0 compared with exponential decrease with time.

Clark, J.S. 1991. Disturbance and tree life history on the shifting mosaic landscape. Ecology 72:1102-1118.

An analytical model of disturbance and plant population dynamics is developed to explore the optimal life history for a plant within a `shifting mosaic' ecosystem. Two plant responses to disturbances are explored: (1) the plant is killed by the disturbance and new recruitment follows; (2) the plant may survive many such disturbances. Predictions of the theory were compared with some actual tree life histories within disturbance regimes, and were found to be accurate: *e.g.* optimal maturation for gap species in temperate North American forests was 30-60 years. The model was also tested against *Pinus resinosa* and *P. banksiana* responses to fire regimes, and the maturation times matched the predicted optima for a species that survives fire (*P. resinosa*) versus one that is killed by fire (*P. banksiana*).

Crow, T.R. 1988. Reproductive mode and mechanisms for self-replacement of northern red oak (*Quercus rubra*)-a review. For. Sci. 34:19-40.

The requirements for regenerating northern red oak can be hypothesized from an understanding of the species' ecological life-history characteristics along with a knowledge of past and present disturbance patterns. The abundance of oak in the eastern forest is closely related to past land use and extensive disturbances. Frequent fires and heavy cutting favored oak because of its sprouting ability, while fires reduced common competitors. Northern red oak is neither an aggressive colonizer that is characteristic of early successional species nor an enduring, shade-tolerant, slow-grower that is typical of late successional species. Its regeneration requires an edge environment; one that is more mesic than exposed, open sites, but less competitive than the deep shade of a forest understory. To regenerate northern red oak, foresters need to create these conditions. Numerous cutting studies, however, have shown that overstory manipulation (partial or complete removal) alone will not regenerate northern red oak, and this competition must be controlled when regenerating this species.

Day, R.J.; Woods, G.T. 1977. The role of wildfire in the ecology of jack and red pine forest in Quetico Provincial Park. Ont. Min. Nat. Res., North Cent. Reg., Atikokan Dist., Quetico Prov. Park Fire Ecol. Study Rep. #5. 79 p.

A photogrammetric survey designed to assess the species composition, structure and successional status of the forest communities in Quetico Park (Woods and Day 1977a) was used to select virgin stands in the jack pine-poplar and red pine-white pine communities for detailed ecological study on the ground. The stands studied in both communities were selected because they represented a wide range of successional stages. The ecology of each stand was examined in detail on circular plots and transects. Tree locations were mapped and the ages, heights, diameters and crown parameters of both living and dead trees were recorded. The results of these stand measurements are presented as a series of case histories that indicate the type of successional change that could occur in the jack pine-poplar and red pine-white pine communities. The case history studied clearly show that regardless of their age, all the jack pine-poplar and red-pine white pine stands studied were initiated by wildfire. They also showed that the reproduction of jack pine and red pine after wildfire differs because of the thin bark and serotinous cone habit of the former species and the thick bark and long seedling periodicity of the latter species. The case history studies also show that in the absence of wildfire, both jack pine and red pine will tend to be eliminated by their competitors in the latter stages of succession. Hypothetical models for the post-wildfire succession of both the jack pine-poplar and red-white pine communities are developed and presented. These indicate that wildfire should be re-introduced into jack pine stands between 80 and 120 years, and into red pine stands between 175 and 200 years depending on site quality.

Guyette, R.P.; Dey, D.C. 1995. A history of fire, disturbance, and growth in a red oak stand in the Bancroft District, Ontario. Ont. Min. Nat. Res., For. Res. Inf. Pap. No. 119. Sault Ste. Marie, ON. 14 p.

The occurrence of fire, and the effects of fire and climate on the regeneration and growth of red oak were studied in an upland red oak forest in central Ontario. Red oak comprises a major portion of the overstorey in this mature, mixed-species forest. Regeneration of red oak occurred over an extended period (*i.e.*, the early 1800s to the 1930s), which was characterized by frequent fire disturbances. The ages of dominant, overstorey oaks ranged from 68 to 179 years. Frequent fire disturbances favoured the development of sapling-sized red oak advance reproduction. With the advent of fire suppression and a reduction in fire frequency, these oak were able to grow into the overstorey. Fires occurred every 2 to 18 years at this site before 1955. The pre-1950s fire regime, with its short fire-free intervals, favoured the development of oak advanced reproduction by limiting the development of less fire-resistant, shade-tolerant species in the understorey (*e.g.* sugar maple, beech and ironwood). There was no evidence of fire after 1955. The absence of fire has led to the dominance of shade-tolerant species over red oak in the overstorey. Consequently, future removal of the overstorey may result in a reduction in the number of red oak and other less shade-tolerant tree species, especially where shade tolerant species dominate the overstorey. Fire suppression and the consequent loss of oak may result in the reduction of both economic and biodiversity values on these sites. [conclusions]

Horton, K.W.; Hopkins, E.J. 1965. Influence of fire on aspen suckering. Can. Dept. For., For. Res. Branch, Ottawa, Ont. Dept. For. Publ. No. 1095. 19 p.

Soil temperature effects and aspen root suckering reactions under various burning conditions were tested in the laboratory and the field. It is shown that the prevention of root suckering through intense burning is impractical if not impossible. Temperatures lethal to root tissue were attained only close to the surface in very dry soil under sustained high surface heating. A moderate degree of burning, one which kills the tree canopy and undergrowth and eliminates the litter and part of the duff, will most effectively stimulate suckering. Lesser intensities of burning will produce less dense and vigorous suckers.

Howe, C.D. 1915. The effect of repeated forest fires upon the reproduction of commercial species in Peterborough County, Ontario. p. 166-211 *in* Forest Protection in Canada: 1913-1914. Can. Comm. Conserv. W. Briggs, Toronto, Ont.

That trees of relatively inferior value, such as birch and poplar, follow fires on areas previously occupied by pine, is a matter of common observation, but the amount of this material and its potential value are not so well known. It is also well known that repeated fires on former pine lands greatly retard, or completely exclude, the re-establishment of pine trees thereon, but the rate of this retardation in relation to the number of fires is not so well known. The financial losses involved in the replacement of valuable pine destroyed by fires, by the less valuable poplar, have been estimated in certain cases, but these estimates have been based upon relatively few actual measurements. Three aspects of the problem of the burned pineries present themselves for solution, namely: (1) an estimate of the amount of young pine and poplar now present in relation to the number of times the area has been burned; (2) an inquiry as to whether the amount of the pine and poplar restocking the burned areas has sufficient present or potential value to justify care and protection; (3) an estimate of the financial losses, if any, incurred by allowing fires to replace pine forests with poplar or other forests.

James, T.D.W.; Smith, D.W. 1977. Short-term effects of surface burning on the biomass and nutrient standing crop of *Populus tremuloides* in southern Ontario. Can. J. For. Res. 7:666-679.

The standing crop of biomass and nutrients (N, P, K, Ca, and Mg) were estimated for *Populus tremuloides* trunk, lateral branch twig, and foliage in a 30-year-old open stand in West Luther Township, Wellington County, Ontario. Separate estimates were made for trees in areas subjected to light surface burning (about 160° C at the surface) and in unburned areas. Allometric relations between a variety of tree measures showed that the best estimates of standing crop were derived from simple log regressions with trunk dbh as the independent variable. The range of 7.0 to 8.9 $t{\cdot}ha^{-1}$ of total aerial aspen biomass was considerably lower than other reported values and reflected both the low stand density and poor site conditions. Accumulation of tree biomass was unchanged by light surface burning. Evidently, the environmental changes were too slight to cause postfire changes in the established overstory. Distribution of nutrients within the tree components was similar to that reported elsewhere; Ca and N were the two most abundant, while P, K, and Mg accumulations were much lower. The relative importance of various tree components as nutrient accumulation sites followed the order leaves > twigs > lateral branches > trunk. The leaves were the site of the accumulation of functionally important N, P, K, and Mg whereas the trunk was the prominent site for structurally important calcium. The total accumulation of all nutrients (103.5 $kg{\cdot}ha^{-1}$) was strikingly low in comparison with amounts reported for other deciduous forests. Accumulation of nutrients in the trunk, lateral branches, and twigs was not appreciably altered by fire. Major proportions of nutrients in these components would have accumulated before burning. Amounts of nutrients contained in leaf biomass were significantly changed after burning. Concentrations in leaves from burned areas were 24-42% higher than control levels, whereas the preburn levels were similar. These substantial postburn increases in leaf nutrient levels, related to a flush of soil nutrients from ash, would have an important effect on those wildlife species utilizing the aspen as a food source.

Logan, K.T.; Brown, W.G.E. 1956. Regeneration of red and white pine (*Pinus resinosa* and *P. strobus)* in the Great Lakes-St. Lawrence forest region. p. 172-180 *in* Proc. 12th IUFRO Congr. (July 7-14, 1956, Oxford, United Kingdom), Vol. I. Forestry Commission, London.

Describes the results of a survey of red and white pine reproduction in the central portion of this region in Eastern Canada. Regeneration is not generally satisfactory, and the survey was undertaken to determine in what circumstances adequate regeneration may be obtained. The forest site types studied are described. It was found that seed supply and relative vigour of pine seedlings and competing vegetation were the two main features controlling establishment of pine regeneration. Examples of these conditions in the various forest site types are described. The importance of seed supply is stressed. Features which discourage competing species, such as drought and severe fire, were found to favour pine regeneration. For application in pine management, the forest site types were grouped into four regeneration groups, based on the ease with which pine could be regenerated.

Maini, J.S.; Horton, K.W. 1966. Reproductive response of *Populus* and associated *Pteridium* to cutting, burning and scarification. Can. Dept. For. Rural Dev., For. Br., Ottawa, Ont., Dept. Publ. No. 1155. 20 p.

Regeneration response of *Populus tremuloides*, *Populus grandidentata* (aspens) and *Pteridium aquilinum* (bracken) to cutting, to two degrees of ground scarification and burning and to removal of ground vegetation were studied in a field experiment in southern Ontario. The treatments resulted in significant increases in superficial soil temperature. The increase was generally related to the degree of disturbance, being greater in relatively more disturbed areas. Soil temperature and density of aspen suckers and bracken fronds were higher on the cut than the uncut treatment plots. Suckering response was very low on the untreated ground and the control. However, data indicate non-aggregation of suckers when the density is low. Root suckering response of aspen as measured by a Reproduction Index (R.I.), was considerably greater in cut than in uncut plots and in burned and scarified plots compared with control. Values for the different ground treatments were remarkably similar in cut plots. Sucker density was generally lower in fall than in mid-summer; R.I. values for bracken were similar for all treatments in mid-summer; in the fall, after early and mid-summer clipping, R.I.'s were greatest in the control and greater in the cut than the uncut plots. To promote aspen regeneration under these conditions, removal of the trees, bracken, litter and duff is advocated; to discourage suckering and bracken competition for conversion of stand to more valuable conifers, removal of bracken only is suggested.

Maissurow, D.K. 1935. Fire as a necessary factor in the perpetuation of white pine. J. For. 33:373-378.

This paper presents the results of studies concerning natural regeneration of white pine in relation to forest fires. The investigation covered an area of about 600 square miles and was made up of approximately 70% softwoods which were white and red pines, black and white spruces, hemlock, and balsam fir. Hardwoods, represented by white birch, aspen, yellow birch and sugar maple made up the remaining 30%. The essential features of natural regeneration of white pine during the period 1850-1930 were: (1) logging did not result in pine reproduction directly following cutting; (2) the bulk of white pine reproduction established during this period was confined to areas burned over and came into being as a direct result of forest fires; (3) pine reproduced in the open, in very thin stands, on exposed mineral soils and on soils partially devitalized and neutralized through submersion; (4) the factors or agents effecting these favourable conditions were, in the order of their importance, as follow: forest fires, erosion, inundation, and wind. These agents, in their effect upon forest soils, tended to reduce soil acidity and to eliminate the competition of forest cover and its roots. Freedom from competition with forest cover and low soil acidity, therefore, seemed to be just as important and deciding factors as abundance of light.

Rouse, C. 1986. Fire effects in northeastern forests: red pine. USDA For. Serv., North Cent. For. Exp. Stn., St. Paul, Minn. Gen. Tech. Rep. NC-129. 9 p.

Fire and red pine are closely associated. Red pine has developed thicker bark and grows taller than its associates such as white pine and spruce. After red pine is 60 feet tall (roughly 50 years old) the bark is thick enough to protect the cambium from all but the most extreme fires. Although tall trees are still susceptible to crown damage, they may survive even though 85 percent of their original crown was scorched. Fires can provide red pine with the mineral soil exposure and freedom from competition it needs to become well established. Fire can also be used to control pests such as the red pine cone beetle. In the Lake States, the beetle can be reduced with low intensity fires carried out between October 22 and May 10. Judicious use of fire might also limit other pests. For instance, hare and mice could be deterred by eliminating understory cover. Fire can also be used to increase tree growth, enhance aesthetics, and improve wildlife habitat. [expanded from original abstract]

Rouse, C. 1988. Fire effects in northeastern forests: oak. USDA For. Serv., North Cent. For. Exp. Stn., St. Paul, Minn. Gen. Tech. Rep. NC-105. 7 p.

Many of today's oak stands have evolved as part of a community subjected to recurring fires. Recent management difficulties in establishing natural oak regeneration may be due, in part, to a changed forest floor brought about by an absence of fire. Existing forest floors on some oak sites provide a more favourable seed bed for more tolerant tree species but a poor seed bed for acorns. Controlled fire may play a critical role in the natural perpetuation of the upland oaks types. For instance, seedling establishment may be increased by burning due to a decrease in litter depth and exposure of mineral soil. Also, competition from other species might be reduced and the proportion of oaks in advanced reproduction might be increased by fire. And, after stand establishment, fire might be used to keep less desirable species from encroaching under oak. [summary]

Van Wagner, C.E. 1970. Fire and red pine. Tall Timb. Fire Ecol. Conf. 10:211-219.

Red pine, even more than white pine, depends on fire for its existence in any quantity in the natural forest. Red pine needs either a mineral seedbed or one lightly covered with duff, as well as fair freedom from brushy competition in the first few years. It is also rather intolerant of shade and does poorly under a full canopy. Fire is the only natural agent capable of providing all the required conditions. Generally speaking, the more intense the fire, the better the job of ground preparation. Red pine produces the most flammable pure stand of any northeastern tree species when growing at high density with a clean floor. In Canada, however, most red pine occurs in combination with white pine or the intolerant hardwoods, and flammability is somewhat reduced. Pine (red and white) stands maintain maximum flammability up to heights of about 60 feet, and thereafter the possibility of crown fire is lessened by the increasing height of the open trunk space. Red pine is a species that depends heavily on fire because of its silvics but has also evolved very little in any way that takes positive advantage of fire. The physical features that distinguish red pine from most other tree species with respect to fire are the flammability of its stands, and its relatively resistant bark. And yet the very flammability that invites the necessary fire also works against red pine since it is very liable to total destruction before the age (about 50) at which it produces appreciable seed and has a fairly protective bark. In view of its rather difficult requirements for regeneration, it may well be that natural red pine is, in the evolutionary sense, on the way out. [abstract adapted from body of report]

Van Wagner, C.E. 1973. Height of crown scorch in forest fires. Can. J. For. Res. 3:373-378.

A relation between fire behavior and crown scorch height is derived from measurements on 13 experimental outdoor fires. The range of data includes fire intensities from 16 to 300 kcal/s-m, and scorch heights from 2 to 17 m. The results agree with established theory that scorch height varies with the 2/3 power of line-fire intensity. The effects of air temperature and wind speed on scorch height are treated as well. The derived relations could be useful to those interested in prescribed burning under a crown canopy, ecological response of trees to fires of varying intensity, and timber losses following forest fires.

Weber, M.G. 1990. Response of immature aspen ecosystems to cutting and burning in relation to vernal leaf-flush. For. Ecol. Manage. 31:15-33.

Vegetative reproduction, above-ground biomass and nutrient pools, and litterfall and substrate nutrient conditions were evaluated in eastern Ontario immature (age 20 years) aspen (*Populus tremuloides* Michx. and *P. grandidentata* Michx.) ecosystems which had been subjected to the following four treatments in relation to vernal leaf flushing: burning before; burning after; cutting before; and cutting after flushing. An untreated control area was set aside for appropriate comparisons. Three years after treatment, the greatest numbers of stems$\cdot$ha^{-1} were supported by the pre-flush cutting treatment (11,000 stems$\cdot$ha^{-1}) followed in decreasing order by post-flush cut (9,000 stems$\cdot$ha^{-1}), post-flush burn (4,000 stems$\cdot$ha^{-1}), and pre-flush burn (2,000 stems$\cdot$ha^{-1}). No suckering was observed on control plots. Above-ground aspen biomass and nutrient-pool values reflected stem densities and these results were discussed in light of known physiological responses of the species to disturbance. Litterfall mass and nutrient inputs over the 3-year observation period were also a function of treatment and reflected stand break-up. There was reduced suckering on the two burning treatments compared with more vigorous suckering on the cuts. Thus, 3-year totals for litterfall mass (kg$\cdot$ha^{-1}) were: post-flush burn 29,470; 21,393; 10,182; 3,022; and 1,762 on post-flush, pre-flush burn, control, pre-flush cut, and post-flush cut, respectively. High litterfall biomass values on the burning treatments were a result of overstorey mortality, which reached 100% after three years. Nutrient returns through litterfall followed litterfall biomass input trends. Forest-floor and mineral-soil nutrient pools on the burns showed treatment effects one month after burning which were interpreted in terms of removal of part of the forest floor, changed N-mineralization rates, cation leaching from ash, and differences in nutrient-uptake patterns by surviving overstorey. After three years some treatment effects were still noticeable in forest-floor and, to a lesser extent, in mineral-soil nutrient pools.

3.2.2 Influence of fire on vegetation: community structure and biodiversity

Abrams, M.D.; Scott, M.L. 1989. Disturbance-mediated acceleration succession in two Michigan forest types. For. Sci. 35:42-49.

In northern lower Michigan, logging accelerated sugar maple (*Acer saccharum*) dominance in a northern white cedar (*Thuja occidentalis*) community, and clearcutting and burning quickly converted certain sites dominated by mature jack pine (*Pinus banksiana*) to early-successional hardwoods, including *Prunus*, *Populus* and *Quercus*. In both forest types the succeeding hardwoods should continue to increase in the future at the expense of the pioneer conifer species. In the cedar example, sugar maple was also increasing in an undisturbed, old-growth stand, but at a much reduced rate than in the logged stand. Traditionally, disturbance was thought to set back succession to some earlier stage. However, our study sites and at least several other North American forest communities exhibited accelerated succession following a wide range of disturbances, including logging, fire, ice storms, wind-throw, insect attack, and herbicide spraying.

Ahlgren, C.E. 1979. Buried seed in the forest floor of the Boundary Waters Canoe Area. Minn. For. Res. Note No. 271. 4 p.

Seed was extracted in 11 areas from soils: (1) beneath pine stands last burned from 3 to 200 years ago; (2) beneath a mixed balsam fir stand, and (3) beneath mature aspen stands. Although the numbers of seed in the soil decreased strikingly with time since disturbance, substantial numbers of seed were still present in soil of old pine forests. Included are seeds of species characteristic of recently disturbed lands: bindweed (*Polygonum cilinode* Michx.), cranesbill (*Geranium bicknelli* Britt.), and raspberry (*Rubus* spp.), plants of which were absent or infrequent and nonfruiting in the old forest. Because seed viability was determined for all plots combined, viability of seed in the old growth stands is not known. If the seed is viable, considerable early post-disturbance vegetation may originate from seeds in the soil before the disturbance, possibly since the last disturbance. This source of seed for the initial stages of post-disturbance plant succession must not be overlooked. [expanded from original abstract]

Ahlgren, C.E. 1979. Emergent seedlings on soil from burned and unburned red pine forest. Minn. For. Res. Note No. 273. 4 p.

Intact soil blocks from an unburned, old red pine forest and comparable soil burned by wildfire were placed in a greenhouse. Seed was extracted from other soil samples on the same area. The stimulus of increased light is often associated to be a major factor in post-fire vegetational response. These results suggest that other, unidentified factors may also be important for the appearance of some species characteristic of early post-fire vegetation. The flats from both burned and unburned areas received similar light, temperature, and moisture. Seedlings were more numerous, however, on the burned soil. This was particularly true for cranesbill (*Geranium bicknelli* Britt.), where 10 times more seed was found in the unburned area, and for sedge where twice as much seed was found in the unburned area. Grass species and bedstraw (*Galium triflorum* Michx.), were also more numerous on soil from the burned area. Species with seeds wind disseminated after fire (*Sonchus arvensis* L., *Cirsium arvense* (L.) Scop., and *Apocynum androsaemifolium* L.) also germinated only in soil from the burned area. Therefore, factors other than light and seed availability are involved in the appearance of at least seven species on burned soil and their absence in older forests. Not all species were similarly affected. One species, vetch (*Vicia americana* Muhl.) appeared to be unaffected by fire since it was similarly present in both areas. Still other species, false lily of the valley (*Maianthemum canadense* Desf.) and violet (*Viola* spp.), were favoured by conditions present in the old forest soil. [expanded from original abstract]

3.2 Influence of fire on vegetation (Great Lakes - St. Lawrence)

Cooper, W.S. 1913. The climax forest of Isle Royale, Lake Superior, and its development. III. Bot. Gaz. 55:189-235.

Eastern North America north of Florida and Mexico is divided into two great phytogeographic regions, the eastern deciduous forest and the northeastern conifer forest. In each of these a number of lines of succession may be traced, all those of a region leading to a certain forest type as the final or climax stage. This final type in its large features is determined by climate, and is much the same throughout the region which it dominates. In the eastern deciduous forest the climax type is made up of *Acer saccharum* Marsh (sugar maple) and *Fagus grandifolia* Ehrh. (beech), with the addition of various other species in some portions of the country. The nature of the climax forest of the northeastern conifer region has not hitherto been determined.

Isle Royale lies just within the limits of the northeastern conifer region, barely within, for one of the farthest outposts of the deciduous forest is located on its southwestern end, where there is a considerable area dominated by the sugar maple, in mixture with more northern trees. Except for the maple and a few of its companion species, the flora of Isle Royale belongs strictly to the northeastern conifer region.

The purpose of the present work was to determine the climax forest of Isle Royale, its composition and character, and to trace the various lines of succession leading to it. It is thus a successional study of small component portion of the northeastern conifer forest.

At the beginning of the investigation Isle Royale was selected as a field of study because it shows transitional features between the two great forest regions, my original purpose being to devote particular attention to the relations between the conifers and the maple. Circumstances made it impossible to give adequate study to the region dominated by the latter, therefore the work developed into an investigation of the balsam-birch-spruce forest (the northeastern climax) and its attendant successions. For a study of the northeastern forest a more centrally located are might have been preferable; for instance, at some point midway between Lake Superior and James Bay. It will be shown, however, that Isle Royale affords a very fair sample of the forest growth of the northeast region. It also possesses certain very important advantages which would be lacking in a more centrally located area. Because of its insular position the forest has been less liable to destruction by fire, and the many bays and channels separating various portions of the main island and the outlying islets have served as effective barriers against its spread. Though they have occurred many times during the island's history, it is certain that fires have been far less frequent and destructive here than upon the mainland. The forest may thus be studied in a condition that is as near to being undisturbed as will be found anywhere. Comparative freedom from the destructive agency of man is a second advantage. Again, the island has had a simple physiographic history during the present vegetative cycle, and thus the relation of vegetation to physiography may be the more readily made out. Further, the proximity of the lake shores permits the observation of the earliest stages in the establishment of vegetation upon the rock surfaces, these stages being frequently absent or poorly developed in an inland locality. Finally, the fact that the field of study is an island gives definiteness to the area covered by the investigation. (part of journal introduction)

Drexler, R.V. 1941. Forest communities of the Quetico Provincial Park of Ontario. Proc. Iowa Acad. Sci. 48:123-127.

The observations outlined in this paper are the result of trips in the Quetico during the summers of 1934, 1938 and 1939. A study of the vascular vegetation was not the primary purpose of these trips, but it was necessary to form some opinion concerning the forest communities. Numerous studies have been published concerning the Coniferous Forest, but none of these papers apply particularly to the forest communities of the Quetico.

Duchesne, L.C.; Weber, M.G. 1993. High incidence of the edible morel *Morchella conica* in a jack pine, *Pinus banksiana*, forest following prescribed burning. Can. Field-Nat. 107:114-116.

Mushrooms of the ascomycetous fungus *Morchella conica* Fr. were observed at a density as high as 2,860 $kg \cdot ha^{-1}$ in a *Pinus banksiana* Lamb. stand in May 1991 at the Petawawa National Forestry Institute, Chalk River, Ontario. This forest stand had been treated with prescribed fire the previous fall. Mushrooms were found singly or in clusters within a radius of 2-3 m around dead *Pinus banksiana* trees but not around dead specimens of *Pinus resinosa* Ait. and *Pinus strobus* L.

Faberlangendoen, D.; Davis, M.A. 1995. Effects of fire frequency on tree canopy cover at Allison Savanna, eastcentral Minnesota, U.S.A. Natural Areas J. 15:319-328.

Allison Savanna (bur oak-northern pin oak barrens) in eastcentral Minnesota has been managed since 1962 using prescribed burns conducted at different intervals in eight units. To evaluate fire management success, preburn tree canopy cover was digitized from aerial photos in 1938 and 1960 (prior to burning) and again in 1987 (following 25 years of burns). The fire interval ranged from 1.6 to 5.0 years. Change in tree canopy cover was compared between 1938 and 1960, and between 1960 and 1987, to determine the relationship between fire interval and canopy cover. In all units, canopy increased between 1938 and 1960, prior to prescribed burning. In 1987, after 25 years of periodic burning, change in canopy cover showed a significant negative relationship with the number of burns. Percent of wetland in each burn unit did not have a significant effect on changes in canopy cover. Three vegetation plots established in 1990 in unburned, low-, and high-burn frequency units showed that, with increased burns, fires limited oak recruitment. Mature bur oaks (*Quercus macrocarpa*) were more abundant than northern pin oak (*Q. ellipsoidalis*) in the high-burn unit. Age of bur oak stems ranged from 20 to 200+ years, whereas northern pin oak was usually < 30 years. Results of these small-scale burns should be interpreted cautiously at larger spatial and temporal scales because of the longevity of oaks and the interactions of fire with climatic conditions and topographic features.

Frelich, L.E.; Reich, P.B. 1995. Neighborhood effects, disturbance, and succession in forests of the western Great Lakes region. Ecoscience 2:148-158.

Neighborhood effects that enhance conspecific replacement at the time of canopy-tree death were examined in 3 cold-temperate forest types, using spatial analyses and historical reconstruction on mapped plots. Important neighborhood effects in these forests include overstory-understory effects whereby a species enhances likelihood of self replacement by influencing the local understory, and disturbance-activated effects that switch on after stand-killing disturbance. Neighborhood analyses (radius 9 m) show that understory composition is significantly related ($p < 0.001$) to overstory composition in a hardwood-hemlock forest, but not in white pine or near-boreal jack pine forests. Jack pine has strong disturbance-activated effects in the form of abundant serotinous seedfall after fire. White pine apparently has no significant neighborhood effects of either type. Other species are likely to replace white pine in treefall gaps, and after fire it must reinvade a given neighborhood by means of outside seed sources. In the forest types with strong neighborhood effects a change in the usual disturbance regime may occur that overwhelms the self-replacement mechanisms. Such events would include lack of fire in near-boreal jack pine forest, which causes succession to a spruce-fir-birch-cedar mixture, and intense fire after heavy windfall in hardwood-hemlock forest, which can convert the forest to paper birch and aspen. From the point of view of species compositional stability, these changes in disturbance regime are true catastrophes, unlike stand-killing fires in jack pine or complete canopy windthrow in hardwood-hemlock. These compositional catastrophes initiate episodes of succession, which are relatively short periods of rapid change in species composition. The neighborhood-effects hypothesis of forest dynamics predicts that forest types with weak neighborhood effects have temporal instability of composition, with recovery from disturbance and related successional sequences nearly always in progress, whereas species composition may be generally stable with sudden alternation between different states in forests with strong neighborhood effects.

Graham, S.A. 1941. Climax forests of the Upper Peninsula of Michigan. Ecology 22:355-362.

Data obtained in this study of mixed hardwood/hemlock forests on clay and sandy clay soils indicate that the probable course of succession following a severe burn several hundred years ago was: (a) invasion of burn by aspen; (b) aspen replaced by white pine, yellow birch, hemlock and sugar maple; (c) decrease of yellow birch and increase of hemlock and sugar maple; (d) gradual disappearance of pine leaving a mixed hardwood/hemlock forest; (e) this would tend more and more toward a hemlock/sugar maple/basswood forest, the ultimate hypothetical climax, though its establishment may be prevented normally over extensive areas by action of wind, fire, fungi, and insects.

Grigal, D.F.; Ohmann, L.F. 1975. Classification, description, and dynamics of upland plant communities within a Minnesota wilderness area. Ecol. Monogr. 45:389-407.

The major upland plant community types of the Boundary Waters Canoe Area (BWCA) of northeastern Minnesota, identified by multivariate analyses (clustering and canonical and discriminant analysis) of 68 stands disturbed by logging and 106 stands undisturbed by logging, include the following: lichen, jack pine-oak, red pine, jack pine-black spruce, jack pine-fir, black spruce-feather moss, maple-oak, aspen-birch, aspen-birch-white pine, maple-aspen-birch, maple-aspen-birch-fir, fir-birch, and white cedar. Each of these types is based on a complex of 53 common species, though the name may incorrectly imply that one or two dominant overstory species are indicative of the type. Other forest stands from the BWCA are quantitatively related to the regional vegetation through discriminant analysis. Succession on the uplands area, without disturbance, leads to fir-birch and ultimately to the white cedar community type. Whitetail deer may have had an impact on restricting the occurrence and reproduction of the white cedar type.

Grigal, D.F.; Ohmann, L.F. 1980. Seasonal change in nutrient concentrations in forest herbs. Bull. Torrey Bot. Club 107:47-50.

Growing season changes in nutrient element concentrations in forest herbs may affect studies of above-ground nutrient mass. We attempted to determine if stable period existed during which concentration variation would be minimized. All herbaceous vegetation in 10 randomly located plots within each of seven stands [1971 Little Sioux Fire area] was clipped at ground level and analyzed biweekly from mid-June through late July, and once again in mid-August [1974]. For elements N, P, K, Ca, and Mg there were generally significant differences in concentrations from mid-June through late July. However, only Ca concentration changed significantly from late July to mid-August. August, a pre-senescence period of minimal above-ground nutrient change, is an appropriate time to sample herbs for nutrient content.

Comments: The seven stands were the same as those sampled by Ohmann and Grigal (1979).

Grimm, E.C. 1984. Fire and other factors controlling the Big Woods vegetation of Minnesota in the mid-nineteenth century. Ecol. Monogr. 54:291-311.

Bearing-tree data from the original land survey records of 1847-1850 were used to reconstruct the vegetation of the Big Woods and adjacent areas along the prairie-woodland border in south-central Minnesota. The characteristic tree taxa of the Big Woods were elm (*Ulmus*), basswood (*Tilia americana*), sugar maple (*Acer saccharum*), ironwood (*Ostrya virginiana*), bitternut hickory (*Carya cordiformis*), butternut (*Juglans cinerea*), and ash (*Fraxinus*). The most common tree was elm, which comprised 27% of the bearing trees. A buffer zone of fire-tolerant oaks and aspen generally lay between the Big Woods and the prairie. The width of this zone depended on topography and on the presence of additional firebreaks, which in places formed sharp boundaries between the Big Woods and oak-aspen. The prairie-woodland border was characteristically a sharp boundary along firebreaks (water bodies and physiographic breaks). In some places very effective firebreaks formed sharp boundaries between prairie and the Big Woods, with no intervening oak-aspen zone. The vegetation was most strongly correlated with the fire-probability pattern, which was a function of both abiotic and biotic factors. Soils influenced the probability of fire, but they also were the major factor controlling the vegetation within areas of similar fire probability. Soil drainage was the most important factor controlling vegetation within the units. Because the locations of firebreaks and the existing pattern of vegetation controlled the fire probability pattern, sites with virtually identical physical characteristics supported qualitatively different types of persistent or stable vegetation.

Heinselman, M.L. 1981. Fire and succession in conifer forests of northern North America. p. 374-405 in Forest Succession: Concepts and Application, West, D.C., Shugart, H.H.; Botkin, D.B. (eds.) Springer-Verlag, N.Y.

From Minnesota and Ontario east to New Brunswick there are large areas of jack pine, black spruce, fir-spruce, and aspen-birch-fir forests not unlike those of the eastern boreal forests. A 3 or 4-year postfire establishment period sets the stage for most subsequent vegetation changes. Most fires are

crown fires or high-intensity surface fires that kill the above-ground vegetation.
Postfire Establishment Period. Two recent fires in the Boundary Waters Canoe Area Wilderness of Minnesota (BWCAW) demonstrate the importance of initial floristics, season of burn, and organic matter consumption in determining stand composition. The Little Sioux Fire of May, 1971, was a human-caused spring fire after a short drought. The Roy Lake Fire of August, 1976, was a lightning-caused summer fire after prolonged drought. Both study areas were on ridges with thin, bouldery soils over granitic bedrock, both had organic layers varying in thickness from 3 to 20 cm, and both supported stands dominated by jack pine and black spruce, with some aspen and paper birch, and variable understories of balsam. I shall compare two jack pine stands from the Little Sioux with three conifer stands from Roy Lake (Ohmann and Grigal 1979).

Both Little Sioux stands occurred in an area previously burned in 1864, supporting jack pine communities 107 years old. Both burned in an intense crown fire, but because the organic layer was still set below the surface, several centimetres of unburned organic matter remained (Ohmann and Grigal 1979). On the Roy Lake Fire, three burned stands, each with different prefire composition and stand age, were sampled in July, 1979. Stand 1, on Sea Gull Lake, was a 175-year-old mixed conifer stand dating from an 1801 burn; Stand 2, on Grandpa Lake, was a 101-year-old upland black spruce area dating from an 1875 fire; and Stand 3, on Saganaga Lake, was a 73-year-old jack pine stand dating from a 1903 burn. All burned in high-intensity crown fires. The organic layer was almost entirely consumed.

Comparison of prefire data with third-year regeneration data (Ohmann and Grigal 1979) leads to the following conclusions: Jack pine and black spruce reproduced abundantly on mineral soil on all sites at Roy Lake. Jack pine also reproduced well on the Little Sioux, although not as abundantly as at Roy Lake, but black spruce failed almost completely. Close inspection shows that most jack pine seedlings became established locally where the organic layer was thin or absent. Some of the failure of black spruce may have been due to seed kill by the intense crown fire, but similar intensities at Roy Lake resulted in heavy spruce reproduction. There was major seeding in of aspen on mineral soils at Roy Lake, although some of these high aspen counts are due to clumps of suckers near fire-killed trees. No comparable seeding of aspen occurred in the Little Sioux jack pine stands. The future of aspen seedlings at Roy Lake is unclear. Many may eventually be eliminated by beaver, hares, and moose, or suppressed by competing jack pine on the drier sites. Moose increased rapidly on the Little Sioux burn, and are now heavily browsing aspen and shrubs (Peek 1974). Balsam, the major potential replacement species on both fires, was eliminated in all stands. However, field observations show that seed trees exist nearby in unburned enclaves, along lakeshores, streams, bog margins, and at the perimeter of the burn. Given a century for reseeding, balsam too will probably regain its former status. Thus, fire will probably have changed the tree stratum little in the end, except for decreases of black spruce on the Little Sioux.

The shrub and herb strata in the Little Sioux stands virtually recovered to prefire conditions within 5 years (Ohmann and Grigal 1979). Vegetative reproduction of many shrubs and herbs and the germination of seeds stored in the organic layer occurred because the organic layer was so lightly burned. The fire ephemerals, *Corydalis*, *Geranium bicknellii*, *Polygonum cilinode*, and *Aralia hispida*, flowered profusely, but by 1975 were much reduced. *Prunus pennsylvanica* became a major tall shrub. Even such plants as *Clintonia borealis* and *Lycopodium obscurum*, not usually considered "pioneers", reproduced vegetatively in abundance. Only the moss and lichen ground layers were temporarily eliminated. As Ohmann and Grigal (1979) summarized it, "The major change in stand structure was lowering of the tree canopy from a former height of 10 to 20 m to 0.2 after the first growing season following the fire.

At Roy Lake, the shrub, herb, and ground layer revegetation was substantially different. The much greater exposure of mineral soil led to abundance of the fire invaders, *Marchantia*, *Funaria, Polytrichum, Polygonum,* and *Epilobium*, but the fire ephemerals that depend on stored seeds were much less common. Most of the herbs and shrubs that reproduce vegetatively were also much reduced. Thus, by removing the organic layer at Roy Lake, fire greatly increased the stocking of black spruce and jack pine, allowed more seeding of aspen, and greatly reduced the competition from the shrubs and herbs that reproduce vegetatively or from seed stored in the organic layer. Ahlgren (1959, 1960) reported similar early revegetation and tree seedling establishment.

Hengst, G.E.; Dawson, J.O. 1994. Bark properties and fire resistance of selected tree species from the central hardwood region of North America. Can. J. For. Res. 24:688-696.

Some physical, thermal, and chemical properties of bark of 16 tree species native to the central hardwood region were measured to determine their potential to protect the vascular cambium from damage by fire. The relationship between DBH and bark thickness for each of 16 species was determined. For purposes of monitoring seasonal trends, two species (*Quercus macrocarpa* Michx. and *Acer saccharinum* L.) were sampled periodically during one growing season. Temperature response to bark surface heating of 11 species was monitored at the cambial layer during simulated fires conducted in the field. Bark samples were analyzed for moisture content, specific gravity, dry weight, volatile matter content, and time until ignition. Overall, during simulated fires, temperature gradients were decreased and maximum cambial temperatures were reduced as bark thickness increased. Thick-barked species had lower maximum cambial temperatures, longer times to reach peak temperatures, slower rates of heat loss, and shorter time until surface ignition. *Populus deltoides* Marsh. was the most heat resistant among species tested, while *Acer saccharinum* was the least. Higher specific gravities were associated with higher rates at which cambial temperatures rose as well as with increased time required for surface ignition.

Martin, N.D. 1959. An analysis of forest succession in Algonquin Park, Ontario. Ecol. Monogr. 29:187-218.

An hypothesis of forest succession in Algonquin Park was made based on the critical observation of large expanses of forest, usually from such vantage points as hilltops. This hypothesis was then tested by establishing study plots in the major forest types and ecotones.

Each plot was about 25 acres and usually square. Grid lines were laid out at 100-ft. intervals, and using these lines the vegetation was sampled on about 5% of the total area of each plot. Trees of all sizes were counted and their diameter measured, and the frequency of the most abundant shrubs and herbs determined.

Although there was often great diversity in the tree species composition of forests, there was a general pattern of forest succession. There was a hydrosere on wet ground and a xerosere on uplands.

In the hydrosere, primary succession following Pleistocene glaciation was from bog to *Picea mariana* forest, to *P. mariana-Thuja occidentalis* forest, to bottomland forest (*Abies balsamea-Alnus*).

In the xerosere, climatic succession, according to pollen analysis, was from *Abies balsamea-Picea glauca* forest to *Pinus strobus*, to hardwoods (*Acer saccharum* and *Betula lutea*) and *Tsuga canadensis*. Secondary succession, following cutting and fire in the xerosere, was from a pioneer forest of either *Betula papyrifera-Populus tremuloides* or *Pinus banksiana*, to a forest of either *Abies-Picea* or *Pinus strobus*, to a subclimax of hardwoods, to a climax of *Tsuga*.

Tsuga invaded stands of *Acer saccharum*. Although its seedlings were relatively few, these grew successfully in the shade of both *Acer saccharum* and parent trees of *Tsuga*. Seedlings of *Acer saccharum* survived under parent trees of *Acer*, but not under the crowns of *Tsuga*.

Corresponding with the succession of trees, there was a succession of shrubs and herbs. The ground changed with the forest cover, being mull in deciduous forests and mor in coniferous.

The vegetation on slopes did not vary noticeably from one exposure to another [summary].

Maissurow, D.K. 1941. The role of fire in the perpetuation of virgin forests of northern Wisconsin. J. For. 39:201-207.

In view of a lack of precise factual data on the importance of fire as a necessary factor in the perpetuation of certain species and types, the author undertook a series of studies, the general purpose of which was to ascertain the role of fire in the perpetuation of the virgin forest. The investigation, carried out for a period of two and half years, was centred in the northern half of the Nicolet National Forest, Wisconsin. The investigation was based primarily on the study of composition and age structure of virgin stands, and the factual data were obtained from the following sources or methods of investigation: (1) comparative study of reproduction and of composition of stands by crown classes, (2) analysis of age structure of stands, and (3) study of composition and age structure of rehabilitating burns. Results indicated that fires had been necessary factors or agents in the perpetuation of a number of species, such as yellow birch, hemlock, pines and intolerant hardwoods, thus shaping and determining the form and composition of the forest. As a result of periodic destruction by fires, the forests have assumed a mixed form, characterized by the presence in the same stand of (1) uneven-aged groups developed during periods of uninterrupted growth and made up of tolerant hardwoods, maple and basswood, and (2) of one or more even-aged groups of fire-origin composed of species which are unable to reproduce readily on the forest floor.

Mayall, K.M. 1941. White pine succession as influenced by fire (interim report). National Res. Council Can., Ottawa, Ont. N.R.C. Publ. No. 989. 32 p.

This report covers a survey, conducted in 1939-1940, of white pine cover-types in the Ottawa Valley Region, to: (1) study present conditions of regeneration on cut-over and burned-over stands; (2) chart probable succession of vegetation; (3) rate the significance of fire, and other factors influencing pine regeneration; (4) deduce improvements in management methods. Historical data, and statistics of present supplies are briefly summarized. Previous regeneration surveys were analyzed, and pertinent deductions are given. Seven widely distributed areas, on both sides of the Ottawa River, were examined. Data of fire history, soil conditions, herbaceous, shrub, and tree vegetation and tree growth, were recorded. The conclusions are: (1) white pine regeneration on cut-over and burned-over lands is insufficient for future requirements; (2) white pine in a tolerant hardwood cover-type is no longer significant; (3) there are not sufficient seed trees after cutting. Maximum number of seedlings is not greater than double the number of the stand present prior to cutting, which is inadequate; (4) burning in stands of mature timber stimulates regeneration. Results of fire in young stands are doubtful. More data are required concerning: (a) seed supply, germination, survival; (b) effect of weevil and blister rust; (c) degree of burn and its effect upon soil; (d) minimum number of seed trees required; (e) relative effect of spring and autumn fires.

Methven, I.R. 1973. Fire, succession and community structure in a red and white pine stand. Environ. Can., Can. For. Serv., Chalk River, Ont. Inf. Rep. PS-X-43. 18 p.

After two consecutive annual, low intensity experimental fires in a 90-year-old *Pinus resinosa/P. strobus* stand in 1970 and 1971, damage to the overstory and consumption of the organic layer were very slight, the *Abies balsamea* understory was eliminated, and the growth of shrubs and herbs was considerably reduced. However, the differences between the vegetation one year after the fires, and that present three years earlier before the fires amounted largely to changes in species density and biomass rather than changes in species composition. There was no radical alteration of the ecosystem but merely the creation of an environment more conducive to pine regeneration.

Ohmann, L.F.; Grigal, D.F. 1985. Biomass distribution of unmanaged upland forests in Minnesota. Forest Ecology and Management, 13(1985) 205-222.

A floristic analysis of natural and logged upland forest communities previously identified 12 forest and one non-forest community-types within the Boundary Waters Canoe Area Wilderness of Minnesota. Data collected for the floristic analysis were applied to biomass estimation equations to produce estimates by species for stands within each community-types. Total above-ground biomass was 4 t/ha in the non-forest community-types, and ranged from 121 t/ha in the jack pine-oak type to 268 t/ha in the red pine type. Highest biomass occurred in community-types with long-lived tree species; however, all community-types have similar mean annual biomass increments. Biomass distribution by vegetative strata within and among the community-types was examined. Distribution of biomass among undergrowth strata varied significantly with community-type. Total undergrowth biomass, however, had a narrow range from 1.9 to 4.4 t/ha because the biomass for the different strata summed in a compensatory manner. Biomass among vegetative strata were related; an increase in biomass of the tree stratum was related to reduced biomass of lower strata. Such relationships were not sufficient to fully explain variations in biomass of those strata among community-types. Significant differences in biomass among community-types, and the lack of differences among random assignments of the same communities into 12 groups, suggests that the original floristic classification provided a valid basis to compare ecosystem properties.

Sidhu, S.S. 1973a. Early effects of burning and logging in pine-mixedwoods. I. Frequency and biomass of minor vegetation. Environ. Can., Can. For. Serv., Inf. Rep. PS-X-46. 47 p.

This report describes the early quantitative changes in frequency and biomass of minor plant species following partial logging and prescribed burning in pine-mixedwoods. A procedure for estimating changes in single species is proposed for forest situations where treated and control plots are not exact replicas of each other. The procedure works well for species of moderate to high abundance and gives unreliable estimates of change for less common species. Several species in the shrub stratum (*Abies*, *Acer*, *Kalmia*, *Vaccinium*) can be temporarily eliminated by prescribed fires. Hazel (*Corylus cornuta*) can be partially controlled by one light fire. *Betula* and *Populus* are favoured by one light fire. There is an increase in number of species of minor vegetation following logging, however the change in the number of species is not significant after burning. Following both logging and burning, there is a definite change in species composition and abundance. Seasonal changes in logged stands are of smaller magnitudes compared with the changes in unlogged-unburned stands. Total biomass of minor vegetation increased after logging and decreased after burning. Seasonally, there was little change in biomass in undisturbed stands, but biomass increased substantially from spring to summer in logged-unburned stands. The species are grouped in five response-categories. There was no apparent relationship between the reproductive biology of the species and their response category. However, species reproducing by seeds viz. *Geranium*, *Convolvulus*, *Polygonum*, *Prunus* become important after burning.

Sidhu, S.S. 1973b. Early effects of burning and logging in pine-mixedwoods. II. Recovery in number of species and ground cover of minor vegetation. Environ. Can., Can. For. Serv., Inf. Rep. PS-X-47. 23 p.

Recovery in number of species and ground cover of minor-vegetation following logging and experimental burning in pine-mixedwoods with standing timber is described in this report. Following logging there is an increase in percent ground cover and the order of importance of the first 8 species is least affected. Following experimental burning, the recovery of minor-vegetation is rapid. The percent ground cover and the numbers of species reach the pre-burn levels by the first spring following the burn. Except *Geranium* (absent or rare on unburned stands), the first 7 species are the same on unburned and burned stands. However, *Pteridium*, *Carex*, and *Aster* become more important while *Aralia*, *Maianthemum* and *Corylus* become less important after burning.

Sidhu, S.S. 1974. Early effects of burning and logging in pine-mixedwoods. III. Diversity. Environ. Can., Can. For. Serv., Inf. Rep. PS-X-54. 22 p.

This report describes the early changes in the diversity indices of three vegetation strata following partial logging and experimental burning in pine-mixedwoods. Shannon's diversity index was used in this study. The diversity index was found to be independent of sample size once the sample size had reached a certain minimum. After partial logging, the diversity decreased in the tree and shrub strata. There was a general increase in the diversity of the minor-vegetation stratum following logging. Following experimental fires, the diversity of the shrub stratum was reduced to zero simply by the temporary removal of the stratum. A decrease of about 50% occurred in the diversity of the minor-vegetation stratum following burning. The diversity loss will continue for decades in the tree stratum and for several years in the shrub stratum, whereas diversity of the herbaceous stratum is estimated to reach the prelogging and preburn levels after five to eight years.

Vogl, R.J. 1969. One hundred and thirty years of plant succession in a southeastern Wisconsin lowland. Ecology 50:248-255.

The post-glacial history of a marl and peat marsh contained evidence that early hydrarch succession may have been relatively rapid due to higher plant as well as invertebrate animal productivity. Pristine open marsh, sedge meadow, and wet prairie were held in quasi-equilibrium by alternations of floods during wet periods and fires during drought. Fires either checked terrestrial advancement or turned it back to earlier aquatic stages by organic substrate removal. Recent fire control and continued lowering of water levels hastened intermediate hydrarch succession by quickly and directly converting aquatic to terrestrial sites. A peat burn increased soil pH and soil nutrients, particularly the phosphates, and eliminated plant competition so that open marsh was immediately invaded by aspen forest, which if uninterrupted, will be converted to lowland hardwood forest. Recurring fires could perpetuate the sucker-sprouting aspen, but burning decadent aspen forest might originate true prairie. Although fire is usually catastrophic and retrogressive, it produced successional stability and even acted as a successional accelerator in this lowland.

3.3 Influence of fire on fauna: populations, habitat

Apfelbaum, S.I.; Haney, A. 1981. Bird populations before and after wildfire in a Great Lakes pine forest. Cooper Ornith. Soc. 347-354.

Birds in a 6.25-ha quadrant in a 73-year old jack pine-black spruce forest (*Pinus banksiana-Picea mariana*) in Cook Co., Minnesota were intensively studied in June 1976. A wildfire burned through the area in August. The following spring we resurveyed the same quadrant to determine the density, territorial space, existence energy, and importance values. Twelve species had territories in the study grid before the fire; six were not there the following spring, but eight additional species had established territories. Tree-foliage searchers had the greatest importance values before the fire and ground-brush foragers the greatest value afterwards. Density, total biomass, and combined existence energy of birds decreased after the fire by 50, 23, and 41%, respectively, but species using the area after the fire were 63% heavier on the average. Average energy consumption per unit of body weight was calculated to be 23% less after the fire. Fire apparently reduced the total food available for birds, but increased the kinds of food, especially at or near the ground.

Apfelbaum, S.I.; Haney, A. 1986. Changes in bird populations during succession following fire in the northern Great Lakes wilderness. p. 10-16 *in* Lucas, R.C. (compiler). Proc. National wilderness research conference (July 23-26, 1985, Fort Collins, CO.). USDA For. Serv., Intmtn. Res. Stn., Ogden, UT. Gen. Tech. Rep. INT-212. 553 p.

Sixteen upland communities, representing 370 years of succession following wildfire in the Boundary Waters Canoe Area Wilderness of Superior National Forest and contiguous Quetico Provincial Park of Ontario were inventoried from 1976 through 1985. Using 15.4 acre grids, all resident bird territories were plotted in each community and transient and peripheral species were recorded. By comparing bird populations, we identified four community types. Early communities, the first 23 years after fire, had as high bird diversity but half the bird density as mature communities that developed 100 to 200 years after fire. Intermediate communities developed within 50 years as jack pine and aspen canopies matured and had a third less species, but comparable bird density as early communities. Old growth communities, 300 or more years after fire, had a lower diversity and density than mature communities with more internal variance of bird density, indicating disruption of community structure. We believe that species and communities in this region have adapted to fire and that in the long-term absence of fire, communities begin to fragment. Fire suppression will likely result in unforeseen changes in populations and community structure.

Basham, J.T. 1957. The deterioration by fungi of jack, red, and white pine killed by fire in Ontario. Can. J. Bot. 35:155-172.

The nature, causes, and rate of pathological deterioration of jack, red and white pine killed by fire in the Mississagi region of Ontario in 1948 were studied to determine the practicability and probable duration of profitable salvage operations in such stands. Blue and brown sapwood stains appeared in all species 1 year after the fire, and became extensive during the succeeding 3 years. Sap rot was first noted 2 years after the fire; 5 years after the fire most of the sapwood was affected, and in some cases this rot extended into the heartwood. The fungi, *Peniophora gigantea* (Fries) Massee, *Polyporus anceps* Peck, and *Polyporus abietinus* Dicks. ex Fries, were isolated consistently from white sap rots, while *Fomes pinicola* (Sw.) Cooke and *Fomes subroseus* (Weir) Overh. were recovered from many of the brown sap rots. The increase in the volume of heart rot encountered during the course of the study chiefly associated with *Fomes pini* (Thore) Lloyd, was much greater than that observed in living pine over a similar period, and for this reason the excess was considered as a form of deterioration. The average rate of radial penetration of visible deterioration was significantly faster in trees with widely spaced annual rings in the outer portion of the bole than in slow-growing trees. Variations in the severity of burn in individual trees or stands apparently had little effect on the rate of pathological deterioration.

Basham, J.T. 1958. Studies in forest pathology. XVII. The pathological deterioration of fire-killed pine in the Mississagi region of Ontario. Can. Dept. Agric., Ottawa, Ont. 38 p.

The present paper is based on studies made on permanent sample plots established in an area devastated by fire in May 1948, on which salvage logging took place from Nov. 1948 till 1952. Detailed results are given for the progress of stain, sap rot, heart rot, total cull; relation between d.b.h. and sap rot and stain, and between severity of burn and depth of penetration of deterioration; volumes of heart rot and other forms of deterioration at different intervals after the fire, reduction of merchantable volume in % of total volume and per acre: all separately for *Pinus banksiana*, *P. resinosa* and *P. strobus*. The various fungi isolated, and the proportions of loss due to them, are also given. An unexpected finding was the striking difference in the rate of increase in volume of heart rot in fire-killed pine compared with that in living trees in the 5 years following the fire; in all 3 species the increase was very much greater than would have been expected in comparable living trees. This form of deterioration appears to be due almost entirely to *Fomes pini*. [For. Abstr. 1959. 20: 92]

Gardiner, L.M. 1957. Deterioration of fire-killed pine in Ontario and the causal wood-boring beetles. Can. Ent. 89:241-263.

Seventeen species of cerambycids known to attack conifers were found active in the Mississagi area during the three-year period after the fire of 1948. Notes on the habits of these species and a key for the identification of their larval forms have been given. By far the greatest damage done to the fire-killed pine was caused by the larvae of *Monochamus* species, which bore deeply into the wood. The outer six inches of any white pine log was found to be susceptible to damage by these insects, with occasional larvae tunneling as deep as 9.5 inches from the wood surface. Penetration was less deep in jack and red pines. Certain of the results of this study appear to be of value in the planning of salvage operations in eastern Canadian pine stands devastated by summer fires. First, it was found that the effects, both direct and indirect, of fire on pine vary greatly with species. Initially, there appears to be a basic difference in susceptibility to fire injury; jack pine succumbs very readily, followed by white and then red pine. This is important in view of the observation that severity of burn injury governs the speed and nature of insect attack. In addition, it has been found that, other things being equal, infestation by harmful, deep-boring species is considerably heavier in white pine than in red, and penetration of the larvae into the wood is deeper. Thus, it is obvious that after fires involving white and red pine the more valuable white pine should, if possible, be salvaged first. There is a corollary of this, of course; dead red pine would probably be more valuable than dead white pine one or two years after a fire. Secondly, it has been shown that the severity of burn injury suffered by a tree, by influencing the time at which the tree dies, governs the insect damage it will sustain. Thus, severity of fire injury indicates the time to salvage in order to minimize losses after summer fires. Trees suffering severe fire injury will receive the earliest attack and the heaviest damage from deep-boring insects, and should be salvaged as soon as possible. It may be uneconomic to attempt salvage of any but the larger trees of this class on a large burn. Moderately injured trees may be left until the following summer, but it would be more desirable to cut them during the winter following the fire when they are still in good condition. Trees suffering only light injury will, in general, be free from serious damage for at least a year, and need not be cut until then. Since many of these trees will survive, it is possible that they would be of greater value if left for the purpose of providing seed for the regeneration of desirable tree species on the burn. This was done in some stands in the Mississagi area, and an examination six years after the fire showed that most of the trees were still alive, with reproduction of white and red pine being best where this practice had been carried out.

Krefting, L.W. 1974. The ecology of the Isle Royale moose with special reference to the habitat. Univ. Minn., Agric. Exp. Stn., St. Paul, Minn. Tech. Bull. 297 (For. Ser. 15). 75 p.

The moose (*Alces alces andersonii*) occupies a prominent position in the fauna of Isle Royale National Park. Drastic die-offs from overpopulation in the early 1930's and the late 1940's, together with the arrival of the timber wolf in the late 1940's, has focused worldwide attention to this island located in northwestern Lake Superior. At the request of the National Park Service, ecological study of the moose - with special reference to its habitat - was initiated by the U.S. Fish and Wildlife Service in 1944. Available funds and manpower limited research to include only winter range requirements. However, the importance of spring, summer, and fall ranges was recognized. Although the winter range regulates the upper limits of the population, the summer range determines the physical stature of the moose.

Moose exclosures were also established. These measured long term effects of winter browsing on survival and growth of trees and shrubs. Population trends were obtained from airplane counts in 1945 and 1947 and from pellet group counts in 1948, 1950, 1961, 1965, and 1970. Procedures and methods varied over the years, depending on the objectives of each phase of research. These procedures and methods are described under individual section headings. During this study, seven papers were published about Isle Royale: three on the moose (Aldous and Krefting, 1946; Krefting, 1951 and 1973); one on the birds of Isle Royale (Krefting *et al.*, 1966); one on the history of the beaver (Krefting, 1963); one on the history of the coyote (Krefting, 1969); one on the forest of Isle Royale in relation to fire history and wildlife (Hansen *et al.*, 1973); and a vegetation map of Isle Royale National Park (Krefting *et al.*, 1970). (introduction)

Vogl, R.J.; Beck, A.M. 1970. Response of white-tailed deer to a Wisconsin wildfire. Am. Midl. Nat. 84:270-273.

An average of 2.4 times more white-tailed deer (*Odocoileus virginianus*) were found on roads through a severe wildfire area eight years after burning than on comparable roads in the unburned control. The results document the prolonged effects of fire, and the necessity of considering long-range effects in evaluating ecological factors.

Vozeh, G.E.; Cumming, H.G. 1960. A moose population and winter browse survey in Gogama District, Ontario. Ont. Dept. Lands For., Gogama For. Dist., Gogama, Ont. Unpubl. Rep. 31 p.

An area in northeastern Ontario that apparently comprised excellent boreal moose range was described with the aid of a forest inventory map. It consisted of 354 ha and supported 1.7 moose per square km in winter. Eighty-two percent of the area was composed of a stand that had reproduced following a burn 19 years previously (1941 Gogama Fire--see Burton 1949 in section 2.2). It contained trees between 4.5-9.0 m tall, of a mixture of species, with a dense understory of shrubs and tree saplings. The remainder of the plot consisted of five rather long and narrow patches of mature conifers totalling 19% of the area. These stands contained some patches of dense cover (8% of total area) and were distributed around the edges of the block. No part of the block was more than 0.5 km from a patch of mature coniferous cover. Also, there may have been patches of young conifers and small unburned patches in the burn sufficiently large to provide suitable shelter for moose.

Weber, M.G. 1991. The effect of cutting and burning on browse production in eastern Canadian aspen forests. Int. J. Wildl. Fire 1:41-47.

Browse production for moose (*Alces alces*) and white-tailed deer (*Odocoileus virginianus*) by 20-year-old aspen (*Populus tremuloides*) was measured 3 years after clear felling or controlled burning of stands both before and after leaf flush. Felling and burning treatments were applied to different areas of the Petawawa Research Forest, Ontario. Browse production was greatest on the area clear felled before flushing (1544 kg/ha in summer, 395 kg/ ha in winter), followed in decreasing order by post-flush felling (635 and 125 kg/ha), post-flush burning (330 and 96 kg/ha) and pre-flush burning (50 and 0 kg/ha). Browse quality (nutrient concentration) was essentially unaffected by treatment.

Woods, G.T.; Day, R.J. 1977b. Ecological effects of forest fire in poplar communities in Quetico Provincial Park. Ont. Min. Nat. Res., North Cent. Reg., Atikokan Dist., Quetico Prov. Park Fire Ecol. Study Rep. #6. 35 p.

In 1975 the Ontario Ministry of Natural Resources and R.J. Day of Lakehead University conducted an ecological study within Quetico Provincial Park to determine the successional patterns which occur in poplar forests and to determine if fire is a necessary process in the renewal and perpetration of this community. Five poplar forests ranging in age from 15 to 120 years were sampled in the field and the results are presented. In addition hypothetical successional developments in a model poplar forest are presented and discussed. The results of the study strongly indicate that natural fire should be allowed to burn in poplar forests which are 70 to 80 years old if the present population of this community species is to be maintained.

Woods, G.T.; Day, R.J. 1977c. Ecological effects of forest fire in black spruce communities in Quetico Provincial Park. Ont. Min. Nat. Res., North Cent. Reg., Atikokan Dist., Quetico Prov. Park Fire Ecol. Study Rep. #7. 34 p.

Fire has played an important role in the establishment of most black spruce stands growing on both lowland and upland sites in Quetico Provincial Park. Lowland stands are capable of developing into uneven-aged stands of black spruce but upland stands are replaced by mainly balsam fir and shade-tolerant hardwoods in the absence of fire. Park managers should consider using fire as a management tool to maintain the black spruce population, particularly on upland sites if Quetico Park is maintained as a wilderness area. Fire may be permitted in black spruce stands over 40 years of age, but ideally it should be excluded until stands reach 90 to 120 years of age. This will permit the maintenance of a wide range of black spruce stands in the park.

3.4 Role of fire in forest management

Baker, W.L. 1992. Effects of settlement and fire suppression on landscape structure. Ecology 73:1879-1887.

Natural landscapes subject to disturbances have a patchy structure that is important to many species living in these landscapes. This structure may be modified when the disturbance regime is altered by either climatic change or human influences (*e.g.*, fire suppression), yet little is known about how this structure will change. I used a GIS (geographic information system)-based spatial model and data on historical changes in fire sizes and intervals to simulate the effects of settlement and fire suppression on the structure of the landscape in the Boundary Waters Canoe Area, Minnesota. I used seven measures to assess change in landscape structure. Settlement and fire suppression altered some but not all components of landscape structure. Settlement produced an immediate significant effect on some measures (age, shape, Shannon diversity, richness, and angular second moment), but no effect on other measures (size, fractal dimension), and a delay for hundreds of years in the case of other measures (size, angular second moment). Landscapes that have been altered by settlement and fire suppression cannot be restored using traditional methods of prescribed burning, which will simply produce further alteration. Causes of landscape change cannot be separated without control landscapes that lack prescribed burning, fire suppression, or other alterations of the natural fire regime.

Baker, W.L. 1993. Spatially heterogeneous multi-scale response of landscapes to fire suppression. Oikos 66:66-71.

Large natural disturbances produce a patchy structure in landscapes. External changes, such as climatic change or the intentional suppression of disturbances, may alter this structure. Species sensitive to this structure may thus experience changes in available habitat, but species use the landscape at different spatial scales. I used a GIS-based spatial model to simulate the long-term effects of fire suppression on landscape structure in the Boundary Waters Canoe Area, Minnesota, USA. I analyzed changes in seven measures of landscape structure at three spatial scales during the simulation runs. The timing of a suppression effect varied with scale. At the coarsest scale there was an immediate effect in the case of some measures, but a delay for more than 250 years in the case of other measures. At the finest scale effects were spatially heterogeneous, with some parts of the landscape responding immediately and other parts not responding for hundreds of years. There are several implications. First, attributing vegetation changes to fire suppression requires identification of fire suppression actions in the area of vegetation change. Second, spatially explicit prescribed burning programs are needed if landscapes altered by fire suppression are to be restored. Third, species that use the landscape at different scales will observe different patterns of change in landscapes subject to fire suppression. Finally, landscapes can be expected to respond in a spatially heterogeneous manner to other kinds of changes (*e.g.*, climatic change). Parks and wilderness areas with unaltered disturbance regimes are essential if we are to understand how and why landscapes change and the role that this change plays in the population dynamics of species.

Baker, W.L. 1994. Restoration of landscape structure altered by fire suppression. Conserv. Biol. 8:763-769.

There is increasing interest in applying landscape ecological research to the management of wildland, particularly regarding the negative effects of fragmentation and the benefits of corridors. Patch-producing large disturbances, such as fires and floods, produce a spatial mosaic structure in landscapes to which many species are sensitive. Management of the spatial structure of the patch mosaic has seldom been an explicit concern, however, in part because of insufficient knowledge about how this spatial structure is affected by alterations in the disturbance regime. Yet the patch mosaic structure of many landscapes has been altered by disturbance control (such as fire suppression), and there is substantial interest in restoring natural disturbance regimes in some wildland landscapes. It has been proposed that, in landscapes subjected to decades of fire suppression, simple reinstatement of the natural fire regime may lead to adverse effects because fuel buildup during fire suppression may result in unusually large fires. It has also been proposed that the use of small prescribed fires may be an effective approach to restoration of landscapes subjected to fire suppression. Here I use a spatial GIS-based simulation model to analyze the effects of reinstating a natural fire regime in the Boundary Waters Canoe Area, Minnesota, after 82 years of fire suppression. The simulation experiment suggests that suppression can be expected to significantly alter landscape structure, but landscape structure can generally be restored within 50-75 years by reinstating the natural fire regime. Unusually large fires would probably hasten the restoration of landscape structure, while small prescribed fires will not restore the landscape but instead will produce further alteration.

Burton, D.H.; Sloane, N.H. 1958. Progress report on prescribed burning in the hard maple-yellow birch cover type in Ontario. Ont. Dept. Lands For., Maple, Ont. Sec. Rep. (For.) No. 25. 10 p. + Appendices.

In October 1958, the Research Branch of the Ontario Department of Lands and Forests began an experimental prescribed burning study within the Swan Lake Research Reserve in Algonquin Provincial Park. The purpose of the burning centered on the silvicultural improvement of low quality hardwood stands (*i.e.*, seedbed preparation and reduction of brush competition). This report, the first of three reports that were published on the work, provides a description of the research site, the experimental study design, environmental conditions prior to and during the prescribed fires (0.2 ha size plots), and the techniques employed in fall burning.

Comments: see Holowacz (1960) below and Sinclair (1962) later in this section.

Flannigan, M.D. 1993. Fire regime and the abundance of red pine. Int. J. Wildl. Fire 3:241-247.

Red pine (*Pinus resinosa* Ait.) is a fire-dependent species. This study examines the relationship between the fire regime and the abundance of red pine. The fire regime is represented by components of the Canadian Fire Weather Index System and outputs from the Canadian Fire Behavior Prediction System as well as the average area burned and the percentage of conifers of each forest section. Extreme as well as averages values were used in this analysis as a large forest fire is a rare event that can occur on only a few days of the year under extreme fire weather conditions. Results from a forward-stepwise regression explained about 70% of the variance in red pine volume (abundance) data. Variables selected in the regression analysis included extreme headfire intensity, area burned and average drought code. These results suggest that abundance of red pine and other fire affected tree species is directly related to the aspects of the fire regime such as fire intensity.

Holowacz, J. 1960. Progress report on prescribed burning in the hard maple-yellow birch cover type in Ontario. Ont. Dept. Lands For., Res. Br., Dorset, Ont. Sec. Rep. (For.) No. 37. 20 p.

A prescribed burning experiment was started at the Swan Lake Research Reserve, Algonquin Park, in the fall of 1958. The object of the experiment was to improve the existing stand of sugar maple, and to create favourable seedbed conditions for other commercial species that normally grow in association with sugar maple. It was planned to burn the area each fall over a five-year period in order to secure areas for comparison, having one, two, three, and so on, successive burns. The preliminary results obtained eight months after the first burn show an elimination of over 90 percent of the sugar maple regeneration. The first of the series of prescribed burns did not significantly decrease in number nor damage the trees within the diameter classes from 0.6 to 4.0 inches D.B.H., namely, the part of the stand most vulnerable to fire. Due to adverse weather conditions, the 1959 fall burn being second in the series, was not executed.

Comments: see Burton and Sloane (1958) earlier in this section and Sinclair (1962) later in this section.

Hopkins-Vanzant, S.; Miyanishi, K. 1993. Impacts of prescribed burning and deer browsing on *Quercus muehlenbergii* in a southern Ontario oak savanna. Bull. Ecol. Soc. Amer. Supplement to 74(2):281.

Prescribed burning is being used at Pinery Provincial Park in southern Ontario to restore an oak savanna community which has been changing into a closed oak woodland due to a past policy of fire suppression and conifer reforestation. *Quercus muehlenbergii*, a shade-intolerant small tree, is an important component of this oak savanna community. Although the objective of the burns is to kill the planted conifers and open the canopy for the maintenance of shade-intolerant savanna species, the population of *Q. muehlenbergii* may be threatened by the burns due to the high density white-tailed deer population. Surveys of *Q. muehlenbergii* populations one and two years after a prescribed burn and an exclosure study in a burned site found a) extremely high-incidence of top-kill by fire, b) complete browsing of all post-fire sprouts by deer, and c) increased mortality in the years following the burn. Comparison of *Q. muehlenbergii* populations subjected to differing intensities of deer browsing pressure in the absence of fire showed that deer alone had no significant impact on mortality rates.

3.4 Role of fire in forest management (Great Lakes - St. Lawrence)

Horton, K.W.; Bedell, G.H.D. 1960. White and red pine: ecology, silviculture and management. Can. Dept. North. Aff. and Natl. Resour., For. Br., Ottawa, Ont. Bull. No. 124. 185 p.

The pines are primarily fire species in that their silvical characteristics are adapted to conditions best effected by forest fires. Climate and local site may not be directly responsible for natural pine distribution, but indirectly through fire history. Fire will in the long run be more common in the drier conditions; so, therefore, will pine. Moreover, once established, the pine vegetation itself through its high combustibility will increase the probability of fire. Thus on dry areas a cycle develops and pine prevails, varying in local density according to seed availability. In contrast, the moister conditions tend to encourage fire-resistant vegetation, tolerant hardwood trees and dense deciduous shrubbery, which become stabilized, excluding pine. Another factor in fire history is the existence of areas with an abnormally high frequency of dry electrical storms, which greatly increase fire frequency. Three such areas are around the Mississagi, Chalk and Coulonge Rivers, each of which features extensive pineries today. Fire is not necessarily beneficial in promoting the distribution of red and white pine. It may, if it is repeated at a short enough interval, or if it follows a clearcutting, destroy all advance growth and seed trees in a locality. In such cases the less desirable pioneer species, jack pine, aspen, or white birch, will replace red and white pine. This, unfortunately, has happened over a large proportion of the pine region, particularly in those sections less suited climatically and physiographically to the prevalence of pine. As Maissurow (1935) put it, the decline of white pine in eastern Canada was not caused by either fire or logging directly, but by disturbance of the general balance between the seed-bearing capacity of the forest and the effectiveness of fires--namely, the elimination of seed sources, the over-frequency of fires in some areas, and the lack of fire in others. Broadcast burning might be the silvicultural panacea. It may in one operation effectively eliminate or reduce slash, undesirable humus, litter, weeds, brush and trees (including *Ribes*, the blister rust host), all injurious insects breeding thereon, and seed eating rodents, thus preparing in every respect for regeneration. But it is not a popular silvicultural measure in the northeast, and trial examples are rare. One, carried out on limited strips in a white pine cutover area at Temagami, Ontario, showed interesting although variable results...Given a ready seed supply and favourable subsequent weather, a light burn was found best for pine reproduction on poorer sites. Better sites supporting mixedwoods required heavier burning to reduce underbrush. Depth of burning varied widely with the season, summer fires penetrating deepest, fall fires slightly less so and spring fires scarcely at all; thus spring burning can encourage rather than reduce competition. Red pine seemed to require a heavier burn than white pine for successful reproduction. It is pertinent to note that red pine, particularly at maturity, is more resistant to fire because of its thicker bark than is white pine...a point to be considered in planning controlled burning with a view to natural seed supply.

Comments: First three paragraphs are also included in: Horton, K.W.; Brown, W.G.E. 1960. Ecology of white and red pine in the Great Lakes-St. Lawrence Forest Region. Can. Dept. North. Aff. and Nat. Resour., For. Br., For. Res. Div., Ottawa, Ont. Tech. Note 88. 22 p.

3.4 Role of fire in forest management (Great Lakes - St. Lawrence)

Kershaw, H.M. 1993. Early successional processes of eastern white pine (*Pinus strobus* L.) and red pine (*Pinus resinosa* Ait.) within the Great Lakes-St. Lawrence forest: a literature review. Ont. Min. Nat. Res., Forest Fragmentation & Diversity Project. Technical Report Series #8. 51 p.

This report reviews literature relating to red pine (*Pinus resinosa* Ait.) and eastern white pine (*Pinus strobus* L.) succession in the Great Lakes - St. Lawrence Forest from establishment to age fifty. Research areas included (1) red and white pine autecology, (2) early red and white pine establishment and survival, (3) post-disturbance natural succession patterns and (4) the effect of past and current management practices on early red and white pine survival and establishment. Post-fire and post-harvest plant community development, seedbed requirements, and conditions that favour early growth are well documented in the literature. Early successional red pine communities develop on xeric, competition free shallow till and deep coarse sandy sites when disturbance coincides with a good seed crop. White pine forms a component of early successional communities under a broad spectrum of conditions. It successfully establishes on moderately dry to fresh coarse loamy till soils of variable depth under low to moderate competition. Detailed information for Ontario was very limited. The effectiveness of natural regeneration prescriptions for establishing red and white pine has not been well documented.

McRae, D.J.; Lynham, T.J.; Frech, R.J. 1994. Understory prescribed burning in red and white pine. For. Chron. 70:395-401.

The alarming loss of forested areas containing red pine (*Pinus resinosa* Ait.) and eastern white pine (*Pinus strobus* L.) in eastern Canada is a situation that must be addressed promptly by changing management approaches. Since the ecological role of fire in the regeneration and perpetuation of these pines is well known, it makes sense to use fire to maintain pine ecosystems through forest management that uses an understory prescribed burn program. Fears of fire escape and a poor knowledge of applying fire correctly to these ecosystems are the result of poor training in the use of prescribed fire, which normally concentrates solely on postharvest slash sites; this has prevented extensive use of understory prescribed burning in the past. However, research in Canada, principally using the Canadian Forest Fire Behavior Prediction (FBP) System coupled with the Canadian Forest Fire Weather Index (FWI) System, allows forest managers to develop burning prescriptions that are safe and economical while meeting objectives for seedbed preparation, natural seeding and control of competing vegetation.

Methven, I.R. 1971. Prescribed fire, crown scorch and mortality: field and laboratory studies on red and white pine. Dept. Environ., Can. For. Serv., Chalk River, Ont. Inf. Rep. PS-X-31. 10 p.

The effect of crown damage on mortality of red pine (*Pinus resinosa* Ait.) and white pine (*Pinus strobus* L.) was examined using both controlled temperature laboratory experiments on pine seedlings and prescribed fires in mature pine stands. Laboratory experiments indicated that two gas temperatures were associated with lethal effects, the first pertaining to needles alone and the second higher one to buds as well, and that under the experimental conditions there was a 20° C spread between the two. Significant mortality did not occur until the 95% needle scorch level. Field studies indicated a much greater susceptibility to crown scorch, mortality commencing with the 46 to 50%

scorch level, reaching 50% within the 81 to 85% level and attaining 100% with the highest scorch class of 96 to 100%.

Methven, I.R.; Murray, W.G. 1974. Using fire to eliminate understory balsam fir in pine management. For. Chron. 50:77-79.

Three experiments with low-intensity controlled burns were carried out in a natural plantation of 90-year-old white and red pine which contained a dense understory of balsam fir. These fires destroyed the young fir without causing damage to pines in the upper story, and aided in the establishment of vigorous white pine, white spruce, balsam fir and white birch.

Comments: The following abstract appeared in Van Wagner (1979).

Three plots in mature red and white pine with dense balsam fir understory were treated with gentle surface fire. The fir was killed everywhere fire passed, without affecting the pines. The stand now has an open trunk space, and several years later considerable pine regeneration is evident. Fire weather and characteristics of the fires are listed.

Prebble, M.L.; Gardiner, L.M. 1958. Degrade and value loss in fire-killed pine in the Mississagi area of Ontario. For. Chron. 34:139-158.

Study of the effects of the Mississagi fire of May 1948 showed that *Pinus strobus* and *P. resinosa* that suffered only light or moderate fire injury, had sustained relatively light damage from insects or fungi by November, 1949, and were mostly salvageable. Trees that were severely burned or killed outright, however, were heavily attacked by borers and stain fungi, average value loss for *P. strobus* being 17.2% for low-quality and 58.8% for high-quality logs, and for *P. resinosa* 13% and 17.3% respectively. [For. Abstr. 1959. 20:85-86]

Quinby, P.A. 1991. Self-replacement in old growth white pine forests of Temagami, Ontario. For. Ecol. Manage. 41:95-109.

Surveys of both live and dead vegetation were conducted to examine long-term successional trends in old growth white pine (*Pinus strobus*) forest. The forest successional trend, for a period of possibly up to seven centuries, shows that white pine has been the dominant species over this time period indicating that these old-growth white pine forests have been self-replacing. Size-class analysis was used as an indicator of age-class structure. Results of this analysis show that the old growth white pine stands are at least partially uneven-aged. The uneven-aged condition, resulting from continuous recruitment, was most likely facilitated by local disturbances such as small surface fires, windthrown trees, and the death of large individual trees through biological or other agents. These findings cast some doubt on the silvicultural theory that catastrophic fire is the only primary facilitator of natural white pine regeneration. Selection logging in white pine forest may make better use of the various non-catastrophic mechanisms of natural white pine regeneration. It is unlikely, however, that the old growth condition can be maintained or enhanced under any cutting regime. In addition to the production of fibre, old-growth forests are valuable components of the landscape from both a functional and ecological perspective and a scientific perspective.

Scheiner, S.M.; Sharik, T.L.; Roberts, M.R.; Vande Kopple, R. 1988. Tree density and modes of tree recruitment in a Michigan pine hardwood forest after clear cutting and burning. Can. Field-Nat. 102:634-638.

Changes in stem density and the relative amount of recruitment by both vegetative reproduction and seedling establishment were assessed for 5 years following clear felling and burning of slash in northern lower Michigan. Prior to disturbance, the community consisted primarily of a mixture of *Quercus rubra*, *Populus grandidentata*, and *Pinus strobus*. Following disturbance, *P. grandidentata* and *Acer rubrum* comprised 66% and 25%, respectively, of all stems. Stem density declined by 41% in the first 5 years following fire. There was no change in the relative number of stems of each species during this time. Animal- and wind-dispersed species had different rates of seedling recruitment. *P. grandidentata*, *Populus tremuloides*, and *A. rubrum* were recruited exclusively by vegetative means. *Q. rubra*, *Amelanchier arborea*, and *Betula papyrifera* were recruited both vegetatively and by seed. *Prunus pensylvanica* was recruited only by seed. No recruitment of *P. strobus* and *Pinus resinosa* occurred in the first 4 years following disturbance. Future recruitment would have to be from seed.

Sharik, T.L.; Ford, R.H.; Davis, M.L. 1989. Repeatability of invasion of eastern white pine on dry sites in northern lower Michigan. Am. Midl. Nat. 122:133-141.

Age-specific densities of eastern white pine (*Pinus strobus*) were determined in a series of forest stands, originating 73, 48, 36, 30 and 4 years prior to the present study, following prescribed logging and burning. These data were used to reconstruct the invasion patterns of eastern white pine and to make inferences about the repeatability of community change following disturbance. Initial invasion of white pine was more rapid in stands of recent origin (1 and 4 years after the disturbance for the 36- and 30-year-old stands, respectively, vs. 15 and 25 years after the disturbance for the 49- and 73-year-old stands, respectively). In contrast, white pine population growth reached an asymptote more quickly in stands of recent origin compared to older stands. There was little recruitment of white pines in any of the stands since the early 1970s. Thus, the hypothesis is rejected that community change proceeds similarly in all stands, independent of their time of origin. The substantial stochastic component in colonization and subsequent increase of populations of potentially dominant forest trees during secondary succession may be affected by different autogenic and allogenic factors.

Sinclair, G.A. 1962. Progress report on prescribed burning in hardwood stands in Ontario. Ont. Dept. Lands For., Maple, Ont. Sec. Rep. (For.) No. 45. 18 p + Appendices.

This report is the third and final document published on the experimental use of prescribed fire in the silvicultural improvement of low quality hardwood stands in the Swan Lake Research Reserve, Algonquin Provincial Park. The initial burns in October 1958 were described by Burton and Sloane (1958) and their effects on the vegetation during the next growing season were recorded in a second report by Holowacz (1960). This report describes the physiographic and biotic site conditions before burning and the environmental conditions and flame characteristics during the re-burning of the same plots and another study area in October 1960.

Smith, D.W.; James, T.D.W. 1978a. Characteristics of prescribed burns and resultant short-term environmental changes in *Populus tremuloides* woodland in southern Ontario. Can. J. Bot. 56:1782-1791.

In a series of prescribed burns of low intensity and short duration in southern Ontario, wind speed, amount of fuel, and fuel moisture were important environmental controls of fire severity. A heterogeneous pattern of burning, related to clumping in the vegetation and to a hummock-hollow microtopography presumably affected and was perpetuated in the reestablishing postfire vegetation. Removal of vegetation cover and surface litter plus surface albedo changes resulted in increased soil temperature 2 months after burning. These increases were short-lived and soil temperatures were close to those of unburned areas 4 months after the prescribed fires. Despite their small magnitude and short duration, the soil temperature increases could have important stimulatory effect on regenerating vegetation. Significant increases in levels of readily available forms of phosphorus, potassium, calcium, and magnesium at surface soil depths immediately after burning could have been depleted through uptake by vegetation and microorganisms. Portions of the nutrients were removed, also, by erosion of fly ash during burning, leaching to subsurface depths, and through fixation in unavailable form.

Smith, D.W.; James, T.D.W. 1978b. Changes in the shrub and herb layers of vegetation after prescribed burning in *Populus tremuloides* woodland in southern Ontario. Can. J. Bot. 56:1792-1797.

The undisturbed condition in the shrub and herb layers of a *Populus tremuloides* woodland in southern Ontario was characterized by a mosaic of two main vegetation groupings, one being relatively species rich and the other species poor. Their distribution was related chiefly to two environmental variables: (a) relative degree of shrub canopy cover, and (b) microtopographic position. Species-poor vegetation was associated with those sites having a closed shrub canopy and low, wet positions on the microtopographic gradient. Prescribed burning added a further dimension to the clumped pattern and species richness of the vegetation. Microscale heterogeneity created by the burns tended to increase species richness, but in general, richness was reduced by burning. Rapid postburn changes in the vegetation were largely restricted to shifts in dominance by the three most abundant species; *Cornus stolonifera* Michx., *Calamagrostis canadensis* (Michx.) Beauv., and *Carex stricta* var. *strictior* Lam. The changes in the dominants after burning appeared to be short lived but affected the overall structure of the shrub and herb vegetation.

Sykes, J.S. 1964. Report on the interim results of prescribed burning in a poor quality hardwood stand. Ont. Dept. Lands For., Res. Br., Maple, Ont. Sec. Rep. (For.) No. 49. 13 p.

The pilot experiment described in this report was undertaken with the object of evaluating the feasibility and effectiveness of prescribed spring burning in eliminating a young hardwood (chiefly hard maple *Acer saccharum* Marsh.) stand composed principally of poor quality coppice stems. Three consecutive annual spring burns killed 55% of all trees between 1.5-11.4 cm d.b.h. and 17% of all trees between 11.4-31.7 cm d.b.h. Sprouting occurred in both large and small size classes though it was more prevalent in the latter. Mortality was higher in stems of sprout origin growing in clumps than in single stems. Sprouting from the root collar of trees whose crowns are dead was more common in trees of small diameter. Sprouting was more common in trees growing in clumps than in those growing as single stems regardless of crown condition.

Tellier, R.; Duchesne, L.C.; Ruel, J.C.; McAlpine, R.S. 1995. Effets du brûlage dirigé et du scarifiage sur l'établissement des semis et sur leur interaction avec la végétation concurrente. For. Chron. 71:621-626.

In 1990, a jack pine forest was clear-cut on a 15 ha area and divided into 40 plots. In 1991, ten plots were burned-over under varying conditions to obtain different fire intensities and ten plots were scarified. Each plot was planted in 1992 with red pine (*Pinus resinosa* Ait.) and white pine (*P. strobus* L.) seedlings. Survival rate and health of the seedlings was evaluated for the first two years after planting and the non-crop vegetation was assessed using a competition index developed for conifer management in Ontario. Our results show seedling survival rate, health, biomass and height to be improved when planted on burned-over or scarified sites and that fire intensity influences certain of those characteristics.

Tester, J.R. 1989. Effects of fire frequency on oak savanna in east-central Minnesota. Bull. Torrey Bot. Club 116:134-144.

From 1964 to 1984, prescribed burning experiments were performed on oak (*Quercus* spp.) forest and oak savanna in east-central Minnesota, U.S.A. Eighty-nine burns were carried out on 9 compartments ranging from 2.6 to 27.5 ha. Intervals between fires varied from 1 to 12 years. Soil pH increased significantly with frequency of burning. Total nitrogen was positively correlated ($P < 0.01$) with percent organic matter. Species richness was highest in areas which were burned approximately every 2 years. Different plant functional groups responded differently to frequency of burning. Cover of true prairie grasses increased from less than 5 to about 15%. True prairie forbs showed a significant increase in cover from less than 2 to about 8% with increasing frequency of burning. Density of true prairie shrubs showed a tendency to increase whereas density of non-prairie shrubs and of trees showed tendencies to decrease with increased frequency of fire. Thus, the frequency of prescribed burning strongly influenced vegetative composition and physiognomy as well as soil characteristics.

Van Wagner, C.E. 1963. Prescribed burning experiments: red and white pine. Can. Dept. For., For. Res. Br., Ottawa, Ont. Dept. For. Publ. No. 1020. 27 p. [Reprinted in 1965].

The behaviour and effects of fire in red and white pine stands were studied by burning quarter-acre plots on three sites as four degrees of fire hazard, and observing the areas for a year after fire. Pines died quickly as a result of more than 75 percent crown scorch, but stem charring alone killed no trees during the first year. The bottom layer duff was appreciably reduced or removed only when its moisture content was less than 40 percent and the fire danger high or extreme. At higher moisture contents, the fires merely ran through the top layer duff, baring no mineral soil. Hazel rootstocks sprouted prolifically after all but the most severe single fire. Two consecutive annual fires practically eliminated hazel on two plots, one on a medium and one on a good pine site. The first-year regeneration and survival of pine and spruce seedlings was greatly favoured by severe fire. Seedling numbers of 9,000 to 26,000 per acre were observed one year after fire on four plots where the soil was well bared and hazel competition reduced. After light fires, seedling counts ranged from 600 to 4,500. Unburned areas had seedling crops of from nearly none to about 1,000 per acre.

Van Wagner, C.E.; Methven, I.R. 1978. Prescribed fire for site preparation in white and red pine. p. 95-100 *in* Cameron, D.A. (compiler). Proc. White and Red Pine Symp. (Sept. 20-22, 1977). Dept. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Symp. Proc. 0-P-6.

Prescribed fire is a promising tool for the preparation of seedbed for white pine (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.). Its twin effects are the removal of duff and the control of competing and minor vegetation. A method of incorporating prescribed fire into white and red pine management has been worked out at Petawawa.

Weber, M.G. 1991. Aspen management options using fire or cutting. For. Can., Chalk River, Ont. Inf. Rep. PI-X-100. 11 p.

Vegetative reproduction, leaf and stem biomass and nutrient pools, soil nutrient pools, soil respiration, litterfall and winter forage (twig) production were monitored in eastern Ontario immature (20 years) aspen (*Populus tremuloides* Michx., *Populus grandidentata* Michx.) ecosystems which had been treated as follows: low intensity burning before, burning after, cutting before, and cutting after spring leaf flush. An untreated control was set aside for comparison. Three years after treatment the greatest numbers of stems per hectare were produced through suckering on the pre-flush cutting plots (12,000) followed in decreasing order by post-flush cut (9000), post-flush burn (4000), and pre-flush burn (2000). No suckering was observed on control plots. Aboveground biomass and nutrient pools, winter browse production, and litterfall patterns consistently reflected sucker stem density trends on the cuts and stand break-up on the burning treatments. The burning treatments reduced aspen to a minor component of the site, particularly on the pre-flush burn. The pre-flush cutting treatment, on the other hand, is representative of the most desirable outcome if vigorous aspen reproduction is the management objective. Substrate nutrient and soil respiration measurements indicated that rates of key ecosystem processes returned rapidly to pre-disturbance levels. This supports our understanding of aspen as a resilient forest ecosystem in the presence of periodic human or natural intervention.

Weber, M.G.; McAlpine, R.S.; Wotton, B.M.; Donnelly, J.G.; Hobbs, M.W. 1995. Prescribed burning and disk trenching effects on early plantation performance in eastern Ontario, Canada. For. Ecol. Manage. 78:159-171.

Prescribed burning was compared with mechanical site preparation prior to planting on a clearcut jack pine (*Pinus banksiana* Lamb.) site in eastern Ontario. Species planted were white (*Pinus strobus* L.)

and red pine (*Pinus resinosa* Ait.). Lack of site preparation resulted in high first year mortality of both species. Soil temperature measurements at three depths indicated that both site preparation techniques extended the growing season in the spring and fall through early and late soil warming, respectively. Increased biomass production and nutrient use efficiency of both pines on either of the two site prepared treatments reflected the improved environmental conditions of both species, with red pine outperforming white pine on all treatments.

White, A.S. 1983. The effects of thirteen years of annual prescribed burning on a *Quercus ellipsoidalis* community in Minnesota. Ecology 64:1081-1085.

A *Quercus ellipsoidalis* community in central Minnesota has been prescribed burned annually since 1965 in an attempt to restore the area to its presettlement oak savanna structure and composition. By 1979 density and basal area of the overstory were significantly lower in the burned area than in an adjacent unburned area but were still higher than estimated savanna values because of the persistence of stems ≥ 25 cm diameter at breast height (dbh). A tall-shrub/small-tree layer was totally lacking in the burned area but averaged 19% cover in the unburned area. Understory richness was significantly higher in the burned area than in the unburned area. Most of the species that showed a significant difference between the two areas peaked in the burned area; this was especially true for grasses and forbs. These results indicate that annual prescribed burning is gradually restoring the area to savanna but that the restoration is not yet complete. Complete restoration may not be possible with annual burning because such burning seems to have little effect on large-tree (≥ 25 cm dbh) mortality.

White, A.S. 1986. Prescribed burning for oak savanna restoration in central Minnesota. USDA For. Serv., North Cent. For. Exp. Stn., St. Paul, Minn. Res. Pap. NC-266. 12 p.

Low intensity, spring prescribed burns have been used since 1964 at the Cedar Creek Natural History Area in Minnesota in an attempt to restore the area to an oak savanna. Burned areas are now more savanna-like (having greater grass and forb and lower shrub and tree representation) than unburned areas but still have higher overstory densities than apparently existed in presettlement times. No particular burning frequency could be distinguished as best for savanna restoration. Results indicated a possible interaction between fire effects and pretreatment stand structure and composition.

Woods, G.T.; Day, R.J. 1976. The forests of Quetico Provincial Park: based on a photogrammetric survey. Ont. Min. Nat. Res., North Cent. Reg., Atikokan Dist., Quetico Prov. Park Fire Ecol. Study Rep. #3. 75 p.

This report presents and discusses the results of a photogrammetric survey conducted in 1975 which gives a comprehensive view of the structure condition, and composition of the major forest communities within Quetico Provincial Park. "The results of this study show that the forest in Quetico Park is mainly composed of a mosaic of early successional and full successional, even and broadly even-aged stands. Almost all the stands in the mosaic are dominated by jack pine, black spruce, poplar, white birch, red pine, and white pine, and range in age from 40 to 120 years. They appear to have originated from large wildfires that occurred in the last 1880's and early 1900's. Evidence of fire on the aerial photographs was obvious because the mosaic was composed of uniform stands of species that characteristically regenerate after fire. Fire origin was also supported by the fact that each individual stand in the mosaic had similar species composition and was uniform in height, crown shape, and crown closure. In addition, obvious boundaries between stands in the mosaic could only result from some form of widespread disturbance, namely fire. The results also show that there are very few young forests in the regenerative phase. This lack of young forest appears to be the direct result of the effective fire exclusion program in the park over the last forty or fifty years. This fire exclusion management, if continued, will bring profound changes upon the present forest communities within the park. The large immature to mature stands in the early successional phase will soon be subject to crown breakup and will begin to compete with shade tolerant secondary growth. Over the next two decades, the extensive mature to overmature stands in the full successional stage will rapidly become overmature and will begin to be replaced by other more shade tolerant species. Most of the present overmature stands in late succession will soon be completely dominated and replaced by shade tolerant secondary growth. The few young stands that are created by the odd wildfire will not be enough to maintain a well balanced age class of forests within the park. If fire is continuously excluded, most of the park will eventually become dominated by decadent late successional forests. They will probably be composed of uneven aged mixed hardwoods, fir and some spruce and, ultimately, the present large stands of jack pine, red pine, white pine, poplar, and birch will slowly disappear." [discussion]

Wray, D.O. 1985. Securing the future of white pine in Ontario. Proc. Ent. Soc. Ont. 116:109-110 (Suppl.)

The demand for white pine (*Pinus strobus* L.) lumber is expected to remain at the current level. Regeneration is not replacing white pine at the rate at which it is being depleted. Control of competing vegetation by prescribed fire or chemical means, and the rapid establishment of new stands of white pine, are the key factors in forest regeneration. A commitment to the continuation of white pine as a commercially valuable tree species and an increase in funding are necessary to ensure that a future supply is available to meet the anticipated demand.

APPENDIX A
Theses (B.Sc., M.Sc. and Ph.D.) related to fire ecology

2.0 Fire and the boreal forest region

Beasleigh, W.J. 1972. Population dynamics of *Equisetum sylvaticum* in post-fire, secondary succession in Cochrane District, Ontario. M.Sc. Thesis, Univ. Toronto, Toronto, Ont. 178 p.

A photographic sampling technique was developed and tested for use in gathering data about vegetation non-destructively, objectively and rapidly. The technique was used to study changes taking place at the level of the individual of one species, *Equisetum sylvaticum* in a post fire succession.

Multiple regression equations were derived for correlations between parameters and morphological measurements from the slides were then used to compile weights of parts of individuals morphology and biomass.

Using these estimates the reproductive strategy of *Equisetum sylvaticum* was studied in the changing environment of the succession. It was found that while individuals were extremely plastic the greatest changes that occurred could be accounted for by site to site and calendar year variation in the sample design. When the data was standardized the only significant change attributed to the succession occurred in the first year after the fire, and it was explained by direct burning effects in the year in which fire occurred. Although the strategy of the species appeared to be unaffected by the course of succession the tactics did change during the process: individuals tended to become taller and heavier as the vegetation developed. This was interpreted as a response to increased competition by the taller adjacent plants.

Bonner, E. 1941. Balsam fir in the Clay Belt of northern Ontario. M.Sc.F. Thesis, Univ. Toronto, Toronto, Ont. 102 p.

The new forest on an extensive area of burn may vary from the preceding stand. As noted by Millar (1936) the serotinous cones of black spruce resist fire damage and shed large quantities of seed after the fire. Balsam retains no seed on the tree except for a limited period in the fall, and following fire there is no supply available. Most fires, if severe enough to kill the trees, will also destroy any seed in the duff. Balsam, therefore, is eliminated from the stand.

From the foregoing it might be judged that fire can be used to control the proportions of fir. On low ground it is doubtful if control of balsam is necessary. On high ground the stand is generally a mixture of hardwoods, white and black spruce and balsam. Of these, white spruce and balsam regenerate very poorly after fire and the hardwoods sprout prolifically. Consequently, unless there is a high proportion of black spruce in the old stand, the new stand will consist of no balsam, very little white spruce, some black spruce and much poplar. With insufficient black spruce, fire may change a mixed stand into a hardwood type.

Repeated burnings, or a single burn in a stand that has not reached seed-bearing age, destroy both the present stand and the possible sources of seed. This tends to produce hardwood types or complete waste areas of shrubbery and grass.

Butson, R.G. 1984. The demography of three naturally occurring red pine stands at the northern limit of red pine's geographic range in Ontario. Bachelor of Science in Forestry Thesis, Lakehead University, 1984.

Demographic characteristics and associated vegetation were assessed for three naturally occurring, disjunct stands of red pine (*Pinus resinosa* Alt.) located west of Armstrong, Ontario and northwest of Jellicoe, Ontario. All sampled trees were mapped, cored for age estimation and increment growth measurements, and measured for diameter and heights. Floristics were described at each community.

An analysis of covariance performed on the overall mean annual radial growth increment data (MAIr) using site as the independent variable, and age as the covariate, indicated a statistically significant difference in growth. An evaluation of the adjusted average MAIr's suggested that the two Armstrong area sites differed from the Jellicoe area site. The two Armstrong area populations showed slow growth rates, all-aged distributions, a long expectation of life, and a high age/diameter correlation. In contrast, the Jellicoe area population showed a much greater rate of growth, an even-aged distribution, a relatively short life span, and a low age/diameter correlation. Diameter distributions were patterned considerably differently from age distributions and represented the one recorded instance where the Armstrong area populations were the least comparable with one another.

It is suggested that the similarities expressed by the Armstrong area populations are characteristic of marginal red pine stands. Rather than demonstrating the colonizing strategy typical of red pine in the better represented parts of its range, these populations have maintained their dynamic nature by exhibiting a "climax" strategy that has enabled them to survive the harsh growing environment characterizing their habitats. This survivorship strategy is one of continual recruitment made possible through species specific seeding, root development, and stem morphology characteristics over a long life. It is further suggested that these marginal populations have been stable for some time and will continue to be so in the future.

Carleton, T.J. 1978. A phytosociological analysis of boreal forests in the region south of James Bay. Ph.D. Thesis, Univ. Toronto, Ont. 348 p. + Appendices. (Diss. Abstr. Int. 39:3126-B).

Extensive vegetation survey was carried out in boreal forests of Ontario and Quebec south of James Bay. Description of the composition, environmental relations and dynamics of the forest vegetation constituted the broad objectives of the study.

Forest stands were selected in the field on a set of *a priori* criteria. Sampling included the point-quarter method for trees and saplings, lists of all vascular species and many terrestrial mosses and lichens as well as quadrat frequency data on these understory taxa. The data accumulated over four summers, 1972-1975 inclusive, comprised 205 forest stands containing 440 vascular and 70 cryptogamic species.

Both simple tabular methods and multivariate techniques of data summary were employed. Multidimensional scaling, centred and non-centred principal components ordinations were produced. Noy-Mein's (1971) extension of the latter approach was adopted in which unipolar, rotated components are regarded as vegetational noda.

Centred ordination models indicated that broad categories of substrate type and moisture status correlated with compositional variation among tree species. A similar conclusion was reached using simple tabular analysis within macroclimatic units corresponding to Hills' (1959) site regions.

Simple bivariate scatter plots and the inclusion of "successional vectors" for trees in the above ordination models showed close agreement in the dynamic pathways indicated for each tree species. Of the dominant trees, *Pinus banksiana, Latrix laricina, Pica glauca, Betulla papyrifera, Populus balsamifera* and *Populus tremululoides* appeared to be species of primary colonization on deforested areas in contrast to *Abies balsamea*, a species of secondary invasion beneath the canopies of other tree species. *Picea mariana* appeared to posses a combination of these dynamic characteristics. The prevalence of trees adapted to primary colonization suggests an environment in which deforestation due to external catastrophe such as fire prevails.

Non-centred components analysis (i.e. nodal orientation) of the tree and sapling data identified mostly monospecific forest types for all of the trees except *A. balsamea*. This was interpreted as confirming the above conclusions in general but some specific successional sequences were identified with this technique. In addition an exclusive classification of stands into canopy classes was achieved.

Nodal ordination of the understory vascular plant presence lists indicated a north-south floristic segregation among stands in the study region and a distinctive deciduous vs coniferous conifer separation in relation to canopy. The north-south segregation emerged due to the persistence of certain widespread taxa while the others seem restricted north of approximately 47° N latitude. An exception were the northern bottomland forests which support a flora of very southern character. While the growing season is shorter further north, this floristic difference is attributed mainly to the poor ability of many of the vascular species in the list to survive recurrent fire.

Nodal ordination of quantitative understory vascular plant data indicated the importance of local substrate conditions in determining vegetation composition. The ecology of individual species are considered with the aid of a summary model of nodal interrelationship based upon multidimensional scaling.

Canopy composition seemed generally to be of minor influence in determining local vegetation cover although certain species seemed extremely intolerant of deep coniferous shade. Canopy influence was assessed by the comparison of overstory and understory noda, the affinity of individual species to canopy classes, and changes in species abundance along overstory successional sequences.

Evidence for forest retrogression appeared in the data and this is discussed with respect to the survival tactics of certain understory shrubs notably Kalmia angustifolia and Acer spicatum.

The composition of the boreal forest is discussed with respect to quaternary history, plant geography, climate and fire disturbance. (abstract)

Coyea, M.R. 1986. Comparative bioassay of jack pine seedlings inoculated with *Laccaria laccata* and grown in soils which have been subjected to prescribed burns. B.Sc.F. Thesis, Univ. Toronto, Toronto, Ont.

Jack pine (*Pinus banksiana* Lamb.) seedlings were grown in a peat vermiculite medium inoculated with *Laccaria laccata*, a fungal species capable of forming ectomycorrhizal associations with tree roots, and combined with soil that was subjected to prescribed burn either in 1977 or 1983. The effect of fire history on seedling growth was significant with a high degree of confidence only on the shoot to root length ratio. However, when this factor was examined as interacting with inoculation or sterilization treatments the response in seedlings showed a high correlation.

The effect of inoculation of *Laccaria laccata* showed a significant correlation with: total shoot length; shoot length; root length; and shoot weight; but surprisingly not with number of ectomycorrhizal infections. Significant correlations between the effect of sterilization and several parameters have been shown. These parameters include: growth of shoot length; shoot to root length ratio; and the number of ectomycorrhizal infections. A two way interaction of inoculation and fire history was well correlated, with root length; shoot weight; root weight; number of ectomycorrhizal infections; shoot to root weight ratio and total shoot length. Analysis of sterilization and inoculation interaction showed significant response in shoot length, shoot weight and total seedling length. Examination of a three way interaction between fire history, inoculation and sterilization showed no correlation. A soil analysis indicated that a deficiency in nitrogen existed in both burn sites. Magnesium levels between the 1983 and 1977 sites were significantly different. All other macro and micronutrient concentrations were not significantly different between 1983 and 1977 soil sources.

Ferris, J.E. 1980. The fire and logging history of Voyageur's National Park: an ecological study. M.Sc. Thesis, Mich. Tech. Univ., Houghton, Mich. 75 p.

To document original vegetation, historic fire patterns, modern fire patterns, logging activities, their impact on the vegetation and successional patterns developing in Voyageur's National Park, a two-year study was conducted (1978-1980). Present vegetation, fire evidence, logging evidence, and relevant historic records were investigated during the course of this study. A type map of the original vegetation was prepared from the original survey notes taken in 1881-1894. Comparison of this map with the current type map shows significant type shifts from predominately pine and spruce-fir forests to predominately aspen forests today. The presettlement fire regime was the primary factor maintaining the pine types while logging has been the primary factor effecting the establishment of the aspen types.

Five general site types were identified using Bray-Curtis ordination and synecological coordinates. These site types ranged from dry jack pine sites to very wet swamp conifer sites. These different types have had differing fire and logging histories and the successional dynamics reflect these differences. In the absence of fire or other major disturbances most stands will climax in spruce-fir types.

Holla, T.A. 1985. The demography of a mixed white pine (*Pinus strobus* L.) and red pine (*Pinus resinosa* Ait.) stand at Sandford Lake, Ontario. An undergraduate Thesis, School of Forestry, Lakehead University, 73p.

Demographical characteristics were examined in naturally occurring white pine (*Pinus strobus* L.) and red pine (*Pinus resinosa* Ait.) stands located at Sandford Lake, Ontario. Sample trees were aged and measured for diameter.

The white pine population showed an all-aged distribution, an intermediate expectation of life, and a high age/diameter correlation. The red pine population exhibited an even-aged distribution, a long expectation of further life, and an intermediate correlation between age and diameter. Diameter distributions for each species were similar to their respective age distribution.

These characteristics of white pine, aong with mass and continual recruitment, are consistent with other white pine populations. This species maintains its dynamic nature by exhibiting a "climax" strategy. The characteristics of red pine, including mass recruitment, seems to be consistent with other red pine populations. Red pine is unable to maintain its numbers through continual recruitment.

It is suggested that white pine, in the absence of fire, will continue to maintain its numbers, and that red pine will be unable to maintain its numbers and will eventually cease to be a component of this particular stand.

Hummel, S.L. 1979. Ecological effects of seven fires in a jack pine (*Pinus banksiana*) stand. M.Sc.F. Thesis, Univ. Toronto, Toronto, Ont. 201 p.

This case study examined vegetation in a jack pine forest, in 1978, after seven fires conducted or observed by C.E. Van Wagner between 1962-65 on the Petawawa Forest Experiment Station, Chalk River, Ontario. The fires ranged in intensity from 70 - 17000 KW/m. Vegetation on the recently burned areas was compared with the vegetation on three control plots established in the same stand but last burned in 1914.

In 1978 there were more and larger jack pine seedlings on those plots which were burned by more intense fire, where more fuel was consumed during fire (where there was more duff remaining after fire), and where there were fewer residual trees left from the mature stand that was burned. There were more mature trees scarred and killed on those plots burned by more intense fires. There was evidence of charcoal further down the LFH layer and closer to the mineral soil on those plots where more fuel was consumed during fire. Plant species showed increased or decreased Importance (abundance + area covered) on more severely burned plots depending on the location of reproductive parts in the organic layer, seeding habits, the presence of protective plant parts, and ability to adapt to post-fire site conditions. Importance of thirty-five plant species was observed. Obvious and subtle evidence of fire in the stand is discussed.

These findings could be generally useful in parks and wilderness reserves where the role of fire in maintaining natural jack pine stands is to be understood and integrated into resource management practices.

Irwin, L.L. 1974. Relationships between deer and moose on a burn in northeastern Minnesota. M.Sc. Thesis, Univ. Idaho, Moscow, Idaho. 51 p.

A study of habitat selection, food habits, distributions, and populations of white-tailed deer (*Odocoileus virginianus*) and moose (*Alces alces* andersoni) was conducted from July, 1972, through December, 1973, on a 5,920 ha burn that occurred in spring, 1971, in northeastern Minnesota. Moose and deer both preferred coniferous stands within the burn most in late fall and early spring but preferred deciduous stands above all others, especially in summer and fall. A radio-collared cow moose confirmed track counts which showed that moose selected aquatic communities from late May through June. Habitats most preferred were post-burn communities that produced large amounts of preferred forage. Sites logged prior to the fire and openings along roads were attractive to deer. Association coefficients confirmed moose and deer selected similar communities in summer and fall, but by December they appeared in similar communities by chance. Aerial and ground observations of animal groups indicated that moose and deer used the burn in summer and retreated to the periphery and unburned forest during winter. A total of 14,368 instances of use by moose recorded at 87 feeding sites showed twenty-two species, including sprouts and suckers of trees such as quaking aspen (*Populus tremuloides*), white birch (*Betula papyrifera*), and red maple (*Acer rubrum*), and shrubs such as willows (*Salix* spp.), pin cherry (*Prunus pennsylvanica*), mountain maple (*A. spicatum*), and beaked hazel (*Corylus cornuta*) formed 90-95 percent of the diet of moose using uplands on the burn. The only terrestrial herbaceous species important to moose was fireweed (*Epilobium angustifolium*), which was used during summer. Deer fed upon at least 42 species within the burn, as determined from 3,827 instances of use at 52 feeding sites. Browse comprised over 50 percent of the diet of deer during all periods except spring. Important foods for deer were grasses, sedges (*Carex* spp.), sarsaparilla (*Aralia nudicaulis*), and white clover (*Trifolium repens*) in spring; fireweed, sweet peas (*Lathyrus* sp.), clover, goldenrod (*Solidago canadensis*), and jewelweed in summer; and red maple, white birch, pin cherry, and bush honeysuckle (*Diervilla lonicera*) during fall. Mutual use of habitats and food items suggested a temporary possibility of competition only for red maple, but competition was deemed unimportant in the interactions between deer and moose during this study. Aerial investigations of moose during November and December indicated the moose population was rapidly increasing through immigration by yearlings (as previous investigations showed) and by increased reproduction as indicated by the presence of twins, which did not appear until three growing seasons after the fire. Aerial censuses of moose pellet group counts for deer indicated fall moose numbers at 1.03/km^2 ($s^2 = 0.157$) and pre-fawning deer numbers at 3.55/km^2 ($s^2 = 0.974$) in 1973. The relationships between habitat selection and naturally occurring large burns or intensive logging in boreal forest, both of which produce large amounts of woody forage and appear to allow moose populations to increase in the presence of deer and the pathogenic nematode parasite (*Parelaphostrongylus tenuis*) was discussed.

Linn, R.M. 1957. The spruce-fir, maple-birch transition in Isle Royale National Park, Lake Superior. Ph.D. Thesis, Duke Univ., Durham, N.C. 101 p.

The boreal white spruce-balsam fir forest and the sugar maple-yellow birch forest, both climax associations in contiguous areas, are present on Isle Royale in Lake Superior. The hardwoods are located at the center of the island at elevations of from 200 feet above Lake Superior to the highest point at 793 feet above the lake, while the conifer forest is at lower elevations in the periphery of the island. The objective of the study which took place during the summers of 1953, 1954, and 1955, were to describe the nature of the transition zone between the two types, and to ascertain the factors causal for existence of both forest types on Isle Royale.

Environmental studies included the establishment and maintenance of six thermograph stations at various distances from the shore of Lake Superior. All were located in open areas to minimize the effects of forest canopy types. Temperatures for the 2-inch air level, the ground surface, and 2-inch soil level were continuously recorded for the months of July, August and September of 1955, at each station. Precipitation and vapor pressure records for the area were obtained from the Mott Island Cooperative Weather station and Feldtmann Lookout Station on Isle Royale. Soil Samples at the soil surface, at the 2-inch level, and at the 10-inch level were obtained before and after a ten-day dry period from pairs of trenched and untrenched plots in spruce-fir forest, in maple-birch forest, and in each forest type of the transition zone.

Paired blocks were established to sample the vegetation at each differing vegetation type along the transects which followed various contours of elevation in the southwestern, central, and northeastern sections of the island. In southwestern Isle Royale, the maple-birch forest reaches it ultimate expression on the higher ridges. The central section contains vast areas of recently burned-over lands with sites otherwise similar to those in the southwest. The northeastern section of the island also contains sites similar to those in the southwestern section, but the island is considerably narrower in the northeast and fires which occurred about 100 years ago have left successional communities dating from that time.

The environmental data indicate that, in areas near to Lake Superior, temperatures are lower and have less range, and atmospheric moisture is greater than at the higher elevations in the center of Isle Royale. Here temperatures are highest and atmospheric moisture is lowest. These two extreme habitats possess climatic patterns which differ enough to be expressed by different climax vegetation types.

In the transition zone between the two forest types, temperatures and atmospheric moisture values are fairly uniform in areas which support spruce and fir and in other areas supporting maple and birch. However, soil moisture values are higher for soils which support spruce and fir or successional communities to spruce-fir than are soil moisture values for sites on which maple and birch are dominant. In turn, the soil moisture values reflect the degree and direction of slope – the maple-birch communities growing on steep, south-facing hillsides and the spruce-fir communities growing on level terrain, valleys, cove-type hillsides, and north-facing slopes.

Data from the vegetation sampling indicate moisture gradients are effectual in community composition. All sites from which vegetation data were gathered were grouped into moisture gradient categories of xeric, mesic and wet-mesic. In the maple-birch climatic climax area of central Isle Royale, *Acer saccharum* is dominant on xeric sites with *Quercus rubra* as a codominant in successional communities; *Acer saccharum* and *Betula alleghaniensis* are codominants on the mesic sites and *Acer saccharum* and *Picea glauca* tend to dominate on wet-mesic sites. In the transition zone *Acer saccharum* is dominant on xeric sites; *Picea glauca, Abies balsamea*, and *Acer saccharum* are dominant on mesic sites; and *Picea glauca* and *Abies balsamea* dominate wet-mesic sites. None of the sites in the conifer climax areas support any of the maple-birch element.

The northern hardwoods, especially *Acer saccharum* and *Quercus rubra*, probably dominated much of Isle Royale during the xerothermic period. Also during the xerothermic, glacial waters had not completely subsided to their present level which suggests the possibility of the present northern hardwood forest being a relic of this past period. Because angles of insolation and water loss are greatest on the steep south-facing slopes of central Isle Royale, and because the temperatures in this central portion are not ameliorated to such an extent at lower elevations by Lake Superior, the hardwoods have remained there as the climax forest. At lower elevations nearer to Lake Superior, temperatures are ameliorated by the lake, atmospheric moisture is high, and angles of insolation and water loss are less than in the central portions of the island; thus the boreal conifers make up the climax forest. In areas of the transition zone, the hardwoods dominate areas of least soil moisture and the conifers dominate those areas where available soil moisture is great enough to permit their existence.

MacQuarrie, D.I. 1975. Stand structure of the boreal forest in northeastern Ontario. M.Sc. Thesis, Univ. Toronto, Ont. 270 p.

The structure of the boreal forest in northeastern Ontario was studied using both variable area horizontal plots and plotless line transects. Single-storied, fire origin, pure stands of jack pine and trembling aspen dominate the upland soils. Water-deposited layers of silt at varying depths limit the growth of these stands, especially jack pine. Growth declines occur on the average after only 30 to 40 years have elapsed.

More complex mixed stands of white birch, white and black spruce, pine, poplar, and balsam fir occur on the till soils and river valley deposits. These stands are multi-layered and are often much older than the pure stands which surround them. Black spruce dominates the poorly drained soils and organic deposits with some areas containing eastern larch and northern white cedar.

Boundaries between stands are often acute on the well-drained upland soils but species intergrading as a result of topographic gradients cause stand boundaries to become more obtuse as the available soil moisture increases at lower elevations.

Millar, J.B. 1936. The silvicultural characteristics of black spruce in the Clay Belt of northern Ontario. M.Sc.F. Thesis, Univ. Toronto, Toronto, Ont. 81 p.

Forest fires have been quite common in the history of Northern Ontario and a large part of the Clay Belt has been burned in the last one hundred and fifty years. The result of the fire depends largely on the stand of timber present at the time of burning. For this reason the following divisions are formed in considering the effect of burns:

1. Type I - Slopes
2. Type II - Flats and Swamps
3. Young Stands & Recent Burns.

1. <u>TYPE I</u>: Fires in this association produce the greatest variety depending upon the intensity of the fire and the original composition of the stand. A light fire will open up the stand and leave considerable residual trees and advance growth. This is similar to the opening of an over-mature stand by windfall. The resulting new crop will contain a large proportion of balsam. The greater tolerance of balsam is the main factor. Added to this a certain amount of balsam advance growth will survive. However, the majority of fires cannot be classed as light, they are severe or heavy and fires resulting in a new stand of balsam are rare.

The reproduction following an ordinary fire is mainly spruce. Poplar and in some cases white birch will form a part of the stand but the coniferous component is entirely spruce. Where the original forest has been a pure hardwood type, the regeneration will be poplar and birch. For some unknown reason balsam will not come in: this may possibly be due to the supply of seed. The balsam cones disperse their seed and disintegrate during the winter and early spring after they mature. It has been observed that a fire in a black spruce stand does not consume the extreme tip of the trees and the cones. Black spruce has a structure peculiar to no other tree. The cones are aggregated at the very top of the tree and occupy two to three feet. Below this clump, the trunk is clear for another two feet, while not all the individual trees have this form, a great many of the mature black spruce do exhibit this phenomenon. It has been attributed partially to squirrels; certainly squirrels do nip off many of the twigs during the late fall. The clear portion on the trunk acts as a barrier to the fire and in many cases the cones are scorched but not consumed. In black spruce the cones are persistent and serotinous; this provides a plentiful supply of viable seed after the fire and consequently black spruce forms a part of the new stand. Large over-mature white spruce, found on most well-drained slopes, also furnish good seed for the new crop.

2. <u>TYPE II</u>: For spruce flats and spruce swamps there is no doubt about the regeneration following a fire, it is invariably black spruce. Balsam, white spruce, poplar and birch are confined to Type I and leave the poorly-drained locations to black spruce. On the very wet sites tamarack may be present but only in small quantities and it does not compete with the spruce to any extent.

3. <u>YOUNG STANDS AND REGENT BURNS</u>: Forest fires are not nearly as disastrous, in certain stands, as the public imagines. Overmature stands, which cannot be cut in the near future, are much better if burned and converted into young fast-growing forests. Likewise inaccessible mature stands, which, according to the working plan, cannot be cut during the next rotation, would be more profitable if burned. This does not mean that fires are a cureall and that the forests should be burned indiscriminately. Fire, in recent burns and in young stands, which have not yet borne seed can cause great damage. Here following a fire there is no regeneration or a little poplar and birch at the most. Therefore, such a fire will seriously affect the rotation. Alder, raspberry and other weed species take possession of the area and, unless planting is done, it will be years before commercial species regain control

The present stands may be roughly divided into two classes based on origin:

1. <u>THE BURNS WHICH ARE THE RESULT OF FIRES</u>: With the exception of the very wet, true muskegs, the whole area has been burned over at least once and often several times. Fire, in northern Ontario causes an even-aged forest. The composition of the new stands depends on the site and particularly the drainage.

(a) Well-drained sites: On the well-drained slopes, river banks, ridges and high ground, the fire type consists of spruce and poplar. Birch does not occur uniformly over the area, but is confined to isolated portions which bear an almost pure hardwood stand of poplar and birch. Balsam is generally lacking in the young stands.

Observations over wide areas have led to the conclusion that the climax forest type on these well-drained sites does not resemble the fire type at all. The climax association is an uneven-aged stand of balsam which develops from the spruce and poplar mixture. The latter grown rapidly until it is about 100 years old. About this time balsam appears in the understory. There are always widely scattered balsam of the same age as the spruce and poplar. Small balsam seedlings first appear under the stand at 50 years of age. These are greatly suppressed but persist. As the stand ages the number of balsam increases.

(b) Poorly-drained flats and swamps: Where the drainage is poor as on flats and in swamps the original fire stands and the climax stands are not radically different.

The stand is at all time preponderantly spruce. Balsam and birch may be present in small amounts and larch is common on the very wet sites. Immediately following the fire alder may take possession of the area. For a number of years this scrub growth will suppress the spruce. At about twenty-five years the alder dies off allowing the spruce to advance normally. Growth continues for possibly a hundred years then the stand tends to thin out. Loss from decimation more than offsets the increase in the individual trees. Alder and scrub cedar now enter the composition but do not form part of the crown cover. The spruce regenerates very slowly in the openings and consists of a very few stems per acre. The cordage is low, in very old stands and may drop to four or five cords per acre.

From the above it follows that the burns are beneficial for both dry slope stands (Type I) and swamp stands (Type II). In the former the climax type is uneven-aged balsam and in the latter scattered spruce with cedar and alder. The yields from these over-mature stands are considerably below normal and a fire would put them back on a productive basis.

It is not suggested that the country be burned at random. Repeated fires are undoubtedly injurious to the soil and on dry sites may lead to pure hardwood stands. But over-mature stands which for economic reasons, cannot be logged, should be burned in order to provide for the future.

2. THE MUSKEGS WHICH HAVE NEVER BEEN BURNED: The only stands which occupy a considerable part of the area and are not fire types are muskegs. These have developed from the filling in of lakes during the past centuries.

Nordin, J.O. 1974. The mapping and characterization of the soils and vegetation of the Little Sioux Burn area in northeastern Minnesota. M.Sc. Thesis, Univ. Minn., St. Paul, Minn. 122 p.

The Little Sioux Fire was first detected on 14 May 1971. During the next three days the fire burned approximately 5900 ha (14,600 acres). A large portion (about 40%) of the burned area was virgin forest. Maps were constructed of fire intensities, forest cover types in 1970, and soils of the Little Sioux Burn Area (LSBA). These three maps, a 1948 U.S. Forest Service cover type map and a U.S.

Geological Survey topographic map for the area were randomly sampled by 997 points and thirteen classifications was analyzed using chi-squares and measures of association. Highest association was found between 1948 and 1970 cover types, with relationships between soil units, soil groups, topographic classes, and cover types also being relatively high. Fire intensity was most closely related to topographic class.

Analysis of vegetation change from 1948 to 1970 showed an 80% decrease in balsam-fir cover types. This decrease was accompanied by a nearly equal increase in aspen cover types. This balsam-fir to aspen cover type reversal was attributed primarily to the spruce budworm epidemic, which occurred from about 1955 to the mid-1960's. Decreases in jack pine, red pine, and white pine cover types were attributed to commercial logging.

Soils in the LSBA are diverse, due to a wide range of parent materials and rugged topography. Clayey lacustrine sediments located in the northwestern portion of the burn area appear to have been deposited during a high stage of glacial Lake Agassiz. Soils developed in varying thicknesses of Rainy Lobe till occupy the majority of the LSBA, and bedrock ridges are common. Surface horizons of many till and lacustrine soils are high in silt-sized material, presumably of aeolian origin. Well-drained water-lain soils are infrequent, with alluvial soils more frequent than soils developed in glacial outwash. Hemists of varying depths occur throughout the burn area.

Shafi, M.I. 1972. Secondary (postfire) succession in the Cochrane District of northern Ontario. Ph.D. Thesis, Univ. Toronto, Toronto, Ont. 347 p. (Diss. Abstr. Int. 35:786-787-B).

The secondary (post-fire) succession of vegetation in the Cochrane district of Ontario was studied in four different ways.

1. It was discovered that the diversity of vegetation increases in the beginning of the succession but declines from 11 years after fire. A number of different measures of diversity were computed but all gave the same results.

2. An agglomerative polythetic classification yielded six species groups which belong to three successional types. The graphs of means of the frequencies of these three vegetation types revealed that there are four stages of succession of vegetation: 1) initial heterogeneous phase (0-1 years); 2) early phase (1-4 years); 3) heterogeneous phase (4-14 years); and 4) late phase (after 14 years). Initial heterogeneity was attributed to spatial differences in the intensity of burning; early phase is dominated by two groups of species, one survives the fire in the wet patches and the other recovers rapidly by means of deep rhizomes; the heterogeneous phase is characterized by environmentally differentiated species groups; after 14 years the paths of succession converge to vegetation dominated by either *Picea mariana* or *Pinus banksiana* depending on the physiography.

It was recognized from the graphs of variances and variance/mean ratios of the frequencies of species groups that the appearance and disappearance of a stage takes place in a heterogeneous manner. This further source of heterogeneity during the succession is attributable to different rates of succession at different sites.

Maturity weightings for each site, calculated on the basis of the time of first occurrence of each species in the succession, indicated the exclusion of ephermeral species at the end of heterogeneous phase. The variances of the maturity weightings at each age confirmed the differential maturing of sites within the areas of given age.

3. The environmental variables, pH, loss on ignition, available moisture, Calcium, Magnesium, Sodium, Potassium, Manganese, Iron, thickness of layers, combined thickness of intermediate layers, depth of parent material, and the amount of ground vegetation were sampled at 168 sites of various ages. Analyses of the environmental variables also suggested that 4 stages of succession exist. These stages very slightly precede the corresponding vegetational stages.

4. Regression analyses of the frequencies of occurrence of species groups on the environmental variables indicate the apparent response of species and groups to given environmental variables at various times during the succession. Graphs of the regression coefficients against time support the recognition of successional stages and confirm information about vegetational heterogeneity and the behavior of some species inferred from earlier results.

Finally the implications of these studies for forest management practices are discussed.

Slaughter, K.W. 1994. Succession following forest fire in northeastern Minnesota; changes in biomass and stand composition. M.Sc. Thesis, Univ. Minn, St. Paul, Minn. 140 p.

This study, conducted in the summer of 1993, was an extension of work begun immediately after the Little Sioux Fire of 1971. The initial work focused on several different questions about ecosystem responses to fire, and the roles that fire plays in northern Minnesota. Changes in vegetation from 1975 to 1993 in the fire area, increased the record of such changes in these upland forests. Within the stands studied, total live biomass increased. Trees made up the largest component of biomass and were the only stratum to increase in biomass in all stands. The other vegetative strata decreased in overall biomass, although individual components increased in some stands. Forest floor increased in mass. Results of changes in soil C were inconclusive.

Questions concerning the role of boreal forests in global warming and in C sequestration provided some of the impetus for returning to study the Little Sioux Fire. The results for C storage were similar to those found by other researchers in the north central U.S.A.

Smith, D.W. 1966. Studies in the taxonomy and ecology of blueberries (*Vaccinium, Subgenus Cyanococcus*) in Ontario. Part II. Ecological study with special reference to the effects of fire on the soil and vegetation. Ph.D. Thesis, Univ. Toronto, Toronto, Ont. (Diss. Abstr. 28:3183-3184-B).

A study of the soil and vegetational changes after fire in a jack pine-blueberry community showed that 30-50 years were necessary for complete return to the pre-fire condition, although levels of many nutrients were similar to pre-burn conditions after two years. Most important soil changes occurred within four months of burning.

The direct effects of burning intensities from 302 to 823°C and of durations from 20 to 80 sec/m^2 were restricted to the top 2 cm of soil. These effects included the loss of surface litter and humus to a maximum of 72 percent, moisture loss of 75 percent, increase in pH from between 4.06-4.22 to 5.10-5.63 and increase in total soluble salts to a maximum of 324 percent. The effects of burning duration were greater than of intensity.

Immediate increase in concentration of nutrients in the surface soil varied with duration to maximum values of: 166 of sodium, 398 of potassium, 351 of calcium, 282 of iron, 277 of aluminum and of phosphorus to 525 percent. These changes resulted mainly from the combustion of vegetation, surface litter and humus.

Erosion of ash after burning decreased pH, total soluble salts and individual nutrients. However, large amounts were leached or fixed in unavailable forms. Leaching of individual cations may have been affected by solubility, ionic charge and size but other factors including precipitation and uptake by plants were more important.

Losses of extractable phosphorus appeared to be mainly related to fixation with iron and aluminum and to wind erosion but leaching was also evident.

Maximum losses of nutrients from the surface over a 14 month period were: 93 percent of potassium, 83 percent of calcium, 88 and 85 percent of iron and aluminum respectively and 76 percent of phosphorus. Replacement of nutrients occurred mainly by leaf fall and precipitation.

The short term productivity and abundance of *Vaccinium angustifolium* was increased by moderate burning but decreased by severe burning. Short term benefits of burning to increase the abundance of *V. angustifolium* could be much less important than the accompanying loss of soil nutrients, especially with repeated burning.

Although recognized as pioneers after fire, *Pinus banksiana*, *Populus tremuloides* and *Betula papyrifera* showed decreased abundance and lower productivity after severe fire. *Prunus pensylvanica*, *Amelanchier sanguinea* and *Comptonia peregrina* were especially tolerant of severe fire as were several herbs including *Carex aenea* and *Danthonia spicata*.

Wright, R.F. 1974. Forest fire: Impact on the hydrology, chemistry, and sediments of small lakes in northeastern Minnesota. Ph.D. Thesis, Univ. Minn., Minneapolis, Minn. 129 p. (Diss. Abstr. Int. 35:972-B). [Also available as: Univ. Minn. Limnol. Res. Cent. Int. Rep. No. 10].

This article is a popularized account of that portion of the fire effects research program on the 1971 Little Sioux Fire in northeastern Minnesota dealing chiefly with the watershed aspects nutrient cycling.

3.0 Fire and the Great Lakes - St. Lawrence forest region

Dominy, S.W.J. 1981. The role of fire in Parke Township, Sault Ste. Marie, Ontario. B.Sc.F. Thesis, Lakehead Univ., Thunder Bay, Ont. 190 p.

The objectives of this study were: 1) to examine the known effects of fire on northeastern North America pine ecosystems; 2) to determine the recent fire frequency and pattern for Parke Township; 3) to determine the effects of fire exclusion on the pine forests of Parke Township; and 4) to educate the general public in the role of fire in forest ecosystems.

A thorough review of the literature dealing with fire's effects upon the northeastern pine ecosystems was prepared. Approximately 300 trees were sampled for age-class and fire scar data. Historical documents and survey, logging, and recent fire records were also examined. A series of fire history maps were constructed. A 0.2 ha transect was established in a mixed pine stand and intensive sampling of the vegetation, and soil and litter layers was carried out.

Results indicate that during the 250 year period from 1700 to 1950, there were 19 recorded fires in Parke Township. The mean fire return interval is 12.3 years. The fire return interval cannot be considered natural because of human influence in the area.

The forest stand structure of a mixed pine area which has had fire excluded for 78 years shows a influx of the shade tolerant hardwood and conifer stand components. Minor understory vegetation is sparse on the acid, sandy soils, with *Gaylussacia*, *Maianthemum*, *Vaccinium*, *Epigea*, and *Pteridium* being the most prominent species.

Continued fire exclusion will see the jack pine (*Pinus banksiana* Lamb.) over the next 40 years, and the red pine (*Pinus resinosa* Ait.) over the next 200 years, being replaced by red oak (*Acer rubrum* L.), white pine (*Pinus strobus* L.) and associated species. A series of low intensity prescribed burns are recommended in order to provide conditions which will maintain the jack, red and white pine, while eliminating the more shade tolerant competition.

James, T.D.W. 1976. Some effects of controlled surface burning in a *Populus tremuloides* Michx. woodland. M.Sc. Thesis, Univ. Guelph, Guelph, Ont. 188 p.

This study dealt with the ecological effects of surface burning in a *Populus tremuloides* (aspen) dominated woodland located on poorly drained, organic, "muck" soils close to Luther Marsh, Wellington County, Ontario.

Research plots were surface burnt in spring 1972 and 1973. Burning in both years was uneven due to heterogeneity in fuel and surface moisture distribution. The most important variable affecting fire intensity was windspeed. Higher windspeeds resulted in incomplete fuel combustion and lower fire temperatures. A second factor influencing the surface temperatures (192°C average on both burn occasions) was the high moisture content of fuel.

Analysis of P, K, Ca and Mg in fly-ash transported from the 1973 burns suggested that airborne removal of particles may result in considerable nutrient depletion in burned areas. Total amounts exported could not be calculated due to incomplete recovery of fly-ash. Nutrient losses by volatilization were very small due to the low fire temperatures.

Release of soluble mineral salts from ash resulted in appreciable increases in concentration of P, K, Mg and Ca in the soil. These were detected chiefly in the surface 10 cm, especially during the first month following burning. Rapid downward movement of cations was indicated by simultaneous increases at the soil surface and at depths of 10-20 cm. On a percentage basis, more potassium than calcium or magnesium was displaced from surface horizons probably because of the differing absorption properties of these two ions. A two-month delay between burning and increases in phosphorus indicated that the mobility of this element was low in organic soil.

Fire-induced changes in surface albedo resulted in significantly higher soil temperatures in burn compared to control areas. Differences of 1.1°C and 0.5°C were evident at depths of 0-10 cm one and three months after burning respectively.

The major changes in ground vegetation following burning related to shifts in dominance. Cover of *Cornus stolonifera* and *Carex stricta* was decreased in the summer following fire. At the same time cover and abundance of *Calamagrostis canadensis* increased substantially. These dominance shifts were a result of: (i) the creation by fire of a more open environment near the soil surface, (ii) differing growth patterns of species, and (iii) edaphic changes following burning. The evident lushness of the regenerating postfire vegetation was probably related to the increases in soil nutrients and temperature. Postfire changes in ground vegetation were short-lived. Vegetation in burned areas closely resembled the control, pre-burn conditions two years after fire.

Standing crop and production of the *P. tremuloides* overstory was estimated using allometric methods. A mean stand range of 7.9-8.9 t/ha total aerial biomass (trunk, lateral branches, twigs and leaves) was low compared to other reported values. This was indicative of low site-productivity and tree density. Mean standing crop density (0.10 kg/m^3), leaf area index (0.37) and net primary production (70.3 $g/m^2/yr$) were low for similar reasons.

There was no evidence to suggest that aerial standing crop of *P. tremuloides* biomass or energy was changed by burning. Production was also unaffected. Presumably, the environmental changes produced by the low-intensity surface fires were too slight to significantly alter biomass accumulation by the established overstory.

The relative importance of various *P. tremuloides* components as nutrient accumulation sites followed the order leaves > twigs > lateral branches > trunk. Functionally important N, P, K and Mg were mainly accumulated in the leaves. The trunk was the most prominent site for accumulation of structurally important calcium. Total accumulation of nutrients in *P. tremuloides* biomass at W. Luther (103.5 kg/ha) was very low compared to other deciduous forest stands. This was largely a reflection of the low tree density.

The standing crop of nutrients in trunk, lateral branches and twigs was unchanged by fire. However, nutrient amounts in foliage were significantly altered. Concentrations of nutrients in leaves from burned areas were 42%-45% greater than comparable control values. Pre-burn concentration were similar. Increases in leaf nutrients were probably related to postfire increases in soil nutrient levels. Enrichment of the soil from ash was greatest during the spring period of maximum assimilation and concentration of mineral elements in actively growing *P. tremuloides* ramets.

APPENDIX B
Books and conference proceedings associated with understanding the ecological role of fire

Ahlgren, C.E. 1974. Effects of fires on temperate forests: North Central United States. p. 195-223 **in** Fire and Ecosystems, Kozlowski, T.T.; Ahlgren, C.E. (eds.). Acad Press, N.Y. 542 p.

Armson, K.A. 1977. Forest soils: properties and processes. Univ. Toronto Press, Ont. 390 p.

Baughman, R.G. (compiler). 1981. An annotated bibliography of wind velocity literature relating to forest fire behavior studies. USDA For. Serv., Intermt. For. and Exp. Stn., Ogden, Utah. Gen. Tech. Rep. INT-119. 28 p.

Dubé, D.E. (compiler). 1977. Fire ecology in resource management - Workshop proceedings. Can. For. Serv. Inf. Rep. NOR-X-210. 111 p.

Goldammer, J.G.; Jenkins, M.J. (eds.). 1990. Fire in ecosystem dynamics. SPB Academic Publishing. The Hague, Netherlands.

West, D.C.; Shugart, H.H.; Botkin, D.B. (eds.). Forest succession: concepts and application. Springer-Verlag. New York, NY. 517 p.

Johnson, E.A. 1992. Fire and vegetation dynamics: studies from the North American boreal forest. Cambridge University Press. Cambridge, UK. 129 p.

Kelsall, J.P.; Telfer, E.S.; Wright, T.D. 1977. The effects of fire on the ecology of the boreal forest, with particular reference to the Canadian north: a review and selected bibliography. Can. Wildl. Serv. Occas. Pap. No. 32. 58 p.

Lotan, J.E.; Brown, J.K. (compilers). 1984. Fire's effects on wildlife habitat - Symposium proceedings. USDA For. Serv., Intermt. For. and Exp. Stn., Ogden, Utah. Gen. Tech. Rep. INT-186. 96 p.

McAlpine, R.S.; Mellors, A. 1995. Annotated bibliography of fire behavior and ecology research at the Petawawa National Forestry Institute 1979-1994. Nat. Res. Can., Can. For. Serv., Chalk River, Ont. 27 p.

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APPENDIX C
List of abbreviated forms and complete titles of journals used in abstracts

Abbreviated Form of Journal	Journal Title
Acta Geogr.	Acta Geographical
Adv. Ecol. Res.	Advances in Ecological Research
Agron. Abstr.	Agronomy Abstracts
AI Appl.	AI Applications
Am. Met. Soc.	American Meteorological Society
Am. Midl. Nat.	American Midland Naturalist
Amer. For.	American Forests
Arct. Alp. Res.	Arctic and Alpine Research
Assoc. Can. Univers. North. Stud.	Association of Canadian Universities for Northern Studies
Atmos. Environ.	Atmospheric Environment
Biol. Conserv.	Biological Conservation
Bull. Ecol. Soc. Amer.	Bulletin of the Ecological Society of America
Bull. Torrey Bot. Club	Bulletin of the Torrey Botanical Club
Can. Dept. For., For. Res. Br., Que. Dist.	Canadian Department of Forests, Forest Research Branch, Québec District
Can. Dept. For. Rural Dev., For. Br. Development,	Canadian Department of Forests and Rural Forestry Branch
Can. Dept. North. Aff. Natl. Res., For. Br.,	Canadian Department of Northern Affairs and National Resources, Forestry Branch
Can. Ent.	Canadian Entomologist
Can. Field-Nat.	Canadian Field-Naturalist
Can. For. Serv., Inf. Rep.	Canadian Forest Service, Information Report
Can. J. Bot.	Canadian Journal of Botany
Can. J. Fish. Aquat. Sci.	Canadian Journal of Fisheries and Aquatic Sciences
Can. J. For. Res.	Canadian Journal of Forest Research
Can. J. Plant. Sci.	Canadian Journal of Plant Science
Can. J. Soil. Sci.	Canadian Journal of Soil Science
Can. J. Zool.	Canadian Journal of Zoology
COJFRC	Canada-Ontario Joint Forest Research Committee
Conserv. Biol.	Conservation Biology
Cooper Orinth. Soc.	The Cooper Orinthological Society
Dept. Environ., Can. For. Serv., Inf. Rep.	Department of the Environment, Canadian Forestry Service, Information Report
Dept. For., Can. For. Serv., Inf. Rep.	Department of Forestry, Canadian Forestry Service, Information Report
Diss. Abstr.	Dissertation Abstracts
Diss. Abstr. Int.	Dissertation Abstracts International
Ecol. Appl.	Ecological Applications
Ecol. Model.	Ecological Modelling
Ecol. Monogr.	Ecological Monographs
Ecol. Res.	Ecological Research

Continued ...

Abbreviated Form of Journal	Journal Title
Environ. Can., Can. For. Serv., Inf. Rep.	Environment Canada, Canadian Forest Service, Information Report
Environ. Conserv.	Environmental Conservation
Environ. Manage.	Environmental Management
Envir. Mon. Assess.	Environmental Monitoring and Assessment
For. Br., Man. Nat. Res.	Forestry Branch, Manitoba Natural Resources
For. Can.-Mar. Reg.	Forestry Canada, Maritimes Region
For. Can.-Ont. Reg.	Forestry Canada, Ontariio Region
For. Chron.	Forestry Chronicle
For. Ecol. Manage.	Forest Ecology and Management
For. Sci.	Forest Science
For. Sci. Monogr.	Forest Science Monograph
Int. J. Rem. Sen.	International Journal of Remote Sensing
Int. J. Wildl. Fire	International Journal of Wildland Fire
J. Appl. Ecol.	Journal of Applied Ecology
J. Biogeogr.	Journal of Biogeography
J. Comb. Sci. Tech.	Journal of Combined Science and Technology
J. Ecol.	Journal of Ecology
J. Environ. Manage.	Journal of Environmental Management
J. Fish. Res. Board Can.	Journal of the Fisheries Research Board of Canada
J. For.	Journal of Forestry
J. Geophys. Res.	Journal of Geophysical Research
J. Range Manage.	Journal of Range Management
J. Veg. Sci.	Journal of Vegetation Science
J. Wildl. Manage.	Journal of Wildlife Management
Lands. Ecol	Landscape Ecology
Mich. Bot.	Michigan Botanist
Minn. Agric. Exp. Stn. Tech. Bull.	Minnesota Agricultural Experiment Station Technical Bulletin
Minn. For. Notes	Minnesota Forestry Notes
Minn. For. Res. Notes	Minnesota Forestry Research Notes
Nat. Can. (Que.)	Naturaliste Canadien
National Res. Council. Can.	National Research Council of Canada
Natural Areas J.	Natural Areas Journal
Nature	Nature
New Phtyol.	New Phytologist
Ont. Cent. Rem. Sens.	Ontario Centre for Remote Sensing
Ont. Min. Nat. Res.	Ontario Ministry of Natural Resources
Ont. Dept. Lands For., Res. Br., Res. Pap. (Wild.)	Ontario Department of Lands and Forests, Research Branch, Research Paper (Wildlife)
Ont. Dept. Lands For., Res. Div., Res. Pap.	Ontario Department of Lands and Forests, Research Division, Research Paper

Continued ...

Abbreviated Form of Journal	Journal Title
Ont. Dept. Lands For., Sec. Rep. (For.)	Ontario Department of Lands and Forests, Section Report (Forestry)
Proc. Ent. Soc. Ont.	Proceedings of the Entomological Society of Ontario
Proc. Minn. Acad. Sci.	Proceedings of the Minnesota Academy of Science
Quat. Res.	Quaternary Research
Rest. Ecol.	Restoration Ecology
Royal Ont. Mus. Zool. Palaeontol.	Royal Ontario Museum Zoology and Palaeontology
Silv. Res. Note. For. Br. Can.	Silviculture Research Note Forestry Branch Canada
Soc. Am. For.	Society of American Foresters
Soil Sci.	Soil Science
Soil Sci. Soc. Am. J.	Soil Science Society of America Journal
Tall Timb. Fire Ecol. Conf.	Tall Timbers Fire Ecology Conference
USDA For. Serv. Gen. Tech. Rep.	United States Department of Agriculture Forest Service General Technical Report
USDA For. Serv. Res. Note	United States Department of Agriculture Forest Service Research Note
USDA For. Serv. Res. Pap.	United States Department of Agriculture Forest Service Research Paper
USDI Bureau Land Manage.	United States Department of Interior Bureau of Land Management
Verh. Int. Verein. Limnol.	Verhandlungen der Internationalen Vereinigung fuer Theoretische und Angewandte Limnologie (Proceedings of the International Association of Theoretical and Applied Limnology)
Water Air Soil Pollut.	Water, Air, and Soil Pollution
Wilderness Res. Found.	Wilderness Research Foundation
Wildl. Monogr.	Wildlife Monographs
Yukon Wildl. Branch	Yukon Wildlife Branch

APPENDIX D
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