Annotated Bibliography of Fire Behavior and Ecology Research at the Petawawa National Forestry Institute 1979-1994/

Bibliographie annotée des travaux de recherche effectués à l'Institut forestier national de Petawawa, de 1979 à 1994, sur le comportement et l'écologie des feux de forêt

R.S. McAlpine and / et A. Mellors
Petawawa National Forestry Institute / Institut forestier national de Petawawa
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Foreword

The present bibliography continues the research publication record reported in the Canadian Forest Service Information Report PS-X-52 (1979)[1]. When the Petawawa Forest Experiment Station and the Forest Fire Research and Forest Management Institutes were merged to form the Petawawa National Forestry Institute (PNFI) in April 1979, the size of the fire research effort at Petawawa increased several-fold. Project PI-4 at PNFI was set up to continue the line of work formerly carried on at Petawawa before 1979. It is known today as the Fire Behavior and Ecology project.

Beginning with the retirement of long-time project leader Charles Van Wagner in 1989 and ending in 1993 with new staff appointments completed, the project has undergone a nearly complete change of personnel. With the new personnel came new research directions and it seemed appropriate to publish this bibliography.

The items herein are arranged alphabetically unlike in the previous bibliography, which listed the publications chronologically. The names of authors affiliated to PNFI are underlined. Included in this document are an author index and a subject area index to facilitate searches. The annotations are from abstracts contained in the referenced publications. They are presented bilingually if the original publication contained a resumé or if the publication came out in both French and English.

Avant-propos

La présente bibliographie constitue une mise à jour du régistre des publications de recherche paru dans le Rapport d'information du Service canadien des forêts PS-X-52 (1979)[1]. Avec la fusion de la Station d'expériences forestières de Petawawa, de l'Institut de recherche sur les feux de forêt et de l'Institut d'aménagement forestier, qui a donné lieu en avril 1979 à la création de l'Institut forestier national de Petawawa, l'effort de recherche déployé à Petawawa dans le domaine des feux de forêts s'est trouvé multiplié par sept. On mit alors sur pied à l'Institut le programme PI-4, soit le Programme sur le comportement et l'écologie des feux de forêt, qui s'inscrivait dans la foulée des travaux menés à Petawawa avant 1979.

Depuis la retraite du directeur de longue date de ce programme, M. Charles Van Wagner, en 1989, jusqu'à ce qu'on ait terminé le recruitement des nouveaux employés, en 1989, le personnel affecté à ce programme a été presque entièrement renouvelé. Il en est découlé de nouvelles orientations de recherche, d'où l'utilité de la présente bibliographie.

Nous avons choisi de présenter ici les publications par ordre alphabétique plutôt que par ordre chronologique, comme nous l'avions fait dans la bibliographie précédente. La présente bibliographie comporte un index des auteurs et un index des matières qui en facilitent la consultation. (Les auteurs dont le nom est souligné sont associés à l'IFNP.) Les annotations sont des résumés des publications en question, et ils sont bilingues si le document de départ était publié soit dans les deux langues officielles, soit il était accompagné d'un résumé français.

[1] Van Wagner, C.E. 1979. Annotated bibliography of forest fire research at the Petawawa Forest Experiment Station, 1961-1979. Can. For. Serv., Petawawa For. Exp. Sta. Inf. Rep. PS-X-52. 21 p.

Author Index / Index des auteurs

Subject Index

Index des matières

1. Brand, D.G.; Flannigan, M.D.; Janas, P.S. 1988. **Using datalogger systems for environmental monitoring in forest research: an overview and case study. PNFI Inf. Rep. PI-X-81.**

This is an introduction for forest researchers to the monitoring of environmental conditions with automatic dataloggers. The report discusses various aspects of the experimental design (definition of what, where, how, and when to measure), the technological design, and the management of environmental monitoring research programs. A case study of a large field installation with continuous monitoring of 92 sensors is used to demonstrate the design, operation, and management of data from a research project. Automatic data collection with environmental sensors increases the ability of forest researchers to quantify conditions and explain secondary influences on results. Care must be taken, however, in: proper selection of variables to measure, and in choice of hardware, sensors, and peripherals; correct installation and system protection; and, effective data management.

Le présent document est un guide d'initiation au processus de surveillance des conditions environnementales à l'aide de consignateurs de données automatiques qui s'adresse aux chercheurs forestiers. Le rapport aborde différents aspects du dispositif expérimental (quoi, où, comment et quand mesurer), du devis technique et de la gestion de programmes de recherche en surveillance environnementale. L'étude de cas d'une importante installation comportant la surveillance constante de 92 senseurs est utilisée pour démontrer les méthodes de conception, d'exploitation et de gestion des données dans le cadre d'un projet de recherche. La collecte automatique de données à l'aide de capteurs environnementaux accroît la capacité des chercheurs forestiers de quantifier les conditions et d'expliquer leurs effets secondaires sur les résultats. Il faut cependant bien choisir les variables à mesurer, le matériel, les senseurs et les périphériques, et avoir une installation et un système de protection appropriés ainsi qu'une bonne gestion des données.

2. Duchesne, L.C. 1994. **Fire and biodiversity in temperate ecosystems. Pages 247-264 *in* Boyle, T.J.B.; Boyle, C.E.B., eds. Biodiversity, temperate ecosystems and global change. Springer-Verlag, New York, NY.**

Fire is a dominant feature in Canadian forests, where it controls diversity at the genetic, microsite, ecosystem, and landscape levels. Fire affects selected indicator organisms and / or ecosystem characteristics differently. At the microsite and stand levels, vesicular arbuscular mycorrhizal fungi, ectomycorrhizal fungi, non-crop vegetation, carabid beetle assemblages, and litter decomposition react in different ways. At the landscape level, fire affects age class distribution, thus controlling the landscape mosaic. At the genetic level, fire has a long term effect. Biodiversity conservation programs in Canada must address the natural impact of fire on natural ecosystems. Likewise, management of biodiversity, within the context of fire exclusion, must introduce disturbances that emulate the effect of fire. Management of biodiversity is contrasted to management for biodiversity.

3. Duchesne, L.C. 1994. **Defining Canada's old-growth forests — problems and solutions. For. Chron. 70: 739-744.**

Conceptual and working definitions of old-growth forests are proposed for Canada. Conceptually, old-growth forests are defined in terms of stand age, structure, species composition, anthropogenic influence, natural disturbance such as wildfire, and landscape ecology. Working definitions based on stand age in relation to age of maximum mean annual increment and site class are formulated for Canada's inventoried timber-productive forests. The difference between stand age and the age of maximum mean annual increment is proposed as a measure of old-growthness. Recommendations are made for improving Canada's forest inventory database to help acquire ecological definitions of old-growth forests and monitor and maintain Canada's old-growth heritage.

4. Duchesne, L.C.; McAlpine, R.S. 1993. **Effect of prescribed burning and clear-cutting on carabid beetle biodiversity in a jack pine forest. PNFI Tech. Rep. 16./Utilisation des carabes (Coleoptera: carabidæ) comme indicateurs des effets des pratiques forestières sur la diversité du sol. Rapp. techn. IFNP, 16F.**

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) the species that were observed in all three sites in similar proportions. Clear-cutting alone and clear-cutting

along with prescribed burning showed a trend toward increasing average carabid catches as compared to average carabid catches from undisturbed sites.

Un inventaire des carabes présentes dans des peuplements non perturbés de pin gris (*Pinus banksiana* Lamb.) (parcelles témoins), des parcelles ayant fait l'objet d'une coupe à blanc (parcelles coupées) et des parcelles ayant fait l'objet d'une coupe à blanc suivie d'un brûlage dirigé (parcelles brûlées) a été effectué à l'aide de pièges à fosses, et les associations d'espèces capturées dans ces trois types de milieux ont été comparées. Au total, 28 espèces de carabes ont été récoltées dans le cadre de cette étude. La plus forte diversité spécifique a été observée dans les parcelles brûlées, et la plus faible dans les parcelles coupées. Chaque type de traitement était caractérisé par une association d'espèces particulière. Les espèces de carabes ont été classées dans quatre groupes distincts, selon qu'elles affichaient une préférence pour : 1) les parcelles brûlées, 2) les parcelles coupées, 3) les parcelles témoins ou 4) qu'elles se retrouvaient en proportions semblables dans les trois types de milieux. Le nombre moyen de carabes capturées était plus élevé dans les parcelles coupées et les parcelles brûlées que dans les parcelles témoins.

5. Duchesne, L.C.; Weber, M.G. **1993. High incidence of *Morchella conica* ascocarps in a pine forest following prescribed fire. Can. Field Nat. 107:114-116.**

Ascocarps of the ascomycetous fungus *Morchella conica* Fr. were observed at a density as high as 2860 kg/ha in a *Pinus banksiana* Lamb. stand at the Petawawa National Forestry Institute. This forested stand had been treated with prescribed fire the previous fall. Ascocarps were found singly or in clusters uniquely within a radius of 1-2 m around dead *P. banksiana* trees but not around dead specimens of *P. resinosa* Ait. and *P. strobus* L. This is the first mention of this species as a phoenicoid fungus.

6. Flannigan, M.D.; Vonder Haar, T.H. **1986. Forest fire monitoring using NOAA satellite AVHRR. Can. J. For. Res. 16:975-982.**

The feasibility of using the Advanced Very High Resolution Radio-meter (AVHRR) carried by the National Oceanic and Atmospheric Administration (NOAA) series of satellites to monitor forest fires was tested during a severe fire outbreak in north central Alberta between June 12 and June 21, 1982. A multispectral technique used AVHRR channels 3 and 4 to identify fires and estimate fire size. This multispectral approach enabled identification of subpixel-sized fires as small as 1 ha. During the study, fires were obscured from satellite view by the presence of cloud and smoke 59% of the time. In the remaining time, 80% of the fires listed by the Alberta Forest Service were identified by satellite. Satellite observations of forest fires are not sufficiently accurate to replace existing monitoring methods, but they are of value in providing a rapid, inexpensive, supplement especially in remote forested areas.

La faisabilité de surveiller les incendies de forêt à l'aide du radiomètre perfectionné à très haut pouvoir de résolution (AVHRR), embarqué par les séries de satellites de la National Oceanic and Atmospheric Administration (NOAA), a été testée lors d'un début d'incendie sévère dans le centre-nord de l'Alberta entre le 12 et le 21 juin 1982. Une technique multispectrale utilisant les canaux 3 et 4 du radiomètre a été employée pour reconnaître les incendies et estimer leur superficie. Cette technique a permis de repérer des incendies de superficie aussi faible que 1 ha, couvrant moins d'un pixel. Au cours de l'étude, la présence de nuages et de fumées a voilé les incendies pour le radiomètre, 59% du temps. Le reste du temps, 80% des incendies relevés par le service des forêts de l'Alberta ont été repérés par le radiomètre. L'observation des feux de forêt par les satellites n'est pas assez précise pour remplacer les méthodes actuelles de surveillance, mais elle constitue un complément rapide et peu coûteux, surtout pour les régions forestières éloignées.

7. Flannigan, M.D.; Harrington, J.B. **1987. Synoptic weather conditions during the Porter Lake experimental fire project. Climatol. Bull. 21:19-40.**

During a series of fire behavior tests in black spruce-lichen woodland near Porter Lake, Northwest Territories (107° 88'W, 61° 79'N) the last fire of the series escaped confinement and burned over 1430 hectares. This report investigates the synoptic weather conditions from June 27 to July 26, 1982, bracketing the test fire period.

It was found that strong surface winds on July 7, 1982, contributed to the escape of the fire. These unexpectedly strong and persistent winds resulted from a deep convective layer near the ground linking the surface wind to the

lower extremity of an upper level jet stream. Such winds could not have been predicted without the help of an experienced weather forecaster.

8. Flannigan, M.D.; Harrington, J.B. 1987. **A study of the relationship of meteorological variables to monthly provincial area burned by wildfire in Canada 1953-80. Pages 229-234 *in* Proc. Ninth Conf. Fire and Forest Meteorology. April 21-24, San Diego, CA. Am. Meteorol. Soc., Boston, MA.**

The relation between meteorological variables and the monthly area burned by wildfire from May to August in nine Canadian 'provinces' was investigated. The variables used in this study included: monthly precipitation, seasonal precipitation, monthly precipitation anomaly, mean relative humidity, minimum relative humidity, mean temperature, maximum temperature, temperature anomaly, temperature-dewpoint spread, dewpoint, weighted sequence of dry days (daily precipitation below 1.5 mm), number of dry days in a month, weighted sequence of days with relative humidity below 60%, and the 700 hectopascal height anomaly. The best predictors of monthly area burned were the 700 hectopascal anomaly, maximum temperature, the weighted sequence of days with the relative humidity below 60%, the weighted sum of windspeeds on dry days, and the weighted sequence of dry days. In western Canada the explained variance exceeded 30%, compared to less than 15% in eastern Canada.

9. Flannigan, M.D.; Harrington, J.B. 1988. **A study of the relation of meteorological variables to monthly provincial area burned by wildfire in Canada 1953-80. J. Appl. Meteorol. 27:441-452.**

The relation between meteorological variables and the monthly area burned by wildfire from May to August 1953-80 in nine Canadian 'provinces' was investigated. A purely statistical approach to estimating the monthly provincial area burned, using meteorological variables as predictors, succeeded in explaining 30% of the variance west of Lake Nipigon and about 11% east of the lake. Long sequences of days with less than 1.5 mm of rain or days with relative humidity less than 60% proved to have the highest correlation with area burned. These long sequences were assumed to be associated with blocking highs in the westerlies. Bad fire months were independent of rainfall amount but significantly dependent on rainfall frequency, temperature, and relative humidity.

10. Flannigan, M.D.; Litwin, P.J. 1989. **Relative humidity measurement for fire danger rating in Canada. PNFI Inf. Rep. PI-X-93./Mesure de l'humidité relative pour l'évaluation des risques d'incendie au Canada. Rapp. d'inf. IFNP, PI-X-93F.**

Wet and dry bulb temperatures from ventilated and non-ventilated screens can be used to obtain realistic values of relative humidity provided the appropriate psychrometric coefficient is used. However, relative humidity from non-ventilated screens is subject to significant error when the weather is sunny or calm. Investigations revealed that thermohygrometers are poor for field measurement of RH whereas the PCRC-11 sensor and Vaisala humicap performed well.

There is a need for a sensitivity study of the Fire Weather Index with respect to relative humidity. The lookup table is to be replaced by the Goff-Gratch equation. Finally, alternatives like using dewpoint temperature to obtain relative humidity or automating the system should be investigated.

Les températures des thermomètres secs et mouillés, installés dans des abris ventilés et non ventilés, peuvent servir à obtenir des valeurs réalistes de l'humidité relative à condition que le coefficient psychrométrique indiqué soit utilisé. Toutefois, les valeurs obtenues dans le cas des abris non ventilés peuvent être considérablement erronées lorsque le temps est ensoleillé ou calme.

Nos recherches ont permis de constater que, pour mesurer l'humidité relative sur le terrain, les thermohygromètres ne donnaient pas de bons résultats, au contraire du bon fonctionnement du détecteur PCRC-11 et du dispositif Vaisala.

Il faudrait effectuer une étude sur la sensibilité de l'indice forêt-météo en ce qui concerne l'humidité relative. Nous proposons également de remplacer les tables des valeurs de l'humidité relative par l'équation Goff-Gratch. Enfin, d'autres solutions devraient être étudiées, comme l'application de la température du point de rosée pour obtenir l'humidité relative, ou bien l'automatisation du système.

11. Flannigan, M.D.; Wotton, B.M. 1989. **A study of interpolation methods for forest fire danger rating in Canada. Can. J. For. Res. 19:1059-1066.**

Canadian fire control agencies use either simple interpolation methods or none at all in estimating fire danger between weather stations. We compared several methods of interpolation using the Fire Weather Index in the North Central Region of Ontario as a case study. Our work shows that the second order least square polynomial, the smoothed cubic spline, and the weighted interpolations had the lowest residual sum of squares in our verification scheme. These methods fit the observed data at both high and low Fire Weather Index values. The highly variable nature of the spatial distribution of summer precipitation amount is the biggest problem in interpolating between stations. This factor leads to highly variable Fire Weather Index fields that are the most difficult to interpolate. The use of radar and (or) satellite data could help resolve precipitation patterns with greater precision. These interpolation methods could easily be implemented by fire control agencies to gain a better understanding of fire danger in the region.

Les organismes canadiens de protection contre les feux de forêt n'utilisent aucune méthode sinon des méthodes simples d'extrapolation pour évaluer les risques de feu entre les stations météorologiques. Nous avons comparé plusieurs méthodes d'extrapolation en utilisant l'indice forêt-météo dans le centre-nord de l'Ontario à titre d'exemple. Notre étude montre que les extrapolations au moyen d'un polynome du second degré utilisant les moindres carrés, d'une languette cubique flexible, et d'une pondération produisaient les sommes des carrés résiduelles les plus faibles selon notre procédés de vérification. Ces méthodes correspondent aux valeurs observées de l'indice forêt-météo autant élevé que faible. La très grande variation dans la distribution spatiale de la quantité de précipitation estivale est l'obstacle le plus important pour extrapoler entre les stations. Ce facteur entraîne une très grande variabilité dans les indices forêt-météo qui deviennent très difficiles à extrapoler. L'utilisation du radar et (ou) de données satellite permettrait de connaître la distribution des précipitations avec une plus grande précision. Ces méthodes d'extrapola-tion pourraient facilement être adoptées par les organismes de protection contre les feux de forêt pour obtenir une meilleure estimation des risques de feu dans la région.

12. Flannigan, M.D.; Lynham, T.J.; Ward, P.C. 1990. **An extensive blowdown occurrence in northwestern Ontario. Pages 65-71 *in* McIver, D., et al., eds. Proc. Tenth Conf. Fire and Forest Meteorology. April 17-21, 1989, Ottawa.**

Severe surface winds were experienced in eastern Manitoba and northwestern Ontario in the evening and overnight on June 24-25, 1988. Four general areas of forest blowdown occurred in northwestern Ontario. Within each general area, contiguous areas of blowdown ranging from a few hectares to over a thousand hectares were observed. Isolated occurrences of private property damage were reported, but the main areas of blowdown were sparsely populated.

The cause of the severe surface winds was investigated using meteorological data from the period June 23-26, 1988. It was found that a vigorous cold front, associated with a fast moving low pressure system, provided the mechanism for higher wind speeds aloft to reach the surface. The high wind speeds aloft were associated with an upper level jet stream over the region.

These blowdown areas are of serious concern to fire managers in the region. Very heavy coniferous fuel loadings were concentrated on the blowdown sites, with a large proportion of fine aerial fuels. As the downed material cures, an increasing amount will be available for combustion. The fuel arrangement will also hamper conventional ground attack should a fire occur. A similar, but more extensive, blowdown occurred in the same region in 1973 and was followed by a wildfire in 1974 that burned 32 000 hectares of blowdown fuel.

13. Flannigan, M.D.; Van Wagner, C.E. 1991. **Climate change and wildfire in Canada. Can. J. For. Res. 21:66-72.**

This study investigated the impact of postulated greenhouse warming on the severity of the forest fire season in Canada. Using CO_2 levels double those of the present ($2 \times CO_2$), simulation results from three general circulation models (Geophysical Fluid Dynamics Laboratory, Goddard Institute for Space Studies, and Oregon State University) were used to calculate the seasonal severity ratings for six stations across Canada. Monthly anomalies from the $2 \times CO_2$ simulation results were superimposed over historical sequences of daily weather. Then, seasonal severity

ratings of the present were compared with those for $2 \times CO_2$ using five variations involving temperature, precipitation, and relative humidity. The relationship between seasonal severity rating and annual provincial area burned by wildfire was explored. The results suggest a 46% increase in seasonal severity rating, with a possible similar increase in area burned, in a $2 \times CO_2$ climate.

La présente étude analyse l'impact reconnu de l'effet de serre sur l'intensité de la saison des incendies de forêts au Canada. À l'aide des niveaux de CO_2 qui se double à l'heure actuelle ($2 \times CO_2$), des résultats de simulation provenant de trois modèles généraux de circulation (Geophysical Fluid Dynamics Laboratory, Goddard Institute for Space Studies, Université de l'État d'Oregon) ont été utilisés pour calculer la cote dans six stations dispersées au Canada. Les anomalies, qui se présentaient chaque mois à la suite des simulations de $2 \times CO_2$, ont été appliquées aux séquences historiques des données météorologiques quotidiennes. Puis, les cotes d'intensité saisonnière actuelles ont été comparées à celles qui ont été obtenues par simulation ($2 \times CO_2$), en utilisant cinq variations qui comprenaient la température, la précipitation et l'humidité relative. Après quoi, le rapport a été établi entre la cote d'intensité saisonnière et la superficie des terres provinciales brûlées. Les résultats semblent indiquer une augmentation de 46% quant à la cote d'intensité saisonnière et une augmentation similaire concernant les superficies brûlées qui se trouverait dans un climat de $2 \times CO_2$.

14. Flannigan, M.D.; Wotton, B.M. 1991. Lightning-ignited forest fires in northwestern Ontario. Can. J. For. Res. 21:277-287.

This study investigates the relationship between lightning activity and the occurrence of lightning-ignited forest fires in the Northwestern Region of Ontario. We found that the Duff Moisture Code (a component of the Fire Weather Index system) and the multiplicity of the negative lightning discharges were the most important variables for estimating the number of lightning-ignited fires on a daily basis for Universal Transverse Mercator zone 15 in Ontario. Also, the results indicate that negative lightning ignited more fires than positive lightning discharges, which is contrary to popular belief. Nearly 50% of the variance in the forest fire occurrence data was explained using linear stepwise regression. Future work will focus on finer temporal and spatial scales.

L'article traite la relation entre les éclaires et les incendies de forêt qui en sont résultés. D'après nos études, l'indice de l'humus (qui fait partie de l'indice forêt-météo) et la multiplication de déchargement négatif des éclaires étaient les variables les plus importantes lors de l'estimation du nombre de tels incendies. L'évaluation a déroulé quotidiennement en Ontario, dans la zone 15 de Projection transversale universelle de Mercator. Selon nos observations, les éclaires de déchargement négatif causaient plus d'incendies que ceux du déchargement positif, ce qui est le contraire de l'opinion répandue dans le public. Presque 50% des variations des données sur les incendies de forêt ont été expliquées en suivant une méthode de régression linéaire. Dans les futurs travaux, des échelles plus petites seront utilisées quant aux mesures du temps ou de références géographiques.

15. Flannigan, M.D.; Woodward, F.I. 1994. Red pine abundance: current climate control and responses to future warming. Can. J. For. Res. 24:1166-1175.

This study investigated the relationship between climatic variables and the abundance of red pine (*Pinus resinosa* Ait.). Two aspects of this climate - abundance relationship were addressed. First, a model was developed to fit the present day range and abundance of red pine using available climatic variables in the expectation of better understanding the processes controlling distribution. Second, General Circulation Models were used to explore the implications of a $2 \times CO_2$ (greenhouse warming) environment on the range and abundance of red pine.

Using a response surface, growing degree-days (base 10°C) and precipitation explained 54% of the variance in an independent data set of red pine volume per unit area. Possible explanations for the present day boundaries of red pine are competition for the southern limit, insufficient moisture for the southwestern limit, and insufficient warmth during the growing season at the northern limit. Greenhouse warming suggested a dramatic northeastward shift of 600 to 800 km in the potential range of red pine and a decrease in total area, but it also suggested higher volumes per unit area.

La présente étude examine la relation entre les variables climatiques et l'abondance du pin rouge (*Pinus resinosa* Ait.). Elle aborde deux aspects de cette relation entre le climat et l'abondance. D'abord, on a élaboré un modèle

qui a permi d'ajuster l'aire de distribution et l'abondance actuelles du pin rouge, à l'aide des variables climatiques disponibles, dans l'espoir de mieux comprendre les processus régissant la distribution de cette essence. On a ensuite utilisé des modèles de circulation générale pour examiner les incidences d'un doublement des concentrations atmosphériques de CO_2 (réchauffement provoqué par l'effet de serre) sur l'aire de répartition et l'abondance du pin rouge. Le nombre de degrés-jours de croissance (au-dessus de 10°C) et la quantité de précipitations, appliqués à une surface de réponse, expliquaient 54% de la variance d'un ensemble indépendant de données sur le volume de pin rouge par unité de surfaces. La concurrence à l'égard de la partie méridionale de l'aire, la teneur insuffisante en eau à la limite sud-ouest et le manque de chaleur pendant la saison de croissance à l'extrémité septentrionale sont trois raisons qui pourraient expliquer l'aire d'extension actuelle du pin rouge. Un réchauffement provoqué par l'effet de serre laisse supposer un déplacement spectaculaire vers le nord-est de 600 à 800 km de l'aire d'extension potentielle du pin rouge et une diminution de la superficie totale, mais laisse également entrevoir des volumes supérieurs de matière ligneuse par unité de surface.

16. Flannigan, M.D. 1993. Fire regime and the abundance of red pine. Intl. J. Wildl. Fire 4:241-247.

Red pine (*Pinus resinosa* Ait.) is a fire dependent species. This study examines the relationship between fire regime and the abundance of red pine. The fire regime is represented by components of the Canadian Fire Weather Index System as well as the average area burned and the percentage of conifers of each forest section. Both extreme and average values were used in this analysis; 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. The results suggest that the abundance of red pine and other fire-affected tree species is directly related to aspects of the fire regime such as fire intensity.

17. Flannigan, M.D.; Woodward, F.I. 1993. A laboratory study of the effect of temperature on red pine seed germination. For. Ecol. Manage. 62:145-156.

This study investigated the influence of temperature on the germination of red pine (*Pinus resinosa* Ait.) seed. Three aspects of the temperature-germination relationship were addressed. First, the influence of temperature on the rate of germination and percentage germination was studied to test the hypothesis that low ambient temperatures inhibit the northward migration of red pine. Second, a model relating degree days to accumulate germination was developed. Third, the role of prechilling red pine seed was explored.

Temperatures of 15°C or greater were required for germination of 80% or more of the seeds, which means that germination capacity is not limiting the expansion of the range of the red pine. Temperatures greater than 10°C were required for completion of the germination process of unchilled seeds. Approximately 75% of the variance in the germination data was explained using a single stepwise linear regression using accumulated thermal time (degree days). Prechilling the seeds (2-5°C) resulted in increased germination at temperatures of 10°C and 12.5°C compared with unchilled seeds (78% vs. 26%). Prechilling also reduced the mean germination time by at least 1 day, even at the optimum temperature (25°C).

18. Forestry Canada Fire Danger Group. 1992. Development and structure of the Canadian forest fire behavior prediction system. For. Tech. Rep. ST-X-3. Replaces Alexander, M.E., et al. 1984. User guide to the Canadian forest fire behavior prediction system. Interim ed. Can. For. Serv.

The Canadian Forest Fire Behavior Prediction (FBP) System is a subsystem of the larger Canadian Forest Fire Danger Rating System which also includes the Canadian Forest Fire Weather Index (FWI) System. The FBP System provides quantitative estimates of head fire spread rate, fuel consumption, fire intensity, and fire description and, with the aid of an elliptical fire growth model, estimates of fire area, perimeter, perimeter growth rate, and flank and backfire behavior. The FBP System has evolved since the mid-1970s from a series of regionally developed burning indexes, to an interim edition of the nationally developed FBP System issued in 1984, to the present complete edition. Sixteen discrete fuel types are included covering most major boreal forest fuel types in Canada. Fire behavior models for spread rate and fuel consumption were derived from a database of over 400 experimental, wild, and

operational prescribed fire observations. The FBP System is intended to supplement the experience and judgment of operational fire managers.

La Méthode canadienne de prévision du comportement des incendies de forêt (PCI) fait partie de la Méthode canadienne d'évaluation des dangers d'incendie de forêt, laquelle englobe également la Méthode canadienne de l'Indice Forêt-Météo (IFM). La première de ces trois méthodes permet l'estimation quantitative de la vitesse de propagation du front de l'incendie (ou suivant la pente), la consumation de combustible, l'intensité de l'incendie et la description de ce dernier; avec l'aide du modèle elliptique de croissance de l'incendie, elle permet d'estimer l'aire et le périmètre de l'incendie, la vitesse de croissance de ce dernier ainsi que le comportement de l'incendie sur ses flancs et son arrière. Depuis le milieu des années 70, la Méthode PCI a évolué, à partir d'une série d'indices de combustion élaborés à l'échelon régional jusqu'à sa forme achevée actuelle, en passant par sa publication sous forme de méthode nationale provisoire, en 1984. On tient compte de 16 types précis de combustibles, qui englobent la plupart des principaux types trouvés dans les forêts boréales du Canada. Les modèles du comportement des incendies, en ce qui concerne la vitesse de propagation et la consumation des combustibles, sont tirés d'un corpus de plus de 400 observations d'incendies expérimentaux, échappés et dirigés. La Méthode PCI devrait servir à étayer l'expérience et le jugement des chefs de l'intervention contre les incendies.

19. Harrington, J.B.; Flannigan, M.D. 1987. Drought persistence at Canadian stations. Pages 204-206 *in* Proc. Ninth Conf. Fire and Forest Meteorology (April 21-24, San Diego, CA.). Am. Meteorol. Soc., Boston, MA.

Various models used to estimate the frequency of spells of dry weather were tested for goodness fit to data from 41 Canadian weather stations representing forested areas of the county during April to September, inclusive for the years 1953-1980. The models tested were: no persistence, Markov chains of order 1 to 8, Williams, geometric, and Eggenherger-Polya.

The conditional probability of a dry day following a sequence of dry days exhibited an initial rapid increase over the probability of a dry day following a wet day, after which there is a slow linear increase. Markov chain distributions fit most dry day sequences accurately over the bulk of data points except at the tails of the distribution.

20. Harrington, J.B.; Flannigan, M.D.; Van Wagner, C.E. 1983. A study of the relation of components of the fire weather index to monthly provincial area burned by wildfire in Canada 1953-80. PNFI Inf. Rep. PI-X-25.

The relationship between the monthly area burned by wildfire from May to August in nine Canadian provinces, and the flammability of the forest as measured by the components of the Fire Weather Index, was investigated. In western Canada, with the exception of Yukon and Northwest Territories, explained variance averaged 33%. In the Territories and eastern Canada explained variance averaged 12%. The best predictors of area burned were the monthly means and extreme maximum values of the Duff Moisture Code and the Daily Severity Rating.

On a étudié le rapport entre la superficie ravagée chaque mois par les incendies forestiers de mai à août dans neuf provinces canadiennes et l'inflammabilité de la forêt telle que mesurée par les divers paramètres de l'indice forêt-météo. Dans l'Ouest du Canada, exception faite du Yukon et des Territoires du Nord-Ouest, la variance expliquée s'élève en moyenne à 33 %, tandis que dans les territoires et l'est du Canada, elle est de 12 %. Les meilleures prévisions de la superficie incendiée sont fournies par les moyennes mensuelles et les valeurs maximales extrêmes de l'indice de l'humus et de l'estimaton journalière de la gravité.

21. Harrington, J.B.; Flannigan, M.D. 1993. A model for the frequency of long periods of drought at forested sites in Canada. J. Appl. Meteorol. 32:1708-1716.

Long dry spells (sequences of dry days) are rare events, but they are important because they correlate significantly with the area burned during bad wildfire years. Previous attempts to model the frequency of dry spells have been successful for spells of short duration, but have failed for prolonged dry spells.

In the current study, an empirical method was developed that yields a realistic estimate of the probability of a spell of any duration. The theoretical framework proposes that the data can be explained partly by the dichotomy of weather into blocked and non-blocked westerly flows. A bimodal distribution of dry consecutive days is a consequence of this dichotomy.

The transitional probability of a dry day following k dry days generally peaks at k = 1, declines to a shoulder for small k values, and then rises slowly to an asymptotic value that must be estimated from sparse and highly irregular data.

22. Herr, D.G.; Duchesne, L.C.; Tellier, R.; McAlpine, R.S.; Peterson, R.L. 1994. Effect of prescribed burning on the ecotomycorrhizal infectivity of a forest soil. Intl. J. Wildland 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 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.

23. Hirsch, K.G.; Flannigan, M.D. 1990. Meteorological and fire behavior characteristics for the 1989 fire season in Manitoba, Canada. Pages B.06-1 to B-06-16 *in* Proc. Intl. Conf. Forest Fire Res., Coimbra, Portugal.

During the 1989 fire season, a record number of fires (1147) and area burned (3.28 million ha) occurred in the Province of Manitoba, Canada. These fires consumed over 9% of the provincial forested land base, forced the evacuation of 24 500 people from 32 different communities, and cost $55 million (US) to suppress. The majority of the fire activity occurred during two distinct periods; the first in mid-May resulting from an outbreak of human-caused fires, and the second in mid- to late July due primarily to lightning-caused fires. In both situations the synoptic weather pattern consisted of a 500 hPa blocking ridge centered over Manitoba that produced maximum temperatures of 30°C to 35°C, and minimum relative humidity values of 15% to 25%. As these ridges weakened wind speeds averaging 25 km / h to 35 km / h produced numerous high intensity crown fires in stands consisting primarily of black spruce and jack pine. Seven major wildfire runs were documented with headfire rates of spread and fire intensities ranging from 16.7 m / min (1 km / h) to 44.4 m / min (2.7 k m / h) and 18057 kW / m to 40226 kW / m, respectively. A probability analysis estimating the return period of such an extraordinary fire season projected that this type of event could be expected in Manitoba only once every 400 years.

24. Johnson, E.A.; Van Wagner, C.E. 1985. The theory and use of two fire history models. Can. J. For. Res. 15:214-220.

The objectives of this paper were to explain the distributions, assumptions, interpretations, and relationships of the two compatible, stochastic models of fire history: the negative exponential and the Weibull. For each model the "fire interval" and "time-since-fire" distributions are given. Both models apply to homogeneous stationary stochastic processes. The negative exponential states that the instantaneous fire hazard rate is constant for all stand ages. The Weibull states that the instantaneous fire hazard rates increases with stand age when the shape parameter is >l (the negative exponential is a special case of the Weibull when shape =1). An empirical method is given for separating from an observed fire history distribution, the pre-and post-fire suppression distributions. Four relationships are derived from the models and defined per study region (per stand): (i) the fire cycle (average fire interval), (ii) the annual percent burned area (fire frequency), (iii) the average age of the vegetation (average prospective lifetime), and (iv) the renewal rate.

L'objectif de ce texte était d'expliquer les distributions, les hypothèses, les interprétations et les rapports entre deux modèles stochastiques compatibles de l'histoire des incendies: celui de l'exponentielle négative et celui de Weibull. Les distributions « intervalle entre les feux » et « temps écoulé depuis un incendie » sont données pour chaque modèle. Les deux modèles s'appliquent à des processus stochastiques homogènes et stationnaires. Le modèle de l'exponentielle négative établit que le niveau de risque de feu instantané est constant pour tous les âges d'un peuplement. Celui de Weibull montre que le niveau de risque de feu instantané augmente avec l'âge du peuplement, lorsque le paramètre de la forme est >1 (le modèle de l'exponentielle négative constitue un cas spécial du modèle de

Weibull où la forme est =1). On présente une méthode empirique pour distinguer les distributions avant et après suppression du feu, à partir d'une distribution observée pour une historique connue. À partir des modèles, on a dérivé quatre sortes de rapports qu'on a défini par région d'étude (par peuplement): i) le cycle du feu (intervalle moyen entre les feux), ii) le pourcentage annuel de superficie brûlée (fréquence des feux), iii) l'âge moyen de la végétation (durée moyenne de l'espérance de vie), et iv) le niveau de renouvellement.

25. Lawson, B.D.; Stocks, B.J.; Alexander, M.E.; Van Wagner , C.E. 1985. A system for predicting fire behavior in Canadian forest. Pages 6-16 *in* Proc. Eighth Conf. Fire and Forest Meteorology, eds. Donaghue, L.R.; Martin. R.E. Soc. Am. Foresters, Bethesda, MD.

The Canadian Forest Fire Danger Rating System (CFFDRS) has been under development in its present form since 1968. The first major sub-system of the CFFDRS, The Canadian Forest Fire Weather Index (FWI) System, was initially completed in 1970. FWI System components provide numerical ratings, based solely on weather observations, of relative fire potential in a standard fuel type The other major sub-system of the CFFDRS, in the original modular approach, was a series of regionally developed guides to actual fire behavior in specific fuel types. This concept has now been replaced by the Canadian Forest Fire Behavior Prediction (FBP) System. The FBP System consists of three components as primary outputs: rate of spread (m/min, km/h), fuel consumption (kg/m^2), and line or frontal fire intensity (kW/m). An interim version of the rate of spread (ROS) component was produced in 1984. The principal input variable is the Initial Spread Index (ISI), a component of the FWI System that combines the effects of wind and the Fine Fuel moisture Code (FFMC). Head fire ROS/ISI relationships were developed for 14 major Canadian fuel types from a database consisting of 245 experimental/operational prescribed fire and 45 wildfire observations. Fuel types in the FBP system consisting of five major groups (coniferous, deciduous, mixedwood, slash, and open) are described mainly in qualitative terms. Graphs and tables have been produced from the ROS component equations. Procedures are given for adjusting the FFMC for time of day and topography, determining upslope/ downslope spread rate relative to wind direction and ground slope, and projecting fire growth from the system. Threshold conditions for crown fire, where applicable, are defined in terms of the ISI and slope adjusted ROS. An illustration of the system's application to an actual wildfire situation will be given and future development highlighted.

26. MacLean, D.A.; Woodley, S.J.; Weber, M.G.; Wein, R.W. 1983. Fire and nutrient cycling. Chap. 7 *in* Wein, R.W.; MacLean, D.A., eds. "The Role of Fire in Northern Circumpolar Ecosystems". SCOPE 18, John Wiley and Sons, Toronto.

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

27. McAlpine, R.S. 1989. Temporal variations in elliptical forest fire shapes. Can. J. For. Res. 19: 1496-1500.

Elliptical fire growth models are dependent on a relationship between the length to width ratio of the ellipse and the prevailing wind speed. A laboratory study of point source fires growing in two fuel types (ponderosa pine *Pinus ponderosa* Laws. needle litter and excelsior) showed that the length-to-width ratio changes from the time of inception until a stabilized "equilibrium" eccentricity is established. The size of fuel bed required to allow stabilization of the length-to-width ratio is dependent on wind speed. Results indicate that a fuel bed 0.93 m wide is insufficient to allow length-to-width ratio stabilization for wind speeds above 1.6 km/h.

28. McAlpine, R.S.; Xanthopoulos, G. 1989. **Predicted vs. observed fire spread rates in ponderosa pine fuel beds: a comparison of Canadian and American sytstems. Pages 287-294 *in* McIver, D., et al., eds. Proc. Tenth Conf. Fire and For. Meteorology, April 17-21, Ottawa, Ontario.**

The Canadian Forest Fire Behavior Prediction (FBP) System and the American BEHAVE fire behavior prediction system differ in many respects. These dissimilarities stem from a basic difference in the two approaches of the fire behavior prediction problem; the Canadians used an empirical approach in system design, while the Americans developed an adaptable theoretical model. In the spring of 1988 a series of 17 experimental fires in ponderosa pine (*Pinus ponderosa* Laws.) needle litter were conducted in the wind tunnel combustion facilities of the Intermountain Fire Sciences Laboratory in Missoula, Montana. The fires were part of investigations into crown fire initiation, and fire acceleration from a point source. However, the data collected allowed the observed equilibrium head fire rate of spread (ROS) to be compared to estimates computed by both the American and Canadian fire behavior prediction systems. The American BEHAVE system tended to under-predict observed ROS by 15-60%, possibly due to wind speed profiles differing from the original developmental study or inaccurate estimation of moisture of extinction. The Canadian FBP System, on the other hand, tended to over-predict observed ROS, due in part to problems in computing a 10-m open wind speed equivalent to the wind tunnel (midflame) wind speed.

29. McAlpine, R.S.; Stocks, B.J. 1989. **The Canadian forest fire danger rating system. Poster presentation at Meeting Global Wildland Fire Challenges; the people, the land, the resources. July 23-26, 1989, Boston, MA.**

30. McAlpine, R.S. 1990. **Seasonal trends in the drought code component of the Canadian forest fire weather index system./Évolution saisonnière de l'indice de sécheresse de la méthode canadienne de l'indice forêt-météo. PNFI Inf. Rep./Rapp. d'inf. IFNP, PI-X-97E/F.**

The Drought Code component of the Canadian Forest Fire Weather Index System is an indicator of long term drought and the associated impact on forest fire management. The Drought Code has definite seasonal trends, which can make interpretation of the current daily value difficult without a good frame of reference. Thirty five years of weather data from 35 selected weather stations across Canada were used to develop mean daily Drought Code average values for each weather station throughout the fire season. The graphs produced provide fire managers with daily mean Drought Code values and historical maximum values throughout the fire season for comparison with observed daily Drought Code values.

L'indice de sécheresse de la Méthode canadienne de l'indice forêt-météo est un indicateur de la sécheresse à long terme et des répercussions de cette dernière sur la prévention et l'extinction des incendies de forêt. Or, cet indice subit sans contredit une évolution saisonnière qui complique l'interprétation de la valeur journalière si l'on ne possède pas les points de repère voulus. Trente-cinq années de données météorologiques provenant de 35 stations météorologiques choisies dans l'ensemble du Canada ont servi à calculer la moyenne de l'indice journalier moyen de sécheresse à chacune de ces stations durant la saison des incendies. Les graphiques que l'on en tire donneront aux responsables de l'intervention contre l'incendie ou de l'aménagement par le feu la valeur journalière moyenne de l'indice de sécheresse et les maximums de ses antécédents durant la saison des incendies, pour qu'ils comparent ces valeurs à la valeur journalière observée.

31. McAlpine, R.S.; Stocks B.J.; Van Wagner, C.E.; Lawson, B.D.; Alexander, M.E.; Lynham, T.J.; 1990. **Forest fire behavior research in Canada. Pages A.02-1 to A.02-12 *in* Proc. Intl. Conf. For. Fire Res. Coimbra, Portugal.**

From the beginning of fire research efforts in Canada, forest fire behavior research has been empirical in nature, producing fire behavior predictions based on models derived from field experiments. The models relate fire behavior to weather-based fuel moisture codes and relative fire behavior indexes. Experimental fire sizes attempt to reflect equilibrium fire behavior conditions for the chosen fuel/weather conditions. Laboratory-based research in moisture physics and heat transfer theory provide the framework by which the field data are analyzed. The Canadian Forest Fire Behavior Prediction System is the culmination of this research on quantitative fire behavior. The ongoing goal is the production of a universal fire behavior model combining field experimental evidence with physically-based models.

32. McAlpine, R.S.; Wakimoto, R.H. 1991. **The acceleration of point source fire to equilibrium spread. For. Sci. 37:1314-1337.**

The acceleration phase of a forest fire, from ignition to the equilibrium rate of spread, is perhaps the most important phase of fire behavior because often it represents the only time period in which suppression efforts could be effective. A series of experimental fires in a wind tunnel were conducted to evaluate this acceleration phase. Two types of fuel and a total of three fuel loadings and four wind speeds were tested. The results were analyzed as distance/time data and a predictive equation produced of the form:

$$\text{Distance} = \beta_0 \times \text{Time}\ \beta_1$$

The derivative of this equation relating rate of spread at a specific elapsed time since ignition compares favourably with theoretical acceleration model curve forms. The elapsed time required to achieve an equilibrium rate of spread was constant for each fuel type over the range of conditions tested.

33. McAlpine, R.S.; Lawson, B.D.; Taylor, E.M. 1991. **Fire spread across a slope. Pages 218-225 *in* Proc. Eleventh Conf. Fire and Forest Meteorol., April 16-19, 1991, Missoula, MT.**

Although the effects of slope and wind on fire spread rate have been well documented, their interactive effects are not as well known. Past methods have added spread rates predicted by the wind and slope separately using vector algebra. Other, simpler, methods have also been used. If, however, a downslope wind produces a spread rate equal to the slope-influenced spread rate, a zero spread rate will result. The model presented herein converts the slope into an equivalent wind speed, which is then added to the on-site wind using the same vector algebra. The resulting net effective wind speed and direction is used to compute spread rate. This method allows computation of spread rates in complex wind/slope interactions and provides a predicted spread direction by resolving the net force acting upon the fire. An actual cross-slope fire compared favourably with the proposed model.

34. McAlpine, R.S.; Wotton, B.M. 1992. **The use of fractal dimension to improve wildland fire perimeter predictions. Can. J. For. Res. 23:1073-1077.**

Fire managers currently use simple elliptical models to predict the perimeter of a fire when the fire starts from a single point. When examined closely, though, wildland fire perimeters are highly irregular. We tested the hypothesis that a fire is actually fractal in nature and thus the true length of a fire perimeter depends on the amount of fine edge detail included in the measurement. The amount of perimeter detail incorporated is dependent on the length of the base unit of measurement; the longer the unit, the less the perimeter detail, and the shorter the perimeter. Different forest fire suppression techniques have inherent scale characteristics associated with different base unit measurements of perimeter; therefore, the length of the fire perimeter is dependent on the suppression technique used. Analysis of 14 forest fire perimeters yielded a consistent fractal dimension of 1.15 and a relationship was found to adjust predicted fire perimeter with this fractal dimension for a specific unit measurement length. The fractal length of fire fronts between two identifiable points can also be calculated given the base unit measurement of the suppression technique. This information should improve fire managers' ability to optimally dispatch suppression resources to forest fires.

Les aménagistes des incendies forestiers utilisent courramment des modèles elliptiques pour prédire le périmètre d'un incendie originant d'un seul point. Toutefois, une étude détaillée révèle que le périmètre d'un incendie est très irrégulier. Nous avons vérifié l'hypothèse qu'un feu est de nature fractale et, par conséquence, la longueur réelle de son périmètre est asujettie au nombre de détails fins inclus dans la mesure. Le nombre de détails d'un périmètre étudié est fonction de la longueur de l'unité de mesure de base; les unités les plus longues donnent moins de détails de périmètre que les unités les moins longues. Différentes techniques de suppression des incendies ont des caractères d'échelle innés qui sont associés aux différentes unités de mesure de base du périmètre. En conséquence, la longueur de périmètre est dépendante de la technique de suppression utilisée. L'étude de 14 périmètres d'incendies forestiers a donée des dimensions fractales qui sont constantes à 1,15 et on a établie une méthode pour ajuster le périmètre avec une dimension fractale pour une unité de longueur donnée. La longueur fractale du front d'un incendie entre deux points donnés peut être calculée à partir de l'unité de mesure de la technique de suppression. Cette information devrait aider les aménagistes des incendies forestiers à distribuer les ressources de suppression.

35. McAlpine, R.S.; Wotton, B.M. 1993. Chaos on the fireline. Pages 506-510 *in* Proc. Twelfth Conf. Fire and Forest Meteorology, October 26-28, 1993. Jekyll Island, GA.

Forest fire perimeters, in both Canada and the United States, are predicted with an elliptical growth model or a cellular growth model that emulates an ellipse. Recently it has been shown that the fractal dimension, a measure of line "wiggles" and a subdivision of the science of Chaos, can be applied to forest fire perimeters. This paper takes the theoretical fractal fire perimeter model, and produces an easily applied, simplified version. In this applied model, not only do the traditional factors such as spread rate and fire shape influence the fire perimeter, suppression tactics, too, enter into the calculation. By using the fractal fire perimeter, rather than the straight line or elliptically predicted fire perimeter, fire managers can better approximate the suppression effort required to contain a wildland fire.

36. McAlpine, R.S.; Hobbs, M.W. 1994. Height to live crown base in boreal forest species plantations. Int. J. Wildl. Fire 4:103-106.

A critical parameter for initiating and propagating a crown fire in the boreal forest is the height to the base of the live crown. The initiation of a crown fire requires that the surface fire intensity must be sufficient to "jump" the gap between the forest floor and the live crown and ignite crown fuels. The greater the height of the live crown base, the more intense the surface fire must be to induce a crown fire. Plantation forest fuels tend to be more structured and have less variability than naturally regenerated areas, allowing prediction of the height of the live crown base to be made from commonly available stand parameters. Plantations of four commonly planted boreal forest species were sampled over a variety of age classes to determine a predictive relationship for height to live crown base. Height to live crown base can be predicted from stand height and density for *Pinus banksiana* (jack pine), *Pinus resinosa* (red pine), *Picea mariana* (black spruce), and *Picea glauca* (white spruce). In addition to predicting the height to live crown base, parameters within the equations lead to other observations. Crown foliar fuel loading does not change with stand height following crown closure in red pine but, in the other three species, crown fuel load increases as the stand grows taller.

37. McRae, D.J.; Flannigan, M.D. 1990. Development of large vortices on prescribed fires. Can. J. For. Res. 20:1878-1887.

A detailed set of data has been compiled on large fire whirlwinds occurring on prescribed burns conducted in Ontario. There appear to be two types of such vortices: one occurs in pairs on the leeward side of the convection column and the other is created after the entire convection column begins to rotate. The second type occurs in association with very intense fires that may be described as fire storms. Fire whirlwind occurrence appears to be related principally to meteorological conditions in which wind speeds are less than 10 km/h, to the stability of the atmosphere up to 3000 m altitude, and to conditions where the amount of energy released from the fire is high. The roles of atmospheric stability, rate of energy release from the fire, and ignition pattern in the development of whirlwinds require further study.

38. Springer, E.A.; Van Wagner, C.E. 1984. The seasonal foliar moisture trend of black spruce at Kapuskasing, Ontario. Can. For. Serv. Res. Notes 4(3):39-42.

During four years, black spruce trees near Kapuskasing were sampled for foliar moisture content from April to September. The usual spring dip in old conifer moisture content during May and June was present. No statistically valid differences among the four years was found, however. The timing of the dip was about two weeks later than for Petawawa 400 km to the south. Its magnitude, about 20 points between spring and mid-summer, matches other such data.

39. Stocks, B.J.; Van Wagner, C.E.; Clark, W.R.; Dubé, D.E. 1980. The 1980 forest fire season in west-central Canada - social, economic, and environmental impacts. Task Force Rep., Can. For. Serv.

This report describes the 1980 forest fire season during which over 9000 fires burned nearly 5 million hectares, mainly in west-central Canada. This annual burned area was, at the time, the largest yet recorded in Canada. The distribution of the fires, the associated weather, and an analysis of recent trends in fire occurrence are included.

One large fire forced the evacuation of Red Lake in northwestern Ontario, and the total direct fire control expense was nearly $200 million. Beyond that, no immediate economic or environmental effect or damage was apparent.

40. Stocks, B.J.; Lawson, B.D.; Alexander, M.E.; Van Wagner, C.E.; McAlpine, R.S.; Lynham, T.J.; Dubé, D.E. 1988. The Canadian system of forest fire danger rating. *In* Proc. Conference on Bushfire Modelling and Fire Danger Rating systems (July 11-12, 1988, Canberra A.C.T.). CSIRO Div. For. and For. Prod., Natl. Bushfire Res. Unit, Canberra, A.C.T., Australia.

41. Stocks, B.J.; Lawson, B.D.; Alexander, M.E.; Van Wagner, C.E.; McAlpine, R.S.; Lynham, T.J.; Dubé, D.E. 1989. The Canadian forest fire danger rating system. For. Chron. 65:450-457.

Forest fire danger rating research in Canada was initiated by the federal government in 1925. Five different fire danger rating systems have been developed since that time, each with increasing universal applicability across Canada. The approach has been to build on previous danger rating systems in an evolutionary fashion and to use field experiments and empirical analysis extensively. The current system, the Canadian Forest Fire Danger Rating System (CFFDRS), has been under development by Forestry Canada since 1968. The first major subsystem of the CFFDRS, the Canadian Forest Fire Weather Index (FWI) System, provides numerical ratings of relative fire potential based solely on weather observations, and has been in use throughout Canada since 1970 The second major subsystem, the Canadian Forest Fire Behavior Prediction (FBP) System, accounts for variability in fire behavior among fuel types (predicting rate of spread, field consumption, and frontal fire intensity), was issued in interim form in 1984 with final production scheduled for 1990. A third major CFFDRS subsystem, the Canadian Forest Fire Occurrence Prediction (FOP) System, is currently being formulated. This paper briefly outlines the history and philosophy of fire danger rating research in Canada, discussing in detail the structure of the current CFFDRS and its application and use by fire management agencies throughout Canada.

42. Stocks, B.J.; Flannigan, M.D. 1987. Analysis of the behavior and associated weather for a 1986 northwestern Ontario wildfire: Red Lake #7. pp. 94-100 *in* Proc. Ninth Conf. Fire and Forest Meteorology (Apr. 21-24, San Diego, CA) Am. Meteorol. Soc., Boston, MA.

The largest Ontario wildfire of 1986 occurred in late May in the boreal forest near Red Lake and burned over 61 200 hectares. Much of this loss occurred in well-stocked jack pine and black spruce stands allocated for immediate harvesting. Approximately 7.65 million cubic metres of wood fibre was destroyed, severely disrupting wood supply in this part of northwestern Ontario. Direct suppression costs for Red Lake # 7 were approximately $6.4 million.

During the most active crown fire phase of Red Lake #7 forward spread rates were in excess of 2.5 kilometres/hr. and average flame heights reaching 60 metres. A towering convection column 12 000 metres high developed on May 29 which generated rain, hail, and lightning, causing the fire to slow somewhat but starting numerous lightning fires downwind.

This paper documents in detail the mesoscale weather and fire danger ratings associated with Red Lake #7, both prior to and during the fire, with particular emphasis on those days which the fire was most active Supplementing conventional meteorological data were on-site vertical profiles of wind and temperature gathered from minisonde ascents. Fire behavior parameters are analyzed relative to fire weather and fuel complex characteristics.

43. Van Wagner, C.E.; Methven, I.R. 1980. Fire in the management of Canada's national parks: philosophy and strategy. Parks Canada - Nat. Parks Occ. Pap. #1.

The paper deals with the question of whether fire has a place in the management of National Parks. It takes as given current national park policies.

There is an initial discussion of ecological principles, the conclusions being that the concept of stability is quite appropriate to an ecosystem that depends on fire for periodic recycling, that the temporary post-fire transformation of the site is necessary for such an ecosystem's survival, and that the same age-class distribution found in

self-perpetuating forests among individual trees is likely to be found also in fire-dependent forests among communities or stands. The paper goes on to discuss:

- the ecological role of fire and its impact on the site;
- renewal rate and age-class distribution;
- fire behavior and its importance;
- fire regimes and fire history; and,
- the implications of fire as a management tool in National Parks.

The paper stops short of discussing individual parks or problems of tactical, day-to-day fire management. It concludes that three options exist for large parks whose vegetation is largely fire-dependent:

- to use fire as a management tool;
- to permit artificial means of vegetative renewal; or,
- to accept pronounced changes in park vegetation and wildlife with time.

44. Van Wagner, C.E. 1981. Forest fire research in Canada - background and potential. Pages 29-42 *in* An Industrial Assessment of Forestry Research in Canada. Vol. II. Pulp and Paper Res. Inst. Can., Symp. Montreal, Apr. 1981.

A description of the state of forest fire research in Canada from the viewpoint of the forest industry's interest in fire. The background is first presented, in terms of a) current fire statistics, b) the ecological impact of fire, and c) its economic impact. The research effort is divided into six categories and the aims of each described. The size of the whole research effort in terms of staff and funds is described along with a breakdown by category. The report ends with some thoughts about the industry's stake in the progress and results of forest fire research in Canada.

45. Van Wagner, C.E. 1981. Initial moisture content and the exponential drying process. Can. J. For. Res. 12:90-92.

Estimation of fuel moisture in Canadian forest fire danger rating during a drying period is accomplished through a negative exponential equation. Data are presented to show that, for pine litter, the slope of this equation is independent of the starting point, a necessary condition for its validity.

L'estimation de la tenur en eau des matières combustibles dans la Méthode canadienne d'évaluation des dangers d'incendie de forêt au Canada au cours d'une période sèche se fait au moyen d'une équation exponentielle négative. Les données sont présentées de façon à indiquer que, pour la litère de pin, la courbe de l'équation est indépendante du point de départ, condition essentielle à sa validité.

46. Van Wagner, C.E. 1982. Practical aspects of the line intersect method. PNFI Inf. Rep. PI-X-12./Aspects pratiques de la méthode d'échantillonnage linéaire. Rapp. d'inf. PI-X-12F.

Information and comment on a number of practical aspects of the line intersect method, including specific equations for volume and weight for various sets of units; problems of orientation bias and sample layout; diameter-class limits and centres; use of the method to determine total length of pieces or networks and piece-length distribution; sample size, length of line, and precision; and others. The report is not a complete review of line intersect literature, nor does it present new theory. It does, however, bring together in one place ideas on the practical application of the method that are presently scattered throughout the literature.

Ce rapport présente des informations et des commentaires sur de multiples aspects pratiques de la méthode d'échantillonnage linéaire, comme les équations spécifiques du volume et du poids pour diverses séries d'unités; les problèmes relatifs aux écarts d'orientation et au relevé des échantillons; les limites et les centres des classes de diamètre; l'application de la méthode à la détermination de la longueur totale des parties ou des réseaux; la répartition de la longueur des parties; la taille des échantillons; la longueur de la ligne; la précision et bien d'autres encore. Ce document ne constitue pas une revue exhaustive de la documentation sur la méthode d'échantillonnage linéaire, ni n'introduit une nouvelle théorie. Il est plutôt une compilation des idées qui se trouvent éparpillées dans les divers documents existants sur l'application pratique de cette méthode.

47. Van Wagner, C.E. 1982. Graphical estimation of quadratic mean diameters in the line intersect method. Forest Sci. 28:852-855.

An *ad hoc* method is described of deriving quadratic mean diameters for use in the line intersect method. No extra field work is required. The method assumes that the diameters tallied in any actual line intersect survey are distributed according to a simple power law. The tallied frequencies are then graphed and a mathematical formula applied. The method adapts readily to any desired set of diameter classes.

48. Van Wagner, C.E. 1983. Fire behavior in northern conifer forests and shrublands. Pages 65-80 *in* Wein, R.W.; MacLean, D.A., eds. The Role of Fire in Northern Circumpolar Ecosystems SCOPE 18, Wiley and Sons.

The chapter begins with a review of northern fuels and fire behavior, and stresses the general uniformity of all spreading fires in vegetation, the two limiting criteria being the rate of forward heat transfer and fuel quantity. Five classes of fire and examples are listed with their approximate intensity ranges, from smouldering fires (<10 kW/m) to high-intensity spotting fires (>150 000 kW/m). The elements of a fire regime, including fire intensity, depth of burn, and fire frequency, are discussed. The link with ecology in the boreal forest is mainly through the process of forest renewal and the distinction is drawn between species that can regenerate and those that survive fires, and also between those species that require mineral seedbeds and those that regenerate vegetatively. The relationship between forest age and flammability is examined, with the conclusion that conifer forests are generally most flammable at a young age and again during stand breakup, with a period of lesser flammability during maturity. Finally, the observation is made that increased interest in the ecological role of fire in the boreal forest will lead to more sophisticated fire management and a greater desire and need for better prediction of fire behavior.

49. Van Wagner, C.E. 1983. Simulating the effect of forest fire on long-term annual timber supply. Can. J. For. Res. 13:451-457.

A model is described that incorporates the effects of forest fire on long-term equilibrium timber supply. Its form is a computer simulation that burns and harvests specified proportions of an hypothetical forest with a given yield curve of volume over age. The primary result is the extent to which the equilibrium maximum sustainable annual harvest is depressed by fire. This depression is always greater than the volume killed on the burned area. On the other hand, when the annual area cut is somewhat below the optimum level, the volume of harvest is relatively insensitive to the amount of fire. The results imply that the real impact of fire in managed forests is properly judged by the effect of the harvest, not from data on area burned and volume killed.

On décrit un modèle des effets des incendies forestiers sur l'approvisionnement en bois à long terme. Il s'agit d'une simulation informatique du brûlage et de la récolte de proportions précises d'une forêt fictive à laquelle est associée une courbe de rendement ou de cubage par rapport à l'âge. Le résultat principal est une indication de la mesure dans laquelle la récolte annuelle maximum est réduite par le feu. La réduction est toujours supérieure au matériel détruit dans la zone incendiée. Par contre, si la superficie annuelle de coupe est légèrement inférieure à la coupe optimale, le cubage de la récolte ne varie relativement pas selon les incendies. Cela indique que les incidences des incendies sur la prévision de l'approvisionnement en bois se mesurent non pas d'après la superficie brûlée ou le volume détruit, mais selon l'effet sur la récolte.

50. Van Wagner, C.E. 1983. Review of "Fire in America" by S.J. Pyne. Quart. Rev. Biol. 58:483-484.

51. Van Wagner, C.E. 1983. Review of "Fire ecology, United States and southern Canada" by H.A. Wright and A.W. Bailey. Quart. Rev. Biol. 58:463.

52. Van Wagner, C.E.; Methven, I.R. 1983. Fire in the management of Canada's national parks. Chap. 18 *in* Singh, T.V.; Kaur, J., eds. Himalayas: Mountains and Men. Print House, Bombay.

This is a reprint of the paper published in 1980 as Occasional Paper No. 1 by Parks Canada. It was included at the editors' request and with Parks Canada's permission.

53. Van Wagner, C.E. 1984. Letter to the Editor, Forestry Chronicle. For. Chron. 60 :319.

This letter is a reply to the claim in the C.I.F. 's brief to the Macdonald Royal Commission on forestry that fire is responsible for a large annual addition to the nation's backlog of unregenerated forest land. The letter argues that regeneration following fire in standing forest must long ago have come to equilibrium and that post-fire forests were generally like pre-fire forests. Additions to the unregenerated forest land are by human agency, whether fire accidentally burns a cutover or not.

54. Van Wagner, C.E. 1984. Forest fire research in the Canadian Forestry Service. PNFI Inf. Rep. PI-X-48./ Recherche sur les incendies de forêt au Service canadien des forêts. Rapp. d'inf. IFNP, PI-X-48F.

The report discusses forest fire research in the Canadian Forestry Service - its present state, something of its past, and some options and ideas about its potential future. The author, who was an active member of the Canadian Forest Service fire research group for over two decades, consulted people concerned with forest fire and research in the various CFS establishments, provincial forest fire agencies, and forestry faculties of Canadian universities. He incorporated their opinions, and differences of opinion, as objectively as possible and the paper was reviewed by CFS management within the Research and Technical Services Directorate.

Le présent rapport porte sur la recherche sur les feux de forêt, effectuée au Service canadien des forêts. On y traite de l'état actuel de la recherche, de certains aspects de son passé et des avenues qui s'ouvrent devant elle. Membre actif du groupe de recherche sur les incendies forestiers du Service canadien des forêts durant plus de deux décennies, l'auteur a consulté des personnes intéressées aux feux de forêt et à la recherche forestière travaillant dans les divers établissements du SCF, les organismes provinciaux responsables des feux de forêt et les facultés de foresterie des universités canadiennes. Il présente leurs opinions et divergences de vues le plus objectivement possible. Ce document a été révisé par la Direction de la recherche et des services techniques du SCF.

55. Van Wagner, C.E. 1985. Forest fire: Entry *in* Page 669 The Canadian Encyclopedia, Vol. II.

56. Van Wagner, C.E. 1985. Does nature really care who starts the fire? Pages 98-102 *in* Lotan, J.E. et al., eds. Proc. Symp. Wkshp. on Wilderness Fire, Missoula, MT., 1983. USDA For. Serv. Gen. Tech. Rep. INT-182, eds. Lotan, Kilgore, Fischer, Mutch.

Fire's effect is independent of its mode of origin. So, rather than recreating the original fire regime *per se*, it might be more feasible to aim for the vegetation a natural fire regime would create. How to arrange the necessary fires then becomes a practical rather than a philosophical problem.

57. Van Wagner, C.E. 1985. Drought, timelag, and fire danger rating. Pages 178-195 *in* Donaghue, L.R.; Martin, R.E., eds. Proc. Eighth Conf. Fire and Forest Meteorology. April 29-May 2, 1985, Detroit, MI. Soc. Am. For., Bethesda, MD.

This paper considers several principles of the construction and presentation of long-term moisture indexes in forest fire danger rating. Five different "drought" indexes are compared as to rate of moisture loss and gain, reservoir size, temperature effect, and whether presented on an absolute or comparative basis. The role of timelag in deciding whether the index should be computed continuously from one fire season to the next is tested. The purpose of the index will determine whether it should be presented in terms of the moisture content of some identifiable component of the fuel complex or in some other form such as the content of a soil reservoir. Its role in fire danger rating is distinctly subsidiary, and not to be confused with the principal short-term indicators of fire ignition potential and rate of spread.

58. Van Wagner, C.E. 1985. Fire behavior modelling — how to blend art and science. Pages 3-5 *in* Donaghue, L.R.; Martin, R.E., eds. Proc. Eighth Conf. Fire and Forest Meteorology. Soc. Am. For. Bethesda, MD.

Control of forest fires depends ultimately on the rate at which a fire will spread, and the question of its frontal intensity is not far behind. Fire management, increasingly more sophisticated, desires quantitative answers in place of the old relative indexes. The true scientific approach is to begin with the basic chemistry and physics of

combustion, link these with fire spread in natural fuel complexes, and eventually produce practical estimates of spread rate, energy output, and growth pattern. By contrast, the "artistic" (or, rather, empirical) approach is to observe fires in the forest, record the attendant burning conditions, describe the fuel complex in some distinguishing sense, and then to derive the necessary regressions. An intriguing result is the tendency of these two approaches to converge to similar final practical states. This idea is illustrated by the past and current fire modelling work in both the United States and Canada. Some future possibilities and roadblocks are explored.

59. Van Wagner, C.E. 1985. **Fire, harvesting, and timber supply. Pages 71-76 *in* Stocks, B.J., et al., eds. Proc. Forest Fire Management Symp., Sault Ste. Marie, Ont. 1984. Can. For. Serv., Great Lakes For. Res. Centre Proc. 0-P-13.**

Two questions about fire management are perennially raised: How does forest fire affect timber supply, and how can the value of fire control activity be judged? The answer to the first is that the effect of fire on timber supply should be analyzed on the basis of the whole forest, not from data taken on the burned area alone. The answer to the second follows on the first. Fire management must be considered an integral part of forest management, and the analysis should be based on the principle of "maximized net return" from the whole forest rather than on "net value change" on the burned area alone. Simple models and hypothetical results are presented. The scale problem is addressed.

60. Van Wagner, C.E. 1985. **The economic impact of forest fire. Pages 13-18 *in* Dubé, D.E., ed. Proc. Intermountain Fire Council Fire Management Wkshp., Banff, Alberta, October 25-27, 1983. Can. For. Serv. Inf. Rep. NOR-X-271.**

Three elements of a simple economic analysis of fire's impact on the forest industry are described. The first is a projection of timber supply and the reduction in annual allowable cut caused by fire. The second is a relationship between fire control expense and the resulting average annual burned area. The third is the value to be placed on a unit volume of wood as it is harvested. The concept focuses on the whole forest and its timber yield rather than on the burned area and its fire-killed timber. The principle that emerges could be called "maximized net return".

61. Van Wagner, C.E.; Pickett, T.L. 1985. **Equations and FORTAN program for the Canadian forest fire weather index system. Can. For. Serv., For. Tech. Rep. 33.**

Improved official equations are presented for the 1984 version of the Canadian Forest Fire Weather Index System. The most recent mathematical refinements serve to further rationalize the Fine Fuel Moisture Code and render it more compatible with other developments in the Canadian Forest Fire Danger Rating System. The effect of these changes is so slight that no problems are anticipated in converting from the previous version to this new one. Also given is a FORTRAN program intended as a standard for processing the equations in their most accurate mathematical form.

Ce rapport présente, en complément au système de l'Indice canadien forêt-météo, des équations connues qu'on a retouchées. Ces précisions mathématiques veulent rendre l'indice du combustible léger plus rationnel et davantage compatible avec les nouveaux développements que connaît la Méthode canadienne d'évaluation des dangers d'incendie de forêt. Il s'agit de changements mineurs qui ne devraient pas faire problème, advenant qu'une équation de la version antérieure soit à convertir. Le programme FORTRAN se veut une base pour traiter des équations dans le plus pur langage mathématique.

62. Van Wagner, C.E. 1986. **Fire. Pages 27-35 *in* Gourlay, J.F.; Borczon, E.L., eds. Managing red pine plantations. Section IV. Ont. Min. Nat. Res., Toronto.**

Red pine plantations are highly flammable, especially at young to moderate ages. This chapter covers fire behavior in relation to the Fire Weather Index System, fire damage, and mortality, and how the fuel complex varies with age, thinning, or pruning. It provides advice on designing layout of plantations for ease of fire control and minimum damage, on detection, and on fire control tactics.

63. Van Wagner, C.E. 1986. Catastrophic losses — strategies for recovery. Pages 85-97 *in* Proc. 1986 Western Forestry Conference, Vancouver, Dec. 1986. Western Forestry and Conservation Assn., Portland, OR.

This paper deals with the effect of fire on timber supply, especially the effect of great annual fluctuations in burned area. It uses a simple simulation model to compare constant annual fire with cases of moderate and extreme variation from year to year. Some conclusions: 1) Strict rotation control would be impractical in forests with appreciable variable annual fire; 2) Average annual yield even under simple strict area control is very stable over a wide range of proportional variability in the annual burned area; 3) Variation in annual harvest under any reasonable strategy is highly damped in comparison with the variation in annual burned area that causes it.

64. Van Wagner, C.E. 1987. Forest fire research — hindsight and foresight. Pages 115-120 *in* Davis, J.B.; Martin, R.E., eds. Proc. Symp. Wildland Fire 2000, Lake Tahoe, NE. April 1987. USDA For. Serv. Gen. Tech. Rep. PSW-101. Pacific SW For. and Range Exp. Stn., Berkeley, CA.

The evolution of forest fire research in Canada is first examined through the works of Wright and Beall, beginning in the 1920s. Some lessons are drawn from the past that ought to bear on the future. Some opinions are delivered on the future course of research on fire danger rating, prescribed fire, and the impact of fire on the forest economy.

65. Van Wagner, C.E. 1987. Development and structure of the Canadian forest fire weather index system. Can. For. Ser., For. Tech. Rep. 35.

The Canadian Forest Fire Weather Index (FWI) System was first issued in 1970 after several years' work by a number of fire researchers in the Canadian Forestry Service. The best features of the former fire danger index were incorporated in the FWI, and a link was preserved between the old and new. The FWI is based on the moisture content of three classes of forest fuel plus the effect of wind on fire behavior. The system consists of six components: three primary sub-indexes representing fuel moisture, two intermediate sub-indexes representing rate of spread and fuel consumption, and a final index representing fire intensity as energy output rate per unit length of fire front. The FWI System refers primarily to a standard pine fuel type but is useful as a general measure of forest fire danger in Canada. Its components are determined every day from noon weather readings: temperature, relative humidity, wind speed, and rain (if any). The development of Fire Weather Index, the concepts behind it, and its mathematical structure are described in this paper. Revised versions of the Fire Weather Index System were issued in 1976 and 1984.

L'Indice Forêt-Météo (IFM) est un indice des conditions météorologiques propices aux incendies de forêts. Il a été publié en 1970 après plusieurs années de travaux par des agents de recherche du Service canadien des forêts. Les meilleures caractéristiques de l'ancien indice de danger de feu ont été retenues dans le nouvel indice, et un lien a été conservé entre l'ancien et le nouveau. L'IFM est fondé sur la teneur en humidité de trois classes de combustibles forestiers, plus l'effet du vent sur le comportement du feu. Il consiste en six composantes: trois sous-indices primaires représentant l'humidité du combustible, deux sous-indices intermédiaires représentant le taux de propagation du feu et la consommation des combustibles, et un indice final représentant l'intensité de feu sous forme de rendement énergétique par unité de longueur. L'IFM se réfère fondamentalement à une forêt standard de pin, mais sert utilement comme indice général du danger d'incendies de forêts au Canada. C'est par des observations journalières des conditions météorologiques, à midi, qu'on le rédige: température, humidité relative, vitesse du vent et pluviosité (si elle existe). Ce document décrit le développement de l'IFM, les concepts qui ont présidé à sa préparation, et sa structure mathématique. De nouvelles versions de l'IFM ont été publiées en 1976 et en 1984.

66. Van Wagner, C.E. 1987. A moisture content model for medium-sized logging slash. Pages 34-40 *in* Proc. Ninth Conf. Fire and Forest Meteorology, April 1987, San Diego, CA. Am. Meteorol. Soc., Boston, MA.

A model is described that follows from day to day the moisture content of 4-cm components of slash on clear-cuts of jack pine and black spruce. It consists of two phases, one for drying and one for wetting. The drying phase is based on the negative-exponential principle, with daily drying rate dependent to some extent on temperature, humidity, and wind speed, but mainly on the initial moisture content; this latter is a novel feature. The wetting phase is dependent on rainfall amount and initial moisture content. The model operates on the standard noon weather observations of the Canadian Forest Fire Danger Rating System. It is based on a 95-day data set of exposures

in northeastern Ontario, in which slash pieces set in trays were weighed daily. The model incorporates routines for varying slash age from first to third summer and diameter from 2 to 10 cm.

67. Van Wagner, C.E. 1988. The historical pattern of burned area in Canada. For. Chron. 64:182-185, plus Erratum 654 (4): 319.

The record of natural annual burned area from 1918 to 1986 is smoothed and presented as three kinds of running averages: simple arithmetic means, exponential means, and binomial means. The main features of the whole sequence are, 1) a gradually decreasing trend for the first few decades followed by a sharp rise in the 1970s and early 1980s, and 2) a subsidiary rise and fall at a fairly regular interval of about ten years. The chance that these patterns are just statistical accidents is very low. Climate cycles or trends that affect the weather with respect to forest fire are the most likely cause. Whatever the reasons, the fires of the 1970s and early 1980s have quite upset the pre-1970 trend of decreasing national annual burned area.

Les données concernant les superficies détruites par le feu chaque année de 1918 à 1986 et compilées à l'échelle nationale sont lissées et présentées en trois modèles de moyenne mobile: moyenne arithmétique simple, moyenne exponentielle et moyenne binômiale. Les principales caractéristiques de cette série sont les suivants : i) une tendance graduellement décroissante pendant les premières décades, suivie d'une augmentation marquée dans les années 70 et début 80, et ii) des augmentations et des baisses subsidiaires à des intervalles assez réguliers d'environ 10 ans. Il est peu probable que ces modèles ne soient que des accidents statistiques. Les cycles ou tendances climatiques qui influencent les conditions météorologiques en ce qui concerne les incendies de forêt en sont la cause la plus vraisemblable. Quelles qu'en soient les raisons, les incendies des années 70 et du début des années 80 ont complètement bouleversé la tendance d'avant 1970 qui montrait une décroissance des superficies détruites par le feu chaque année au pays.

68. Van Wagner, C.E. 1988. Effect of slope on fires spreading downhill. Can. J. For. Res. 18:818-820.

A laboratory experiment was performed to determine the effect of slope on the downhill spread rate of forest fire. Results with beds of pine needles showed that the spread rate decreased to 64% of the level rate as slope was raised to 22°, then gradually increased back to the level rate at 45°. Some theory about how the flame radiates to the unburned fuel was advanced to account for this phenomenon.

Une expérience en laboratoire a été effectuée pour déterminer les effets de la déclivité sur la vitesse de propagation d'un feu de forêt progressant vers le bas d'une pente. Les résultats du brûlage de lits d'aiguilles de pin montrent que la vitesse de propagation le long d'une pente s'abaissant à 22° diminuait à 64% de la vitesse de propagation en terrain plat pour ensuite remonter graduellement et redevenir identique à la vitesse de propagation en terrain plat à 45°. Une théorie sur le mode de rayonnement de la flamme vers le combustible imbrûlé a été avancée pour expliquer ce phénomène.

69. Van Wagner, C.E. 1989. Prediction of crown fire behavior in conifer stands. Pages 207-212 *in* Mac Iver, D.C. et al., eds., Proc. Tenth Conf. Fire and Forest Meteorology. April 17-21, 1989, Ottawa, Ont.

A scheme is presented for dealing with the full range of fire behavior in conifer forests. It is based on empirical data from fires in Canadian forests plus a theory to describe the physical conditions for the transition from surface to crown fire. In its ideal form, the model consists of two distinct equations for spread rate in a given forest, one each for surface and crown fire, plus the rules for the transition upward or downward between them. For lack of enough data in some cases, a compromise has been devised that distinguishes between surface and crown fires, but does not provide for complete separation of the spread-rate functions. The scheme will form part of the forthcoming Canadian Forest Fire Behavior Prediction (FBP) system.

70. Van Wagner, C.E. 1990. Six decades of forest fire science in Canada. For. Chron. 66:133-137.

This account of the history and accomplishments of forest fire research in Canada begins with a few basic statistics, and some background on changing attitudes to fire. An historical note on the contributions of Wright and Beall in the 1930s and 1940s follows: Fire science is then divided into six diverse categories: fire behavior, fire management

systems, fire ecology, prescribed fire, fire economics, and fire suppression, with a note on developments and accomplishments in each. The references given are examples of the wide range of activity within the whole field of fire-related science and technology, but do not constitute a bibliography.

Cet article est un compte rendu de l'histoire et des réalisations dans les champs de recherche sur les feux de forêt au Canada. Le début est illustré de quelques statistiques et d'éléments de changement d'attitude à l'égard de l'incendie. Dans la partie suivante est décrite la contribution apportée à ces recherches par Wright et Beall dans les années 30 et 40. Depuis lors, les études scientifiques sur l'incendie se sont divisées en six catégories: comportement du feu, systèmes de gestion des incendies, pyro-écologie, brûlage contrôlé, économie relative aux incendies, extinction d'incendie. Des notes sur l'évolution de chacune ainsi que sur les accomplissements sont incluses dans la description. Les références sont des exemples d'une vaste gamme d'activité dans le cadre de la science et technologie de l'incendie sans constituer cependant une bibliographie.

71. Van Wagner, C.E. 1991. **Forest fire statistics and the timber supply. Pages 111-118 *in* Brand, D.G., ed. "Canada's Timber Resources". For. Can. Inf. Rep. PI-X-101.**

The article looks first at the kind of forest fire statistics currently available in Canada. The main statistics are number of fires, area burned, causes, and control costs. Good inventory data on burned areas are not available. The recent rising trend in national burned area is then presented, with its uncertain implications for the future. Next follows a comparison of two methods of portraying the impact of fire on timber supply: 1) by a static accrual-depletion balance; and, 2) by dynamic analysis of the interaction between harvesting and fire in a managed forest. The two approaches do not give the same result. The conclusion is drawn that modern dynamic analysis is necessary to clarify the impact of fire and that the answer will be found in the timber output from the whole forest, not in the killed timber on the burned area. Some examples of simple dynamic simulation are presented with implications for management in a fire-prone forest.

L'article présente d'abord le type de statistiques disponibles actuellement au Canada en matière d'incendies de forêt. Parmi les statistiques les plus importantes, on notera celles qui concernent le nombre d'incendies, les superficies brûlées, les causes et le coût de la lutte contre les incendies. Des données d'inventaire efficaces sur les superficies brûlées ne sont pas disponibles. En outre, on décrit l'augmentation récente des superficies brûlées au Canada ainsi que les répercussions incertaines dans l'avenir. Dans la partie qui suit, deux méthodes d'analyse sont comparées visant l'impact des incendies sur la réserve de bois: 1) une analyse statique de l'équilibre (pertes et gains), et 2) une analyse dynamique en tenant compte des interactions qui se lient entre la récolte et l'incendie dans une forêt aménagée. Ces deux approches ne donnent pas le même résultat. On arrive à la conclusions qu'une analyse dynamique moderne est nécessaire d'éclairer l'impact des incendies, et que la réponse se trouvera dans le rendement en bois provenant de la forêt entière et non dans le volume de bois détruit par le feu sur une superficie. Quelques exemples de simulation dynamique simple sont présentés ayant égard à la stratégie d'un aménagement optimal de la forêt menacée par le feu.

72. Weber, M.G.; Van Cleve, K. 1981. **Nitrogen dynamics in the forest floor of interior Alaska black spruce ecosystems. Can. J. For. Res. 11:743-751**

Low addition levels of high enrichment isotope (>1% of the total nitrogen pool with 99 at % excess ^{15}N) were used to follow nitrogen movement through selected forest floor components of permafrost-free and permafrost-dominated black spruce ecosystems in subarctic Alaska. The nitrogen pool examined in this study was the total nitrogen pool. ^{15}N was retained most effectively by the feather moss layer (*Pleurozium schreberi* (BSG.) Mitt. and *Hylocomium splendens* (Hedw.) BSG.) on both black spruce sites. Twenty-eight months after isotope application the feather moss layer still contained over 90% of the ^{15}N that could be recovered. The limited movement of ^{15}N between feather moss layers and underlying forest floor horizons appeared to be slightly affected by climatological events. Differences in ^{15}N movement patterns between permafrost-free and permafrost-dominant black spruce sites are discussed in terms of precipitation, soil temperature, and biological controls.

73. Weber, M.G.; Van Cleve, K. 1984. Nitrogen transformations in feather moss and forest floor layers of interior Alaska black spruce ecosystems. Can. J. For. Res. 14:278-290.

Permafrost-free and permafrost-dominated black spruce (*Picea mariana* (Mill.) B.S.P.) ecosystems in interior Alaska were treated with low addition levels of high enrichment isotope (<1% of the total nitrogen pool with 99 at % excess ^{15}N) to describe nitrogen dynamics through pools of selected forest floor components. A thick carpet of mosses, made up primarily of the feather moss species *Hylocomium splendens* (Hedw.) B.S.B. and *Pleurozium schreberi* (B.S.G.)Mitt., seemed to play a vital role in the nitrogen economy of the forest floor. Nitrogen, quickly immobilized in the moss layers (green, brown) and retained there, was released very slowly to the lower organic layers (021 + 022)where most of the vascular plant roots were located. ^{15}N uptake by the vascular understorey was minimal, as was ^{15}N export via the soil solution. Periodic mineralization episodes, more frequent and dynamic at the permafrost-free site (where C/N ratios were lower), were largely restricted to the moss layers because available N fractions in deeper frost floor layers incorporated little label over the 3-year period. In the lower layers of the forest floor (021 + 022) temperature rather than organic matter quality appeared to be the overriding factor controlling N flow.

Pour étudier la dynamique de l'azote dans les horizons de la couverture morte des écosystèmes de *Picea mariana* (Mill.) B.S.P. en Alaska, les auteurs ont appliqué de faibles quantités d'azote à fort enrichissement isotopique (<1% du stock d'azote total à 99% ^{15}N en excès. Un épais tapis de mousses, formé surtout des mousses hypnacées telles que *Hylocomium splendens* (Hedw.) B.S.G. et *Pleurozium schreberi* (B.S.G.) Mitt., semble jouer un rôle déterminant dans l'économie en azote de la couverture morte. Rapidement immobilisé et retenu dans les couches de mousses (vertes, burnes), l'azote fut cédé très lentement aux couches organiques inférieures (021 + 022) où sont localisée la plupart des racines des plantes vasculaires. L'absorption de ^{15}N par la sous-végétation vasculaire fut infime, de même que l'exportation de ^{15}N par la solution du sol. Les événements périodiques de minéralisation, plus fréquents et dynamiques dans les sites sans permagel (où les rapports C/N sont plus faibles), se confinaient largement aux couches de mousses, puisque les fractions d'azote disponible dans les horizons plus profonds de la couverture morte renfermaient peu d'azote marqué au cours des trois années qu'ont duré les observations. C'est la température, plutôt que la nature de la matière organique, qui semble être le principal facteur de contrôle dans les couches inférieures (021 + 022) de la couverture morte.

74. Weber, M.G. 1984. Review of "A time for burning: traditional Indian use of fire in the western Canadian boreal forest" by H.T. Lewis. For. Chron. 60:260.

75. Weber, M.G. 1984. Review of "Introduction to wildland fire: fire management in the United States" by S.J. Pyne. For Chron. 60: 381.

76. Weber, M.G.; Methven, I.R.; Van Wagner, C.E. 1985. The effect of forest floor manipulation on nitrogen status and tree growth in an eastern Ontario jack pine ecosystem. 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 material, and broadcast spreading of the ash onto exposed mineral soil; and an untreated control. Eight years after treatment radial tree growth on the treated plots showed a 30% reduction compared with the untreated plot. Annual removal of the forest floor caused more severe nitrogen depletion in jack pine foliage, forest floor, and mineral soil. Effects of one-time removal and burning treatments were less severe but significant. Any interference with the normal buildup of the forest floor during stand development should be avoided if site quality is to be maintained for tree growth.

Les auteurs ont appliqué quatre traitements de manipulation de la couverture morte d'un écosystème de pin gris (*Pinus banksiana* Lamb.) de l'est de l'Ontario. Ces traitements sont les suivants: l'enlèvement de la couverture morte jusqu'au sol minéral sans récolte subséquente de la litière annuelle; l'enlèvement de la couverture morte suivi de ratissages annuels de la litière; l'enlèvement de la couverture morte accompagné du brûlage du matériel et de la restitution des cendres au sol minéral décapé (sans ratissage subséquent de la litière annuelle); et le traitement témoin. Huit ans après le traitement, la croissance radiale des arbres des parcelles traitées accusait une réduction de 30% par rapport à la parcelle-témoin. L'enlèvement annuel de la litière a eu les conséquences les plus néfastes sur

l'azote du feuillage, de la couverture morte et du sol minéral. Les effets des autres manipulations furent moins marqués, mais néanmoins significatifs. Pour assurer le maintien de la productivité des stations, on doit éviter de perturber le développement normal de la couverture morte.

77. 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 burns (non-lethal 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 · m^{-2} · d^{-1}) in response to ambient warming (5000 mg · m^{-2}·d^{-1} in August) and decreased in late fall as seasonal temperatures declined (4000 mg · m^{-2}·d^{-1} in November). Precipitation and autumnal litterfall apparently acted as secondary modifiers of this general trend by affecting 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.

La respiration du sol forestier *in situ* est utilisée comme mesure comparative de l'activité métabolique du substrat dans des écosystèmes de pins gris situés dans la partie est de l'Ontario, après différents traitements par le feu, incluant le feu de végétation. Ces cinq traitements consistaient en un feu de végétation remontant à 1920, un feu expérimental de sous-étage (non létal pour l'étage dominant) de ce site en 1962 et 1963, un feu de végétation en 1964 suivi d'un feu expérimental en 1977. Les patrons de la respiration saisonnière sont similaires pour tous les traitements. Le dioxide de carbone augmente au printemps (4000 mg·m^{-2}·d^{-1}) suivant le réchauffement ambiant (5000 mg·m^{-2}·d^{-1} en août) et diminue en fin d'automne comme la température saisonnière décroît (4000 mg·m^{-2}·d^{-1} en novembre). Les précipitations et les chutes de feuilles en automne semblent agir comme modificateurs secondaires de cette tendance générale en modifiant respectivement l'humidité et la qualité nutritive du substat. Les plus hautes activités métaboliques sont mesurées après le traitement par le feu du sous-étage de 1963 suivi, par ordre décroissant, du feu de végétation de 1920, du feu naturel de 1964, du feu expérimental du sous-étage de 1962 et de l'incendie de 1977 de la classe d'âge de 1964. La comparaison multiple des moyennes de respiration saisonnière révèle que les deux derniers traitements sont significativement inférieures ($P < 0,01$) au traitement de 1963. L'influence des traitements d'incendie du sous-étage sur les activités de respiration apparaît dépendante de la profondeur brûlée et du développement subséquent de la couverture morte. La destruction de la repousse par le feu, se produisant une seconde fois durant les premiers stades de développement de l'écosystème de pin gris, diminue significativement l'activité métabolique d'un site.

78. 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 W/m, were documented. Forest floor moisture content prior to burning was negatively correlated with weight of forest floor consumed per unit area ($r^2 = 0.97$) and per cent mineral soil bared ($r^2 = 0.95$). Frontal fire intensity was positively correlated with per cent tree mortality ($r^2 = 0.98$) and mean height of char ($r^2 = 0.76$). Frontal fire intensities of 17 000 kW/m resulted in seedling numbers of 30 000 to over 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 per cent tree mortality ($r^2 = 0.62$) and forest floor consumption ($r^2 = 0.79$).

Dans les écosystèmes à pin gris (*Pinus banksiana* Lamb.) de l'est de l'Ontario, on a mesuré les variables du comportement du feu et on s'est servi des résultats pour interpréter les effets observées du feu. Sept incendies, dont l'intensité du front de combustion s'établait entre 70 et 17 000 kW/m, ont été pris en compte dans le procédé expérimental. L'humidité du sol forestier, antérieurement à l'incendie, a été corrélée de façon négative à la masse du sol forestier consommée par unité de surface ($r^2 = 0,97$) et au pourcentage de sol minéral mis à nu ($r^2 = 0,95$). L'intensité de l'incendie a été positivement corrélée au pourcentage de mortalité des arbres ($r^2 = 0,98$) et à l'épaisseur moyenne de la couche carbonisée ($r^2 = 0,76$). La production de semis consécutive aux incendies de 17 000 kW/m d'intensité a été de 30 000 à plus de 50 000 à l'hectare, densité considérée comme idéale pour l'implantation de la génération ultérieure. La hauteur moyenne des sujets de pin gris, de 13 à 16 ans après l'incendie, a aussi été corrélée de façon positive à l'intensité de l'incendie ($r^2 = 0,82$), et elle était comprise entre 0,5 et 3,8 m, respectivement, sur les terrains soumis à un incendie d'intensité minimale et maximale. La même relation a été constatée par la régression de la hauteur des sujets sur le pourcentage de mortalité des arbres ($r^2 = 0,62$) et la consommation de combustible du sol forestier ($r^2 = 0,79$).

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

Decomposition, litterfall, 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 class (Stand No. 1), two stands within this age class which were treated with non-lethal understorey fires in 1962 and 1963 (Stand No. 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 litter technique over a two-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 No. 1, 2, and 3) compared to the younger stands (No. 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 litterfall ranged from 119 $kg.ha^{-1}.yr^{-1}$ in the 8-year-old age class to 4182 $kg.ha^{-1}.y^{-1}$in the other stands. Forest floor nutrient organic matter residence times were longest in the 8-year-old stand indicating harsh environmental controls over nutrient dynamics. Recovery of the 21-year-old age class to turnover rates approaching equilibrium conditions was rapid, demonstrating ecosystem stability in its interaction with fire. Detrimental effects on ecosystem processes can be expected if stand-replacing fire recurs during early stages of jack pine ecosystem development.

On a mesuré la décomposition ainsi que le renouvellement de la litière, des matières nutritives et des matières organiques dans cinq peuplements de pins gris (*Pinus banksiana* Lamb.) de l'est de l'Ontario qui ont été exposés à divers régimes de brûlage, notamment à des feux de friches. On a étudié un peuplement de 65 ans (peuplement n° 1), deux autres du même âge dont le sous-étage a été brûlé par un incendie non létal en 1962 et en 1963 (n° 2 et 3), un peuplement de 21 ans (n° 4) et un peuplement de 8 ans (n° 5) créé après un brûlage expérimental de parcelles dans le peuplement de 21 ans. On a évalué séparément la décomposition de la litière de l'étage dominant et du sous-étage par la technique du sac à litière (mailles de 1 mm) sur une période de 2 ans. L'analyse de la baisse du poids n'a révélé de différences significatives ($P < 0,05$) que dans le cas de la litière du sous-étage : on a constaté que la baisse de poids mesurée dans les peuplements âgés (n° 1, 2 et 3) dépasse dans une mesure significative celle qui a été mesurée dans les peuplements plus jeunes (n° 4 et 5). La technique du sac à litière a également servi à étudier la dynamique des matières nutritives entre l'étage dominant et le sous-étage : pour P, K et Ca, on a noté des différences significatives ($P < 0,05$) dans tous les peuplements. La dynamique de Mg et de N était la même dans les deux types de litières dans tous les peuplements; il en va de même pour celle de Fe, sauf que dans le peuplement de 65 ans cet élément était significative ($P < 0,04$) plus abondant dans la litière du sous-étage à la fin de la période d'échantillonnage. On a mesuré la quantité moyenne de litière recueillie annuellement en 3 ans : elle va de 119 $kg \cdot ha^{-1} \cdot an^{-1}$ dans le peuplement de 8 ans à 418 $kg \cdot ha^{-1} \cdot an^{-1}$ dans les peuplements plus âgés. La quantité de matières nutritives apportée par la litière correspond au stade de développement du peuplement; il y a une évolution progressive entre les conditions observées dans les jeunes peuplements et l'équilibre atteint dans les peuplements de 65 ans. Le temps de séjour (ou renouvellement fractionnaire annuel) des matières nutritives et des matières organiques était maximal (la quantité

transformée était minimale) dans le peuplement de 8 ans (matières organiques : 57,6 ans), ce qui dénote l'influence marquée du milieu sur la dynamique des matières nutritives. Dans le peuplement de 21 ans, le renouvellement s'est vite rétabli à des valeurs proches de celles de l'équilibre (temps de séjour des matières organiques : 10 ans), ce qui montre la stabilité de lécosystème en interaction avec les incendies. Si un peuplement de pins gris est brûlé à plusieurs reprises durant les premiers stades de son développement, ses caractères fonctionnels devraient en subir des effets délétères.

80. Weber, M.G. 1988. Fire and ecosystem dynamics in eastern Canadian *Pinus banksiana* forests. Pages 93-105 *in* Verhoeven, J.T.A., et al., eds. Vegetation structure in relation to carbon and nutrient economy.

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 intensity.

Functional ecosystem attributes such as soil respiration (CO_2 evolution), decomposition (assessed by using litterbags), and litterfall 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 established or when forest floor layers were mechanically disturbed in mature stands.

81. Weber, M.G. 1990. Forest soil respiration after cutting and burning in immature aspen ecosystems. For. Ecol. Manage. 31:1-14.

Soil respiration was estimated in immature aspen (*Populus tremuloides* Michx. and *P. grandidentata* Michx.) ecosystems of eastern Ontario subjected to cutting and burning treatments in relation to vernal leaf flush. Soil respiration was measured as CO_2 evolved *in situ* using soda lime.

Respiration levels varied seasonally from a midsummer high of around 7000 mg CO_2 m^{-2} day^{-1} to spring and autumn lows of slightly over 2000 mg $CO_2 m^{-2}$ day^{-1}. Cut and burned plots showed temporary declines in CO_2 evolution rates for two growing seasons compared with an untreated control. During the third growing-season, respiration rates had fully recovered to pretreatment levels.

Soils surface temperatures, soil moisture content, and rainfall were monitored on all treatments. Cutting and burning treatments resulted in elevated maximum soil temperatures and reduced soil temperatures and reduced soil moisture contents. Interactions of environmental variables with respiration patterns were examined through correlation analysis. Maximum soil surface temperature and soil moisture content proved to be the most reliable predictors of CO_2 evolution in all treatments.

82. 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, aboveground biomass, 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 ha^{-1} were supported by the pre-flush cutting treatment (11 00 stems ha^{-1}) 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 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 breakup. 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.ha^{-1}) were: 29 470, 21 393, 10 182, 3022, and 1762 on post-flush burn, pre-flush burn, control, pre-flush cut, and post-flush cut, respectively. High litter fall 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, these were interpreted in terms of removal of part of the forest floor, changed N-mineralization rates, action leaching from ash, and differences in nutrient-uptake patterns by the surviving overstorey. After three years some treatment effects were still noticeable in the forest-floor and, to a lesser extent, in mineral-soil nutrient pools.

83. Weber, M.G. 1990. Selected ecosystem processes in a *Pinus resinosa* Ait. forest in relation to other fire-affected eastern North American forest ecosystems. Pages 137-157 *in* Goldammer, J.G.; Jenkins, M.J., eds. Third Intl. Symp. Fire Ecology. SBP Publishing, Den Haag, The Netherlands.

Litterfall, decomposition, organic matter turnover, and forest soil respiration (CO_2 evolution) in a mature (75 years) eastern Ontario red pine (*Pinus resinosa* Ait.) ecosystem were compared with similar eastern North American fire-affected forest types. Litterfall patterns were shown to be variable seasonably as well as from year to year. Annual litter mass inputs varied from a high of 5300 kg ha^{-1} to a low of 2400 kg.ha^{-1} during the three-year observation period. Nutrient inputs through litterfall followed mass input patterns. Understorey litter decomposed more readily than overstorey litter (needles) probably because of the higher nutrient content in understorey material, pointing to the importance of the understorey in overall nutrient cycling process.

Organic matter turnover rates, or residence time, were between 19 and 16 years for the three red pine stands studied. This represents intermediate values between rapid rates such as 2 to 3 years for south central Wisconsin forests and relatively slow rates such as 43 years for jack pine (*Pinus banksiana* Lamb.) ecosystems in northern New Brunswick. Strong climatic control over ecosystem processes, as well as substrate quality, is implicated in the observed variability among forest types. It is apparent that climatic controls will assume added importance in studies of ecosystem structure and function in light of anticipated global greenhouse warming.

Soil respiration was measured *in situ* with soda lime and shown to be very similar to levels observed in adjacent jack pine forests. Seasonal respiration means in red pine and jack pine forests with various fire histories were around 4300 mg of CO_2 m^{-2}.d^{-1}. In comparison, local fire-origin aspen stands had soil respiration rates in excess of 5000 mg CO_2.m^{-2}.d^{-1}, reflecting better nutritional status of the aspen site. Temperature appeared to be the overriding controlling factor in determining substrate respiration patterns. Soil moisture content and rainfall proved to be poor predictors of respiration activities in this study.

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

A 20-year-old aspen (*Populus tremuloides* Michx.) ecosystem was subjected to two cutting and two burning treatments. Cutting and prescribed burning were carried out on separate areas. One cutting and one burning treatment was applied both before and after spring leaf flush. An untreated control area was set aside for comparison.

Three years after treatment summer and winter aspen browse production for moose (*Alces alces*) and white-tailed deer (*Odocoileus virginianus*) were greatest on the pre-flush cutting treatment (summer→1544 kg.ha^{-1}; winter→395 kg.ha^{-1}) followed in decreasing order by post-flush cut (summer→635 kg.ha^{-1}; winter→125 kg.ha^{-1}), post -flush burn (summer→330 kg.ha^{-1}; winter→96 kg.ha^{-1}), and pre-flush burn (summer→50 kg.ha^{-1}; winter→no browsing). Aspen browse quality (nutrient concentration) was essentially unaffected by treatment. Post-treatment biomass production of aspen is discussed in terms of known physiological and ecological responses to disturbance.

85. Weber, M.G. 1991. Aspen management options using fire or cutting. Forestry Canada. PNFI Inf. Rep. PI-X-100. /Options de l'aménagement des peupliers au moyen du feu ou de la coupe. Forêts Canada. Rapp. d'inf. IFNP, PI-X-100F.

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 ha 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. Above ground biomass and nutrient pools, winter brouse 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.

On a surveillé la multiplication végétative, la biomasse ainsi que la teneur en éléments nutritifs (y compris en oligo-éléments) du feuillage et des tiges de même que la teneur en éléments nutritifs du sol, la respiration de ce dernier, le dépôt de la litière et la production de broutilles pour l'hiver dans des écosystèmes à jeunes peupliers de 20 ans(*Populus tremuloides* Michx., *Populus grandidentata* Michx.) de l'est de l'Ontario, qui avaient été traités comme suit : brûlage à faible intensité avant le débourrement, brûlage après ce dernier, coupe avant et après le débourrement. Un écosystème non traité a servi de témoin.

Trois ans après le traitement, on a observé le nombre maximal de drageons à l'hectare (12 000) dans les parcelles coupées avant le débourrement, puis, dans l'ordre décroissant, dans les parcelles coupées après (9 000), les parcelles brûlées après (4 000) et les parcelles brûlées avant (2 000). Il n'y a pas eu de drageonnement dans les parcelles témoins. La biomasse aérienne et les éléments nutritifs, la production de broutilles pour l'hiver et le dépôt de la litière ont constamment reflété l'évolution de la densité des drageons sur les parcelles coupées, et la dégradation des peuplements traités par le feu. Le brûlage, particulièrement avant le débourrement, a réduit le peuplier à une proportion mineure de la station. D'autre part, la coupe avant le débourrement donne les résultats les plus satisfaisants si la reproduction vigoureuse du peuplier reste l'objectif de l'aménagement.

Les mesures des éléments nutritifs ainsi que de la respiration du sol ont montré que les processus déterminants des écosystèmes sont rapidement revenus à leur intensité d'avant le traitement. Ainsi se trouve confirmée notre hypothèse des peupleraies qui résistent aux perturbations causées soit par l'intervention de l'homme, soit par les phénomènes naturels périodiques.

86. Weber, M.G.; Taylor, S.W. 1992. The use of prescribed burning 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 fires uses are separated into six categories: (1) hazard reduction which evolved into, (2) silviculture (including fire use for site preparation, managing competing vegetation, stand conversion, and stand rehabilitation), (3) wildlife habitat enhancement, (4) range burning, (5) insect and disease control, and (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.

Cet article constitue une révision des présentes utilisations du brûlage contrôlé au Canada. Le feu est une composante naturelle de plusieurs paysages forestiers nord-américains depuis des millénaires, au point d'être un choix logique en tant qu'outil effectif d'aménagement forestier. Il peut être utilisé harmonieusement en tenant compte des modifications reconnues de brûlage sur des écosystèmes à être aménagés. Les utilisations du brûlage contrôlé sont regroupées en six catégories: 1) la réduction des risques qui évolue vers 2) la sylviculture (comprenant l'utilisation du feu pour la préparation de site, le contrôle de la végétation compétitive, la conversion des peuplements, et la réhabilitation des peuplements), 3) l'amélioration de l'habitat faunique, 4) le brûlage d'un habitat, 5) le contrôle des insectes et des maladies, et 6) la préservation des écosystèmes naturels. Quelques exemples de l'évolution du brûlage controlé sont présentés, ainsi que les superficies brûlées selon cette méthode par province et territoire. Le brûlage contrôlé peut être considéré comme une pratique effectivement rentable qui est écologiquement compatible avec plusieurs objectifs d'aménagement forestier, faunique et récréatifs. Son utilisation dans l'avenir à des fins d'aménagement forestier au Canada semble assuré, en autant que le brûlage soit continuellement élaboré et adapté aux besoins et aux priorités sans cesse en changement du grand public.

87. Wotton, B.M.; Flannigan, M.D. 1993. **Length of the fire season in changing climate. For. Chron. 69:187-192.**

The Canadian Climate Centre's Circulation Model provides two 10-year data sets of simulated daily weather for a large array of gridpoints across North America. A subset of this data, comprised of only those points within the forested part of Canada, was selected for study. Fire season length was calculated from data sets of both the 1 x CO_2 and 2 x CO_2 runs of the model as well as for the actual climate, using observed data from weather stations. A comparison made between the results of the 1 x CO_2 and 2 x CO_2 runs indicated a significantly longer fire season across the country under a doubling of atmospheric CO_2 levels. Implications of this result, such as a fall fire season in Canada's east and greater strains on management agencies, are discussed.

Le Modèle de circulation générale du Centre climatique canadien fournit deux séries de données réparties sur dix ans qui simulent la température quotidienne d'un grand ensemble de points répartis sur un réseau couvrant l'Amérique du Nord. Un sous-ensemble de ces données, représentant seulement les points faisant partie du territoire forestier du Canada, a été sélectionné pour fins d'étude. La durée de la saison de feux a été calculée à partir des données simulant une fois le taux de CO_2 et deux fois le taux de CO_2, ainsi que pour le climat actuel, en utilisant les données recueillies à partir des stations météorologiques. Une comparaison établie entre une fois le taux de CO_2 et deux fois le taux a démontré une saison de feux significativement plus longue partout au pays lorsque le taux de CO_2 atmosphérique est doublé. Les répercussions de ce résultat, à savoir par exemple la saison de feux à l'automne dans l'est du Canada et les plus grandes pressions exercées sur les organismes de lutte, sont discutées.