ANNOTATED BIBLIOGRAPHY OF FOREST FIRE RESEARCH AT THE PETAWAWA FOREST EXPERIMENT STATION 1961 - 1979

BY

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ABSTRACT

This Report is a bibliography of publications on all aspects of forest fire produced during the period 1961 to 1979 at the Petawawa Forest Experiment Station. There are 76 items, listed chronologically in four categories. A short descriptive note accompanies each item.

RESUME

Voici une bibliographie des publications sur tous les aspects des incendies de forêts produits de 1961 à 1979 à la Station expérimentale forestière de Petawawa. Il y a 76 articles, énumérés chronologiquement en quatre catégories. Chaque article est décrit brièvement.

ANNOTATED BIBLIOGRAPHY OF FOREST FIRE RESEARCH AT THE PETAWAWA FOREST EXPERIMENT STATION 1961-1979

Introduction

This Report lists all of the published works on the subject of forest fire by resident research staff of the Petawawa Forest Experiment Station up to the end of its official existence on April 1, 1979. On that date the new Petawawa National Forestry Institute came into being at the same location, comprising program elements of the former Station plus the Forest Management and Forest Fire Research Institutes moved from Ottawa.

The Petawawa Forest Experiment Station saw the beginnings of Canadian research on forest fire in 1928, and has supported a fire research program almost continuously since then. The early workers, J.G. Wright, H.W. Beall, J.C. Macleod, and others, used the Station as a field site, but their publications were issued from Ottawa headquarters. These are all listed in G.S. Ramsey's "Bibliography of Departmental Forest Fire Research Literature", available as Information Report FF-X-2 of the Forest Fire Research Institute.[1]

It was not until 1958 that a permanent resident fire research position was created at the Station. The post was occupied for two years by W.A.G. Hannaford, who laid the foundations for most of the work that came to fruition in the early 1960's. Professional Station staff who devoted all or part of their effort to research on fire and its effects between 1958 and 1979 are listed below, together with the period spent on the Station:

W.A.G. Hannaford, B.Sc.F.	1958-1960
C.E. Van Wagner, B.Eng., B.Sc.F.	1960-Present
A.J. Kayll, B.S.F., M.F., Ph.D.	1960-1968
*J.R. Clements, B.S., M.F., Ph.D.	1962-1973
B.J. Stocks, B.Sc.F., M.Sc.F.	1967
J.D. Walker, B.Sc.F., M.F.	1967
I.R. Methven, B.Sc.F., Ph.D.	1969-1979
S.S. Sidhu, B.Sc., Ph.D.	1972-1973

Technical staff on fire research or whose names appear here as coauthors are:

J.W. Bell	1960-Present
W.G. Murray	1960-Present
*W.A. Kean	1967-Present
*R.L. Engisch	1967-1972
*J.J. Williams	1966-Present
D.M. Burgess	1975

(Asterisk signifies part time only on research related to fire.)

[1] This and other publications of the Forest Fire Research Institute are now available from the Petawawa National Forestry Institute.

In keeping with the Station's status as an Institute of the Canadian Forestry Service, the forest fire research program here was oriented as much as possible toward results of national rather than local use. It was designed to complement both the field-oriented research carried on in the Regional Establishments and the operations research and statistical work of the Forest Fire Research Institute in Ottawa.

The literature produced on forest fire and all its aspects by resident Station staff up to April 1979 comprises 76 items, which are listed herein with short annotations in four categories, chronologically within each category:

Journal Articles	Items 1-28
Departmental Publications	Items 29-40
Information Reports	Items 41-68
Miscellaneous Publications	Items 69-76

All items listed in this Report may be obtained free on request from the Petawawa National Forestry Institute.*

A simple breakdown of the 76 items according to subject matter is given below:

Fire behaviour - 1, 3, 4, 5, 8, 13, 22, 24, 25, 36, 38, 42, 48, 51, 55.
Fuel moisture content - 14, 20, 28, 37, 39, 44, 47, 49, 52, 54, 67, 69.
Fire danger rating - 40, 41, 45, 46, 53, 61, 62, 63, 64, 71.
Christmas tree flammability - 2, 29, 32.
Prescribed fire - 9, 15, 17, 21, 31, 35, 57, 58, 59, 60, 73.
Fire ecology - 7,16, 18, 26, 43, 56, 65, 66, 75.
Fire damage to trees - 10, 19, 30, 34, 50.
Fire management - 6, 27, 33, 72, 76.
Research methods - 11, 12, 23, 68, 70, 74.

With the addition of the former Forest Fire Research Institute program, fire research activity at the new Petawawa Institute has been multiplied several times. The information transfer activities of the former Petawawa Forest Experiment Station and Forest Fire Research Institute will be blended in the future reporting of work done and publications available.

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Journal Articles

1 Van Wagner, C.E. 1962.
ON THE VALUE OF A NUMERICAL CONCEPT OF FIRE INTENSITY. Pulp and Paper Mag. of Canada, Woodlands Review. Nov. 1962:458-459.

Describes the rating of forest fire intensity in terms of energy output per unit length of fire front (after Byram). For more detailed treatment, see Item 5.

2 Van Wagner, C.E. 1962.
CHRISTMAS TREES LIKE WATER. Fire Fighting in Canada 6(6):16.

Christmas trees will remain fresh, moist, and relatively non-flammable if the butts are kept continuously immersed in water. For more detailed treatment see Item 25.

3 Van Wagner, C.E. 1964.
HISTORY OF A SMALL CROWN FIRE. Forest. Chron. 40(2):202-205, 209.

The course of a small (1/4 acre) experimental fire in a red pine plantation. Transition from still-air surface fire to crown fire with sudden increase in wind. Intensities at various stages in terms of energy output rate.

4 Van Wagner, C.E. 1965.
STORY OF AN INTENSE CROWN FIRE AT PETAWAWA. Pulp and Paper Mag. of Canada, Woodlands Review. June, 1965.

On May 7, 1964, an intense fire burned 375 acres of forest on the Petawawa Military Reserve, in several pine and aspen forest types. The weather was the most severe on record for that date (85°F, 16% RH, wind 16 mph), and the fire exhibited probably the most extreme behaviour likely in this region. Data are presented on weather, fuel, rate of spread and energy output rate. Control action is described, especially backfiring.

5 Van Wagner, C.E. 1965.
DESCRIBING FOREST FIRES--OLD WAYS AND NEW. Forest Chron. 41(3): 301-305.

A review of traditional methods of rating forest fire behaviour and their shortcomings. The advantages of quoting fire intensity as rate of energy output per unit length of fire front are listed. The factors of fire intensity, namely rate of advance, fuel weight consumed, and heat of combustion, are discussed separately.

6 Van Wagner, C.E. 1965.
THE EFFECT OF THE EARTH'S CURVATURE IN VISIBILITY MAPPING. U.S. Forest Serv. Fire Control Notes 26(4):10-11.

An equation is developed to measure the effect of the earth's curvature on the screening of distant points by intervening ridges as seen from forest fire lookout towers. If not taken into account this effect can result in substantial errors in visibility maps prepared from contour maps. The error is greatest in rolling country with long distances between ridges.

7 Kayll, A.J. and C.H. Gimingham. 1965.
VEGETATIVE REGENERATION OF *CALLUNA VULGARIS* AFTER FIRE. Jour. Ecol. 53:729-734.

The effects of age and fire on vegetative regeneration of *Calluna* were investigated by applying controlled high temperature (400°C) to the bases of plants of ages 12, 17, and 24 years, and then comparing the results with similar clipped but unheated plants. Fewer stem bases regenerated after burning than after clipping, and the younger plants produced a significantly higher number of sprouts. These results confirm the belief that after 15 years of age *Calluna* tends to lose its ability to regenerate vegetatively.

8 Kayll, A.J. 1966.
SOME CHARACTERISTICS OF HEATH FIRES IN NORTH-EAST SCOTLAND. Jour. Appl. Ecol. 3:29-40.

Two autumn and seven spring fires were conducted in mature and over-mature *Calluna* heath. Stand characteristics, fuel quantity, rate of spread, fire temperatures, and weather were measured. Highest temperatures occurred in the crowns rather than close to the ground. Regeneration was much more prolific following complete fuel consumption than partial.

9 Kayll, A.J. 1967.
MOORE BURNING IN SCOTLAND. Sixth Ann. Tall Timbers Fire Ecol. Conf. Proc.:29-39.

Common heather (*Calluna vulgaris*) has been burned on the moors of northeast Scotland for 300 years to maintain forage for hill sheep and red grouse. This paper describes the moorland vegetation, methods of burning, and some characteristics and consequences of the fires. A representative bibliography (30 items) is attached.

10 Kayll, A.J. 1968.
HEAT TOLERANCE OF TREE SEEDLINGS. Eighth Ann. Tall Timbers Fire Ecol. Conf. Proc.:89-105.

Heat tolerance of physiologically-active and dormant seedlings (six species) was determined by applying controlled-temperature heat to restricted area on the stems, and also by heating whole seedlings in a hot air shroud. For a duration of 1 minute, lethal exposures for active seedlings ranged from 62°C to 78°C on the stems, and 52°C to 65°C for whole tops. Dormant lethal temperatures were 30 to 50 degrees higher.

11 Van Wagner, C.E. 1968.
THE LINE INTERSECT METHOD IN FOREST FUEL SAMPLING. Forest Science 14(1):20-26.

A method for estimating wood volume on the ground is derived and discussed mathematically. It requires only a diameter tally of pieces intersected by a sample line of known length, and application of a simple formula. The method was tested indoors with match splints on a 54-inch square, and outdoors on a 20-acre cut-over. It produces reliable estimates of quantity of logging slash in much less time than area sampling.

12 Stocks, B.J. and J.D. Walker. 1968.
THERMOCOUPLE ERRORS IN FOREST FIRE RESEARCH. Fire Technology 4(1): 59-62.

Temperatures measured in forest fires are often low on account of radiant heat loss from thermocouples to cool surroundings outside the flame. Since this error is proportional to the diameter of the thermocouple wire, the true temperature can be estimated by exposing a series of thermocouples of different sizes side-by-side. The measured temperatures are graphed and the curve extrapolated to zero diameter. The procedure was tested in the laboratory in flames of varying thickness.

13 Van Wagner, C.E. 1969.
A SIMPLE FIRE GROWTH MODEL. Forest. Chron. 45(2):103-104.

Expressions to predict the area of a forest fire and its rate of growth at any time since ignition are given, in terms of the linear rates of spread at head, flanks, and rear. A variable elliptical shape is assumed. Length of perimeter and its rate of increase are also derived. The model can be simplified to use whatever spread data are available.

14 Van Wagner, C.E. 1969.
DRYING RATES OF SOME FINE FOREST FUELS. U.S. Forest Service Fire Control Notes 30:5, 7, 12.

In lab experiments, dead pine needles and aspen leaves with waxy cuticle intact dried much more slowly than bits of wood of comparable size. Also, removal of the wax and resin with solvent resulted in much faster drying. Drying runs were begun with wet samples, and there was no indication of different drying behaviour as moisture content passed from above fibre saturation to below. Drying was generally exponential.

15 Van Wagner, C.E. 1970.
TEMPERATURE GRADIENTS IN DUFF AND SOIL DURING PRESCRIBED FIRES. Bi-Monthly Res. Notes 26(4):42.

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

16 Van Wagner, C.E. 1970.
FIRE AND RED PINE. Tenth Tall Timbers Fire Ecol. Conf. Proc.: 211-219.

Based on both local experience and the literature, this paper discusses the place of periodic fire in the ecology and management of red pine. Requirements for good natural regeneration are: 1) seed year, 2) summer fire of moderate intensity, 3) some seed trees left alive, 4) some duff removed, 5) hardwood brush controlled, 6) much of overhead canopy killed.

17 Van Wagner, C.E. 1972.
DUFF CONSUMPTION BY FIRE IN EASTERN PINE STANDS. Can. Jour. Forest Res. 2(1):34-39.

Amount of duff (F and H layers) consumed by fire in jack pine and mixed red and white pine stands was found to correlate well with duff moisture content at time of fire, and with the Duff Moisture Code, a component of the Fire Weather Index. Physical theory to account for the weight of duff consumed is presented in terms of a) downward heat transfer within the flaming front, and b) the energy required to heat the duff to ignition temperature at a given moisture content.

18 Van Wagner, C.E. 1973.
FOREST FIRE IN THE PARKS. Park News (Jour. of Nat. and Prov. Parks Ass.) 9(2):25-31.

This article is a non-technical description of the role of forest fire as a periodic disturbance and agent of renewal in many important Canadian forest types. If forest fire is excluded from the large parks, orderly renewal of the forest may fall behind schedule, and unnatural or undesirable successional trends take over. Allowing certain fires to run and even starting some deliberately are suggested if the large parks are to continue to represent Canadian forest ecosystems in their natural state.

19 Van Wagner, C.E. 1973.
HEIGHT OF CROWN SCORCH IN FOREST FIRES. Can. Jour. Forest Res. 3(3):373-378.

Presents theory and field evidence to show that the height to which forest tree foliage is scorched and killed in forest fires is proportional to the 2/3 power of line fire intensity.Gives equation to account for the additional effects of ambient temperature and wind. Results of potential use in damage estimation and prescribed burning operations.

20 Van Wagner, C.E. 1974.
EFFECT OF DUFF WEIGHT ON DRYING RATE. Bi-Monthly Res. Notes 30(2): 11-12.

During work on the drying rates of duff layers, it was discovered that the log drying rate (slope of semilog graph of free moisture versus time) correlated well with the inverse of duff dry weight per unit area. This relation holds fairly well over a wide range, from heavy boreal duff layers of 20 kg/m^2 down to litter layers of 0.25 kg/m^2.

21 Methven, I.R. and W.G. Murray. 1974.
USING FIRE TO ELIMINATE BALSAM FIR IN PINE MANAGEMENT. Forest. Chron. 50(2):77-79.

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

22 Van Wagner, C.E. 1975.
CONVECTION TEMPERATURES ABOVE LOW INTENSITY FOREST FIRES. Can. Forest. Serv. Bi-Monthly Res. Notes 31(2):21.

Presents a theoretical equation for the temperature profile above a line heat source. Uses this equation to analyse temperature data taken at various heights above the flame over several experimental outdoor forest fires, with reasonably good agreement. Calibrates the equation, which can then be used to predict temperature at a given height depending on the frontal intensity in terms of energy output rate per unit length of front.

23 Van Wagner, C.E. and A.L. Wilson. 1976.
DIAMETER MEASUREMENT IN THE LINE INTERSECT METHOD. Forest Sci. 22(2):230-232.

The question of which diameter to measure in the line intersect method is discussed. Of three possible approaches, 1) both-end diameters, 2) diameter at mid-length, or 3) diameter at point of intersection, the intersection diameter is judged superior,since it is not theoretically limited by any assumption about piece shape and is also much faster. A comparative field test is described.

24 Van Wagner, C.E. 1977.
EFFECT OF SLOPE ON FIRE SPREAD RATE. Can. Forest. Serv. Bi-Monthly Res. Notes 33(1):7-8.

Presents a proposed equation for estimating the effect of upward slope on fire spread. A subjective blend of five references on this subject, three based on laboratory fire experiments, two on informal field observation. All roughly exponential in form.

25 Van Wagner, C.E. 1977.
CONDITIONS FOR THE START AND SPREAD OF CROWN FIRES. Can. Jour. Forest Res. 7(1):23-34.

Some theory and observations are presented on the factors governing the start and spread of crown fire in conifer forests. Crown fires are classified in three ways according to the degree of dependence of the fire's crown phase on the surface phase. The crown fuel is pictured as a layer of uniform bulk density, moisture content, and height above ground. Simple criteria are presented for the initiation of crown combustion and for the minimum rates of spread and heat transfer into the crown combustion zone at which the crown fire will spread. The theory is partially supported by some observations in four kinds of conifer forest.

26 Van Wagner, C.E. 1978.
AGE-CLASS DISTRIBUTION AND THE FOREST FIRE CYCLE. Can. Jour. Forest Res. 8(2):220-227.

The expected age-class structure of a forest dependent on random periodic fire for disturbance and renewal is derived and presented. It is simply the negative exponential distribution, well known in probability mathematics. An important feature of this concept is that the present age-class structure of such a forest is the key to its past fire history. Its limitations are discussed, and the computer simulation of variations, including the interaction of fire and logging, is described. Three examples of its use in interpreting fire history are given.

27 Van Wagner, C.E. 1979.
THE ECONOMIC IMPACT OF INDIVIDUAL FIRES ON THE WHOLE FOREST. Forest. Chron. 55(2):47-50.

A method is presented whereby the economic impact of a forest fire can be calculated, not just on the burned area alone but on the whole forest under management. The main question is whether, when the burned area would have been cut, another area will be substituted in its place. If so, then the present value of the burned area alone may not be a fair measure of loss. A better measure might be the change in present value of the whole forest. Some examples are given, and the effects of varying the rates of interest and forest growth are illustrated.

28 Van Wagner, C.E. 1979.
A LABORATORY STUDY OF WEATHER EFFECTS ON THE DRYING RATE OF JACK PINE LITTER. Can. Jour. Forest Res. 9(2):267-275.

This paper describes the variation in drying rate of jack pine (*Pinus banksiana* Lamb.) litter with external conditions. Temperature, relative humidity, and wind speed were varied separately in a controlled cabinet and in the laboratory. Most drying runs followed the exponential pattern, and the drying rates were measured in terms of the slope of the semilog graph of free moisture content versus time. This slope was tested with fair success against theoretical relations involving the three weather variables. These principles were used in the design of the equations for the Fine Fuel Moisture Code of the Canadian Forest Fire Weather Index.

Departmental Publications

29 Van Wagner, C.E. 1961.
MOISTURE CONTENT AND INFLAMMABILITY IN SPRUCE, FIR, AND SCOTS PINE CHRISTMAS TREES. Forest Res. Branch Tech. Note 109. 16 p.

Now obsolete. Revised and issued as Departmental Publication 1034. See Item 32.

30 Kayll, A.J. 1963.
HEAT TOLERANCE OF SCOTS PINE SEEDLING CAMBIUM USING TETRAZOLIUM CHLORIDE TO TEST VIABILITY. Can. Dep. Forest. Pub. 1006. 12 p.

Scots pine seedling stems were exposed to a stream of hot air at several temperatures and durations. Cambium was killed after about 3 min at 60°C, and less than 2 min at 65°C. Twenty-four hours immersion in a 1% tetrazolium chloride solution was found to be a satisfactory indicator, turning live tissue pink while dead tissue remained uncoloured.

31 Van Wagner, C.E. 1963.
PRESCRIBED BURNING EXPERIMENTS: RED AND WHITE PINE. Can. Dep. Forest. Pub. 1020. 27 p.

Eleven quarter-acre plots in a mature red and white pine stand were burned at different degrees of dryness. Intensity ranged from 25 to 370 Btu/sec-ft. Fires' effects were measured on crowns and subsequent mortality, shrubs and subsequent resprouting, and conifer regeneration. Conclusion was drawn that it is quite feasible and safe to control shrubs, prepare seedbed, and obtain satisfactory pine regeneration through the use of prescribed fire, all without serious damage to the overstory.

32 Van Wagner, C.E. 1963.
FLAMMABILITY OF CHRISTMAS TREES. Can. Dep. Forest. and Rural Develop. Pub. 1034. Revised 1967. Available in French as Pub. 1034F.

Three species of conifer were included in this experiment: balsam fir, white spruce, and Scots pine. As expected, dry trees were highly flammable, but fresh trees could be ignited only with a continuous ring of fire around the base, and then burned very slowly. Trees can be kept in fresh, moist condition for two weeks or more by continuous immersion of butt in water. Use plain water only, since additives only reduce efficiency; salt retardants cannot be taken into foliage in any quantity, and the tree has more difficulty extracting water from a solution. The conclusion reached was that real trees with butts in water are not a fire hazard.

33 Van Wagner, C.E. 1965.
AIDS TO FOREST FIRE CONTROL PLANNING AT PETAWAWA. Can. Dep. Forest. Pub. 1127. 20 p. Available in French as Pub. 1127F.

Presents tables, graphs and maps that form the basis of forest fire control planning at the Station. Classified into those describing: a) patterns of fire weather, b) trends in fire occurrence, c) history of fire size and area burned, and d) features of the protected area. Examples given of procedures and processed information of possible interest to fire control agencies.

34 Kayll, A.J. 1966.
A TECHNIQUE FOR STUDYING THE FIRE TOLERANCE OF LIVING TREE TRUNKS. Can. Dep. Forest. Pub. 1012. 22 p.

An apparatus consisting of a propane torch with fine controls, mounted on a frame and directed against the tree trunk, was used to measure the time required to reach lethal cambium temperature (60°C) in white pine, as a function of applied surface temperature and bark thickness. At highest temperature, 500°C, time required was such that gentle fires would not be expected to affect mature trees, say 10 in dbh and up.

35 Van Wagner, C.E. 1966.
THREE EXPERIMENTAL FIRES IN JACK PINE SLASH. Can. Dep. Forest. Pub. 1146. 22 p.

This paper is a description in general and quantitative terms of three 4-acre experimental fires in an area of clear-cut jack pine slash, burned at different levels of fire danger. Their effects in reducing the fire hazard, cleaning the area for access or planting, and as preparation for seeding are described and rated. Weather and fuel conditions for different fire purposes are discussed along with control problems.

36 Van Wagner, C.E. 1967.
CALCULATIONS ON FOREST FIRE SPREAD BY FLAME RADIATION. Can. Dep. Forest and Rural Develop. Pub. 1185. 14 p.

Observation suggests that certain types of fire advance by preheating the fuel ahead with radiation from the flames. A mathematical model was devised to explain the rates of advance and energy output of such fires in terms of fuel amount and moisture content, flame length and angle, and the intensity of thermal radiation emitted by the flame. The theory was tested in a series of laboratory fires in beds of red pine needles at different slopes, with some confirmation of the basic concept.

37 Van Wagner, C.E. 1967.
SEASONAL VARIATION IN MOISTURE CONTENT OF EASTERN CANADIAN TREE FOLIAGE AND THE POSSIBLE EFFECT ON CROWN FIRE. Can. Dep. Forest. and Rural Develop. Pub. 1204. 15 p.

Five conifer and two hardwood tree species were sampled for four years to determine the seasonal variations in the moisture content of their foliage. New conifer and hardwood foliage were very moist (ca. 300%) just after flushing, but dropped to less than half this level by midsummer. Old conifer foliage passed through a distinct minimum (80 to 100%) just before the new foliage appeared, some 20 or 30% below its summer level. According to heat balance calculations and lab flammability tests, these variations should have a substantial effect on crown fire behaviour.

38 Van Wagner, C.E. 1968.
FIRE BEHAVIOUR MECHANISMS IN A RED PINE PLANTATION: FIELD AND LABORATORY EVIDENCE. Can. Dep. Forest. and Rural Develop. Pub. 1229. 30 p.

This paper is based on a series of experimental fires in a red pine plantation, ranging from gentle surface fires to crown fires of intensity over 20,000 kW/m, and also on lab fires in level and sloped pine needle beds. Three classes of fire are described: 1) surface fires (backing or in still air), 2) surface head fires, 3) crown fires (with surface phase linked). A propagation mechanism for each class is developed, consisting of a balance between the radiant heat transferred ahead of the fire and the energy needed to preheat the fuel to an ignition state. The information needed to predict fire behaviour in such a fuel complex is discussed.

39 Van Wagner, C.E. 1970.
AN INDEX TO ESTIMATE THE CURRENT MOISTURE CONTENT OF THE FOREST FLOOR. Can. Dep. Fish. and Forest. Pub. 1288. 23 p.

An index was developed to estimate day-to-day moisture content of duff layers of dry weight about 5 kg/m^2. It is based on four years' daily weighings of trays set into duff layers in pine stands. There were separate analyses of drying and rainfall effects. The drying phase is exponential, with log slope depending on temperature, humidity and season. The rainfall effect provides that wetting effect per increment of rain decreases as amount of rainfall increases. The index is on a logarithmic scale, and was incorporated into the Canadian Forest Fire Weather Index as the Duff Moisture Code (DMC).

40 Van Wagner, C.E. 1974.
STRUCTURE OF THE CANADIAN FOREST FIRE WEATHER INDEX. Can. Dep. Environ. Pub. 1333.

The Forest Fire Weather Index (FWI) was issued in table form in 1970 after several years work by a number of fire researchers in the Canadian Forestry Service. This paper describes its development, the concepts behind it, and its mathematical structure. The best features of the former fire danger index were retained and a link preserved between old and new. The FWI consists of six components: three moisture codes that follow the moisture content of three classes of forest fuel, two intermediate subindexes representing rate of spread and fuel consumption and the final index representing line fire intensity in a standard pine fuel type. The FWI is found daily from noon readings of temperature, humidity, wind, and rain. It can be worked out from a set of nine tables or by direct computation through a series of 29 working equations.

Information Reports

41 Van Wagner, C.E. 1966.
COMPARISON OF AMERICAN AND CANADIAN FOREST FIRE DANGER RATING SYSTEMS. Can. Dep. Forest. Inform. Rep. PS-X-2. 18 p.

An analysis and comparison of the two danger rating systems as they existed in 1966, pointing out some strengths and weaknesses in each. The separate functions of fine and heavy fuel moisture are quite different and both could not possibly be consistent in the same forest type. The Canadian index appears best suited to a closed forest with litter and duff layer, the American system to an open forest with grassy fine fuel. Because both systems have changed markedly since 1966, this Report is now obsolete. See Item 64.

42 Stocks, B.J. and J.D. Walker. 1968.
THE EFFECT OF GREEN VEGETATION ON SURFACE FIRE SPREAD IN THE LABORATORY. Can. Dep. Forest. and Rural Develop. Inform. Rep. PS-X-5. 6 p.

Describes an experiment to test the effect of green herbaceous vegetation on the behaviour of fire in pine needle litter. Various quantities of fresh green material were set as realistically as possible into pine needle beds 4 x 2½ ft in size. Much of the flame was suppressed, but rate of spread was surprisingly little affected. The fires were burned in still air, and it was surmised that headfires burning with the wind would be more affected, since they depend more on their overhead flame as a means of propagation than do still air or backing fires.

43 Kayll, A.J. 1968.
THE ROLE OF FIRE IN THE BOREAL FOREST OF CANADA. Can. Dep. Forest. and Rural Develop. Inform. Rep. PS-X-7. 15 p.

Review of literature on the boreal forest and fire as an agent of disturbance, regulation, and cycling. Discusses beneficial role of fire of right periodicity and intensity, harmful effects of repeated fire at short intervals or under wrong conditions. Treats individual tree species and ecological effects of fire, also effects on soils and wildlife. Foresees greater use of prescribed fire in northern forest management. Lists 93 references.

44 Van Wagner, C.E. 1969.
COMBINED EFFECT OF SUN AND WIND ON THE SURFACE TEMPERATURE OF LITTER. Can. Dep. Fish. Forest. Inform. Rep. PS-X-10. 7 p.

Describes a laboratory experiment to measure the combined effects of thermal radiation and wind on the surface temperature of jack pine and aspen litter. Semi-empirical equations are derived from theory and results. The rise in surface temperature above ambient was found to be proportional to the radiant intensity, and its logarithm inversely proportional to wind speed. There is possible application in fuel moisture prediction and work on seedling mortality at high temperature.

45 Van Wagner, C.E. 1970.
NEW DEVELOPMENTS IN FOREST FIRE DANGER RATING. Can. Forest. Serv. Inform. Rep. PS-X-19. 4 p.

A non-technical description of the Forest Fire Weather Index suitable for introductory purposes. See Item 40 for complete treatment.

46 Van Wagner, C.E. 1970.
CONVERSION OF WILLIAMS' SEVERITY RATING FOR USE WITH THE FIRE WEATHER INDEX. Can. Forest. Serv. Inform. Rep. PS-X-21. 5 p.

The daily values of the Fire Weather Index cannot be simply accumulated to determine fire season severity without weighting. This Report contains equation and table of daily weighting factors, based on the original severity factors developed by D.E. Williams for the old fire danger index.

47 Clements, J.R. 1971.
INTERCEPTION PER CANOPY IN A MULTI-STORIED LARGETOOTH ASPEN COMMUNITY. Can. Forest. Serv. Inform. Rep. PS-X-26. 13 p.

This report presents equations describing the amounts of interception per canopy in an aspen forest in relation to total rain. The four canopies were, from top down, largetooth aspen (*Populus grandidentata* Michx.), red maple (*Acer rubrum* L.), hazel shrub (*Corylus cornuta* Marsh.), and bracken fern (*Pteridium aquilinum* (L.) Kuhn). The relationships were curvilinear, and the proportion of rain intercepted decreased with increasing total rain.

48 Van Wagner, C.E. 1971.
TWO SOLITUDES IN FOREST FIRE RESEARCH. (Paper prepared for XV IUFRO Congress). Can. Forest. Serv. Inform Rep. PS-X-29. 7 p.

This Report compares the difficulties and advantages of indoor versus outdoor research on forest fire behaviour. The conclusion is drawn that theoretical and small-scale modelling of forest fire is so difficult as to render it unlikely that the main desired practical information on forest fire behaviour can be produced by these approaches; that observation and study of both accidental and experimental outdoor fires is required if valid progress is to be made.

49 Clements, J.R. 1971.
MEASUREMENT OF THROUGHFALL AT TWO LEVELS IN A YOUNG ASPEN STAND. Can. Forest. Serv. Inform. Rep. PS-X-30. 7 p.

Rainfall was measured at 25 and 75 cm above ground in a seven-year-old sucker stand of largetooth aspen (*Populus grandidentata* Michx.) 8.5 m tall. Ten rain gauges were set out at each height. There was some evidence of splashing from the ground into the lower gauges, but no observable difference in measured rain amounts at the two heights.

50 Methven, I.R. 1971.
PRESCRIBED FIRE, CROWN SCORCH AND MORTALITY: FIELD AND LABORATORY STUDIES ON RED AND WHITE PINE. Can. Forest. Serv. Inform. Rep. PS-X-31. 10 p.

Describes lab and field work to evaluate the extent of crown damage following prescribed fire under forest canopy. Lab experiments indicated needles killed at 20°C below level lethal to buds, also that seedlings survived up to 95% crown scorch. Field observations on large trees, on the other hand, showed mortality commencing at 45 to 50% crown scorch, with equal probability of death or survival at 80 to 85% crown scorch. Concludes that gentle prescribed fire under mature pine is quite feasible with no serious crown damage.

51 Van Wagner, C.E. 1972.
HEAT OF COMBUSTION, HEAT YIELD, AND FIRE BEHAVIOUR. Can. Forest. Serv. Inform. Rep. PS-X-35. 7 p.

Presents experimental heats of combustion of some forest fuels, and discusses calculation of net heat yield from gross heat of combustion. Also concludes that variation in heat of combustion among forest fuels is not an important factor affecting forest fire behaviour in Canada.

52 Van Wagner, C.E. 1972.
EQUILIBRIUM MOISTURE CONTENTS OF SOME FINE FOREST FUELS IN EASTERN CANADA. Can. Forest. Serv. Inform. Rep. PS-X-36. 11 p.

Presents data and curves of equilibrium moisture content for six fine fuels as it varies with relative humidity and temperature, and provides empirical equations for calculation. Concludes that EMC's of most kinds of leaf and needle litter are fairly similar, but EMC of wood is distinctly less.

53 Van Wagner, C.E. 1972.
A TABLE OF DIURNAL VARIATION IN THE FINE FUEL MOISTURE CODE. Can. Forest. Serv. Inform. Rep. PS-X-38. 8 p.

Development and rules for use of a table to show how fine fuel moisture varies throughout the 24-hour cycle, for different starting values and varying current relative humidity. Permits determination of the Fire Weather Index at any time of day.

54 Clements, J.R. and W.A. Kean. 1973.
RAIN SPLASH ON BURNED AND UNBURNED FOREST FLOORS. Can. Forest. Serv. Inform. Rep. PS-X-39. 8 p.

Rain splash heights were measured on two plots in a red and white pine stand. One plot was undisturbed, the other had been twice treated with gentle fire, the second time 2 months before the 10 measured rainfalls. Splash heights were about twice as great on the burned as on the unburned plot. The results are of importance to any work on the chemical qualities of rain collected in the forest.

55 Van Wagner, C.E. 1973.
ROUGH PREDICTION OF FIRE SPREAD RATES BY FUEL TYPE. Can. Forest. Serv. Inform. Rep. PS-X-42. 5 p.

Presents the general form of a power law equation linking the Initial Spread Index with rate of spread. Constants can be adjusted to suit individual fuel types wherever reasonable correlation exists. Examples are given for four fuel types based on Petawawa data, also three others from published references. Results are useful in converting relative index values to quantitative predictions.

56 Methven, I.R. 1973.
FIRE, SUCCESSION, AND COMMUNITY STRUCTURE IN A RED AND WHITE PINE STAND. Can. Forest. Serv. Inform. Rep. PS-X-43. 18 p.

Describes the effects of two consecutive annual light fires on the shrub and minor vegetation in a mature pine stand over two growing seasons. The pine canopy suffered little damage. Small balsam fir were eliminated, shrub and minor plant biomass reduced, but species composition little changed. The treatment appeared to be a minor perturbation in the life of the plant community, creating temporary conditions favourable to pine regeneration, but not of radical effect.

57 Sidhu, S.S. 1973.
EARLY EFFECTS OF BURNING AND LOGGING IN PINE MIXEDWOODS.
I. FREQUENCY AND BIOMASS OF MINOR VEGETATION. Can. Forest. Serv. Inform. Rep. PS-X-46. 47 p.

Presents detailed results of changes in minor vegetation during first growing season after partial logging with and without subsequent prescribed fire. A procedure for comparing changes in single species is proposed for cases where treated and control plots are not identical. Logging and fire each successively lowered plant biomass below the original level, and further altered the frequency pattern.

58 Sidhu, S.S. 1973.
EARLY EFFECTS OF BURNING AND LOGGING IN PINE MIXEDWOODS.
II. RECOVERY IN NUMBERS OF SPECIES AND GROUND COVER OF MINOR VEGETATION. Can. Forest. Serv. Inform. Rep. PS-X-47. 23 p.

Second of a series begun in previous Report. After logging only, ground cover of minor vegetation increases and ranking of species importance is affected. After fire as well, ground cover and number of species reach pre-burn levels in one growing season. Again, order of importance is altered.

59 Methven, I.R. 1974.
DEVELOPMENT OF A NUMERICAL INDEX TO QUANTIFY THE AESTHETIC IMPACT OF FOREST MANAGEMENT PRACTICES. Can. Forest. Serv. Inform. Rep. PS-X-51. 20 p.

Describes a simple numerical index to quantify the aesthetic impact of forestry practices on particular stands. Hypothesizes the idealized normal observer and the dominance of the visual response in human aesthetic relations with the environment. Index is constructed of six variables: 1) species variety, 2) structural complexity, 3) forest view, 4) slash visibility, 5) pattern, and 6) boundary form. These variables are assigned equal value in arbitrary units. Method can be extended to include economic evaluation as well. Examples given of effects of prescribed fire on aesthetic impact.

60 Sidhu, S.S. 1974.
EARLY EFFECTS OF BURNING AND LOGGING IN PINE-MIXEDWOODS.
III. DIVERSITY. Can. Forest. Serv. Inform. Rep. PS-X-54. 22 p.

Third of a series comprising Items 57 and 58 as well. Diversity in terms of Shannon's index was computed for the tree, shrub, and minor vegetation layers. Diversity was reduced as expected in tree and shrub layers after logging or logging plus burning. Diversity in the minor vegetation layer increased after logging only, but decreased following burning as well. This loss is expected to be made up over the next few years.

61 Van Wagner, C.E. 1974.
A SPREAD INDEX FOR CROWN FIRES IN SPRING. Can. Forest. Serv. Inform. Rep. PS-X-55. 9 p.

Describes a Crown Spread Index of the relative rate of spread of crowning forest fires during spring and early summer. Depends on proposition that conifer crowns are more flammable during this period because foliar moisture is lower than in mid-summer. Calculations based on heat transfer theory and on energy required to heat moist foliage to ignition temperature, supported by some field evidence of foliar moisture trends and crown spread rates. Uses Initial Spread Index (ISI) as starting point.

62 Kean, W.A. 1975.
A PDP-8L PROGRAM FOR CALCULATING THE FIRE WEATHER INDEX. Can. Forest. Serv. Inform. Rep. PS-X-57. 12 p.

An improvement on Item 71, incorporating some mathematical changes. Rendered obsolete by decision to convert to metric, also further mathematical changes. Replaced by Item 63.

63 Van Wagner, C.E. and T.L. Pickett. 1975.
EQUATIONS AND FORTRAN IV PROGRAM FOR THE 1976 METRIC VERSION OF THE FOREST FIRE WEATHER INDEX. Can. Forest. Serv. Inform. Rep. PS-X-58.

Presents equations and computer program for the 1976 metric version of the Fire Weather Index (FWI). Some mathematical changes as well. The standard form of the FWI as of 1979.

64 Van Wagner, C.E. 1975.
A COMPARISON OF THE CANADIAN AND AMERICAN FOREST FIRE DANGER RATING SYSTEMS. Can. Forest. Serv. Inform. Rep. PS-X-59. 19 p.

A technical comparison of these two national systems of fire danger rating. Deals with the three fuel moisture indicators in each plus the indexes of spread and energy release or buildup. Final comparison is with the American family of Burning Indexes and the Canadian Fire Weather Index. American system has, relative to the Canadian, less variation of spread rate with fuel moisture, and less response to rain; also no slow-drying moisture indicator such as Canadian Duff Moisture Code. American system judged best suited to grassy or open forests, Canadian to closed forest with substantial duff layer.

65 Methven, I.R., C.E. Van Wagner and B.J. Stocks. 1975.
THE VEGETATION ON FOUR BURNED AREAS IN NORTHWESTERN ONTARIO. Can. Forest. Serv. Inform. Rep. PS-X-60. 10 p.

As the initial step in a study of forest fire cycles in the boreal forest of northwestern Ontario, four burned areas of different ages were visited. This Report describes their present condition in terms of forest cover and minor vegetation. Tentative hypotheses on the role of fire in this forest are put forward. Apparently, in most cases, the same dominant tree species return immediately after fire, implying that cycling by fire rather than succession is the basic mechanism in this forest. Proposed further work is described.

66 Burgess, D.M. and I.R. Methven. 1977.
THE HISTORICAL INTERACTION OF FIRE, LOGGING, AND PINE: A CASE STUDY AT CHALK RIVER, ONTARIO. Can. Forest. Serv. Inform. Rep. PS-X-66. 18 p.

Describes the history and present condition of two adjacent pine stands, one a three-aged jack pine stand, the other a single-aged red pine stand containing a few white pine. History includes various loggings between 1837 and 1897, plus fires in 1914, 1882, and 1864 as well as several earlier ones. Conclusions are drawn about the intensity of the fires and how the pine species react to varying fire intensity. Natural regeneration consists of white pine only, leading to conclusion that, on this sandy site, white pine would eventually dominate in the absence of fire. Results have implications for forest management.

67 Van Wagner, C.E. 1977.
A METHOD OF COMPUTING FINE FUEL MOISTURE CONTENT THROUGHOUT THE DIURNAL CYCLE. Can. Forest. Serv. Inform. Rep. PS-X-69. 15 p.

A method is presented for computing fine fuel moisture content at hourly intervals around the clock. It is derived from the standard daily Fine Fuel Moisture Code used in the Canadian system of forest fire danger rating. It produces diurnal cycles of fuel moisture content that match the behaviour of real pine litter fairly well. It also progresses from day to day at rates similar to the standard Fine Fuel Moisture Code. Equations are included, and possible applications discussed.

68 Van Wagner, C.E. 1978.
METRIC UNITS AND CONVERSION FACTORS FOR FOREST FIRE QUANTITIES. Can. Forest. Serv. Inform. Rep. PS-X-71. 6 p.

This report presents a suggested list of metric units and conversion factors for quantities commonly used in forest fire research, and suitable also for practical use in operational work. It follows the approved standards of the International System of Units (SI).

Miscellaneous Publications

69 Van Wagner, C.E. 1968.
DUFF MOISTURE PROFILES AT PETAWAWA. Can. Forest. Serv. Intern. Rep. PS-8. 6 p.

Describes and portrays the variation in the moisture content of pine duff with depth found on six days of different average moisture content. The maximum moisture content was found somewhat above the lowest duff level rather than right next to mineral soil. Shape of profile varies with past history of rain and dry weather.

70 Van Wagner, C.E. 1970.
ON THE VALUE OF TEMPERATURE DATA IN FOREST FIRE RESEARCH. Can. Forest. Serv. Intern. Rep. PS-20. 3 p.

Opinion given that temperature measurement in forest fire research is usually more hindrance than help. Reasons are: 1) It is nearly impossible to describe a fire in terms of temperature field in space and time. 2) Basic features of forest fire are spread, fuel consumption, energy output. 3) It is through these latter features that fire behaviour can be predicted and controlled. 4) It is with these features that fire effects are most easily correlated.

71 Engisch, R.L. and J.D. Walker. 1971.
PDP-8L VERSION OF SIMARD'S FIRE WEATHER INDEX PROGRAM. Can. Forest. Serv. Intern. Rep. PS-23. 10 p.

Simplified version of a program for computing a season's output of the FWI on a small computer. Requires complete verified weather data, one station, one season at a time. Obsolete, replaced by Item 63.

72 Van Wagner, C.E. 1975.
IMPRESSIONS OF FOREST FIRE AND FORESTRY IN AUSTRALIA. Can. Forest. Serv. Petawawa Forest Exp. Sta. Special Rep. 16 p.

Describes a nine-week visit to various forest areas in Australia, and the impressions gathered on forest fire research and its achievements, the role of fire in Australian forests, use of prescribed fire, and forest management in general.

73 Van Wagner, C.E. and I.R. Methven. 1977.
PRESCRIBED FIRE FOR SITE PREPARATION IN WHITE AND RED PINE. Pap. given at White and Red Pine Symp., Petawawa Forest Exp. Sta., Sep. 1977. *In* Great Lakes Forest Res. Centre Symp. Proc. O-P-6, pp.95-100.

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

74 Methven, I.R. 1977.
FIRE RESEARCH AT THE PETAWAWA FOREST EXPERIMENT STATION: THE INTEGRATION OF FIRE BEHAVIOUR AND FOREST ECOLOGY FOR MANAGEMENT PURPOSES. Pap. given at Workshop on Fire Ecology in Resource Management, Edmonton, Dec. 1977. *In* Proc. pub. by Northern Forest Res. Centre.

Describes the strategy behind fire research at Petawawa. Two examples given: prescribed fire use in white and red pine, and ecological work in the boreal forest.

75 Van Wagner, C.E. and I.R. Methven. 1978.
DISCUSSION: TWO RECENT ARTICLES ON FIRE ECOLOGY. Can. Jour. Forest Res. 8(4):491-492.

Comments on the importance of proper measurement and consideration of forest fire behaviour in ecological work related to fire, with reference to two particular articles.

76 Van Wagner, C.E. 1978.
METEOROLOGY AND FOREST FIRE MANAGEMENT. Pap. given at Symp. on Forest Met., Ottawa, Aug. 1978. Pp. 102-107 *in* Proc. pub. by Can. Forest. Serv. on behalf of World Met. Org.

Deals with the scientific and practical links between forest fire and meteorology, and argues for consideration of forestry (especially forest fire) problems at the primary policy level in national meteorological agencies. Cites the increasing technological sophistication in forest fire control practices and the increasing awareness of fire's ecological significance in forest management.