FIRE RESEARCH AT THE
PETAWAWA FOREST EXPERIMENT STATION:
THE INTEGRATION OF FIRE BEHAVIOUR AND
FOREST ECOLOGY FOR MANAGEMENT PURPOSES

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Paper Presented at the Fire Ecology in
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Fire is not an absolute, it is a variable. This may appear
to be a somewhat trite and self-evident statement, but the most con-
spicuous feature of much of the literature on fire ecology has been the
lack of reference to the nature of the fires that caused the effects
being measured. This has been a consequence of another example of the
"two solitudes in forest fire research" noted by Van Wagner (1971) with
reference to field versus laboratory research on fire behaviour. In
the case of ecological effects, the two solitudes have been composed of
fire researchers concerned with behaviour, and ecologists concerned with
fire effects. This situation probably goes a long way towards explaining
the dearth of literature on fire prescriptions to attain specific eco-
logical ends.

Although the title refers to the integration of fire behaviour
and fire ecology as subject matters, it could as easily refer to the
integration of fire behaviourists and fire ecologists. Not merely in
the sense of close cooperation between separate individuals, but in the
sense of the knowledge of both subject areas being possessed by the same
individual.

The guiding principle of fire research should be the inte-
gration of fire behaviour and biological effects so that the consequences
of specific fires can be predicted. This ability of course has a dual
pay-off: (1) it allows the forest manager to predict the consequences
of a wildfire, thereby providing him with an ecologic-economic input into
the fire management decision-making process, and (2) it provides a pre-
scription ability for the application of prescribed fire to manipulate
vegetation, and of course its dependent wildlife, towards specified
management objectives.

Our current research at Petawawa, which is guided by the
above principle, is concentrated on two forest regions: the Great Lakes-
St. Lawrence and the Boreal. In both we are studying the biological
consequences of fires of known behaviour where possible, but in the
former our approach is based on the use of experimental fires on a stand
scale, and in the latter it is based on the sampling of large wildfire
areas on a landscape scale. Before going into more detail on this
research however I would like to say a few words on fire variability,
since this is really the crux of the whole business.

Fire variability is best broken down into three aspects:
(1) fire intensity, (2) depth of burn, and (3) fire interval. Fire
intensity refers to the frontal energy output rate, which is compounded
of the quantity of fuel consumed in the flaming front, the rate of

movement of the front, and the heat of combustion of the fuel. The fuels generally consumed in the flaming front are the surface litter and the above-ground fine materials such as needles, twigs and lichens. Thus the intensity is very much a function of the moisture content of these fine exposed fuels and the wind, or in other words the short term and current weather.

One breakdown of intensity associated with surface fire is that resulting from wind direction and topography; namely headfire, flanking fire and backfire. These are all present in every fire, so that for any given set of weather and fuel conditions, considerable variability in behaviour and intensity will occur. However, the greater proportion of any given fire area will usually be burned by headfire, so that this within-fire variability is not generally important on an area basis, except in a prescribed fire where the prescription calls for backfire.

Although intensity can vary enormously from approximately 70kW/m for a surface backfire to 150,000kW/m for an active crown fire, there is an effective limit in terms of direct ecological effects, since any intensity above that required to kill the overstory trees is meaningless. Trees are easily killed by intense surface fire, so crown fires can be lumped with the more intense surface fires, thereby limiting the effective intensity limit to approximately 4000kW/m. Effects can vary from the minor and ephemeral at the lower end of the scale, to a complete recycling of the age class, and even a change of the cover type, at the upper end of the intensity scale.

Depth of burn involves consumption of the duff or deeper organic layers, largely the result of smouldering behind the front. While this consumption also is dependent on moisture content, it is a function of longer term weather. Its biological effect is two-fold since it influences both the quantitative and qualitative aspects of regeneration through the amount of seedbed exposed, and the differential consumption of regenerative organs, depending on the depth at which they occur in the organic or mineral soil.

Fire interval is simply the time between two consecutive fires at a point location, and the average fire interval for a large number of fires is theoretically equal to the more abstract fire cycle. Since plants vary in the time required to attain maturity and in the capacity of their regenerative organs to withstand repeated fire, fire interval can exert a selective influence on the vegetation.

In determining direct ecological effects therefore, it is essential that the following three parameters of fire variability be considered: (1) fire intensity, (2) depth of burn, and (3) fire interval.

To illustrate the way all these principles can be put into practice, I will discuss part of our work in the two forest regions mentioned earlier.

In the Great Lakes-St. Lawrence forest region we are faced with the continuing liquidation of our natural red and white pine forests, the result of modern logging techniques and fire exclusion, leading to inadequate regeneration, unlike the logging techniques followed by fire of the nineteenth century, which provided us with our present pine stands (Burgess and Methven 1977). Not exactly a unique story, except that the situation is probably more critical than for most other species. The silvics and ecology of these two species have been well known for some time (Rudolf 1957, Horton and Bedell 1960, Wilson and McQuilkin 1963), including the fact that fire is an integral component of their ecology (Maissurow 1935, Candy 1939, Van Wagner 1970), so that regeneration requirements are also well established. These are: (1) a live overhead seed source, (2) a seedbed either bared to mineral soil or with its duff cover substantially reduced, (3) relative freedom from competition by shrubs and understory trees of undesired species, and (4) considerable opening of the overhead canopy to satisfy the light requirements of the two species. Given these requirements and the ecology of the species, it was apparent that fire could offer a solution to the problem.

The first and most vital step in problem solution is proper formulation of the problem, which in this case could be expressed as follows: What kind of fire regime would satisfy the regeneration requirements of red and white pine, given the constraint of minimal damage to the overstory trees?

Note that nothing is said about the fire being prescribed or wild, since the necessary regime will be the same regardless of whether it involves initiation of prescribed fire or response to wildfire. Fire is fire regardless of ignition source, and response should be based on whether it fits management objectives, not on ignition source.

The above problem formulation can be subdivided into a sequence of logical steps.

(1) The development or adaptation of a system by which fire behaviour can be predicted.

(2) Correlation of this system with fire variables and ecological effects.

(3) Formulation of fire prescriptions that will result in the desired objectives as stated in the problem formulation.

The basic criteria for a good predictive system for fire behaviour are universal availability and simplicity of application. Fortunately the makings for such a predictive system are available in the indexes of the Canadian Forest Fire Danger Rating System (FDRS), a system based on past and current weather, and devised to predict standard fuel moisture conditions and expected fire behaviour, at least in a relative sense.

A number of experimental fires indicated that the FDRS could serve as a reasonably good quantitative guide to choice of burning day for a given fuel type (Van Wagner 1972, 1973a). The indexes finally chosen as being most useful were the Fine Fuel Moisture Code (FFMC), a numerical rating of the moisture content of litter and an indicator of relative ease of ignition and flammability; the Initial Spread Index (ISI), a numerical rating of expected rate of spread based on wind and the FFMC; the Buildup Index (BUI), a numerical rating of total available fuel; and the Forest Fire Weather Index (FWI), a numerical rating of fire intensity based on a combination of the ISI and the BUI.

The first biological effect of interest is that on the mature pines, the future seed source. Ensuring a live seed source is greatly facilitated by the thick corky bark of the mature pines, which protects the cambium from heat damage. However the pines are susceptible to scorching of the crown foliage which, if severe enough, can result in mortality. This immediately raises the following multiple question: How much scorching can be tolerated in terms of tree mortality, what is the allowable intensity to avoid excessive crown scorching, and how can this be related to the FDRS? Experimental and theoretical work on this question (Methven 1971, Van Wagner 1973b, 1974, Methven and Van Wagner unpubl.) has yielded a number of equations for relating crown or scorch height, fire intensity, the FWI, percent crown scorch, and the probability of mortality.

The next biological effect of importance is that associated with duff consumption or seedbed preparation. In the case of seedbed, particularly for red pine, the greater the duff consumption and exposure of mineral soil the better, but there exist three constraints on this consumption: (1) the contribution to available fuel and thus fire behaviour, and particularly postfire mop-up, (2) the effect of deep burning on the roots of crop trees, particularly on shallow tills over bedrock, and (3) the role of the duff as a nutrient bank and site of exchange capacity. Thus a compromise needs to be effected between seedbed requirements and these constraints. Where white pine is desired rather than red pine, the problem is considerably simplified, since white pine is able to germinate on a full duff layer, so that by controlling duff consumption through the BUI, the relative quantities of the two species can be manipulated.

The index most closely correlated with duff consumption is the BUI, so it is necessary to at least set an upper limit for this index that will improve seedbed conditions and at the same time take account of the constraints. The theoretical underpinnings for duff consumption, based on downward heat transfer within the flaming front and the energy required to heat the duff to ignition temperature, were developed by Van Wagner (1972), who was able to demonstrate a linear relation between the duff consumed and the Duff Moisture Code (DMC). The required practical data to calibrate this relationship are now on hand.

The final biological effect of direct concern is that on the understory vegetation, which often constitutes lethal competition for young pine seedlings. Since the pines are adapted to fire, it is only logical to assume that the associated vegetation is also adapted. This is in fact the case, the major adaptation being the possession of underground stems or rhizomes, and the ability to sprout from the root collar. Since these species need to be controlled by fire a dilemma arises: how to control fire adapted species with fire?

The competition problem can be reduced to three species: namely balsam fir (Abies balsamea (L.) Mill.), red maple (Acer rubrum L.), and beaked hazel (Corylus cornuta Marsh.). The stems of all three species are killed easily by fire, but while balsam fir has no immediate regenerative response, and thus is eliminated (Methven and Murray 1974), both red maple and hazel sprout vigorously after aerial stems are killed (Van Wagner 1963, Methven 1973), the former from the root collar and the latter from rhizomes. Fortunately the adaptation of both of these species is limited, in that they are susceptible to repeated fires (Buckman 1962, 1964) which exhaust root and rhizome reserves, particularly if carried out after full leafout and before the leaves become net exporters of photosynthate. Though sprouting still occurs, its vigour is considerably reduced after two fires. In practice the first fire in dense brush understory must be run in the spring before leafout, since flammability in such stands is too low in the summer.

Formulation of the fire prescription can now be achieved in terms of the FFMC, ISI, BUI, and FWI, and the technique is ready for recommendation to forest management people in the white and red pine region (Van Wagner and Methven 1977).

Our work in the Boreal forest region, as mentioned earlier, is on a landscape scale, and its basic purpose is to provide a fire effects input into forest management planning and fire management decision-making. Whether the management plan is for industrial lands, non-designated crown lands, parks, or wilderness areas, and whether it calls for total fire exclusion, prescribed burning, or letting wildfires burn, fires will always occur, and rational management must take this into account and be able to predict the biological consequences.

The basic problem formulation therefore is a fourfold one.

(1) What is the natural fire cycle and associated age class distribution?

(2) What is the natural fire-controlled species distribution?

(3) How are 1 and 2 related to habitat types?

(4) What are the alternatives for postfire development given the four preconditions of (a) fuel conditions and expected fire behaviour as expressed in the FDRS, (b) stand age, (c) cover type, and (d) habitat type?

The answer to question 1 is being developed primarily through a combination of a theoretical approach to age class distribution (Van Wagner 1978), and collation of age class data collected from field surveys. This is also being supplemented with fire scar data derived from direct field sampling. The theoretical development of the age class structure of a forest dependent on random fire for renewal results in a negative exponential distribution in which the fire cycle equals the average age. This provides a powerful tool for interpreting fire history and for management planning.

Answers to questions 2, 3 and 4 are being developed from field sampling. Stands or associations are subjectively sampled by forest regions and sections in order to obtain as wide a range of ages, cover types, and apparent habitat types as possible. Wherever possible information is obtained on fire behaviour, weather conditions, and the FDRS at the time of the last fire. Where this is not possible an attempt is made to induce the fire variables from such evidence as the age structure of the stand, fire scars, stand density, tree growth rate, and depth of the organic layer.

Vegetation analysis involves three main steps:

(1) Identification of habitat type by (a) grouping stands in association tables, (b) separating stands by ordination techniques, and (c) constructing height/age curves of dominant trees.

(2) Correlation of cover types with habitat types over time.

(3) Development of predictive equations for relations between stand parameters such as age, height, diameter, and density.

The eventual result will be a model of forest development, in which cycling is induced by fire, and the variables are habitat type, cover type, stand age at the time of fire (which is equivalent to fire interval), fire intensity as expressed in the ISI and FWI, and drought or depth of burn as expressed in the BUI and the Drought Code (DC).

The most striking feature of fire on a landscape scale is variability in fire intensity. This is most apparent from the air immediately after fire, when the ground appears as a mosaic of green, brown, and black, corresponding to unburned or light surface fire, intense surface fire, and crown fire. Sometimes brown and green are interspersed indicating moderate surface intensity. All this at first presents a somewhat complex predictive problem, but as pointed out earlier, intense surface fire and crown fire can be lumped together. Thus for all practical purposes three kinds of effect can be identified: total tree kill, partial tree kill, and no tree kill. The relative amounts of these three categories are dependent on weather and fuel conditions at the time of the fire (which can be described by the FDRS), the relative proportions of upland and lowland, and possibly topographic roughness.

After some exploratory field work in the B.22a section in northwestern Ontario we felt emboldened enough to propose some hypotheses (Methven et al. 1975), which are presently in a slightly revised form as follows:

(1) Fire is a normal and necessary component of the boreal forest, and almost always results in the reestablishment of forest.

(2) The exclusion of fire from the boreal forest is abnormal, and could result in the degeneration of the forest and loss of the forest cover.

(3) Whether the same species predominate after fire as before, depends partly on the fire interval, and partly on the proximity of other seed sources.

(4) Seeding-in is completed quickly, and almost all young trees capable of taking part in the stand development are present from the start. There is no succession in the normal sense of the term, only development in the form of changes in dominance with time, and cycling of the forest by fire.

After some aerial reconnaisance of recent burns however, it appeared that hypothesis 1 was in difficulty, and that we might not have too much trouble disproving it, particularly on bog sites and bedrock ridges. Field sampling of some such areas, however, showed that they were regenerated. The negative appearance of the bog sites was due to the much slower development vis à vis the adjacent uplands. For example black spruce regeneration on one very large lowland site 15 years after fire numbered 80 thousand stems per hectare, but was generally under one metre in height, whereas jack pine regeneration on the adjacent uplands numbered only 15 thousand stems per hectare, but was up to six metres in height. Thus from the air the former looked totally unregenerated.

On certain bedrock ridges, where virtually nothing but bare rock was visible from the air after fire, we found that there were enough pockets of soil present to form a seedbed for an adequately stocked stand. On one such area, one year after fire, we counted 150 thousand jack pine seedlings per hectare. On an adjacent area of deep soil there were 350 thousand seedlings per hectare so regeneration conditions were very good. However this does not obviate the fact that what appeared to be, from the air, an area of nothing but bare rock, was in fact well regenerated. Thus where an adequate seed supply is present, there does not seem to be a problem with regeneration, and hypothesis 1 remains intact.

One potential problem does exist however, due to a combination of climate and the flammability of young conifer stands; namely fire in immature stands where an adequate seed supply does not exist. In other words a short fire interval problem. On such areas examined so far in the northwestern Ontario boreal forest, conifer regeneration was inadequate, but the slack has been taken up by aspen seedlings from outside the fire area. Experimental fires in young (13-year-old) jack

pine at Petawawa have demonstrated their flammability and resulted in zero regeneration, even though the trees were carrying approximately 100 thousand viable seeds per hectare. Thus, although we have not demonstrated short fire interval to be an actual problem in the boreal forest, it is obviously a problem of potential importance that requires further investigation.

In the B.1b section of northern Quebec we find a somewhat different situation. Preliminary indications are that the climate is generally less conducive to fire, in that days suitable for fire do not occur as often, and when they do occur, they do so under lower drought conditions.

A ground survey of fires from 1961, 1971, and 1976 showed heavy duff accumulations remaining after fire, and consequent very poor regeneration. In other words depth of burn was a problem even though many of the fires were intense crowning fires in upland black spruce, demonstrating the independence of fire intensity and suitable seedbed. Confirmation of the fact that depth of burn was the problem was graphically demonstrated on a 1976 fire, where virtually the only regeneration found was on mineral soil exposed by some blowdown that had occurred before the fire.

Thus in section B.22a, poor regeneration is a potential problem that could arise from short fire intervals, whereas in the B.1b section, poor regeneration is an actual problem resulting from inadequate depth of burn. From the point of view of timber management as an example therefore, efforts in the former should tend towards increasing the fire cycle through preventing the reburning of immature conifer stands, while in the latter it should be directed towards decreasing the area burned under low drought conditions (low BUI and DC), and being less concerned about those occurring under high drought conditions (high BUI and DC).

This demonstrates once more that rational management policy can only be developed if the biological consequences of fire are interpreted in terms of the fire variables.

In conclusion I would like to emphasize that the use to which fire ecology work is to be put must be kept in mind, namely to predict postfire vegetation development for an ecologic-economic input into fire and land management decision-making. This cannot be done without taking the variability of fire behaviour into account, and integrating or correlating this with the biological effects.

Now whether the management function involves planning of prescribed fire or responding to wildfire, rational decisions can be made only if three conditions are satisfied:

(1) Specification of land use objectives.

(2) Characterization of fires as to their expected behaviour and occurrence in terms of fire intensity, depth of burn, and fire interval.

3) Prediction of the response of the vegetation, i.e. the biological effect, according to the expected fire behaviour.

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