Fire Behavior and Effects in Aspen-Northern Hardwood Stands

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Abstract

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

Résumé

Six brûlages expérimentaux ont été effectués, dans des peuplements purs de peupliers faux-tremble et de feuillus mélangés, dans la région des Etats des Grands-Lacs des Etats-Unis. Ces feux, qui ont eu lieu au printemps et tard à l'automne (suite à la chute des feuilles) ont été pratiqués sur des quantités de combustible de surface disponible dont la moyenne était de 2.5 t/ha et ce, sous des conditions de brûlage élevées à extrêmes, selon l'Indice Forêt-Météo Méthode Canadienne (IFM). Les taux de propagation du feu sous le vent ont varié de 1.5 à 8.8 m/min et montrèrent une haute corrélation avec la composante Indice de Propagation Initiale de la Méthode IFM (r = 0.91). Les intensités du front de flammes ont varié entre 115 et 672 kW/m. Malgré l'importante mortalité des arbres au diamètre à hauteur de poitrine (d.h.p.) inférieur à 7.6 cm, les tiges de l'étage supérieur au d.h.p. excédant 15 cm n'ont cependant que rarement été affectées. La plupart des espèces d'arbustes accusèrent rapidement une mort en cîme due au feu mais ne prirent cependant que peu de temps à repousser. Le nombre total de tiges d'arbustes feuillus et de petits arbres s'est souvent accru, suite au passage du feu.

Introduction

Although trembling aspen (Populus tremuloides Michx.) is considered a fire type[1] and a wealth of fire effects literature exists (e.g., Rouse 1986a), surprisingly little empirical fire behavior data is available. In 1968 and 1970, six experimental fires were carried out within pure aspen and mixed hardwood stands in Minnesota and Wisconsin in order to formulate guidelines for the use of prescribed burning in wildlife habitat improvement programs (Sando 1972). These six fires have also proved valuable in the development of a guide to predicting wildfire behavior in the context of the Canadian Forest Fire Danger Rating System (CFFDRS) and contributed to our understanding of prescribed fire effects in northeastern deciduous forests. Originally, the 1964 version of the U.S. National Fire Danger Rating System (Nelson 1964) was used by Sando (1972) to characterize the fire danger conditions. The main purpose of this paper is, in addition, to formally document the CFFDRS indexes associated with these fires. Some of the basic information and data on stand and fuel characteristics, fire weather observations, fire behavior, and initial effects of fire on woody vegetation have been recapitulated, with a minimum of discussion. In contrast to Sando's (1972) original paper, metric units are used here throughout.

Description of Study Areas

Five of the experimental fires were carried out on lands managed by the Minnesota Department of Natural Resources (MDNR) at the Mille Lacs Wildlife Management Area (Table 1) in the central part of the state (Fig. 1). The other experimental fire occurred in central Wisconsin (Fig. 1) on the Necedah National Wildlife Refuge (Table 1), which is administered by the U.S. Department of Interior, Fish and Wildlife Service. The terrain in both study areas is flat. The experimental fire at Necedah (No. 3) took place in an

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Table 1. Locations, deciduous stand classifications, preburn stand characteristics, and burning dates associated with the six experimental fires carried out in the aspen-northern hardwood fuel type (adapted from Sando 1972).

Experimental fire no.	Study area location	Forest cover type[a]	Stand age (years)	Live tree density (stems/ha)	Basal area (m²/ha)	Date of burning
1	Mille Lacs	Northern hardwood	52	2570	20.2	30.04.68
2	Mille Lacs	Aspen	22	2540	7.6	02.05.68
3	Necedah	Aspen	45	1327	16.8	27.04.70
4	Mille Lacs	Northern hardwood	34	2637	21.6	06.05.70
5	Mille Lacs	Northern hardwood	54	2209	22.5	08.05.70
6	Mille Lacs	Northern hardwood	54	2703	25.7	19.10.70

[a] The aspen stands exemplify Type 16 (Aspen) in the forest cover type classification of the Society of American Foresters (Eyre 1980) whereas the northern hardwood stands represent a mixture of aspen together with sugar maple, basswood and other shade tolerant tree species.

FIG 1. Location of the two study areas for the experimental fires carried out in the aspen-northern hardwood forest.

aspen stand with potential dominant tree heights of 14 m at 50 years of age. The soil was a fine outwash sand, and there was very little aspen regeneration. The area is typical of the poor sandy sites in the U.S. Lake States region.

The stands at Mille Lacs all represent a range of habitat conditions in Minnesota. Soils in the area are largely clay loam. The sites studied ranged from poor to medium for aspen, with potential dominant tree heights of 14-17 m at 50 years of age. Much of the Mille Lacs area was originally occupied by eastern white pine (Pinus strobus L.). Three of the experimental fires (Nos. 1, 5 and 6) took place in what were once pure aspen forests but are best described as either mixed or northern hardwood cover types (Table 1). The remaining aspens in these stands were often larger than 25 cm in diameter at breast height (dbh), and most of them by then in their decadent state were being replaced by more shade tolerant tree species such as sugar maple (Acer saccharum Lam.) and basswood (Tila americana L.). Little aspen regeneration was evident prior to burning. One of the experimental fires (No. 2) was carried out in an aspen stand containing some burr oak (Quercus macrocarpa Michx.) for which the site index was 14 m at 50 years of age and the commercial forest potential was very low. The stand area contained many small openings and some large aspen stems located in wet places. These trees had obviously escaped the fire that was responsible for the present stand's origin. Experimental fire No. 4 was carried out in a northern hardwood stand that was considerably younger than the other mixed deciduous types. Again in this stand the aspen was being replaced by sugar maple and other more shade tolerant tree species. A few larger aspen trees that had evidently escaped the stand originating fire were still standing.

Methods

Available fuel loads were estimated from random samples taken of the litter (L) layer of the forest floor using a 30.48 cm x 30.48 cm sampling frame. All of the material within the 929 cm² area was collected, placed in paper bags, and returned to the laboratory, where the samples were oven-dried for 24 hours at 105°C and then weighed. Only the hardwood leaf cast and cured herbaceous material were sampled, because the combined fermentation (F) and humus (H) layers of the forest floor contributed very little to the available fuel for combustion of the fires due to their generally high moisture content in the spring and late fall.

On-site weather observations were taken immediately prior to and during the fires. Dry- and wet-bulb temperatures were measured with a sling psychrometer, and relative humidity subsequently was determined from the appropriate psychrometric tables as determined from the elevation above mean sea level (MSL) for the area. Wind speed was measured with a hand-held pilot tube anemometer and at a height of 6.1 m in the open with a recording anemometer.

Unfortunately, on-site weather observations leading up to the fires were not available. For the purpose of fire danger rating calculations, this was not considered to be a major concern because there had been a rain-free period (generally 4-5 days) before the fires very early in the spring and a large amount of rain before the one fall fire. In addition, the relatively flat terrain in both localities would have contributed to uniform heating and atmospheric moisture conditions over fairly large areas. Daily readings of temperature, relative humidity, wind speed, and 24-hour accumulated rainfall measured at 1300 Central Standard Time (CST) were obtained from the closest permanent fire weather stations (see the Appendix). The station at Brainerd, operated by the MDNR, is located 63 km northwest of Mille Lacs. The station at Friendship, operated by the Wisconsin Department of Natural Resources, is located 24 km southeast of Necedah. The weather records utilized in the present study are not listed with the USDA Forest Service's National Fire Weather Data Library (Furman and Brink 1975)[2].

Wind speeds, measured at the U.S. standard of 6.1 m in the open, were adjusted to the CFFDRS standard of 10 m according to the procedure suggested by Turner and Lawson (1978). All weather data were converted to metric units. The six standard components of the Canadian Forest Fire Weather Index (FWI) System (Van Wagner 1987) were calculated by computer program (Van Wagner and Pickett 1985). The standard fuel moisture code starting values following 3 days of snow-free cover in the spring were used (Canadian Forestry Service 1984). The basic observation time in the CFFDRS is 1200 local standard time. The difference of one hour is not considered to be of any great significance (Turner and Lawson 1978).

Fuel moisture content samples were taken immediately prior to ignition of the fires. The samples were collected and placed into metal sampling tins, sealed with masking tape to prevent moisture loss, and returned to the laboratory, where they were oven-dried for 24 hours at 105°C and the moisture content determination was made.

The areas to be burned varied from 4 to 65 ha in size. Several rate of spread (ROS) measurements were made during each fire. The ROS observations were made at selected locations either visually using metal stakes as reference markers or by sound using small exploding devices (i.e., commercially available fireworks) placed at predetermined intervals along a line oriented parallel to the general wind direction during the fire.

Within the areas selected for burning, several circular-shaped 0.04 ha stand inventory plots were located from a random starting point. All trees greater than 2.5 cm dbh on these plots were described and measured before and after burning. The dbh, species, and condition (i.e., live or dead) of each stem were recorded. Five circular-shaped 4.0m^2 shrub and small tree inventory plots were systematically located in each stand inventory plot. The number of only live stems of all shrubs and small trees less than 2.5 cm dbh were recorded by species before and after burning.

Results and Discussion

The six experimental fires took place prior to the initiation of new plant growth in the spring (i.e., between April 27 and May 8) or in the late fall (October 19) after plant growth had ceased (Table 1). The surface fuels were therefore in a dry, cured state. All the experimental fires were ignited around 1300 CST.

STAND AND FUEL FEATURES

The stand age, live tree density, and basal area associated with the experimental fires were from 22-54 years, 1327-2703 stems/ha, and 7.6-25.7 m^2/ha, respectively (Table 1). Deciduous leaf litter was the major surface fuel component in the burning areas. Grasses, ferns, and other herbaceous material also contributed. Available surface fuels averaged 2.47 t/ha. The fuel loads in this study were considerably less than those in other aspen-northern hardwood stands sampled at Mille Lacs (Beyerhelm and Sando 1982). The impact of the lower available fuel volume in this study became evident once the burning began.

BURNING CONDITIONS

The average dry-bulb temperature, relative humidity, and 10-m open wind speed during the experimental fires ranged as folows: 12.7-30.6°C, 22-49%, and 15-28 km/h, respectively (Table 2). The length of time since rain varied from 4 to 9 days. The observed moisture content of fine dead surface fuels was 8.3-14.8%. The daily weather observations preceding each fire have been documented in the Appendix for reasons described elsewhere (Alexander 1982b, 1984).

The three fuel moisture codes and three fire behavior indexes comprising the FWI System, are listed in Table 3 for each experimental fire. They indicate high (FWI 11-22) to extreme (FWI 23+) fire danger according to the classification scheme currently used in Ontario (Stocks et al. 1989).

FIRE BEHAVIOR CHARACTERISTICS

The head fire ROS varied from 1.52 to 8.84 m/min (Table 4), which would be considered moderately slow (i.e., 1-3 m/min) to moderately fast (i.e., 3-10 m/min) (Alexander and Lanoville 1989). The maximum observed ROS was 15 m/min. The importance of wind, within defined limits of fuel moisture, in the propagation of free-burning fires became very evident once the burning began. Several unsuccessful attempts to burn

Table 2. Fire weather observations and fuel moisture conditions associated with six experimental fires carried out in the aspen-northern hardwood forest (adapted from Sando 1972).

Experimental fire no.	Dry-bulb temperature (°C)	Relative humidity (%)	10-m open wind speed (km/h)	Days since rain[a]	Fuel moisture content[b] (% ODW basis)
1	25.6	32	15	7	8.3
2	23.9	22	28	9	9.9
3	30.6	32	28	4	12.0
4	17.2	29	28	4	10.0
5	12.7	49	18	6	11.2
6	18.3	45	28	5	14.8

[a] Amount greater than 0.6 mm.

[b] Pertains to leaf litter and cured herbaceous vegetation. ODW = over-dry weight.

Table 3. Fire danger indexes associated with six experimental fires carried out in the aspen-northern hardwood fuel type.

Experimental fire no.	Fine Fuel Moisture Code (FFMC)	Duff Moisture Code (DMC)	Drought Code (DC)	Initial Spread Index (ISI)	Buildup Index (BUI)	Fire Weather Index (FWI)
1	91.6	20	26	11.5	19	15
2	93.5	29	39	28.7	29	35
3	92.5	26	47	25.2	26	31
4	90.6	20	40	19.2	30	23
5	88.4	24	50	8.4	24	14
6	87.6	8	410	12.4	15	15

[a] Refer to Canadian Forestry Service (1984) for definitions of the six standard components of the Canadian Forest Fire Weather Index (FWI) System.

Table 4. Fire behavior characteristics associated with six experimental fires carried out in the aspen-northern hardwood fuel type (adapted from Sando 1972).

Experimental fire no.	Energy per unit area[a] (kJ/m²)	Head fire rate of spread (m/min)	Frontal fire intensity (kW/m)
1	4570	1.83	139
2	4560	8.84	672
3	4548	7.01	531
4	4560	1.83	139
5	4553	1.52	115
6	4531	2.13	161

[a] Numerically equal to the product of the low heat of combustion and fuel consumed (Van Wagner 1978). A low heat of combustion value of 18 700 kJ/kg was used and reduced for fuel moisture content (Table 2) equivalent to 24 kJ/kg per moisture content percentage point (Alexander 1982a).

were made on days with weather conditions that would have allowed the fire to spread in many other fuel types. Because of the relatively closed canopy and the light fuel loads in the aspen-northern hardwood stands in the present study, the fires did not spread well, except when the 10-m open winds exceeded ≈18 km/h. The two experimental fires with the highest ROS values (Nos. 2 and 3) occurred in stands that did not have complete crown closure. The wind therefore had more influence on fire spread. Furthermore, the quantity of surface fuels in these two stands was generally greater than the other four and consisted largely of grass and other herbaceous material that burned considerably better than the deciduous leaf litter fuels.

The simple linear correlation coefficient (r) between ISI and head fire ROS for the six observations is 0.913 (significant at the 1% probability level). Some basic analyses of head fire ROS in relation to the ISI are given in Figure 2. Van Wagner's (1973, 1983) ISI-ROS equations tended to overpredict head fire ROS based on the present study results. The coefficient of determination (r^2) values for the linear, exponential, and power function equations given in Figure 2 are 0.83, 0.84 and 0.75, respectively. The standard error of the estimates ($s_{y.x}$) are in turn 1.49, 0.35, and 0.43, respectively. Since these regressions are based on so few data, there is little point in quoting any further statistics of probability or precision. The quantitative information on fire behavior provided by the present study has been combined with other similar experimental data from Ontario and Alberta (e.g., Kiil 1970, Van Wagner 1973, 1975, Perala 1974, Alexander 1982b, Quintilio et al. 1990, Weber 1989), including selected wildfire observations (e.g., Van Wagner 1965, 1973), for use in the derivation of an ISI-ROS relationship for the leafless aspen fuel type (D-1) in the Canadian Forest Fire Behavior Prediction (FBP) System (Alexander et al. 1984, Lawson et al. 1985) (Fig. 3). It's worth noting that the average head fire spread rates observed during the present study represent the highest recorded values for any outdoor experimental fires included in the FBP System data base for Fuel Type D-1. Frontal fire intensities of 115-672 kW/m (Table 4) were calculated on the basis of Byram's (1959) formula (Alexander 1982a):

$$I = Hwr \qquad (1)$$

where I = frontal fire intensity (kW/m), H = fuel low heat of combustion (kJ/kg), w = weight of fuel consumed in the active combustion zone (kg/m²), and r =

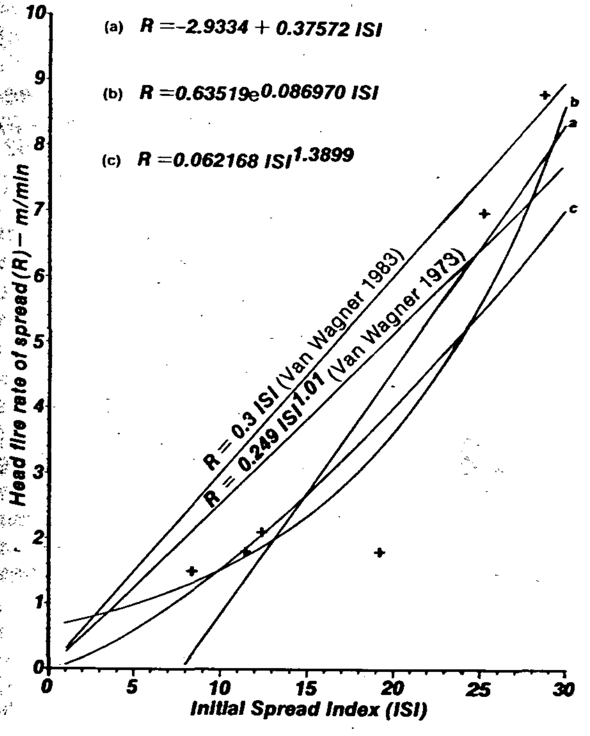

FIG 2. Head fire rate of spread (ROS) as a function of the Initial Spread Index (ISI) according to three commonly used equation forms based on six experimental fires conducted in the aspen-northern hardwood fuel type. The plotted ISI-ROS data points are also included. Existing ISI-ROS relationships for leafless aspen stands, published prior to the introduction of the ROS component of the Canadian Forest Fire Behavior Prediction System in 1984, are included for comparison with results from the present study.

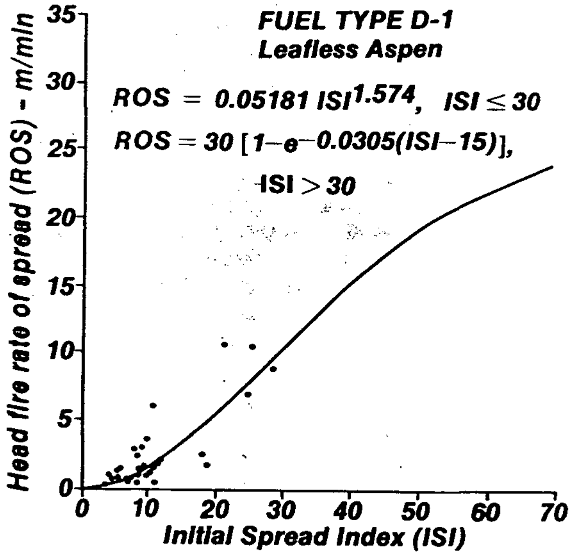

FIG 3. Scattergram of Initial Spread Index (ISI) versus head fire rate of Spread (ROS) observations from experimental fires and wildfires in Fuel Type D-1 (Leafless Aspen) in the 1984 interim edition of the Canadian Forest Fire Behavior Prediction (FBP) System. The S-shaped curve represents the plotted regression equations for this ISI-ROS relationship in the FBP System.

rate of fire spread (m/sec). The predicted flame lengths were 0.7-1.6 m based on Byram's (1959) flame length-fire intensity relationship (from Alexander 1982a):

$$L = 0.0775(I)^{0.46} \quad (2)$$
$$I = 259.833(L)^{2.174} \quad (3)$$

where L = flame length (m) and I = frontal fire intensity (kW/m). These predictions agree reasonably well with the flame lengths actually observed on the fires. Note that equation (3) is simply the inverse of equation (2).

Burning conditions such as those indicated in Tables 2 and 3 would result in uncontrollable fires in most other fuel types but only moderately vigorous fire behavior in aspen-northern hardwood forests during the spring and late fall. For example, according to the ISIs and FWIs reported in Table 3, the expected head fire ROS and frontal fire intensity in mature jack pine (Pinus banksiana Lamb.) stands would be about 5-50 m/min and from perhaps 500 kW/m to in excess of 10,000 kW/m, respectively (Stocks 1989). Two of the fires (Nos. 2 and 3) would have been considered as bordering on moderately difficult to control rating (I = 500-2000 kW/m) from the standpoint of intensity (Alexander and Lanoville 1989), whereas the other four fires would be rated as fairly easy (I < 500 kW/m).

The fire behavior characteristics chart or nomogram (Alexander et al. 1989) is a useful way of interpreting the behavior of free-burning wildland fires having different spread rates and varying degrees of fuel consumption but being of similar intensities (Fig. 4). The amount of fuel potentially available for combustion to a spreading fire in the aspen-northern hardwood fuel type is generally limited because of the distinct differences in the moisture content and bulk density of the litter and duff layers of the forest floor. It is obvious that any variation in frontal fire intensity is generally due to changes in head fire ROS, which in turn is determined primarily by the moisture content of fine dead surface fuels and wind speed. Note that all of the fires plotted in Figure 4 occurred in natural, uncut stands except for that of Perala (1974) which involved moderate amounts of roundwood slash fuels. The "re-burn" documented by Quintilio et al. (1990) did involve a substantial quantity of downed-dead woody fuels.

One documented wildfire not included in Figure 4 is the 1971 Little Sioux Fire in north-eastern Minnesota (Sando and Haines 1972), which made its major run on May 14 under extreme burning conditions. The frontal fire intensity experienced in one aspen-dominated stand was estimated to have exceeded 10,000 kW/m (Ohmann and Grigal 1979). The 1300 CDT fire weather observations at nearby Ely, MN, were (after Sando and Haines 1972): dry-bulb temperature 24.4°C; relative humidity 15%; 10-m open wind 30 km/h; and 10 days since > 0.6 mm of rain. The FWI System components calculated on the basis of the weather data given in Table 1 of Sando and Haines (1972) were: FFMC 95; DMC 45; DC 93; ISI 40; BUI 45; and FWI 53.

FIRE EFFECTS

The above ground effects of a fire on trees and shrubs are related to frontal fire intensity and the vulnerability of the vegetation. Changes in intensity may result in dramatically different fire effects. The vulnerability of woody vegetation is related to several important physical characteristics and also the season and growth activity (i.e., plant phenology). Stem size is an important factor in woody vegetation vulnerability, as demonstrated by many authors (e.g., Ryan and Reinhardt 1988). The two are inversely related, and this was evident from the results obtained in the present study (Table 5). The direct, fire-induced tree mortality occurred primarily in the smallest dbh size classes (i.e., < 7.6 cm). Trees larger than about 8 cm

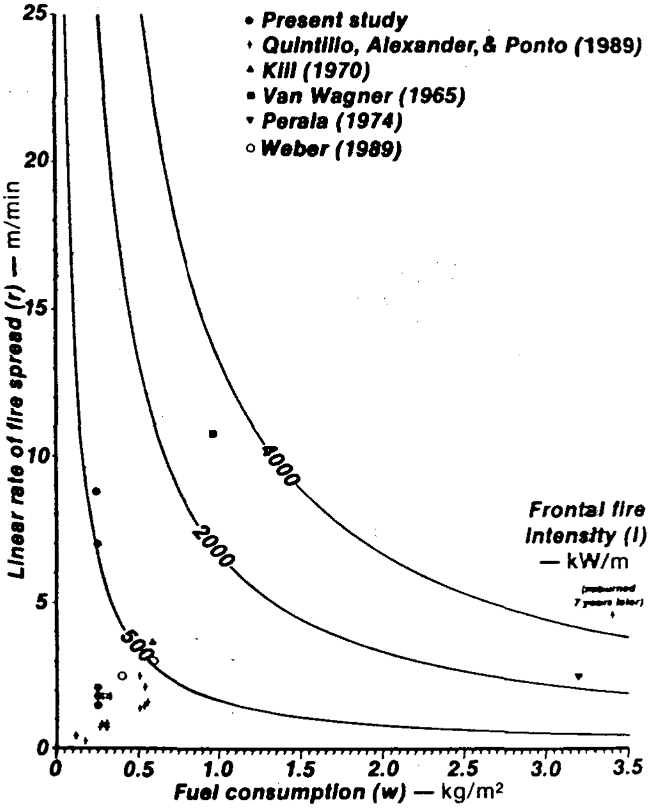

FIG 4. Head fire spread rate and fuel consumed plotted in relation to four distinct levels of frontal fire intensity for six experimental fires conducted in the aspen-northern hardwood fuel type (net heat of combustion = 18 000 kJ/kg). Other experimental fires and wildfires in similar deciduous fuel complexes, in the leafless state, are included for comparison with results from the present study.

Table 5. Tree mortality associated with experimental fires carried out in six aspen-northern hardwood stands (after Sando 1972). The diameter at breast height (dbh) stem tallies were made at the end of the first growing season following fire.

Experimental fire no.	Dbh size class[a] 2.5-5.1 cm (%)	5.1-7.6 cm (%)	7.6-10.2 cm (%)
1	91	52	-[b]
2	90	81	65
3	94	47	57
4	64	71	49
5	33	21	11
6	2	1	0

[a] The stems were originally tallied by 1-inch dbh size classes (i.e., 1-2 in., 2-3 in., and 3-4 in.).
[b] Not sufficient data.

dbh were seldom killed, and negligible mortality occurred in trees larger than 15 cm dbh. Brown and Simmerman (1986) have suggested that flame lengths of at least 0.52-0.64 m, or frontal fire intensities of 63-98 kW/m accordingly to equation (3), are required to kill aspen trees in the western U.S. No dbh size classes were specified, however. The broadleaf tree species that occur in both study areas appear to be equally vulnerable to fire with the exception of burr oak, which has a relatively thick bark whose insulating qualities help to reduce the killing effect of the fires (Rouse 1986b).

Shrub stems were easily top-killed by fire, but regrowth by sprouts quickly occurred and was quite prolific in some cases (Fig. 5). The frequency of shrub stems is thereby often increased by burning. Red-osier dogwood (Cornus stolonifera Michx.) did not increase dramatically, except where most of the overstory was killed by the fire; in some cases it was reduced by the fire (Fig. 5). Most of the deciduous tree species killed by fire promptly sprouted. Most eastern hardwoods share the ability to regenerate vegetatively (Johnson 1983). The advanced reproduction of sugar maple and other shade tolerant species was temporarily eliminated or their occurrence reduced. The regeneration of aspen was stimulated by fire. Aspen responded to the burning with prolific root suckering. Several instances were noted where aspen suckers originated up to 15 m from the nearest parent tree. Consequently, the total number of woody stems often increased following the fires as a result of the aspen suckering and shrub sprouting. The effects of the five spring fires on the shrub and small tree layer, conducted just prior to the initiation of new growth, were much greater than those observed following the one fall fire (Fig. 5). The average increase in total stem density for the spring fires was 67%, with a range of 22-152%. There was a 10% decrease associated with the fall fire.

IMPLICATIONS FOR PRESCRIBED FIRE MANAGEMENT

The use of prescribed burning for the management of wildlife habitat in aspen-northern hardwood stands not subjected to cutting poses a difficult problem because of the nature of the fuel complex. Burning conditions must be much more severe than in other fuel types for success. The most important variable is wind speed. Without sufficient wind the fire will not spread well in the light fuels found in these stands. The results of this study indicate that it is important to treat aspen stands with fire before they are of advanced age. An alternative technique is to cut the stands before burning. Where commercial harvesting is not possible, fire must be used before the average dbh of the trees in a stand exceed at 13 cm. Fuels that will support a fire of adequate intensity to kill the overstory trees are generally much greater in young stands, while the dominant trees will have a smaller average dbh and consequently thinner bark at or near ground level, thereby increasing the susceptibility to girdling by surface fires. The prescribed fire manager must therefore carefully evaluate fuel and stand conditions for successful burning. Sando (1972) has provided some burning prescriptions in terms of basic fire weather elements. The frequencies of suitable weather conditions for prescribed burning have been reported elsewhere (e.g., Sando 1969, Beyerhelm and Irving 1980).

Conclusions

Sando (1972) provided a reasonably well-documented account of six fires conducted primarily for reasons other than the scientific study of forest fire behavior. No doubt the additional knowledge gained about certain fire effects in relation to documented burning conditions and quantified fire behavior has or will eventually lead to improved prescriptions for the use of fire in forest vegetation management (e.g., Beyerhelm 1979). More important perhaps is the fact that the quantitative data on fire behavior as furnished by Sando (1972) have resulted in a small but direct contribution to the development of the CFFDRS. The ROS component of the FBP System was developed largely from experimental burning projects and wildfire investigations carried out in Canada (e.g., Alexander and Lanoville 1987, Stocks 1989); however, the empirical data base associated with the FBP System was also supplemented with a few relevant observations adapted from U.S. sources (e.g., Alexander 1982b, 1984). Field research to gather experimental fire behavior data can be time consuming and expensive. This paper serves as an example of how to capture outside information for FBP System data base purposes. If the basic weather observations are available, then it is possible to redescribe the burning conditions of previously documented forest fires in terms of the weather-dependent components of the FWI System and thereby permitting possible correlations with actual ignition probabilities,

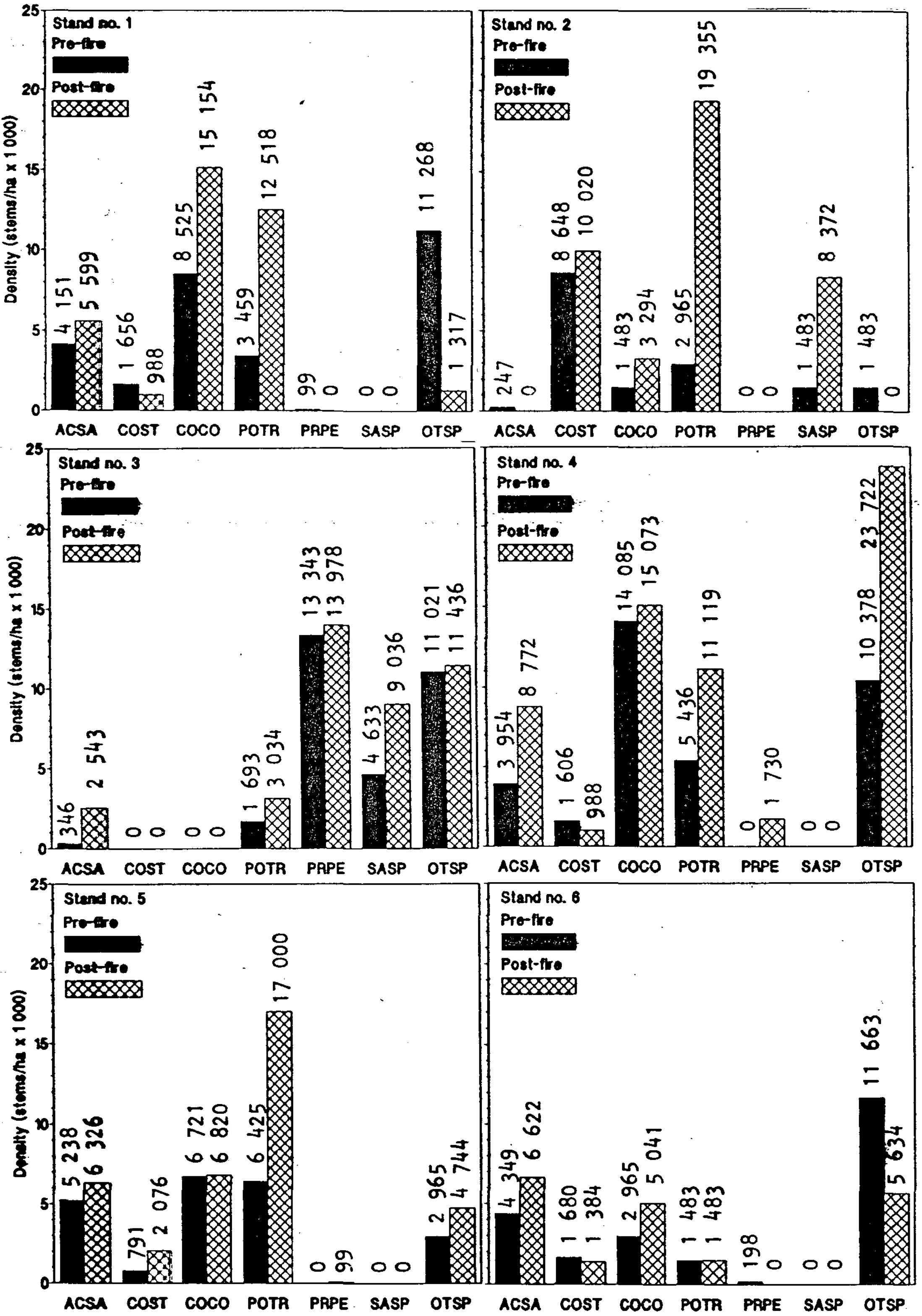

Fig 5. Shrub and small tree stem densities associated with the experimental fires carried out in six aspen-northern hardwood stands (adapted from Sando 1972). Stem tallies were made at the end of the first growing season following fire. The actual stem density is given at the top of each plotted bar. Abbreviations used are: ASCA = Acer saccharum Lam. (sugar maple); COST = Cornus stolonifera Michx. (red-osier dogwood); COCO = Corylus cornuta Marsh. (beaked hazel); POTR = Populus tremuloides Michx. (trembling aspen); PRPE = Prunus pensylvanica L. (pin cherry); SASP = Salix spp. (willow); and OTSP = other species. There is an arithmetic error in Sando's (1972) Table 3 shrub data summary that was in turn repeated in Table 3.1 of Beyerhelm (1979). For Stand 2 (postburn), the total number of stems for all species is given as 24,442 stems per acre. This should have been 16,609 stems per acre.

fire behavior characteristics, and fire impact/effects in specific fuel types.

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[1] A particular forest cover or vegetation type that commonly follows or is otherwise dependent on fire (Merrill and Alexander 1987).

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APPENDIX:

DAILY FIRE WEATHER OBSERVATIONS RECORDED AT 1300 CST

Table A.

Data recorded at Brainerd, MN, from April 22 to May 1, 1968, April 26 to May 7, 1970, and October 12-18, 1970 (station elevation: 366 m MSL).

Calendar date (1968/1970)	Dry-bulb temperature (°C)	Relative humidity (%)	10-m open wind speed (km/h)	24-h rain (mm)
April 22	7.2	79	24	0.5
23	2.8	74	48	21.8
24	4.4	53	30	0.0
25	9.4	32	13	0.0
26	14.4	33	18	0.0
27	12.2	43	17	0.0
28	14.4	42	2	0.0
29	18.3	25	28	0.0
30	25.0	27	11	0.0
May 1	22.2	32	15	0.0
April 26	18.9	30	14	0.0
27	17.2	65	13	3.6
28	19.4	58	24	12.4
29	18.9	66	5	0.0
30	10.6	46	16	0.0
May 1	0.0	90	8	0.5
2	12.8	39	18	2.0
3	17.8	41	31	0.0
4	13.9	32	10	0.0
5	8.9	31	16	0.0
6	13.9	32	18	0.0
7	18.9	42	11	0.0
Oct. 13[a]	6.7	93	22	27.9
14	6.7	64	20	1.5
15	5.0	61	11	0.0
16	11.1	41	17	0.0
17	14.4	52	17	0.0
18	13.9	51	4	0.0

[a] The DMC and DC on October 12, 1970, were 6 and 537, respectively.

Table B. Data Recorded at Friendship, WI, April 7-26, 1970 (station elevation: 291 m MSL).

Calendar date (1970)	Dry-bulb temperature (°C)	Relative humidity (%)	10-m open wind speed (km/h)	24-h rain (mm)
April 7	16.7	33	24	0.0
8	15.6	27	30	0.0
9	11.1	25	35	0.0
10	6.7	31	17	0.0
11	7.2	51	20	0.0
12	3.3	75	22	1.8
13	4.4	61	22	1.8
14	14.4	29	15	3.3
15	18.3	32	22	0.0
16	17.8	24	22	4.1
17	9.4	49	18	0.0
18	6.1	49	15	0.0
19	4.4	68	24	0.0
20	4.4	76	22	16.8
21	6.1	56	26	0.5
22	6.7	78	26	0.0
23	11.7	42	26	1.8
24	15.6	27	22	0.0
25	23.9	25	24	0.0
26	26.1	35	17	0.0

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