FIRE BEHAVIOR AND STEM SURVIVAL IN THE NEW JERSEY PINE PLAINS

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ABSTRACT

The vegetation effects associated with different fire behavior types within two recent New Jersey Pine Plains wildfires were analyzed. Sampling was done to allow calculation of prefire canopy density, absolute canopy stem survival (ABCANSS), and estimated percent canopy system survival in patches of dwarf Pine Plains burned by the differing fire behavior types. The purpose of this study was to characterize the dynamics between fire-induced patches of New Jersey Pine Plains physiognomic types (A-Plains, B-Plains and Low- to Mid-transitional Plains [LM Trans]) in response to differing fire intensity types typical of Plains wildfires. Fire behavior types (crown fire [CF], convective column surface fire [CCSF], wind shift backing fire [WSBF], and man made backing fire [MMBF]), were sampled in each Plains type for each wildfire. In order to assess long-term interaction between fire behavior type and fire interval, age class distributions and stand densities were determined for stands last burned in 1936, 1946-8(?), and 1963 by crown fires and for stands with various surface fire histories.

The dominant canopy species, which include pitch pine (*Pinus rigida*), blackjack oak (*Quercus marilandica*), scrub oak (*Q. ilicifolia*), and mountain laurel (*Kalmia latifolia*), all exhibit prolific basal sprouting after fire, and varying degrees of prefire stem survival after surface fires. There was a consistent decrease in ABCANSS and percent canopy stem survival in both wildfires, in the order MMBF, WSBF, CCSF, CF, due to increasing flame height (inferred from char height) and scorch height. All A-Plains and B-Plains subjected to crown fire showed virtually no stem survival, or when stems were emergent, very low survival. Most A- and B-Plains subjected to surface fires in the 1982 wildfire (with more typical ambient air temperatures of 16 °C and scorch heights of 1.0 to 2.8 m) showed ABCANSS high enough (over 1000 stems/ha) to establish or maintain B-Plains or LM Trans structures and densities, given continued height growth of survivors. However, xeric verses semimesic A-Plains stands burned by a WSBF 20 years earlier developed A-Plains at xeric sites with ABCANSS of 2500 stems/ha, none of the surviving stems becoming emergent, while semimesic sites with similar ABCANSS developed B-Plains with all the surviving stems achieving emergent status. These patterns suggest edaphic factors may influence the development of B-Plains from A-Plains as well. A xeric site burned by successive WSBFs in 1936 and 1963 did show the development of B-Plains emergent structure by 1983. After a 20-year fire interval, densities in all these WSBF sites were significantly

lower than their crown fired counterparts and were closer to those of LM Trans encountered in this study, suggesting that Plains burned by one or more surface fires tend to develop into B-Plains and eventually LM Trans, particularly if coupled with prolonged fire intervals. Fire management practices which permit repeated surface firing of Plains and associated communities, instead of the more typical crown firing, should therefore be avoided if the Plains are to be maintained.

INTRODUCTION

Located on the outer coastal plain of southern New Jersey, within the pine-oak-heath dominated forests of the Pine Barrens, several unusual stands of dwarfed forest known as the New Jersey Pine Plains are found on broad, centrally located divides. The Pine Plains, or simply Plains, support a 1- to 2-m tall, dense, closed coppice growth of pitch pine, blackjack oak, scrub oak, and mountain laural (in decreasing order of importance) (Lutz 1934, McCormick and Buell 1968). A heath-shrub synusia is present and composed of black huckleberry (*Gaylussacia baccata*), as well lowbush blueberry (*Vaccinium vacillans, V. angustifolia*) and dangleberry (*G. frondosa*) (Reiners 1965). A high incidence of serotiny in pitch pine is associated with the Pine Plains area, where fires have historically been more frequent than on other Pine Barren sites (Givnish 1981). This shorter interval between fires in the Plains than in other Pine Barrens communities is perhaps due to a higher degree of fuel continuity and because the Plains occur on broad upland divides where those fires that do occur are generally larger because they are unimpeded by streams (Lutz 1934, Givnish 1981).

Characteristic of the Plains are multiple stems per root crown and high canopy stem densities commonly ranging from 14,000 to 36,000 stems per hectare (McCormick and Buell 1968, Buchholz and Good 1982). Also very characteristic of the Plains are the unusual, dwarf growth-forms of pitch pine. These pines are usually contorted, flat-topped, and without apical dominance (Little 1972, 1981), or shrubby, with angular to prostrate, laterally sprawling stems (Harshberger 1916, Good and Good 1975, Windisch 1986). Blackjack oak also exhibits a contorted growth form with rosetting of leaves and buds in stems roughly over 10 years old, similar to that observed by Reich and Hinckley (1980) at Buzzard's Roost, Missouri. Both the high stem densities and contorted, laterally sprawling growth forms contribute to a closed (or very dense), low canopy, which tends to increase fuel continuity and flammability of the stand (Whittaker 1979, Buchholz 1983).

Buchholz and Good (1982) indicated that multiple stem production in pitch pine following fire is characterized by a burst of sprout production, followed by continued, although increasingly reduced production of new sprouts each year for at least 15 years after the fire. Buchholz (1983) suggested that post-fire sprout mortality and sprout turnover are also very high. Windisch (1986) noted that these later sprouts likely produce subordinate stems which tend to fill the gaps not occupied by the initial dominant post-fire stems and only slowly replace the dominant stems in the canopy as they die of causes other than direct fire damage.

The lower stature, higher stem density, and higher fuel continuity in the Pine Plains compared to other Pine Barrens forests, encourage more severe, crowning wildfires that cause very high (often 100%) stem mortalities (Lutz 1934, Buchholz and Good 1982). The dominant species of the Plains all sprout prolifically at the base after fire, so a killing fire will result in complete stand replacement by basal sprouts (Lutz 1934).

However, not all wildfires in the Plains burn exclusively as crown fires, nor do they produce 100% stem mortality throughout. Several discrete types of fire behavior can be observed in most Plains wildfires, as in many wildfires elsewhere. These fire behavior types include crown fires and three categories as surface fire, including convective column surface fire, often referred to as crown stripes; wind shift backing fire; and man made backing fire. Areas burned by each type are readily identifiable after the fact by observing differences in bark char height and crown consumption, as well as by burn patterns observed on aerial photographs of wildfire sites (Wade and Ward 1973, Haines 1982, Simard et al. 1983).

Also, the Plains are not homogeneous, but are instead a mosaic of differing stem-size age-class patches, related at least in part to fire history. Windisch (1986) and Windisch and Good (1985) described three categories of Plains patches based on canopy height and structure. A-Plains have a uniformly low, closed canopy 0.5 to 2 m tall. B-Plains have a uniformly low, closed canopy 1.5 to 2 m tall, with about 1000 or more emergent stems 2.1 to 5 m tall per ha. Low- to Mid-transitional Plains have an open to semiopen canopy 3 to 6 m tall with a semiopen shrub canopy dominated by shrub oaks.

We believe these differences in fire behavior are an important source of the significant variation in stem survival after most Plains wildfires. These fire-behavior-induced variations in stem survival (along with edaphic and genetic influences on stand characteristics) increase the diversity of stem-size and age-class patches in the Plains landscape mosaic, which in turn influences fire behavior. We hypothesize that the interactions between fire behavior type and fire interval influence successional pathways between A-Plains, B-Plains, and Transitional Plains vegetation types.

Fire Behavior and Effects On Vegetation

The degree of damage to trees and shrubs of a dwarf pine plains or transitional plains community is greatly dependent upon fire behavior type and flame height. Where flame heights are great enough to ignite and sustain a crown fire, nearly all stems less than 3-4 m tall are top-killed back to ground level. Pitch pine over 3-5 m tall and 8-10 cm at DBH show increasingly higher crown fire survival rates (Lutz 1934, Little 1946). Even though the crowns are destroyed, the corky, plate-like bark becomes thicker in more mature stems and protects the stems' cambium, thereby allowing resprouting along the bole and larger branches from epicormic buds (Little 1959, Ledig and Little 1979). Oak stems of a similar size would likely perish in any crown fire because they lack this thick, plate-like bark and stem sprouting resilience, but oaks of all sizes and younger pines can resprout from their root collar. The result is that in dwarf pine plains, a young coppice growth is produced, while in transitional plains and taller pine barrens, a tall open overstory of older, fire damaged pitch pines is found, with a younger subcanopy coppice growth of scrub oak, blackjack oak and pitch pine (Little 1946).

Fires which do not crown, such as CCSF, WSBF, and MMBF, can also cause mortality due to crown scorch and bole damage. Crown scorch is the browning of live needles or leaves cause by heat exposure and should not be confused with consumption, which involves the actual combustion of foliage and twigs. Scorch height is the average maximum height above ground to which foliage is browned by fire without actually burning (USDA 1989). In a given stand, scorch height is primarily controlled by flame height and ambient air temperature. Flame height (which can only be approximated from bark char height) determines the vertical distance the released heat energy has to travel to reach the live crown. Ambient air temperature approximates living fuel temperature, which determines how much additional heat is needed to raise the foliage to its lethal threshold temperature. Plant tissue death occurs in seconds at 60 °C, and temperatures as low as 45-50 °C can be lethal if sustained for 10 minutes or more (Hare 1961, Kayll 1968). Scorch of an entire Plains canopy results in only partial above-ground stand mortality among the pitch pine, because of this species' thick bark and bole sprouting resilience, while most oak stems perish (Windisch and Good 1986).

METHODS

A 570-ha burn site within the East Plains was analyzed in June-December of 1984 and 1985, following a July 30, 1983, convection-driven wildfire located 1.5 to 5 km south of Warren Grove, New Jersey, along Route 539. A portion of the 1683-ha burn site encompassing the entire 200-ha Spring Hill Plains was analyzed in June-December of 1984 and 1985, following an April 22, 1982, convection-driven wildfire located north of Chatsworth Road.

Pilot study sampling in 1984 involved determining canopy stem densities (stems over 0.5 m), percent canopy stem survival (absolute canopy stem survival/canopy stem density x 100), and in some cases stem heights, within areas of A-Plains, B-Plains, and LM Trans at and near the wildfire sites. Nine to 12 circular quadrats, each totaling 16 m^2 in area, were placed in each Plains type at random intervals along transects. In each Plains type, areas which had been burned by crown fires and surface fires were sampled. High variability in absolute stem survival, even within a single stand, indicated a much larger sample size was necessary.

Aerial photographs were taken on November 21 and 25, 1984, of the entire 1983 East Plains burn site and the Spring Hill Plains portion of the 1982 burn site. Aerial photographs were assembled into mosaics and used to analyze the burn patterns for locating the various fire behavior types in the field. The percent area covered by each fire behavior type in the 1983 wildfire was estimated graphically from the aerial photographs. Old Agricultural Stabilization and Conservation Service and Forest Service aerial photographs of past wildfires in the Plains and surrounding region were also analyzed for burn patterns, including the May 16, 1963, and May 23-26, 1936, wildfires at the East Plains study site (Buchholz and Zampella 1987, New Jersey Bureau of Forest Fire Management [NJBFFM] records).

Bark char heights, used to infer flame heights, were determined from 10 to 20 (58 in one more variable stand) measurements of charcoal height on stems of surface fired sites. Two char heights were obtained from each stem, a low value on the upwind (during the fire) side and a high value on the downwind side. Oak stems were primarily used because of their smooth, low flammability bark, as well as pitch pine stems without evidence of flare-ups. Scorch heights were estimated from photographs taken immediately after the 1983 surface fires and estimated from several observations of surviving stems in both fires made during the sampling period. Height of prefire foliage not derived from stem sprouting was used to determine scorch height.

Stem survival sampling in 1985 involved placing twenty circular quadrats, each totaling 16 m^2 in area, at random intervals along transects within areas burned by each of the various fire behavior types (crown fire, convective column surface fire, wind shift backing fire, and man made backing fire). The above sampling set was repeated within areas of A-Plains, B-Plains and Low- to Mid-transitional Plains for each wildfire, giving a total of $20 \times 4 \times 3 = 240$ quadrats for each wildfire. In most of these quadrats, only absolute stem survival was determined, because of increasing difficulty in counting the dead, decaying, and often prostrate stems. An estimated percent stem survival was determined by using the average absolute canopy stem survival found in 1985 divided by the average canopy stem density found in that particular Plains type stand in 1984.

The Spring Hill Plains fire burned a 34- to 36?-year-old stand, last burned in 1946-8? (McCormick and Buell 1968). Most of the East Plains wildfire burned a 20-year-old stand, last burned in May 1963 (Buchholz and Zampella 1987, NJBFFM records). Both of the recent wildfires exhibited the 4 fire behavior types and were sampled with 240 quadrats each, as described above. Within the 1983 East Plains wildfire, a small portion of the fire also burned a 47-year-old stand last burned in May, 1936 (NJBFFM records). This portion of the 1983 wildfire however only burned with two different fire behavior types, crown fire and man made backing fire. This stand was also sampled, using only $20 \times 2 \times 3 = 120$ quadrats. Estimated percent stem survival was determined as described above. Effects of the different wildfires were assessed by comparing sets of absolute stem survivals of analogous plains types/fire behavior types, using one-tailed student t-tests and a Bonferroni correction for multiple comparisons (α set at .0005 to maintain an experimentwise α of less than .01; P. Morin, pers. comm.).

Canopy densities were determined for A-Plains and B-Plains burned by a wind shift backing fire in the 1963 East Plains wildfire, and a B-Plains burned by repeated wind shift backing fires in the 1963 and 1936 East Plains wildfires. Locations of these sites within the East Plains study site were determined from old (1963 and 1940) aerial photographs of the earlier burns. Five to six randomly placed circular, 16 m^2 quadrats were used to determine canopy densities at each area.

Tree ring counts were conducted for all stems in six circular, 16 m^2 quadrats to determine age class distributions in various Plains sites. Sites were chosen on the basis of known fire history. Three A-Plains sites were chosen as a time sequence of fire recovery. Sites last burned 20, 34 and 47 years earlier, all by crown fires, were chosen. Three additional sites, all burned by a wind-shift backing fire 20 years earlier, were chosen, including an A-Plains, B-Plains, and LM Trans site. Quadrats were located in the recently crown fired sites only, so that all stems were already killed by the 1982 and 1983 wildfires. Stems were sawed off at the base and a cross section removed. Sections were polished on a fine-grit grinding wheel, and annual growth rings counted using a dissecting microscope. Annual growth rings were recognized as a paired band sequence of early wood with large, thin walled, less dense cells, followed by late wood with smaller, thick walled, denser cells (Fritts 1976).

RESULTS AND DISCUSSION

Wildfire Characteristics

Burn Patterns

The distribution of fire behavior types within the entire 1983 wildfire site is shown in Figure 1 and the area and percentage of each fire behavior type is presented in Table 1. An incomplete distribution of fire behavior types is shown within the Spring Hill Plains portion of the 1982 wildfire site in Figure 2. A synopsis of pertinent events derived from New Jersey Bureau of Forest Fire Management records and from observations of burn patterns is provided for each wildfire (Figures 1 and 2).

Large man-made backing fires were set downwind from both wildfires along north-south oriented roads to burn against winds from the west (1982 fire) and the southwest (1983 fire). Wind shift backing fires were documented for both wildfires, when winds blew against the south flank of the 1983 fire from 17:22 until 21:34 and against the north flank of the 1982 fire from about 15:00

Figure 1. East Plains wildfire of July 30, 1983, outlined with bold line. Areas burned by crown fire (CF) are unshaded. Low intensity surface fires, such as convective column surface fires (CCSF), wind-shift backing fires (WSBF), and man-made backing fires (MMBF) are stippled. Unburned pockets of forest within the fire perimeter are shaded black. Lines represent roads and trails.

SYNOPSIS OF FIRE CHRONOLOGY: 13:53—Fire started from stray practice missile at bombing range. Winds from the southwest to west-southwest, 8-10 mph, relative humidity 45%, temperature 92°F. 14:29—Backfire started on north-south sand road. Does not stop main run. 15:00—Backfires started on Route 539. 16:44-17:00—Main run headfires reaching Route 539. Several spot fires starting east of highway (66-ft cleared right-of-way). Main run held at Route 539. 17:13—All spotfires contained. 17:22—Wind shifts to the south. North flank picks up into a crown fire and is held at sand road and gravel pit to north. South flank burns against the wind as a slow moving wind shift surface fire. 17:40-21:25—Crown fires set from sand roads south of main run, to burn out intervening forest and contain the wildfire. 21:25—Fire is contained. 21:34—Wind shifts to the north-northwest as storm front passes. Winds up to 20-25 mph. Surface fire along south flank of main run intensifies into a crown fire and burns most of the remaining intervening forest. 21:48—Light showers hit burn site. Most of fire extinguished. Few pockets of intervening forest left unburned.

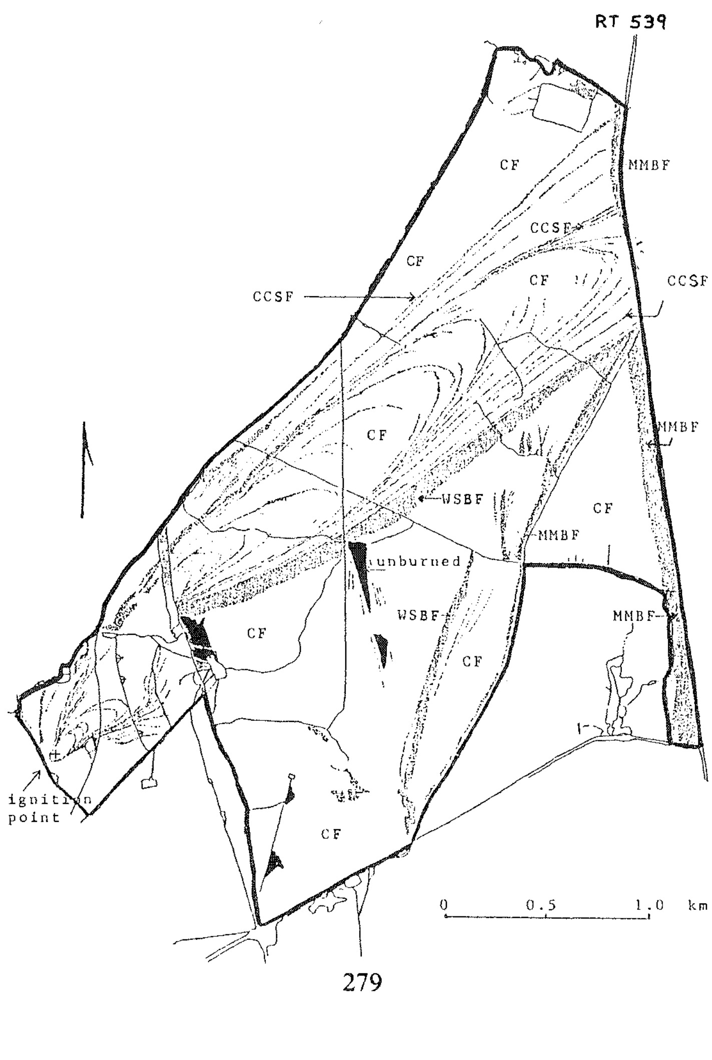


Figure 2. Spring Hill Plains portion of April 22, 1982 wildfire. Areas burned by crown fire (CF) are unshaded. Low intensity surface fires, such as convective column surface fires (CCSF), wind-shift backing fires (WSBF), and man-made backing fires (MMBF) are stippled. Lines represent roads and trails.
SYNOPSIS OF FIRE CHRONOLOGY: 13:53—Fire started on Chatsworth Road (outside of map area). Winds from the west at 18 mph, relative humidity 21%, temperature 60 °F. 14:49—Main run crosses Spring Hill Plains and enters area burned in 1980. 15:00-18:00—Wind shifts to the west-northwest. Main run reorients accordingly, but becomes disorganized as it crosses wetlands and forest burned in 1980 (outside of map area). North flank of east-west oriented main run burns against the wind as a wind-shift backing fire. 20:08—Wind shifts to the north. Wind-shift backing fires continue to burn slowly against the wind. 21:34 until predawn—Crown fires are set from sand roads (outside map area) north of main run, to burn out intervening forest and contain the wildfire. A strip of Plains adjacent to a northwest oriented sand road burns as a man-made back fire.

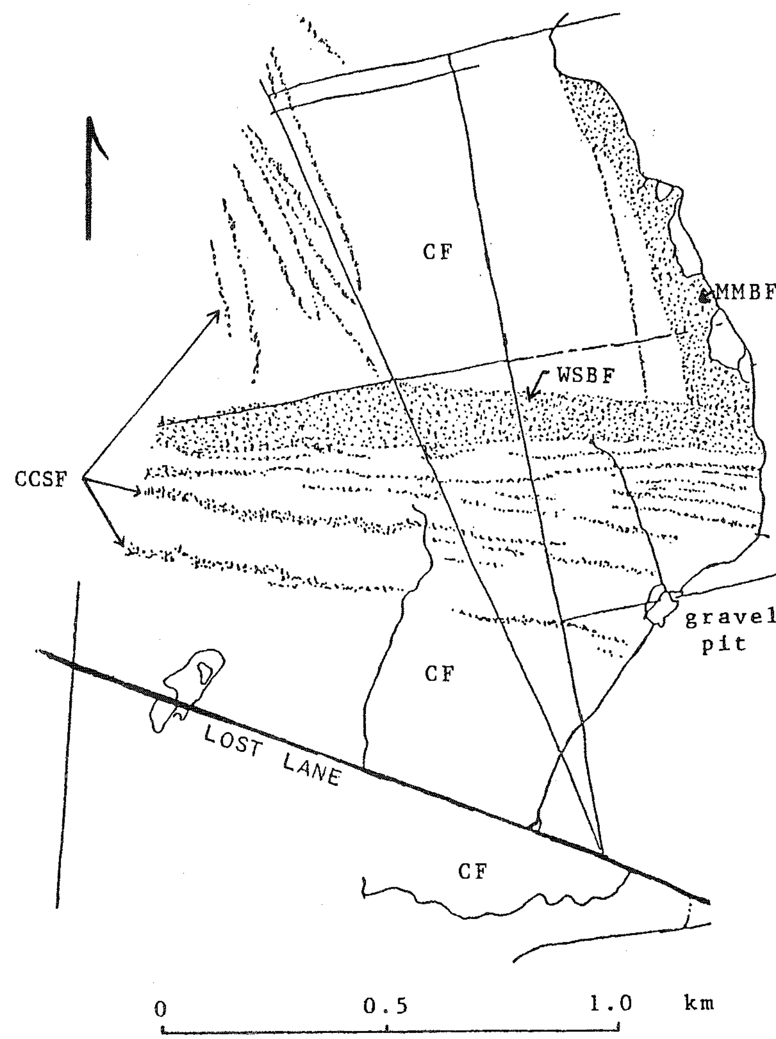


Table 1. Area and percent of fire behavior types which occurred in the 570-ha wildfire of July 30, 1983, East Plains.

CROWN FIRE (CF)	513 ha (90%)
CONVECTIVE COLUMN SURFACE FIRE (CCSF)	8 ha (1.4%)
WIND-SHIFT BACKING FIRE (WSBF)	28 ha (5%)
MAN-MADE BACKING FIRE (MMBF)	21 ha (3.6%)

until at least 21:34 (Figures 1 and 2). Convective column surface fires or crown strips occurred in a concentric set of narrow bands typical of the main run of many blowup wildfires (Wade and Ward 1973, Haines 1982, Simard et al. 1983).

Bark Char Heights and Scorch Heights

Mean bark char heights, which are used to infer flame height, and scorch heights for the two wildfires are presented in Table 2. The overall low flame heights of MMBF, WSBF, and CCSF stands are indicated by the values of mean bark char height, which are all less than 0.5 m in height. This is consistent with field observations made immediately after these and other Plains wildfires, where the lower intensity surface fire types burn the surface litter and foliage below approximately 0.5 m and leave some or all of the foliage above this unburned but scorched to a yellow or brown color. This foliage dies, with the resultant partial or complete mortality of the stem. The lowest mean bark char heights were observed in MMBF and WSBF stands, at 20 to 25 cm height, while somewhat higher values, ranging from 42 to 45 cm, were found in CCSF stands. Mean bark char heights were slightly, although not significantly, higher for all surface fire behavior types in the July 30, 1983, wildfire compared to similar fire behavior types of the April 22, 1982, wildfire. This was likely due to higher fireline intensities in the 1983 wildfire resulting from the higher ambient air temperatures (which provide a higher initial fuel temperature) and lower live fuel moisture following the July 1983 drought. Crown fired stands showed complete charring from the ground to the tops of the tallest stems, indicating flame heights were observed to be about 1 m higher in the July 1983 wildfire than in the April 1982 wildfire, most likely because of the very high ambient air temperatures (37 °C) at the time of the July 1983 wildfire.

Stand Characteristics

The canopy stem densities used to characterize the prefire stands at the 1982 and 1983 wildfire study sites are given in Table 3. There is a general trend

Table 2. Mean bark char height used to infer flame height ± one standard deviation, n = sample size) and observed scorch height (approximate) for each fire behavior type*, in the July 30, 1983 East Plains wildfire and April 22, 1982 Spring Hill Plains wildfire.

* MMBF = man-made backing fire; WSBF = wind-shift backing fire
CCSF = convective column surface fire; CF = crown fire

A) July 30, 1983 East Plains Wildfire

FIRE BEHAVIOR TYPE	MEAN BARK CHAR HEIGHT (cm)	OBSERVED SCORCH HEIGHT (approx.) (m)
MMBF	25 ± 21 (n=58)	2.2
WSBF	25 ± 25 (n=20)	2.4
CCSF	45 ± 24 (n=10)	4.0
CF	over 400	not applicable

B) April 22, 1982 Spring Hill Plains Wildfire

FIRE BEHAVIOR TYPE	MEAN BARK CHAR HEIGHT (cm)	OBSERVED SCORCH HEIGHT (approx.) (m)
MMBF	20 ± 10 (n=10)	1.0
WSBF	23 ± 16 (n=16)	1.5
CCSF	42 ± 35 (n=20)	2.8
CF	over 400	not applicable

of decreasing canopy stem density in going from A-Plains to B-Plains to LM Trans.

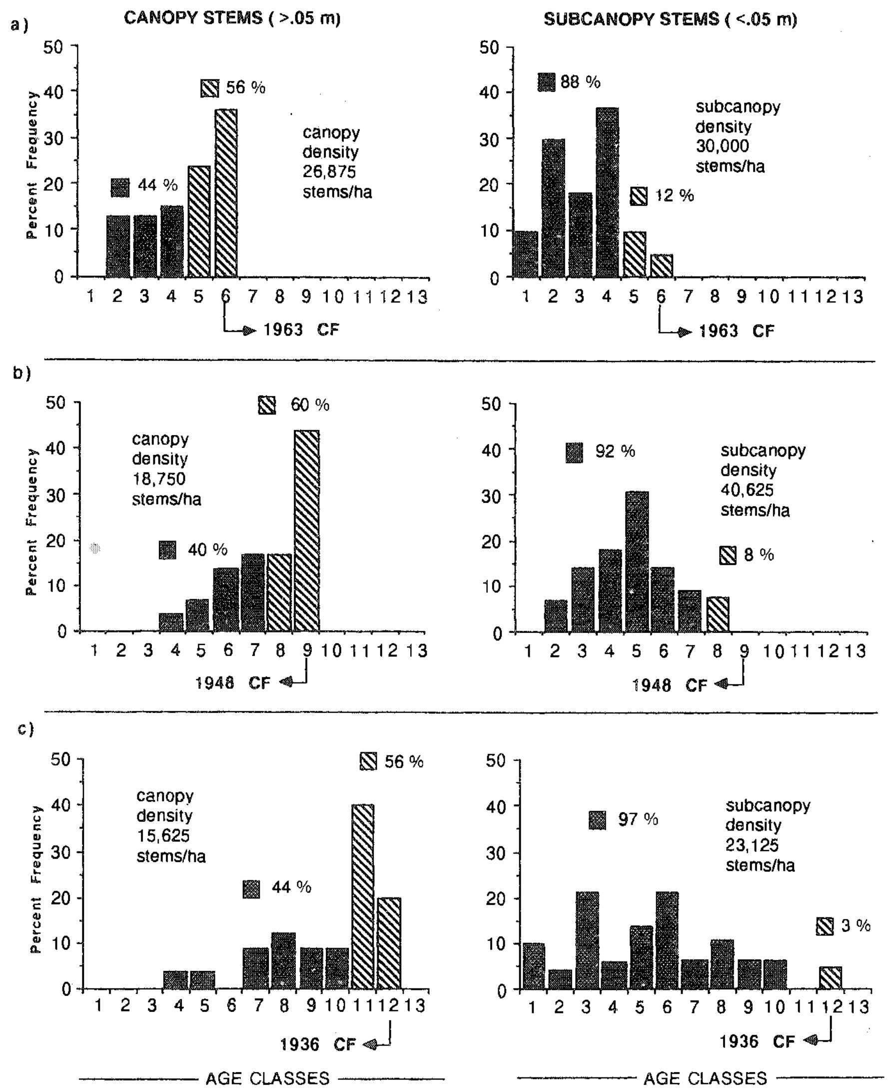
The age-class distributions of three A-Plains sites last burned by crown fires, but with fire-free periods of 20, 34 and 47 years, are presented in Figure 3. Canopy stem age-class distributions reveal that a high 56 to 60% of these recovery stems were "immediate post-fire stems," produced 0 to 6 years after the crown fire. In all 3 cases, no stems which predate the fire are found, since crown fires usually cause complete stem mortality. Stems which are younger than the "immediate post-fire recovery" make up 40 to 44% of the canopy. These "delayed post-fire stems" are important in canopy stem recruitment for 16 to 20 years after the crown fire, and diminish rapidly thereafter. It is

Table 3. Absolute canopy stem survival (ABCANSS) and estimated percent canopy stem survival in four fire behavior categories.

The Stand Characteristics used to describe each site included fire interval (FI) in years, date of new burn, Plains type (A-Plains—uniformly low, closed canopy 0.5-2.0 m tall; B-Plains—uniformly low, closed canopy 1.5-2.0 m tall, with about 1000 or more emergent stems 2.1-5.0 m tall, per ha; LM Trans—open to semiopen canopy 3-6 m tall with a semiopen shrub canopy dominated by oaks), and average canopy density in stems ≥ 0.5 m/ha (±1 standard deviation, with sample size given as n). ABCANSS in stems ≥ 0.5 m/ha (±1 standard deviation, n = 20 for each value) are given for each Plains type burned by each fire behavior type, in fires E20, E47, and S34. The estimated percent canopy stem survival was obtained by dividing each ABCANSS value by its corresponding average canopy density value × 100. The ×s within fire E47 indicate these fire behavior types did not occur at this fire.

STAND CHARACTERISTICS: FIRE INTERVAL & DATE OF NEW BURN	PLAINS TYPE & AVERAGE CANOPY DENSITY	ABSOLUTE CANOPY STEM SURVIVAL (ABCANSS) and Estimated Percent Canopy Stem Survival in four fire behavior catagories: MAN-MADE BACKING FIRE (MMBF)	WIND-SHIFT BACKING FIRE (WSBF)	CONVECTIVE COLUMN SURFACE FIRE (CCSF)	CROWN FIRE (CF)
(E20)					
20 yr 7/30/ 1983	A-PLAINS 29869 ± 5690 (n=12)	156 ± 278 0.5%	500 ± 748 1.7%	31 ± 140 0.1%	0 ± 0 0%
" "	B-PLAINS 19125 ± 5864 (n=10)	844 ± 843 4.4%	656 ± 798 3.4%	94 ± 229 0.5%	0 ± 0 0%
" "	LM TRANS 16000 ± 3775 (n=10)	1969 ± 133 12.3%	1688 ± 975 10.6%	563 ± 700 3.5%	0 ± 0 0%
(E47)					
47 yr 7/30/ 1983	A-PLAINS 23000 ± 4398 (n=10)	531 ± 583 2.3%	X	X	0 ± 0 0%
" "	B-PLAINS 18125 ± 2219 (n=11)	1000 ± 960 5.5%	X	X	0 ± 0 0%
" "	LM TRANS 14438 ± 3313 (n=10)	2219 ± 127 15.4%	X	X	63 ± 192 0.4%
(S34)					
34 yr 4/22/ 1982	A-PLAINS 20688 ± 3110 (n=10)	8438 ± 267 40.8%	5094 ± 2419 24.6%	844 ± 818 4.1%	31 ± 140 0.1%
" "	B-PLAINS 20486 ± 5684 (n=9)	10125 ± 237 49.4%	5031 ± 1785 24.5%	1969 ± 105 9.6%	469 ± 399 2.3%
" "	LM TRANS 12250 ± 2481 (n=17)	6345 ± 165 51.8%	4531 ± 1658 37.0%	1500 ± 742 12.2%	938 ± 591 7.7%

Figure 3. Age class distribution of three A-Plains sites last burned by crown fires (CF), but with fire intervals of (a) 20 years, (b) 34-36? years, and (c) 47 year. Canopy stem distributions are on the left, subcanopy stem distributions are on the right. (Age classes in years: 1 = 0-4, 2 = 5-8, 3 = 9-12, 4 = 13-16, 5 = 17-20, 6 = 21-24, 7 = 25-28, 8 = 29-32, 9 = 33-36, 10 = 37-40, 11 = 41-44, 12 = 45-48, 13 = 49 and over.)



presumably at about this stage of fire-free recovery that the Plains canopy becomes completely closed, precluding any additional delayed basal sprouts from entering the canopy.

Subcanopy stem age-class distributions reveal that only 3 to 12% of these recovery stems were immediate post-fire stems, produced 0 to 6 years after the crown fire. However, stems which are younger than the immediate post-fire recovery make up a very large percentage (88 to 97%) of the subcanopy, and are important in all age classes right up to the youngest. Thus, basal sprouting which produces subcanopy stems occurs throughout the fire-free recovery period of A-Plains. These facts imply that stem turnover may indeed be important in Plains communities, as Buchholz (1983) suggested, except that most of the turnover occurs in the subcanopy and to a much lesser extent in the canopy. The presence of abundant dead stems in the subcanopy of most Plains sites (pers. obs.) supports this.

High canopy stem turnover, which maintains an abundance of small dead stems within 0.5 m of the ground, may actually be an adaption of the Plains pitch pine that greatly increases flammability and vertical fuel continuity of the stand. The abundant dead stems act as highly flammable ladder fuels which permit flames to spread from the litter to the living foliage of the subcanopy and, in head fires, to the living foliage of the canopy. Along with the other traits of the Plains which increase flammability and fuel continuity, such as low stature, unique growth forms which help close the canopy, and high stem densities, high subcanopy stem turnover adds even more support to the theory that the Plains are a stable fire climax which promotes self-maintaining crown fires.

Canopy Stem Survival Analysis

Absolute canopy stem survival means (± 1 standard deviation) for each Plains type burned by each fire behavior type in each wildfire are presented in Table 3, as well as an estimated percent canopy stem survival for each. Note that Fire E20 and E47 are two portions of the same July 1983 East Plains wildfire, each portion differing in duration since the last wildfire (20- and 47-year fire in tervals, respectively). Fire S34 is the 1982 Spring Hill Plains wildfire, last burned 34 years earlier.

As might be expected, there was a consistent decrease in Plains ABCANSS and percent canopy stem survival in both wildfires, going from stands burned by man-made backing fire to wind shift backing fire to convective column surface fire to crown fire. The one exception in the trend was a man made back fired area of A-Plains in fire E20 along Watering Place Pond Road, which probably developed higher intensities than the nearby wind shift ground fired area because of the SSW orientation of the road and fireline during the SW wind. This would have permitted the upwind advancing fireline to burn at some angle less than 90 degrees, perhaps closer to 30 degrees, and thus with higher fireline intensity and flame height.

There is generally some degree of increase in estimated percent canopy stem survival in all the fire, if not in ABCANSS as well, going from A-Plains to B-Plains to LM Trans. (ABCANSS in LM Trans of fire S34 are atypically below those of the A- and B-Plains of the same fire, apparently due to the very low average canopy density of the LM Trans and the very high ABCANSS of the A- and B-Plains here.)

The t-test comparisons of ABCANSS between analogous stands of different fires showed the following results (Table 4). In all the comparisons between fire E20 and fire E34, except one, the 34-year fire interval (FI) stands burned in 16 °C spring air temperatures had a significantly higher (α = .05) ABCANSS than the 20-year fire interval stands burned in 37 °C summer air temperatures. The significant difference based on this block of t-tests could be due to either the difference in fire interval or ambient air temperatures. Either the larger fire interval in E34 caused higher ABCANSS here or the higher ambient air temperatures in E20 caused lower ABCANSS there. The crown fired A-Plains sites burned by fires E20 and S34 showed no significant difference. This is because any A-Plains subjected to crown fire shows virtually no stem survival, regardless of fire interval or ambient air temperature.

In all the comparison between fires E20 and E47, except one, there was no significant difference in absolute canopy stem survival. Since fires E20 and E47 (actually parts of a single July 7, 1983 wildfire) burned under identical temperature conditions and differed only in fire interval, this block of t-tests suggests that the difference in fire interval is not a major factor in controlling stem survival for A- and B-Plains stands. Stem survival was significantly higher (α = .05) in the 47-year fire interval Transitional Plains stand which was back fired, compared to the 20-year fire interval Transitional Plains stand. This may suggest that older Transitional Plains stands, relative to younger ones, have a somewhat higher proportion of stems exceeding the scorch height of backing fires and thicker, plate-like bark, thus permitting some increase in canopy stem survival.

In all the comparisons between fire E47 and S34, except one, the canopy stem survival was significantly higher (α = .05) in fire S34, which burned during ambient air temperatures of 16 °C, rather than 37 °C as in fire E47. The difference in fire interval between the two stands is considered insignificant, being that both had a relatively high fire interval for the Plains region. (In fact, fire E47, which had the longer fire interval showed a significantly lower canopy stem survival in all comparisons but one, strongly suggesting that the difference in fire interval was indeed insignificant.) This strongly suggests that ambient air temperature at the time of the fire, rather than fire interval, was the more important factor controlling canopy stem survival for any given fire behavior type or Plains type. The exception to this trend is A-Plains burned by crown fire. The crown fired A-Plains of fires E47 and S34 showed no significant difference in canopy stem survival, as in all the other comparisons of crown fired A-Plains. This indicates that regardless of ambient air temperature or stand age, stem survival among crown fired A-Plains stands is generally near zero.

Table 4. T-test comparisons (one-tailed) of absolute canopy stem survival (ABCANSS) between analogous stands of different fires.

a) Fire E20 (20 yr FI, ambient air temperature 37°C) vs
S34 (34 yr FI, ambient air temperature 16° C)

PLAINS TYPE	(FIRE INTENSITY TYPE) MMBF	WSBF	CCSF	CF
A-Plains of E20 vs S34	* *	* *	* *	N S
B-Plains of E20 vs S34	* *	* *	* *	* *
LM Trans of E20 vs S34	* *	* *	* *	* *

b) Fire E20 (20 yr FI, ambient air temperature 37° C) vs
E47 (47 yr FI, ambient air temperature 37° C)

PLAINS TYPE	(FIRE INTENSITY TYPE) MMBF	CF
A-Plains of E20 vs E47	N S	N S
B-Plains of E20 vs E47	N S	N S
LM Trans of E20 vs E47	* *	N S

c) Fire E47 (47 yr FI, ambient air temperature 37°C) vs
S34 (34 yr FI, ambient air temperature 16°C)

PLAINS TYPE	(FIRE INTENSITY TYPE) MMBF	CF
A-Plains of E47 vs S34	* *	N S
B-Plains of E47 vs S34	* *	* *
LM Trans of E47 vs S34	* *	* *

* * = Experimentwise Significance at a = .01
N S = No significant difference; FI = fire interval

Ecological Implications

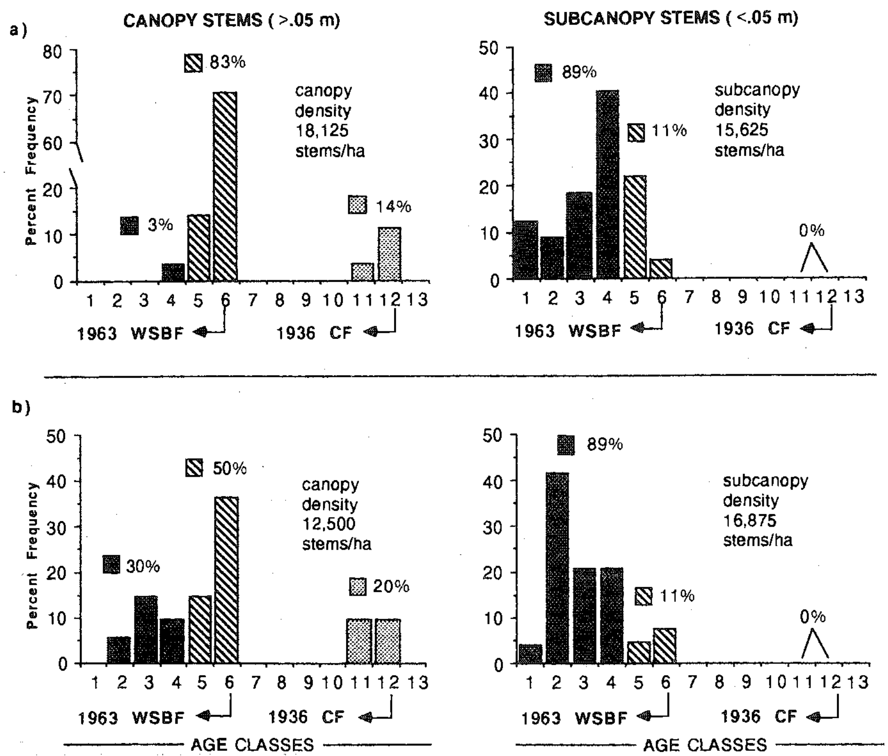
Plains

Large wildfires dominated by crown fire have been and still are the prevailing burning regime maintaining the New Jersey Pine Plains. Stems of the main closed canopy in both A-Plains and B-Plains are killed by crown fires and set back to basal sprouts, as well as all to most of the emergent stems in B-Plains. But the 10% or so of surface fires which occur in most Plains wildfires are not insignificant, and may actually play a very important role in maintaining a diversity of patch types in the Plains landscape mosaic by producing linear patches of lower density, taller, older canopies, compared to crown fired Plains. The taller canopy stems which survive these surface fires have in effect been selectively "missed" by a fire cycle, enabling them to continue height growth and canopy closure by filling out. These missed patches may be in the form of the different canopy structure types in Plains communities, such as A-Plains and B-Plains, or differing stem size, density, and age-class patches within a Plains structural type (Watt 1947). These Plains patches prevail during the ensuing fire-free period, until they are destroyed by crown fires within a subsequent wildfire and set back to basal sprouts (Figure 4.)

The number of A-Plains or B-Plains stems which survive a single surface fire will greatly influence the density, height, and age structure of the surface fire patch created. Stem survival depends upon flame height and ambient air temperature during the fire, which control scorch height. The Plains canopy structure type initially present also influences the effect of a surface fire on canopy survival and future structure. In virtually all surface fires, the low (< 0.5 m), often angular to prostrate stems of the subcanopy are killed by burning the foliage and cambial heat damage, and return by basal sprouting. The main closed canopy of a Plains community, from 0.5 to 2.0 m high, and emergent stems over 2 m if present, will suffer varying mortality by scorch.

Where flame heights are 20 to 25 cm high, as in MMBF and WSBF stands of both fires, ambient air temperatures largely control how high scorch reaches in the vegetation strata. Lethal scorch heights of 1.0 and 1.5 m were generally below much of the main Plains canopy in the April 1982 wildfire, leaving most of the taller canopy stems and foliage unscorched and alive after the fire. A-Plains ABCANSS of 8438 ± 267 (40.8%) and 5094 ± 2419 (24.6%) stems/ha illustrate the high survival during 16 °C ambient air temperatures. B-Plains ABCANSS of $10{,}125 \pm 237$ (49.4%) stems/ha in MMBF stands are somewhat higher due to the additional survival of the emergent stems, although ABCANSS of 5031 ± 1785 (24.5%) stems/ha in WSBF stands were about the same as in A-Plains. If most of these surviving stems lived and continued to gain height, the A-Plains might develop a B-Plains or LM Trans structure. The B-Plains would remain as such or develop an LM Trans structure.

Figure 4. Age class distribution in (a) A-Plains and (b) B-Plains sites previously burned by a 1936 crown fire (CF) and a 1963 wind-shift backing fire (WSBF), with a 20-year fire interval following the WSBF. Canopy stem distributions are on the left, subcanopy stem distributions on the right. (Age classes in years: 1 = 0-4, 2 = 5-8, 3 = 9-12, 4 = 13-16, 5 = 17-20, 6 = 21-24, 7 = 25-28, 8 = 29-32, 9 = 33-36, 10 = 37-40, 11 = 41-44, 12 = 45-48, 13 = 49 and over.)



This contrasts sharply with MMBF and WSBF stands of the July 1983 wildfire, where scorch heights of 2.2 to 2.4 m were generally above the main Plains canopy, scorching all of the canopy and causing low survival. A-Plains ABCANSS of 156±278 (0.5%) and 500±748 (1.7%) stems/ha illustrate the low survival during 37 °C ambient air temperatures. B-Plains ABCANSS of 844±843 (4.4%) and 656±798 (3.4%) stems/ha are higher due to the additional survival of those emergent stems above 2.2- and 2.4-m scorch height. If most of these surviving stems lived and continued to gain height, the A-Plains would remain as such or develop a very sparse B-Plains emergent canopy in scattered places. The B-Plains would be set back to A-Plains in many areas and remain as B-Plains of low emergent densities in others.

Where flame heights are 40 to 50 cm high, as in the CCBF stands of both wildfires, scorch heights are generally above the main Plains canopy, causing very high mortality there. In the April 1982 wildfire, scorch heights were 2.8 m high. Stem survival occurred only among the taller Plains canopy stems which were able to resprout from epicormic buds, despite the foliage scorch. A-Plains ABCANSS of 844±818 (4.1%) stems/ha indicate the degree of this epicormic bud sprouting. Most of the B-Plains emergent stems (generally over 1000 stems/ha) survived this CCBF as well, adding to the B-Plains ABCANSS for a total of 1969±1059 (9.6%) stems/ha. If all these surviving stems lived and continued to gain height, the A-Plains might develop a sparse B-Plains structure with low emergent densities, and B-Plains would remain as such. In the July 1983 wildfire however, where scorch heights were 4.0 m high, all stems of both the Plains canopy and emergent strata were scorched, producing ABCANSS of 31±140 (0.1%) and 94±229 (0.5%) stems/ha for A-Plains and B-Plains respectively. This survival response is virtually identical to that expected from a crown fire, and an A-Plains would develop from basal sprouts in both.

Differences in canopy stem survival due to species composition appear to be minor, since pitch pine is generally the canopy dominant in most Plains sites. Fire resistance is lower in the oak species of the Plains compared to pitch pine, because of their thinner bark and lack of dormant bud sprouting from the trunk after fire. Despite this, there is a contribution to canopy stem survival from the oaks in most WSBF and MMBF. For example, in WSBF burning A- and B-Plains of the 1982 wildfire, oaks (mostly blackjack oak) contributed 656±744 and 938±1191 stems/ha, respectively (n=20 for each). In MMBF A- and B-Plains of the 1982 wildfire, oaks contributed 1031±1170 and 1062±863 stems/ha, respectively (n=20 for each). Convective column surface fires of this fire showed no oak survival. There was also no oak survival among the surface fires of the July 1983 wildfire, which had higher ambient air temperatures and elevated scorch heights compared to most spring wildfires. No oak survival was observed in any crown fired stand as well.

The long-term effects of a single surface fire on Plains communities was analyzed by determining canopy densities for A-Plains and B-Plains sites burned in 1963 by a WSBF (Table 5). Canopy stem densities were significantly lower in both the A-Plains sites (α = 0.01) and the B-Plains sites (α = 0.05) burned by the 1963 WSBF and 1936 CF, compared to A- and B-Plains burned by successive crown fires in 1963 and 1936 wildfires. The reduction in canopy stem density after a single surface fire is likely due to the selective survival of the large canopy stems (and emergent stems in B-Plains), which tend to fill out and close the canopy before basal sprouts have a chance to become established in the canopy. The canopy densities observed in these WSBF stands more closely resemble those found for LM Trans in this study, suggesting that Plains subjected to surface fires may have a tendency to develop into lower density B-Plains or Transitional Plains, given a moderate period free of crown fire.

The age-class distribution of an A-Plains and B-Plains burned by a WSBF in 1963 is presented in Figure 4. These A- and B-Plains sites are similar to the crown fire sites of Figure 3 in that the canopy has a high percentage of stems produced shortly after the 1963 fire (83 and 50%) and a much smaller percentage of canopy stems produced by delayed sprouting (3 and 30%). The

Table 5. Canopy stem densities in A-Plains and B-Plains burned by wind-shift backing fires (WSBF) in 1963, and B-Plains burned by WSBF in 1963 and 1936. One t-test comparison was made between the WSBF A-Plains below and A-Plains burned by consecutive crown fires (CF) in 1963 and 1936 with 29,869 ± 5690 canopy stems/ha (n=12). One t-test comparison was made between each WSBF B-Plains below and B-Plains burned by consecutive CF in 1963 and 1936 with 19,125±5864 canopy stems/ha (n=10).

PLAINS TYPE in 1983	FIRE BEHAVIOR TYPE TREATMENTS	TOPOGRAPHIC POSITION	CANOPY STEM DENSITY (stems/ha)
A-PLAINS	1963 - WSBF 1936 - CF	knoll (xeric ?)	15,417 ± 3,079 * * (n=6)
B-PLAINS	1963 - WSBF 1936 - CF	head of drainage (semi-mesic ?)	13,000 ± 2,227 * (n=5)
B-PLAINS	1963 - WSBF 1936 - WSBF	5 % slope (xeric ?)	12,500 ± 1,369 * (n=6)

(* Significant at $\alpha = .05$, * * Significant at $\alpha = .01$)

subcanopy age class distributions are also very similar, with 89% of the stems attributed to delayed sprouting, only 11% to post-fire sprouting, and none which predate the 1963 fire (100% subcanopy mortality achieved by the 1963 WSBF). The important difference among these WSBF Plains stands is the 14 to 20% of the canopy stems in age classes which predate the 1963 wildfire. These stems date back to the last wildfire at that site before the 1963 WSBF, a 1936 crown fire. The presence of these stems 20 years after a WSBF confirms the long-term role that surviving stems of surface fires play in the Plains canopy. The 14 and 20% of surviving stems in the A-Plains and B-Plains samples represent ABCANSS of 2500 stems/ha in both cases. This is a density of ABCANSS intermediate between those observed in WSBF stands of the 1982 and 1983 wildfires (Table 3), about 4 to 5 times greater than the July 1983 wildfire and about half the April 1982 wildfire. This density of surviving stems is high enough to create a B-Plains, if most survivors continue height growth about 2 m.

Although the older age class stems which survived the 1963 WSBF are present in both the A- and B-Plains, only in the B-Plains site do they appear as an emergent stem stratum. In the A-Plains site, the older stems are slightly taller and have larger diameters, but are still under 2 m tall. The 1963 WSBF A-Plains sites were situated on knolls and slopes of the Plains landscape in xeric sites, while similarly burned B-Plains sites were most often situated in heads of drainage or along minor drainages in semimesic sites (Table 5). This might imply that improved soil moisture conditions of the mesic sites allowed the surviving stems of the WSBF to gain height growth and emergent status more rapidly then in the xeric site. However, B-Plains were also found in semimesic sites burned by crown fire in 1963, suggesting that semimesic sites can initiate B-Plains development only 15 to 20 years after a stem-killing crown fire instead of the 50 years needed by xeric sites. If surface fires should occur, the emergent stems tend to survive because of their height-related fire resistance.

Where surface fires of consecutive wildfires fortuitously overlap, the lower density, taller, older canopy is reinforced, by being missed by yet another fire cycle. This can in some cases transform a former A-Plains to B-Plains or Transitional Plains. For example, only with repeated surface fires would the most xeric A-Plains sites develop emergent stems and a B-Plains structure, such as the xeric B-Plains site (Table 5), which was repeatedly burned by WSBF in 1936 and 1963. Under the regime of randomly occurring wildfires, the repeated burning of Plains by surface fire is not a rare event considering the abundance and great length of strips, but the overlap patches would generally be small due to the narrowness of the strips.

CCSF overlap patches would be the smallest, but most abundant type. They could be as small as 0.01 ha, based on the overlap of two 10-m-wide strips, but the patches would tend to occur in clusters since these strips often occur in very proximal concentric bands. The higher intensity and flame heights of CCSF compared to the other surface fires would make their patches and overlap patches most important in perpetuating already established B-Plains, rather than creating new ones.

WSBF overlap patches would be relatively large in size, from one to several ha, based on the > 100-m width of most WSBF strips. The WSBF overlap patch observed in the East Plains was about 3.6 ha in size, based on aerial photographs of the 1936 and 1963 wildfires. Typically, the very low flame height and high canopy stem survival associated with these surface fires would permit all A-Plains, even those of xeric sites, to be transformed to B-Plains (or Transitional Plains eventually) with repeated surface fire burning. The WSBF overlap patch would be a somewhat rare event however, since usually only one to a few WSBF strips occur in any given wildfire. One overlap patch occurred between the 1963 WSBF and 1983 WSBF, but when surface fires occur during ambient air temperatures of over 30 °C, such as the July 1983 wildfire, scorch height is often great enough to cause complete canopy mortality, and the effect is similar to a crown fire with low survival.

MMBF overlap patches tend to be fairly large, from 10 to 50 ha, because there is often almost complete overlap of successive MMBFs. This is because MMBFs are often set along established roads during wildfire suppression, their line of ignition and orientation often being the same as those set during preceding wildfires in the same forest block. The random nature of the other surface fire types is absent in MMBF so their overlap patches occur with unusual frequency. The presence of tall B-Plains and Transitional Plains along Route 72 and Stephenson Road in the West Plains, where MMBFs have been repeatedly set during many fire suppressions, confirms the effect of repeated surface firing on the Plains communities.

Transitional Plains

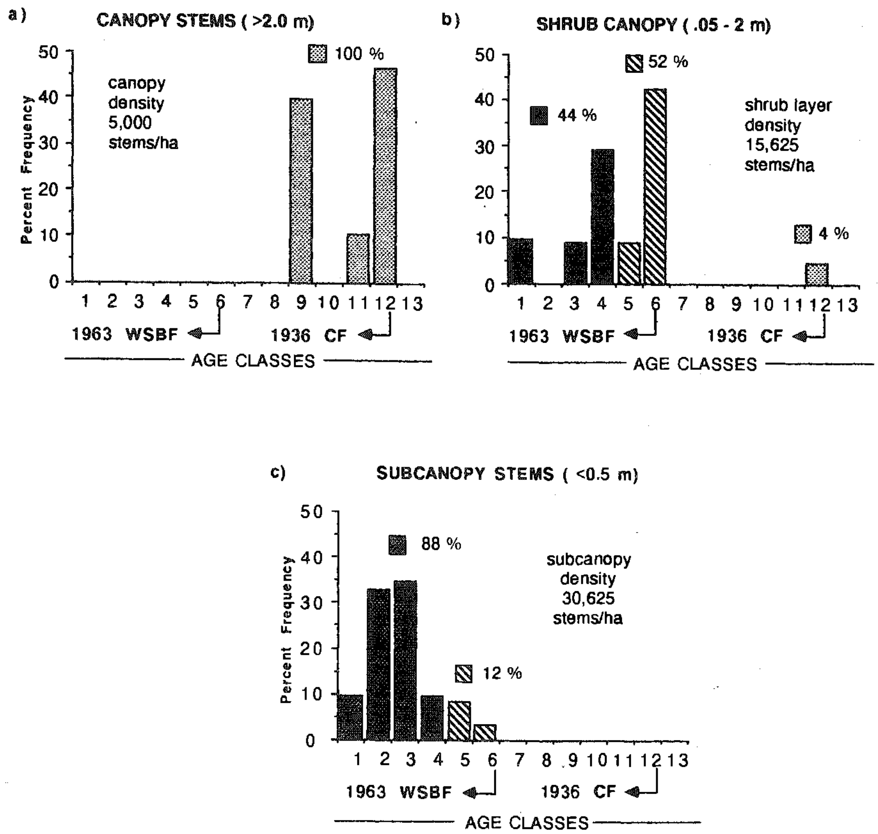
Transitional Plains often respond to crown fires with a much higher stem survival than A- and B-Plains, due to the high density of stems over 3 m high. In the LM Trans site of the 1982 wildfire, ABCANSS of 938±591 stems/ha were found, compared to 31±140 stems/ha for A-Plains and 469±399 stems/ha (mostly the emergent stratum) for B-Plains of the same fire. Only crown fires during very high ambient temperatures or those of a wildfire's head are hot enough to cause 100% mortality, as in the LM Trans sampled in the 1983 wildfire. When the taller stems of a Transitional Plains canopy are killed back and the roots survive, many of the basal sprouts retain their apical dominance, unlike most Plains basal sprouts, and quickly reestablish their former height, often within 15 to 20 years (Windisch 1986). The difference between Plains and Transitional Plains in these two traits are considered enough to classify them as different, yet closely related, communities. Genetic differences in pitch pine established by long-term differences in stand fire history may be important in establishing Plains versus Transitional Plains communities, as well as edaphic influences on long-term fire behavior and pitch pine growth rates. These traits make Transitional Plains quite stable under the recent, increasingly moderate fire regime associated with fire suppression.

The effects of surface fires on Transitional Plains are most clearly shown by the age class distribution of Figure 5, in which a LM Trans community burned by a WSBF 20 years earlier is shown. Of the 5000 tall (over 2.0 m) canopy stems/ha, 100% predated the 1963 WSBF, suggesting that most of the stems over 2 to 3 m tall in 1963 survived the WSBF. The shrub canopy 0.5 to 2.0 m in height showed only 4% of the stems predating the 1963 fire, 52% produced shortly after the fire, and 44% by delayed sprouting. The subcanopy stem distribution was very Plains-like, with only 12% produced shortly after the 1963 fire and 88% by delayed sprouting.

The ABCANSS for LM Trans burned by MMBF and WSBF of the 1982 wildfire, where scorch heights were 1.0 to 1.5 m high, were 6345±165 and 4531±1658 stems/ha, respectively. These represent survival among most of the tall canopy stems over 2.0 m. The corresponding percent canopy stem survival of 51.8% and 37.0% are based on percent survival among tall canopy (> 2.0 m) and shrub canopy (0.5-2.0 m) stems, and so are less than that expected for the percent canopy stem survivals alone. ABCANSS for the 1982 CCSF of 1500±742 stems/ha were much lower than the pair just discussed due to scorch heights of 2.8 m, which increased mortality among the stems over 2.0 m. ABCANSS for all the 1983 surface fires were also much lower (from 1969±133 to 563±700 stems/ha), due to scorch heights of 2.2 to 4.0 m, which also increase mortality among the stems over 2 m tall.

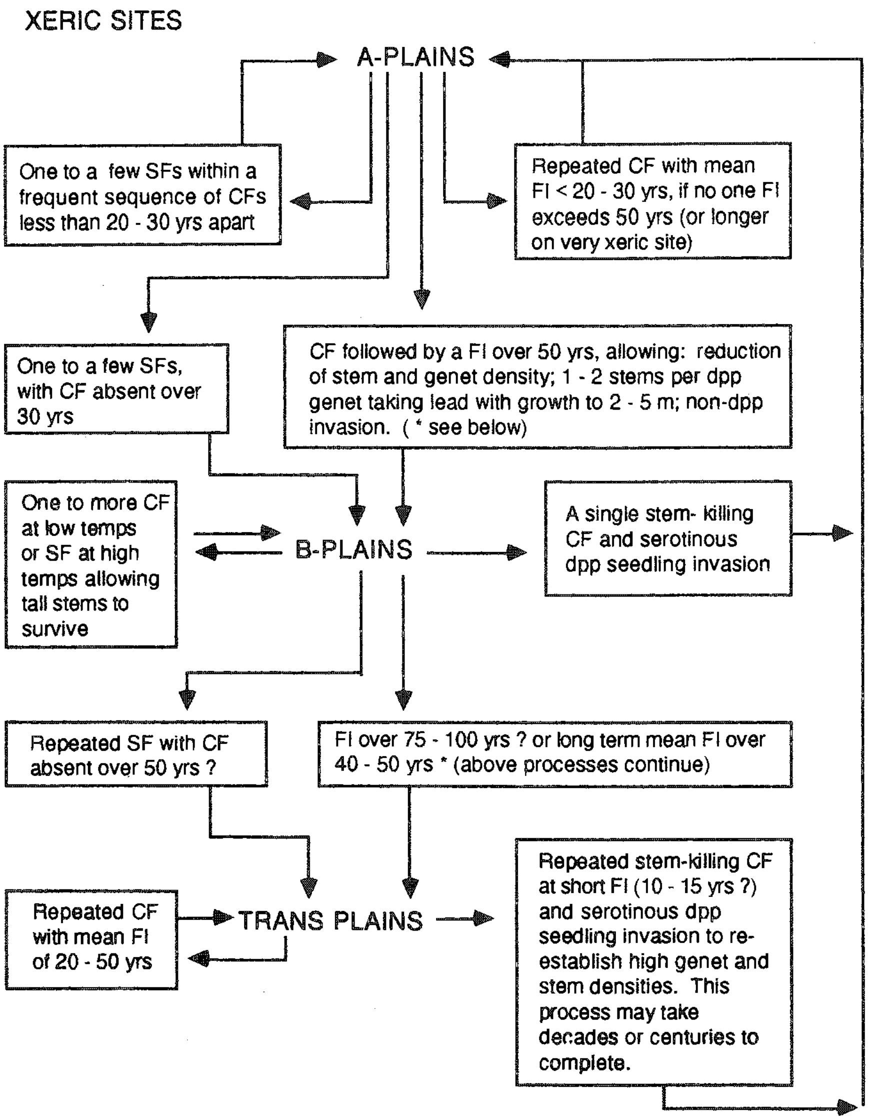
Because of the retention of apical dominance in many Transitional Plains post-fire basal sprouts, stands burned by completely or partially killing-fires

Figure 5. Age class distribution in an LM Transitional Plains, in site previously burned by a 1936 crown fire (CF) and a 1963 wind-shift backing fire (WSBF), with a 20-year fire interval following that WSBF. Canopy (a), shrub canopy (b), and subcanopy (c) age-class distributions are presented. (Age classes in years: 1 = 0-4, 2 = 5-8, 3 = 9-12, 4 = 13-16, 5 = 17-20, 6 = 21-24, 7 = 25-28, 8 = 29-32, 9 = 33-36, 10 = 37-40, 11 = 41-44, 12 = 45-48, 13 = 49 and over.)



still recover and/or maintain a canopy with enough tall stems over 2 to 3 m to be classified as Transitional Plains. The age structure and density of the tall canopy will vary depending on the number of stems which survive the fire, but Transitional Plains heights prevail or are quickly reestablished. However, the high post-fire and delayed sprouting of the shrub canopy and subcanopy are quite Plains-like, and suggest a close relationship to Pine Plains communities. Perhaps only with many repeated stem-killing crown fires at short (10-to 15-year?) intervals, would the loss of apical dominance become established in all stems of every genet through physiological loss of vigor, permitting the transformation of a Transitional Plains community into a Plains community (Figure 6). Perhaps even more importantly, a repeatedly short crown fire interval would allow reestablishment of high genet (root stock) and stem densities by invading serotinous pitch pine seedlings, which may

Figure 6. Hypothesized pathways for the fire-related dynamics between A-Plains, B-Plains, and Transitional Plains on the predominantly xeric sites of the Plains landscape. Different pathways likely occur on mesic sites (not shown). CF = crown fire, SF = surface fire, FI = fire interval, dpp = dwarf pitch pine, non-dpp = nondwarfed pitch pine.



in fact carry the genetic propensity for the dwarfing growth forms (Good and Good 1975). These may have been the processes which were in effect during the earliest stages of the Plains community development, and they may be the processes needed to restore former Pine Plains that have been degraded by disturbance or prolonged fire suppression into Transitional Plains.

Management Implications

A preliminary analysis of a 1985 controlled burn at Warren Grove Target Area in the East Plains was conducted by Windisch and Good (1986). Strip-heading fire techniques (USDA 1989) used on 3 ha of undisturbed A-Plains showed crown fired areas with ABCANSS of 94±231 stems/ha (0.5% survival) compared to MMBF areas with 7378±2188 stems/ha (41.3% survival). These ABCANSS are similar to those observed in the 1982 wildfire site of this study.

One important conclusion reached in this study in terms of fire management is that repeated surface fires, coupled with moderate fire intervals, will transform the characteristic A-Plains of the region's most xeric uplands into taller, less dense B-Plains and eventually Transitional Plains, due to selective survival and continued growth of the taller canopy stems. Therefore, any controlled burning program in the Plains should minimize the use of MMBF, which burns with survivable fireline intensities, and maximize the use of head fires, which generally crown and cause 100% stem mortality and basal sprout recovery. Where the use of back firing is necessary to establish a base control line during prescribed burning or to contain a wildfire, follow up burning with crowning head fires should be conducted in these sites within a few years. This is to avoid the selective stem survival of repeated back fires along roads, and the eventual loss of A-Plains structural types there. Crown firing along these roads will not only counteract the loss of A-Plains there, but will reduce fuels and effectively broaden the firebeaking effect of the roads for periods up to 5 years. (D. Harrison NJBFFM, pers. comm.).

A large scale, frequent (less than 20-year fire interval) controlled crown firing program for the entire Plains region is not recommended, because it would undoubtedly reduce the diversity of stand age and canopy structure patch types in the Plains. Such a program would also require the installation of a network of bulldozed fire breaks, which are far more destructive than somewhat prolonged fire intervals, and cause a long lasting if not permanent replacement of Plains by successional and tall Transitional Plains communities (Windisch and Good 1986).

A frequent controlled crown firing program in the Plains, with fire intervals of 5 to 20 years, should be restricted to those portions with already established sand road networks and with high fire ignition potentials, such as around Warren Grove Target Area. Frequent controlled crown firing could also be used to rehabilitate severely disturbed and bulldozed Plains and Transitional Plains around Warren Grove Target Area and Coyle Field, and in stands with extremely prolonged fire intervals (over 50 to 60 years) where extensive loss of the unique Plains canopy has occurred. Controlled crown firing in these few trouble spots may reestablish the self-perpetuating, high-density, low-statured Plains canopy in the way that frequent wildfires are thought to have initially created the Plains from Transitional Plains (Figure 6). By restricting frequent controlled crown firing to only a small portion of the Plains where it is most needed, the major portion of the Plains region will be left to the prevailing regime of randomly occurring wildfires. These randomly overlapping, crown-fire dominated wildfires with variable stem survival in surface fired strips provide the greatest potential for Plains patch diversity while still maintaining the low Plains canopy in most of the landscape mosaic. Mesic sites supporting B-Plains and Transitional Plains within the core of the main Pine Plains areas should not be managed by very frequent burning with crown fires either, because they generally represent part of the natural diversity within the Plains landscape created by presuppression wildfire regimes.

Wildfire suppression techniques using existing roads and fire breaks whenever possible are preferable to the creation of new fire breaks, because of the long-lasting negative impacts that mechanical disturbances have on Plains vegetation. The containment of Plains wildfires after the main run has been stopped has often been done by "burning out" with head fires that unburned forest between the wildfire perimeter and existing roads. Wind orientations must generally be such that set head fires burn toward the broad flank of the main run burn. This technique, which was used in parts of both the 1982 and 1983 wildfires of this study, is encouraged because it increases the overall size of each fire and increases the proportion of A-Plains generating crown fired area.

ACKNOWLEDGEMENTS

We would like to acknowledge M. Morgan, J. Kuser and M. Windisch, for critical reviews of early drafts and to M. Morgan for many helpful suggestions on the experimental design and statistical analysis. We would like to thank the New Jersey Department of Environmental Protection, Division of Parks and Forestry for providing partial funding for the controlled burn analysis at Warren Grove Target Area. Finally, we would like to thank J. B. Durand, who kindly permitted the use of the Rutgers Marine Field Station in Tuckerton throughout the investigation.

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