

Post-fire Stand Development and Potential Fire Behavior for the
Waterboro Barrens, Southwestern Maine

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by

William A. Patterson III

Department of Forestry and Wildlife Management
University of Massachusetts, Amherst 01003

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INTRODUCTION

Most of The Nature Conservancy's Waterboro Barrens Preserve in the towns of Newfield, Shapleigh, and Waterboro, ME burned in the great fire of October, 1947. The "'47 Fires", which burned during the worst recorded drought in Maine history, consumed an estimated 70 square kilometers (169,000 acres) of forest, fields and scrub land, and burned out several towns, including most of Newfield (Wilkins 1948, Copenheaver et al. 1999). Today, 50 years after the fire, much of the burned area is second-growth pioneer hardwoods. On dry, sandy sites like those at the Waterboro Barrens, pitch pine and scrub oak prevail. These and associated species comprise pyrogenic plant communities that some have called an edaphic- or dis-climax. Harris (1991) and Patterson (1994) provide preliminary descriptions of the vegetation, and Copenheaver et al. (1999) describe the factors responsible for current stand development. Land-use history (especially logging and blueberry cultivation), fire and soil characteristics have combined to produce vegetation with varying amounts of pine barrens species (e.g. pitch pine, scrub oak and blueberry) as well as species characteristic of more mesic sites (e.g. red oak, white pine, red spruce, maple and beech).

Most fire ecologist familiar with barrens in the Northeastern United States assume that typical fire return intervals in barrens areas are on the order of 10-20 years. More frequent fires lead to the development of grassland, heath and scrub oak barrens, whereas less frequent fires lead to dominance by pitch pine at the expense of shrubs and graminoids and, with very infrequent fire (e.g. return intervals greater than 75-100 years) eventual dominance by conifers and hardwoods more typical of mesic site conditions.

Fire return intervals, as well as the intensity of fires that do occur, depend in part on the rate and magnitude of fuel accumulation following fire. Fires at frequent intervals (e.g. less than 10 years) burn at lower intensities in fuels that are dominated by non-woody and small-diameter woody material. As live and dead fuels accumulate, fire intensities increase, and it is these high intensity fires that are most likely to retard the replacement of barrens species by more mesic species. Fire severity, which is measured by the degree of consumption of large diameter fuels, duff and soil organic matter, is a function of both fuel accumulation and climatic factors (e.g. drought). Severe fires burning at long intervals can have much the same effect as more frequent, high intensity fires in maintaining barrens vegetation and preventing succession to mesic-site species. Thus barrens vegetation can be maintained by high intensity fires burning at short intervals (e.g. less than 10-20 years), or severe fires burning once every several decades. Fires burning at intervals that exceed the life span of barrens species (e.g. 100-150 years for pitch pine on most sites) will result in a shift in vegetation to communities dominated by more shade tolerant (and fire intolerant) conifers and hardwoods.

Dormant season burns (i.e. those occurring in late fall or before green-up in spring) are characterized by long flame lengths (i.e. high fire line intensities) and high rates of spread. Severe fires are most likely to occur during mid-to-late summer (i.e. during the growing season), when abundant green plant material in the fuel complex reduces fire intensity. Until the first frost in autumn, this is true even under moderate to severe drought. Burning when soil moisture conditions are low is problematic, however, because of the extended burning periods involved (fires during drought conditions can smolder for weeks, even in the Northeast) and the general concern about the threat of wildfire under such conditions. Thus duplicating the effects of severe fire with growing-season burns is difficult. Managers trying to maintain barrens vegetation are left with the problem of developing prescriptions that will result in the safe implementation of high-intensity (dormant-season) burns.

Resource managers use the fire behavior system BEHAVE in developing prescribed burn plans. Standard fuel models available through BEHAVE have been shown to be poor predictors of prescribed fire behavior in barrens dominated by pitch pine, scrub oak and heath shrub species. Custom fuel models specific to individual sites are required. Because The Nature Conservancy is considering the use of prescribed fire to manage the Waterboro Barrens, we undertook this study to 1) characterize present stand conditions and fuel loading in a portion of the Waterboro Barrens burned by the 1947 fire and 2) develop a custom fuel model for stands of pitch pine-scrub oak thicket (PP-SOT), the dominant vegetation type (40% of the Preserve area) in the Waterboro Barrens, and 3) provide the Maine Chapter of The Nature Conservancy with a protocol for future custom fuel model development.

METHODS

We sampled 20 plots in an approximately 14 hectare (34 acre) area west and north of the TNC parking lot in the southeastern portion of the Preserve (see Figure 1). Sampling procedures are outlined in detail in Appendix 1. Parameters sampled included cover and basal area by species for overstory strata, downed woody fuel using a modification of Brown's (1974) planar intercept method, cover and height of shrubs by low (blueberry) and high (scrub oak) shrub categories, litter load, and density and estimated biomass of scrub oak. The NEWMODEL subroutine of the BEHAVE software was used to develop a custom fuel model for the PP-SOT community type based on average values for cover, depth, and loading in the grass, litter, and shrub fuel categories.

RESULTS

Stand Characterization

Average slope within the stand we sampled is 5.1% with a predominantly northwest aspect (12 of 20 sample points). Average basal area and stocking of pitch pine in the stand were 95.0 ft² and 560.1 stems per acre (Table 1). Pitch pine comprises 98.2% of the basal area and 92.5% of the stems. Average canopy cover and height are 59.1% and 36 ft, with the subcanopy dominated by scrub oak (high shrub cover of 55.4% to a height of 6.5 ft). The soil surface is nearly completely covered by litter below a carpet of blueberry (72.5% cover to a height of 0.7 ft). Grasses, sedges and forbs are sparse (See Table 2)

Fire History and Stand Development

In August, 1998 25 pitch pines varying in diameter (at breast height) from 3.0 to 44.3 cm and two white pines (22.7 and 34.7 cm dbh) were cored at 20-40 cm above the ground. Ages were determined in the field using a 10X hand lens. Diameters (at breast height) were recorded to the nearest 0.1 cm based on measurements taken with a diameter tape. Age since establishment was estimated by adding four years to the core age (except two years for one stem sectioned at the base). Field notes are reproduced in Table 3. For pitch pines, stems were distributed by age class and estimated year of establishment as indicated in Tables 4 and 5.

Individual trees showed periods of slow growth about 30 y.a. (ca. 1968), 45-50 y.a (ca. 1948-1953) and 70-75 y.a (ca. 1923-1928). Trees 50-80 years old showing slow growth 45-50 y.a. had evidence of fire scars, but trees less than 50 years had no evidence of having been scared by fire. The 60-69 year old trees appear to have been about 20 years old (estimated age from establishment) and 12-15 cm in diameter when scared by the fire of October, 1947. The two oldest trees (100+ years) had decayed wood in the center. The core reached the center of one tree but not the other. White pines cored were 33 and 36 years old at core height.

All of this suggests that the area was clearly burned in 1947 but has not been burned since that time. There appear to have been additional fires ca. 75-80 years (ca. 1919-1924) ago and 100+ (before 1895) years ago. Thus, since about 1870, the area has burned at 20-40 year intervals, but not in the past 50 years. More frequent (lower intensity) fires may have burned before about 1920, but for the last 100-150 years, there is no clear evidence for high-intensity fires other than the three noted above. The slow growth about 30 years ago may be associated with the dry years of the mid-1960's, or perhaps insect defoliation. The lack of any evidence of fire on the <50-year-old cohort rules out a fire in the area since 1947. Abundant regeneration as evidenced by 10 stems in the 31-40 year old (core age) cohort suggests delayed regeneration

following the 1947 fire. By adding 4 years to the age at core height to reach an estimated date of seedling establishment (Table 3), 44% (11 of 25 stems) of the pitch pines appear to have established from seed during the period 1948-60). Because of the severe soil burning associated with the 1947 fire, it may have taken some time for soil conditions to ameliorate and/or for abundant seed production to coincide with favorable soil moisture conditions allowing seedling establishment and survival. Some of the oldest trees show periods of slow growth (e.g. 10,30,62,94,102,115 years before 1998), at least some of which were not associated with fires (as we know that the ca. 1988 and 1968 growth reductions were not caused by fire).

Stems less than 10 cm dbh might be seen as evidence of a fire about 30 years ago, however the extremely slow growth of these trees (see Tables 1-3) suggests that it is more likely that they are actually older than the ages estimated in the field. For intolerant species, one would normally expect younger trees to have higher rates of radial increment, but that is not the case with the stems I sampled. The growth data, and general appearance of the stems in question, suggest that these stems either regenerated some years before the dates I have estimated and have missing rings, or established among a stand of trees that was too young to survive a fire (the 1948-1960 cohort of Table 3) 30 years ago.

Information on fire history and the growth of individual stems can be used with stand structure data to further evaluate the status of the post-fire development of this stand. For 25 pitch pine, core ages range from 27 to 126 years and diameters from 3 to 44.3 cm. Regression of age on diameter results in a significant correlation of:

$$\text{age} = 1.89 \cdot \text{dbh} + 9.9 \quad (r^2 = 0.71) \quad (\text{Figure 2a}).$$

When variable radius plot data for our 20 sample points are converted to stem density and graphed against diameter, the resulting graph (Figure 3) shows that most stems are in the 3 to 8 inch diameter classes. Based upon the regression above, these stems would be 24 to 48 years old. The presence of stems in all size classes up to 15 inches (38.1 cm), with densities declining as an inverse "j-shaped" curve, suggests an all-aged stand. The lack of stems in the smallest size classes (<3 inches) suggests a lack of replacement by new recruits, however, and a more careful examination of the age/diameter data suggests that this lack of stems in the smaller diameter (age) classes may be even more pronounced than appears on Figure 3. The regression of age on diameter using only the 15 stems <25 cm dbh (i.e. those with core ages of 27-45 years that have regenerated since the 1947 fire) shows:

$$\text{age} = 0.69 \cdot \text{dbh} + 26.48 \quad (r^2 = 0.71) \quad (\text{Figure 2b}).$$

Although the regression is still significant, the low slope of

the line (0.69), which is apparent from the distribution of points with dbh <10 cm on Figure 3, suggests that for the smaller stems, the correlation between age and diameter is less strong. The y-intercept of 26.5 suggests, in fact that a stem with no diameter would be 26 years old. These results indicate that predictions of age based on diameter overestimate the importance of younger stems in the stand and caution against the use of diameter as an estimator of age, especially for smaller diameter stems.

Overall, the results are consistent with what one would expect for a pitch pine stand subjected to periodic, high intensity fire. A few older pitch pines have survived a series of two or more fires dating back to the late 19th century. Most stems in the stand appear to have regenerated in the 10-15 year period following the last fire in 1947, whereas few stems have regenerated in the last three decades. The stand is currently heavily overstocked, and it seems likely that natural thinning will soon remove stems from the smaller diameter classes (i.e. those stems <10-15 cm = 4-6 inches established since 1961 and experiencing the slowest growth - see Table 3).

Post-fire Fuel Accumulation

Custom fuel models require information on the loading, fuel depth, and cover of live and dead fuels in the litter, shrub, grass and slash categories. Only the first two categories were present at Waterboro, as there are few grasses and sedges present in the understory and the area has not been logged since before the 1947 fire. We obtained estimates of parameters using several different sampling techniques. Downed wood loading, and fuel (litter and downed wood) and duff depths were estimated by sampling 50-foot (15.2 m)-long lines (Brown 1974) at each of the 20 VRP/relevé sample points. Depths of the shrub layers were estimated on the relevé plots as well as at three points along each DWF line. Fuel loading was also estimated by harvesting all litter, downed wood, and rooted live and dead woody and herbaceous material from 10, 40cm by 40cm (1600 cm²) plots. Scrub oak stems were tallied by 0.25 cm size classes on 10, 1 m by 1m (1m²) plots. On 10 additional plots, we tallied scrub oak stems irrespective of size class (to see if our initial density estimates were accurate). Eleven individual scrub oak stems with basal diameters between 0.6 and 4.15 cm were harvested and separated into leaves and wood (in 0-0.64, 0.65-2.53, and 2.54-7.62 cm fuel size categories = 1-, 10- and 100-hour time lag classes), dried and weighed. Diameter and weight data for these eleven stems were used to develop regression equations allowing us to convert stem density by size class to weight by fuel size category. In some instances, parameters were estimated by more than one method, and we compared results and chose those that appeared most representative of the stand. As an example, the DWF lines and 40 by 40 cm plots each gave estimates of fuel loading by size class of woody material. The 40 by 40 cm plots would, intuitively,

tively, provide a more direct measure of fuel load, but variability for estimates in the larger size class were high due to the small sample size and non-random distribution of larger fuels in the sample area. The DWF lines sampled these categories of fuels more intensively, so we used estimates of loading for larger fuels that were derived from the DWF lines for our fuel modeling exercise. Only the 40 by 40 cm plots provided estimates of litter weight (1-hour, non-woody fuels), however, and we found estimates of loading for the 0-0.64 (1-hour) woody size class to have low variability, so we used data from the 40 by 40 plots for all estimates of 1-hour fuels. Data are summarized in Tables 6 and 7

The fuel bed at Waterboro, 51 years after the 1947 fire, is dominated by non-woody, 1-hour fuels, chiefly pitch pine needles and scrub oak leaves. These fuels, which are highly volatile and well-aerated because they are largely caught amongst dense low blueberry ground cover, allow for the development of high intensity, relatively fast moving surface fires that can quickly involve the scrub oak sub-canopy, which has an estimated 1.1 t/ha (0.5 ton/acre) of leaves during the growing season plus 5.33 t/ha (2.4 ton/acre) of 1 and 10-hour live plus dead woody branches and stems. Our prescribed burning experiments at Hollis, Maine have demonstrated that green leaves of scrub oak will "torch" and provide heat that can contribute to torching of overstory pitch pine. Under high wind conditions, crowning of pitch pine is facilitated by the low 6.1 m (20 ft) height to the base of the live crown (Table 7). During the dormant season, intensities are greater due to the lack of live, high-moisture content leaves in the fuel complex, and the transfer of fire from the surface to crowns could be expected to occur under even moderate wind conditions. Estimates of fire behavior parameters for Waterboro fuel complexes are provided by the custom fuel model developed in the following section.

Custom Fuel Model Development

The NEWMODEL subsystem of BEHAVE was used to develop a custom fuel model for the Waterboro Barrens. Most wildland fire managers in the United States use English units to characterize wildland fire behavior, so we used English units in our fuel modeling exercise.

Past experience has shown us that BEHAVE custom fuel models are especially sensitive to fuel depth. Both fuel depth and fuel loading are adjusted according to the cover of the fuel categories entered into the model building exercise (in our case litter and shrubs). Thus, it is extremely important to have estimates of cover and depth that are representative of the area sampled. We obtained estimates of litter depth from the downed woody fuel lines and cover from the relevé plots. While measuring fuel depth, we recorded whether the measurements were made for litter, or for

downed wood above the litter layer. The two values (0.2 and 1.3 ft) are sufficiently different to require us to choose one or the other. Subjective examination of the fuel bed showed it to contain a large amount of litter caught up in the downed wood and dead and live standing blueberry that cover much of the area. Our estimate of the height of the low shrub layer (0.8 ft) was used as an "average" value representing the height to which litter could be distributed. Litter cover was estimated to be nearly 100% and low shrub cover 73%, so a value of 88% litter cover was entered into NEWMODEL. Low and high shrub height estimates from the DWF lines were 0.8 and 3.3 respectively, whereas values from the relevé plots were 0.7 and 6.5 ft. We used the average of the two DWF line values, recognizing that this would give a conservative estimate of shrub depth. Calculating a combined cover value was complicated by the fact that low shrubs (blueberry) often grow beneath high shrubs (scrub oak). Thus we could not simply average (for a low estimate) or add (for a high estimate) the two values (73% for low shrubs, 55% for high shrubs). Instead we added the average of the two values to the sum of the two values and divided by two. This yielded an estimate of total shrub cover of 96% - a figure indicating nearly complete cover of shrubs, which we feel is not unrealistic. This ultimately results in NEWMODEL reducing shrub fuel load and depth by 4% to account for less than 100% shrub cover.

Parameters for our custom fuel model are presented in Table 8. Surface area to volume ratios and heat content were taken from guidelines for volatile fuels found in the BEHAVE user manual. The moisture of extinction is sensitive to heat content and SAV ratios and the value calculated by NEWMODEL (26%) is very close to the value of 25% that we have measured for similar fuels at Cape Cod National Seashore. The calculated wind reduction factor of 0.6 is consistent with the 50-60% canopy cover measured for the canopy and high shrub layers.

Using a standard set of environmental data (Table 9), the Waterboro custom fuel model predicts moderate rates of spread and high flame lengths and fire line intensities for 1, 10 and 18 mph mid-flame wind speeds (1.7, 16.7, and 30 mph 20-ft winds). When compared with model outputs for standard fuel models 6 and 7, the Waterboro model yields predictions for rates of spread that are similar to fuel models 6 and 7, but flame lengths that are 1.5-2 times higher. Predicted outputs for the Waterboro model are substantially lower than those for fuel model 4, but the results (Table 10) do illustrate the generally high intensity with which barrens fuels burn. Values for heat/area, fire line intensity, and reaction intensity for the Waterboro model are all closer to FM 4 outputs than to those for FMs 6 and 7.

Custom Fuel Model Testing

Because there have as yet been no prescribed burns conducted

at Waterboro, we can not test the accuracy of the Waterboro custom fuel model directly. We have compared model estimates with observed fire behavior in barrens elsewhere in New England, however, and results confirm that barrens fuels burn with rates of spread comparable to fuel models 6 and 7, but with intensities that are substantially higher (Woodall, 1998). This confirms observations by prescribed burn managers throughout the region who have found that none of the standard fuel models adequately predict fire behavior in barrens fuels. Woodall's results show that fuel loading, depth and cover vary among barrens, and it is for this reason that we have, as at Waterboro, recommended the development of custom fuel models unique to individual management units. Woodall (1998) was able to compare BEHAVE custom fuel models with fire behavior on five prescribed burns. He found that BEHAVE estimates were low by as much as 30-40% for some areas. He adjusted model outputs by factors of 1.0 to 1.6 to bring predicted values in line with observed values. We suspect that the failure of even custom fuel models to accurately predict fire behavior is due to the difficulty in measuring fuel depth and cover, and Woodall's results underscore the importance of testing custom fuel models against observed fire behavior.

Literature Cited

- Anderson, P.L. 1986. BEHAVE: fire behavior prediction and fuel modeling system --BURN subsystem, part 1. USDA Forest Service General Technical Report INT-194. Ogden, UT.
- Anderson, P.L. and C.H. Chase. 1989. BEHAVE: fire behavior prediction and fuel modeling system --BURN subsystem, part 2. USDA Forest Service General Technical Report INT-260. Ogden, UT.
- Brown, J.K. 1974. Handbook for inventorying downed woody material. USDA Forest Service General Technical Report INT-16. Ogden, UT. 24 pp.
- Burgan, R.E. and R.C. Rothermel. 1984. BEHAVE: fire behavior prediction and fuel modeling system --FUEL subsystem. USDA Forest Service General Technical Report INT-167. Ogden, UT. 126 pp.
- Copenheaver, C.A., A.S. White, and W.A. Patterson III. 1999. Vegetation development in a southern Maine pitch pine-scrub oak barren. *Journal of the Torrey Botanical Society* 126(4):
- Del'Orfano, M. 1996. Fire behavior prediction and modeling of flammable shrub understories in northeastern pine-oak forests. M.S. Thesis, Worcester Polytechnic Institute. Worcester, MA. 208 pp.
- Harris, P. 1991. Waterboro Barrens. A report on file with the Maine Chapter of The Nature Conservancy, Brunswick, ME.
- Patterson, W. A. III. 1993. The Waterboro Barrens: Fire and vegetation history as a basis for the ecological management of Maine's unique scrub oak-pitch pine barrens ecosystem. Report on file with the Maine Chapter of The Nature Conservancy, Brunswick, ME.
- Wilkins, A. H. 1948. The story of the Maine forest fire disaster. *Journal of Forestry* 46: 569-573.
- Woodall, C.A. 1998. Prescribed fire behavior and custom fuel modeling in the pitch pine-scrub oak barrens and pine-oak forests of New England. Unpublished M.S. project, University of Massachusetts, Amherst. 33 pp. + App.

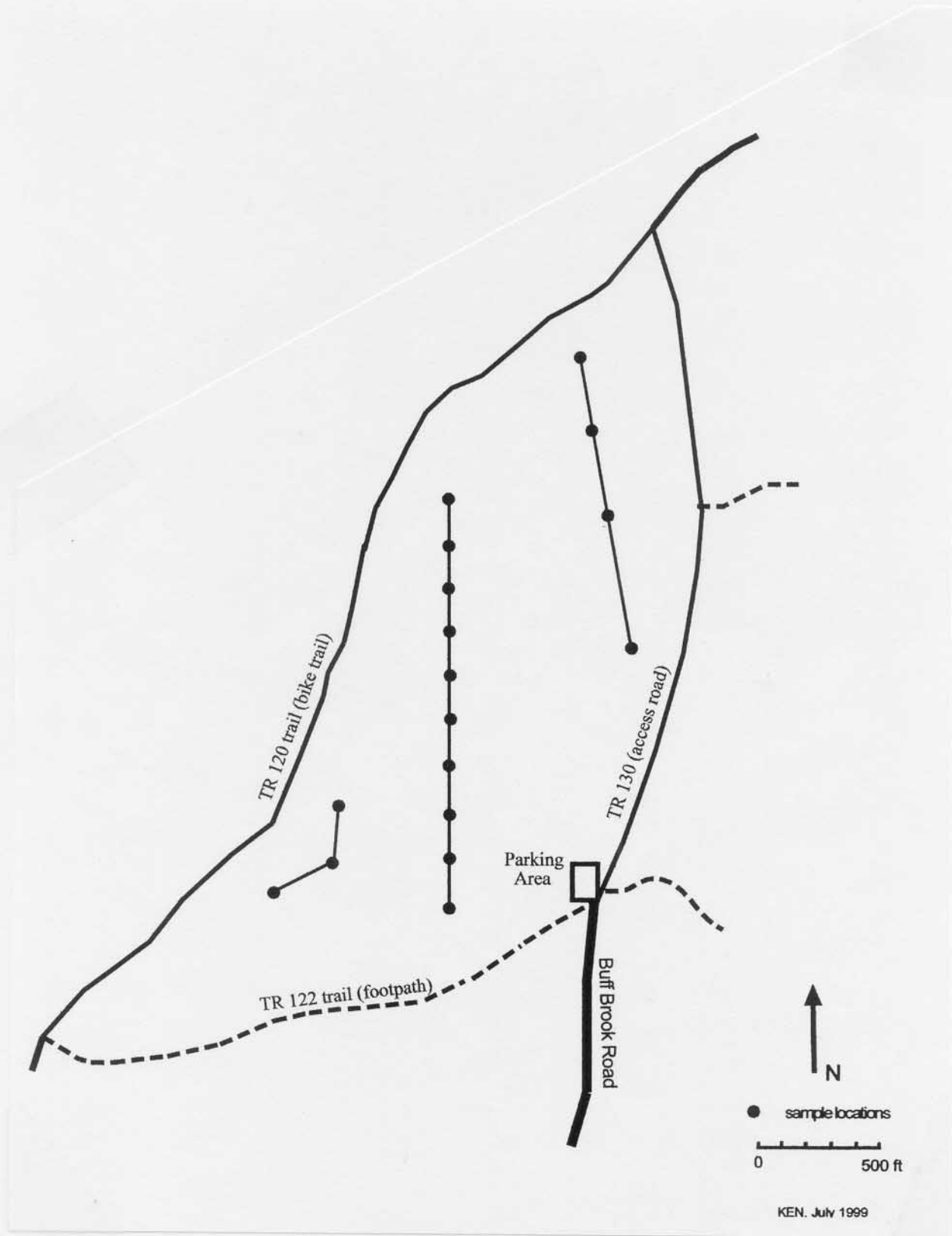
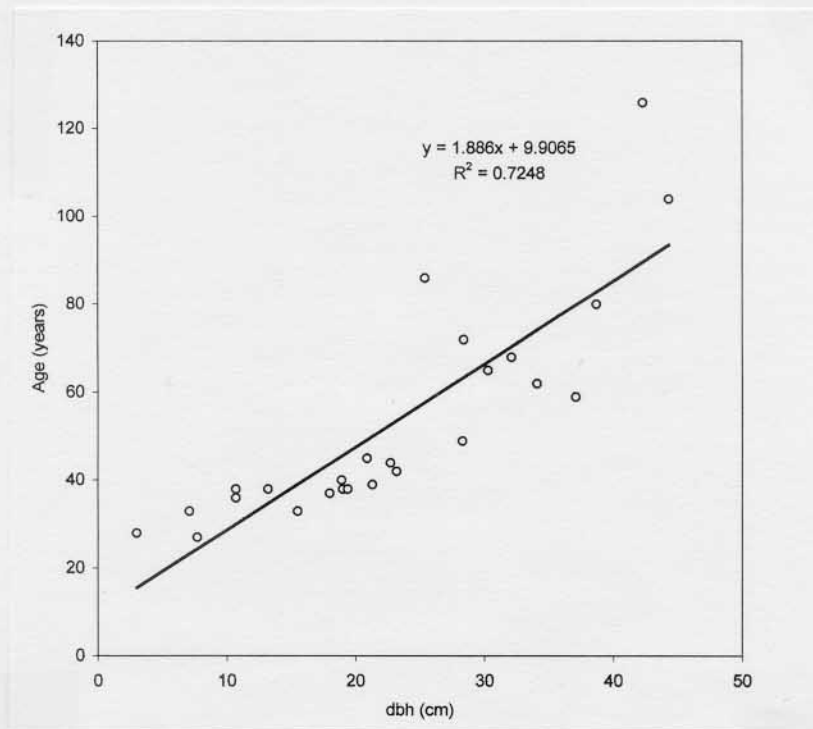


Figure 1. Location map for points sampled at the Waterboro Barrens, Maine TNC parking lot stand.

a.) All stems.



b.) Only those stems <25 cm dbh.

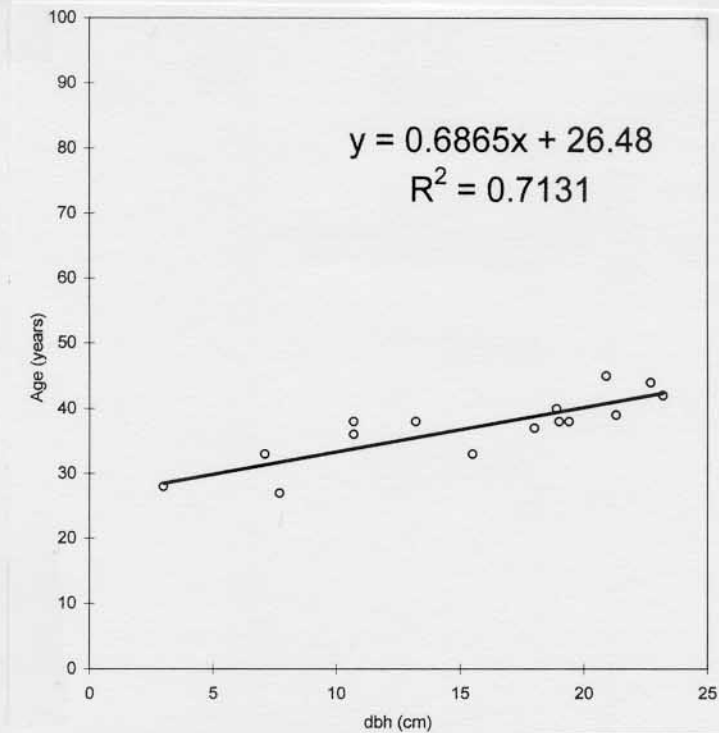


Figure 2. Regression of tree age on diameter at breast height for pitch pine stems sampled at the Waterboro TNC parking lot location.

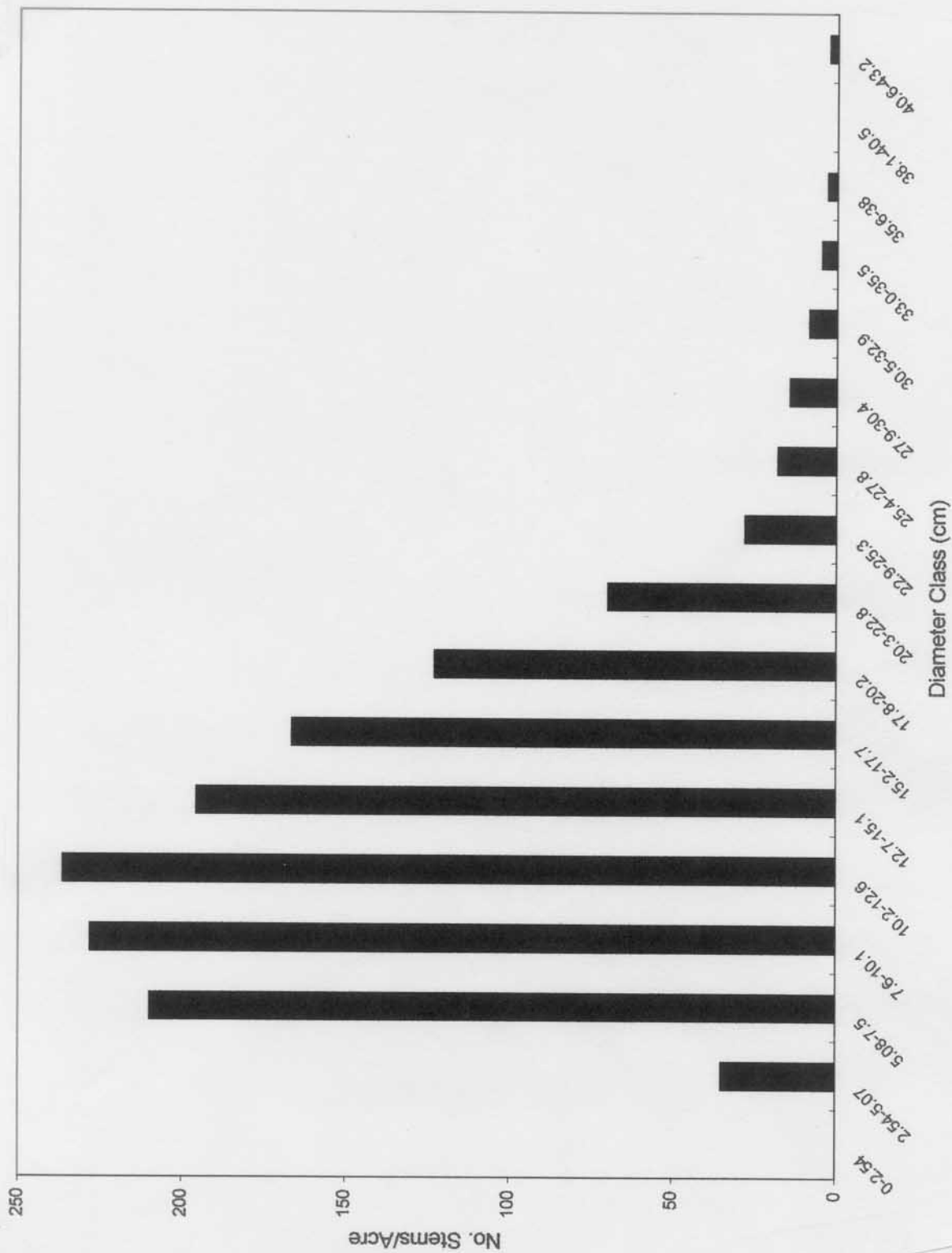


Figure 3. Stem density by diameter class for pitch pine, with density estimated from diameter sampled on variable radius plots.

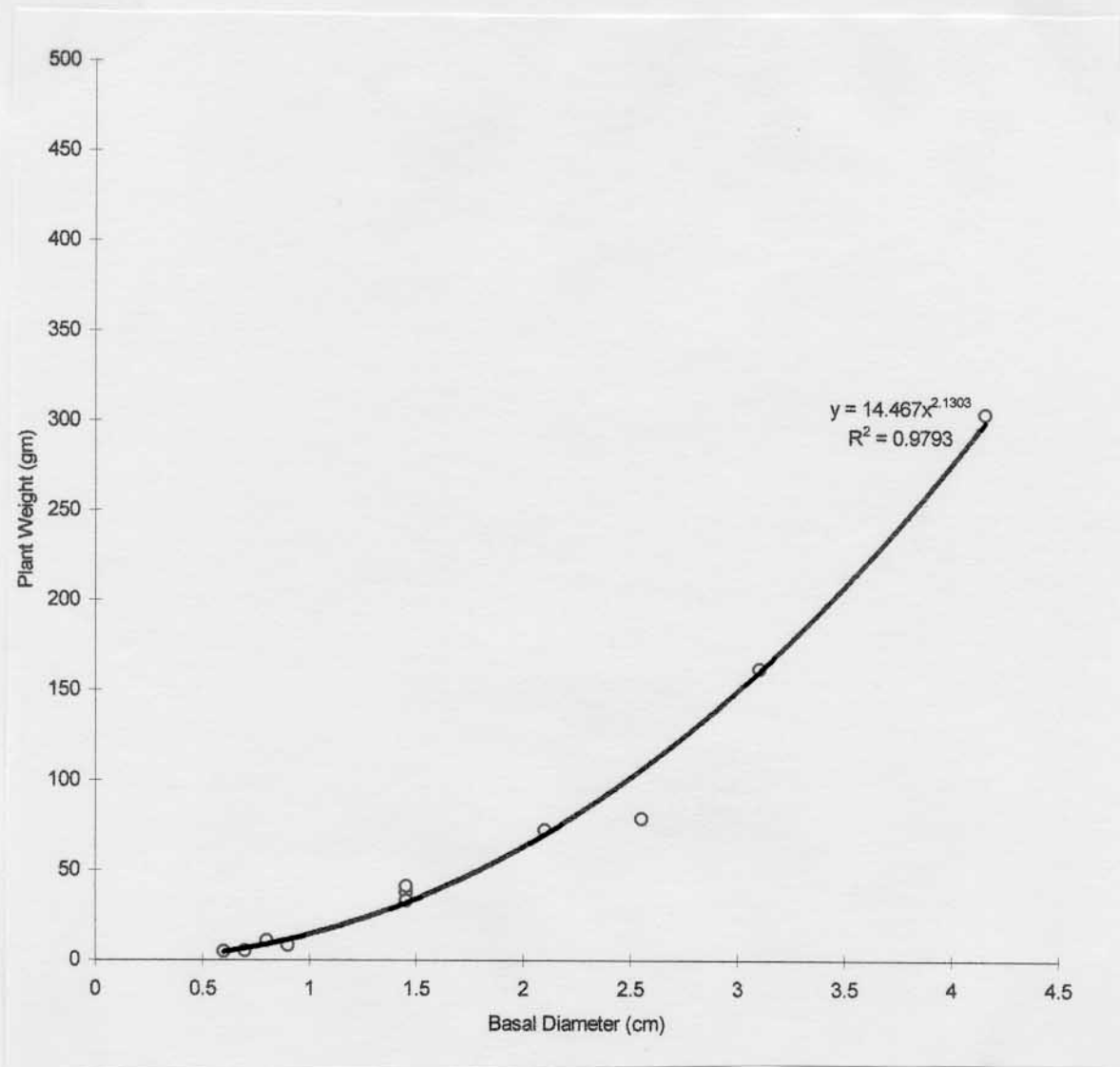


Figure 4. Regression of above ground weight (leaves, branches and stem) on basal diameter for scrub oak sampled at the Waterboro TNC parking lot location.

Table 1. Average basal area and stocking of overstory species sampled on 20 variable radius plots at the Waterboro Barrens.

Species	Basal Area (ft ² /acre)	Stem Density (#/acre)
<i>Pinus rigida</i>	234.7	1383.2
<i>Populus grandidentata</i>	0.7	5.9
<i>Populus tremuloides</i>	0.7	2.7
<i>Betula populifolia</i>	2.0	9.1
<i>Prunus pensylvanica</i>	0.7	10.4
Total	238.8	1411.3

Table 2. Average stand characteristics based on 20, 10 m² relevé samples at the Waterboro Barrens.

Slope (%)	5.1
Aspect	NW
Canopy	
Cover (%)	59.1
Tree Height (ft)	36
Height - base of live crown (ft)	20
High Shrubs	
Cover (%)	55.4
Height (ft)	6.5
Low Shrubs	
Cover (%)	73.5
Height (ft)	0.7
Grass/forbs	
Cover (%)	1.5
Height (ft)	0.5
Litter	
Cover	87.5

Table 3. Field notes on trees cored at the Waterboro Barrens TNC "parking lot" site, August 19-20, 1998.

Tree #	Species	DBH (cm)	Core Age (yrs.)	Est. Estab. Date ¹ (yr. AD)	Radial Growth (cm/yr)	Note
1	PINRIG	37.1	59?	ca. 1930	0.31	slow growth ca. 40 y.a.
2*	PINRIG	20.9	45	1949	0.23	slow growth at start
3	PINRIG	18.9	40	1954	0.24	
4	PINRIG	34.1	62	1932	0.28	slow growth ca. 30 & 46 y.a.
5	PINRIG	15.5	33	1961	0.23	very slow recent growth
6	PINRIG	25.4	86	1908	0.15	slow growth 46 y.a.
[dead snag between trees no. 6 and 7 was 12-15 cm dbh when scarred by the 1947 fire. Tree no. 6 clearly damaged by 1947 fire]						
7	PINRIG	42.3	~126	ca. 1868	0.17	center rotten; slow growth 9,48,19,32,62,75,94,102,115 y.a.
8*	PINRIG	23.2	42	1952	0.28	
9*	PINRIG	28.3	49	1949	0.29	
10*	PINRIG	7.7	27	1967	0.14	very slow recent growth
11	PINSTR	34.7	33	1961	0.53	
12	PINRIG	13.2	38	1956	0.17	
13	PINRIG	28.4	~72	1922	0.19	very slow growth ca. 46 y.a.; fire-scarred branches mid-bole
14	PINRIG	32.1	~68	1926	0.24	very slow growth 40-50 y.a.; heavily fire scarred on bole and branches
15	PINRIG	30.3	~65	1928	0.23	slow growth 10 and 30 y.a.; some scarring but not as much as on #14
16	PINRIG	18.0	37	1957	0.24	
17	PINRIG	22.7	44	1950	0.26	
18	PINSTR	22.7	36	1958	0.31	
19*	PINRIG	3.0	28	1968*	0.05	count basal section of felled stem
20*	PINRIG	38.7	80	1914	0.24	fire scarred branches
21	PINRIG	19.4	38	1956	0.26	
22	PINRIG	44.3	104+	<1890	0.21	center rotten; charred bark, scarred branches; slow growth 30,51,67,76 y.a.
23	PINRIG	7.1	33	1961	0.11	
24	PINRIG	10.7	36	1958	0.15	
25	PINRIG	19.0	38	1956	0.25	
26	PINRIG	10.7	38	1956	0.14	
27	PINRIG	21.3	39	1955	0.27	

* indicates 2 years added to "core" age.

* indicates core/section included pith.

1 Age at core height plus 4 years.

Table 4. Number of pitch pines and average radial growth by age class for 25 pitch pine stems sampled at the Waterboro Barrens TNC "parking lot" site.

Core Age (yrs.)	No. of Trees	Ave. Radial Growth (cm/yr)
0-30	2	0.10
31-40	10	0.21
41-50	4	0.27
51-60	1	0.31
61-70	3	0.25
71-80	2	0.22
81-90	1	0.15
91-100+	2	0.19

Table 5. Number of pitch pines and average radial growth by estimated year of establishment for 25 pitch pine stems sampled at the Waterboro Barrens TNC "parking lot" site.

Estimated Year of Establishment (yr. AD)	No. of Trees	Average Radial Growth (cm/yr)
≤1930	8	0.22
1931-1947	1	0.28
1948-1960	12	0.25
1961-1967	3	0.16
1968-present	1	0.05

Table 6. Summary of fuel bed characteristics derived from sampling downed woody fuel lines and 40 by 40 cm "harvest" plots and 1 by 1 m "scrub oak" plots at the Waterboro barrens.

Downed Woody Fuel (average for 20, 50-foot lines)

Fuel Depths (in ft)

Duff	0.2
Litter	0.2
Fuel (litter and downed wood combined)	1.3
Low Shrubs (corrected for cover)	0.8
High Shrubs (corrected for cover)	3.3

Woody Fuel Load (tons/acre)

1-hour	0.5
10-hour	1.7
100-hour	1.7
1000-hour sound	0.7
1000-hour rotten	0

Total	4.6

40 X 40 cm "harvest" plots (average for 10 plots)

Litter (dead/downed) (tons/acre)

Non-woody	6.0
1-hour woody	1.1
10-hour woody	1.0
100-hour woody	0.2

Total	8.2

Live Rooted (tons/acre)

Leaves, grasses/forbs	0.4
1-hour woody	0.4
10-hour woody	0.003
100-hour	0

Total	0.8

Dead Rooted (tons/acre)

Leaves, grasses/forbs	0
1-hour woody	0.1
10-hour woody	0
100-hour woody	0

Total	0.1

Table 7. Mass of live scrub oak leaves and stem/branches by time-lag (size) class estimated from stem density by size class sampled on 20, 1 by 1 m plots and regression equations (see below).

Plant Component	Mass (tons/acre)
Leaves	0.5
1-hour wood	0.9
10-hour wood	1.5
100-hour wood	0.1

Total	3.0

Regression equations for estimating scrub oak weight based on basal diameter (weight, y, in grams; diameter, x, in cm):

Leaves:	$y = 14.467x^{2.1303}, r^2 = 0.98$
1-hour wood:	$y = 23.931x^{2.0716}, r^2 = 0.97$
10-hour wood:	$y = 286.97x - 271.04, r^2 = 0.96$
Total above-ground:	$y = 58.247x^{2.8467}, r^2 = 0.97$ (see Figure 4)

Note: 100-hour wood is estimated as the difference between total weight and weight of leaves, 1- and 10-hour components.

Table 8. Parameters for the Waterboro pitch pine-scrub oak custom fuel model (fuel load and depth corrected for cover).

Loads (t/acre)		S/V ratio	Other	
1 hr	7.59	2178	Depth (ft)	1.02
10 hr	2.94	-	Heat content (BTU/lb)	8073
100 hr	1.59	-	Moisture of extinction (%)	26
Live herb	0	0	Wind reduction factor	0.6
Live wood	0.86	1500		

Table 9. Fire behavior characteristics predicted by the Waterboro custom fuel model using fixed environmental data (fuel moisture and slope) and mid-flame winds of 1, 10 and 18 mph.

Environmental Data (%)

1-hr FM	6
10-hr FM	10
100-hr FM	15
Live herb	150
Live wood	80
Slope	5

Mid-flame Wind Speed (mph)

Model Outputs	1	10	18
Rate of spread (ch/hr)	5	78	192
Flame length (ft)	4.6	16.6	25.1
Reaction Intensity (Btu/ft ² /min)	9669	9669	9669
Heat/area (Btu/ft ²)	1778	1778	1778
Fire Line Intensity (Btu/ft/sec)	154	2544	6258

Table 10. Waterboro custom fuel model (WCFM) outputs compared with standard fuel models 4, 6 and 7 run under similar environmental conditions (see Table 9) and a mid-flame wind of 5 mph (8.3 mph, 20-ft wind speed).

Fuel Model

Model Outputs	WCFM	4	6	7
Rate of spread (ch/hr)	28	88	33	31
Flame length (ft)	10.4	21.1	6.0	6.2
Reaction Intensity (Btu/ft ² /min)	9669	12069	1880	2119
Heat/area (Btu/ft ²)	1778	2665	462	524
Fire Line Intensity (Btu/ft/sec)	917	4305	281	300

APPENDIX A

Methods used to sample vegetation and fuels Waterboro Pine Barrens Preserve, Waterboro, ME

Supervisor - William Patterson

Field Workers - Kent Nelson, Erin Kenney and Nate Gourd.

I. Equipment

A. measuring devices

1. tree calipers
2. 100' measuring tapes, marked in feet and tenths (2)
3. sturdy, readable yard stick, marked in feet and inches
4. go-no-go gauges, with increments that correspond to time lag classes (2)
5. spherical densiometer, concave
6. clinometer
7. "cruz-all" or prism

B. other equipment

1. rear sighting compass
2. map of study area
3. blank data sheets and clipboard
4. pencils, permanent markers, calculator
5. chaining pins (2)
6. small trowel or old knife for digging through duff
7. paper bags for litter samples
8. 40cm x 40cm (1600 m²) frame made from 1/2" PVC pipes
9. 1m x 1m frame made from 1/2" PVC pipes
10. pruning shears

II. Gathering data for sample plots

A. Downed woody fuel inventory (per Brown 1974 and Patterson 1998)

1. select directions (N-S or E-W) for transects based on presence of roads, trails and changing forest types.

- a. four transect lines, 100' apart
- b. five points on each transect, each 100' apart

2. measure 150' from plot center of the first plot in a direction perpendicular to transects (to avoid sampling through the plot center, which is fairly well trampled by now). this is point #1.

3. at each point:

a. use the densiometer to measure % cover of all vegetation above waist height.

b. use cruz-all to tally all live stems (variable radius plots).

(1) BAF of 5 or 10 can be used, based on the amount of trees tallied.

(a) record diameters at breast height to the nearest 10th of an inch.

c. look at the second hand of a watch. The sampling plane will extend 50' in the direction which corresponds to 30 times the number at which the second hand points *plus* the bearing of the transect line.

(1) example: transect runs west at 270.

Your second hand is on the 3. $3 \times 30 = 90$. $90 + 270 = 360$, or true north.

(2) example: transect line runs south at 180.

Your second hand is on the 10. $10 \times 30 = 300$. $300 + 180 = 480$.

$480 - 360 = 120$. Your sampling plane should run at a bearing of 120.

d. attach a measuring tape to a chaining pin at the point

e. extend the measuring tape for 50' in a straight line following the bearing calculated above. The tape should lie as close to the ground as possible and vegetation surrounding the plane should be disturbed as little as possible.

f. with one person standing at the end of the sampling plane and another at the point, the clinometer should be used to measure the slope along the line.

g. along the sampling plane:

(1) in the first 6':

(a) count all intersections between the sampling plane and any dead, unrooted woody material less than 9' in height. Intersections should be divided into size classes:

(i) 0 - 1/4" diameter

(ii) 1/4 to 1" diameter

(iii) 1 - 3" diameter

(iv) >3" diameter

Note 1: for all intersections with pieces > 3", measure actual diameter where intersected, perpendicular to the center axis of the piece and record as either sound or rotten.

Note 2: dig into litter along the ground and record intersections of wood within the litter as well as those above it.

(2) between 6 and 12':

(a) count all intersections between the sampling plane and any dead, unrooted woody material > 1/4" in diameter and below 9' tall. Intersections should be divided into size classes:

(i) 1/4 to 1" diameter

(ii) 1 - 3" diameter

(iii) >3" diameter

Note: for all intersections with pieces > 3", measure actual diameter where intersected, perpendicular to the center axis of the piece and record as either sound or rotten.

(3) between 12' and 20':

(a) count all intersections between the sampling plane and any dead, unrooted woody material > 1" in diameter and below 9' tall.

Intersections should be divided into size classes:

(i) 1 - 3" diameter

(ii) >3" diameter

Note: for all intersections with pieces > 3", measure actual diameter where intersected, perpendicular to the center axis of the piece and record as either sound or rotten.

(4) at 15':

(a) measure the height of the tallest scrub oak or tree shorter than 9' in height that intersects the sampling plane between 15 and 16'.

(b) measure the height of the tallest other shrub that intersects the sampling plane between 15 and 16'.

(c) measure the depth of the litter layer or the highest dead woody fuel (whichever is greater) that intersects the sampling plane between 15 and 16'.

(5) at 20':

(a) measure the depth of the duff layer -

(the base of the litter down to the top of the mineral soil)

(6) between 20 and 50':

(a) count all intersections between the sampling plane and any dead, unrooted woody material > 3" in diameter and below 9' tall. Note: for all intersections with pieces > 3", measure actual diameter where intersected, perpendicular to the center axis of the piece and record as either sound or rotten.

(7) at 30':

(a) measure the height of the tallest scrub oak or tree shorter than 9' that intersects the sampling plane between 30 and 31'.

(b) measure the height of the tallest other shrub that intersects the sampling plane between 30 and 31'.

(c) measure the depth of the litter layer or the highest dead woody fuel (whichever is greater) that intersects the sampling plane between 30 and 31'.

(8) at 40':

(a) measure the depth of the duff layer -

(the base of the litter down to the top of the mineral soil)

(9) at 45':

(a) measure the height of the tallest scrub oak or tree shorter than 9' that intersects the sampling plane between 45 and 46'.

(b) measure the height of the tallest other shrub that intersects the sampling plane between 45 and 46'.

(c) measure the depth of the litter layer or the highest dead woody

fuel (whichever is greater) that intersects the sampling plane between 45 and 46'.

4. move along the transect to the next point, 100' away from the first, and repeat procedure.

B. Relieve / Stand Survey to record vegetation types

Note: plots can be set up along a similar transect (and with similar spacing) as the downed woody fuel inventory plots as long as the area isn't too heavily disturbed from previous sampling. Transects should stay within known cover types.

1. Relieve plots - Estimate % cover of all woody and herbaceous plant species by
 - a. canopy
 - b. high shrub
 - c. low shrub
 - d. grasses / forbs
 - e. leaf litter

note: percent cover is a subjective measure that uses a reference area of a 10m² circle. The vertical projection of the crown or shoot area of each plant species is projected on the ground surface and estimated by using the following cover classes:

- 1 = < 1% (1 sq. meter)
- 2 = 1 – 5%
- 3 = 5 – 25%
- 4 = 25 – 50%
- 5 = 50 – 75%
- 6 = 75 – 100%

After the percent cover of individual plant species is recorded, a subjective estimate of *total % cover by strata* is also recorded.

2. Stand Survey

- a. originate from the same plot center as the relieve plots.
- b. 10 subplots are completed at aprx. 1 chain intervals away from the original relieve plot center.

(1) Based on a 6' radius circle, the following observations are recorded:

- (a) slope/aspect
- (b) % canopy listed by dominant species
 - (i) average height (ft)
 - (ii) distance to live crown (ft)
- (c) % cover of strata by classes listed above
 - (i) % high shrub and average height (to nearest .5 meter)
 - (ii) % low shrub and average height (to nearest 2" class)
 - (iii) % grass/forbs and average height (to nearest inch)
 - (iv) % leaf litter

(2) other observations such as fire scars, unique plants and a sketch map of the sampling scheme are also recorded.

C. Clip Plots - used to measure litter accumulation

1. using aprx. 1 chain spacing, harvest samples of fine fuels from untrampled locations within known cover types. Each 40cm x 40cm (1600cm²) frame encompasses 1 subplot; 10 subplots per plot.
 - a. randomly throw 40cm x 40cm (1600cm²) frame until it lies flat on forest floor
 - b. clip all stems < 1" at base, sorting material as you cut
 - c. place stems into properly labeled bags
 - (1) live stems
 - (2) dead standing material
 - (3) litter
 - d. store bags of litter in a dry area until they can be oven dried.

D. Scrub oak plots to measure scrub oak density

1. using approx. chain spacing, sample scrub oak stems from locations within known cover types. Each 1m x 1m frame encompasses 1 subplot; 10 subplots per plot.
 - a. randomly throw yard stick (made visible w/ flagging) in area to be sampled.
 - b. line 1m x 1m frame up with yard stick so it lies flat on forest floor.
 - c. measure and record the amount of stems using go/no-go gauge (to avoid double counting, destructive sampling may be used).
The gauge should have .25 cm increments ranging from .25 cm up to 3 cm.
In addition, a tally should be kept on stems larger than 3 cm.

III. laboratory procedures

A. clip plots

1. dry bags and contents at 70 degrees Celsius
2. separate herbaceous material from woody material
3. weigh components and record according to the categories collected:
 - a. live vegetation
 - b. dead standing vegetation
 - c. litter
4. record weight of woody components by timelag class
 - a. 0 - 1/4" diameter = 1 hour fuels
 - b. 1/4" - 1" diameter = 10 hour fuels
 - c. 1" - 3" diameter = 100 hour fuelsnote: no 1000 hour fuels were collected

IV. preparing data for input to BEHAVE

- A. input data into spreadsheet, sorted by cover type.
- B. use ordination analysis to determine distinct custom fuel models.
- C. organize data according to distinctions made using ordination analysis.
 1. get fuel loads from dry weights from clip plot samples
 - a. shrub loads must include scrub oak weights estimated using allometric equations.
 2. depth calculations
 - a. litter and shrub depth are the average of actual sample points along DWF lines (do not include points with no observations).
 - b. grass depth is taken from Stand Survey data
 3. cover percent
 - a. litter and grass are taken directly from Stand Surveys.
 - b. shrub cover is the average of the low and high shrub covers from the Stand Survey.
- D. follow prompts to enter data into the NEWMDL program of BEHAVE.
 1. Litter load and depth
 2. Grass load and depth
 3. Shrub load and depth
 4. Heat content
 5. Surface area-to-volume ratio