

## Acknowledgements

This report was made possible by the guidance and expertise of Dr. William A. Patterson III and the funding provided by the Maine Army National Guard. I am grateful to both for allowing me to participate in this study. This research was supported by funds from the Legacy

### **Determining the Optimal Prescribed Burn Frequency for Ecological Restoration in the Pitch Pine - Scrub Oak Barrens of Hollis, Maine**

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## Abstract

The Hollis Training Site (HTS) of the Maine Army National Guard is located in Hollis, Maine, and contains approximately 350 acres (140 ha) of boreal pitch pine-scrub oak barrens, a globally rare and critically imperiled plant community. Vegetation at the site is fire dependent and has been degraded by fire suppression and soil disturbance associated with decades of military activity. Controlled burns were conducted at the HTS from 1995-1999 in an effort to restore and to manage this rare community. My research examined fuel load recovery following burns in an effort to determine appropriate fire return intervals if burning is continued.

The interval at which pitch pine - scrub oak barrens can burn depends on fine fuel loading which is a function of vegetative recovery. Post-fire fuel loading was determined over two field seasons for the two dominant cover types: pitch pine-scrub oak (PP-SO), and scrub oak-grey birch (SO-GB). Pre- and post-burn fuel loads by time lag class were sampled in each cover type. Percentage recovery of fine fuels for the PP-SO cover type was 69.8% after two years and 91.2% after three years. For the SO-GB cover type, percentage recovery of fine fuels was 93.6% three years after the initial burn. Fuel bed characteristics including loading by size class, fuel height and plant cover were used with BEHAVE - a computer-based fire behavior prediction system - to create six custom fuel models for the unburned and recently burned conditions in the two cover types. The results indicate that the dominant cover types at the Hollis Training Site could burn in a minimum of 3 years. However, considering how weather conditions can vary post-burn growth of vegetation, it is likely that the optimum prescribed burn interval would be closer to 4 - 5 years.

### Appendix C

Fuel Models in BEHAVE, a computerized fire prediction system

1. Standard Fuel Model Parameters
2. Chart used for developing Custom Fuel Models

### Appendix D

Inputs for Custom Fuel Models

1. Inputs for Pitch Pine-Scrub Oak Custom Fuel Models
2. Inputs for Scrub Oak-Grey Birch Custom Fuel Models

### Appendix E

Results of Custom Fuel Model Runs

1. Results of Custom Fuel Model Runs in FIRE 1
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## Introduction

The Hollis Training Site (HTS) is a 350 acre (140 ha), pitch pine-scrub oak barren (PP-SO) on an outwash plain in Hollis, Maine (figure 1). It is located in York County and administered by the Maine Army National Guard. The barrens vegetation has a sparse, open canopy of pitch pine (*Pinus rigida* Miller) above dense scrub oak (*Quercus ilicifolia* Wangenheim) and /or grey birch (*Betula populifolia* Marshall). The low shrub layer consists primarily of lowbush blueberry (*Vaccinium* spp.), bracken fern (*Pteridium aquilinum*) and sweetfern (*Comptonia peregrina*). Schweitzer and Rawinski (1988) describe the plant community as the northeastern boreal variant of PP-SO barrens. This ecosystem supports several regionally and globally rare plant and insect species (Gawler and Jessee 1997) and is ranked critically endangered in the United States (Widoff 1987, Patterson and White 1993). Compared to other barrens, the condition of the Hollis plant community is poor (W.A. Patterson III, pers. comm.). Years of fire suppression, military training and unauthorized off road vehicle use have left the vegetation with inadequate pitch pine regeneration and abundant grey birch that is outcompeting scrub oaks and blueberries in many areas. If controlled fire is not permitted in the HTS, it is likely that this rare plant community would succeed to a more common forest type, such as mixed conifer/hardwood, which is not tolerant of fire (Patterson 1997).

The pitch pine-scrub oak barren at the HTS is a fire dependent community, and many of the unique plant species require periodic fires to successfully regenerate. Although the barrens were burned by wildfires in the past, ignitions are now aggressively suppressed due to increased human development in the area. When wildfires occur, fire fighting efforts are costly and may actually damage barrens soils. The Maine Army National Guard and the Maine Natural Areas Program are instituting a prescribed fire program to ensure that the area is burned periodically without undue harm to the environment. In order to successfully use prescribed fire to restore and maintain this rare community, it is necessary to determine how often to burn. We need to determine a fire return interval so that the frequency of burning can be incorporated into fire management plans for the site. An appropriate fire return interval depends on pre-burn fuel loading and will be based on present conditions with heavy fuel build-up. Ideally, the pre-burn fuel loading should be sufficient to carry a surface fire but not so intense as to threaten control lines.

Figure 1. Location map for the Hollis Training Site



# Hollis Training Site

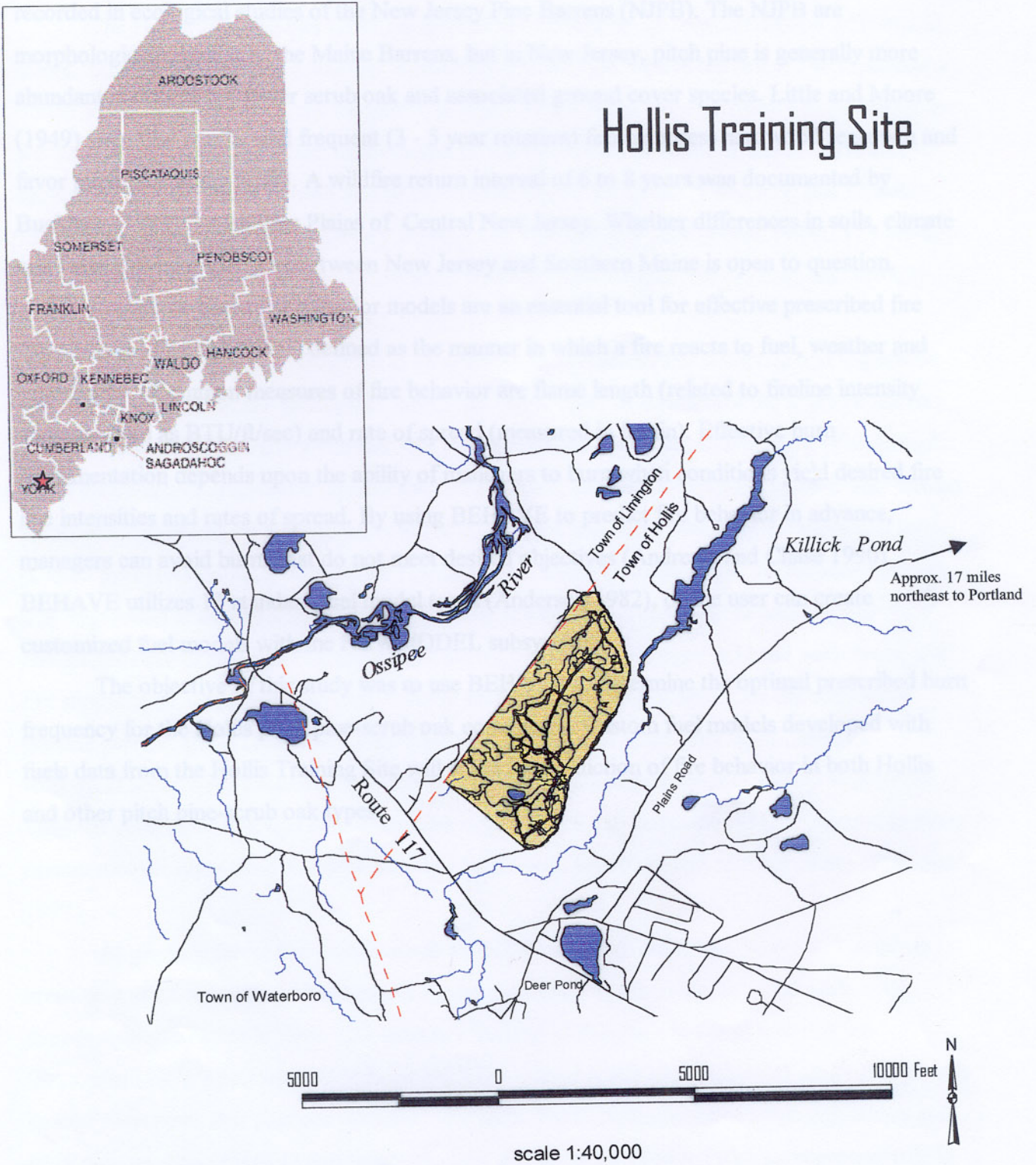


Figure 1. Location map for the Hollis Training Site

There are limited data on optimum fire return intervals for pitch pine-scrub oak communities like those at the HTS. However, observations of fire return intervals have been recorded in ecological studies of the New Jersey Pine Barrens (NJPB). The NJPB are morphologically similar to the Maine Barrens, but in New Jersey, pitch pine is generally more abundant and there are fewer scrub oak and associated ground cover species. Little and Moore (1949) state that regular and frequent (3 - 5 year rotation) fires suppress hardwood regrowth and favor pitch pine in the NJPB. A wildfire return interval of 6 to 8 years was documented by Buchholz (1983) for the Pine Plains of Central New Jersey. Whether differences in soils, climate and fuels allow comparisons between New Jersey and Southern Maine is open to question.

Computer-based fire behavior models are an essential tool for effective prescribed fire management. Fire behavior is defined as the manner in which a fire reacts to fuel, weather and topography<sup>1</sup>. Common measures of fire behavior are flame length (related to fireline intensity and measured as BTU/ft/sec) and rate of spread (measured in ft/min). Effective burn implementation depends upon the ability of managers to burn when conditions yield desired fire line intensities and rates of spread. By using BEHAVE to predict fire behavior in advance, managers can avoid burns that do not meet desired objectives (Andrews and Chase 1990). BEHAVE utilizes 13 standard fuel model types (Anderson 1982), or the user can create customized fuel models with the NEWMODEL subsystem.

The objective of this study was to use BEHAVE to determine the optimal prescribed burn frequency for the Hollis pitch pine-scrub oak community. Custom fuel models developed with fuels data from the Hollis Training Site will aid in the prediction of fire behavior in both Hollis and other pitch pine-scrub oak types.

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<sup>1</sup> Helms, J.A. 1998, editor. The Dictionary of Forestry. The Society of American Foresters. Bethesda, Maryland.



## Study Area

The Hollis Training Site (HTS) is located approximately 20 miles southwest of Portland, Maine, on a glacial outwash plain that is between 280' and 300' above sea level. The topography on the site is nearly level except for gently sloping terrain within close proximity to the two main wetland areas. The mean annual temperature in Sanford, 14 miles south of the HTS, is 46.1 degrees Fahrenheit and the mean annual precipitation is 46.09 inches (Flewelling and Lisante 1982). Growing seasons in Hollis vary from 134 to 164 days per year (Fobes 1946). The primary soil on the site consists of Adams loamy sand which is deep, excessively drained, and strongly acidic (Flewelling and Lisante 1982).

The area of interest within the HTS consists of 355 acres (143 ha) of upland vegetation primarily composed of the pitch pine - scrub oak cover type. In addition to the sparse overstory of pitch pine, grey birch and scrub oak, the low shrub layer has lowbush blueberry (*Vaccinium* spp.), bracken fern (*Pteridium aquilinum*), sweetfern (*Comptonia peregrina*) and in very limited areas, black huckleberry (*Gaylussacia baccata*). Sedges and herbs including Pennsylvania sedge (*Carex pensylvanica*) and cow-wheat (*Melampyrum lineare*) are found in the herbaceous layer. The vegetation at the HTS has been degraded by fire suppression as well as military and recreational use of the site. The effects of military training, unmanaged off-road vehicle use and fire suppression are apparent in altered stand structure and composition. Compared to more pristine barrens, the HTS has less pitch pine regeneration and more grey birch. From an ecological standpoint, excessive amounts of grey birch outcompete desired PP-SO vegetation. With the absence of fire, this overabundance of grey birch can cause the HTS to succeed to more common cover types such as mixed conifer / hardwood, which are less tolerant of fire (Patterson 1997).

At present, forest fuel conditions at the HTS vary from areas with heavy fuel build-up to areas with small amounts of fuels due to recent controlled burns. Because of the xeric soils, decomposition of litter is slow. This creates a buildup of fine fuels in the absence of fire (Patterson 1997). Many areas within the HTS have dense scrub oak thickets or clusters of closely spaced pitch pines that produce abundant fine fuels. These fuels consist of scrub oak leaves and pitch pine needles as well as thatch from sedges and ferns, all of which play an important role in determining the fire return interval.

During 1995-1999, prescribed fires at the Hollis Training Site were completed during the growing season and were of low intensity. The initial prescribed fire consumed fine fuels and dead standing stems but only top killed grey birch and scrub oak stems, leaving root systems unharmed. Depending on the fire return interval and the litter buildup, a second fire can have intensity similar to the first, as dead woody material created by top killing shrubs in the first fire is consumed by the second fire (Patterson 1997).

Twenty seven prescribed burn units were delineated at Hollis using vegetation types and existing fire breaks (Patterson 1997 see figure 2). Most of the fire breaks are 6' wide off-road vehicle trails and narrower foot trails created by the Maine Army National Guard in the early 1960's, when the HTS was first developed. The management units range in size from 2 to 30 acres and have been prioritized in three categories based on abundance of grey birch in the overstory. Management units with abundant grey birch are designated by Roman numeral "I" and were to be burned first. Between 1995 and 1999, crews lead by Dr. Patterson conducted 32 prescribed burns at Hollis (see Appendix A for complete burn history).



Figure 2. Cover type map for the Hollis Training Site (after Gawler et al. 1997).  
Note: management unit designations are based on the abundance of grey birch and are designated as: I = first priority, II = second priority and III = third priority.



## Cover Types and Burn Units of the Hollis Training Site

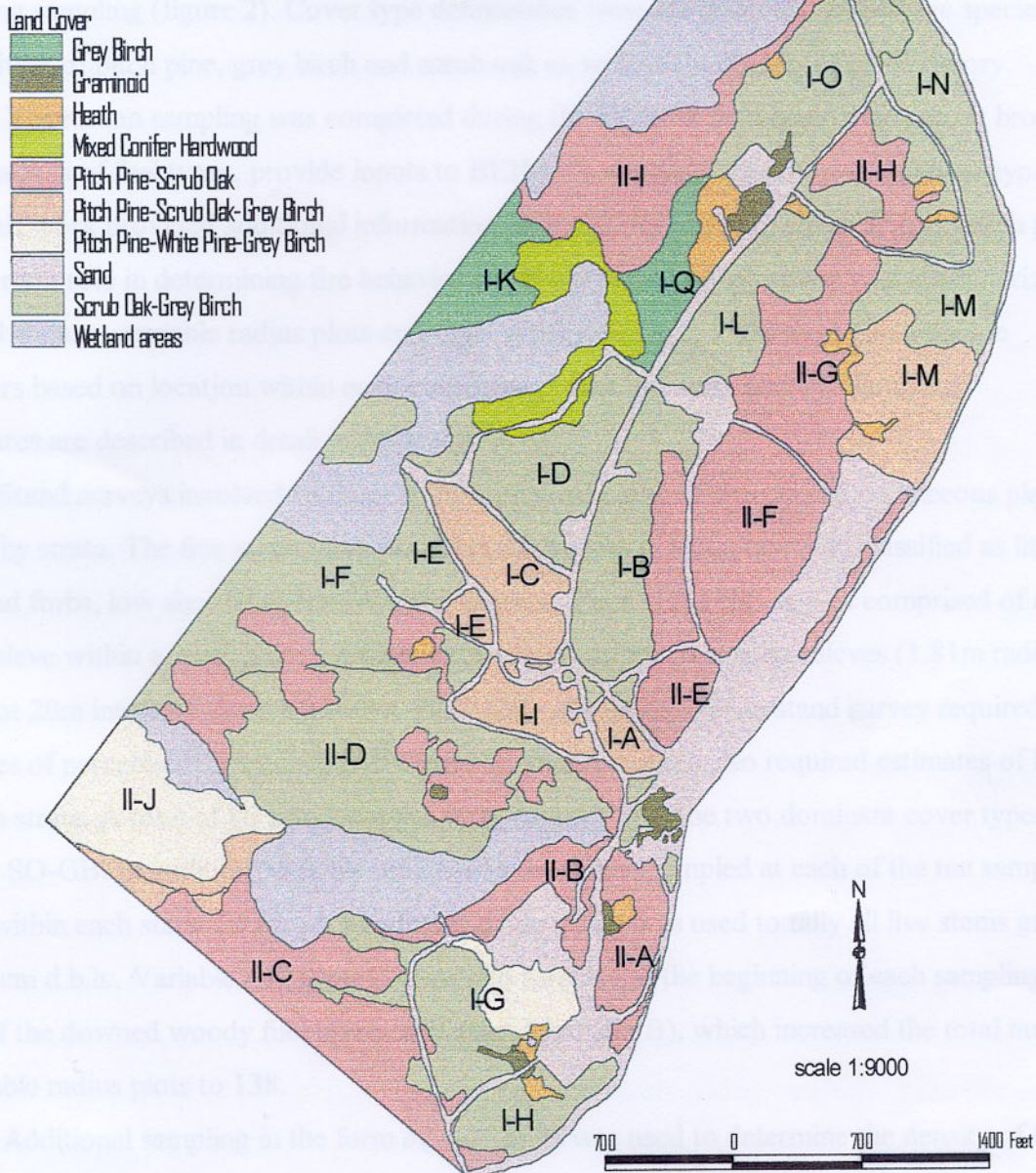


Figure 2. Cover type map for the Hollis Training Site (after Gawler *et al.* 1997).

Note: management unit designations are based on the abundance of grey birch and are designated as: I = first priority, II = second priority and III = third priority.

## Methods

### Determining Vegetative Communities

Overstory vegetation types defined by Gawler et al. (1997) were used as a basis for stratifying sampling (figure 2). Cover type delineations were based on the percentage species composition of pitch pine, grey birch and scrub oak as well as the density of all overstory species. Vegetation sampling was completed during the 1998-99 field seasons to permit broad classifications of fuel types, provide inputs to BEHAVE and field check Gawler's cover-type map. This work provided additional information on the composition of shrub layers, which play an important role in determining fire behavior in PP-SO barrens. Vegetation was characterized by stand surveys, variable radius plots and  $1\text{m}^2$  scrub oak plots. Plots were given unique identifiers based on location within each management unit and burn history. Sampling procedures are described in detail in Appendix B.

Stand surveys involved estimating the combined cover of woody and herbaceous plant species by strata. The five strata were based on differences in vegetation and classified as litter, grass and forbs, low shrubs, high shrubs and canopy. Each stand survey was comprised of an initial releve within a  $20\text{m}^2$  (2.5m radius) circle, followed by 10 smaller releves ( $1.81\text{m}$  radius) spaced at 20m intervals along a transect. Both sizes of releves in each stand survey required estimates of percent cover by strata, whereas the smaller releves also required estimates of height for each strata. A total of 86 stand surveys were completed in the two dominant cover types: PP-SO and SO-GB. In addition, variable radius plots were also sampled at each of the ten sample points within each stand survey. A five-factor angle gauge was used to tally all live stems greater than 10cm d.b.h.. Variable radius plots were also sampled at the beginning of each sampling plane of the downed woody fuel inventories (see Appendix B), which increased the total number of variable radius plots to 138.

Additional sampling in the form of  $1\text{m}^2$  plots was used to determine the density of live scrub oak. The 110 "scrub oak" plots were sampled using a systematic sample design. Each burn unit sampled had approximately 10 plots for each cover type represented within the unit. Stems were tallied in 13, 0.25cm wide size classes from 0-0.25cm to 2.75-3cm, with the last class reserved for all stems  $>3\text{cm}$ . Analysis of these data provided information on the variation of scrub oak density among cover types and provided inputs for shrub fuel loading in BEHAVE.



## Quantifying Fuel Load

Harvest plots, scrub oak plots and downed woody fuel inventories were completed to determine fuel loading by vegetation type and burn history. One hundred seventy-seven separate 40cm x 40cm "harvest plots" were sampled to provide data on fine fuel loading. As vegetation from the ground was clipped, it was sorted in three categories: litter, live standing, and dead standing woody material. In the lab, materials were dried, sorted by timelag class and weighed (in grams to the nearest 0.1gm). Timelag is an expression of the rate a fuel approaches its equilibrium moisture content (Pyne et al. 1996). Timelag classes range from 1 hour to 1000 hour and are based on the amount of time needed for live herbaceous and dead woody material to lose 63% of the difference between its current moisture content and its equilibrium moisture content<sup>2</sup>. Equilibrium moisture content occurs when the moisture content of a fuel becomes very close to the moisture of the air which surrounds it. Sizes of wood for timelag classes are based on the following stem diameters: 0 to .25" for the 1 hour class, .25 to 1" for the 10 hour class and 1" to 3" for the 100 hour class. This fuel classification system was developed by Byram in 1963 (unpublished) and also includes a 1000 hour class which is not used by BEHAVE fuel models. The procedures for gathering and processing harvested material are detailed in Appendix B.

Most management units sampled had sufficient area to permit 10 harvest plots to be sampled in each cover type. In cases where recently burned areas were smaller than approximately 2 acres, less than ten plots were sampled. In addition to data gathered during 1998 and 1999, supplementary harvest plot data collected in 1995 by Patterson and his students (unpublished data) were used in my analysis. Processing the data involved sorting the harvest plots by cover type and burn history, and converting mean weights to tons per acre.

Data analysis involved calculating several sets of averages. First, I averaged the 10 plots sampled in each burn unit to determine average fuel loading by cover type and burn history. These averages were used as inputs to the custom fuel models and for analysis of the distribution of fine fuels. Next, I averaged all the unburned 1-hour fine fuel data from all the harvest plots, regardless of cover type. This average, based on a large sample size, was compared to averages based on smaller samples which had been sorted by cover type and burn history. The results permitted comparisons to be made between overall fuel load of the HTS and fuel loads of both unburned and recently burned plots, the data which were eventually used as inputs for custom

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<sup>2</sup> Helms, J.A. 1998, editor. The Dictionary of Forestry. The Society of American Foresters. Bethesda, Maryland.

fuel models.

The fuel load of live scrub oak was estimated from  $1\text{m}^2$  plots, where scrub oak stems were tallied by basal diameter. Allometric equations developed through sampling scrub oak at nearby Waterboro Barrens, Maine (Patterson 1999) were used to convert size / density data to fuel load. Descriptive statistics for scrub oak weight by plot were used to determine the uniformity of the shrub layer and the fuel load.

Using procedures outlined in appendix B, a modified version of Brown's (1974) planer intercept sampling method was used to sample downed woody fuels. The method was modified to better characterize fuel depths in a similar PP-SO cover type (Patterson 1999). Predictions of fire behavior (using BEHAVE) are especially sensitive to fuel depth (Patterson 1998). One hundred and ten downed woody fuel lines were sampled over the two-year study period.

### **Custom Fuel Model Development**

BEHAVE allows the user to predict fire behavior either with 13 standard fuel models or with user-defined custom fuel models (Anderson 1982). The standard fuel models were developed to help fire managers realistically estimate fire behavior. They are based on typical fuel complexes in the United States including grass dominated vegetation, Chaparral and shrub fields, the litter associated with standing timber, and various amounts of logging slash within harvested areas. Woodall (1998) indicates that the use of standard fuel models 4 (Chaparral), 6 (dormant brush, hardwood slash) and 7 (Southern rough) poorly estimates fire behavior in PP-SO fuels. The parameters for standard fuel models 4, 6 and 7 are listed in Appendix C, page 1. Therefore, several custom fuel models (CFM's) were created for the HTS. Once the CFM's for Hollis were developed, estimates of fire behavior derived from these models were compared with those for standard fuel models 4, 6 and 7 to verify Woodall's conclusion.

Inputs for CFM's based on unburned units were derived from sampling one or two burn units with similar fuelbed / cover type characteristics. Custom fuel models which represented post-burn conditions were developed from several different burn units with burn histories ranging from 1 to 3 years post-burn. Enough data were collected to create four CFM's for the PP-SO cover type (1. unburned 2. one year post-burn 3. two years post-burn and 3. three years post-burn) and two CFM's for the SO-GB cover type (1. unburned 2. three years post-burn).

The inputs for the CFM's were based on fuel load characteristics from the fieldwork completed in 1998-99 as well as surface area-to-volume ratios and heat contents suggested by Patterson (pers. comm).

Data characterizing fuel beds were used with the NEWMODEL subsystem of BEHAVE and were input in three categories of fuels: litter, grass and shrubs (see Appendix C, page 2). Inputs for litter required fuel load in tons per acre by timelag class. For the 1 hour fuel load, the weights for herbaceous non-woody litter and 1-hr woody litter from the harvest plots were combined. The 10- and 100-hour fuel loads were taken from the downed woody fuel inventories. Originally, litter and duff depth were combined from the fuel depth section of the downed woody inventories. This average fuel depth was used as the input for litter depth for each CFM. After several experimental runs of custom fuel models in BEHAVE, it was determined that litter depth was too shallow and the fire behavior predictions were inaccurate. In an effort to improve the fire behavior predictions, litter depth data was taken from the low shrub heights recorded in the stand surveys (per W. A. Patterson III, pers. comm.). He rationalized that fire burns above the litter layer when blueberry plants (*Vaccinium* spp.) are present. However, for custom fuel model #98 (scrub oak-grey birch 3 years post-burn), stand survey data were not available, so inputs for litter depth were derived from average fuel depths listed in the downed woody fuel inventories. The figures used for percent cover of litter were taken from relevés in stand surveys.

For the grass category, live standing herbaceous weights from the harvest plots were used for fuel load. Fuel depth (i.e., grass / forb height) and percent cover of grass originated from the stand survey data. "Maximum percent live" is an estimate of the greatest proportion of the total grass fuel load that can be alive at anytime during the year (Burgan and Rothermel 1984). My estimate of 30% for this study was based on guidelines set by Burgan and Rothermel (1984) and W. A. Patterson III, (pers. comm.) and considers the accumulation of dead grass from previous seasons.

Data for the shrub category were obtained from several sources. The harvest plots provided inputs for fuel load by timelag class. Data from the "dead standing" fuels were used for the 1 hour, 10 and 100 hour fuel loads. For "live foliage and twigs," the weights of live standing 1 hour fuels from the harvest plots were combined with the weight of the leaves from the 1m<sup>2</sup> scrub oak plots.



The shrub height data were available from the stand surveys as well as the downed woody fuel inventories. The average shrub height from the stand surveys was usually slightly different than the average shrub height data from the downed woody fuel inventories, which were calculated without using the zeroes listed on the field data sheet. Based on observations of shrub heights at the Hollis Training Site, the shrub height estimates from stand surveys represent actual site conditions better than similar data from the downed woody fuel inventories. However, this was problematic because NEWMODEL requires only one input for shrub height, yet the stand survey data contain separate high and low shrub estimates. To solve this problem, the average shrub height data required the following mathematical adjustments before being entered in BEHAVE:

$$\text{Adjusted height} = (\text{low shrub} + \text{high shrub}) / 2 * .7 \quad \text{for example, } (20 + 40) / 2 * .7 = 21$$

The maximum depths for grass and shrubs were multiplied by 0.7. Rothermel and Burgan (1984) recommended doing this to provide a reasonable estimate of depth for input into BEHAVE.

The overall percent cover of shrubs is an important input into BEHAVE that affects how the software predicts fire behavior. The following calculation developed by Patterson (unpublished) was used to combine and adjust the low and high shrub cover values from the stand survey samples:

$$\frac{(\text{avg. low shrub} + \text{avg. high shrub})}{2} + \frac{(\text{avg. low shrub} + \text{avg. high shrub})}{2}$$

$$\begin{aligned} \text{For example,} \\ \frac{(41\% + 59\%)}{2} + \frac{(41\% + 59\%)}{2} &= \frac{50\% + 100\%}{2} = 75\% \end{aligned}$$

This method produced an average cover for the shrub category that resulted in estimated fire behavior predictions from BEHAVE which were close to observed fire behavior at the HTS (Woodall 1998).



## **Fire Behavior Prediction**

For consistency, all fire behavior predictions were based on the headfire settings of the FIRE 1 subsystem of BEHAVE. Zero percent slope was used as an input to BEHAVE, because Hollis has very flat terrain and minor changes in the upslope condition setting had little effect on the fire behavior predictions. Inputs for fuel moisture and weather conditions were estimated based on data recorded during the 1998 -1999 field seasons (see table 8). A wind reduction factor of .3 was used for all the FIRE1 runs which predicted fire behavior. This allowed the midflame windspeed and 20' high windspeed to remain constant at 3 m.p.h. and 10 m.p.h. respectively.

The method used to determine how many custom fuel models were needed to accurately predict fire behavior at the HTS was based on the distribution of fine fuels. The distribution of fine fuels is an important determinant of fire behavior in barrens ecosystems and indicates how much fuel has accumulated in each vegetation type. The reason for characterizing fine fuels into fuel model groups was to reduce within-group variability and therefore increase the accuracy of the custom fuel models. A histogram showing the frequency of fine fuels by weight within each cover type was created to look for patterns in the distribution of fine fuels for the two main cover types (PP-SO and SO-GB). The graph was created from the sum of herbaceous and woody fuels in the 1-hour timelag class. Descriptive statistics were compiled for fine fuel loading in the two main cover types.

## **Determining the Optimal Fire Return Interval**

An optimal interval between fires was estimated based on pre- and post-burn fine fuel loading and the results of fire behavior predictions from BEHAVE. Two fire return interval matrices were developed: mean fine fuel load for PP-SO and SO-GB cover types by time since the last burn. Fine fuel was defined as the sum of herbaceous litter and woody 1-hr fuels. The FIRE1 Subsystem of BEHAVE was used to predict fire behavior in the dominant cover types. Predictions of flame length and rate of spread from BEHAVE were compared to flame lengths and rates of spread observed during prescribed burns. If predicted flame length and rate of spread for reburned units were below previously observed levels, I concluded that the amount of fine fuels was inadequate to permit a successful reburn.

## Results

### Vegetative Communities

Data from the variable radius plots, scrub oak surveys and stand surveys confirmed that the broad classification of community types provided by Gawler et al. (1997) still apply. However, Gawler's pitch pine overstory data in the PP-SO and SO-GB cover types were 27% and 48% greater, respectively, than my figures (table 1). I classified burn units (with pitch pine overstories) as PP-SO if they had mean basal areas greater than 21 ft<sup>2</sup> per acre.

**Table 1.** Comparison of pitch pine overstory data at the HTS.

		Avg. basal area			Avg. basal area
data source	cover type	(sq. ft./acre)	data source	cover type	(sq. ft./acre)
Nelson	PP-SO	35.3	Nelson	SO-GB	4.8
Gawler et al.	PP-SO	45	Gawler et al.	SO-GB	7.1

For tall shrubs, the average density of scrub oak stems varied between SO-GB and PP-SO, depending on the size of the stems. Scrub oak stems between 0 and 1.5 cm had similar average densities, regardless of overstory cover type (table 2). However, mean scrub oak density for stems > .75cm were generally 1.5 - 2 times higher for SO-GB than PP-SO.

**Table 2.** Average scrub oak stems per 1m<sup>2</sup> for the PP-SO and SO-GB cover types.

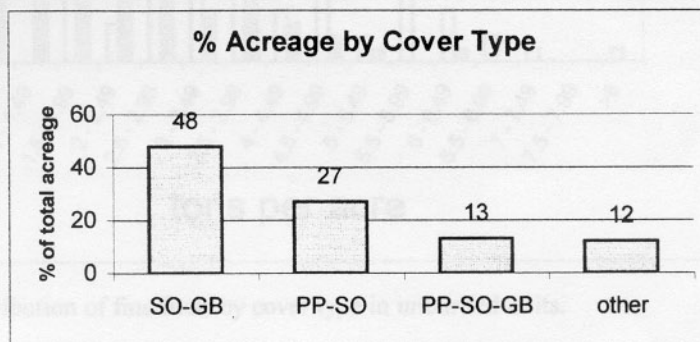
	cover type			cover type	
dia. class (cm)	PP-SO	SO-GB	dia. class (cm)	PP-SO	SO-GB
0.25	4.02	3.48	1.75	0.14	0.22
0.5	6.46	6.3	2	0.04	0.28
0.75	2.36	1.58	2.25	0.02	0.12
1	0.94	1.56	2.5	0	0.14
1.25	0.3	0.52	2.75	0	0.06
1.5	0.12	0.46	3	0	0
			>3	0.06	0.14
total	14.2	13.9	total	0.26	0.96

Statistical analysis indicated that within the PP-SO cover types, the scrub oaks in the high shrub layer were hyperdispersed (table 3). Human-caused and natural disturbances which occurred prior to this study have created clumps of scrub oak thickets surrounded by open patches of grass and herbaceous shrubs. The recent prescribed fires at Hollis have top-killed many of the scrub oaks and allowed them to resprout vigorously. As a result of the sprouting, a dense high shrub layer has formed around individual multi-stem scrub oaks.

**Table 3.** Statistics for mean scrub oak weight from a representative burn unit in the PP-SO cover type.

Burn Unit	n	mean weight		variance	ratio of		SE mean	(SEM/mean)*100	95% C.I.	width of C.I.
		(tons/acre)	StDev		var. to mean					
II-F	10	2.61	2.531	6.405	2.45		0.801	30.7	.8 to 4.42	3.62

Based on their aerial distribution at the Hollis Training Site, PP-SO and SO-GB are the two main cover types (figure 3). In order to make accurate predictions of fire behavior with BEHAVE, two different custom fuel models will be required.



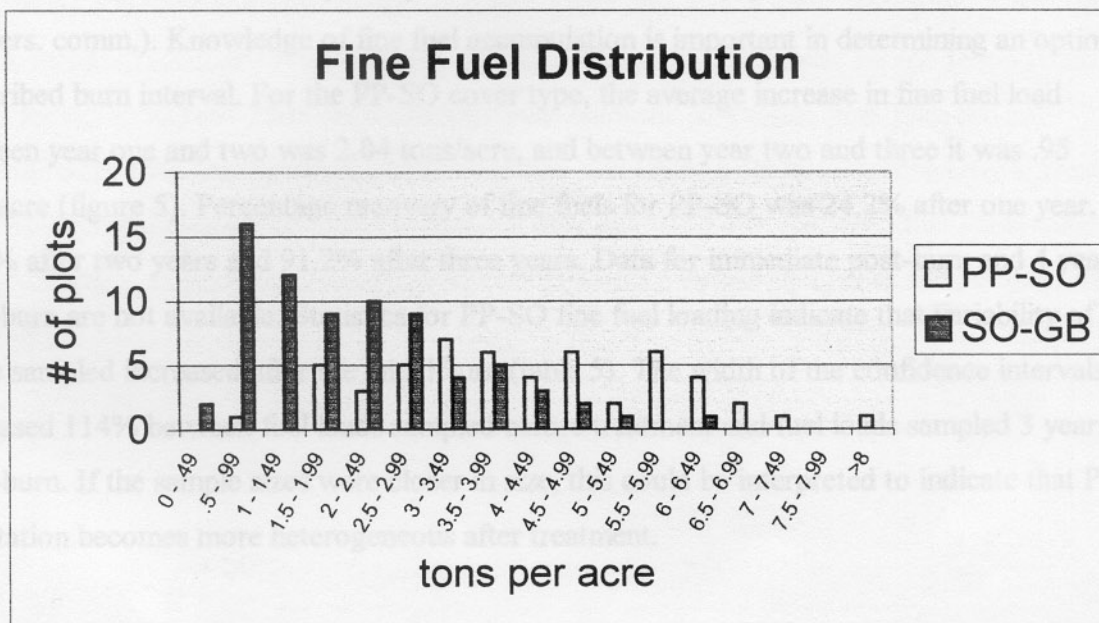
**Figure 3.** Distribution of cover types at the Hollis Training Site by percentage of total acreage indicates that SO-GB and PP-SO are the two main cover types (after Patterson 1997).

Overall, the HTS has more area in the SO-GB cover type than in the PP-SO cover type. However, I sampled more plots in the PP-SO cover type because there are more areas which were treated with prescribed fire in the PP-SO cover type. If additional sample plots had been sampled in SO-GB, then data for more CFM's (for each year post-burn - not just 3 years post-burn) would have been available. A chart labeled "Hollis Custom Fuel Model Inputs" is listed in Appendix D and can be used as a guideline for specific data needed by future researchers at the HTS.



## Distribution of Fine Fuels

The distribution of fine fuels is important in predicting fire behavior. If the fine fuels are uniformly distributed, then fire behavior is more predictable. Prior to treatment, fine fuel distribution differed between the PP-SO and SO-GB cover types (figure 4). The distribution of PP-SO was roughly bell shaped, although several readings between 3 and 6 tons per acre are similar. The build-up of pitch pine needles caused average fuel loads for PP-SO to be nearly twice that of SO-GB (4.13 tons/acre vs. 2.09 tons/acre). There was one value out of 53 less than 1 ton per acre for PP-SO, whereas SO-GB had 18 values out of 74 less than 1 ton per acre.



**Figure 4.** The distribution of fine fuels by cover type in unburned units.

The Anderson - Darling (A-D) normality test in Minitab statistical software produced a p value of .68, which confirms that the PP-SO data are normally distributed. By contrast, the distribution of SO-GB was positively skewed to the right and was not considered a normal distribution (the A-D test was 0.0). Because the confidence intervals don't overlap, this analysis of fine fuel data confirms that two separate custom fuel models are needed for Hollis, one for PP-SO and another for SO-GB (table 4).



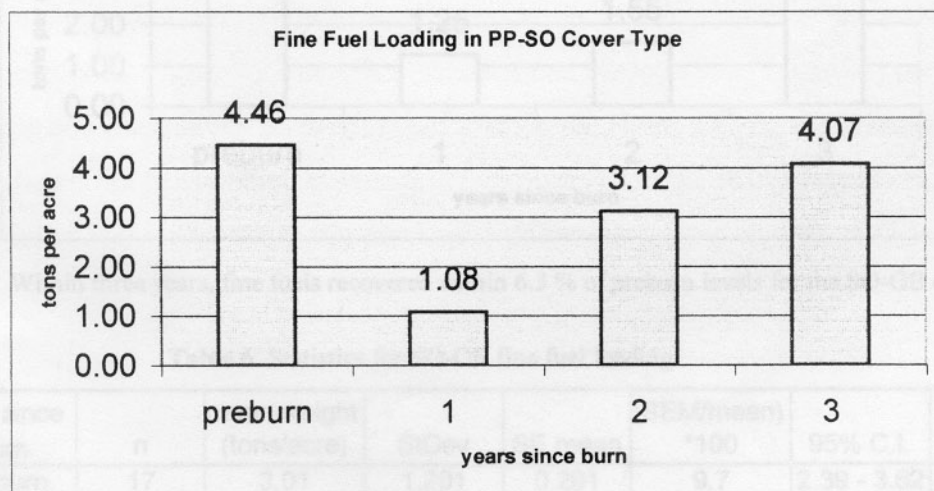
**Table 4.** Statistics for fine fuel distribution from areas sampled at the HTS prior to treatment.

Cover type	n	mean weight (tons/acre)	StDev	SE mean	(SEM/mean)		width of C.I.
					*100	95% C.I.	
PP-SO	53	4.13	1.64	0.226	5.5	3.67 - 4.58	0.91
SO-GB	74	2.09	1.28	0.149	7.1	1.80 - 2.39	0.59

Note: PP-SO is from a normal distribution and SO-GB is skewed to the right.

### Fuel Accumulation Following Burning

Dead fine fuels are the primary carrier of surface fires in pine barrens (W. A. Patterson III, pers. comm.). Knowledge of fine fuel accumulation is important in determining an optimal prescribed burn interval. For the PP-SO cover type, the average increase in fine fuel load between year one and two was 2.04 tons/acre, and between year two and three it was .95 tons/acre (figure 5). Percentage recovery of fine fuels for PP-SO was 24.2% after one year, 69.8% after two years and 91.2% after three years. Data for immediate post-burn and 4 years post-burn are not available. Statistics for PP-SO fine fuel loading indicate that variability of fuel loads sampled increased after the initial burn (table 5). The width of the confidence intervals increased 114% between fuel loads sampled before treatment and fuel loads sampled 3 years post-burn. If the sample sizes were closer in size, this could be interpreted to indicate that PP-SO vegetation becomes more heterogeneous after treatment.

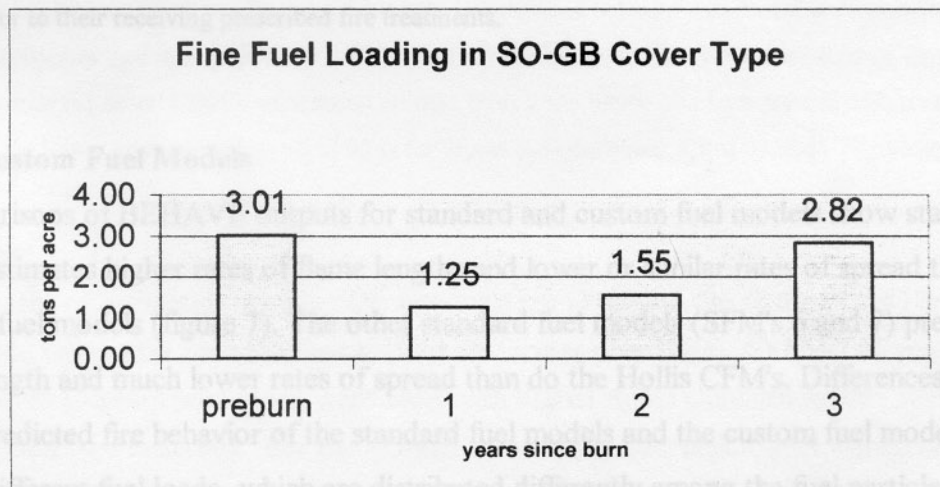


**Figure 5.** For the PP-SO cover type, fine fuels recovered to within 8.7% of preburn levels by the third year.

**Table 5.** Statistics for PP-SO fine fuel loading.

CFM	years since burn	n	mean weight (tons/acre)	StDev	SE mean	(SEM/mean) *100	95% C.I.	width of C.I.
90	preburn	23	4.46	1.613	0.336	7.5	3.76 - 5.15	1.39
91	1	10	1.08	0.609	0.193	17.9	.647 - 1.52	0.873
92	2	20	3.12	1.628	0.364	11.7	2.36 - 3.88	1.52
93	3	10	4.07	2.069	0.654	16.1	2.58 - 5.55	2.97

For SO-GB, average increases in fine fuel load were 0.3 tons/acre between the first and second year and 1.27 tons/acre between year 2 and 3 (figure 6). Percentage recoveries of fine fuels was 41.5% after one year, 51.5% after two years and 93.6% after three years. Compared to PP-SO, fuel load recovery in SO-GB was higher for the first year, lower for the second year and similar for the third year. Data for immediate post-burn and four years post-burn are not available. Unlike PP-SO, variability of SO-GB fine fuel loading did not increase after burning (table 6). The width of the confidence intervals only increased 14% between fuel loads sampled before treatment and fuel loads sampled 3 years post-burn. In this case, both sample sizes were equal with n = 17.

**Figure 6.** Within three years, fine fuels recovered within 6.3 % of preburn levels for the SO-GB cover type.**Table 6.** Statistics for SO-GB fine fuel loading.

CFM	years since burn	n	mean weight (tons/acre)	StDev	SE mean	(SEM/mean) *100	95% C.I.	width of C.I.
95	preburn	17	3.01	1.201	0.291	9.7	2.39 - 3.62	1.23
96*	1	20	1.25	0.726	0.162	13.0	.915 - 1.59	0.675
97*	2	20	1.55	0.854	0.191	12.3	1.15 - 1.95	0.8
98	3	17	2.82	1.36	0.33	11.7	2.12 - 3.52	1.4

\*CFM's 96 & 97 have not been created yet, due to insufficient data at this time.

Average 1 hour fuel loads used as inputs to custom fuel models were compared to similar fuel loads from all unburned plots combined. The results show that mean 1 hour fuel loads for unburned CFM's #90 (PP-SO) and #95 (SO-GB) were 22.8% greater and 12.5% lower, respectively, than the mean for all unburned plots combined (tables 5, 6 & 7). Statistical measures such as SEM/mean\*100 and the width of the 95% confidence intervals indicate that for each cover type, enough samples were collected and samples within each cover type had similar fuel loads. The fact that confidence intervals for unburned PP-SO and SO-GB cover types do not overlap confirm that two separate CFM's are needed at the HTS.

**Table 7.** One hour fine fuel load statistics for "all pre-burn plots combined" at the HTS.

type of plot	n	mean weight (tons/acre)	StDev	SE mean	(SEM/mean)		width of C.I.
					*100	95% C.I.	
all pre-burn plots combined	56	3.44	1.656	0.221	6.42	2.99 - 3.88	1.11

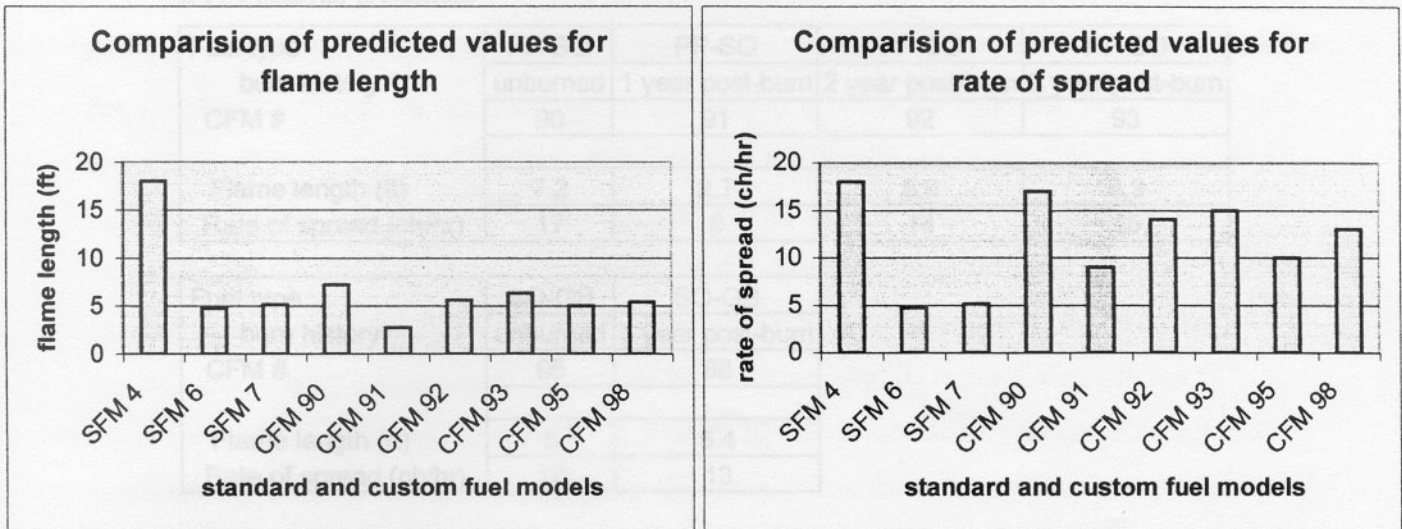
Note: "All pre-burn plots combined" is based on data from PP-SO, SO-GB and PP-SO-GB management units prior to their receiving prescribed fire treatments.

### Evaluating Custom Fuel Models

Comparisons of BEHAVE outputs for standard and custom fuel models show standard fuel model 4 estimates higher rates of flame lengths and lower or similar rates of spread than the Hollis custom fuel models (figure 7). The other standard fuel models (SFM's 6 and 7) predict lower flame length and much lower rates of spread than do the Hollis CFM's. Differences between the predicted fire behavior of the standard fuel models and the custom fuel models are based on the different fuel loads -which are distributed differently among the fuel particle size classes- and fuel depths.



Table 8. BEHAVE predictions of fire behavior at the Hollis Training Site (a) based on a standard set of environmental parameters (b).



**Figure 7.** Computer based predictions of fire behavior differed between standard fuel models (SFM's) 4, 6 & 7 and the Hollis custom fuel models (CFM's). CFM's 90 (PP-SO) and 95 (SO-GB) were based on data from unburned areas, while the other CFM's were based on data from areas which had been treated with prescribed fire (e.g., CFM 91 is for 1-year post-burn data, CFM 92 is for 2-year post-burn and CFM 93 and CFM 98 are for 3-year post-burn ).

As a means of estimating whether the fine fuels could carry a fire in the PP-SO cover type one to three years after the initial burn, CFM 91 (1 year post-burn), CFM 92 (2 years post-burn) and CFM 93 (3 years post-burn) were used with FIRE1 and a standard set of environmental data (see table 8b). For the SO-GB cover type, insufficient data were available to create CFM's for 1 year post-burn and 2 years post-burn. However, data were available to create CFM 98 (3 years post-burn). The results indicate that a successful prescribed burn in recently burned PP-SO cover type with typical environmental conditions is unlikely one year after a burn but reburns are possible within three years (table 8). More detailed information on the custom fuel model runs are listed in Appendix E.

**Table 8.** BEHAVE predictions of fire behavior at the Hollis Training Site (a) based on a standard set of environmental parameters (b).

a. Fire behavior predictions

Fuel type	PP-SO	PP-SO	PP-SO	PP-SO
burn history	unburned	1 year post-burn	2 year post-burn	3 year post-burn
CFM #	90	91	92	93
Flame length (ft)	7.2	2.7	5.6	6.3
Rate of spread (ch/hr)	17	9	14	15

Fuel type	SO-GB	SO-GB
burn history	unburned	3 year post-burn
CFM #	95	98
Flame length (ft)	5	5.4
Rate of spread (ch/hr)	10	13

b. Environmental parameters used in testing CFM's

Time lag class	Fuel moistures (%)		
1 hour	10	midflame windspeed	3 m.p.h.
10 hour	12	wind reduction factor	0.3
100 hour	18	percent slope	0
live herbaceous	150		
live woody	80		

## Discussion

The behavior of fire in boreal pitch pine-scrub oak barrens is affected by horizontal and vertical distribution of fine fuels, especially as they are affected by burn history. The growth and recovery of post-burn vegetation can vary considerably based on initial burn intensity and post-fire weather conditions. At the Maine Army National Guard's Hollis Training Site, the two main cover types (PP-SO and SO-GB) have fine fuels that are distributed differently. Fine fuels in PP-SO have a bell shaped distribution (figure 4) and permit more accurate predictions of fire behavior than the fine fuels in SO-GB, which are not distributed normally and are more variable. Statistical analysis of fine fuel loads shows only half of the confidence interval widths for PP-SO and SO-GB overlap (tables 5 and 6) because fine fuels are slightly more uniform in the SO-GB cover type. In the mid story, scrub oak > 1.5 cm in PP-SO is less dense and not distributed as uniformly as scrub oak of similar size in SO-GB. In addition, the two main cover types have fuel bed characteristics that differ enough to produce distinct fire behavior. BEHAVE predictions of fire behavior indicate that PP-SO burns more intensely than SO-GB (table 8).

To determine an optimal prescribed burn interval for the Hollis Training Site, knowledge of rates of fine fuel recovery for the main cover types was required. In general, the percentage recovery for fine fuels 1 and 2 years post-burn differed between PP-SO and SO-GB, but recovery after 3 years was similar. By the third year after an initial burn, fine fuel loads for PP-SO were within 8.7% of preburn levels and fine fuels for SO-GB were within 6.3% of the pre-burn amount. However, the variability of the fine fuel loads differed. The confidence interval widths of 3-year post-burn fine fuel loads was 112% larger for PP-SO than for SO-GB (tables 5 and 6).

Because Pitch Pine-Scrub Oak Barrens are globally imperiled (Gawler and Jessee 1997), it is important that future prescribed fires at the Hollis Training Site meet management objectives and avoid unnecessary destruction of this rare ecosystem. Computer-based fuel models are a useful tool for predicting the behavior of fire, especially in rare ecosystems which are fire dependent. If used properly, computer-based fuel models reduce some of the risks associated with prescribed fire and lessen the chance of prescribed fires turning into wildfires. Standard fuel models do not predict fire behavior of PP-SO and SO-GB cover types accurately for PP-SO Barrens vegetation (Woodall 1998).



The six custom fuel models created for the Hollis Training Site indicate that successful reburns less than 3 years after an initial burn are unlikely. Therefore, an appropriate prescribed fire return interval for the PP-SO and SO-GB cover types at the Hollis Training Site is at least 3 years, but more likely 4 to 5 years. Determining fine fuel recovery after four years would have been helpful, but was not feasible due to time constraints. Perhaps future researchers at the Hollis Training Site could gather data needed to determine fine fuel recovery after four years and provide inputs needed to complete custom fuel models 96 and 97 in the SO-GB cover type. Another suggestion would be to increase the sample sizes (i.e.,  $n > 10$ ) of the fine fuels used in custom fuel models 91 and 93. The larger sample sizes would reduce the variability and increase the accuracy of future fire behavior predictions.

Buchholz, K. 1983. Initial responses of pine and oak to wildfire in the New Jersey Pine Barrens Plains. *Bulletin of the Torrey Botanical Club*. 110(1): 91-96.

Byram, G.M. 1963. An analysis of the drying process in forest fuel material. Paper presented at the 1963 International Symposium on Humidity and Moisture, Washington, D.C., May 20-23, 1963. 38 pp. (unpublished) cited in Pyne, S.J., Andrews, P.L. and Lavan, R.D. 1996. *Introduction to Wildland Fire*. John Wiley and Sons, Inc. New York:110-111.

Dewelling, L.R. and R.H. Lisane. 1982. Soil survey of York County, Maine. USDA Soil Conservation Service. U.S. Government Printing Office 1982-308-719/1125. 143 pp. plus maps.

Fobes, C.B. 1946. Climatic divisions of Maine. Bulletin no. 40, Maine Technology Experiment Station, Orono, Maine. No longer in print. Cited in Gawler, S. and C. Jessee 1997. Conservation plan for the Hollis Training Site, Hollis, Maine. Maine Natural Areas Program, Augusta, Maine.

Gawler, S.S. and C. Jessee. 1997. Conservation plan for the Hollis Training Site, Maine Army National Guard. Maine Natural Areas Program, Department of Conservation, Augusta, Maine. 59 pp.

Little, S. and E.B. Moore. 1949. The ecological role of prescribed burns in the pine-oak forests of Southern New Jersey. *Ecology* 30:223-233.

Patterson, W. A. III. 1997. Fire management plan for the Hollis pitch pine-scrub oak barren, York County, Maine. Appendix A in Gawler, S.S. and C. Jessee. Conservation plan for the Hollis Training Site, Maine Army National Guard. Maine Natural Areas Program, Department of Conservation, Augusta, Maine. June, 1997. 59 pp. plus appendices.

Patterson, W. A. III. 1998. Fuel inventories and potential wildfire behavior in Southeastern Massachusetts. Report prepared as partial fulfillment of U.S. Forest Service Rural Fire Prevention and Control Grant No. NA-96-0298. 22 pp.

## Literature Cited

- Anderson, H.E. 1982. Aids to determining fuel models for estimating fire behavior. USDA Forest Service General Technical Report INT-122. Intermountain Forest and Range Experimentation Station, Ogden, UT. 22 pp.
- Andrews, P.L. and C.H. Chase. 1990. The BEHAVE fire prediction system. The Compiler. Vol.8, No. 4, Winter 1990: 9 pp.
- Brown, J.K. 1974. Handbook for inventorying downed woody material. USDA Forest Service General Technical Report INT-16. Intermountain Forest and Range Experimentation Station, Ogden, UT. 24 pp.
- Buchholz, K. 1983. Initial responses of pine and oak to wildfire in the New Jersey Pine Barrens Plains. Bulletin of the Torrey Botanical Club. 110(1): 91-96.
- Byram, G.M. 1963. An analysis of the drying process in forest fuel material. Paper presented at the 1963 International Symposium on Humidity and Moisture, Washington, D.C., May 20 -23, 1963. 38 pp. (unpublished) *cited in* Pyne, S.J., Andrews, P.L. and Laven, R.D. 1996. Introduction to Wildland Fire. John Wiley and Sons, Inc. New York:110-111.
- Flewelling, L.R. and R.H. Lisante. 1982. Soil survey of York County, Maine. USDA Soil Conservation Service. U.S. Government Printing Office 1982-308-719/1125. 143 pp. plus maps.
- Fobes, C.B. 1946. Climatic divisions of Maine. Bulletin no. 40, Maine Technology Experiment Station, Orono, Maine. No longer in print. *Cited in* Gawler, S. and C. Jessee 1997. Conservation plan for the Hollis Training Site, Hollis, Maine. Maine Natural Areas Program, Augusta, Maine.
- Gawler, S.S. and C. Jessee. 1997. Conservation plan for the Hollis Training Site, Maine Army National Guard. Maine Natural Areas Program, Department of Conservation, Augusta, Maine. 59 pp.
- Little, S. and E.B. Moore. 1949. The ecological role of prescribed burns in the pine-oak forests of Southern New Jersey. Ecology 30:223-233.
- Patterson, W. A. III. 1997. Fire management plan for the Hollis pitch pine-scrub oak barren, York County, Maine. Appendix A *in* Gawler, S.S. and C. Jessee: Conservation plan for the Hollis Training Site, Maine Army National Guard. Maine Natural Areas Program, Department of Conservation, Augusta, Maine. June, 1997. 59 pp. plus appendices.
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Patterson, W. A. III. 1999. Post-Fire stand development and potential fire behavior for the Waterboro Barrens, Southwestern, Maine. Report submitted to the Maine Chapter, The Nature Conservancy in partial fulfillment of Contract No. NHFO 4/24/98. 19 pages plus 7 appendix pages.

Patterson, W.A. III and A.S. White. 1993. Fire behavior, fire ecology and site relations in northeastern barrens ecosystems. Grant proposal to the Ecological Research Program of the Nature Conservancy. 27 pp.

Pyne, S.J., Andrews, P.L. and Laven, R.D. 1996. Introduction to Wildland Fire. John Wiley and Sons, Inc. New York. 769 pp.

Rothermel, R.C. and R.E. Burgan. 1984. BEHAVE: fire prediction and fuel modeling system-fuel subsystem. General Technical Report. INT-167. Ogden, UT: U.S.D.A. Forest Service, Intermountain Research Station. 126 pp.

Schweitzer, D.F. and T.J. Rawinski. 1988. Element Stewardship Abstract for Northeast Pitch Pine/Scrub Oak Barrens. The Nature Conservancy Eastern Regional Office, Boston, Massachusetts. 19 pp.

Widoff, L. 1987. Pitch pine / scrub oak barrens in Maine. Critical Areas Program planning report number 86, draft, Augusta, Maine. 103 pp.

Woodall, C.A. 1998. Prescribed fire behavior and custom fuel modeling in the pitch pine- scrub oak and pine-oak forests of New England. Unpublished masters project report, University of Massachusetts, Amherst. 33 pp.



burn unit	total area (acres)	dates burned	1995	1996	1997	1998	1999	cover type	notes
1A	2.6	6/23 - 7/31			6/6			PP-SO-GB	
1B	18.7			6/8 - 3 acres				SO-GB	strip along NW
1B					7/25 - 6 acres			SO-GB	SW of sand pit
1B						6/11 - 6 acres		SO-GB, PP-SO	
1C	8.8	6/17 - 2 acres						PP-SO-GB	selected areas
1C				6/16 - 6.3 acres				PP-SO-GB	southern half
1C					6/5 - 4 acres + 2 acres (no burn)			PP-SO-GB	east section
1D	11.2	6/16 - 4 acres			6/26 - 11 acres			SO-GB	
1E	6.8			6/19 - 5 acres				PP-SO-GB, SO-GB	
1H	6.3	6/24 - 20/1, 6/1						PP-SO-GB, SO-GB	
1J	2.2	7/31 - 1.3 acres						SO-GB	
1J					6/5 - 2.2 acres			SO-GB	
1L	~16			6/17 - 2 acres				SO-GB	SW corner
1L					7/25 - 3 acres			SO-GB	north of sand pit
1M	18.3					6/26 - 10 acres		SO-GB, PP-SO-GB, heath	
1N	12.4			6/8 - 6/20				SO-GB	
1-A	7.1			6/19 - 6/7				PP-SO	
1-B	4.9			6/18 - 5 acres				PP-SO	
1-D	39					6/2 - 7 acres		SO-GB, PP-SO	east end
1-E	4.4			7/12 - 4 acres				PP-SO	
1-F	15.3					6/11 - 15 acres		PP-SO	
1-H	11.1			6/20 - 3.3 acres				PP-SO	north section
1-H					7/24 - 3 acres			PP-SO, SO-GB	west section
1-H						7/15 - 5 acres		PP-SO	southern half

## Appendix A

### Prescribed Burn History of the Hollis Training Site

## Hollis Training Site Prescribed Burn History

burn unit	total size (acres)	dates burned		1996	1997	1998	1999	cover type	notes
		1995							
I-A	2.5	6/23	7/31		6/5			PP-SO-GB	
I-B	15.7			8/8 .3 acres				SO-GB	strip along NW
I-B					7/23 6 acres			SO-GB	SW of sandpit
I-B						6/11 9 acres		SO-GB, PP-SO	
I-C	8.8	8/17	2 acres					PP-SO-GB	selected areas
I-C				6/18 6.3 acres				PP-SO-GB	southern half
I-C					6/5 4 acres + 2 acres reburn			PP-SO-GB	mid-section
I-D	11.2	8/16	.8 acres		6/28 11 acres			SO-GB	
I-E	5.6			6/18 5 acres				PP-SO-GB, SO-GB	
I-I	6.3	6/24, 7/31, 8/1				7/16		PP-SO-GB, SO-GB	
I-J	2.2	7/31	1.3 acres					SO-GB	
I-J					6/6 2.2 acres			SO-GB	
I-L	~10			8/17 .2 acres				SO-GB	SW corner
I-L					7/23 ~ 3 acres			SO-GB	north of sand pit
I-M	16.3						8/25 ~10 acres	SO-GB, PP-SO-GB, heath	
I-N	12.4			8/8 8/20				SO-GB	
II-A	7.1			6/19 8/7				PP-SO	
II-B	4.9			6/18 ~.5 acres				PP-SO	
II-D	39					9/2 ~ 7 acres		SO-GB, PP-SO	east end
II-E	4.4			7/12 ~ 4 acres				PP-SO	
II-F	15.3					6/11 ~15 acres		PP-SO	
II-H	11.1			8/20 ~ 3.5 acres				PP-SO	north section
II-H					7/24 ~ 3 acres			PP-SO, SO-GB	west section
II-H						7/15 ~ 5 acres		PP-SO	southern half





## Methods Used to Sample Vegetation and Downed Woody Fuels Hollis Training Site, Hollis, Maine

Supervisor - Dr. William Patterson III

Field Workers (1998) - Kent Nelson, Adam Mouny, Erin Kenney and Nate Gourd

Field Workers (1999) - Kent Nelson and Kevin Michalak

### I. Equipment

#### A. measuring devices

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

## Appendix B

### Details of Vegetative Inventories

#### 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 m<sup>2</sup>) 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.

## **Methods Used to Sample Vegetation and Downed Woody Fuels**

### **Hollis Training Site, Hollis, Maine**

Supervisor - Dr. William Patterson III

Field Workers (1998)- Kent Nelson, Adam Mouw, Erin Kenney and Nate Gourd.

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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
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  - 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 10<sup>th</sup> 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. Relve / 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.

- Note: 1. Relve plots - Estimate % cover of all woody and herbaceous plant species by plot and overhead plot can also be cut at the point where they cross into the plot.
- 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 20m<sup>2</sup> 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

- Note: only stems that originate from the same plot center as the releve plots.
- a. originate from the same plot center as the releve plots.
  - b. 10 subplots are completed at aprx. 1 chain intervals away from the original releve 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.

Note: if stand surveys are to be completed in areas that haven't been sampled using downed woody fuel inventory methods, then variable radius plots should be completed at each of the ten subplots.

### C. Harvest 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 (1600cm<sup>2</sup>) frame encompasses 1 subplot; 10 subplots per plot.
  - a. randomly throw 40cm x 40cm (1600cm<sup>2</sup>) frame until it lies flat on forest floor
  - b. clip all stems < 1" at base, sorting material as you cut

Note: all stems within the sampling frame should be cut. Stems that are rooted outside the plot and overhang into the plot can also be cut at the point where they cross into the plot.

- 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 by size class using the 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.

Note: only stems within the sampling frame should be counted. Stems that are rooted outside the plot and overhang into the plot should not be cut at the point where they cross into the plot.

\*For future reference, separate tallies of live stems and dead, rooted stems would improve the accuracy of fire behavior prediction with custom fuel models in BEHAVE.

## III. laboratory procedures

### A. harvest 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 fuels

note: no 1000 hour fuels were collected



# Fuel Model Parameters from Standard Fuel Models 4, 6 and 7.

## FM4 CHAPARRAL

LOADS, T/AC		S/V RATIO, L/FT	OTHER
1 HR	5.01	1 HR	2000
10 HR	4.01	10 HR	150
100 HR	2.00	100 HR	1500
LIVE HERB	.00		
LIVE WOODY	5.01		
		DEPTH, FT	4.00
		HEAT CONTENT, BTU/LB	8000
		EXT MOISTURE, %	20

## FM6 DORMANT BRUSH/HARDWOOD

### Appendix C

### Fuel Models in BEHAVE

LOADS, T/AC		S/V RATIO, L/FT	OTHER
1 HR	1.50	1 HR	150
10 HR	1.50	10 HR	190
100 HR	2.80	100 HR	190
LIVE HERB	30		
LIVE WOODY	90		
		DEPTH, FT	2.50
		HEAT CONTENT, BTU/LB	8000
		EXT MOISTURE, %	25

## FM7 SOUTHERN GRASS

LOADS, T/AC		S/V RATIO, L/FT	OTHER
1 HR	1.13	1 HR	1750
10 HR	1.87	10 HR	190
100 HR	1.50	100 HR	1550
LIVE HERB	00		
LIVE WOODY	37		
		DEPTH, FT	2.50
		HEAT CONTENT, BTU/LB	8000
		EXT MOISTURE, %	40

# Fuel Model Parameters from Standard Fuel Models 4, 6 and 7.

## FM4 CHAPARRAL

LOADS, T/AC		S/V RATIOS, 1/FT	OTHER	
1 HR	5.01	1 HR	2000.	DEPTH, FT 6.00
10 HR	4.01	LIVE HERB	190.	HEAT CONTENT, BTU/LB 8000.
100 HR	2.00	LIVE WOODY	1500.	EXT MOISTURE, % 20.
LIVE HERB	.00			
LIVE WOODY	5.01			

## FM6 DORMANT BRUSH,HARDWOOD SLASH

LOADS, T/AC		S/V RATIOS, 1/FT	OTHER	
1 HR	1.50	1 HR	1750.	DEPTH, FT 2.50
10 HR	2.50	LIVE HERB	190.	HEAT CONTENT, BTU/LB 8000.
100 HR	2.00	LIVE WOODY	190.	EXT MOISTURE, % 25.
LIVE HERB	.00			
LIVE WOODY	.00			

## FM7 SOUTHERN ROUGH

LOADS, T/AC		S/V RATIOS, 1/FT	OTHER	
1 HR	1.13	1 HR	1750.	DEPTH, FT 2.50
10 HR	1.87	LIVE HERB	190.	HEAT CONTENT, BTU/LB 8000.
100 HR	1.50	LIVE WOODY	1550.	EXT MOISTURE, % 40.
LIVE HERB	.00			
LIVE WOODY	.37			

Chart used for developing Custom Fuel Models

This chart indicates where data were used to create custom fuel models for the Hollis Training Site.									
For some inputs to BEHAVE, data were available from two different types of sampling, but only one value could be used. Italicized notes indicate that I had to select the higher or most representative value.									
<b>CFM variable</b>		<b>DWF inv.</b>	<b>harvest plots</b>	<b>releve</b>		<b>notes</b>			
<b>Litter</b>									
1 hr herbacious									
1 hr woody									
1 hour total									
10 hr									
100 hr									
depth (ft)			<i>use higher value</i>			low shrub height (stand survey)			
% coverage						% cover litter			
			<i>sources</i>						
<b>Grass</b>		<b>40 x 40's</b>	<b>stnd survey</b>						
fuel load in t/acre						live standing herbs			
depth (ft)						grass/forb height			
max % live						30% based on conditions at site			
% coverage						grass/forb % cover			
			<i>sources</i>						
<b>Shrubs</b>		<b>40 x 40's</b>	<b>1 x 1's</b>	<b>stnd survey</b>		<b>DWF inv.</b>			
1 hour dead									
total									
10 hour dead									
total									
100 hour dead									
total									
live foliage						leaf weight from allometric equations			
live stems < 1/4"						live standing 1 hour			
total live foliage & twigs						<i>use most representative data</i>			
low shrub height									
high shrub height									
adjusted depth (ft)									$(hs + ls)/2 * .7$
low shrub % cover									
high shrub % cover									$(hs + ls)/2 + (hs + ls)$
adjstd. % coverage									2
shrubs burn green?									yes
Note: this chart was created specifically for the Hollis Training Site in Southwestern Maine.									
For other pitch pine - scrub oak barrens, this chart should only be used as a guide.									



Radii Custom Fuel Model Inputs									
fuel type	PP-30			time after initial burn					
fuel variables	unburned	burn unit(s)	1 year	burn unit(s)	2 years	burn unit(s)	2 years	burn unit(s)	
fuel model #	90		91		92		93		
fuel									
herbaceous	3.71	I-G/H-H&B-C	0.36	I-H weat	2.35	I-G/H-H weat	3.03	I-E	
woody	0.82	I-G/H-H&B-C	0.22	I-H weat	0.73	I-G/H-H weat	1.04	I-E	
total	4.53	I-G/H-H&B-C	1.06	I-H weat	3.12	I-G/H-H weat	4.07	I-E	
1 hr	1.43	I-G	0.26	I-F	0.27	I-C (1999)	0.34	I-E	
10 hr	1.7	I-G	0.81	I-F	0.94	I-C (1999)	0.77	I-E	
100 hr	1.7	I-G	1.4	I-F	1.4	I-C (1999)	1.5	I-E	
coverage	94.5	I-G	94.5	I-F	97.3	I-C (1999)	79.3	I-E	
fuel									
fuel in vapor	0.32	I-G/H-H&B-C	0.4	I-F	0.5	I-C/H-H weat	0.85	I-E	
100 hr	0.4	I-G	0.4	I-F	0.46	I-C (1999)	0.3	I-E	
fuel % fuel	29		30		30		30		
coverage	44	I-G	10.3	I-F	20.3	I-C (1999)	6	I-E	
fuel									
fuel dead	0.02	I-G/H-H&B-C	0	I-F	0.26	I-H	0	I-E	
100 hr dead	0.01	I-G/H-H&B-C	0.11	I-F	0	I-H	0.03	I-E	
1000 hr dead	0	I-G/H-H&B-C	0	I-F	0	I-H	0	I-E	
fuel									
fuel	0.37	I-G/H-H	0.14	I-F	0.26	I-C/H-H weat	0.29	I-E	
standing 1 hr	0.33	I-G/H-H&B-C	0.26	I-F	0.32	I-C/H-H weat	0.44	I-E	
fuel foliage & twigs	0.70		0.4		0.55		0.73		
fuel dead (ft)	3.4	I-G	1.3	I-F	1.6	I-C (1999)	1.8	I-E	
fuel % coverage	75	I-G	70.4	I-F	60.5	I-C (1999)	70.1	I-E	
fuel burn green?	yes		yes		yes		yes		
						Note: zeroes indicate that on fuels of that size no samples were found in sample area.			
fuel ratio									
fuel dead	2500			fuel content					
1 hr dead	1750			fuel loss	50.0				
1 hr standing	1550			fuel loss	30.0				
fuel loss	2250			fuel loss/coverage	90.0				
fuel loss	1550								

## Appendix D

### Inputs for Custom Fuel Models

Hollis Custom Fuel Model inputs									
Fuel type	PP-SO								
					time after initial burn				
CFM variable		unburned	burn unit(s)	1 year	burn unit(s)	2 years	burn unit(s)	3 years	burn unit(s)
fuel model #	90			91		92		93	
<b>Litter</b>									
1 hr herbacious		3.71	II-G/II-H & II-C	0.86	II-H east	2.39	I-C/II-H west	3.03	II-E
1 hr woody		0.82	II-G/II-H & II-C	0.22	II-H east	0.73	I-C/II-H west	1.04	II-E
1 hour total		4.53	II-G/II-H & II-C	1.08	II-H east	3.12	I-C/II-H west	4.07	II-E
10 hr		1.43	II-G	0.26	II-F	0.27	I-C (1999)	0.34	II-E
100 hr		1.7	II-G	0.81	II-F	0.94	I-C (1999)	0.77	II-E
depth (ft)		1.7	II-G	1.4	II-F	1.4	I-C (1999)	1.5	II-E
% coverage		94.5	II-G	84.5	II-F	87.8	I-C (1999)	78.5	II-E
<b>Grass</b>									
fuel load in t/acre		0.32	II-G/II-H & II-C	0.4	II-F	0.6	I-C/ II-H west	0.65	II-E
depth (ft)		0.8	II-G	0.4	II-F	0.46	I-C (1999)	0.3	II-E
max % live		30		30		30		30	
% coverage		44	II-G	10.9	II-F	20.3	I-C (1999)	8	II-E
<b>Shrubs</b>									
1 hour dead		0.07	II-G/II-H & II-C	0	II-F	0.28	II-H	0	II-E
10 hour dead		0.01	II-G/II-H & II-C	0.11	II-F	0	II-H	0.03	II-E
100 hour dead		0	II-G/II-H & II-C	0	II-F	0	II-H	0	II-E
live foliage		0.37	II-G/II-H	0.14	II-F	0.28	I-C/ II-H west	0.29	II-E
live standing 1 hr		0.33	II-G/II-H & II-C	0.26	II-F	0.37	I-C/ II-H west	0.44	II-E
total live foliage & twigs		0.70		0.4		0.65		0.73	
adjusted depth (ft)		3.4	II-G	1.3	II-F	1.6	I-C (1999)	1.8	II-E
adjstd. % coverage		75	II-G	70.4	II-F	60.8	I-C (1999)	78.1	II-E
shrubs burn green?		yes		yes		yes		yes	
Note: zeroes indicate that on fuels of that size, no samples were found in sample area									
<b>S/V ratio</b>									
dead grass		2500			<b>heat content</b>				
1 hr litter		1750			dead fuels	8000			
1 hr shrub		1550			herb fuels	9000			
live herb		2250			live leaves/twigs	9000			
live woody		1550							

Hollis Custom Fuel Model inputs									
Fuel type	SO-GB	time after initial burn							
CFM variable	unburned	burn unit(s)	1 year	burn unit(s)	2 years	burn unit(s)	3 years	burn unit(s)	
fuel model #	95						98		
<b>Litter</b>									
1 hr herbacious	2.07	I-L/I-M & I-L	0.89	I-B / I-D	1.09	I-B / I-L & I-N	2.13	I-B/ I-I	
1 hr woody	0.88	I-L/I-M & I-L	0.37	I-B / I-D	0.45	I-B / I-L & I-N	0.71	I-B/ I-I	
1 hour total	2.95	I-L/I-M & I-L	1.26	I-B / I-D	1.54	I-B / I-L & I-N	2.84	I-B/ I-I	
10 hr	1.69	I-L/I-M			2.14	I - N	2.55	I - I	
100 hr	1.52	I-L/I-M			1.98	I - N	2.49	I - I	
depth (ft)	1.3	I-L/I-M			1.96	I - N	2.19	I - I	
% coverage	93.5	I-L/I-M					100	I - I	
<b>Grass</b>									
fuel load in t/acre	0.44	I-L/I-M & I-L	0.78	I-B / I-D	1.15	I-B / I-L & I-N	0.6	I-B/ I-I	
depth (ft)	0.55	I-L/I-M					0.3	I - I	
max % live	30		30		30		30		
% coverage	34.2	I-L/I-M					23.3	I - I	
<b>Shrubs</b>									
1 hour dead	0.08	I-L/I-M & I-L	0.04	I-B / I-D	0.07	I-B / I-L & I-N	0.05	I-B/ I-I	
10 hour dead	0	I-L/I-M & I-L	0	I-B / I-D	0	I-B / I-L & I-N	0.03	I-B/ I-I	
100 hour dead	0	I-L/I-M & I-L	0	I-B / I-D	0	I-B / I-L & I-N	0	I-B/ I-I	
live foliage	0.9	I-L/I-M					0.24	I-N	
live standing 1 hr	0.51	I-L/I-M & I-L	0.28	I-B / I-D	0.68	I-B / I-L & I-N	0.49	I-B/ I-I	
total live foliage & twigs	1.41	I-L/I-M & I-L	0.28	I-B / I-D	0.68	I-B / I-L & I-N	0.73	I-B/ I-I & I-N	
adjusted depth (ft)	2.85	I-L/I-M					1.4	I - I	
adjstd. % coverage	58	I-L/I-M					53.7	I - I	
shrubs burn green?	yes		yes		yes		yes		
Note: zeroes indicate that on fuels of that size, no samples were found in sample area.									
Blank spaces indicate no data were collected.									
<b>S/V ratio</b>									
dead grass	2500	<b>heat content</b>							
1 hr litter	1750	dead fuels	8000						
1 hr shrub	1550	herb fuels	9000						
live herb	2250	live leaves/twigs	9000						
live woody	1550								



## **Appendix E**

### **Results of Custom Fuel Model Runs**

## FIRE1 PREDICTIONS OF FIRE BEHAVIOR

DYNAMIC CUSTOM MODEL 90 -- HOLLIS PP-SO UNBURNED  
FROM FILE NAME: HOLLIS CFM'S

FILE DESCRIPTION:

OCTOBER 2001

LOADS, TON/AC	S/V RATIOS, 1/FT	OTHER
1 HR 4.43	1 HR 1772.	DEPTH, FT 1.65
10 HR 1.36	LIVE HERB 2250.	HEAT CONTENT, BTU/LB 8104.
100 HR 1.61	LIVE WOODY 1550.	EXT MOISTURE (%) 17.
LIVE HERB .04		
LIVE WOODY .52		

RATE OF SPREAD, CH/H ----- 17.  
HEAT PER UNIT AREA, BTU/SQFT -- 1365.  
FIRELINE INTENSITY, BTU/FT/S--- 415.  
FLAME LENGTH, FT----- 7.2  
REACTION INTENSITY, BTU/SQFT/M 6114.  
EFFECTIVE WINDSPEED, MI/H----- 3.0

DYNAMIC CUSTOM MODEL 91 -- HOLLIS PP-SO 1 YR P-B  
FROM FILE NAME: HOLLIS CFM'S

FILE DESCRIPTION:

OCTOBER 2001

LOADS, TON/AC	S/V RATIOS, 1/FT	OTHER
1 HR .94	1 HR 1784.	DEPTH, FT 1.12
10 HR .30	LIVE HERB 2250.	HEAT CONTENT, BTU/LB 8217.
100 HR .68	LIVE WOODY 1550.	EXT MOISTURE (%) 17.
LIVE HERB .01		
LIVE WOODY .28		

RATE OF SPREAD, CH/H ----- 9.  
HEAT PER UNIT AREA, BTU/SQFT -- 305.  
FIRELINE INTENSITY, BTU/FT/S--- 51.  
FLAME LENGTH, FT----- 2.7  
REACTION INTENSITY, BTU/SQFT/M 1350.  
EFFECTIVE WINDSPEED, MI/H----- 3.0

## FIRE1 PREDICTIONS OF FIRE BEHAVIOR

DYNAMIC CUSTOM MODEL 92 -- HOLLIS PP-SO 2 YR P-B

FROM FILE NAME: HOLLIS CFM'S

FILE DESCRIPTION:

OCTOBER 2001

LOADS, TON/AC	S/V RATIOS, 1/FT	OTHER
1 HR 2.99	1 HR 1770. DEPTH, FT	1.17
10 HR .24	LIVE HERB 2250. HEAT CONTENT, BTU/LB	8116.
100 HR .83	LIVE WOODY 1550. EXT MOISTURE (%)	17.
LIVE HERB .04		
LIVE WOODY .40		
RATE OF SPREAD, CH/H ----- 14.		
HEAT PER UNIT AREA, BTU/SQFT -- 927.		
FIRELINE INTENSITY, BTU/FT/S--- 242.		
FLAME LENGTH, FT----- 5.6		
REACTION INTENSITY, BTU/SQFT/M 4202.		
EFFECTIVE WINDSPEED, MI/H----- 3.0		

DYNAMIC CUSTOM MODEL 93 -- HOLLIS PP-SO 3 YR P-B

FROM FILE NAME: HOLLIS CFM'S

FILE DESCRIPTION:

OCTOBER 2001

LOADS, TON/AC	S/V RATIOS, 1/FT	OTHER
1 HR 3.23	1 HR 1762. DEPTH, FT	1.20
10 HR .29	LIVE HERB 2250. HEAT CONTENT, BTU/LB	8168.
100 HR .60	LIVE WOODY 1550. EXT MOISTURE (%)	18.
LIVE HERB .02		
LIVE WOODY .72		
RATE OF SPREAD, CH/H ----- 15.		
HEAT PER UNIT AREA, BTU/SQFT -- 1121.		
FIRELINE INTENSITY, BTU/FT/S--- 306.		
FLAME LENGTH, FT----- 6.3		
REACTION INTENSITY, BTU/SQFT/M 5017.		
EFFECTIVE WINDSPEED, MI/H----- 3.0		



## FIRE1 PREDICTIONS OF FIRE BEHAVIOR

DYNAMIC CUSTOM MODEL 95 -- HOLLIS SO-GB UNBURNED  
FROM FILE NAME: HOLLIS CFM'S

FILE DESCRIPTION:

OCTOBER 2001

LOADS, TON/AC	S/V RATIOS, 1/FT	OTHER
1 HR 2.91	1 HR 1785.	DEPTH, FT 1.25
10 HR 1.58	LIVE HERB 2250.	HEAT CONTENT, BTU/LB 8209.
100 HR 1.42	LIVE WOODY 1550.	EXT MOISTURE (%) 18.
LIVE HERB .05		
LIVE WOODY .82		

RATE OF SPREAD, CH/H ----- 10.  
HEAT PER UNIT AREA, BTU/SQFT -- 1089.  
FIRELINE INTENSITY, BTU/FT/S--- 191.  
FLAME LENGTH, FT----- 5.0  
REACTION INTENSITY, BTU/SQFT/M 4807.  
EFFECTIVE WINDSPEED, MI/H----- 3.0

DYNAMIC CUSTOM MODEL 98 -- HOLLIS SO-GB 3 YR P-B  
FROM FILE NAME: HOLLIS CFM'S

FILE DESCRIPTION:

OCTOBER 2001

LOADS, TON/AC	S/V RATIOS, 1/FT	OTHER
1 HR 2.96	1 HR 1783.	DEPTH, FT 2.08
10 HR 2.57	LIVE HERB 2250.	HEAT CONTENT, BTU/LB 8117.
100 HR 2.49	LIVE WOODY 1550.	EXT MOISTURE (%) 16.
LIVE HERB .04		
LIVE WOODY .39		

RATE OF SPREAD, CH/H ----- 13.  
HEAT PER UNIT AREA, BTU/SQFT -- 929.  
FIRELINE INTENSITY, BTU/FT/S--- 225.  
FLAME LENGTH, FT----- 5.4  
REACTION INTENSITY, BTU/SQFT/M 4047.  
EFFECTIVE WINDSPEED, MI/H----- 3.0

# TESTMODEL PREDICTIONS OF FIRE BEHAVIOR

SIX FUEL MODEL TEST RUNS -- BASED ON THE FOLLOWING USER DEFINED ENVIRONMENTAL INPUTS:

MOISTURES (%)		OTHER
1 HR	10.	MIDFLAME WIND, MI/H 3.
10 HR	12.	SLOPE, PERCENT 0.
100 HR	18.	
LIVE HERB	150.	
LIVE WOODY	80.	

1. DYNAMIC 90. HOLLIS PP-SO UNBURNED BY: NELSON

LOADS, T/AC		S/V RATIOS, 1/FT	OTHER
1 HR	4.43	1 HR 1772.	DEPTH, FT 1.65
10 HR	1.36	LIVE HERB 2250.	HEAT CONTENT, BTU/LB 8104.
100 HR	1.61	LIVE WOODY 1550.	EXT MOISTURE, % 17.
LIVE HERB	.04	SIGMA 1720.	PACKING RATIO .00692
LIVE WOODY	.52		PR/OPR .92

ENVIRONMENTAL DATA		FIRE BEHAVIOR RESULTS		
1 HR FM	10.	FIRE VARIABLE	MIDFLAME WIND, MI/H	
10 HR FM	12.		2.	3. 6.
100 HR FM	18.		---	---
LIVE HERB FM	150.	ROS (FT/M)	11.	18. 45.
LIVE WOODY FM	80.	FL (FEET)	6.	7. 11.
		IR (BTU/SQFT/M)	6114.	6114. 6114.
		H/A (BTU/SQFT)	1365.	1365. 1365.
SLOPE, %	0.	FLI (BTU/FT/S)	258.	415. 1016.

2. DYNAMIC 91. HOLLIS PP-SO 1 YR P-B BY: NELSON

LOADS, T/AC		S/V RATIOS, 1/FT	OTHER
1 HR	.94	1 HR 1784.	DEPTH, FT 1.12
10 HR	.30	LIVE HERB 2250.	HEAT CONTENT, BTU/LB 8217.
100 HR	.68	LIVE WOODY 1550.	EXT MOISTURE, % 17.
LIVE HERB	.01	SIGMA 1701.	PACKING RATIO .00283
LIVE WOODY	.28		PR/OPR .37

ENVIRONMENTAL DATA		FIRE BEHAVIOR RESULTS		
1 HR FM	10.	FIRE VARIABLE	MIDFLAME WIND, MI/H	
10 HR FM	12.		2.	3. 6.
100 HR FM	18.		---	---
LIVE HERB FM	150.	ROS (FT/M)	6.	10. 25.
LIVE WOODY FM	80.	FL (FEET)	2.	3. 4.
		IR (BTU/SQFT/M)	1350.	1350. 1350.
		H/A (BTU/SQFT)	305.	305. 305.
SLOPE, %	0.	FLI (BTU/FT/S)	31.	51. 126.

# TESTMODEL PREDICTIONS OF FIRE BEHAVIOR

3. DYNAMIC 92. HOLLIS PP-SO 2 YR P-B

BY: NELSON

LOADS, T/AC		S/V RATIOS, 1/FT		OTHER	
1 HR	2.99	1 HR	1770.	DEPTH, FT	1.17
10 HR	.24	LIVE HERB	2250.	HEAT CONTENT, BTU/LB	8116.
100 HR	.83	LIVE WOODY	1550.	EXT MOISTURE, %	17.
LIVE HERB	.04	SIGMA	1740.	PACKING RATIO	.00552
LIVE WOODY	.40			PR/OPR	.74

## ENVIRONMENTAL DATA

1 HR FM	10.
10 HR FM	12.
100 HR FM	18.
LIVE HERB FM	150.
LIVE WOODY FM	80.
SLOPE, %	0.

## FIRE BEHAVIOR RESULTS

FIRE VARIABLE	MIDFLAME WIND, MI/H		
	2.	3.	6.
ROS (FT/M)	10.	16.	39.
FL (FEET)	4.	6.	9.
IR (BTU/SQFT/M)	4202.	4202.	4202.
H/A (BTU/SQFT)	927.	927.	927.
FLI (BTU/FT/S)	149.	242.	598.

4. DYNAMIC 93. HOLLIS PP-SO 3 YR P-B

BY: NELSON

LOADS, T/AC		S/V RATIOS, 1/FT		OTHER	
1 HR	3.23	1 HR	1762.	DEPTH, FT	1.20
10 HR	.29	LIVE HERB	2250.	HEAT CONTENT, BTU/LB	8168.
100 HR	.60	LIVE WOODY	1550.	EXT MOISTURE, %	18.
LIVE HERB	.02	SIGMA	1719.	PACKING RATIO	.00581
LIVE WOODY	.72			PR/OPR	.77

## ENVIRONMENTAL DATA

1 HR FM	10.
10 HR FM	12.
100 HR FM	18.
LIVE HERB FM	150.
LIVE WOODY FM	80.
SLOPE, %	0.

## FIRE BEHAVIOR RESULTS

FIRE VARIABLE	MIDFLAME WIND, MI/H		
	2.	3.	6.
ROS (FT/M)	10.	16.	40.
FL (FEET)	5.	6.	9.
IR (BTU/SQFT/M)	5017.	5017.	5017.
H/A (BTU/SQFT)	1121.	1121.	1121.
FLI (BTU/FT/S)	189.	306.	751.



# TESTMODEL PREDICTIONS OF FIRE BEHAVIOR

5. DYNAMIC 95. HOLLIS SO-GB UNBURNED

BY: NELSON

LOADS, T/AC		S/V RATIOS, 1/FT		OTHER	
1 HR	2.91	1 HR	1785.	DEPTH, FT	1.25
10 HR	1.58	LIVE HERB	2250.	HEAT CONTENT, BTU/LB	8209.
100 HR	1.42	LIVE WOODY	1550.	EXT MOISTURE, %	18.
LIVE HERB	.05	SIGMA	1695.	PACKING RATIO	.00778
LIVE WOODY	.82			PR/OPR	1.03

ENVIRONMENTAL DATA		FIRE BEHAVIOR RESULTS			
		FIRE VARIABLE	MIDFLAME WIND, MI/H		
			2.	3.	6.
1 HR FM	10.	ROS (FT/M)	7.	11.	26.
10 HR FM	12.	FL (FEET)	4.	5.	8.
100 HR FM	18.	IR (BTU/SQFT/M)	4807.	4807.	4807.
LIVE HERB FM	150.	H/A (BTU/SQFT)	1089.	1089.	1089.
LIVE WOODY FM	80.	FLI (BTU/FT/S)	119.	191.	463.
SLOPE, %	0.				

6. DYNAMIC 98. HOLLIS SO-GB 3 YR P-B

BY: NELSON

LOADS, T/AC		S/V RATIOS, 1/FT		OTHER	
1 HR	2.96	1 HR	1783.	DEPTH, FT	2.08
10 HR	2.57	LIVE HERB	2250.	HEAT CONTENT, BTU/LB	8117.
100 HR	2.49	LIVE WOODY	1550.	EXT MOISTURE, %	16.
LIVE HERB	.04	SIGMA	1673.	PACKING RATIO	.00583
LIVE WOODY	.39			PR/OPR	.76

ENVIRONMENTAL DATA		FIRE BEHAVIOR RESULTS			
		FIRE VARIABLE	MIDFLAME WIND, MI/H		
			2.	3.	6.
1 HR FM	10.	ROS (FT/M)	9.	15.	35.
10 HR FM	12.	FL (FEET)	4.	5.	8.
100 HR FM	18.	IR (BTU/SQFT/M)	4047.	4047.	4047.
LIVE HERB FM	150.	H/A (BTU/SQFT)	929.	929.	929.
LIVE WOODY FM	80.	FLI (BTU/FT/S)	140.	225.	546.
SLOPE, %	0.				