FUEL BED CHARACTERISTICS AND FIRE BEHAVIOR IN CATBRIER SHRUBLANDS

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ABSTRACT

Invasion of grasslands by woody shrubs can alter existing fire regimes and give rise to problem fire behavior. Invaded areas are likely to burn less often but with more intensity. Abandoned pastures on the Elizabeth Islands, Massachusetts, that have been invaded by the woody vine catbrier (*Smilax rotundifolia)* follow this pattern. We evaluated the usefulness of standard and custom fuel models (CFMs) for predicting fire behavior in a 0.2-ha (0.5-acre) experimental burn. Developing the custom fuel model required characterizing fuel load and fuel bed depth of catbrier fuels, which contain a dense mat of vines with nearly 100% cover and a height of 1 to 2 m. This was done by measuring the height of litter and shrub components of the fuel bed; estimating cover by point-intercept sampling; and harvesting live vines and leaves, woody and non-woody litter, and dead vines from 1-m^2 plots. From these data, we developed regression equations to estimate fuel load using fuel bed depth.

Measured 1-h dead fuel loads (23 t/ha) were greater than that of any standard fuel model. Total (live and dead) 1-h fuel loads were accurately predicted by shrub height (R^2 = 0.82). All standard fuel models (SFMs), including SFM 4 (chaparral), underestimated flame length observed during an experimental burn conducted in mid-June 2004 following leaf-out, while our custom fuel model more accurately predicted these values. Observed flame length was 5 m (17 ft) (CFM prediction 4.9 m [16 ft]) and rate of spread 11 m/min (37 ft/min) (CFM prediction 14 m/min [46 ft/min]). Results of our work will aid in developing fuel reduction programs for managers interested in restoring early successional habitats, providing guidance for suppressing wildfires, and implementing prescribed fire management in catbrier-dominated habitats.

keywords: Atlantic Coastal Plain, BEHAVE, catbrier, fire intensity, fuel loads, fuel models, Massachusetts, shrublands, *Smilax rotundifolia*.

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INTRODUCTION

Catbrier (*Smilax rotundifolia*) is a thorny vine that invades abandoned pastures, grasslands, and open woodlands of the Atlantic Coastal Plain. On the Elizabeth Island chain southwest of Woods Hole, Massachusetts, catbrier has invaded large expanses of maritime grasslands, forming dense thickets of near 100% cover (Richburg 2005). These thickets reduced native plant species diversity, degraded the recreational value of the land, and altered fire regimes (Schroeder 2002, Richburg 2005; T. Simmons, Massachusetts Division of Fisheries and Wildlife, personal communication) on the islands. Shrubs and woody vines such as catbrier have several characteristics that can produce extreme fire behavior and alter fire regimes. These include their often having a higher volatile chemical content that makes them more flammable than many other wildland fuels, a high percentage of dead stems that require less heat to ignite, and a ratio of fuel to air (packing ratio) that is nearly ideal for promoting fire spread (Miller 1994). An example is the invasion of South African grasslands by woody plants, which reduced fine fuels in the understory, resulting in a decrease in fire frequency. When the fuels in shrub crowns did ignite, fire behavior was more intense than in uninvaded areas (van Wilgen and Richardson 1985).

Resource managers in the Northeast use computer-generated fire behavior models to aid in planning for prescribed fire and wildfire control, and in evaluating the potential effectiveness of fuel management options. The most common fire behavior software is the BEHAVE Fire Behavior Prediction and Fuel Modeling System, which utilizes user-defined fuel, weather, and topographic inputs to predict fire behavior (Andrews and Bevins 1999). BEHAVE predictions are driven by mathematical algorithms that accurately predict fire behavior characteristics in many fuel types (Rothermel 1972). BEHAVE can be used either with standard fuel models (Anderson 1982) or with custom fuel models developed from parameters entered by the user.

Fuel properties that influence fire behavior include fuel loading, fuel size-class distribution, surface-area-to-volume ratio, packing ratio, fuel continuity, and fuel bed depth. These properties, along with heat content and live fuel characteristics, are the most important determinants of fire behavior (Miller 1994). Sampling of shrub fuel beds has often focused on fuel size and loading. To simplify collection of these data, basal diameters, crown diameters, and shrub heights have been used as indices of the total weight of stems (or of specific components, e.g., leaves, stems of a given size

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class, etc.) (Telfer 1969, Brown 1976, Schlessinger and Gill 1978, Gray and Schlesinger 1981, Brown et al. 1982). To relate easily measured plant characteristics to weight of common desert plants, Ludwig et al. (1975) measured canopy height, diameter, and shape to calculate canopy volume. Plants were then harvested and canopy volume was correlated with oven-dried weight ($R^2 > 0.90$) for many plants. Rittenhouse and Sneva (1977) developed predictive equations ($R^2 > 0.90$) for aboveground shrub weight by measuring crown width, crown area, and total plant height.

Although we know, anecdotally, that fires burn intensely in catbrier, there has been no attempt to document how this species alters fuel beds or to quantify fire behavior in thickets where it dominates. The goal of our research was to quantify the fuel characteristics and fire behavior that result from catbrier invasion in a coastal grassland. We describe the fuel bed of catbrier thickets using direct measurements and then use that information to develop and test a custom fuel model to predict its fire behavior.

STUDY AREA

The study area consisted of catbrier thickets in the Protected Field area of Naushon Island, Massachusetts. The 37.5 ha of the Protected Field were historically maintained as grassland by sheep and, to a lesser extent, cattle grazing before agricultural activities were largely abandoned in the early 20th century (Schroeder 2002). In its current condition, the Protected Field has large, nearly impenetrable monocultures of catbrier interrupted by patches of grasses and sedges (chiefly Pennsylvania sedge [*Carex pensylvanica*]), black huckleberry (*Gaylussacia baccata*), and the exotic Scotch broom (*Cytisus scoparius*).

Catbrier is found in 33 U.S. states and in all counties in Massachusetts (Carey 1994, Sorrie and Somers 1999). Also known as greenbrier and roundleaf greenbrier, this native woody vine with long thorns along the entire length of its stem uses tendrils to climb to heights of 3–6 m in invaded woodlands and can spread over shrubs and herbaceous plants in open areas. It regenerates vegetatively from rhizomes (sprouting prolifically following fire [Richburg 2005]) and can form dense thickets with up to 20,000 stems/ha (48,000 stems/acre) (Morong 1894, Niering and Goodwin 1962, Carey 1994).

METHODS

Describing and Quantifying the Catbrier Fuel Bed

To determine catbrier fuel bed characteristics (fuel depth and loading, cover, vertical fuel continuity, fuel particle surface-area-to-volume ratio, and packing ratio), we sampled 9 quadrats during the summer of 2003. We used a stratified random sampling design of low (<60 cm), medium (60–120 cm), and high (>120 cm) canopy heights to capture the range of fuel loads (Ludwig et al. 1975). Quadrats 1 m^2 in area were randomly located within each height class and sampled for percent cover of catbrier and fuel depth (litter and shrub), using point-intercept sampling (10 points/quadrat; Mueller-Dombois and Ellenburg 1974). Vertical continuity (3-dimensional cover) of the fuels was recorded by noting the heights and types of fuels (alive or dead, stem or leaf) intersecting each point throughout the fuel column (Ohman 2006). All live and dead vegetation and litter was then harvested from each 1-m^2 quadrat, collected, and taken to the laboratory for further processing. After stems were harvested, stem density was tallied by counting the stumps in the quadrat.

In the laboratory, 20 sections of catbrier, randomly selected from among the nine sample plots, were measured for diameter to determine fuel class size and surface-area-to-volume ratio. All of the material was then sorted into live stem, live leaf, and dead stem components. Litter samples were sorted into herbaceous (leaf and grass–sedge) and downed woody fuels. Sorted fuels were dried at 70°C to constant weight. Packing ratio was determined by entering component fuel loads and depths into the TSTMDL (Test Model) module of BEHAVEW (DOS-based version).

Predicting Catbrier Fuel Load

Models to predict the weight of catbrier were developed separately using three fuel characteristics: vertical continuity (3-dimensional cover), stem density, and shrub height. The strength of predictors was determined using linear regression to calculate coefficients of determination (R^2).

Custom Fuel Model Development and Evaluation

We modeled fire behavior using BEHAVEW and BEHAVEPLUS3 software. Inputs to the model included fuel load and depth, surface-area-to-volume ratio, and heat content by fuel size class and category (litter, grass, slash, and shrubs). A preliminary model was developed using, for the most part, data we collected on Naushon Island. Standard estimates were used for parameters that we were unable to measure directly.

A prescribed fire was conducted on 13 June 2004 on a 0.2-ha (0.5-acre) research plot in the Protected Field. Eight samples each of litter, live leaves, and live stems were gathered from throughout the plot and returned to the laboratory to determine fuel moisture (Ohman 2006). Dead stem fuel moisture was measured in the field using a protimeter capable of recording fuel moistures >7%. Key weather parameters were measured before, during, and after the burn, including state of the weather (an estimate of the degree of cloud cover and precipitation status), ambient air temperature, relative humidity, and wind speed and direction. Wind speed was measured at 1.5 and 2 m (5 and 7 ft) above the ground (i.e., at approximately midflame height) using a digital anemometer.

The fire was ignited as a headfire with a drip torch and allowed to burn freely without the influence of backing or flanking fires. Flame lengths and rates of spread were compared to 1.2-m (4-ft) iron poles with horizontal arms at 0.3-m (1-ft) intervals placed at

Table 1. Average fuel bed characteristics (with 95% confidence intervals [CI]) in a catbrier-dominated grassland, Naushon Island, Massachusetts, 2003.

Characteristic	*n*	Mean	95% CI Lower	95% CI Upper
Shrub height (m)	9 plots	1.00	0.74	1.26
Percent cover	9 plots	99	96	100
Total fuel load (t/ha)	9 plots	22.8	16.4	29.4
Basal stem diameter (cm)	20 stems	0.56	0.52	0.59
Percent dead	9 plots	72	66	79
Relative packing ratio		0.79		
Heat content (kJ/kg)		18,622		

6.1-m (20-ft) intervals within and parallel to the expected path of the headfire. We recorded the average length of flames as they reached the pole and the time it took the headfire to travel the 6.1-m sections between the poles. The entire burn was video-recorded to provide verification of field measurements taken during the burn.

The custom fuel model was evaluated by comparing BEHAVEPLUS3 outputs (predicted) for flame length and rate of spread—using as environmental inputs the fuel moisture and weather conditions at the time of the burn—with observed fire behavior.

Sensitivity Analysis

We performed an analysis to evaluate the sensitivity of our custom fuel model to variations in the following parameters: 1-h dead fuel load, live fuel load, heat content, fuel bed depth, surface-area-to-volume ratio, and moisture of extinction. Using environmental variables from the June 2004 burn, each of these parameters was increased and decreased by 5, 10, 20, and 40%, while holding other input parameters constant. Because changing the heat content by 40% produced an input value outside of the bounds acceptable to BEHAVEPLUS3, heat contents were changed by ±5, 10, and 20%, and to the upper (27,933 kJ/kg) and lower (13,966 kJ/kg) acceptable limits. For each run, the resulting flame length and rate of spread were recorded. We then compared the ratio of degree of change in the output to change in the input (Dell'Orfano 1996).

RESULTS

Describing and Quantifying Catbrier Fuel Beds

Fuel bed characteristics are summarized in Table 1. The average quadrat sampled was 1.0 m (3.3 ft) tall, had 99% cover, and was vertically continuous (as evidenced by the presence of 1-h fuels throughout the column). The total fuel load was composed (by weight) of 37% litter, 35% dead stems, 21% live stems, and 7% live leaves. The average diameter of catbrier stems 5 cm (2 inches) above their base was 0.56 cm (0.22 inches), with none >0.64 cm (0.25 inches); thus, the entire fuel bed was composed of 1-h (fine) fuels.

We calculated the surface-area-to-volume ratio for the catbrier fuel model by combining directly measured and estimated values. The average diameter of catbrier stems and branches was 0.23 cm (0.09 inches). Assuming vines are a perfect cylinder, this represents a surface-area-to-volume ratio of 17.5 cm^{-1} (535 ft^{-1}) for live and dead stems. Litter and live leaf material could not be directly measured, so we used a BEHAVEPLUS3-estimated value of 82.0 cm^{-1} (2,500 ft^{-1}).

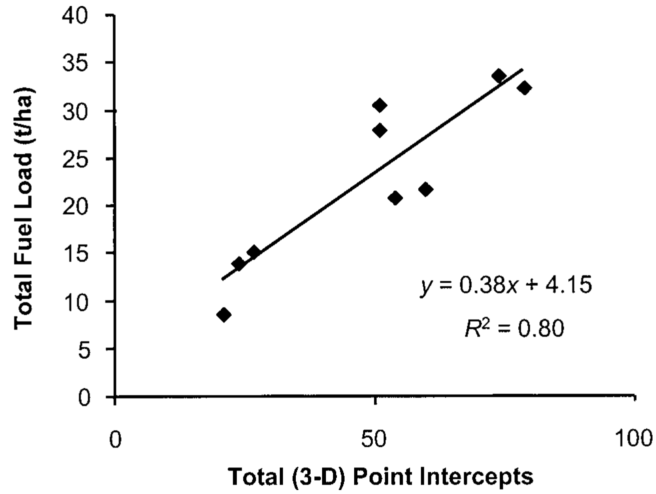

Fig. 1. Three-dimensional (3-D) cover as a predictor of total fuel load in catbrier fuel beds on Naushon Island, Massachusetts, 2003.

On average, 72% (range = 66–89%) of the fuel load was dead stems and litter, which tended to be concentrated in the lower 0.4 m (1.3 ft) of the fuel bed but were present throughout. The presence of dead stems in the upper parts of the fuel bed was due both to dead stems branching off of live stems and to dead, broken stems entwined in live catbrier. Dead catbrier leaves tend to curl as they dry, and this effect, coupled with small stems present in the litter layer, keeps the litter layer well aerated. The average depth of litter was 5.2 cm (2.0 inches).

The BEHAVEW module TSTMDL calculates the packing ratio based on component fuel loads and fuel bed depths. It further calculates a relative packing ratio by dividing the theoretical optimum packing ratio by the calculated observed packing ratio. The BEHAVE analysis for catbrier yielded a relative packing ratio of 0.79, which is close to the optimal value of 1.0.

Predicting Catbrier Fuel Load

Stem density, 3-dimensional cover sampling, and shrub height were sampled and evaluated independently as predictors of catbrier fuel load. Stem density was a poor predictor of fuel load ($R^2 = 0.06$), possibly due to the small sample size. The total number of intercepts (3-dimensional sampling) per quadrat predicted the total weight of fuels well ($R^2 = 0.80$) (Figure 1). There were, on average, 49 intercepts/quadrat, of which 27 (55%) were live and 22 (45%) were dead material. Live intercepts served as a good predictor of live weight, while dead intercepts were somewhat less useful as a predictor of dead weight ($R^2 = 0.73$ and

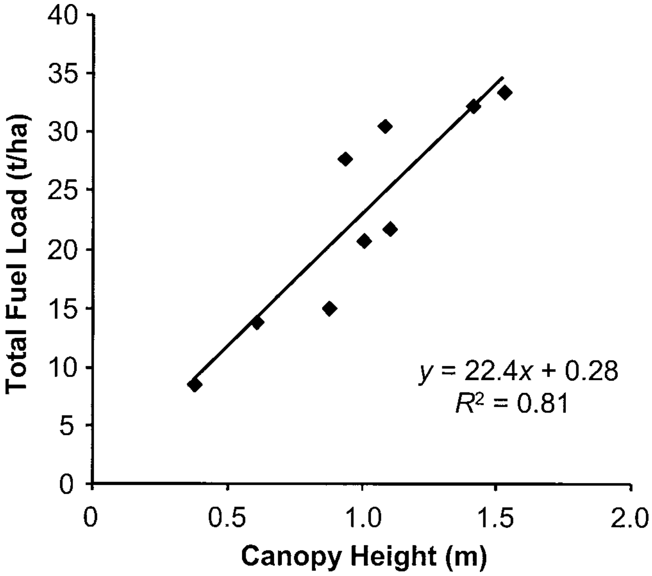

Fig. 2. Shrub canopy height as a predictor of total fuel load in catbrier fuel beds on Naushon Island, Massachusetts, 2003.

0.40, respectively). Average shrub height was the best predictor of the total weight of fuels, with $R^2 = 0.81$ (Figure 2). The average shrub height of catbrier was 1.00 m (3.27 feet), with a range of 0.38–1.53 m (1.25–5.02 ft). This parameter, which describes the overall fuel bed height, was also the most time-efficient method of the three for estimating the total weight of fuel.

Custom Fuel Model Development

We created a custom fuel model in the Windows-based BEHAVEPLUS3 and the DOS-based BEHAVEW using information from the fuel sampling portion of the project. We then used data from the prescribed fire to evaluate the model output and modify the input parameters. The two modeling programs differ in the way that data are entered and in the detail provided by their output, with BEHAVEPLUS3 having a simplified input interface requiring less information and an output report that omits predictions of packing ratio and packing ratio:optimum packing ratio. The two programs do, however, always yield identical predictions of flame length and rate of spread.

The components of the custom fuel model are presented in Table 2. No fuels larger than 0.64 cm (0.25 inches) basal diameter were present, so the loads for 10- and 100-h fuels were zero. In constructing this model, we considered all fuel particles in the leaf litter, including dead catbrier stems, to be litter. All fuels above the litter layer, including dead stems, live stems, and live leaves were entered into the fuel model as part of the shrub component. The live shrub component is made up of all the live fuel particles in the fuel bed, including live leaves. A slash component was not used in this model. We used the standard heat content of 18,622 kJ/kg, which is widely used in fire modeling (Pyne et al. 1996) and is used for all 13 standard fuel models.

Table 3. Average observed (with range in parentheses) and predicted flame lengths and rates of spread for a catbrier custom fuel model (CFM) versus standard fuel models (SFM 3, 4, and 7), Naushon Island, Massachusetts, 2004.

Fuel model	Flame length (m)	Rate of spread (m/min)
Observed	5 (4.5–6)	11 (9–14)
Catbrier CFM	5	11
SFM 3 Tall Grass	3	24
SFM 4 Chaparral	2	6
SFM 7 Southern Rough	1	5

During the June 2004 prescribed fire, wind speeds averaged 16.1 km/h (range = 13–24 km/h), litter (non-woody) moisture content was 19%, 1-h dead wood was 8%, and live (leaf) fuels were 175%. Flame lengths averaged 4.6–6.1 m with rates of spread of 9.1–13.7 m/min. When time-of-the-burn fuel moisture and weather conditions are used with BEHAVEPLUS3, the custom fuel model predicts rates of spread and flame lengths that closely match observed fire behavior. The relevant standard fuel models all underpredict flame length and, with the exception of fuel model 3, underpredict rate of spread (Table 3).

Sensitivity Analysis

Rate of spread and flame length reacted differently to varying input parameters for the custom fuel model, with rate of spread generally changing more; i.e., a change in an input parameter usually caused the model to predict a greater percent change in rate of spread than in flame length. We calculated a combined sensitivity by averaging the sensitivity values for rate of spread and flame length (Table 4).

Generally, the custom fuel model was least sensitive to moisture of extinction and live fuel load. Decreasing the moisture of extinction by 40% resulted in a predicted change in flame length of 12%, whereas increasing the moisture of extinction by 40% resulted in no change in predicted flame length. Similarly, reducing the live fuel load by 40% resulted in no predicted change in flame length in the model, whereas increasing the live fuel load by 40% decreased flame length by only 6%.

Table 2. Custom fuel model inputs for a catbrier-dominated grassland, Naushon Island, Massachusetts, 2003.

Fuel component	Category	Size class	Load (t/ha)	SA:V[a] (cm^{-1})	Heat content (kJ/kg)	Moisture of extinction (%)	Fuel bed depth (m)
Litter	Dead	1 h	8.55	82	18,622	32	0.05
Shrub	Dead	1 h	7.96	17	18,622	32	1.00
Shrub	Live	1 h	6.28	32	18,622	32	1.00

[a] Surface-area-to-volume ratio.

Table 4. Sensitivity of catbrier custom fuel model predictions to changes in tested fuel inputs. Sensitivity is measured as the ratio of the degree of change in the output (the predicted fire behavior parameter) to the degree of change in the input (the fuel parameter). Combined sensitivity is the average of the rate of spread and flame length sensitivities.

Fuel input	Combined sensitivity	Rate of spread sensitivity	Flame length sensitivity
Fuel bed depth	0.79	1.21	0.38
Surface area to volume	0.68	1.23	0.13
Heat content	0.55	0.47	0.62
1-h fuel load	0.30	0.29	0.31
Live fuel load	0.17	0.26	0.09
Moisture of extinction	0.13	0.15	0.11

The model was most sensitive to changes in surface-area-to-volume ratio and fuel bed depth. With all other fuel parameters held constant, increasing the fuel bed depth decreased the packing ratio and vice versa. The net result was a 45% increase in rate of spread with a 40% increase in fuel bed depth and a 45% decrease with a 40% decrease in fuel bed depth. Similarly, a 40% increase in the surface-area-to-volume ratio of dead fuels caused a 53% increase in predicted rate of spread, and a 40% decrease in dead fuel surface-area-to-volume ratio decreased predicted rate of spread by 42%.

DISCUSSION

Characteristics That Contribute to Extreme Fire Behavior

Several characteristics of catbrier fuels contribute to extreme fire behavior. Among these is the absence of a large fuel component that would act as heat sink and slow rates of spread. With no fuels >0.64 cm in diameter, more of the fire's energy is being expended in the flaming stage of combustion and little heat is being expended raising large fuel particles to the point of ignition. Nearly three-quarters (72%) of the fuel in catbrier fuel beds is dead, so little energy is used to drive water from live fuels.

Average 1-h dead fuel load of 16.5 t/ha (the sum of litter and dead stem fuels) is unusually large. None of the 13 standard fuel models has a fine dead fuel load larger than 11.4 t/ha. Although the surface-area-to-volume ratio of catbrier fuels is less than that of grass fuels, they are higher than those for most associated shrubs, including Scotch broom and huckleberry, which support lower rates of spread and flame lengths (Richburg et al. 2004).

High fuel loads distributed through a deep fuel bed contribute to the extreme fire behavior observed in catbrier. The proportion of the fuel bed that is occupied by fuel is defined as the packing ratio (Burgan and Rothermel 1984). A fuel bed with no fuel has a packing ratio of 0, and a solid block of wood has a packing ratio of 1 (Burgan and Rothermel 1984, Miller 1994). A very tightly packed (high packing ratio) fuel bed often will not burn well because of a lack of available oxygen. By contrast, a very loosely packed fuel bed will similarly not burn well because fuel particles are spread so far apart that heat is not transferred readily among particles even though oxygen is readily available (Miller 1994). Every fuel bed has a theoretically ideal mix of fuel and air, and this mix is referred to as the optimum packing ratio (Burgan and Rothermel 1984). In catbrier fuel beds, fuel load and depth combine to produce a relative packing ratio of 0.79—a near ideal mix of fuel and air.

The way fuel is distributed within a fuel bed influences the rate of spread of a fire. Fires spread fastest in vertically and horizontally continuous fuels. Horizontal continuity is related to the horizontal distance between fuel particles, which is a function of percent cover, whereas vertical continuity is related to the distance between surface and crown fuels (Miller 1994). Our data show that both horizontal and vertical continuity of catbrier fuels is high.

Predicting Catbrier Fuel Load

A simple, efficient, and reliable method of predicting catbrier fuel load is necessary for reliable predictions of fire behavior and for documenting the effects of management on fuel beds. We evaluated three methods for estimating catbrier fuel loads and found canopy height to be the simplest and most reliable. Stem density predicts fuel load poorly, and counting stems is not practical without harvesting stems individually. Three-dimensional cover accurately predicts total fuel load, but sampling requires approximately 40 min/1-m^2 quadrat to perform. Attempts to correlate live intercepts with live fuel load and dead intercepts with dead fuel load were less successful because determining whether a catbrier stem was alive or dead without harvesting is difficult. Stand height, on the other hand, is both simple and efficient, and can be done with precision and accuracy. Sampling can be performed quickly with minimal equipment (a stick for measuring height and brush chaps for walking through the thorny vines).

Total fuel load has little value in predicting fire behavior; predictions are more accurate when fuel load is broken down by category (shrub, slash, litter, grass), size class (1-, 10-, or 100-h), and status (live or dead). The catbrier fuel beds we sampled comprised exclusively shrub and litter components and were all <0.64 cm in diameter (i.e., 1-h fuels). A variation of our 3-dimensional cover sampling, where fewer points are sampled, might facilitate the determination of the proportion of live and dead shrub stems.

Utility of Custom Fuel Models

Our custom fuel model accurately predicted fire behavior observed during a June 2004 prescribed burn. Custom fuel model predictions were superior to those produced by the standard fuel models (Table 3), which, for the most part, underpredicted observed flame length and rate of spread. In a related study, Richburg et al. (2004) compared observed versus custom fuel model–predicted flame lengths for a variety of shrubs and found a correlation coefficient (r) of 0.96. The fact that these custom fuel models predict fire behavior well, coupled with the fact that standard fuel model predictions were generally much poorer, supports the use of custom fuel models for catbrier. The June 2004 prescribed fire was useful in confirming the accuracy of the catbrier custom fuel model, and the extreme fire behavior was effective in showing the potential danger of this fuel condition.

Identifying Important Fuel Bed Characteristics

By evaluating how variations in input values affected the flame length and rate of spread predicted by our custom fuel model, we were able to determine which fuel bed characteristics were most important in affecting fire behavior. This knowledge is useful to managers wishing to modify fuel beds to reduce fire hazard. Both parameters were most sensitive to changes in fuel bed depth and least sensitive to moisture of extinction. The former is easily manipulated in the field (as by chopping or flail-mowing—see Richburg et al. [2004]), whereas moisture of extinction depends not only on fuel arrangement but on the thermodynamic properties of individual fuel components.

Surface-area-to-volume ratio and heat content both strongly influence rate of spread and flame length, but both are difficult to measure. Although we directly measured catbrier stem surface-area-to-volume ratio, we had to approximate the ratio for the litter component. Additional measurements of catbrier heat content are needed. The live leaves of catbrier appear waxy, suggesting the presence of volatile compounds that should yield a higher heat content than those without waxy leaves (Burgan and Rothermel 1984). Neither surface-area-to-volume nor heat content are easily manipulated, however, and therefore should not be a focus of management efforts.

Although 1-h size-class fuel load has less effect on rate of spread than most fuel characteristics, it is next in importance (after heat content and fuel bed depth) in its effect on flame length. Coefficients of determination suggest that we can accurately predict 1-h fuel load with both 3-dimensional cover sampling and by measuring shrub heights. High live fuel loads, because of their high moisture content, tend to suppress fire behavior. This effect is demonstrated by the sensitivity analysis. Increasing the live fuel load in BEHAVE has the effect of reducing both rate of spread and flame length, and decreasing live fuel load increases fire behavior. But catbrier fuels are unique among northeastern U.S. fuel complexes in their ability to support extreme fire behavior with live fuel moistures in excess of 150%, as our June 2004 prescribed burn illustrated.

MANAGEMENT IMPLICATIONS/AREAS FOR FURTHER STUDY

Fire managers working in the Atlantic Coastal Plain have long recognized the extreme fire hazard associated with catbrier-dominated landscapes. We have, for the first time, quantitatively described the fuel bed characteristics associated with this hazard and identified components that might be most effectively manipulated to reduce problem fire behavior. Our fuel sampling protocol and the custom fuel model we developed will allow managers to more effectively manage catbrier fuels and evaluate outcomes in the context of altered fire behavior. Additional sampling in other areas dominated by catbrier is necessary to determine if the catbrier fuel bed is similar among sites. Although difficult to implement, additional research prescribed burns in catbrier monocultures will increase our knowledge of how fire behavior is affected by variations in environmental conditions. Our one research burn was conducted under moderate fire weather conditions during the growing season and resulted in impressive fire behavior. To more fully test our custom fuel model, we need additional documentation of burns under other conditions, especially those in the dormant season. Only with additional research will we be able to provide fire managers with the tools that they need to effectively manage this hazardous fuel type.

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