Turbulence and Energy Fluxes During Prescribed Fires in the New Jersey Pine Barrens

Kenneth L. Clark[1], Nicholas Skowronski[1], Michael Gallagher[1], Warren E. Heilman[2], John L. Hom[1], Matthew Patterson[1], Xindi Bian[2]

[1]Silas Little Experimental Forest, USDA Forest Service, 501 Four Mile Road, New Lisbon, NJ 08064

[2] Eastern Area Modeling Consortium, USDA Forest Service, East Lansing, MI

Introduction

Prescribed fires are essential for the protection of homes and property from wildfires. Emission of gasses and particulates from prescribed fires contributes to atmospheric pollutant loads, and where prescribed fires are conducted near urban centers or in non-attainment areas, the potential exists for exceeding federal, state or local air quality standards. In addition, impairment of visibility by smoke on roads and highways is a safety hazard.

As part of our effort to develop better tools for predicting smoke dispersion from low intensity burns, we evaluated components of the forest energy balance during three prescribed fires conducted in the Pine Barrens of New Jersey, and compared above-canopy fluxes to energy release estimated from fuel consumption measurements.

We measured turbulence and energy exchange at the landscape scale using eddy covariance and standard meteorological sensors. At least one flux tower was operating within the burn block during the prescribed fire, and two other "control" towers were operating simultaneously in unburned stands. Stand energy balance was approximated as: $R_{net} - G = H + \lambda E$, where R_{net} = net radiation, G = soil heat flux, H = sensible heat flux, and λE = latent heat flux. Fuel consumption was quantified using pre- and post-burn sampling of the forest floor and understory in 1 m^2 plots.

Figure 1. Eddy flux towers in the New Jersey Pinelands. Towers are located in the dominant forests types; an oak-dominated stand at the Silas Little Experimental Forest, a mixed stand at Fort Dix, and a pine-dominated stand near the Cedar Bridge fire tower. The mixed stand was burned in an operational prescribed fire in on February 9, 2006, and the pine stand was burned on March 22, 2008. A third burn was conducted in a mixed stand on March 20, 2011.

Acknowledgements: We thank the Natural Resources Division at Fort Dix and the New Jersey Forest Fire Service. This research was supported by NRS-06, USDA Forest Service, and The Joint Fire Science Program.

Figure 2. Eddy flux tower during the prescribed fire in the mixed stand at Fort Dix on February 9, 2006.

Results and Discussion

Instantaneous vertical windspeed and air temperature measured at 10 Hz four meters above the canopy were enhanced up to 2.4 and 11.6 times ambient conditions in control stands (Table 1).

Table 1. Maximum vertical windspeed (w) and air temperature (T) measured at 10 Hz above burned and control stands during three prescribed fires.

Date	w ($m\ s^{-1}$) burn	w ($m\ s^{-1}$) control	T (°C) burn	T (°C) control
Mixed 2006	4.0	3.6	23.2	2.0
Pine 2008	3.8	3.6	44.2	12.8
Mixed 2011	8.3	3.4	117.8	11.3

10 Hz upward vertical windspeed velocity and air temperature were positively correlated during each fire, with correlations highest at the hottest burn ($r^2 = 0.48$).

Friction velocity (u*, $m\ s^{-1}$) was only slightly enhanced during the two cooler burns compared to the control stands. For example, u* during the prescribed burn at the pine stand on March 22, 2008, is similar to values measured above the oak and mixed stands (Fig. 3).

Pre- and post-burn energy balance closure was high in all stands; at the mixed stand in 2006, H + λLE = 0.91 R_{net}-G 0.91 + 14.41, $r^2 = 0.892$, n = 7760, and at the pine stand in 2008, H + λE = 0.87 R_{net} –G + 14.53, $r^2 = 0.905$, n = 10810.

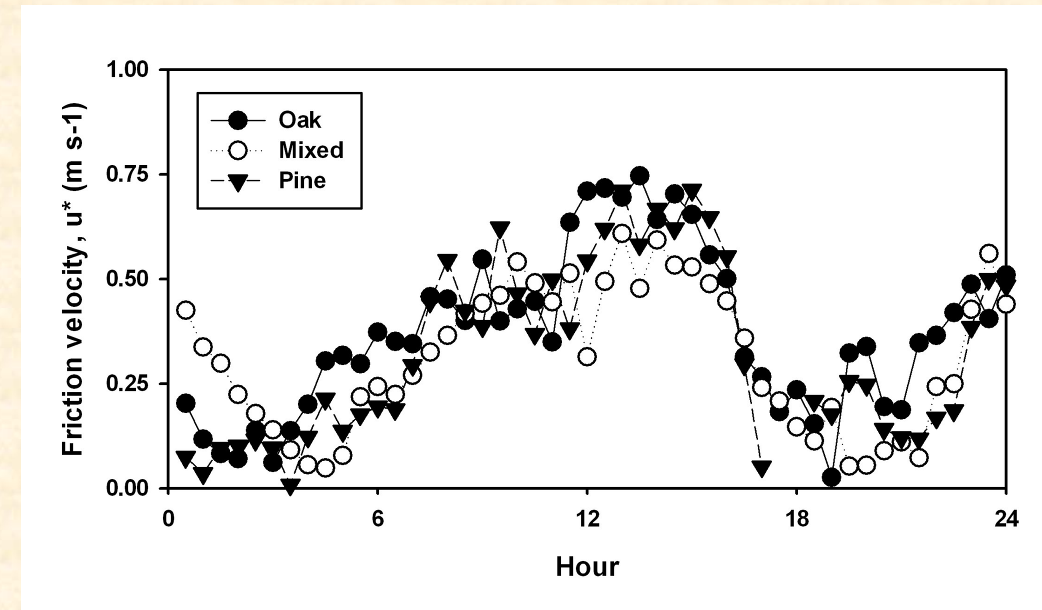

Figure 3. Half-hourly values of friction velocity (u*, m s^{-1}) four meters above each canopy on March 22, 2008.

During the burns, the sum of latent and sensible heat fluxes above the canopy for the two cooler burns was 4.8 and 5 times greater than available energy, $R_{net} - G$. Half-hourly sensible heat flux peaked at 3128 and 1675 W m^{-2}, and water vapor flux at 443 and 483 W m^{-2}, respectively. Energy release during these fires calculated from the "excess" H and LE flux after correction for available energy was 4,824 and 7,256 kJ m^{-2}.

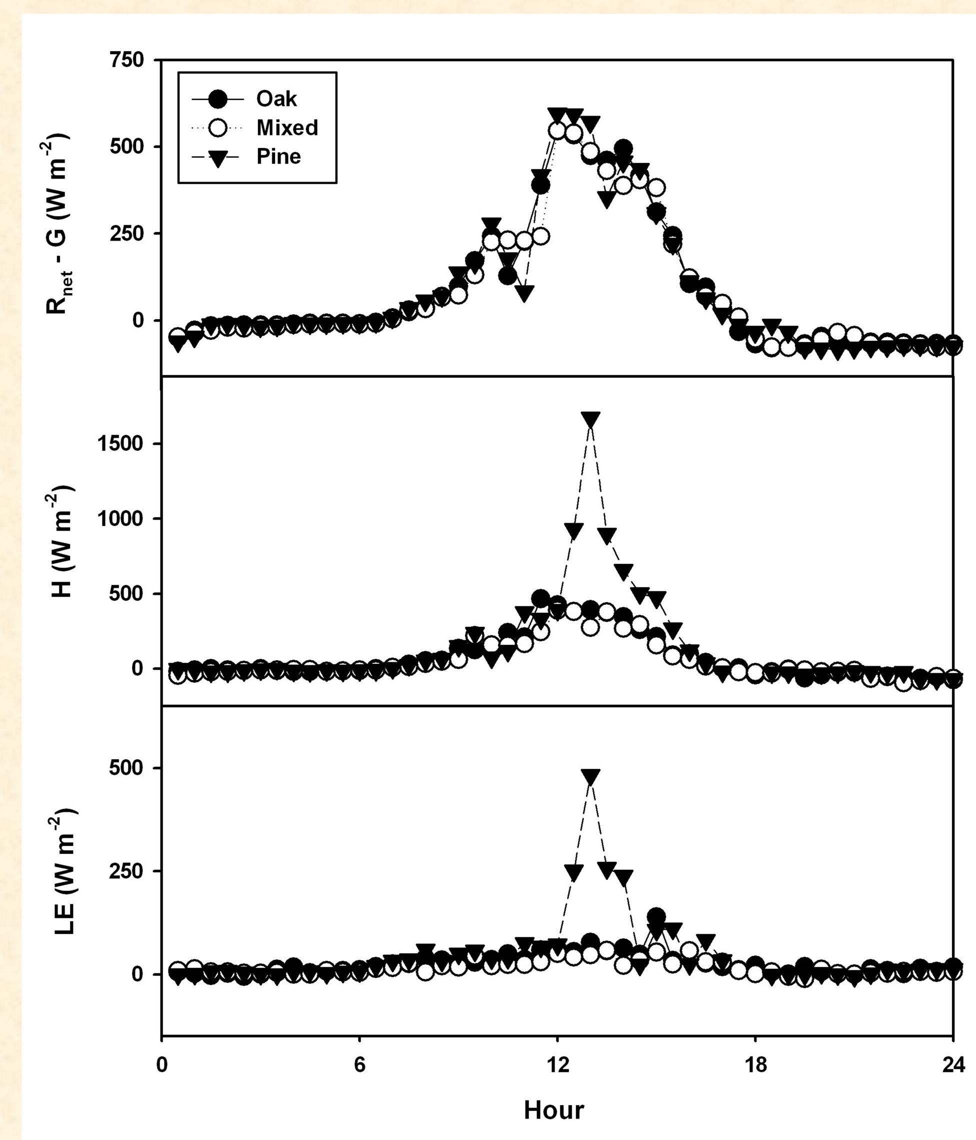

Figure 4. Half-hourly values of available energy, sensible heat flux, and latent heat flux at the three sites on March 22, 2008. All units are W m^{-2}.

Fuel consumption in the understory and forest floor totaled 8.2, 9.8 and 7.1 metric tons ha^{-1}; 53, 44 and 49 % of pre-burn loadings, respectively (Fig. 5). Corresponding heat of combustion values, calculated assuming complete combustion of consumed fuels at measured water contents, were 10,776, 12,894, and 9,110 kJ m^{-2} , respectively.

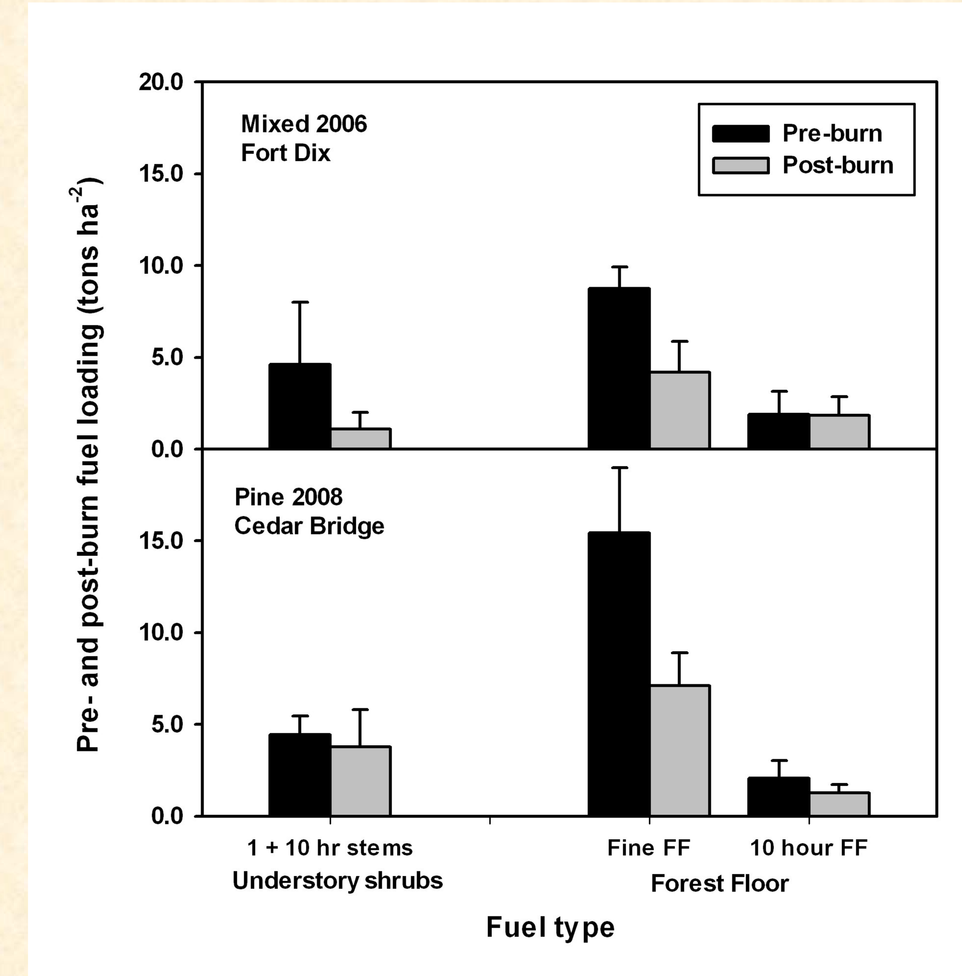

Figure 5. Pre- and post-prescribed burn fuel loading in the understory and forest floor at the mixed stand in 2006 and the pine stand in 2008. Values are tons ha^{-1} ± 1 SD.

Flux measurements totaled ca. 47% and 56% of the estimated energy release during combustion calculated from fuel consumption measurements. Energy was consumed in the heating of the surrounding air and soil, and radiant energy flux is not sampled directly using eddy covariance sensors. In addition, it is possible that the flux measurements only sampled a limited portion of the plume, 10 Hz data may underestimate instantaneous fluxes during enhanced turbulent transfer occurring in fires, smoke occasionally interfered with the sonic sensors, and the LiCor LI-7000 used to sample water vapor may not accurately sample such large fluctuations in H_20 concentrations.

Quantifying consumption using pre- and post-burn field plots also is not without error. For example, the calculated SD for consumption of 1-hour fuels represents 23-32% of the mean value. In addition, char particles < 2 mm diameter that were produced from litter during the prescribed fire were not sampled, because we sifted samples through 2 mm mesh size screens to remove sand and fine-grained organic matter.

Conclusions

Landscape-scale tower networks are valuable for evaluating energy fluxes during prescribed burns. Approximately half of the estimated energy released from complex fuel beds was measured as "excess" H + LE above the canopy. Despite sampling limitations, simultaneous quantification of fluxes and fuel consumption during fires are essential for evaluating predictive plume dispersion models (see Heilman et al. Wednesday, 19 October 2011: 8:30 AM in the Grand Zoso Ballroom).