DEVELOPMENT OF SMOKE PLUME, FIRE EMISSIONS, AND WILDLAND FIRE FUEL MODELS ON COASTAL PLAIN ECOSYSTEM

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INTRODUCTION

Use of prescribed fire is an important forest management activity in the southeastern United States. Fire is used to remove logging slash prior to plantation establishment, reduce hardwood and herbaceous competition in young stands, improve habitat for threatened and endangered species, and to minimize a catastrophic wildfire hazard by fuel reduction. Burning activity is projected to increase as managers on federal, private, and industrial lands seek to reduce dry fuel accumulation and minimize wildfire dangers, especially in the Coastal Plain of North Carolina in the wake of Hurricane Isabel in October 2003. Land managers using prescribed burns for silviculture and ecosystem management do so while recognizing and planning for the liabilities of smoke, human health effects, and the danger of prescribed burns igniting wildfires and organic soil ground fires. Near ground smoke poses a risk to public safety by reducing visibility on roadways; increases human health risks from exposure to fine particulate matter (PM) and ozone precursors; and increases the public's perception that prescribed burning is deleterious to their families and community at the wildland/urban interface.

Fire has played a major role in determining the distribution of plants across the Coastal Plain of the southeastern US. The extent of fire dependent ecosystems such as

the pond pine/high pocosin forest type have been reduced as a result of fire exclusion and land conversion. Wildland fire fuel loading in this area has become a hazard to life, property, ecosystem health, and the habitat of threatened and endangered species as a result of past fire exclusion policies and practices. The President's National Fire Plan is concerned that fuel loads are reaching hazardous levels that can lead to widespread catastrophic wildfires in forest ecosystems and the wildland/urban interface. This wildland fire risk is currently impacting ecosystem management planning throughout the region.

Land managers from federal and state agencies will be challenged to develop management plans to lower wildland fire risk, while implementing ecosystem management, threatened and endangered species (TES) management and recovery plans, remaining in compliance with federal and state air quality standards, and protecting the public's heath and safety. Federal and state lands are experiencing encroachment and fragmentation by coastal residential development. These areas are critical to maintaining and protecting species diversity.

Measurement and Modeling of Down Woody Debris and Fuels

Fuel classification during the last 75 years has evolved from a fire control planning focus to the beginning of predictive fire behavior modeling in the 1970s. Current fuel classification models have focused on the rate of spread, resistance to control, and the flame length of fires in surface fuels. Fire behavior is predicted by land managers with thirteen stylized fuel models (Rothermel, 1972; Albini, 1976). Decision support systems such as FARSITE and the National Fire Danger Rating system are based on the Rothermel's fire spread model and are the basis of predicting fire behavior today. Land managers recognize that these models are limited in their ability to predict extreme fire behavior, persistent fires, and fuel consumption. Some of these limitations are currently being addressed by a fuel characteristic classification (FCC) research (Sandberg et al., 2001).

The availability of fire-spread models has increased the need for quantitative fuel field data. A line-intersect method developed by Brown (1974) has been widely adopted to quantify fuel-loading inputs. The USDA Forest Service Forest Inventory and Analysis (FIA) program recognized the need for extensive information on fuels across the landscape. Fuel field protocols were piloted by the former Forest Health Monitoring Program between 1998 and 2000, and implemented in 2001 on a 1/16th subset of the standard base FIA grid plots. These FIA methods generally partition the forest ecosystem into pools for live trees, down deadwood, standing dead trees, understory vegetation, forest floor materials, and soil. Estimating site-specific fuels from this database has been particularly problematic. The data is not consistently available from the largest inventory data source, FIA, and there is little data on fuel pools in the scientific literature. Additionally the biomass algorithms are based nationally on data collected primarily on western US tree, shrub, and herbaceous species and associated wood density for decay classes.

Land managers in the Coastal Plain of the southeastern US recognize general fuel types on organic soils (i.e., low pocosin, high pocosin, open cane, and overstoried cane). Past fuel and fire behavior research has resulted in only qualitative measures of fuel loads and rates of spread. A more detailed fuel classification based on species composition, standing dead and down deadwood, fuel size classification, understory vegetation, and vertical distribution of fuels would have much more utility than the broad fuel model classification system now in use. Fire in the organic soil areas of the Coastal Plain centers around the frequent and costly blowup wildfires occurring there and the use of fire as a fuel reduction and habitat management tool. Wildfires in this area can under certain combinations of fuel and weather, grow from a low intensity burn to a virtually uncontrollable burn until weather conditions change or the fire has run out of fuel. Control efforts are often hampered by inaccessibility, poor soil trafficability on wet organic soils in the area, and fires that tend to burn deeply into the organic soils. A better understanding of the behavior of fires and the role of fuel loading in fire behavior in the pocosins, especially the factors that contribute to the occurrence of major fires, will contribute to the control of wildfires and the use of prescribed fire as a management tool in the region.

Prescribed Burning Emissions Monitoring and Modeling

Biomass burning in the southeastern US can be a potentially significant source of photochemically active and radiatively important trace gases as well as particulate matter (PM) (Vose et al., 1997). Areas burned in the region vary annually, but are typically several million acres per year, resulting in trace gas and PM emissions that range from 2 to 15% of total emissions from other sources. Little data on emissions from prescribed burning is currently available, and this fire type in particular is projected to increase in the southeastern U.S. Emissions of reduced compounds, many of which are air toxins, are thought to be lower during prescribed fires compared to wildfires covering the same area. This is suspected largely because it is known that wildfires occur typically during excessively dry periods when much of the forest floor is dry and susceptible to smoldering incomplete combustion, the source of many toxic compounds.

Continuous monitoring of ozone (O_3), PM, and oxides of nitrogen (NO_x) have shown that air pollutant concentrations are enhanced by forest fire emissions. In the rural environment, the influence of the forest fire on air quality can be detected, and significantly higher (50-150%) pollution levels than seasonal median values have been documented (Cheng et al., 1998). While fire events can cause high transient air pollutant concentrations, for most criteria pollutants, the fire emissions are a relatively small fraction of the annual emission inventory. For fine particulate matter, however, the annual emission estimates from biomass burning represent a significant fraction of many southern States' emission inventories, especially in the counties where the emissions are concentrated (Dennis et al., 2002). Given the current emphasis by the EPA on particles, it is imperative that real-world emission data from open burning sources be developed.

It is generally thought that emission factors or pollutants are among the more consistent and reliable components of biomass burning emission models. However, comparisons of recent studies suggest that under some conditions, especially where smoldering combustion is important, emission factors (EF) are still quite uncertain (Andreae and Merlet, 2001; Hays et al., 2002). Residual smoldering combustion (RSC) emissions from forest floor burns can be produced for up to several weeks after the passage of a flame front and they are mostly unaffected by flames. Fuels prone to RSC include downed logs, duff, and organic soils. Limited observations suggest that RSC is a globally significant source of emissions to the troposphere (Bertschi et al., 2003). These authors used a model that predicts trace gas EF for fires in a wide variety of aboveground fine fuels. It failed to predict emission factors for RSC. For many compounds, the EF for RSC-prone fuels is very different from the EF for the same compounds measured in fire convection columns above forest ecosystems. Some large changes resulted in estimates of biomass fire emissions with the inclusion of RSC. For instance, EF increases by a factor of 2.5 even when RSC accounts for only 10% of fuel consumption. This shows that many more measurements of fuel consumption and emission factors for RSC are needed to improve estimates of biomass burning emissions. The ecosystems we propose to study are particularly susceptible to this type of combustion. Fine particulate matter estimates from this type of combustion in southern ecosystems is non-existent and needs to be developed.

Smoke Modeling

Smoke emissions from wildland fires is one the most important constraints on land mangers conducting prescribed burns. The quantity, duration, time of day, and spatial dispersion of smoke must all be considered when assessing the impacts on human health and safety. Existing smoke models do a poor job of estimating smoke production and duration. This is especially true on the deep organic soils found in the Coastal Plain of the southeastern US. Many of the dispersion models in use by wildland mangers today (SASEM (Sestak and Riebau, 1988), VALBOX (Sestak et al., 1989), VSMOKE (Lavdas, 1994), NFSpuff (Harison, 1995), TSARS (Hummel and Rafsnider, 1995), and CALPUFF (Scire et al., 1994)) have been adapted from industrial stack models for use in wildland fires. Smoke models for prescribed burning differ from point-source industrial models due to additional data requirements for pattern of ignition, fuel moisture by size, fuel loading by size, fuel distribution, and local weather that influences burn rates and dispersion. The FARSITE (Finney, 1998) model was developed to address these data requirements and is used to model forest fire behavior in variable fuels, terrain, and changing local weather conditions. Recent improvements to FARSITE had allowed simulation of model smoke production by incorporating a fuel consumption model (BURNUP). FARSITE does not model smoke dispersion, but output from the combined models can now be used in smoke dispersion models.

Approximately six million acres of forest and agricultural land are burned each year in the southern US, an area defined roughly by lands located south of the Ohio River and from Texas eastward. Most burning is done during the period from January through

March. Although the vast majority of prescribed burns are completed without incident, there are occasions when smoke from smoldering fuels persists after sunset and becomes entrapped within slow-moving drainage flows. Entrapped smoke can drift into populated areas and impact residents, particularly those with respiratory problems. PB-Piedmont (Achtemier, 2000) was developed to simulate local smoke movement at night over terrain typical of that of the Piedmont of the southeastern US. PB-Piedmont simulates the movement of night wind as it drifts through the shallow gaps in ridges and down road and stream cuts of the Piedmont. A recently developed smoke dispersion model, PB-Coastal Plain, was designed to track smoke movement over the flat Coastal Plain and nearby water surfaces. PB-Coastal Plain is intended to extend the theory of PB-Piedmont to model for coastal land/water interfaces and to include differences in vegetative land use. PB-Coastal Plain is more complex than its sister model for several reasons. First, the forces that move smoke in the Coastal Plain are not always local. Interactions between land and water surfaces 100 km or more away from a burn site can steer the winds at the burn site during a typical nighttime period. PB-Coastal Plain must be capable of modeling land/water interactions over large areas. Second, there exist few stream basins of sufficient depth to channel smoke. Smoke over the Coastal Plain can be channeled by differences in vegetative land use.

The BlueSky smoke prediction system (Ferguson et al. 2001; O'Neill et al. 2003) is an automated centralized framework for predicting cumulative concentrations of smoke from wildland and agricultural fire. It integrates tools and knowledge about fire location, fuel loads, moisture conditions, combustion processes, fire behavior and spread, weather, and smoke dispersion. The model is designed to predict cumulative impacts of smoke from prescribed and wild fires from forestland, agricultural fields, and rangeland (http://www.fs.fed.us/bluesky). An automated system for validating BlueSky with monitoring data in the northwestern U.S. has been operating in many western states to implement the BlueSky Rapid Access Information System (BlueSkyRAINS).

METHODS

We established a permanent plot network on the Alligator River and Pocosin Lakes National Wildlife Refuges, the Croatan National Forest, and the Air Force Dare County Bombing Range modeled on USDA Forest Service FIA P2 and P3 plots to measure and characterize live biomass and pre- and post-burn down deadwood (DWD). We used field protocols based in methods establish by the USDA Forest Service in Field Instructions for Southern Forest Inventory. The collection of DWD data was collected using a line-intersect method to sample down wood along linear transects. Plot-level data on the amount, distribution, and characterization of DWD was related to the detailed attribute data for other ecosystem components on the same plot (i.e., shrub and herbaceous understory, live and dead herbs (including grasses), and litter (Figure 1.). FIA methodology will be augmented with additional data on the vertical distribution of DWD for input into the FARSITE fire behavior model. Down deadwood was characterized as coarse woody debris (woody pieces greater than 3.0 inches in diameter), or fine woody

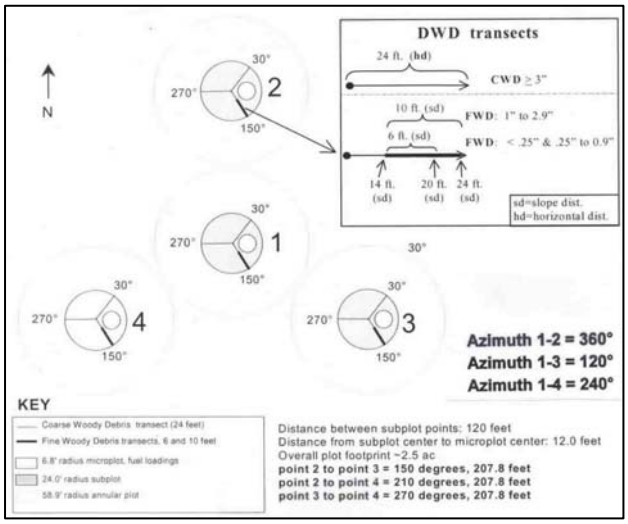


Figure 1. FIA cluster subplot design with three 24-ft. transects (slope corrected, horizontal distance) established at each subplot location. All subplot clusters are laid out in a fixed pattern regardless of different condition classes and only the transect segments that fall in the forest condition are sampled. The 6.8-ft radius micro plot is used to estimate the percent cover and height of live and dead shrubs, live and dead herbs (includes grasses) and litter. Fuel loading is estimated in accessible forestland conditions on the micro plot.

debris (small = 0 to 0.24 inch, medium = 0.25 inch to 0.9 inch, and large= 1 inch to 2.9 inches, which correspond to 1-hour, 10-hour, and 100-hour fuels, respectively). The depth of the duff layer, litter layer, and overall fuelbed was taken at the 24-foot location on each transect. These components were used to estimate fire behavior, fire spread, fire effects, and smoke production. Plot-level per-unit-area sums were expanded by the area associated with the inventory plot or averaged across the plots to produce a mean per-unit-area biomass value. Biomass computations for each fuel class have been previously developed in a pond pine/high pocosin forest type. Fuel class biomass algorithms were developed for additional forest species and decay classes in the forest types for each of the burn sites. Additional micro plots was established for destructive sampling of shrub and herbaceous vegetation to develop biomass equations. Previous equations were developed primarily for western US species (Brown et al, 1982).

We acquired USGS NAP color infrared (CIR) negatives of stereo aerial photography for study areas and collected field data on fuel loads and/or fuel accumulation. Aerial photos were scanned to generate digital coverages and stereo models for interpretation as well as orthorectified mosaics of the study areas. We incorporated existing GIS vegetation data from the USFWS and the US Air Force, or classify newly acquired aerial photography (US Air Force FY‘2004 leaf off 1:600 scale color infrared) using onscreen stereoscopic techniques to create a digital vegetation database. Fire fuel data from field based sample plots, digital photos, and vegetation data were used to develop fire fuel polygons. Additional field data was used to assess the thematic accuracy of the

vegetation classification, the positional accuracy of the digital orthophoto mosaic, and the fuel load polygons. Metadata was created for the digital orthophoto mosaics and vegetation and fuel load databases.

Prescribed Burning Emissions Monitoring and Modeling

In order to assess emissions of fine PM from prescribed fire, we investigated emissions from this burning practice during the course of prescribed burns for the fall and spring of 2005 and 2006. Mass balance techniques were used to support flux measurements of dioxin, methyl chloride, methyl bromide, and other compounds. Grab samples (stainless steel canisters for trace gases, filter packs for PM, and polyurethane foam traps for semi-volatiles (Hays et al., 2002) were collected in the plumes of the fire during both flaming and smoldering conditions. These samples will then subjected to particle and total gaseous carbon analysis using a thermo-gravimetric analysis and gas chromatography/mass spectroscopy (GC/MS). Total emissions were determined by multiplying emission ratio by the estimate of total fuel carbon consumption. Total fuel carbon by mass is approximately half of the fuel dry weight following the general cellulosic molecular formula of $C_6H_9O_4$.

We sampled air that has cooled to approximately ambient temperature (within 100 meters of the fire) to allow partitioning of semi-volatiles between the gas and aerosol phase. We sampled directly through PM2.5 cyclones using high volume pumps, onto 47 mm quartz (for organic PM components) and teflon filters (for inorganic ions and elements). These were backed by polyurethane foam plugs for quantitative analysis of semi-volatile organic compounds that pass through or are volatilized from the filters. Trace gases (methane, C2-C12 volatile organic carbon (VOC)) were characterized separately using Summa stainless steel canisters and GC/MS. Target compounds in the gas and PM phase included saturated (alkane) and unsaturated hydrocarbons, aldehydes, ketones, organic acids, and polycyclic organic hydrocarbons (PAH). We also measured CO via gas filter correlation (Teco 46C) and CO^2 via infrared gas techniques (Licor 7000) to characterize carbon fluxes for the mass balance flux techniques and to characterize the nature of plume dispersion and proximity to the combustion. We used the CO/CO^2/VOC measurements to help us in chemically identifying the flaming and smoldering stages of the fires.

We quantitatively analyzed these samples to determine emission factors for individual trace gases. These were compared with factors from other fuel types. We also compared current source apportionment chemical fingerprints from these fires with those from our laboratory and “burnhut” studies (Hayes et al., 2002). This allowed us to assess these signatures with *in situ* data. We compared emission factors and fluxes with any available data from wildfire emissions from corresponding forest types.

Smoke Modeling

Data was collected for validating PB-Coastal Plain. This information included: (1) Depth of the nocturnal boundary layer over the course of the night; (2) Temperature of

the nocturnal boundary layer over the course of the night; (3) Ground level (2m) measurements of wind speeds down to 0.1 m/sec, temperature, and relative humidity from a dense network of surface weather stations surrounding the burn site; and (4) Observations of smoke location.

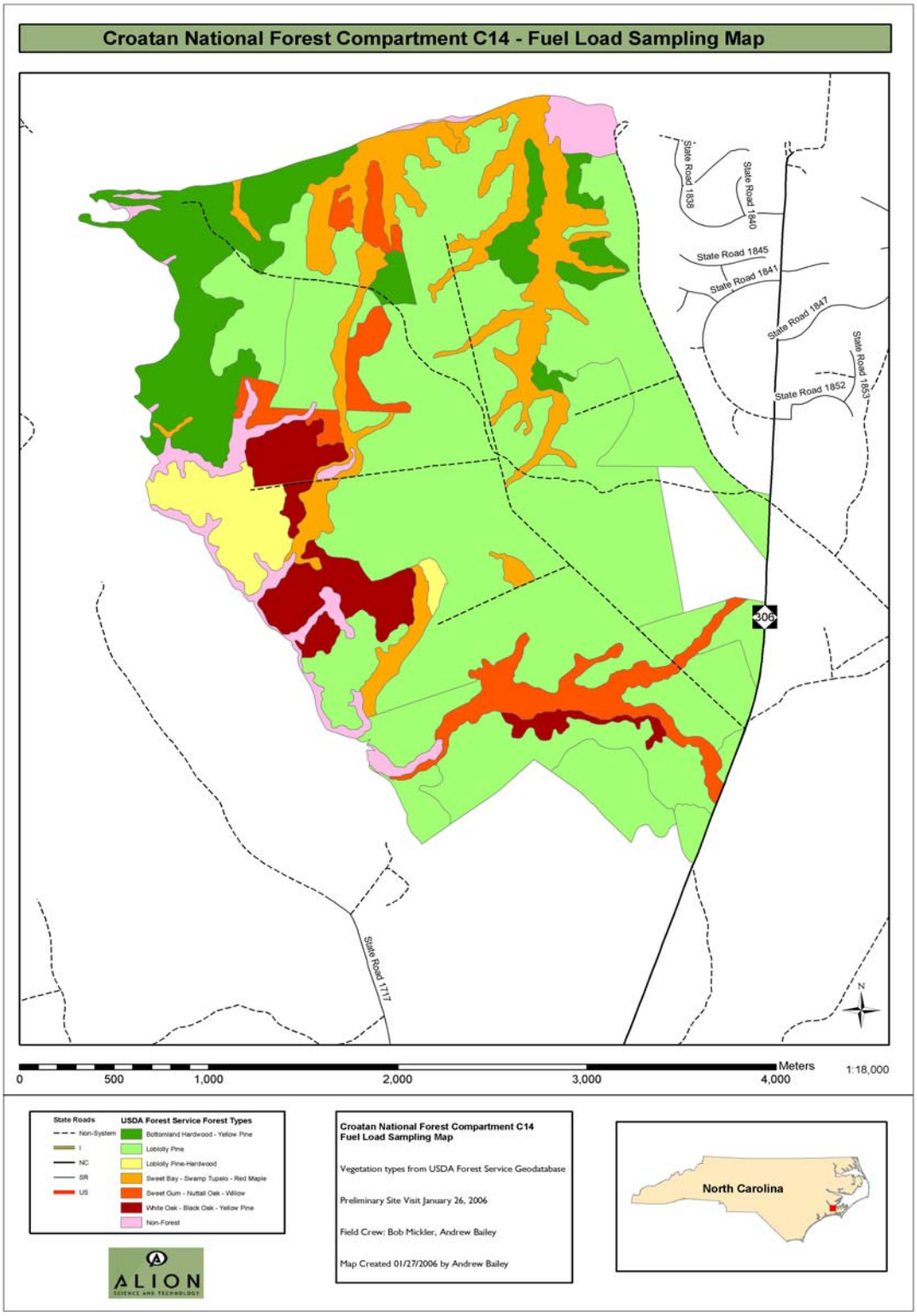
A forecast of expected weather and smoke behavior was developed before each experimental prescribed burn. On-site meteorological information was gathered to enable a run and test the BlueSky smoke prediction system. The forecast was necessary to help anticipate fire and smoke behavior and to determine the most effective observational configuration. On-site meteorological information was used to validate and improve the weather components of BlueSky and PB-Coastal Plain. A standard configuration of BlueSky was run to help with pre-burn forecasting and used to demonstrate the uncertainty in predicting smoke in the region. An enhanced configuration of BlueSky was run with measured information from each experiment to help quantify areas of needed improvement. The meteorological observations included four surface weather stations at strategic points around the fire perimeter to capture surface drift smoke and influencing weather. Each station measured wind, temperature, humidity, and carbon monoxide every 5 minutes. Additional stations (Data-logging Real-time Aerosol Monitors (DataRAM) and Environmental Beta-Attenuation Mass Monitor (E-BAM)) outfitted with a particle sampler were placed in expected downwind locations away from the fire perimeter to capture outflow rates. The location of each sampling station was based on the topographic configuration of the area, expected weather, and anticipated fire and smoke behavior. The meteorological data was monitored during each experiment to ensure quality control. This sampling methodology has been successfully deployed at the FROSTFIRE experimental burn in Alaska (Ferguson et al., 2003) and the surface measurements have been tested during experimental burns in Washington, Oregon, and the Piedmont region of northern Georgia with success. Before each experiment a standard configuration of the BlueSky smoke modeling system was run which used the CALPUFF dispersion model. The system was rerun following each experiment in an enhanced mode that adjusts available pre-burn information with information that was measured during the experiment. The two runs were compared to quantify uncertainty in the modeling system and determine areas of needed improvement.

RESULTS AND DISCUSSION

Vegetation Classification and Current Forest Biomass

Six research prescribed burns were monitored during the first two years of the study. The following preliminary information characterizes one research burn conducted on February 28, 2006 at the Croatan National Forest in North Carolina. Six forest types were identified on the research site. 1. These forest type associations were (1) bottomland hardwood-yellow pine (2) loblolly pine, (3) loblolly pine-hardwood, (4) sweet bay-swamp tupelo-red maple, (5) sweetgum-nuttail oak-willow, and (6) white oak-black oak-yellow pine (Figure 2.).

Figure 2. Map of forest vegetation types on prescribed fire research burn



Forest biomass in four forest types was consumed during the prescribed burn. The two forest types associated with saturated soils in low-lying drainages did not have any combustion of DWD.

Table 1. Summary of prescribed burn forest type acres.

Forest Type	**Acres**	**Pct.**
Bottomland Hardwood – Yellow Pine	253.79	13.68%
Loblolly Pine	1,403.88	75.67%
Loblolly Pine-Hardwood	76.26	4.11%
White Oak – Black Oak – Yellow Pine	121.25	6.54%
Total	1,855.18	

Preliminary trends in pre- and post-burn biomass is shown in Table 2. Fuels were characterized in12 foot diameter microplots into live and dead herbaceous plant biomass, and live and dead shrub biomass. Litter, 1, 10, 100, and 1,000 hour fuels were estimated from line intersects. The large source of carbon emissions was found in the litter layer (93.2%), followed by 1 hour DWD (1.8%), 10 hour DWD (1.8%), dead herbaceous plants (1.6%) and live herbaceous plants (1.4%). The quantity of carbon ranged from 4.54 tons/acre to 0.07 tons/acre.

Table 2. Summary of forest biomass for 1,855.18 acres Loblolly pine prescribed burn on the Croatan National Forest, North Carolina (Burn Compartment C14).

	1 hr fuels	**1 hr fuels**	**1 hr Fuels**	**1 hr fuels**	**1 hr fuels**	**1 hr fuels**	**10 hr fuels**	**100 hr fuels**	**1000 hr fuels**	**Total fuels**
	Live Herb	Dead Herb	Live Shrub	Dead Shrub	Litter	(0-.25 in.)	(.25-1.0 in.)	(1-3 in.)	(>3in.)	
Pre Burn										
tons C/acre	0.07	0.09	0.79	0.12	5.02	0.14	0.95	1.18	0.95	9.31
total tons C	129.86	166.97	1,465.59	222.62	9,313.00	259.73	1,762.42	2,189.11	1,762.42	17,271.73
Post Burn										
tons C/acre	0.00	0.01	0.79	0.12	0.48	0.05	0.86	1.18	0.95	4.44
total tons C	0.00	18.55	1,465.59	222.62	890.49	92.76	1,595.45	2,189.11	1,762.42	8,237.00
Consumed										
tons C/acre	0.07	0.08	0.00	0.00	4.54	0.09	0.09	0.00	0.00	4.87
total tons C	129.86	148.41	0.00	0.00	8,422.52	166.97	166.97	0.00	0.00	9,034.73

The emission factors (EFs) resulting from the samples collected during each phase of the prescribed burn is presented in Table 3. $PM_{2.5}$ typically composes at least 2/3 of total PM, and roughly 80% of PM_{10} from biomass combustion sources (Andreae and Merlet, 2002). Our data is consistent with these relative proportions. The $PM_{2.5}$ and PM_{10} EFs determined using the Met One sensor are lower than the filter based methods, likely because this instrument has a 0.5 μm lower diameter detection limit. A large fraction of biomass burning particles fall below this size cut (Hays et al. 2002). CO_2 emission factors are important since they represent the largest carbon component of emissions. The integrated concentration values from the continuous CO_2 emission monitor exceeded or was nearly equal to the concentration determined from the Summa canister during the flaming stages of the fires. It is not known if possible reactions with in the canister might affect this comparison. In any case, this method-induced variability in CO_2 concentrations induced an uncertainty in emission factors of all gasses and particles of 0-10%.

Table 3. Emission factors derived from smoke samples of the Croatan National Forest, North Carolina prescribed fire (Emission Factors in g kg (fuel dry weight)$^{-1}$).

Stage*	**Time**	**PM10**	**PM10M**	**PM2.5**	**PM2.5Q**	**PM2.5M**	**CO**	**CO2**	**CO2c**	**NOX**	**THC**	**SO2**
Fl	14:40-15:10	4.14	5.39	5.40	5.48	0.37	167.7	1802	1817	6.69	12.7	1.57
Fl	15:15-16:00	1.13	0.94	0.67	0.61	0.64	32.14	1971	2159	1.08	4.3	0.29
Fl/Sm	16:00-16:40	0.61	0.48	0.47	0.32	0.38	22.32	1940	2267	0.56	3.3	0.22
Sm	16:55-18:20	1.43	0.80	1.12	0.99	0.62	34.67	2097	2691	0.79	6.0	0.24

Stage* Fl=Flaming stage, Sm=smoldering stage
PM10 determined gravimetrically from Teflon filter in single stage impactor.
PM10M determined from Met One detector, measures PM 0.5 to 10 m.
PM2.5 determined gravimetrically from Teflon filter in single stage impactor.
PM2.5Q determined gravimetrically from Quartz filter in single stage impactor.
PM2.5M determined from Met One detector, measures PM 0.5 to 2.5 m.
CO determined using TECO 46C continuous emission monitor.
CO2 determined using GC/TCD analysis on Summa can samples.
CO2c determined using TECO continuous emission monitor.
NOX determined using TECO 42S continuous emission monitor.
THC determined using TECO continuous emission monitor.
SO2 determined using TECO continuous emission monitor.

In general, the $PM_{2.5}$ and PM_{10} EFs are lower those published in other open biomass burning studies. Observed NOx EFs are also lower, while those for SO_2 and total NMHC fall within the ranges of previously reported biomass burning studies.

For all of the prescribed fires, emission factors for CO_2 are higher than reported ranges (Andreae and Merlet, 2002). The combination of lower PM EFs and higher CO_2 EFs

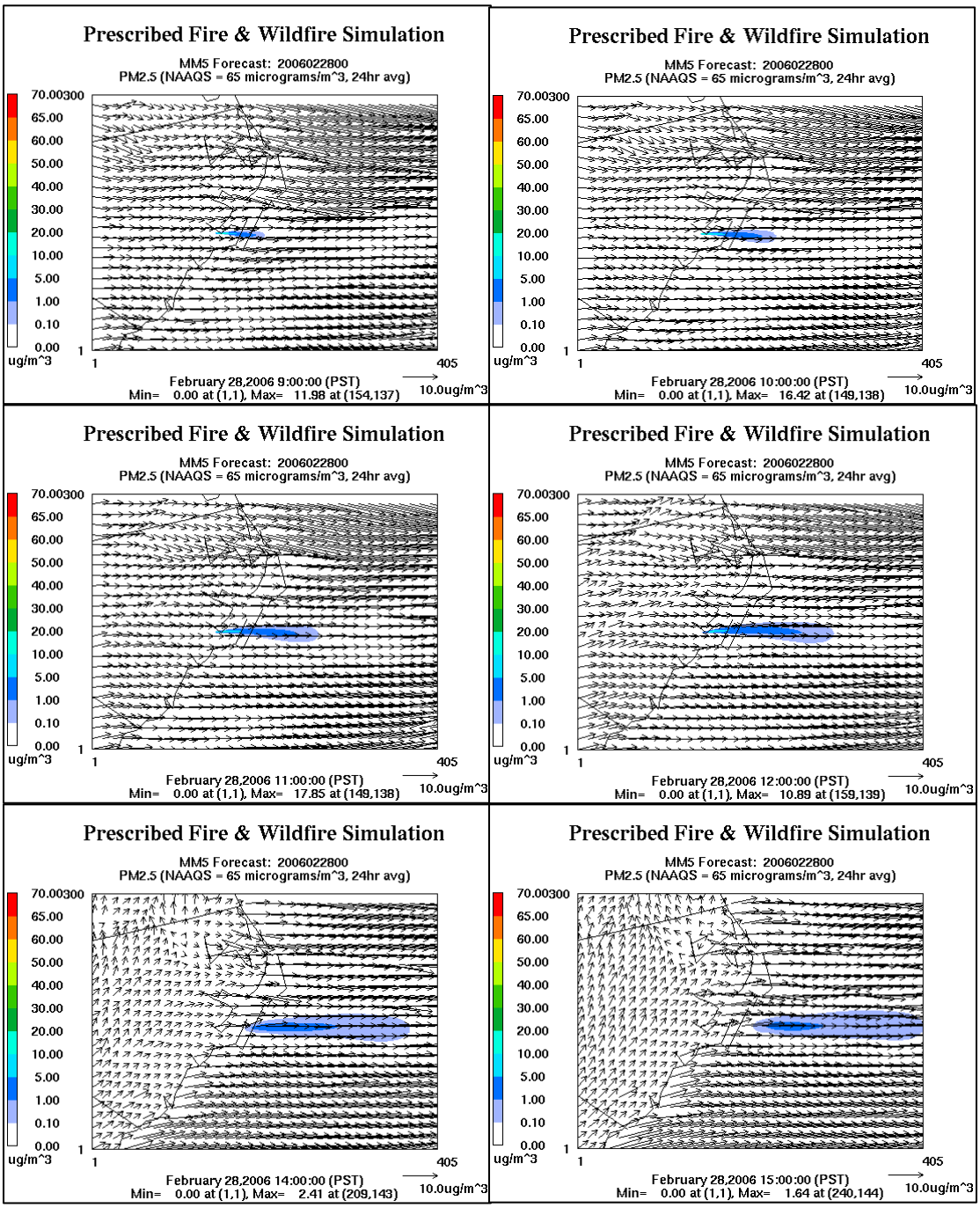
indicates that the prescribed fires exhibited more efficient combustion than wildfires or slash reduction burns. This is likely due to effectively burning primarily fine fuels under prescription conditions, which minimizes consumption of soil organic layers and smoldering of heavy fuels. Combustion of these fuel components often results in higher emission of products of incomplete combustion.

CO EFs are lower than previously report values except for the initial flaming stages of the Croatan National Forest fire. CO EF values were high, and corresponded with the highest $PM_{2.5}$ values observed in this study.

The BlueSky modeling framework output products include animations of PM2.5 concentrations and wind flow patterns at the surface. Examples of hourly images from the animation are shown in Figure 3. Fire characteristics are processed through the Emissions Production Model (EPM) to give emission estimates of particulates ($PM_{2.5}$, PM_{10}, and total PM), carbon compounds (CO, CO_2, CH_4, non-methane hydrocarbons), and heat. The emission estimates from EPM along with meteorology from MM% are processed for the CALPUFF dispersion model and the HYSPLIT trajectory model. The BlueSky system framework merges meteorology with emission estimates to yield an integrated regional-scale analysis of Smoke and aerosol concentrations.

Primary inputs to BlueSky include weather, fire characteristics, and fuels. Predictions of wind speed and direction as well as mixing height are required to determine smoke trajectories and $PM_{2.5}$ concentrations. Weather inputs come from the MM5 mesoscale meteorology model. In order to arrive at an accurate predicting of smoke emissions it is necessary to get detailed information about size, location, and timing of the prescribed burn. Fuel model and fuel loading information is essential to emissions modeling. BlueSky uses general fuel characteristics derived from the Fuel Characteristic Classification System (FCCS), but for this project detailed pre- and post-burn fuel characteristics were collected from permanent field plots. Emissions are computed using Consume/EPM v1.03, which calculates the heat release rate and emissions for particulate matter and carbon compounds as a function of time since fire ignition. These emission values are input data for CALFUFF v5.711 that calculates the dispersion and plume rise. Trajectories are computed using the HYSPLIT model. HYSPLIT uses a full 3-dimensional wind field for computational purposes but does not include any heat or buoyancy effects from fire.

Figure 3. Prescribed fire simulation from BlueSky for Croatan National Forest prescribed fire research burn. PM 2.5 ground concentrations (μg/m^3) and wind flow patterns are shown as houly images starting at burn iniation. MM5 meterology simulation was done on a 1.33km resolution.



SUMMARY AND CONCLUSIONS

Land managers in the Coastal Plain of the eastern US recognize general fuel types on organic soils mineral soils. Past fuel and fire behavior research has resulted in only qualitative measures of fuel loads and rates of spread. A more detailed fuel classification based on species composition, standing dead and down deadwood, fuel size classification, understory vegetation, and vertical distribution of fuels would have much more utility than the broad fuel model classification system now in use. Fire in the organic and mineral soil areas of the Coastal Plain centers around the frequent and costly blowup wildfires occurring there and the use of fire as a fuel reduction and habitat management tool. Wildfires in this area can under certain combinations of fuel and weather, grow from a low intensity burn to a virtually uncontrollable burn until weather conditions change or the fire has run out of fuel. Control efforts are often hampered by inaccessibility, poor soil trafficability on wet organic soils in the area, and fires that tend to burn deeply into the organic soils. A better understanding of the behavior of fires and the role of fuel loading in fire behavior in the pocosins, especially the factors that contribute to the occurrence of major fires, will contribute to the control of wildfires and the use of prescribed fire as a management tool in the region.

The methodology of using modified National Vegetation Classification Alliance level vegetation maps, created from digital photogrammetry and FIA P3 data, shows promise as an approach to fuel mapping. Softcopy photogrammetry, coupled with ground truthing, provides a high level of accuracy for mapping to the association level of the ICEC system. Fuel loads generated from the FIA P3 plots differ from fuel loads estimated using the standard fire models. These differences could have an impact on the prediction of fire spread and behavior. Fuel loads within fuel size classes did vary between the modified association level classifications. Disturbance history appears to play a significant role in explaining why fuel loads differ and could help in creating more accurate fuel maps. Research of this nature may lead to use of FIA P3 plot data to generate an index of fuel load by ICEC association level vegetation classification. This could lead to a valuable multi-purpose tool for land managers and researchers for use in predicting, preventing and managing forest biomass for wildfire.

The United States Environmental Protection Agency (EPA) has implemented new regulations for the management of $PM_{2.5}$, tropospheric ozone, and regional haze. In accordance with sections 108 and 109 of the Clean Air Act (Act), EPA has reviewed the air quality criteria and national ambient air quality standards (NAAQS) for $PM_{2.5}$. Based on these reviews, EPA revise the current primary PM_{10} standards by adding two new primary $PM_{2.5}$ standards set at 15 g m^{-3}, annual mean, and 50 g m^{-3}, 24-hour average, to provide increased protection against a wide range of PM-related health effects. These include premature mortality and increased hospital admissions and emergency room visits; increased respiratory symptoms and disease; decreased lung function; and alterations in lung tissue and structure and in respiratory tract defense mechanisms. Recent proposals would reduce the 24-hour average $PM_{2.5}$ standard to 35 g m^{-3}. Fire generates $PM_{2.5}$ and other ozone precursor gases that reduce visibility. Hence, natural

area and agricultural land management, nationwide, may come under increased scrutiny as regulators seek reductions in pollutant emissions that contribute to NAAQS violations.

Little data on emissions from prescribed burning is currently available, and this fire type in particular is projected to increase in the southeastern U.S. We hypothesize that emissions of $PM_{2.5}$ and PM_{10} and gas phase reduced compounds, many of which are air toxics, will be lower during prescribed fires compared to wildfires covering the same area. This is suspected largely because it is known that wildfires occur typically during excessively dry periods, when much of the forest floor is dry and susceptible to smoldering incomplete combustion, the source of many toxic compounds. It is likely that burning under prescriptions will reduce human exposure and emissions of hazardous air pollutants, and net risk to property and human welfare.

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