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Development and demonstration of smoke plume, fire emissions, and preand post-prescribed fire fuel models on North Carolina Coastal Plain forest ecosystems

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Project Title: Development and demonstration of smoke plume, fire emissions, and pre- and post-prescribed fire fuel models on North Carolina Coastal Plain forest ecosystems

Project Number: 04-2-1-80

Announcement for Proposals this proposal is responding to: Locally important knowledge or data gaps associated with planning and implementation of wildland fire, fuel treatments, or post-fire treatment actions (post-fire stabilization/rehabilitation) that are specifically identified by an agency administrator

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Duration of Project: August 1, 2004-August 1, 2007

Project Objectives

The objectives are to (1) Inventory, map, and model live and down woody debris/fuels biomass utilizing USDA Forest Service Forest Inventory and Analysis P2 and P3 field plot protocols, develop fuel loading formulas for fire behavior models in the Alligator River National Wildlife Refuge and the Air Force Dare County Bombing Range in the North Carolina Coastal Plain, and incorporate data from Coastal Plain forest types into the fuel characteristic classification (FCC) system and the FARSITE fire behavior model; (2) Validate the USDA Forest Service PB-Coastal Plain smoke model, the BlueSky smoke prediction system, and the BlueSky Rapid Access Information System (BlueSkyRAINS) for the near-coastal land-water interface, including differences in vegetative land use; (3) Characterize photochemically active and radiatively important trace gases as well as PM emissions from prescribed burns in Coastal Plain forest types and histosol soils, and (4) Deliver personal computer and web-based decision support tools for estimating inputs of live biomass and down woody debris/fuels into a fire behavior model, real-time smoke plume models, and an emissions model for prescribed burns for use by federal and state land managers in North Carolina specifically, and other users throughout the Coastal Plain of the southeastern US.

Summary of Finding to Date

Wildland and prescribed fires on deep organic soils pose unique challenges to the characterization of fuels, fire behavior, and fire emissions.

Land managers in the Coastal Plain of the Eastern United States recognize general fuel types on organic soils and 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.

USDA Forest Service FIA field protocols for down woody debris were effective methods for accurately estimating pre- and post-burn biomass. Herbaceous and shrub biomass estimates should be qualified using destructive sampling and weighing in the field.

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 fuel 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 multipurpose tool for land managers and researchers for use in predicting, preventing, and managing forest biomass for wildfire.

The US Environmental Protection Agency's revised NAAQS for $PM_{2.5}$ will likely impact prescribed fire planning and implementation, especially near urban corridors.

The U.S. Environmental Protection Agency (EPA) has implemented new regulations for the management of PM2.5, tropospheric ozone, and regional haze. In accordance with sections 108 and 109 of the Clean Air Act, EPA has reviewed the air quality criteria and national ambient air quality standards (NAAQS) for $PM_{2.5}$. Based on these reviews, EPA revised the current primary PM10 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.

Prescribed fire result in lower emissions than wilfire.
Little data on emissions from prescribed burning are currently available, and this fire type in particular is projected to increase in the Southeastern United States. 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 and incomplete combustion, the source of many toxic compounds. It is likely that burning under prescriptions will reduce human exposure and emissions

There is always a tradeoff between reduction of fine fuels and prevention of organic soil combustion during prescribed fires.
The goals of the prescribed fire plan were to reduce accumulations of fine fuels, top-kill midstory shrubs encroaching into pine ecosystems, and top-kill encroaching hardwoods. Within the loblolly pine forest and pond pine woodland alliances, these conditions were met successfully. The litter and small fine woody material levels were reduced by 48 percent and 56 percent, respectively, in the loblolly pine forest. Litter and small FWM consumption was particularly high in the pond pine woodland alliance, where the canopy coverage was generally below 80 percent. The open canopy permitted sunlight to reach the forest floor, which combined with air circulation to desiccate the fine fuel classes and permit more active fire behavior. Within the pond pine woodland alliance, the fire consumed 81 percent of the total litter fuel load and 80 percent of the small FWM fuel load. Fuel consumption from the prescribed burns described here generally fall within the range of values (3-20 tons $acre^{-1}$ or 6.8-45 tons ha^{-1}) assumed in current models and smoke management guidelines (NCDFR, 2006). In cases where fine fuels (such as marsh grass or pine litter) accumulate, fuel loads range from 3-6 tons $acre^{-1}$ (6.8-13.5 tons ha^{-1}). Where flammable shrubs (such as gallberry and fetterbush) colonize sites, fuel loads and consumption may be considerably higher. These circumstances occur when fire frequency is reduced and fuels are allowed to build up, creating wildfire risks. Light fuel loading and a variable fuel bed in the mixed pine/hardwood forest alliance limited fire activity. The encroaching hardwood bay (*Gordonia lasianthus / Persea borbonia*) midstory and dense overstory canopy inhibited fuel desiccation, which suppressed fire behavior and restricted the spread of fire. Future burns in this area may need to be conducted with lower relative humidity and 10-hour fuel moistures to successfully reduce fuel loads in this vegetation type. The maple forest alliance burned poorly, as it

contained little litter, areas of flooded soil, and a discontinuous fuel bed. This area would likely only burn under wind-driven wildfire conditions, when medium and large fine woody fuels, coarse woody fuels, and live canopy fuels could ignite. Under typical prescribed fire conditions, the maple forest serves as an effective fire barrier.

There was poor correlation between estimates of fuel loading utilizing FIA protocols and the FCCS.

The mapping technique distinguished vegetation types that had different fuel loadings. The level of detail in the map was high enough to show the distribution of vegetation communities with differing fuel loads in the landscape. This information was useful for planning and implementing the prescribed burn. A distinction was drawn between high canopy coverage and low canopy coverage areas within the pond pine woodland alliance, due to appearances of different fuel loadings and fire behavior potential. This distinction did not reveal any actual differences in preburn fuel loading, but appeared to be more important for postburn fuel loading. This is likely due to increased drying from greater sunlight and wind reaching the fuels in the low canopy coverage areas. This illustrates the utility of mapping within-alliance distinctions in order to better anticipate fire behavior. Comparison of our results to standardized fuel models was problematic because the maple forest and mixed/pine hardwood forest alliances could not be cross-walked to analogous Coastal Plain fuelbeds from the FCCS system. For the pond pine woodland alliance, the FCCS fuel loads underpredicted our measured values for total litter by 56 percent. This is likely due to site-specific variation from past fire suppression. Within the loblolly pine forest alliance, FCCS underpredicted litter by 27 percent and small FWM by 5 percent. Loblolly pine forests on saturated deep organic soils, such as those present on this research site, are somewhat atypical throughout much of the Southeastern United States and may not be accounted for in the FCCS model. Duff measurements were much higher than those reported by FCCS for the research unit due to the deep peat soil types typical of the Dare County peninsula.

Fuel loading estimates utilizing Brown's Transect techniques resulted in similar estimates as reported in published studies for unique vegetation types.

Although detailed accuracy assessment was beyond the scope of this study, fuel loads for the pine-dominated ecosystems were similar to those reported by Rosenfeld (2003) and Wendel and others (1962). The presence of two vegetation alliances that have no analogue in standardized fuel models suggests that detailed site-specific fuel loading measurements may be necessary for land managers. Fine-scale mapping of vegetation alliances and their associated fuel loads is a feasible technique for reducing or eliminating the limitations associated with standardized fuel models. Standardized fuel models may provide ballpark numbers that are, in many cases, appropriate for prescribed burn planning. However, site-specific differences that affect both fuel loading and fuel consumption can become apparent after direct measurements are compared to standardized models. These differences may be important to research and land management activities where smoke management and fuel reduction goals depend on using accurate fuel loadings.

Fire gradients on coastal plain ecosystems are driven by salinity.

The pronounced east-west fire frequency gradient on the Dare County peninsula is driven by salinity. The brackish water along the eastern margin sustains flammable saltmeadow cordgrass (*Spartina patens*) / saltgrass (*Distichlis spicata*) and black needle rush (*Juncus roemarianus*) marshes, which form a continuous wide shoreline band stretching some 50 miles (80 km) from the Albemarle sound, down the length of mainland Dare, to the Pamlico sound at the bottom of the peninsula. This fire corridor graded into flammable canebrake immediately to the west. The boundary between brackish marsh and salt-intolerant canebrake likely occurs at the western limit of storm overwash. In contrast, on the west side, nonpyrophytic cypress-gum swamp fringes the fresh waters of the Alligator River in a narrow band. The short fire interval marsh and cane communities of the eastern side and the nonflamable river swamp on the west comprise the extremes of a cross-peninsula fire frequency gradient. Between these extremes, a kilometer wide swath of canebrake graded into pocosin vegetation where fire frequency was low enough to allow the development of a dense shrub understory. To the west of the pocosin vegetation, a large-scale patch mosaic of wooded wetland ecotypes occurred at decreasing fire intervals. This mosaic was made up of pocosin, pond pine forest, black gum (*Nyssa biflora*) forest, pond cypress (*Taxodium ascendens*), loblolly bay (*Gordonia lasianthus*) forest, and Atlantic white cedar. Fire-exposed pine-gum and fire-sheltered oak-pine forests occurred on mineral soil lenses in the peninsula's interior. The patch mosaic was bounded on the west by a relatively narrow band of cypress-gum swamp, only 100 to 300 m wide, along the Alligator River.

Landscape ecology principles can be applied to reconstruction of historical fire frequency in coastal plain ecosystems.

The principles of landscape fire ecology were applied to construct a map of presettlement fire regimes and presettlement vegetation in Dare County, North Carolina. In an area of the country where traditional fire history reconstruction techniques such as fire scar chronologies are not available, these techniques provide a method to create a useful product for the land manager. These presettlement maps should serve as a useful guide for prescribed fire management, restoration ecology, and ecosystem management planning for the current and future ecosystems of Dare County.

Mapping historical fire frequency is best though of as a snapshot in time in a changing mosaic of fuel loading and subsequent fuel reduction by wildfires.

A certain amount of uncertainty is inherent in the construction of presettlement maps. The polygons delineated represent our best estimate of the locations of specific fire-adapted communities and fire regimes. In many cases these estimates are confirmed by 1934 aerial photography, land grant documents, and historic maps, but it is important to realize these sources have limited spatial accuracy. This form of mapping does not lend itself to quantitative accuracy assessment, and the resulting maps should not be regarded as truth. Instead, they represent a snapshot of the many likely fire and vegetation patterns that have existed since these communities became dominant nearly 5,000 years ago.

Presettlement vegetation and fire regime maps should not be used to demonstrate what the current landscape should look like, but rather used as background information for managing existing vegetation.

No ecosystem is static, and many things have changed over the 400 years since European settlement, including extensive logging of Atlantic white cedar and loblolly pine, conversion of hardwood forests on mineral soils to agricultural fields, widespread alteration of hydrology, changing climate, and rising sea level. The changes dictate that these presettlement vegetation and fire regime maps should not be used to demonstrate what the current landscape should look like, but rather used as background information for managing existing vegetation. For example, special attention may be appropriate for the oak-pine and pine-gum forest types. These forest types occupied a moderate-frequency fire niche in the landscape that is currently not replicated by fire or management activity in Dare County. Frequent-fire vegetation communities such as low pocosin and canebrake are much smaller than they would have been in the presettlement landscape. At the present, 43 percent of presettlement extent of low pocosin and no pure canebrake communities remain. On the western portion of the Dare County peninsula, fire-intolerant vegetation types are now encroaching into what were once areas of low- and mid-frequency fire. This encroachment reduces habitat for threatened and endangered species, particularly the red-cockaded woodpecker, which inhabits open, frequently burned pond pine woodland ecosystems. Active management to increase the acreage of pond pine woodland burned would benefit these species.

Emission factors from prescribed fires were shown to lower values reported for wildland fire.

The emission factors determined from the samples collected during each of the individual prescribed burns 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 were within 3-10% of the concentrations determined from the Summa canisters. This method-induced variability in CO_2 concentrations induced an uncertainty in emission factors of all gasses and particles of less than 10%. For all of the prescribed fires, emission factors for CO_2 are in the upper half of reported ranges (Andreae and Merlet, 2002). This indicates clean, efficient combustion relative to other forms of biomass burning.

In general, our $PM_{2.5}$ and PM_{10} EFs are lower those published in other open biomass burning studies. Our $PM_{2.5}$ EFs are at the low end of the range of those published in AP-42 and those summarized by Vose et al (1997). The $PM_{2.5}$ EFs for coniferous and mixed fine fuels are approximately half of those used in the emission model (9-12 g kg^{-1}) described by Weidinmyer et al. (2006) for coniferous, mixed, and shrubland fuel classes. The $PM_{2.5}$ EF of 8.0 g kg^{-1} used by Dennis et al (2002) for litter and fine woody fuels is similar to, but still higher than the range observed from our forest Rx burns. The wetland $PM_{2.5}$ EFs (5.6-11.2 g kg^{-1}) of Wiedinmyer et al (2006) are 4 to 8 times higher than the marsh grass $PM_{2.5}$ EFs observed here. The PM and CO EFs for the marsh grass fuels are more similar to (but somewhat lower than) values observed for grasses and agricultural residues.

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 the latter fuel components often results in higher emission of products of incomplete combustion (McMahon et al.,1980; Bertschi et al, 2003). Organic soil burning $PM_{2.5}$ EFs can exceed 40 g kg^{-1} (McMahon et al, 1980; Chen et al, 2007).

Carbon monoxide emission factors were lower than previously reported in the literature.

CO EFs are lower than previously reported prescribed and wildfire values except for the Pocosin Lakes and the February 28 Croatan National Forest fires. CO EF values were highest at these two sites and fall in the upper end of the range of reported EFs. These CO EF values also corresponded with the highest $PM_{2.5}$ and lowest CO_2 EF values observed in this study. Ozone concentrations were enhanced above 20 ppb v/v background levels to as high as 2 ppm v/v during the most intense periods of these fires. These values are likely high due to interference from aromatic compounds emitted from the fire. The Pocosin Lakes fire produced a thick black smoke when the waxy foliage of the fetterbush and gallberry were consumed. The CO and $PM_{2.5}$ concentrations were highest during these periods.

Nitrogen oxide emission factors fell within the range of reported values.

NO_X EFs are typically thought to be related to the amount of nitrogen in the fuel, since biomass fires typically do not get hot enough to generate NO from atmospheric N_2 (Andreae and Merlet, 2002). Our NO_X EFs span the range of published values for biomass open burning. The EF for the Pocosin Lakes fire may have been low due to ozone titration, since NO_X was measured as NO here. However, the performance of the NO monitor during this fire was more uncertain than for the other fires.

Sulfur dioxide emission factors on wetland soils were higher than reported values.

SO_2 EFs from the Stumpy Point and Feb 28 Croatan NF fires exceeded 1 g kg^{-1} and were somewhat higher than the values given by Andreae and Merlet, 2002. These sites feature significant fractions of wetland soils prone to high reduced sulfur emissions which may be oxidized during combustion. This probably warrants further study, especially where the possibility of extensive organic soil consumption during wildfire is a likely scenario. The remaining three fires yielded SO_2 EFs that were consistent with previous studies.

$PM_{2.5}$ typically composes at least 2/3 of total ambient PM, and roughly 80% of PM_{10}.

Previous studies have found that $PM_{2.5}$ typically composes at least 2/3 of total ambient PM, and roughly 80% of PM_{10} from biomass combustion sources (Andreae and Merlet, 2002 and references therein). Our data is consistent with these 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).

DataRam4 yielded $PM_{2.5}$ estimates within 3-4% of the FRM for samples collected during both flaming ($PM_{2.5}$ concentrations ranging from 300-5000 $\mu g\ m^{-3}$) and smoldering ($PM_{2.5}$ concentrations ranging from 10-300 $\mu g\ m^{-3}$).
During the March 23 Croatan fire we compared co-located EBAMS and DataRam4 smoke monitors with the Federal Reference Method EPA Method IP-10A (FRM, $PM_{2.5}$ Inertial Impaction/Gravimetric Teflon filter). We found that the DataRam4 yielded $PM_{2.5}$ estimates within 3-4% of the FRM for samples collected during both flaming ($PM_{2.5}$ concentrations ranging from 300-5000 $\mu g\ m^{-3}$) and smoldering ($PM_{2.5}$ concentrations ranging from 10-300 $\mu g\ m^{-3}$). The EBAMS estimates were within 50% of the FRM values, and were higher during flaming combustion and lower during the smoldering phase. This is in contrast to the findings of Trent (2003), who found better agreement between the EBAMS and the FRM.

Total hydrocarbon emission factors fell into the lower half of the reported range.
Total hydrocarbon (THC) data collected using EPA Method 25A employs flame ionization detection with no chromatographic separation, and therefore includes methane. Previous biomass burning EFs for THC range from 4-20 $g\ kg^{-1}$, and ours fall into the lower half of this range, with the exception of the Stumpy Point and March 23 Croatan NF fire, where EFs were 46 and 50 $g\ kg^{-1}$, respectively. However, we suspect that fossil-based ignition fuels may have biased these estimates since they were applied in the vicinity of our sampling systems during the early stages of sampling from these fires.

Acetone was the dominant VOC measured during prescribed fires.
Acetone was the dominant VOC measured at these fires, with an EF ranging from 0.3 to 1.4 $g\ kg^{-1}$. This factor overlaps with, but is higher than the range (0.25-0.63 $g\ kg^{-1}$) given by Andreae and Merlet. Benzene emissions were also significant (0.04-0.33 $g\ kg^{-1}$) but fell in the lower half of the published range. The exception was the Pocosin Lakes fire, which yielded a benzene EF of 0.6 $g\ kg^{-1}$. Toluene, styrene, xylenes, and ethylbenzene all had lower EFs than benzene, and fell in the lower half of the respective ranges published by Andreae and Merlet (2002).

Formaldehyde and acetaldehyde EFs were higher in fires with less efficient combustion.
Emissions factors of 0.90 and 0.86 $g\ kg^{-1}$ were observed for formaldehyde and acetaldehyde, respectively, from the Pocosin Lakes fire. These values are in good agreement with previous measurements. EFs for these species were lower from the other fires, usually from the low end to mid-range of previous observations (0.2-2 $g\ kg^{-1}$ for formaldehyde and 0.1-1.0 $g\ kg^{-1}$ for acetaldehyde).

Tetrachloroethylene was detected at one prescribed burn site in close proximity to the marine environment.
Tetrachloroethylene found in all samples at Stumpy Point but was not detected at the other sites. Its EF is estimated to be 0.14 $g\ kg^{-1}$. It is possible that the proximity to the marine environment contributed to presence of the highly chlorinated air toxic compound. The potential emission of halogenated air toxic compounds from Rx and wildfire in these ecosystems likely warrants further attention.

Levoglucosan (LG), a sugar anhydride produced from cellulose combustion, composed a high percentage of $PM_{2.5}$.

Using the thermal desorption and GC^2 methods of Ma and Hays (2007) on the impactor $PM_{2.5}$ filters, we determined that LG accounted for 7 to 38% of total $PM_{2.5}$ mass. It was highest in $PM_{2.5}$ from the fires at Pocosin Lakes and Dare County Bombing Range, the fires with the highest $PM_{2.5}$ EFs. High volume samples from the March 23 Croatan NF fire were also analyzed for LG using the extraction/derivitization techniques of Hays et al 2002, and good agreement (within 1.5%) was obtained for LG using the two methods. Other sugar anhydride compounds (primarily mannosan) composed less than 1% of the $PM_{2.5}$. LG has been used extensively as a quantitative tracer of biomass combustion (see, for example, Leithead et al. 2006). However, its contribution to $PM_{2.5}$ mass appears to vary from <1% to 40% in both laboratory and field studies. Hays et al (2002) examined several fine forest litter fuels, many of which were similar to those burned in our field studies and reported that LG consistently accounted for 2-3% of $PM_{2.5}$ mass. Similar values (2.5-3%) for simulated wheat stubble and bluegrass burns were observed by Dhammapala et al (2007). Mazzoleni et al (2007) reported LG fractions of $PM_{2.5}$ mass ranging from 0.5 to 5% for fireplace and in-field prescribed burns of various fuels but laboratory studies of various fuels ranged from <1 to 40%, and higher values were associated with moist or fresh fuels.

LG in ambient smoke samples is also variable. Ward et al. (2006) found LG values of 4.2% in Montana wildfire smoke plumes. Jordan et al. (2006) found values ranging from ~10 to 26% in Australian ambient samples dominated by wood burning, but only 3-6% for brush fires, speculating that the difference may be due to lower cellulose composition of foliage in comparison to wood. On the other hand, dos Santos et al. (2002) found that LG fractions of PM from Brazilian sugar cane burning were higher in leaf smoke than that from bagasse burning, which could have been due to combustion temperature differences. Overall, the LG fraction of PM was very low, <<0.1%. Saarikoski et al. (2007) found that $PM_{2.5}$ in smoke from northern European wildfires contained between 0.5 and 1% LG. Wildfires may consume considerable amounts of organic soil. Cellulose and hemicellulose are susceptible to microbial decomposition and their content in organic soils is considerably lower than that of the original plants (McMahon et al. 1980). This may lead to LG levels in $PM_{2.5}$ from wildfires compared to burning of less decomposed plant tissues. Schkolnik et al (2005) found ratios varying from 0.5-5% for Brazilian deforestation fires. From the data of Graham et al (2002), we estimate that LG composed 2-8% of $PM_{2.5}$ from pasture and primary forest burning in Rondonia, Brazil. Samples dominated by biomass smoke fell in the upper end of this range. Lee et al (2005) found that LG composed 5.7 % (std dev=2.3%) of $PM_{2.5}$ from prescribed burning on two coastal plain pine ecosystems in Georgia.

Schauer et al (2001) also found that 14.5% of $PM_{2.5}$ from fireplace combustion of wood was LG. The data of Fine et al. (2001, 2002) indicates that LG ranged from 3.6 to 14.7% of $PM_{2.5}$ from residential combustion of 13 species of wood commonly burned in the eastern U.S. LG percentages were higher from hardwood species and wood with higher moisture content. Our highest LG percentage was also observed from the Pocosin Lakes fire, which consumed the greatest fraction of hardwood fuels.

An inverse relationship between LG EFs and CE has been observed (Dhammapala et al. 2007). These trends were not readily apparent in our data, although field tests, with their inherent spatial and temporal variability in fuel and combustion conditions, are not conducive to detection of such relationships. As mentioned by Fraser and Lakshmanan (2000), the large variability in reported LG percentages of $PM_{2.5}$ indicates that regional fuel type and combustion conditions should be considered when using LG as a quantitative tracer for biomass burning contributions to ambient $PM_{2.5}$ concentrations.

Organic acids accounted for 2-13% of $PM_{2.5}$ on two filters, but well over 50% on the third, suggesting that combustion conditions may impact the relative abundance of acids.
Methoxyphenols (primarily syringealdehyde) composed from 0.5-1.0% of the $PM_{2.5}$.

Protein composition of the PM ranged from 1 to 7% of the PM mass.
A separate set of smoke samples collected on the March 23 Croatan fire using quartz filters in the impactors were analyzed for proteins using the methods of Menetrez et al. (2007). Protein composition of the PM ranged from 1 to 7% of the PM mass. The highest value was observed in PM_{10}, although the $PM_{2.5}$ sample during a latter stage of the burn also contained 3.5% protein. Background ambient $PM_{2.5}$ samples collected in the absence of smoke contained 0.8% protein.
Since much of the organic material in smoke and ambient samples has yet to be identified, protein contributions may warrant further attention.

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.
Little data on emissions from southeastern US prescribed burning is currently available, and this fire type in particular is projected to increase in the future. Our data, when examined in the context of other studies, suggest 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 and heavy debris are dry and susceptible to smoldering incomplete combustion, the source of many toxic compounds. These wildfires may increase fuel consumption by an order of magnitude or more since soil and heavy fuels can be consumed under these dry conditions. In addition, emissions factors for PM and reduced trace gases may be 2 to over 10 times higher from these soil and heavy fuels (McMahon et al, 1988; Bertschi et al, 2003; and Chen et al. 2007) compared to the lighter fuels consumed during Rx burns. Amounts of smoke may therefore be many times higher per acre than emissions from prescribed burns. In addition, human exposure to fire and smoke is likely to be much greater during wildfires since ventilation and other factors influencing smoke dispersion cannot be coordinated with wildfire as they can with Rx burning. Wildfires in southeastern peat soils also may smolder beneath the surface and re-

ignite without detection. Thcsc subsurface fires are dangerous to firefighters and others present on the landscape. Long-term ecosystem damage may result from southern wildfires. In Southeastern U.S. forests this can mean damage to red cockaded woodpecker nest trees, habitat which can take many decades to restore. This habitat has been reduced by over 97% due to land management practices since the 1700s, placing the RCW and other species such as the gopher tortoise in endangered status.

Long time intervals between burns may result in higher fuel accumulations than are assumed in some current emission models.

Our data also suggest that long time intervals between burns may result in higher fuel accumulations than are assumed in some current emission models, especially when fuels such as gallberry and fetterbush colonize the sites. It appears likely that burning under prescriptions will reduce 1) human exposure to and emissions of hazardous air pollutants, 2) net risk to property and human welfare, and 3) damage to critical (RT&E) wildlife habitat by reducing wildfire hazards.

Proposed	Delivered	Status
Pre-burn BlueSky model runs using standard configuration	http://www.airfire.org/bluesky	Done
Collect smoke dispersion data from four prescribed burns	Data available at http://wildlandfirescience.alionscience.com	Done
BlueSky model runs for each prescribed burn	Output available at http://wildlandfirescience.alionscience.com	Done
Training workshop	Rorig, M., Larkin, N., Solomon, R., and Krull, C. BlueSkyRAINS Workshop. 2nd Fire Behavior and Fuels Conference, Destin, FL, 26 March 2007.	Done
Web-based interface for models	National BlueSkyRAINS web site at http://marlin.cfr.washington.edu/nat/fcamms_map.htm	Done
Paper	Rorig, M., Mickler, R., Geron, C., Krull, C, Bailey, A. Evaluation of the BlueSky Smoke Modeling Framework on Prescribed Burns in the North Carolina Coastal Plain.	In progress (Draft to be complete by 10/30/2007)
Assist in sighting for ground-level surface weather measurements	Sites selected and data set for 3 sites collected through auspices of Mr. Gary Curcio (Navy site only)	Done
Assist in collecting smoke at night data	Provided initial assistance on how and where relative to burns to look for smoke at night.... Most burns did not smolder after dark	Done
PB-Coastal Plain (PB-CP): Assemble prototype codes into a working model	Model codes for small grid model (adaption from PB-Piedmont) combined with large grid model spring 2006	Done
PB-CP: Design user interface for a working PB-CP	Complete user interface constructed after the user-tested PB-Piedmont userface for both large and small grid models spring 2006	Done
PB-CP: Build weather, elevation, and SST data required to support the working model	Model designed to incorporate both observed weather data (nowcast) and predictive weather data from MM5 (prediction), SST data grabber developed and linked with PB-CP, elevation data done for parts of SE Atlantic and Gulf coasts only	Done with exception that PB-CP must be yet linked with national

		elevation data set. And model remains to be validated
Provide forecast of expected weather along with support from SHRMC	Brief worded forecasts out to 72 hr prepared on request.	Done
Provide SHRMC weather products and assist with integrating them into standard configuration of BlueSky	Special 1 km runs of SHRMC MM5 were done for five events in 2006 (Feb 13, 16, 28; Mar 3, 4). Data for one 2007 event provided at 12 km resolution.	Done
Assist AirFire on depth and temperature of nocturnal boundary layer	Tethersonde balloon and instrument package lost during deployment on RX burn.	Abandoned
Presentation	Mickler, Bailey, Rorig, Achtemier, and Geron. Integrating Fuel, Emissions, and Smoke Dispersion Models in Coastal Plain Forest Ecosystems. 2007. 2nd Fire Behavior and Fuels Conference, Destin, FL, March 26-30, 2007	Done ✓
Presentation	Mickler, Bailey, Rorig, Geron, Achtemier, and Brownlie. Development of Smoke Plume, Fire Emissions, and Wildland Fire Fuel Models on Coastal Plain Ecosystems. 2006 Fire Ecology & Management Congress. November 13-17, 2006, San Diego, CA	Done ✓
Presentation	Rorig, Miriam. 2006. Validation of the BlueSky Smoke Modeling Framework on Prescribed Burns in North Carolina Coastal Plain Forest Ecosystems. 2006 BlueSky Community Modeling Consortium Annual Meeting. Seattle, WA. July 11-12, 2006.	Done ✓
Presentation	Mickler, Robert A., and A.D. Bailey. 2005. Quantifying Wildland Fire Fuel Loading and Fire Risk in Coastal Plain Forests. Proceedings of the 2005 American Society of Photogrammetry and Remote Sensing Annual Conference. ASPRS, Baltimore, MD. March 7-11, 2005.	Done ✓
Presentation	Bailey, Andrew D. and R.A. Mickler. 2005. Vegetation Classification and Fuel Load Mapping Using Softcopy Photogrammetry. Proceedings of the	Done

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	2005 American Society of Photogrammetry and Remote Sensing Annual Conference. ASPRS, Baltimore, MD. March 7-11, 2005.	✓
Poster	Mickler, Robert A. and A.D. Bailey. 2005. Characterizing wildland fire fuels and risk in the southeastern United States. 2005 International Union of Forest Research Organizations World Congress. Brisbane, Queensland, Australia. August 8-13, 2005.	Done ✓
Poster	Mickler, Robert, A. Bailey, G. Achtemier, C. Geron, M. Rorig, and B. Potter. Development and Demonstration of Smoke Plume, Fire Emissions, and Pre- and Post-Prescribed Fire Fuel Models on North Carolina Coastal Plain Forest Ecosystems. 2005 Joint Fire Science Program Principle Investigators Annual Workshop. San Diego, CA. November 1-3, 2005.	Done ✓
Poster	Krull, C., Rorig, M., Solomon, R., Larkin, N., Mickler, R., and Bailey, A. 2007. Validation of the BlueSky Smoke Modeling Framework: Field Campaigns. 2nd Fire Behavior and Fuels Conference, Destin, FL, March 26-30, 2007	Done ✓
Poster	Mickler, Geron, Rorig, Achtemier, Bailey, Brownlie. Development and Demonstration of Smoke Plume, Fire Emissions, and Pre- and Post-prescribed Fire Fuel Models on North Carolina Coastal Plain Forest Ecosystems. 2nd Fire Behavior and Fuels Conference, Destin, FL, March 26-30, 2007	Done ✓
Paper	Mickler, Robert A., and A.D. Bailey. 2005. Quantifying Wildland Fire Fuel Loading and Fire Risk in Coastal Plain Forests. Proceedings of the 2005 American Society of Photogrammetry and Remote Sensing Annual Conference. ASPRS, Baltimore, MD. March 7-11, 2005.	Published ✓
Paper	Bailey, Andrew D. and R.A. Mickler. 2005. Vegetation Classification and Fuel Load Mapping Using Softcopy Photogrammetry. Proceedings of the 2005 American Society of Photogrammetry and Remote Sensing Annual Conference. ASPRS, Baltimore, MD. March 7-11, 2005.	Published ✓
Paper	Mickler, Rorig, Geron, Achtemier, Bailey, Krull, and Brownlie. Development and Demonstration of Smoke Plume, Fire Emissions, and Pre-and Postprescribed Fire Fuel Models on North Carolina Coastal Plain Forest Ecosystems. In: Butler, Cook. 2007. The fire environment-innovations, Management, and policy. USDA Forest Service, RMRS-P-46. Ft. Collins, CO.	Published ✓

Paper	Bailey and Mickler. Fine Scale Vegetation Classification and Fuel Load Mapping for Prescribed Burning. In: Butler, Cook. 2007. The fire environment-innovations, Management, and policy. USDA Forest Service, RMRS-P-46. Ft. Collins, CO.	Published ✓
Paper	Bailey, Mickler, and Frost. Presettlement Fire Regime and Vegetation Mapping in Southeastern Coastal Plain Forest Ecosystems. In: Butler, Cook. 2007. The fire environment-innovations, Management, and policy. USDA Forest Service, RMRS-P-46. Ft. Collins, CO.	Published ✓
Paper	Mickler, Bailey, Rorig, Krull, Geron, Achtemier, Otwell, and Brownlie. Development of Smoke Plume, Fire Emissions, and Wildland Fire Fuel Models on Coastal Plain Ecosystems. 2006. In: Proceedings 2006 Fire Ecology & Management Congress. DVD. Extension Meeting Management + Program Support, 305 Hulbert Hall, Washington State University, Pullman, WA, 99164-6244 USA, pp.1-17.	Published ✓
Paper	Rorig, M., Mickler, R., Geron, C., Krull, C, Bailey, A. Evaluation of the BlueSky Smoke Modeling Framework on Prescribed Burns in the North Carolina Coastal Plain.	In progress (Submission by 10/30/2007)
Paper	Geron, Mickler, Brownlie, Stephenson, and Bowling. Air Emissions from Prescribed Burning on the Coastal Plain of North Carolina	In progress (Submission by 10/30/2007)
Paper	Mickler, Bailey, Otwell, and Brownlie. Vegetation Classification, Fuel Load Mapping, and Biomass Consumption Following Prescribed Burning	In progress (Submission by 10/30/2007)
Paper	Mickler, Rorig, Geron, Bailey, Krull, and Brownlie. Smoke Plume, Fire Emissions, and Prescribed Fire Fuel Models on Coastal Plain Forest Ecosystems	In progress (Submission by 10/30/2007)
Website	Joint Fire Science Project #04-2-1-80. 2006. Wildland Fire Science. http://wildlandfirescience.alionscience.com	Website active and update planned for papers. JFSP homepage link. ✓
Dataset	Long Shoal River Prescribed Burn. Alligator River National Wildlife Refuge. February 13, 2006. Dataset includes fuel loading data, smoke dispersion data, emissions characterization data, and photographic documentation of research activity, fire behavior, and plume behavior.	Done ✓

Dataset	Pungo Central Prescribed Burn. Pocosin Lakes National Wildlife Refuge. February 16, 2006. Dataset includes fuel loading data, smoke dispersion data, emissions characterization data, and photographic documentation of research activity, fire behavior, and plume behavior.	Done
Dataset	Pine Cliffs Recreation Area Prescribed Burn. Croatan National Forest. February 28, 2006. Dataset includes fuel loading data, smoke dispersion data, emissions characterization data, and photographic documentation of research activity and fire behavior.	Done
Dataset	North Navy Shell Prescribed Burn Compartments 4.5.3 and 4.5.5. Alligator River National Wildlife Refuge. March 3, 2006. Dataset includes fuel loading data, smoke dispersion data, emissions characterization data, and photographic documentation of research activity, fire behavior, and plume behavior.	Done
Dataset	North Navy Shell Prescribed Burn Compartments 4.5.1, 4.5.2, and 4.5.4. Alligator River National Wildlife Refuge. March 4, 2006. Dataset includes fuel loading data, smoke dispersion data, emissions characterization data, and photographic documentation of research activity, fire behavior, and plume behavior.	Done
Dataset	Haywood Landing Prescribed Burn. Croatan National Forest. March 23, 2006. Dataset includes fuel loading data, smoke dispersion data, emissions characterization data, and photographic documentation of research activity and fire behavior.	Done