Fine Scale Vegetation Classification and Fuel Load Mapping for Prescribed Burning

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Abstract—*Fire managers in the Coastal Plain of the Southeastern United States use prescribed burning as a tool to reduce fuel loads in a variety of vegetation types, many of which have elevated fuel loads due to a history of fire suppression. While standardized fuel models are useful in prescribed burn planning, those models do not quantify site-specific fuel loads that reflect land use change, natural disturbances, and previous management. Furthermore, data on the fuel consumed during prescribed burning are generally unavailable. In an effort to accurately measure and map fuel loading and consumption at a site-specific level, fuels and vegetative communities were characterized in five burn compartments at the Air Force Dare County Bombing Range and Alligator River National Wildlife Refuge in eastern North Carolina. Aerial photography, digital softcopy photogrammetry, and GIS were used to map vegetation to the alliance level of the National Vegetation Classification System (NVCS). Within each vegetation alliance, fuel loads in the shrub, herbaceous, litter, duff, and 1-, 10-, 100-, and 1000- hour down woody fuel categories were measured using USDA Forest Service Forest Inventory and Analysis (FIA) phase 3 protocols. In addition, FIA phase 2 protocol plots were used to characterize live and standing dead tree biomass and forest canopy. Measured fuel loads were then compared to standardized fuel models to describe site-specific deviations. Following prescribed burning, fuel load plots were remeasured, and fuel consumption was calculated from pre- and postburn biomass. Consumption measurements were used to calculate prescribed fire emission factors, assess the achievement of prescribed burn goals, and validate the Blue Sky Smoke Modeling Framework in the Southeastern U.S. Coastal Plain.*

Introduction

The area burned by uncontrolled wildland fires increased over the latter decades of the 20th century (GAO 2005), and into the 21st century. This increase can be attributed to effective wildland fire suppression during the middle of the 20th century, which has lengthened fire return intervals in many parts of the country. Longer fire intervals have led to a buildup of flammable dead and live vegetation in unburned areas. Elevated levels of fuel loading, combined with the extreme weather conditions under which wildfires typically burn, create uncontrollable wildfires that often put human life and private property at risk. Fires under these conditions frequently burn with more intensity than areas managed for fuel reduction by mechanical or prescribed fire fuel treatments (Graham and others 2004; Carey and Schumann 2003).

In an effort to reduce the risk of wildfire, land managers are using prescribed fire to burn areas under controlled conditions. Using prescribed fire, land managers hope to periodically reduce fuel loads and modify forest structure to become more resistant to catastrophic wildfire. Managers use fire behavior modeling tools such as FARSITE (Finney 1998) and BEHAVE

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(Andrews and others 2005) to plan for prescribed burns and predict fire behavior. The BlueSky RAINS Smoke Modeling Framework (O'Neill and others 2003; McKenzie and others 2006) and VSmoke (Lavdas 1996) models allow managers to determine and mitigate the impacts of smoke from prescribed fires. The successful implementation of these tools necessitates the accurate quantification of wildland fuel loads.

Fuel loadings are typically reported in tons/acre by component for the standard 1-hour, 10-hour, 100-hour, 1000-hour, and litter fuel load classes. Often, fuel reporting also includes fuel bed depth and heights of live and dead herbaceous plants and shrubs. Standardized fuel models developed by Rothermel (1972), Albini (1976), Anderson (1982), and Scott and Burgan (2005) use a text description or a key so that managers may choose an appropriate set of fuel loadings for a specific site. The Natural Fuels Photo Series Publications (Ottmar and Vihnanek 2000) use close range stereo photography to depict vegetation types and fuel loads. The manager chooses the best representation of a site by browsing the photography and then reading the associated fuel loadings from a chart. Computer models may also be used to determine fuel loads. In the Fuelbed Characterization and Classification System (FCCS) (Sandberg 2001) users choose from a series of prototype fuelbeds representing vegetation descriptions and are able to modify vegetation composition and structure. The model then calculates or infers quantitative fuel characteristics and probable fire parameters.

Fuel loads from the approaches described above are based on measurements made in the field, but usually have been generalized across the continental United States or across a region of the country. The generalizations can lead to inaccuracies when applied to a specific site. Site history, including land use change, natural disturbances, and previous management actions—including previous prescribed burns—can lead to significant deviations from standard fuel loading models. Rosenfeld (2003) found that measured fuel loads based on ecological associations are more accurate than those provided with standard fuel models.

In situations where a high degree of accuracy is required, plot- or transect-based inventory procedures that directly measure site conditions are more appropriate (Otmar and Vihnanek 2000). Georeferenced fuel load measurement plots are a means to describe actual fuel loading characteristics, because fine woody fuels, litter, and duff are hidden by the canopy or are too small to detect with aerial imagery (Keane and others 2001). The most widely used method for the direct measurement of wildland fuels is Brown's (1974) line-intersect method. The U.S. Department of Agriculture, Forest Service integrated this method into the Forest Inventory Analysis (FIA) Program plot design to determine fuel loads, carbon storage, and wildlife habitat. Coupling the FIA plot design with GPS plot locations provides the necessary accuracy for fuel load measurement that can be combined with computer mapping techniques to make fine scale maps useful for a number of purposes.

In this study, the FIA plot design was applied in tandem with fine-scale softcopy aerial photography and digital mapping to quantify and map pre- and postfire wildland fuel loading for a prescribed burn on the Air Force Dare County Bombing Range (DCBR) and Alligator River National Wildlife Refuge (ARNWR) in the Coastal Plain of North Carolina. Large-scale maps of fuel loading developed during this project were designed to be useful to local land managers working on individual burns. These fuel loadings and the associated maps were used for prescribed burn planning, assessment of prescribed burn objectives, and to provide data for the validation of the BlueSky RAINS Smoke Modeling Framework in the Southeastern United States.

Methods

Site Description

The mainland of Dare County, North Carolina, is made up of numerous fire-adapted ecosystems under Federal ownership in proximity to one another. Nearly 200,000 acres in Dare County are managed by the U.S. Fish and Wildlife Service and the U.S. Air Force. The Dare County mainland is a peninsula 14 miles across, bordered on the north by the Albemarle Sound, on the east and south by the brackish Croatan and Pamlico Sounds, respectively, and on the west by the freshwater Alligator River. The long axis of the peninsula extends 29 miles from north to south. The Outer Banks barrier island chain provides protection from the Atlantic Ocean some 20 miles to the east. Though there are two small tidal creeks on the peninsula, there is virtually no relief, and elevations range from sea level to 4 ft above sea level. Over 90 percent of the peninsula is made up of organic "muck" soils. Fire, salinity, and organic soil depth are the main ecological factors affecting vegetation development. Our study site (fig. 1) consisted of two burn units totaling 1,525 acres on Ponzer, Belhaven, and Pungo muck soils, with peatland pocosin vegetation.

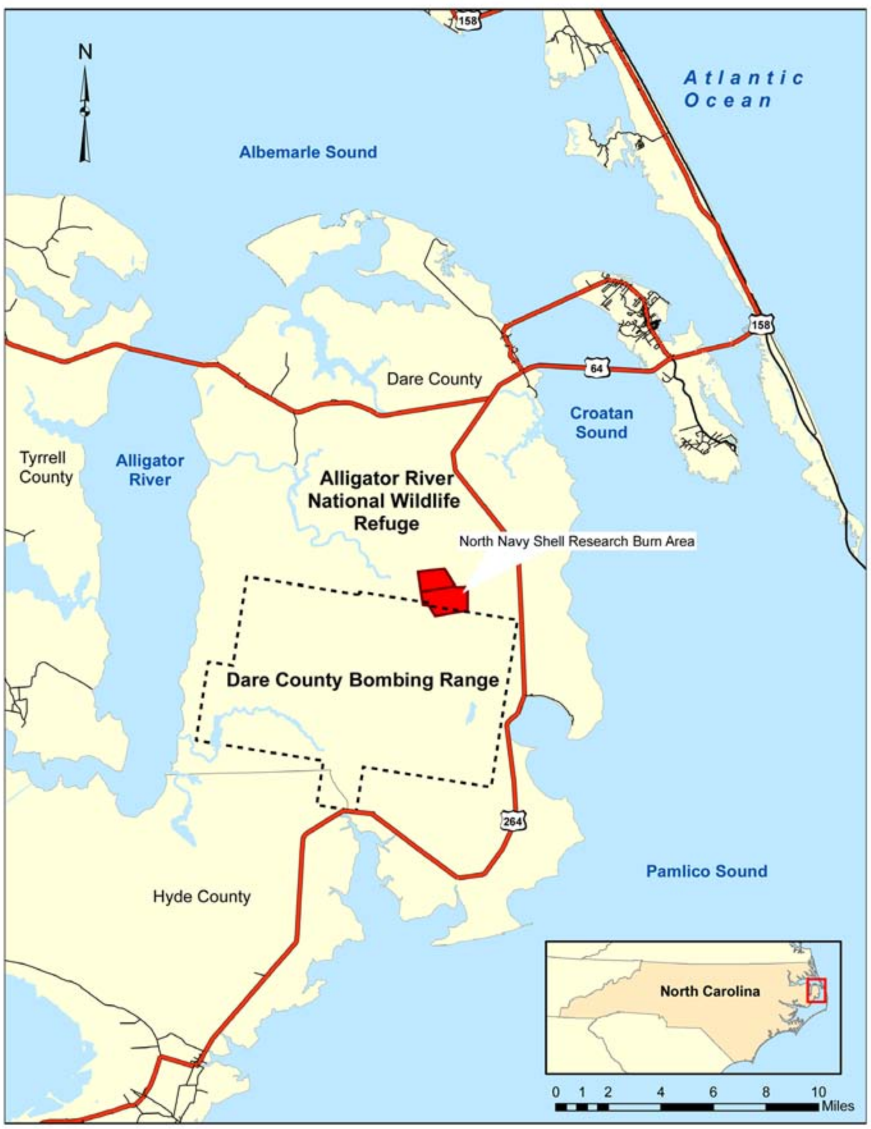

Figure 1—Location of the research site. The Alligator River National Wildlife Refuge and Dare County Bombing Range are located on a long, low peninsula in eastern North Carolina near the Atlantic Ocean.

Aerial Photography

An aerial photography mission flown in spring 2004 captured 496 color-infrared photographs with a spatial resolution of 7.5 inches per pixel (Bailey and Mickler 2005). Twenty-five of these photographs were used to provide 100 percent coverage of the research burn units. The digitized photographs were orthorectified and used to develop an orthophoto mosaic for use as a base layer during fuel load and vegetation community mapping. The digitized photographs were also used to develop a "block file" product, which allowed stereo photo pairs to be viewed on a computer in 3-D, as if viewing the imagery with a stereoscope. Benefits of this approach include onscreen panning and zooming, direct GIS database creation, and image manipulation capabilities. This product allowed the viewer to discriminate between objects in the canopy and objects on the ground, providing further analysis capabilities for determining canopy and understory vegetation and canopy cover estimates.

Mapping

Using the orthophoto mosaic, stereo blockfile, a digital elevation model, surface hydrology data, and a digital soil survey, polygons representing distinct vegetation communities were delineated to the alliance level of the NVCS (http://www.natureserve.org/explorer/servlet/NatureServe?init=Ecol). The NVCS is an ecosystem-based classification scheme in which vegetation communities are grouped by their characteristic physiognomy and floristic composition. To differentiate vegetation types on the orthophoto mosaic and stereo blockfile, seven photogrammetric interpretation attributes were used: size, shape, shadow, color, texture, pattern, and association with other objects (Avery 1992). The heads-up stereo photography allowed easy differentiation of vegetation communities with differing dominant tree heights, canopy shapes, and canopy closure. These were the critical strata used to discriminate between NVC alliances (Grossman 1998). Soil, elevation, and hydrology data were used to further inform the vegetation classification. When variation in structure within a vegetation alliance appeared great enough to affect fuel loading and fire behavior, a modifier was added to indicate this difference. A large minimum mapping unit of 2.5 acres was used to ensure that polygons captured variation in fuel loading within ecosystems.

Fuel Load Measurement

A permanent plot network was established to directly measure fuel loading within the research units. The plot design (fig. 2), based on the USDA Forest Service FIA phase 2 and phase 3 plots, was used to characterize live biomass and pre- and postburn down woody materials (DWM). A sampling grid was laid over the study area, and one plot was placed randomly within each grid cell. Grid cells were subsampled to ensure that a minimum of three plots were placed within each vegetation alliance. We used field protocols based on methods establish by the USDA Forest Service in Field Instructions for Southern Forest Inventory (http://fia.fs.fed.us/library/field-guides-methods-proc/). DWM data were collected using a line-intersect method to sample down wood along transects (Brown 1974). Down deadwood was characterized as coarse woody material (CWM, woody pieces greater than 3.0 inches in diameter), or fine woody material (FWM, small = 0.1 to 0.24 inch, medium = 0.25 to 0.9 inch, and large = 1 to 2.9 inches in diameter). The extent and height of live and dead shrub and herbaceous vegetation were measured on a

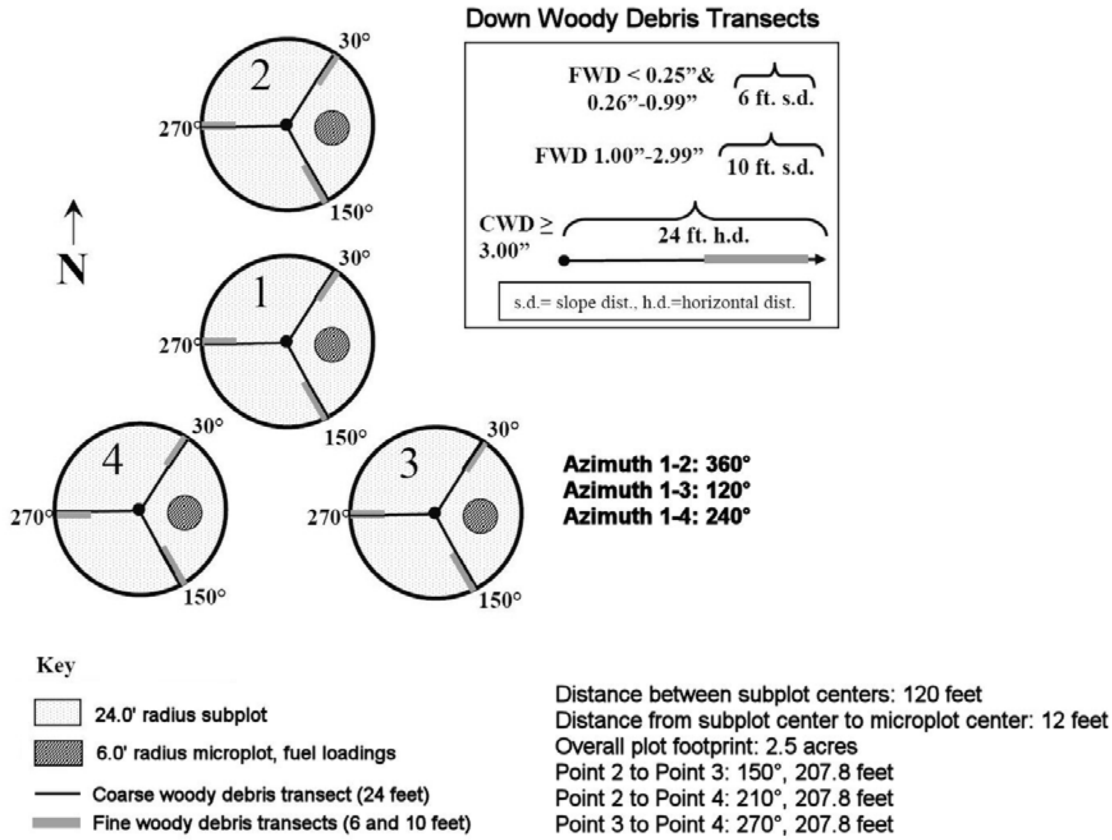

Figure 2—The USDA Forest Service Forest Inventory and Analysis plot design, used in this study to quantify wildland fuel loading. Each plot contains four circular subplots, each with a radius of 24 ft. Fine and coarse woody material is inventoried along three transects on each subplot. Litter layer and fuelbed depths are measured at the end of each transect. Live and dead shrub and herbaceous fuels are assessed in a 6-ft radius circular microplot within each subplot. (Figure adapted from fig. 14-1 in the USDA Forest Service Phase 3 Field Guide – Down Woody Materials.)

6-ft diameter microplot located within each subplot. FIA methodology was augmented with additional data on the vertical distribution of DWM for input into the FARSITE fire behavior model. The depths of the litter layer and fuelbed were taken at the 24-ft location on each transect. The biomass of the duff layer (Oa soil horizon) was estimated from the specific gravity of oven dried sampling frame soil samples for each soil series found on the field plots.

Biomass Scaling

Plot-level biomass estimates were combined to produce a mean per-unit-area biomass value for each vegetation alliance. The measurements were combined with material density (specific gravity) values in linear equations to compile dry-weight mass (tons/acre) for each DWM component (Mickler and Bailey 2005). Previous equations have been developed primarily for Western U.S. species (Brown 1974), necessitating the development of fuel class biomass algorithms for additional forest species and decay classes in the research area. Additional microplots were established for destructive sampling of shrub and herbaceous vegetation to develop new biomass equations.

Prescribed Burn and Post Burn Fuel Load Measurement

Following fuel load measurement, the research units were burned according to the North Navy Shell Compartment Prescribed Fire Plan (Simpson, and others 2004) on March 4, 2006. Aerial ignitions were conducted via helicopter using a Plastic Sphere Dispenser (PSD) machine to implement a grid pattern of ignitions that allowed for a backing fire with short periods of downwind fire activity. Fire intensity was generally moderate; most fire activity occurred in the litter and dead shrub strata, with occasional torching of the overstory aided by fuel ladders. The burn was substantially extinguished by rising humidity overnight with little residual smoldering. Following the prescribed burn, all plots were relocated and remeasured following the same protocols. The difference between prefire and postfire measurement represents the actual amount of fuel consumed during the burn.

Results

The aerial photo mosaic and vegetation map are displayed in figures 3 and 4, respectively. Seven vegetation alliances were mapped and appeared to occur along an increasing moisture gradient from southeast to northwest. The Shining Fetterbush – Little Gallberry Saturated Wooded Shrubland (12 acres) and the Sweetbay – Swampbay Saturated Forest (3 acres) made up a small proportion of the study area and were excluded from fuel loading analysis. In order of increasing moisture, the five alliances mapped were:

- Pond Pine Saturated Woodland (457 acres)
- Pond Pine Saturated Woodland – Overstocked (1349 acres)
- Loblolly Pine Saturated Forest (65 acres)
- Loblolly Pine – Atlantic White Cedar – Red Maple – Swamp Blackgum Saturated Forest (mixed pine/hardwood forest, 94 acres)
- Swamp Blackgum – Red Maple – Tuliptree Saturated Forest (maple forest, 68 acres)

Within the pond pine woodland alliance, high canopy coverage and low canopy coverage variants were observed and mapped separately. Following field measurements, the values within these variants were determined to be similar and were combined for this analysis into one pond pine woodland alliance.

Fuel loadings for each plot before and after the prescribed burn are reported in table 1. Fuel loadings by vegetation alliance are reported in figure 5. Prior to the prescribed fire, litter and FWM fuel loading were highest in the loblolly pine forest (12.09 tons/acre) and pond pine woodland (11.19 tons/acre). These two forest alliances each contained more than 7 tons/acre in the litter fuel class. The mixed pine/hardwood forest alliance contained 9.64 tons/acre of litter and FWM, with 4.94 tons/acre occurring in litter fuel class and 4.23 tons/acre in the medium (0.25 to 0.9 inch) and large (1.0 to 2.9 inch) classes. While duff made up the largest component in the fuel load, the prescribed burn was conducted when the possibility of consuming duff was at its lowest. No duff or coarse woody material (3+ inches in diameter, 1000 hour fuels) were consumed in any vegetation class during the burn.

Consumption is reported in table 2. The fire consumed 4.94 tons/acre in the loblolly pine forest alliance, which was 40.8 percent of the preburn litter and FWM fuel load. The most complete consumption occurred in the litter

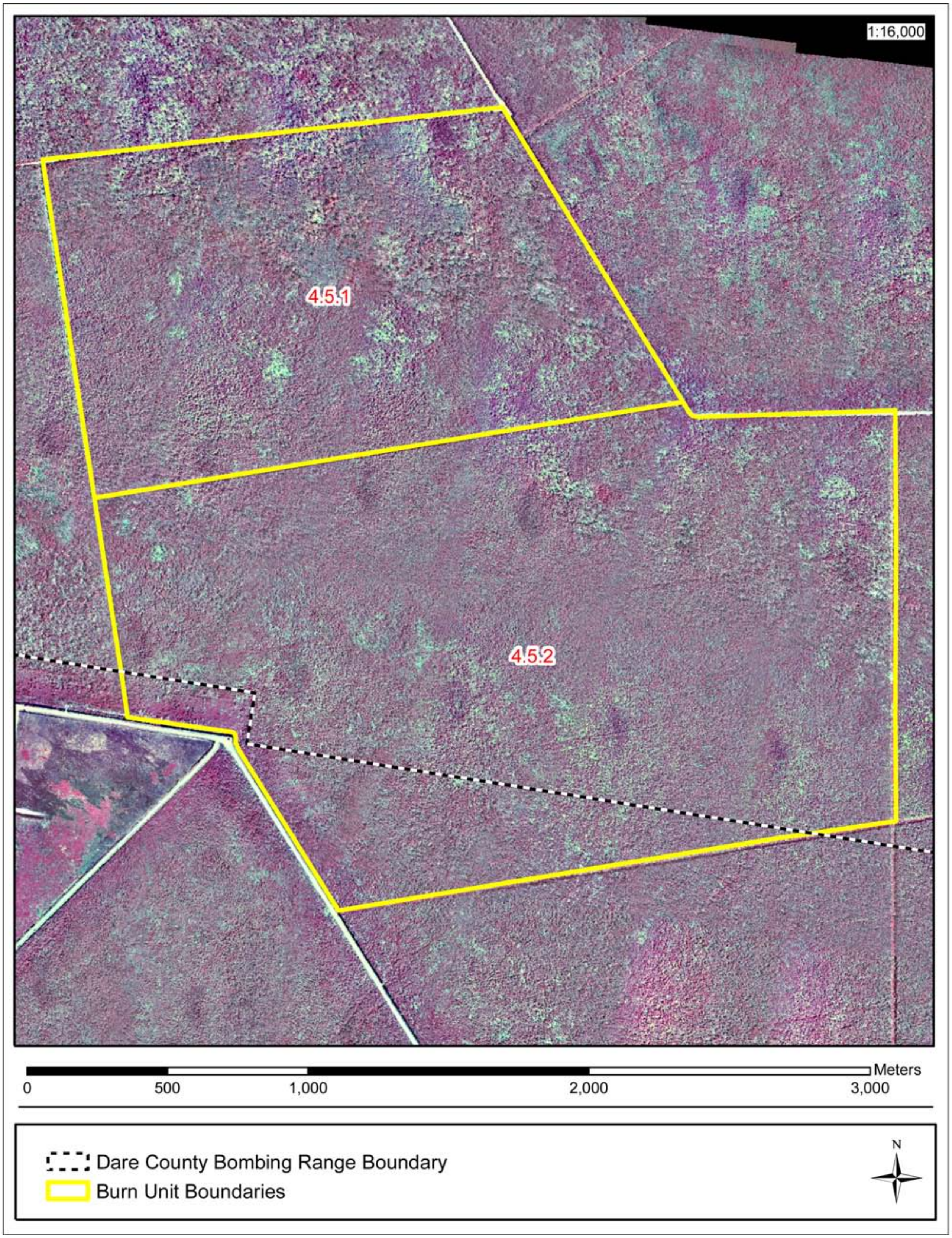

Figure 3—The finished orthorectified aerial photo mosaic for the study site. Each pixel represents a 7.5 x 7.5 inch area on the ground.

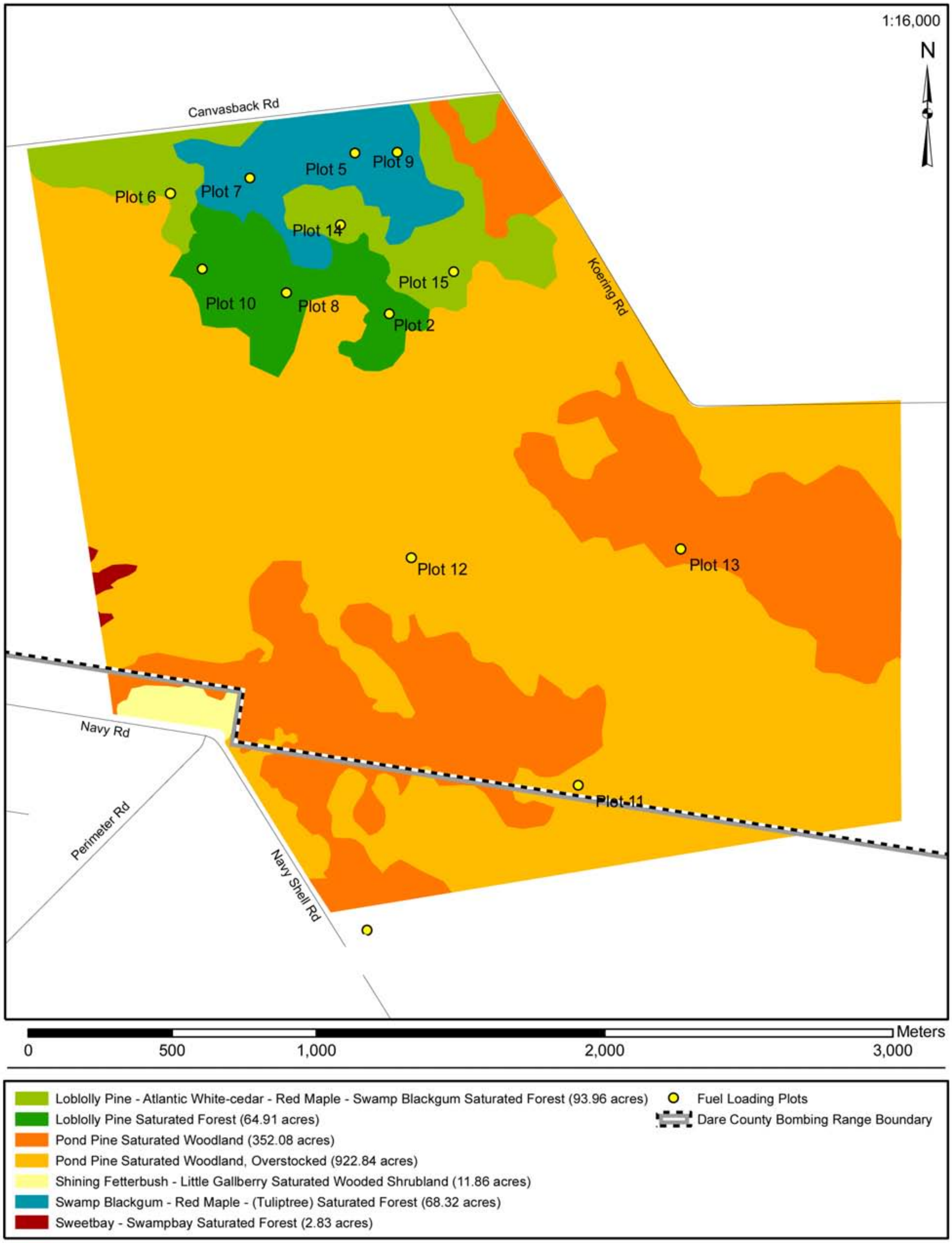

Figure 4—The finished vegetation alliance map for the study area. Seven alliances were mapped on 1,525 acres.

Table 1—Pre- and postburn biomass (all measurements in tons/acre).

Plot	Vegetation alliance	Preburn biomass Duff	Litter	FWM small	FWM medium	FWM large	Postburn biomass Duff	Litter	FWM small	FWM medium	FWM large
2	Loblolly pine forest	299.95	7.23	0.25	1.33	1.94	299.95	7.23	0.15	1.16	1.25
8	Loblolly pine forest	299.95	8.32	0.28	2.52	2.36	299.95	1.80	0.08	1.74	1.67
10	Loblolly pine forest	299.95	7.14	0.29	1.99	2.64	299.95	2.75	0.12	1.58	1.94
	Average	**299.95**	**7.56**	**0.27**	**1.95**	**2.31**	**299.95**	**3.93**	**0.12**	**1.49**	**1.62**
11	Pond pine woodland	513.07	6.75	0.39	1.67	1.11	513.07	2.62	0.15	1.28	0.83
12	Pond pine woodland	513.07	7.37	0.38	2.01	2.22	513.07	0.84	0.03	0.92	2.08
13	Pond pine woodland	189.44	7.57	0.24	1.77	2.08	189.44	0.68	0.04	1.31	2.36
	Average	**405.20**	**7.23**	**0.34**	**1.82**	**1.81**	**405.20**	**1.38**	**0.07**	**1.17**	**1.76**
6	Mixed pine/ hardwood forest	189.44	3.07	0.42	1.33	1.94	189.44	3.07	0.42	1.33	1.94
14	Mixed pine/ hardwood forest	299.95	4.52	0.31	1.48	1.39	299.95	4.52	0.31	1.48	1.39
15	Mixed pine/ hardwood forest	189.44	7.23	0.70	3.49	3.05	189.44	5.30	0.70	3.49	3.05
	Average	**226.28**	**4.94**	**0.48**	**2.10**	**2.13**	**226.28**	**4.30**	**0.48**	**2.10**	**2.13**
5	Maple forest	299.95	1.46	0.40	1.02	1.67	299.95	1.46	0.40	1.02	1.67
7	Maple forest	299.95	1.75	0.30	1.21	0.42	299.95	1.75	0.30	1.21	0.42
9	Maple forest	189.44	2.28	0.29	1.19	2.92	189.44	2.28	0.29	1.19	2.92
	Average	**263.11**	**1.83**	**0.33**	**1.14**	**1.67**	**263.11**	**1.83**	**0.33**	**1.14**	**1.67**

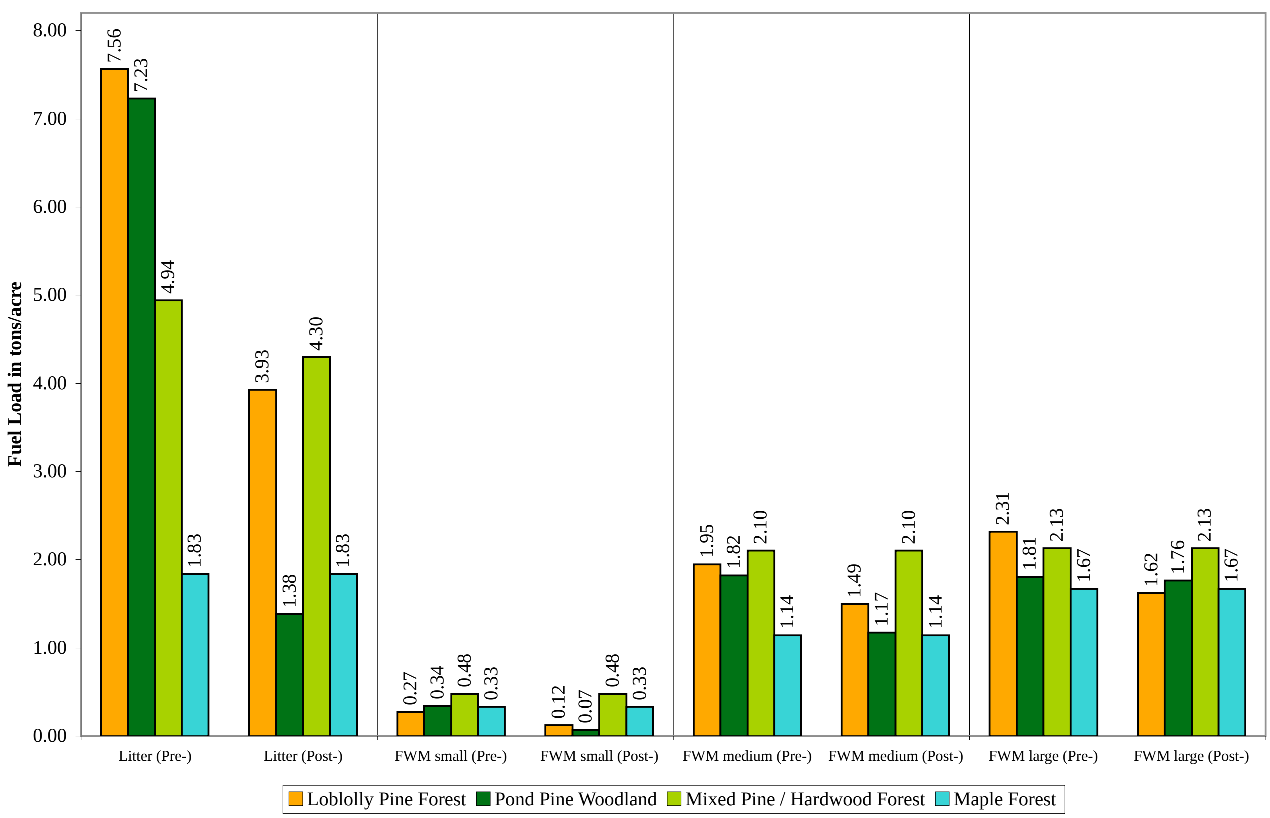

Figure 5—Pre- and postburn fuel loading by component in tons per acre. Colors correspond to the colors used on the vegetation map in figure 4.

Table 2—Consumed biomass by vegetation alliance.

Vegetation alliance	Tons/acre consumed					
	Total consumed	Litter	FWM small	FWM medium	FWM large	FWM total
Loblolly pine forest	4.94 (40.81%)	3.63 (48.07%)	0.15 (56.61%)	0.45 (23.24%)	0.69 (30%)	1.3 (28.69%)
Pond pine woodland	6.81 (60.86%)	5.85 (80.91%)	0.27 (79.53%)	0.65 (35.56%)	0.05 (2.56%)	0.96 (24.27%)
Mixed pine/hardwood forest	0.64 (6.66%)	0.64 (13.01%)	0	0	0	0
Maple forest	0	0	0	0	0	0

and small FWM classes. Fire consumed 6.81 tons/acre (60.9 percent) of the fuel load in the pond pine woodland alliance, including 80 percent of the litter and fine woody material classes. Litter consumption occurred on only one of the three plots in the mixed pine/hardwood forest alliance, removing 0.64 tons/acre. No consumption occurred in the maple forest alliance.

Discussion

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.

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.

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 (table 3). 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.

Although detailed accuracy assessment was beyond the scope of this study, fuel loads for the pine-dominated ecosystems measured within the research unit 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 with nonstandard vegetation types, or standard vegetation types growing on atypical sites.

Table 3—Comparison to fuelbed characterization classification system (FCCS).

	Measured biomass					FCCS				
Vegetation type	Duff	Litter	FWM small	FWM medium	FWM large	Duff	Litter	FWM small	FWM medium	FWM large
Loblolly pine forest	299.95	7.56	0.27	1.95	2.31	22.10	5.55	0.60	1.70	2.00
Pond pine woodland	405.20	7.23	0.34	1.82	1.81	56.00	3.15	1.00	1.50	1.50
Maple forest	263.11	1.83	0.33	1.14	1.67	N/A	N/A	N/A	N/A	N/A
Mixed pine/ hardwood forest	226.28	4.94	0.48	2.10	2.13	N/A	N/A	N/A	N/A	N/A

Conclusions

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.

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