ABSTRACT

GERCKE, DIANE MARIE. A Method for Rapid Assessment of Historic Fire-Dependent Vegetation Communities. (Under the direction of Gary B Blank.)

In the effort to restore historic landscapes, it is necessary to first specify spatially explicit target vegetation communities. Previously, botanists or other local experts have used landscape and environmental factors, historical evidence, and evidence from remnant vegetation to define presettlement vegetation communities on the landscape. Once these communities are defined, they must be mapped in order to be truly understandable and useful. Efforts to map the location of these presettlement communities on a particular landscape are often laborious and time consuming. In this study, we discuss a rapid method for assessing the location of these vegetation communities using Geographic Information Systems (GIS) and the current science of fire behavior modeling. Fire behavior models are proven predictors of fire intensities across a landscape, considering vegetation, slope, aspect, wind, and weather. Our hypothesis was that these fire behavior models could be used to make inferences about presettlement vegetation community distributions in former frequent-fire landscapes. GIS software was used to find simple combinations of variables associated with vegetation distribution, including soil type, aspect, slope, and orientation to gradient winds. A conventional fire model (FlamMap) was then used to find areas that are distinctly fire sheltered. In a survey of 78 fire sheltered

community sites visited on the study landscape, 91% of the areas were considered to be correctly identified based on the presence of remnant presettlement vegetation indicator species. Success in finding a single community as related to a specified range of fire behavior outputs suggests that there is potential for expanded utility of fire models in making inferences about vegetative distribution on the frequent-fire landscape. The fire model adds to the utility of the GIS by considering the effects of fire spread direction and variation in fuel moistures in conjunction with terrain variables. The resulting fire intensity outputs represent environmental effects on vegetation distribution that cannot be modeled solely with a GIS. A final presettlement vegetation layer was completed for the study site, located at Fort Bragg on the Southeastern coastal plain of North Carolina, and compared to a layer generated by an extensive 2-year study considered to be definitive. The results showed an overall map accuracy of 78 percent for the proposed procedure. This output may be used as a preliminary map that, in conjunction with groundtruthing, will shorten the process of mapping presettlement vegetation for use in the restoration of historic fire dependent communities.

A Method for Rapid Assessment of Historic Fire-Dependent Vegetation Communities

by

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A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Natural Resources

Raleigh
2005

APPROVED BY:

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DEDICATION

To my best friend, Maya

BIOGRAPHY

Diane Gercke was born and grew up in Denver Colorado. She attended Colorado State University from 1986 until 1989, at which point she realized that the federal government was willing to PAY her to run chainsaws and play with fire. Ten years later, while working as a fire crew supervisor on the San Juan National Forest, Diane finished her BA in Humanities at Fort Lewis College in Durango Colorado. This thesis marks the completion of a Masters of Science degree from North Carolina State University. During her career as a wildland and prescribed fire professional, Diane has traveled throughout the western and southeastern United States working for the National Park Service, the US Forest Service, and the Bureau of Indian Affairs and volunteering with county and local fire departments, as well as private conservation agencies.

ACKNOWLEDGEMENTS

Pat Stephen, Fuels Data Development/Fire Behavior Technical Specialist
Intermountain Regional Office, National Park Service

Robert Seli, Forester, Missoula Fire Sciences Lab, Rocky Mountain Research Station, United States Forest Service

Justin Shedd and the helpful graduate students and staff, Center for Earth Observation, North Carolina State University

Ryan Boyles, Associate State Climatologist, State Climate Office of North Carolina

Dr Al Riordan, Associate Professor, Dept of Marine, Earth and Atmospheric Sciences, North Carolina State University

Margit Bucher, Assistant Director of Science & Stewardship, North Carolina Chapter, The Nature Conservancy

John Ward, Fire Management Officer, Fort Bragg, North Carolina, United States Department of Defense

Luis Carrasco, PhD Candidate, Department of Forestry and Environmental Resources, North Carolina State University

TABLE OF CONTENTS

LIST OF TABLES

Page

METHOD FOR RAPID ASSESSMENT OF HISTORIC FREQUENT-FIRE VEGETATION COMMUNITIES

THE USE OF FIRE BEHAVIOR MODELS IN RECONSTRUCTING PRESETTLEMENT VEGETATION ON A FREQUENT-FIRE LANDSCAPE

APPENDICES

LIST OF FIGURES

Page

METHOD FOR RAPID ASSESSMENT OF HISTORIC FREQUENT-FIRE VEGETATION COMMUNITIES

THE USE OF FIRE BEHAVIOR MODELS IN RECONSTRUCTING PRESETTLEMENT VEGETATION ON A FREQUENT-FIRE LANDSCAPE

APPENDICES

Introduction

Changes in the historic vegetative composition of formerly fire-dependent ecosystems across the nation have piqued interest in the dynamics of natural systems and related restoration concerns. In the presettlement southeastern United States, longleaf pine (*Pinus palustris)* was a dominant plant, especially in coastal plain areas such as the Sandhills of North Carolina. Current research in the Fort Bragg area involves defining and spatially reconstructing presettlement vegetation communities to guide landscape conservation and restoration efforts. Though dominated by longleaf pine, these areas were far from homogenous, containing a variety of community types. Many of these community types remain discernable because of a few preserved natural systems, detailed descriptions of the presettlement landscape found in historic journals and records, and the existence of remnant indicator species found on the landscape, today. The interest in developing similar presettlement vegetation maps for surrounding areas concerned with restoring fire-dependent systems, led to the formation of the first question of this thesis:

> *Is it possible to develop a quick and inexpensive method to generate presettlement vegetation community maps for use in restoration planning for fire-dependent ecosystems?*

The influence of fire on the distribution of these presettlement vegetation communities was paramount. It occurred to me that there might be a relationship between the patterns of vegetation found on the landscape and variations in fire behavior. Conventional fire behavior modeling software has been successful in predicting fire spread and behavior across a given landscape, incorporating terrain, weather, winds, and fuels. These are similar to gradients (latitude, elevation, aspect, climate) recognized by ecologists as having a direct influence on vegetation distributions on many landscapes throughout the world. If the effects of terrain were isolated with historic weather and wind in the fire model inputs, it follows that variations found in fire behavior outputs might be used to make inferences about vegetation on a landscape affected by fire. This led to my second question:

> *Can conventional fire behavior models be used in an unconventional way: To make inferences about the distribution of vegetation on fire-dependent landscapes?*

Two articles were constructed for audiences that might have discreet and particular interests in this research. Practitioners such as botanists, ecologists, land and fire managers are concerned with issues of fire-dependent and historic ecosystems and may be interested in a comprehensive description of this method for rapidly assessing vegetation distribution for a particular period of time, on a landscape targeted for restoration. Fire modelers, fire behavior experts, and ecologists may be interested in a novel use of the traditional fire behavior modeling software and in expanding the connection between conventional fire models and historic vegetation community distribution on fire-affected landscapes.

This document is organized in the following manner: The first article, *A Method for Rapid Assessment of Historic Frequent-Fire Vegetation Communities,* examines the analysis process used to evaluate the entire presettlement landscape. A second article follows, *The Use of Fire Behavior Models in Reconstructing Presettlement Vegetation on a Frequent-Fire Landscape*, is focused on fire model outputs and how they worked to make inferences about the location of presettlement vegetation communities. The traditional written scientific framework (Abstract, Introduction, Methods, Results, Discussion, Conclusion) is self-contained within each article. This is followed by an epilogue that summarizes final thoughts and discussion not already covered in the articles, which might be of interest to someone wishing to duplicate the process. A “Literature Cited” section is collectively organized, following the epilogue. Finally, appendices documenting pertinent supporting information, complete tabular weather data inputs, and a comprehensive methods and procedure log are displayed.

A Method for Rapid Assessment of Historic Frequent-Fire Vegetation Communities

Abstract

In the effort to restore historic landscapes, it is necessary to first specify spatially explicit target vegetation communities. Previously, botanists and other local experts have used environmental factors, historical evidence, and remnant vegetation to define presettlement vegetation communities on the landscape. Once these communities are defined, they must be mapped in order to be truly understandable and useful. Efforts to map the location of these presettlement communities on a particular landscape are often laborious and time consuming. In this study, we discuss a rapid method for assessing the location of these vegetation communities using Geographic Information Systems (GIS) and the current science of fire behavior modeling. Fire behavior models are proven predictors of fire intensities across a landscape, considering vegetation, terrain, elevation, latitude, seasonality, wind, and weather. Our hypothesis was that these fire behavior models could be used to make inferences about presettlement vegetation community distributions in former frequent-fire landscapes. GIS software was used to find simple combinations of variables associated with vegetation distribution, including soil type, aspect, slope, and orientation to gradient winds. A conventional fire model (FlamMap) was then used to find areas that are distinctly fire-sheltered. The fire

model adds to the utility of the GIS by considering the effects of fire spread direction and variation in fuel moistures in conjunction with terrain variables. The resulting fire intensity outputs represent environmental effects on vegetation distribution that would be difficult to model solely with a GIS. A final presettlement vegetation layer was completed for the study site and compared to a layer generated by an extensive 2-year study considered to be definitive. The results showed an overall map accuracy of 78 percent for the proposed procedure. This output may be used as a preliminary map that, in conjunction with ground-truthing, will shorten the process of mapping presettlement vegetation for use in the restoration of historic fire-dependent communities.

Introduction

Open woodlands have dominated presettlement vegetation on the Coastal Plain of the southeastern United States for the past 7000 years (Carroll et al. 2002). Ecosystems ranging from as far north as the Virginia-Maryland border and as far west as Texas contained at least some longleaf pine (*Pinus palustris*) and are estimated to have covered approximately 37 million hectares at the time of European settlement (Frost 1995). Fire played a leading role in shaping these longleaf pine-dominated and associated communities of the southeastern U.S., including those found in the Sandhills region of North Carolina. The majority of this landscape was characterized by open pine savanna with an understory of wiregrass *(Aristida stricta)*, herbaceous plants, and oaks. Pockets of vegetation composed of larger oaks and sparse understory existed in fire-sheltered portions of the uplands.

Mid-story vegetation and late-successional vegetation was kept to a minimum by frequent, low-intensity surface fires. Historic Coastal Plain longleaf pine-dominated savannas are probably among the best known of fire-dependent areas, with fire return intervals of 1-3 years. Only 3% of longleaf communities currently remain in their natural condition due to fire suppression, commercial logging practices, conversion to agriculture, and development (Landers et al 1995). Such a decline has prompted land managers and ecologists to focus on restoration of these and other historic ecosystems, creating a need for spatial and descriptive information concerning historic vegetative as a target for the planning process (Egan and Howell 2001).

Experts in the field of historical ecology have the knowledge and experience to discern vegetation communities for periods like the one just prior to European settlement, where remnant vegetation and historic documentation makes identification of specific vegetation communities possible. Identification of these communities and related environmental conditions requires significant knowledge of native vegetation associations and conditions as well as knowledge of how fire affects their distribution. Beyond defining historic vegetation, a further and significantly time-consuming task is to locate these historic communities on a map for specific landscapes.

The objective of this study was to use GIS and fire model outputs to locate previously defined presettlement vegetation communities on a frequent-fire landscape, greatly reducing the amount of time required for an expert to produce a presettlement vegetation community map. We were most interested in using conventional fire model outputs to suggest the location of fire-sheltered communities on the historic landscape. The fire model adds to the utility of the GIS by considering the affect of prevailing winds in addition to topographic variables in relation to vegetation distribution influenced by fire. We assumed that vegetation communities were relatively static on the landscape throughout the presettlement period and that fire-sheltered community types consistently experienced lower fire behavior, as compared to the surrounding landscape, because of topographic position and protection from the effects of higher intensity fires caused by the alignment of slope and prevailing winds.

Vegetation distribution is related to soils, climate, and terrain. In a frequent fire landscape, vegetation distribution is also related to fire regime, including fire intensity and frequency, which is also influenced by terrain, local climate, and winds. While most attributes (soils, climate, terrain) are readily available from maps, databases, etc., variables concerning fire behavior and spread are best predicted by models created for that specific purpose.

Various models may be used to provide spatial data related to fire effects on the landscape. FARSITE Fire Area Simulator (Finney 1998) and FlamMap (Finney et al. 2004) are PC-driven models that quantify fire behavior and spread, based on extensive research in the field (Rothermel 1972, Albini 1976, Anderson 1982, Albini 1983, Rothermel 1983, Van Wagner 1977). These models consider shading, weather and wind variables, fuel moistures, slope, aspect, elevation, latitude, and seasonality. Potential outputs include rate of spread, fireline intensities, flame lengths, perimeter and area of fire spread, and crown fire behavior. FARSITE has been demonstrated to be a relatively accurate predictor of fire spread and intensities in the field (Van Wagtendonk 1996, Finney 1998).

Small changes in fire frequency can alter tree and ground cover composition in the longleaf pine-dominated landscape of the Coastal Plain of the Southeast United States (Glitzenstein et al. 1995). Though the majority of the presettlement landscape was open pine savanna with an understory of wiregrass, herbaceous plants, and oaks, remnant vegetation and representative landscapes in other areas show that there was definable variation in community type. Pockets of vegetation composed of larger oaks and sparse understory existed in fire-sheltered portions of the uplands (Figure 1). We assume that such communities occurred in areas that consistently experienced less severe fire behavior because of topographic position and sheltering from gradient winds. It is these areas that consistently experienced low fire behavior that we set out to locate with fire behavior outputs from the FlamMap fire model.

After combining fire behavior data with conventional terrain and soils data in a GIS, we tested our procedure to map historic fire-influenced vegetation in a Southeast landscape where prior spatial data concerning the distribution of historic vegetation communities were available.

Analysis Area:

Fort Bragg National Military Reserve is located 16 kilometers northwest of Fayetteville in the Sandhills region on the Coastal Plain of North Carolina. The Sandhills represent a transitional area between the Coastal Plain and the Piedmont. The specific study area is the Overhills tract, 4,250 hectares located at the northern boundary of Fort Bragg in Harnett and Cumberland counties. Elevations on the tract range from 43-119 meters above sea level, representing moderate terrain relief. Overhills is historically part of a large fire compartment, defined by Frost (1995) as an area of continuous vegetation without natural barriers that disrupt the flow of fire across the landscape.

Presettlement vegetation in this region was affected by climate, location on the landscape, soils, and fire. Fire was a primary factor shaping the vegetative structure and composition of the historic longleaf pine forest. Many early travelers in the area reported observing settlers and native people setting fire to the woods (Schaw 1776). They also reported extensive open stands of large timber with a species diverse, easily traversed understory (Lawson 1714). Since that time, fire's positive effects on the maintenance of open, diverse longleaf pine forests and their associated understory vegetation have been well documented (Andrews 1917, Heyward 1939, Myers 1985, Rebertus et al. 1989).

Beginning in the mid-18th century, the Fort Bragg area was settled by European immigrants. Land grants were most commonly divided into 20-80 hectare parcels that were cleared and farmed for family subsistence. In the 19th century, the

Overhills tract was at the heart of a large turpentine plantation. By 1910, the majority of virgin timber had been harvested, with few of the original trees remaining. The Rockefeller family acquired the property in 1917 and maintained it as a hunting resort and, later, in farmland, until the 1970s. The Army purchased the Overhills tract from the Rockefellers in 1997. Currently the tract is undergoing an environmental assessment to determine future plans for the area and the resulting impacts to natural and cultural resources. (Fort Bragg Cultural Resources web page. *Highlights in Fort Bragg History: Overhills*.
http://www.bragg.army.mil/culturalresources/overhills.htm. 2005.)

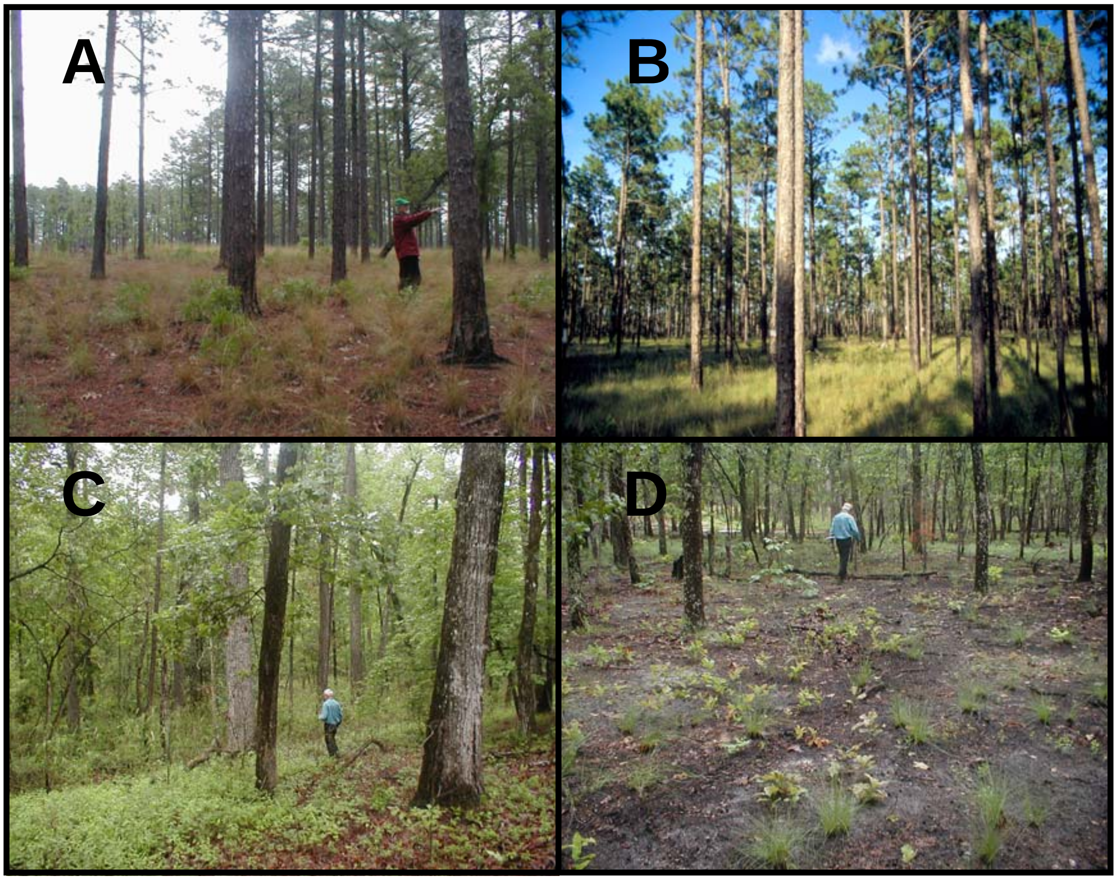

Figure 1: Communities of upland sites; A: Xeric Longleaf Pine/Wiregrass Savanna B: Mesic Longleaf Pine/Wiregrass Savanna. C: Pyrophytic Oak-Hickory Woodland. D: Oak Savanna and Woodland.

Though there are areas of the Overhills tract that were developed or continue to be maintained in agricultural fields, a large portion of the tract has been maintained in second-growth native forest. Despite human disruptions to the landscape, native plant species continued to persist and many undisturbed or second growth indicator species are visible today. Much of this area is longleaf pine savanna, impacted by logging and fire exclusion. Over the past 80 years, occasional fires, representing a 5-20 year fire return interval, have produced an understory of dense blackjack and turkey oak and intermittent wiregrass. Fort Bragg fire management staff have begun dormant season burns to reduce fuel loading in preparation for growing season burns that will reduce oak and increase the abundance of wiregrass and other understory species (John Ward, Fort Bragg Fire Management Officer, *pers. comm.* 2005). Many of the presettlement species are still present, though vegetation communities are in varied levels of departure from their nineteenth century conditions.

Methods

Overview:

The following methods were based on the assumption that the distribution of presettlement vegetation communities on the Fort Bragg landscape was influenced by soils, position on the landscape (aspect and slope), and by exposure to fire. Fire-sheltered vegetation communities found in depressions and wind-sheltered areas on the landscape were located with FlamMap fire behavior model outputs. Historic weather data were collected from local remote automated weather stations (RAWS) and organized with Fire Family Plus and other statistical sorting methods. Accurate terrain data were provided from satellite collected Light Detection and Ranging (LIDAR) data. A sensitivity analysis was performed in FlamMap to determine the reaction of the model to changes in individual inputs. Remnant presettlement communities were associated with terrain orientation and soils, including the fire-exposed upland communities, wetlands, and those influenced by more extreme fire behavior associated with the funneling of prevailing winds.

Defining Presettlement Community Types:

Presettlement vegetation communities were previously defined and delineated in a 2-year study of the Fort Bragg area by an expert in local vegetation and historic fire ecology (Frost 2005, *in prep*). These communities are similar to those described in the *Classification of the Natural Communities of North Carolina* (Schafale and Weakley 1990). They were derived from (1) a consideration of existing historic conditions maintained elsewhere in the Southeast, (2) remnant vegetation at Fort Bragg, and (3) general knowledge of the effects of frequent fire on a continuous landscape (Frost 1995). Historic journals and early settlement survey plats containing information on indicator tree species were used to confirm the location of the individual communities across the landscape. The accuracy of these community locations was checked extensively in the field by searching for remnant vegetation.

Table 1 presents a list of the presettlement community types defined at Fort Bragg, including a comparison to modern communities as defined by Schafale and Weakley (1990). Remnant fire indicator species include longleaf pine, wiregrass, cane (*Arundinaria gigantea*), southern red oak (*Quercus falcata*), loblolly pine (*Pinus taeda*), pond pine (*Pinus serotina*), blackjack oak (*Quercus marilandica*), post oak (*Quercus stellata*), mockernut hickory (*Carya tomentosa*), Atlantic white cedar (*Chamaecyparis thyoides*), and turkey oak (*Quercus laevis*). Presettlement vegetation communities are based on and limited to what can be verified or substantiated from early land grant surveys and other historical sources. As such, they are sometimes coarser and sometimes finer than the types described by Schafale and Weakley (1990). Because all but a few presettlement vegetation communities were influenced by fire they may differ from modern fire-suppressed communities especially as applies to the structure of vegetation. Frost's classification differs in its emphasis on fire-maintained two-layered vegetation structure (savanna and woodland) and on vegetation types whose dominants and structure are dependent on fire such as canebrake, in contrast to the modern multi-layered fire suppressed forests.

Table 1: Seven presettlement vegetation communities at Fort Bragg, listed in order from most xeric upland communities to most mesic bottomland communities (Schafale and Weakley 1990. Frost 2005.)

Frost Community Name *(Schafale and Weakley Community Type)*	***Community Description***
Xeric Longleaf Pine/Wiregrass Savanna. *(Pine-Scrub Oak Sandhill)*	On convex uplands with excessively drained or somewhat excessively drained sand soils. The driest parts of the landscape, and, usually, the most fire-exposed and fire-frequent. Fire intensity (sometimes frequency) may be reduced, however, if the site is on the downwind side of a substantial firebreak such as the Lower Little River, or in the area downwind from the confluence of two streams.
Mesic Longleaf Pine/Wiregrass Savanna. *(Pine-Scrub Oak Sandhill)*	On fire-exposed landscape positions on convex or gently rolling uplands, south slopes, and well-drained upland flats with substrate of loamy sand and sandy loam soils.
Oak Savanna and Woodland (blackjack oak with post oak, mockernut hickory, and scattered stems or patches of turkey oak and longleaf pine/grass). *(Pine-Scrub Oak Sandhill, Blackjack-Mixed Oak Variant)*	On any upland soil type in slightly fire-sheltered sites with an impermeable layer within 1 meter of the surface. Can occur on slopes facing in any direction, even south, if there is a sufficient topographic break in the upwind direction to create a flat or pocket.
Pyrophytic Oak-Hickory Woodland (southern red oak, post oak, loblolly pine, pond pine. Fire influenced, but with reduced fire effect on more fire-sheltered lower slopes and steep-sided ravines). *(Mixed Mesic Hardwood Forest, Swamp Island Variant on the bottomlands)*	On moderately well drained and somewhat poorly drained soils in ravines that lie perpendicular to the prevailing wind direction. Also on lower north slopes where slope is >10% and in bottomlands on islands of higher soil that are still accessible to light surface fire but where side slopes are steep enough to prevent full access by rapidly moving fire.

Table 1: Seven presettlement vegetation communities at Ft Bragg (continued)

Pond Pine/Canebrake. *(Pond Pine Woodland; Sandhill Seep; High Pocosin; Streamhead Pocosin)*	On poorly drained and somewhat poorly drained soils. Can occur in the upper part of the landscape in gently concave stream head depressions where an impermeable layer is close enough to the surface to create a perched water table. Also found in pockets or seepage zones on side slopes where the impermeable layer outcrops along a side slope, creating a seepage zone, or in mid-slope and lower concave or V- shaped drainage sloughs. These may be so narrow as to create a string of single pond pine trees, with a band of cane only 2-3 meters wide beneath them. Cane was extensive in major and minor bottomlands where side slopes are gentle enough (<6%) to permit easy access by every passing fire.
Wet-mesic Longleaf Pine Savanna. *(Pine Savanna; Wet Pine Flatwoods)*	On mineral soils in large and small stream bottoms where water table remains near the surface during most of the year, either because the site is the lowest in the landscape or on slightly higher flats where there is an impermeable layer near the surface.
Small Stream Swamp and Pyrophytic Wetland Mosaic (pond pine canebrake, hardwood canebrake, beaver ponds and marshes, bottomland hardwoods, loblolly pine, tulip poplar, sweetgum, Atlantic white cedar). *(Coastal Plain Small Stream Swamp; Cypress-Gum Swamp, Blackwater Subtype; Streamhead Atlantic White Cedar Forest; Coastal Plain Bottomland Hardwoods, Blackwater Subtype; Bay Forest; High Pocosin; Coastal Plain Semi-Permanent Impoundment)*	Original fire frequency variable: margins and bottoms with gentle side slopes readily accessible to fire burned as frequently as adjacent uplands. Sections with steep side slopes burned less frequently or not at all in the wettest swamps.

Based on these presettlement vegetation community descriptions, a decision matrix was designed to guide the analysis process. The following graphic illustrates this decision matrix in detail. Further explanation of the methods employed in the analysis process follows.

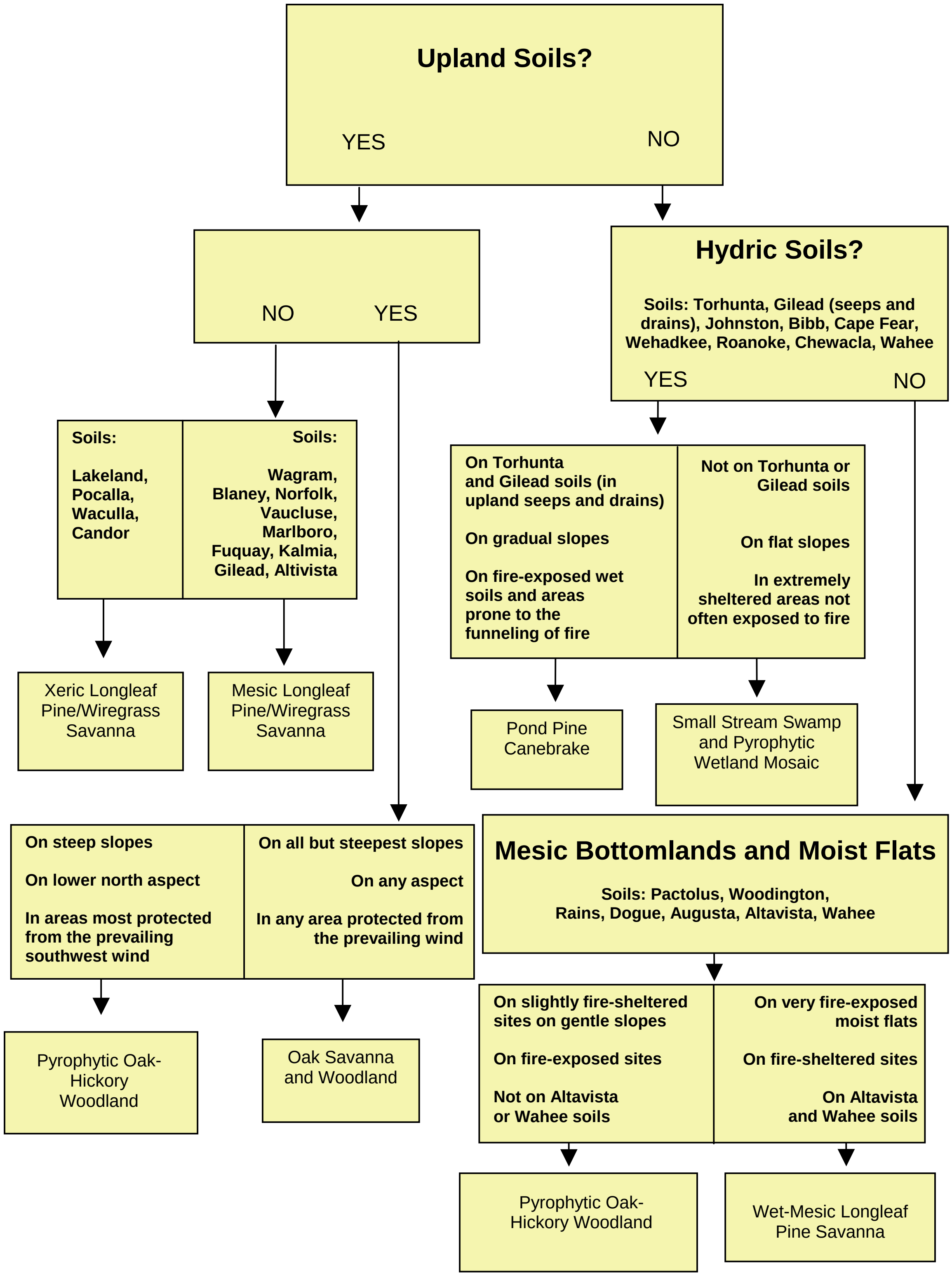

Figure 2: Decision matrix used to locate vegetation communities on the landscape

Data and Software:

Soils and stream layers were provided by the Department of Defense, Fort Bragg GIS Department.

A countywide elevation grid file at 6-meter resolution was obtained from the North Carolina Department of Transportation (http://www.ncdot.org/planning/tpb/gis/DatatDist/GIS ContourMaps.html). This grid was created from original Light Detection and Ranging (LIDAR) data generated by the North Carolina Flood Mapping Program. (www.ncfloodmaps.com)

Hourly weather and wind data, from local remote automated weather stations (RAWS), was accessed online at the Western Regional Climate Center's Desert Research Institute website (http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?ncNFBR). The National Wildfire Coordination Group's Fire and Aviation Management Web Applications (FAMWEB) also provided historic daily RAWS data (http://famweb.nwcg.gov/weatherfirecd/).

FARSITE and FlamMap fire modeling software and Fire Family Plus software for summarizing weather data are available from the Rocky Mountain Research Station Fire Sciences Lab at http://fire.org.

Generating Vegetation Communities on Fire-Sheltered Uplands:

Fire-sheltered communities on upland soils (Lakeland, Pocalla, Wakulla, Candor, Wagram, Blaney, Norfolk, Vaucluse, Marlboro, Fuquay, Kalmia, Gilead) were located with FlamMap. Fireline intensity outputs in kilowatts per meter (kW/m) were generated from landscape, weather, and fuels conditioning inputs and exported to ArcView. The lowest fire behavior outputs were assumed to represent fire-sheltered areas on the landscape where Pyrophytic Oak-Hickory Woodland and Oak Savanna and Woodland were found.

Completing Fire-Sheltered Upland Vegetation Layers:

A FlamMap run was completed with inputs describing a representative fire day. The fireline intensity output was exported and the lowest portion of the fire behavior outputs were selected and saved as a shapefile. These polygon outputs were assumed to show the location of fire-sheltered Pyrophytic Oak-Hickory Woodland and Oak Savanna and Woodland communities on the landscape.

Pyrophytic Oak-Hickory Woodland areas were generated from the intersection of the low fire behavior polygons, upland soils (Lakeland, Pocalla, Wakulla, Candor, Wagram, Blaney, Norfolk, Vaucluse, Marlboro, Fuquay, Kalmia, and Gilead), aspects greater than 10%, and drainages perpendicular to the prevailing southwest winds.

Oak Savanna and Woodland communities comprised the remainder of the fire-sheltered areas on upland soils.

Generating Vegetation Communities Based on Soils and Location on Landscape:

Aspect and slope grids generated for the fire behavior modeling process were used, along with a soils layer, to determine the location of the remaining communities. Simply selecting the soil types where upland communities occurred was sufficient for identification of upland fire-exposed communities. Xeric Longleaf Pine/Wiregrass Savanna occurred on Lakeland, Pocalla, Wakulla, or Candor soils. Mesic Longleaf Pine/Wiregrass Savanna occurred on Wagram, Blaney, Norfolk, Vaucluse, Marlboro, Fuquay, Kalmia, or Gilead soils.

Wet-Mesic Longleaf Pine Savanna occurred on Pactolus, Woodington, or Rains soils, on slopes less than 6%, and in drainages that are parallel to the prevailing southwest winds and on side-slopes facing southwest to southeast.

Pyrophytic Oak-Hickory Woodlands occurred on both the uplands and lowlands. The upland sites were found with the fire modeling process as described above. The lowland sites were the sites not already occupied by Wet-Mesic Longleaf Pine Savanna on Pactolus, Woodington, Rains, Dogue, Altivista, Augusta, Wahee, and Roanoke soils. The upland and lowland sites were merged to create a complete Pyrophytic Oak-Hickory Woodland layer.

Pond Pine Canebrake occurred on hydric Johnston, Bibb, Cape Fear, Wehadkee, Torhunta, and upland Gilead soils, on flat to shallow slopes (less than 4%), and in drainages conducive to funneling of the prevailing southwest winds.

Small Stream Swamp and Pyrophytic Wetland Mosaic occurred on the remainder of the hydric soils areas not already occupied by Wet-Mesic Longleaf Pine Savanna or Pond-Pine Canebrake. These sites are defined by Johnston, Bibb, Cape Fear, and Wehadkee soils.

Fire Behavior Model Inputs:

FARSITE and FlamMap require the following inputs: A landscape file, including aspect, slope, elevation, fuel model and canopy cover grid files, wind inputs, and weather inputs. FARSITE models fire behavior and spread spatially and temporally given heterogeneous terrain, weather, and fuels conditions across a landscape (Finney 1998). FlamMap models fire behavior as if each raster cell on the landscape were ignited simultaneously. Time is only significant in FlamMap when using a fuels conditioning period. Fuels conditioning across the landscape renders variability in fuel moistures in response to changing weather conditions and topography, as they might occur on the actual landscape (Finney et al 2004). The FlamMap model generates fire behavior outputs for individual raster cells from conditions generated at the end of the fuels conditioning period.

Landscape:

Because we considered them a more accurate representation of the actual terrain, “Bare earth” light ranging and detection (LIDAR) data were chosen over digital elevation model (DEM) cartographically digitized from 1:24000 quadrangle maps. Slope and aspect grids were derived from the clipped LIDAR elevation grid. This step provided three of the five elements required to generate a FARSITE landscape.

Fuel Models:

The final two grid files required to generate a FARSITE landscape relate to vegetation. Fire Behavior Prediction System (FBPS) [formerly National Forest Fire Laboratory (NFFL)] fuel models were designed by Rothermel (1972) and Albini (1976) to describe the physical properties of surface vegetation for use in predicting fire behavior. Each fuel model is described by fuel load, the ratio of surface area to volume of the various size classes of fuel, the depth of the available vegetation, and fuel moisture, including the moisture of extinction of the fuel (Anderson 1982). There are 13 models in 4 categories: grass, shrub, timber, and slash. Fuel model 2, a grass model, which represents surface fire spread through fine herbaceous fuels in addition to litter and dead stem wood, best describes the majority of presettlement vegetation at Fort Bragg. In order to keep the fire modeling inputs as uniform as possible, fuel model 2 with a 50% canopy cover was held constant across our study landscape.

The five grids (elevation, slope, aspect, fuels, and canopy cover) were combined in FARSITE and a landscape file was generated for use in FlamMap.

Weather and Fire Season:

FlamMap Weather Inputs:

Historic 90th percentile weather inputs were generated with Fire Family Plus from available RAWS data. All weather data for the months of March and April were considered and fuel moisture inputs were determined to define a “representative fire day”.

Prevailing Wind:

A wind rose was generated using daytime March and April hourly wind observations from all available years (2000-2005). The most common wind direction was from the Southwest, with winds averaging 16 kilometers per hour at the 6-meter level. It is assumed that the predominant wind direction has remained constant since before the presettlement period.

Fuel Conditioning Files:

Daily 1300 weather observations, from FAMWEB RAWS files, were averaged to determine daily high and low temperatures and humidities. Maximum of high temperature, minimum of low temperature, low relative humidity, and high relative humidity columns were averaged for all data from the Fort Bragg RAWS station (1968-88 and 2000-04).

Other hourly Fort Bragg RAWS data (2000-2005) were organized in Microsoft Excel®. A mode of each hourly wind direction, windspeed, and cloud cover was taken to create the wind and weather fuels conditioning files for the dates March 25-31. An inverse relationship was assumed between recorded hourly solar radiation and cloud cover.

Seasonality:

Historic data from local RAWS stations were accessed (NWCG, FAMWEB archives) and sorted. An examination of the entire dataset revealed that March and April were the driest weather months. This is confirmed by Uwharrie National Forest fire records (1970-2004) showing that all acres burned during the months of March and April (Figure 3). The Uwharrie fire records correlate with research done by Barden and Woods (1973) showing historic fire occurrence in North Carolina, in the Appalachian Mountains, to have occurred in March, April, and May. Because it is at a lower elevation and represents a warmer and drier climate, the Coastal Plain of North Carolina has its fire season about a month in advance of the fire season in the Appalachians.

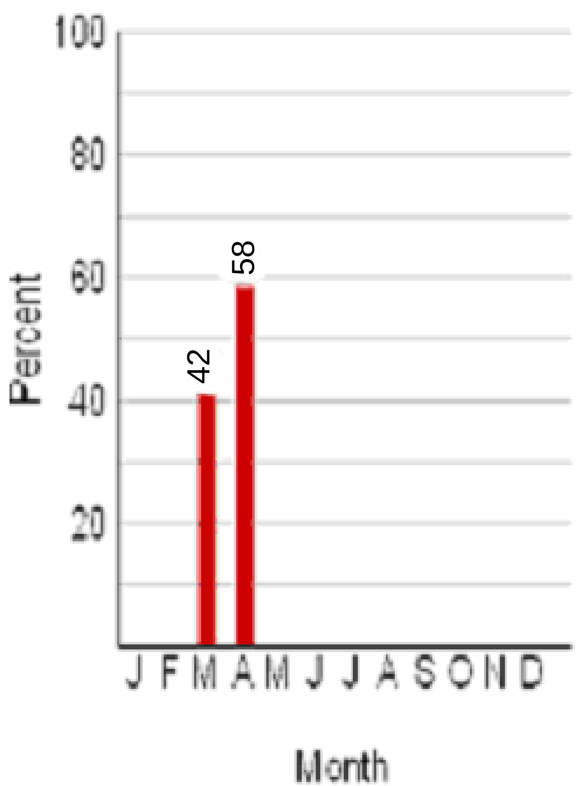

Figure 3: Fire summary output from Fire Family Plus software showing the historic (1970-2004) season of fire occurrence for Fort Bragg's neighboring Uwharrie National Forest. Fires during this period primarily occurred in March and April

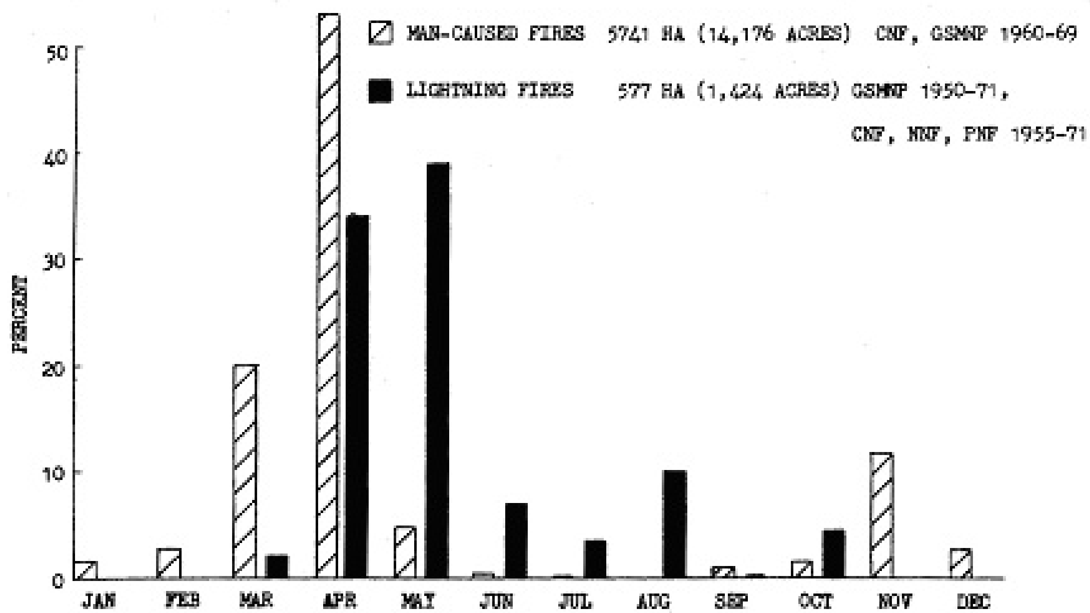

Figure 4: Lightning and man-caused fire frequencies in the southern Appalachians (Barden and Woods 1973)

Ignition Sources:

Historically, both cultural and natural ignitions were probably common. The Uwharrie fire report database (National Fire and Aviation Management Web Applications, http://famweb.nwcg.gov/) contains records from 1972 to the present, representing ignitions on a fragmented and generally more mesic landscape than what was described in presettlement times (Lawson 1714, Brickell 1737, Schaw 1776). No lightning caused fires were recorded in the Uwharrie database, though lightning fires likely occurred on the Coastal Plain in the historic landscape. It is probable that lightning strikes would have resulted in some quantity of acres burned on a continuous, more xeric presettlement landscape. Historic savanna fuels such as wiregrass would have been available to burn within a day or two of wetting rain (Margit Bucher, Assistant Director of Science & Stewardship, NC Chapter, TNC, *pers. comm*. 2005). Weather records show that these windows existed throughout the year. Any lightning ignition in March and April would certainly have resulted in a large acreage burned, while even during the wet season in July and August windows of dry weather would have occurred where many frequent lightning strikes would have resulted in some acres burned.

Special Weather Considerations:

It is feasible that hotter temperatures or higher relative humidities may have affected fire behavior on the landscape, making seasonality of predominant presettlement fire occurrence potentially a significant factor influencing vegetation distribution. To test this idea, a sensitivity analysis was performed to gauge the effect of changes in weather inputs to the fire model on the resulting fire intensity outputs. Two results were of possible interest: The first would be a change in the actual range of fire intensity throughout the landscape. The second would be a change in the distribution across the landscape of the polygons spatially representing the lowest fire behavior.

Accuracy Assessment:

Finally, all of the seven resulting data layers were merged to create a finished vegetation community layer, with special attention given to the correct classification of areas designated with more than one community type by the analysis process. The final accuracy assessment was made in ERDAS Imagine v. 8.6. Fifty random points were generated in each of the seven community types and compared to the presettlement community map generated by Frost's extensive study. Each point was checked manually and recorded according to its location on the reference layer. Communities within 50 meters of the target community were considered correct. The Accuracy Assessment function then compared the reference points to the classified map, generating a summary sheet, an error matrix, and accuracy totals.

Results

Our analysis process produced a vegetation community layer that was qualitatively very similar to Dr Frost's layer (Figures 5 and 6). Frost's layer is the product of extensive fieldwork during which sites representing all of the discernable community types were visited on a portion of the 4,250-hectare Overhills landscape. Our layer is the result of a few days of computer analysis, the framework for which was based on Frost's expert knowledge of local vegetation and presettlement fire-dependent communities. The Xeric Longleaf Pine/Wiregrass Savanna, Mesic Longleaf Pine/Wiregrass Savanna, and Wet-Mesic Longleaf Pine Savanna, and Small Stream Swamp and Pyrophytic Wetland Communities are all in very similar locations as compared to Frost's map, due to their strong correlation with soil types. Pond Pine/Canebrake and fire-modeled Oak Savanna and Woodland are distributed in largely the same portions of the landscape, though the character of the polygons is distinctly different. Frost's polygons are smooth-edged and generalized, a result of manual mapping of remnant vegetation as seen in the field. Our process displayed these communities in a patchy manner across the landscape, which is an artifact of the pixilated nature of the GIS analysis process. The agreement between the maps is on general landscape location and not necessarily total spatial extent.

For the most part, our model worked well. However, the Pyrophytic Oak-Hickory Woodlands that were historically on the most fire-sheltered sites were not adequately represented by our model, which placed these communities in low fire behavior fire model output polygons occurring on north aspects and on slopes greater than 15%. Pyrophytic Oak-Hickory Woodlands on Frost's map are, indeed, located on steep, north-facing slopes and are related to the distribution of the fire-sheltered Oak Savanna and Woodland. However, instead of being a portion of the lowest fire behavior polygons, they seem to be located down-slope from Oak Savanna and Woodland, especially at the base of long slopes.

The quantitative accuracy assessment produced the error matrix in Table 2. The columns represent the reference data (Frost's "true" layer) and the rows show the classification data generated by our analysis process. The column total is the determinant of "producer's accuracy" (or "omission error"), an expression of the probability of a sample being correctly classified. The row total determines "user's accuracy", which is commission error or the probability that a map unit represents actual vegetation on the ground (Congalton 2001). Overall producer's accuracy was excellent for the community types that had very simple analysis parameters. The more complicated analysis techniques used for Pond Pine/ Canebrake and the Oak Savanna and Woodland produced accuracies of 70% and 74% respectively. As noted above, the Pyrophytic Oak-Hickory Woodland proved to be modeled incorrectly (with only 10% accuracy), not showing any correlation to the “most fire-sheltered of the low fire behavior” sites, as we had assumed.

The extent of each community type affected its total accuracy scores. The most prevalent communities, Xeric Longleaf Pine/Wiregrass Savanna and Mesic Longleaf Pine/Wiregrass Savanna, scored high for producer’s accuracy. Yet Mesic Longleaf Pine/Wiregrass Savanna had a 59% user’s accuracy (the lowest of all) because it serves as a background for many of the smaller community types and has a higher probability to absorb an incorrect score. This also suggests that the equal sample size of 50 points for all communities surveys smaller communities more thoroughly than it does the larger communities.

The model output is subject to inaccuracies towards the edges of the map or in isolated islands. The isolated island in the northeast corner of the landscape demonstrates this effect. Pond Pine canebrake is noticeably absent from this area in the model output because of the inability of the hydrological model to produce accurate drainages without input data from the larger surrounding landscape. When the island was removed from consideration and sample points were regenerated for the remaining landscape in a new accuracy assessment, the producer’s accuracy of the Pond Pine community increased slightly, from 70% to 74%.

Overall map accuracy was 78%, including the 10% accuracy for the Pyrophytic Oak-Hickory Woodland community type. When we excluded this obviously misidentified community type, by removing the 50 Pyrophytic Oak-Hickory sample points and recalculating the overall map accuracy with 300 total points, the overall map accuracy increased to 89%.

The sensitivity analysis determined that seasonality and ignition sources were not important factors influencing fire effects and related vegetation community distribution in this landscape. Fuel moistures, wind speeds, and time of ignition are all factors that change the flammability of vegetation, resulting in a varying range of fire intensities and effects. However, only wind direction affected the actual distribution of low fire behavior polygons on the landscape. Since prevailing winds in the analysis area were from the southwest year-round, seasonality was not a factor affecting fire-sheltered polygon distribution. Ignition sources also were insignificant since the sensitivity analysis demonstrated that changes in weather and resulting changes in fuel conditions related to seasonality do not change the location of the most fire-sheltered areas on the landscape.

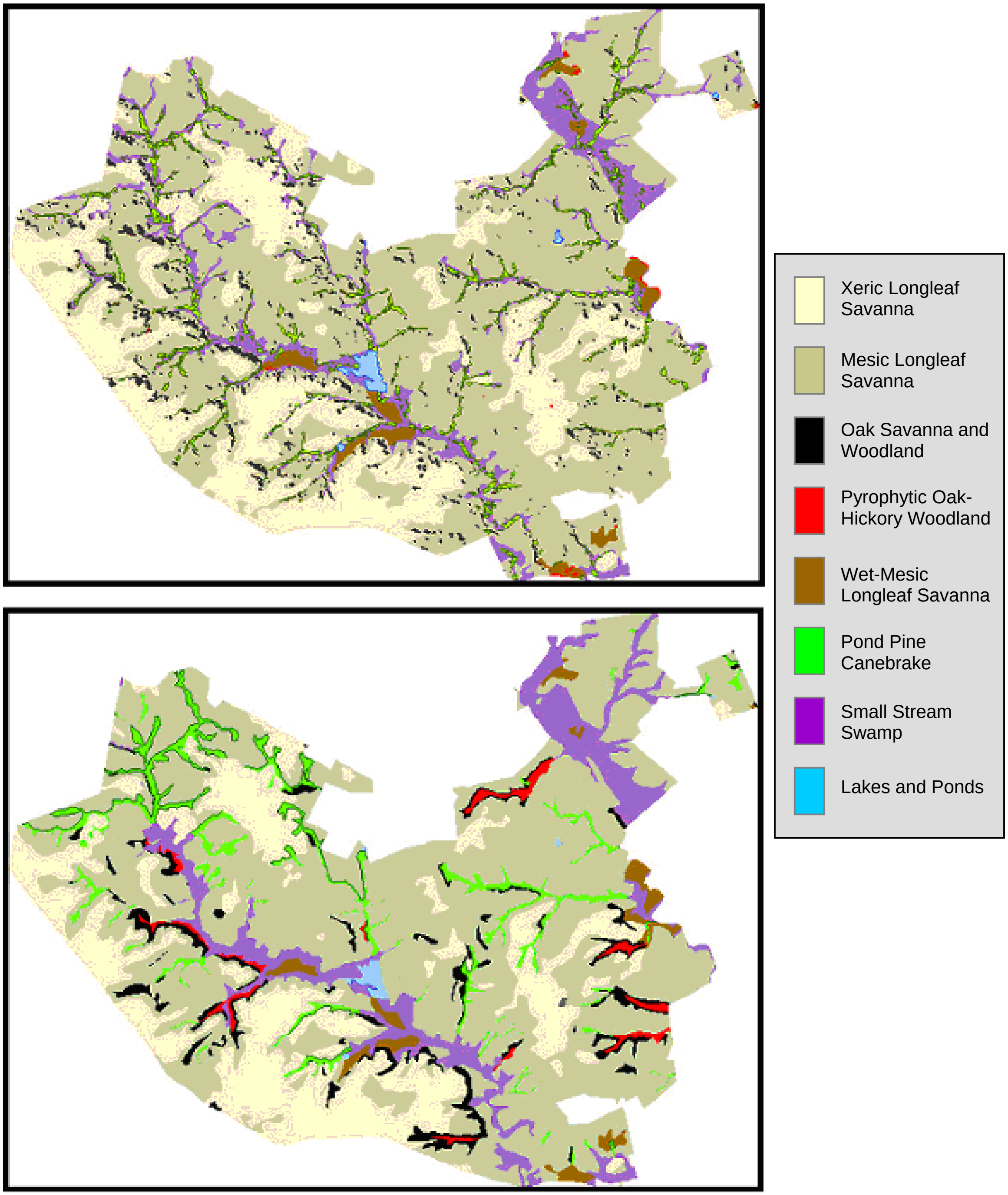

Figure 5: Comparison of the two historic landscape assessments of the Overhills tract. The reference layer (Frost's) is displayed on the bottom and the classified (our analysis process) layer is on the top

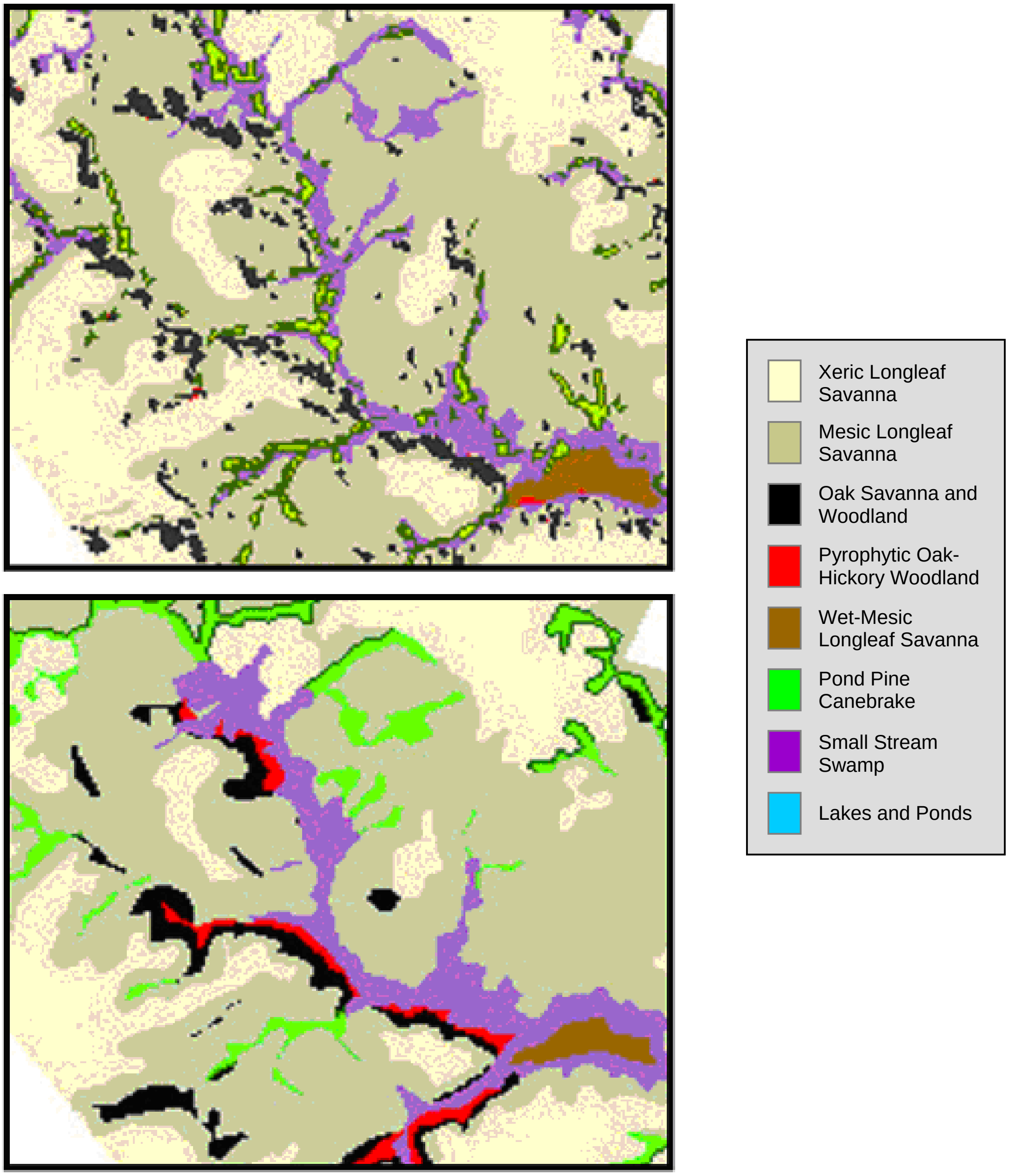

Figure 6: Close up of Overhills landscape comparison with the reference (Frost's) layer on the bottom and the classified (our analysis process) layer displayed on the top

Table 2: Error matrix describing quantitative accuracy for comparisons of our process-generated presettlement vegetation reference layer (classified data) to Frost's field-generated presettlement vegetation classification layer (reference data)

Reference Data

Classified Data

	X	*M*	*O*	*Py*	*W*	*Pc*	*S*	Row Total
X	**48**	0	0	0	0	0	0	48
M	2	**50**	10	14	3	6	0	85
O	0	0	**37**	20	0	0	0	57
Py	0	0	0	**5**	0	0	0	5
W	0	0	0	0	**47**	0	0	47
Pc	0	0	3	8	0	**35**	0	46
S	0	0	0	3	0	9	**50**	62
Column Total	50	50	50	50	50	50	50	**350**

Presettlement Community Categories

X = Xeric Longleaf Pine/Wiregrass Savanna
M = Mesic Longleaf Pine/Wiregrass Savanna
O = Oak Woodland and Savanna
Py = Pyrophytic Oak-Hickory Woodland
W = Wet-Mesic Longleaf Pine Savanna
Pc = Pond Pine/Canebrake
S = Small Stream Swamp and Pyrophytic Wetland Mosaic

OVERALL ACCURACY
272/350 = **78%**

USER'S ACCURACY
X = 48/48= 100%
M = 50/85 = 59%
O = 37/57= 65%
Py = 5/5 = 100%
W = 47/47 = 100%
Pc = 35/46 = 76%
S = 50/62 = 81%

PRODUCER'S ACCURACY
X = 48/50 = 96%
M = 50/50 = 100%
O = 37/50 = 74%
Py = 5/50 = 10%
W = 47/50 = 94%
Pc = 35/50 = 70%
S = 50/50 = 100%

Discussion

This method provided a reasonably accurate primary assessment of presettlement vegetation distribution across the Overhills landscape.
The output presettlement vegetation layer created by this process is only meant to be a “rough” estimate or starting point for further exploration on a given landscape. The model simply predicts where presettlement communities could have been based on conditions conducive to their presence. The entire process is dependent on a pre-assessment of the landscape to define historic vegetation communities. This pre-assessment was accomplished with onsite fieldwork to locate remnant vegetation, studies of the historic record about Fort Bragg vegetation, and comparison to fragment historic vegetation communities in similar areas. Remnant vegetation discernable to community type must be present on the landscape or on a landscape comparable to the one being modeled.

Gradients in latitude, elevation, and topography have a direct and noticeable influence on vegetative distribution (Whittaker 1956). The FlamMap fire behavior prediction model also considers latitude, elevation, and topography, along with climate inputs in the form of local wind and weather observations (Finney 2004). Therefore, the fire behavior outputs that we used to locate fire-sheltered areas on the landscape are dependent on the influences of slope, aspect, and other terrain inputs. However, the FlamMap fire model offers a unique way to assess vegetation distribution on the landscape by also considering the effect of local weather and winds on fire behavior. In particular, fire intensities are physically affected by slope reversal related to fire spread direction (influenced by prevailing wind direction) and changes in fuel moistures in the model as calculated according to position on the landscape. Fire behavior outputs represent the natural range of variation in fire across the landscape, which in turn affects vegetative structure. No other method that we are aware of so simply and succinctly identifies in a spatially explicit way the influences of both the commonly recognized environmental gradients (latitude, elevation, and topography) and gradients in fire behavior across the landscape (including the influences of wind and weather).

Fire regimes include frequency, intensity, and seasonality. Fire frequency affects the distribution of vegetation (Frost 1995, Batek et al. 1999). Intensity must also be a factor influencing vegetation in areas that demonstrates a mosaic of distinctive communities where fire frequency is high and all available fuels are regularly consumed. That the FlamMap fire behavior model contributes to predictive power of the GIS generating fire intensity outputs that may be linked to various vegetation communities. In our study, FlamMap outputs displayed a range of fire intensities, the lowest end of which was positively correlated with remnant fire-sheltered communities.

Fire is a significant variable affecting vegetation distribution, as demonstrated by the relationship between fire behavior outputs and the location of fire-sheltered Oak Savannas and Woodlands on the Overhills landscape. Recent research using dynamic global-vegetation modeling has shown that fire independently influences vegetation formations across the globe (Bond et al. 2005). Herbaceous ground cover has been highly degraded in the historic vegetation communities at Fort Bragg because of fire exclusion. Yet historic communities are still distinguishable by the presence of remnant indicator species found in the canopy and sub-canopy. The photos of upland communities found in Figure 1 represent the most distinctive examples of these communities found at Fort Bragg. It may be that these communities will become more distinguishable across the landscape with the return of the presettlement fire regime. Finer-scale community classification may even be possible once the presettlement landscape has been restored.

Predicting the placement of Oak Savanna and Woodland communities on the landscape would have been very difficult without the help of the FlamMap fire behavior model. The model accounts for a wider range of environmental factors affecting the actual location of these communities on the landscape by considering the effects of fire in addition to topographic influences. A major factor determining variation in fire behavior across the landscape is the interaction of fire spread direction (ultimately affected by wind on this landscape) and slope. Fuel moisture, as determined through the interaction of weather inputs and terrain inputs like slope and aspect, also contributes to changes in fire behavior across the landscape. Modeling the effects of wind and weather as applied to fire spread, intensities, and the resulting effects on vegetation community distribution with a GIS alone would be labor-intensive or impossible and would only serve to mimic the predictive power already provided by the fire model. In addition, the FlamMap fire model is a user-friendly software package that is available for download online at no cost.

Since there is some uncertainty concerning the historic fire season on this landscape, a sensitivity analysis was performed to gauge how seasonal fluctuations in temperature, relative humidity, and fuel moistures might affect the distribution of fire-sheltered communities. Our sensitivity analysis of the FlamMap model showed that, when critical inputs were changed, there was a difference in the range of fireline intensities on the landscape. Change in many of the inputs created differences in intensity outputs. The most significant of these resulted from changes in wind speed and the time of day of ignition, resulting in much higher or lower intensities, fuel moistures, and flame lengths. When the lowest portions of these fire behavior outputs were placed on the landscape, however, they resulted in no significant difference pertaining to the spatial location of the lowest fire behavior areas. Hence, fire-sheltering is static across the landscape, regardless of changes in fire intensities caused by temporal or climatic fluctuations influencing fire regime. Change in wind direction did affect spatial distribution of the low fire behavior polygons. In order to be an effective predictor of the distribution of fire-sheltered communities, one must be able to assume a single predominant wind direction, as was revealed by the historic weather records to be the case in the Overhills study area. Another possibility would be to combine the influences of multiple predominant wind directions by modeling each separately and combining the results.

The quality and accuracy of terrain inputs also contributed to our model's limitations. Digital elevation models used in generating slope and aspect grids are key to analysis outputs. Community output locations, shape, and size are sensitive to the resolution of the terrain model inputs. The model may find locations where conditions exist for a specific community; however, the output may not be consistent with the shape and size of the remnant vegetation defining the extent of that community on the landscape. These polygons may need to be manually adjusted after ground-truthing. It is important to note that presettlement communities may not have been static on the landscape, shrinking and expanding, or disappearing completely, for a period because of changing climate. These climate-driven shifts were probably rendered more dramatic when they were combined with the effects of fire, though consistent clearing of fine fuels by frequent fire may have tempered these effects.

The reliability of initial presettlement vegetation layers is improved with employment of the techniques described in our analysis model, and the quality of the final map has a direct relationship to the amount of effort put into research in the field. Several iterations of this map were required to adjust the scale and distribution of various communities. This method is not intended to be as definitive as an extensive field study would be, but can result in an inexpensive, preliminary presettlement vegetation map and can be combined with field techniques to greatly shorten the analysis process as a whole.

Conclusion

The analysis process for rapidly creating provisional presettlement vegetation community maps on the Overhills tract at Fort Bragg, NC was successful. The process produced a useful baseline product, the accuracy of which will be improved upon by field checking the study landscape. There is promise for this non-traditional use of fire behavior and spread models for ecological applications. Future studies are needed to determine the success of fire model outputs in predicting vegetative composition in other landscapes, fuel types, and fire regimes.

The Use of Fire Behavior Models in Reconstructing Presettlement Vegetation on a Frequent-Fire Landscape

Abstract

We established a rapid method for assessing the distribution of presettlement vegetation and generating fine-scale presettlement vegetation maps using conventional fire behavior models. Such models, including FARSITE and FlamMap have been demonstrated to be relatively accurate predictors of fire behavior and spread on the landscape. These models consider slope, aspect, elevation, latitude, and climate; the same factors observed to influence vegetation distribution in more conventional ecological analyses. Fire behavior is an important factor affecting vegetation distribution on a frequent-fire landscape. Fireline intensity outputs from a conventional fire behavior model (FlamMap) were used to locate fire-sheltered plant communities in a longleaf pine-dominated forest on a historic landscape in the southeastern United States. In a survey of 78 sites visited on the study landscape, fire model outputs correctly identified fire-sheltered oak-dominated vegetation communities in 91% of the areas where the presence or absence of presettlement vegetation was determinable. Success in finding a single community related to a specified range of fire behavior outputs suggests that there is potential for expanded

utility of fire models in making inferences about vegetative distribution on fire-influenced landscapes.

Introduction

Fire behavior models have been used extensively for modeling spread and behavior, of both prescribed fire and wildfires in natural landscapes. Based on decades of fire behavior research (Albini 1976; Albini 1983; Anderson 1982; Rothermel 1972; Rothermel 1983; Van Wagner 1977), the FARSITE Fire Behavior and Spread model (Finney 1998) is one of the most widely used and extensively proven in the field. FlamMap (Finney et al 2004) models potential fire behavior on an entire landscape without the temporal component integral to the FARSITE model. FlamMap has been used to model the effectiveness of fuels treatments. (Stratton 2004). FlamMap output represents a reproducible gradient of fire behavior across a landscape, based on fuels, terrain, weather, and wind inputs.

Scholars and practitioners concerned with ecological questions have developed an interest in determining the changes in catastrophic fire risk in natural systems as related to fire suppression and anthropogenic disturbance. Coarse-scale national level spatial data on degree and nature of departure from historic vegetation conditions have been generated by the United States Department of Agriculture (Hann and Strohm 2002). A variety of finer scale spatial data are being developed by the LANDFIRE project using remote sensing and gradient modeling, but this data is available in limited areas and may not be sufficient in detail to address many local vegetation community management issues. In addition, detailed maps concerning historic vegetation distribution are not currently being generated by LANDFIRE, leaving a need for finer-scale spatial historic vegetation data for use in planning restoration.

Ecologists have long recognized that gradients in topography, latitude, climate, and elevation have a direct influence on the distribution of vegetation communities (Whittaker 1956). Fire interacts with local factors like soils, topography, and climate to create microhabitats with unique vegetative composition (De Steven and Toner 2004; Franklin et al 1997; Menges and Hawkes 1998). Fire suppression alters the interrelationships between plant species and disturbance regime (Platt et al 1991). Modeling of forest landscape dynamics has shown that interactions between plant species, disturbance, and environment have resulted in the re-emergence of pre-settlement landscape patterns (He and Mladenoff 1999).

The spatial distribution of fire effects has been found to influence the re-establishment of plant species in stand-replacing fires in lodgepole pine (*Pinus contorta*) in the West (Turner et al 2003). We suggest that there are also gradients in fire behavior in low-intensity fires, influenced by local environmental factors, which determine the distribution of plant communities on a frequent-fire landscape. These gradients may be predictable and correspond with fire behavior outputs provided by a spatial fire behavior model. We used FlamMap to model the location of historic fire-sheltered communities. The results of this modeling exercise were field checked against remnant presettlement vegetation communities on the landscape. Our purpose was to determine if the spatial location of low fire behavior outputs from the

FlamMap model correlated with the physical location of actual remnant fire-sheltered communities on the landscape.

Analysis Area:

Fort Bragg National Military Reserve is located in the Sandhills region on the Coastal Plain of North Carolina, 16 kilometers northwest of Fayetteville. The Sandhills represent a transitional area between the Coastal Plain and the Piedmont. The specific area of study is referred to as the Overhills Tract: 4,250 hectares located at the northern boundary of Fort Bragg in Harnett and Cumberland counties. Elevations on the tract range from 43-119 meters above sea level, representing moderate terrain relief. Overhills is historically part of a large “fire compartment”, defined by Frost (1998) as an area of continuous vegetation without natural barriers that disrupt the flow of fire across the landscape.

Presettlement vegetation in this region was affected by climate, location on the landscape, soils, and fire. Fire was a primary factor shaping the vegetative structure and composition of historic longleaf pine (*Pinus palustris*) forest. Many early travelers in the area reported settlers and Native Americans setting fire to the woods (Schaw 1776). They also reported extensive open stands of large timber with a species diverse, easily traversable understory (Lawson 1714). Since that time, fire’s positive effects on the maintenance of open longleaf pine forests and their associated understory vegetation has been well documented (Andrews 1917; Heyward 1939; Myers 1985; Rebertus et al 1989).

Though the majority of the presettlement landscape was open pine savanna with an understory of wiregrass (*Aristida stricta*), herbaceous plants, and oaks, remnant vegetation and representative landscapes in other areas show that there was definable variation in community type. Pockets of vegetation composed of larger oaks and sparse understory existed in fire-sheltered portions of the uplands. We assume these areas consistently experienced less severe fire behavior because of topographic position and sheltering from gradient winds. These areas represent the lowest fire behavior ranges on the landscape that we proposed to locate with fire behavior outputs from the FlamMap fire model.

Beginning in the mid-18th century, the Fort Bragg area was settled by European immigrants. Land grants were most commonly divided into 20-80 hectare parcels that were cleared and farmed for family subsistence. In the 19th century, the Overhills tract was at the heart of a large turpentine plantation. By 1910, the majority of virgin timber had been harvested with few of the original trees remaining. The Rockefeller family acquired the property in 1917 and maintained it as a hunting resort and, later, in farmland, until the 1970s. The Army purchased the Overhills tract from the Rockefellers in 1997. Currently the tract is undergoing an environmental assessment to determine future plans for the area and resulting impacts to natural and cultural resources. (Fort Bragg Cultural Resources web page. *Highlights in Fort Bragg History: Overhills*. http://www.bragg.army.mil/culturalresources/overhills.htm. 2005.)

Though areas of the Overhills tract were developed or continue to be maintained in agricultural fields, a large portion of the tract has been maintained in second-growth native forest. Despite human disruptions to the landscape, native plant species continued to persist and many undisturbed or second growth indicator species are visible today. Much of this area is longleaf pine savanna, impacted by logging and fire exclusion. Over the past 80 years, only occasional fires, on a 5-20 year fire return interval, have produced an understory of dense blackjack (*Quercus marilandica*) and turkey oak (*Quercus laevis*) with intermittent wiregrass. Fire managers at Fort Bragg have begun dormant-season burns to reduce fuel loadings in preparation for growing season burns that will reduce oak and increase the abundance of wiregrass and other understory species (John Ward, Fort Bragg Fire Management Officer, pers. comm. 2005). Many of the presettlement species are still present, though vegetation communities are in varied levels of departure from their nineteenth century conditions.

Methods

Overview:

The distribution of presettlement vegetation communities on the Fort Bragg landscape was influenced by soils, position on the landscape (aspect and slope), hydrology, and exposure to fire. Fire-sheltered vegetation communities located in depressions and wind-sheltered areas on the landscape were found with the FlamMap fire behavior model. Historic weather data were collected from local remote automated weather stations (RAWS) and analyzed with Fire Family Plus and other statistical sorting methods. Accurate terrain data were provided from aerially collected Light Detection and Ranging (LIDAR) data. A sensitivity analysis was performed in FlamMap to determine the reaction of the model to changes in individual inputs.

Defining Presettlement Community Types:

Cecil Frost, a botanist specializing in North Carolina vegetation and fire dependent species defined seven presettlement vegetation community types for Fort Bragg (Frost 2005 in prep.). These communities are similar to those described in the Classification of the Natural Communities of North Carolina (Schafale and Weakley 1990). They were derived from existing historic conditions maintained elsewhere in the Southeast, determined by observing remnant vegetation at Fort Bragg, and consider the effects of frequent fire on a continuous landscape (Frost 1998). Historic journals and early settlement survey plats containing information on locatable indicator tree species were used to confirm the location and environmental parameters associated with individual communities across the landscape.

Table 1 presents a list of the presettlement community types broadly categorized as upland fire-exposed and upland fire-sheltered communities at Fort Bragg (Frost 2005), including a comparison to the modern communities as defined by Schafale and Weakley (1990), and a list of associated indicator species. Figure 1 illustrates two broad categories of upland communities.

Table 1: Upland fire-exposed and sheltered vegetation communities at Fort Bragg

	Fire-Exposed	**Fire-Sheltered**
Frost Community Associations	- Xeric and Dry-mesic Longleaf Pine/Wiregrass Savanna - Mesic Longleaf Pine/Wiregrass Savanna	- Oak Savanna and Woodland - Pyrophytic Oak-Hickory Woodland with Pines
Schafale and Weakley Associations	- *Xeric Sandhill Scrub* - *Pine-Scrub Oak Sandhill*	- *Pine-Scrub Oak Sandhill* - *Blackjack-Mixed Oak Variant* - *Mixed Mesic Hardwood Forest*
Indicator Plant Species	longleaf pine, wiregrass, turkey oak	blackjack oak with post oak, mockernut hickory, southern red oak

Generating Vegetation Communities on Fire-Sheltered Uplands:

Fire-sheltered communities on upland soils were located with FlamMap. Fireline intensity outputs in Kilowatts per meter (kW/m) were generated from landscape, weather, and fuels conditioning inputs and exported to ArcMap (ESRI ArcGIS v. 8.3). Determinants of fire intensity include fuel size class, arrangement, and loading, fuel moisture, local climate, and topography (Albini 1976. Anderson 1982). The lowest fire behavior outputs were assumed to represent fire-sheltered areas on the landscape where remnant fire-sheltered hardwood-dominated vegetation communities were found.

Figure 1: Broadly categorized communities of upland sites. A, B: Fire-exposed longleaf pine savannas. C, D: Fire-sheltered hardwood-dominated vegetation communities

Fire Behavior Model Inputs:

FARSITE and FlamMap require spatial data in the form of a landscape file including aspect, slope, elevation, fuel model and canopy cover grid files, wind and weather inputs, and temporal inputs. FARSITE models fire behavior and spread spatially and temporally given heterogeneous terrain, weather, wind, and fuels conditions across a landscape (Finney 1998). FlamMap models fire behavior as if each raster cell on the landscape were ignited simultaneously. Time is only significant in FlamMap when using a fuels conditioning period. Fuels conditioning across the landscape renders variation in dead fuel moisture in response to changing weather conditions and topography, as occurs on the real landscape (Finney et al 2004). The FlamMap model generates fire behavior outputs from conditions found at the end of the fuels conditioning period.

Landscape:

A countywide elevation grid file at 6-meter resolution was obtained from the North Carolina Department of Transportation (http://www.ncdot.org/planning/tpb/gis/DatatDist/GIS ContourMaps.html**).** This grid was generated from Light Detection and Ranging (LIDAR) data originally generated by the North Carolina Flood Mapping Program (www.ncfloodmaps.com). “Bare earth” LIDAR data were chosen over a digital elevation model (DEM) cartographically digitized from 1:24000 quadrangle maps, because we considered these a more accurate representation of the actual terrain.

The countywide LIDAR elevation grid was clipped to the extent of the tract of interest. Slope and aspect grids were then derived from the clipped LIDAR elevation grid using ArcGIS Spatial Analyst tool. This provided three of the five elements required to generate a FARSITE landscape.

Fuel Models:

Fire Behavior Prediction System (FBPS) [formerly National Forest Fire Laboratory (NFFL)] fuel models were designed by Rothermel (1972) and Albini (1976) to describe the properties of vegetation on the ground for use in predicting surface fire behavior. Each fuel model is described by fuel load, the ratio of surface area to volume of the various size classes of fuel, the depth of the available vegetation, and fuel moisture, including the moisture of extinction of the fuel (Anderson 1982). There are 13 models in 4 categories: Grass, shrub, timber and slash. Fuel model 2, a grass model, which represents surface fire spread through fine dead and herbaceous fuels with an open timber overstory, best describes the majority of presettlement vegetation at Fort Bragg.

Fuel Model 2 Loading: *1 hour: 4.5 tons (metric)/hectare*
10 hour: 2.25 tons (metric)/hectare
100 hour 1.13 tons (metric)/hectare
Live: 1.13 tons (metric)/hectare
Fuel bed depth: 0.3048 meters
Moisture of extinction of dead fuels: 15%

In order to keep the fire model inputs as uniform as possible, fuel model 2 with a 50% canopy cover was held constant across the landscape. The elevation grid was reclassified in ArcGIS Spatial Analyst to provide a uniform fuel model grid

(2) and a uniform canopy cover grid (50%). This simple process provided the final two grid files required to generate a FARSITE landscape. The five grids (elevation, slope, aspect, fuels, and canopy cover) were combined in FARSITE and a landscape file was generated.

Weather:

Basic Data sources:

Daily historic weather observations were gathered from the National Wildfire Coordinating Group's Fire and Aviation Management Web Applications (FAMWEB) website: http://famweb.nwcg.gov/weatherfirecd/

RAWS station data were available from:

- Ft Bragg (1968-1988, 2000-2004)
- Uwharrie National Forest: Troy (1968-1970, 1975-1998, 2000-2004)
- Rockingham (1986, 2000-2004)

Hourly data were found in the Western Regional Climate Institute: Desert Research Institute RAWS archives. http://www.wrcc.dri.edu/wraws/ncF.html Hourly data were available from 2000 to the present (2005) for the Fort Bragg RAWS station.

Seasonality:

An examination of the entire historic RAWS dataset found that March and April were the driest weather months. This was confirmed verbally (John Ward, Fort Bragg Fire Management Officer, pers. comm. 2005) and by Uwharrie National

Forest (located 56 kilometers west of Fort Bragg) fire records (1970-2004) (NWCG FAMWEB) showing most acres burned during the months of March and April.

The Uwharrie fire records correlate well with research done by Barden and Woods (1973) showing historic fire occurrence in the Appalachian Mountains of North Carolina to have occurred in March, April, and May. Because it is at a lower elevation and representing a warmer climate, fire season on the Coastal Plain of North Carolina would have occurred about a month in advance of the fire season in the mountains.

Ignition Sources:

Historically, both cultural and natural ignitions were probably common. The Uwharrie fire report database (FAMWEB) contains records from 1972 to the present, which represent ignitions on a fragmented and generally more mesic landscape than what was described in presettlement times (Lawson 1714, Brickell 1737, Schaw 1776). No lightning caused fires were recorded in the Uwharrie database, though lightning fires likely occurred on the Coastal Plain in the historic landscape. It is probable that lightning strikes would have resulted in some quantity of acres burned on a continuous, more xeric presettlement landscape. Historic savanna fuels such as wiregrass would have been available to burn within a day or two of wetting rain (Margit Bucher, Assistant Director of Science & Stewardship, NC Chapter, TNC, *pers. comm*. 2005). Weather records show that these windows existed throughout the year. Any ignition in March and April would certainly have resulted in large acreage burned, while even during the wet season in July and August windows of dry weather would have occurred where many frequent lightning strikes may have resulted in some acres burned. It is feasible that, if xeric forest and open grass savanna existed, lightning fire acreage might have been much more significant than is commonly assumed.

Wind:

A wind rose was generated via the Desert Research Institute website (http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?ncNFBR), using daytime March and April hourly wind observations from all available years (Figure 2). The most common wind direction, regardless of season, was from the southwest, with winds averaging 16 kilometers per hour at the 6-meter level. It is assumed that the predominant wind direction has remained constant since before the presettlement period. Wind speeds were doubled in the model inputs to account for an exaggerated wind reduction factor that consistently resulted in the under-prediction of fire spread and behavior (Pat Stephen, Fire Behavior Technical Specialist, US National Park Service, pers. comm. 2005).

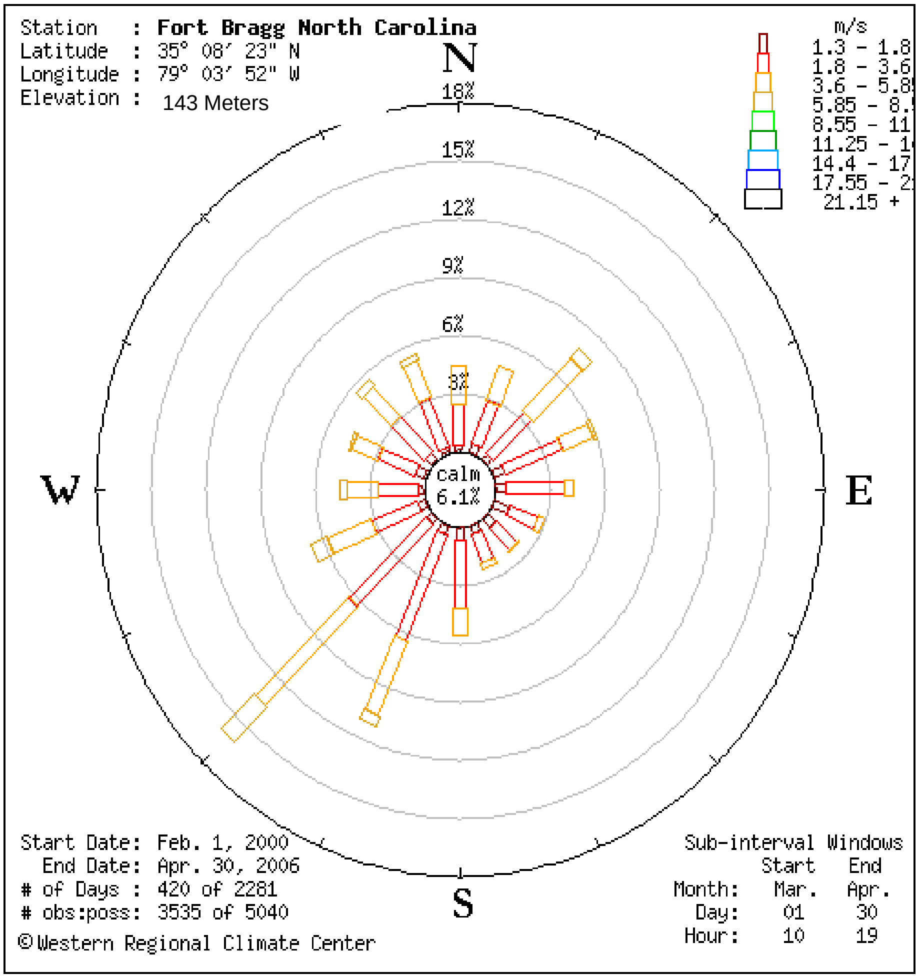

Figure 2: Wind rose for daytime March-April winds from 2000-2006 data generated at Desert Research Institute national remote automated weather station (RAWS) archives (http://www.wrcc.dri.edu/wraws)

FlamMap Weather Inputs:

Local RAWS data were loaded into Fire Family Plus.

A Special Interest Group (SIG) was created with Fort Bragg given the highest weight of 2.0 and Rockingham and Troy both rated at 0.25. This should enable missing data in the Fort Bragg set to be backed up by the other stations, while retaining the integrity of the “representative” Fort Bragg RAWS weather dataset for the analysis area.

Fuel Moisture:

To determine fuel moistures RAWS temperature and relative humidity data were analyzed with the low critical percentile set at 90. All weather data for the months of March and April were considered. Resulting values of 1, 10, 100, live woody, and live herbaceous fuel moistures were loaded into the fuel moisture file in FARSITE. These values were meant to equate to a representative “fire day”.

One hour	**Ten hour**	**One Hundred Hour**	**Live Herbaceous**	**Live Woody**
5	7	13	30	70

Fuel Moisture Conditioning Files:

Daily 1300 weather observations, from FAMWEB RAWS files, were averaged to determine daily high and low temperatures and humidities (Table 2). Maximum of high temperature, minimum of low temperature, and low relative humidity and high relative humidity columns were averaged for all data from the Ft Bragg RAWS station (1968-88 and 2000-04). Representative times of low temperature/high relative humidity and high temperature/low relative humidity were simply estimated from the DRI hourly RAWS dataset. It was assumed that no precipitation occurred during the conditioning period.

Table 2: Historic daily weather observations for FlamMap fuel moisture conditioning period

Month	Day	Rain amt.	AM low	PM high	Temp. low (°C)	Temp. high (°C)	R.H. high (%)	R.H. low (%)	Elevation (meters)
3	25	0	600	1500	-0.6	25.5	52	22	152
3	26	0	600	1500	-1.1	27.8	52	23	152
3	27	0	500	1400	-2.2	27.8	50	22	152
3	28	0	500	1400	-1.1	27.8	48	24	152
3	29	0	500	1400	1.7	28.9	54	24	152
3	30	0	400	1300	4.4	30	53	27	152
3	31	0	400	1300	3.3	29.4	55	27	152

Other hourly data were organized in Microsoft Excel®. A mode of each hourly wind direction and windspeed, cloud cover, was taken from available Fort Bragg RAWS data (2000-2005) to create the wind and weather fuels conditioning files for the dates March 25-31

An inverse relationship was assumed between recorded hourly solar radiation and cloud cover, based on observed highs and lows and their relationship to precipitation events. The following criteria were used to determine hourly cloud cover inputs:

Table 3: Converting solar radiation recorded by RAWS station to percent cloud cover for use in FlamMap fuels conditioning

Solar Radiation	Cloud Cover %
0-5	100
6-20	80
31-37	60
38-53	40
54-69	20
>70	0

Completing Fire-Sheltered Upland Vegetation Layers:

A FlamMap run was completed with the above parameters. The “fireline intensity” output was exported in ASCII format and converted to a grid in ArcMap. The grid was projected and converted to a shapefile. The shapefile was classified according to the fireline intensity output value histogram. The lowest portion of the histogram was selected manually and exported into a separate shapefile.

Ground Truthing Data:

The resulting low fire intensity polygons were then placed on a map of the area and visited randomly in the field. The distribution of sites visited was spread evenly across the entire landscape. A set of parameters was developed to decide if a mapped site actually correlated to a historic fire-sheltered site based on remnant vegetation on the current landscape. Indicator canopy and sub-canopy species for historic fire-sheltered hardwood-dominated vegetation communities included blackjack oak, post oak (*Quercus stellata*), mockernut hickory (*Carya tomentosa)*, and the occasional southern red oak (*Quercus falcata*). The historic herbaceous layer contained a diverse mixture of mesophytic grasses and forbs, though this was seldom found on sites visited on the current landscape.

Five categories were chosen to describe the conditions found at each site visited (Table 4). Sites were scored according to these conditional categories and further delineated into positive, negative, and undeterminable fields. From these categories, simple statistics were developed to assess the success of the model in locating historic fire-sheltered communities.

Table 4: The five categories used to evaluate the accuracy of FlamMap fire-sheltered community placement as checked against remnants on the landscape. A scoring system is associated with the category description to determine sites that likely harbored fire-sheltered hardwood-dominated vegetation communities

Category	**Description**	**Scoring**
A	No fire-sheltered community remnants found.	Incorrect
B	Presettlement or disturbed natural canopy, subcanopy and herbaceous layer are present.	Correct
C	Canopy, subcanopy, presettlement species are intact. Herbaceous layer is missing.	Correct
D	Canopy, subcanopy are disturbed, but distinguishable presettlement remnants are visible.	Correct
E	Site is so disturbed that a determination of presettlement species is impossible (e.g., pastures, highly herbicided timberland, sandpits, or dumps.)	No Score

FlamMap Sensitivity Analysis:

An analysis was performed to test the sensitivity of the fire model to changes in individual inputs. Significant inputs were determined by referencing the fuel model 2 composition in Anderson's guide (1982) and by discussion of the model with fire modeling professionals. Inputs tested include one-hour, ten-hour, one hundred-hour, and live herbaceous fuel moistures, wind speed, and wind direction. Varying starting and ending times tested the conditioning period parameters. Cloud cover was also tested because it is considered to be a significant factor influencing model output (Pat Stephen, Fire Behavior Technical Specialist, US National Park Service, pers. comm. 2005). A baseline run was made, using the inputs generated from the historic weather data sorting process as described previously. A single parameter at a time was changed in 20 subsequent model runs (including a single run with all of the standard inputs) with high and low inputs substituted as indicated in Table 5.

Table 5: Weather inputs used for FlamMap sensitivity analysis

Inputs	***Standard Input***	***High Input***	***Low Input***
1 hr FM (%)	5	9	3
10 hr FM (%)	7	11	5
100 hr FM (%)	13	17	9
LH FM (%)	30	90	50
Wind Spd (km/h)	16(32)	48(97)	3(6)
Wind Dir (° from N)	225	45	135
Conditioning period			
Time Start	1200	100	2000
Time End	1300	100	2000
Cloud Cov (%)		100	0

Table 6 represents the results of the sensitivity analysis. Outputs were compared for flame length in meters (FL), fireline intensity in kW/m (FLI), and one-hour fuel moistures, across the landscape after conditioning period, in percent (1 hr FM).

Table 6: FlamMap sensitivity analysis outputs and results. Highlighted areas specify runs exported for spatial low fire behavior accuracy assessment.

	Standard Input			***High Input***			***Low Input***		
Outputs:	FL	FLI	1 hr FM	FL	FLI	1 hr FM	FL	FLI	1 hr FM
Inputs									
1 hr FM	0.6-1.5	***125-588***	6-7	0.6- 1.5	125-588	6-7	0.6- 1.5	125-588	6-7
10 hr FM				0.6- 1.5	125-588	6-7	0.6- 1.5	125-588	6-7
100 hr FM				0.6- 1.5	125-588	6-7	0.6- 1.5	125-588	6-7
LH FM				0.6-1.5	125-588	6-7	0.6- 1.5	125-588	6-7
Wind Spd				2.4- 2.7	***1706-2349***	6-7	0.6- 1.2	72-460	6-7
Wind Dir.				0.9- 1.5	173-713	6-7	0.6- 1.5	72-720	6-7
Cond. Period									
Time Start				0.6- 1.5	121-550	7-8	0.6- 1.5	125-588	6-7
Time End				0.6-0.9	***55-263***	12	0.6- 1.2	87-398	11
Cloud Cov				0.6- 1.2	111-505	9	0.6- 1.5	131-640	5-6

Three of the output files, representing high, low, and standard fireline intensity ranges, were exported in ASCII format and converted to polygon shapefiles in ArcGIS. The outputs were then classified using the same method employed in locating the “low fire behavior” polygons for the fire-sheltered hardwood-dominated vegetation communities on the landscape (as described previously). These three sensitivity analysis output layers were then compared to verify the presence or absence of statistical difference between the locations of the “low fire” polygon outputs for the various ranges of fire behavior. Points were assigned to the center of the 500 largest polygons on the standard output. The high and low fire behavior outputs were then individually compared to this layer. Correct points were those with positive polygon identification at the assigned random point, or those with polygons of similar pattern or extent within 15 meters of the test layer. The comparison of standard output fireline intensities to the highest output of fireline intensities resulted in 490/500 or 98% agreement between layers. The comparison of standard output fireline intensities to the lowest output of fireline intensities resulted in 496/500 or 99.2% agreement between layers.

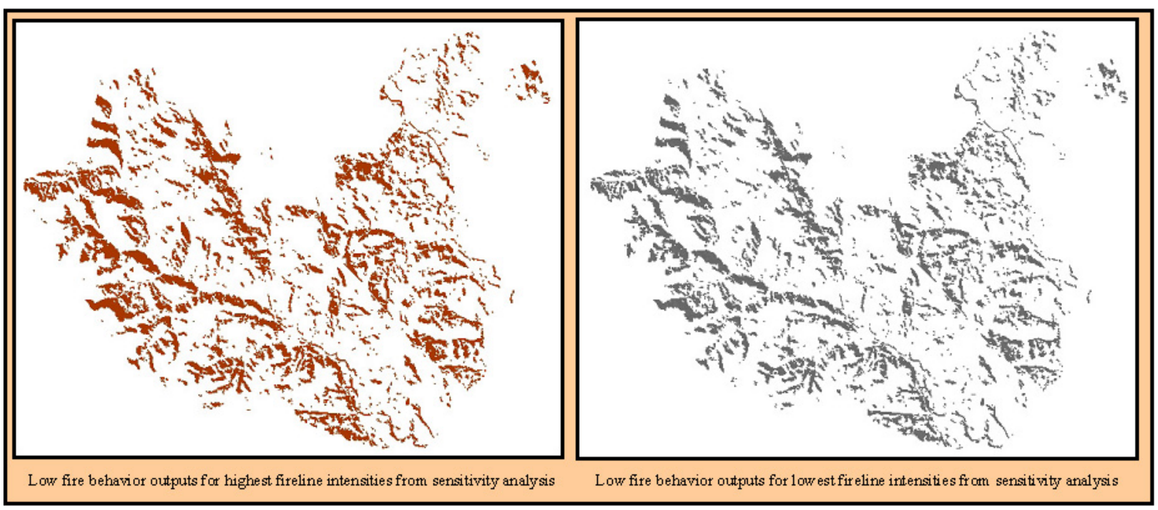

Figure 3: Lowest fire behavior polygon for high and low fireline intensities show a similar spatial pattern on the landscape

Results

Seventy-eight sites were visited and scored according to presence or absence of remnant indicator species associated with fire-sheltered hardwood-dominated vegetation communities (Table 7). Of the 78 sites surveyed, 11 no longer had distinguishable remnant vegetation. The most common cause for this was planting of slash pine (*Pinus elliottii*) followed by herbicide treatments that greatly reduced the pattern of native vegetation. Other causes for a "no score" or indeterminable area were mowed pastures, gravel pits, and dump sites. Deleting these 11 sites left 67 to be counted.

Table 7: Results from individual community condition categories used in ground truthing process

Category Codes as described in Table 3	**Number of sites found**	**% total sites surveyed**
A: No fire-sheltered vegetation indicator species found	6	8%
B: All presettlement vegetation layers present	1	1%
C: Canopy and subcanopy intact, but no herbaceous layer	41	53%
D: Canopy and subcanopy are disturbed but distinguishable	19	24%
E: Site is so disturbed that no remnant vegetation is present.	11	14%
Total	78	100%

Six sites were incorrectly identified as supporting fire-sheltered vegetation communities by the fire model. The most common factor in determining incorrect sites was their location very high on the landscape, surrounded by the most xeric of sites. In all probability, these sites may have been slightly fire-sheltered, but not enough to support fire-sheltered hardwood-dominated vegetation communities, given the extreme conditions of their surroundings.

The rarest of the 61 positive scoring sites were those identified as having all layers of the presettlement community intact. Only a single site visited contained an intact herbaceous layer. The herbaceous layer, principally comprised of wiregrass, has been the last to recover from the absence of frequent-fire.

The most common of positive scoring sites was the next category, which has both canopy and sub-canopy intact, but is largely missing the herbaceous layer. Forty-one of the 61 sites counted as positive fell under this condition category. These areas were relatively explicit in their probability of having been historic fire-sheltered hardwood-dominated communities on the historic landscape.

Eighteen sites were rated with only overstory remnant species intact, but were still determinable as positive sites with remnant fire-sheltered hardwood-dominated community species.

Thus, with 61 sites out of 67 correctly identified, a 91 percent success ratio was achieved by using this technique to predict locations of fire-sheltered communities on the Overhills Tract (Table 8).

Table 8: Results from final search for fire-sheltered communities on the landscape at Fort Bragg's Overhills tract

Total Sites Surveyed	78	
Total Sites Counted	67	
Total Correct	61	
Total Incorrect	6	
Ratio Total Correct/Total Counted	61/67	91%
Ratio Total Incorrect/Total Counted	6/67	9%

Discussion

The focus of this study was to find historic fire-sheltered communities on the landscape by interpreting FlamMap fireline intensity outputs. The study found the fire model to be very useful in locating the fire-sheltered hardwood-dominated vegetation communities on upland sites. Correctly identified fire-sheltered communities comprised 91% of the sites where the presence or absence of presettlement vegetation was determinable. Incorrect labeling of sites was most commonly the result of soil mapping errors or sites located near the highest elevations on the landscape where conditions were too xeric for the persistence of fire-sheltered communities. The success in finding a single community related to a specified range of fire behavior outputs suggests that the potential exists to expand the utility of spatial fire behavior models to make inferences about vegetative distribution on the landscape.

The model works because it considers the environmental gradients known to affect vegetation distribution as well as the effects of wind and weather. These environmental gradients affecting vegetation in the longleaf pine-dominated Sandhills region may be amplified by frequent fire. In our study, we removed variation in fuel models to create a static vegetation layer that serves to isolate the effects of terrain and direction of fire spread (as affected by prevailing wind) on the fire behavior outputs. Though no fire burns across the landscape in exactly the same manner as previous fires, landscapes experiencing a very frequent fire return interval, especially in evenly distributed surface fuels like those dominated by grasses, have a tendency toward more consistent fire behavior and relatively uniform fire effects from one fire to the next.

The FlamMap fire behavior model does not consider wind reduction on the landscape, as would be the real world effect of lee-side wind-sheltering. The model sees wind inputs on every pixel as constant. In the model, the effect of slope is combined with the constant wind on the upslope southwest aspects to create the highest fire behavior on the landscape. Lower fire behavior outputs occur on the lee aspects because the slope and wind relationship is changed as slope and wind counteract each other instead of reinforcing as on the upslope. This is an effective “wind-sheltering”, and yet it really has nothing to do with the constant wind in the model.

To isolate the effects of critical environmental inputs to the model, a comparison was made between the initial fire behavior run and a run with no slope, a run with no wind, and a run without a conditioning period. A comparison of the fireline intensity outputs on the landscape with wind versus the landscape without wind showed a slight increase in intensities in the low fire behavior areas on the control landscape with an overall great decrease in intensities in other areas. A comparison of the two fireline intensity outputs on a portion of the landscape (Figure 5) shows a range of fireline intensities. The lowest intensities are found within our study's fire-sheltered areas on the control landscape that includes the effects of wind, whereas the highest intensities are found in the same areas on the landscape without wind. Lack of wind on the landscape greatly lowers the value of possible intensities as seen in the histograms (Figure 6) where the landscape with wind generally ranges from 300- 390 kW/m and the same landscape without wind ranges from 74- 134 kW/m.

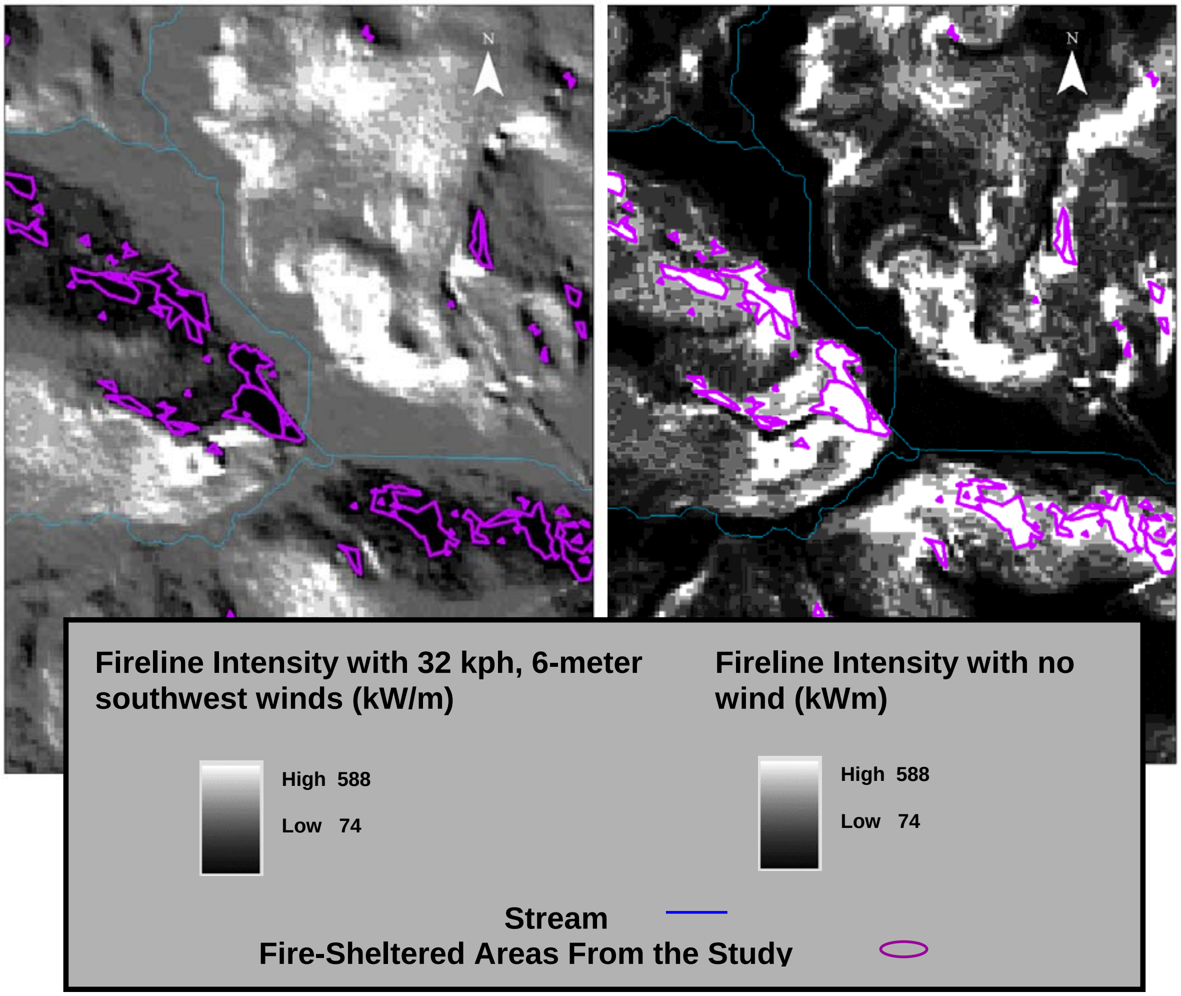

Figure 4: A portion of the study landscape that compares fireline intensities with the effects of wind (left) and without the effects of wind (right)

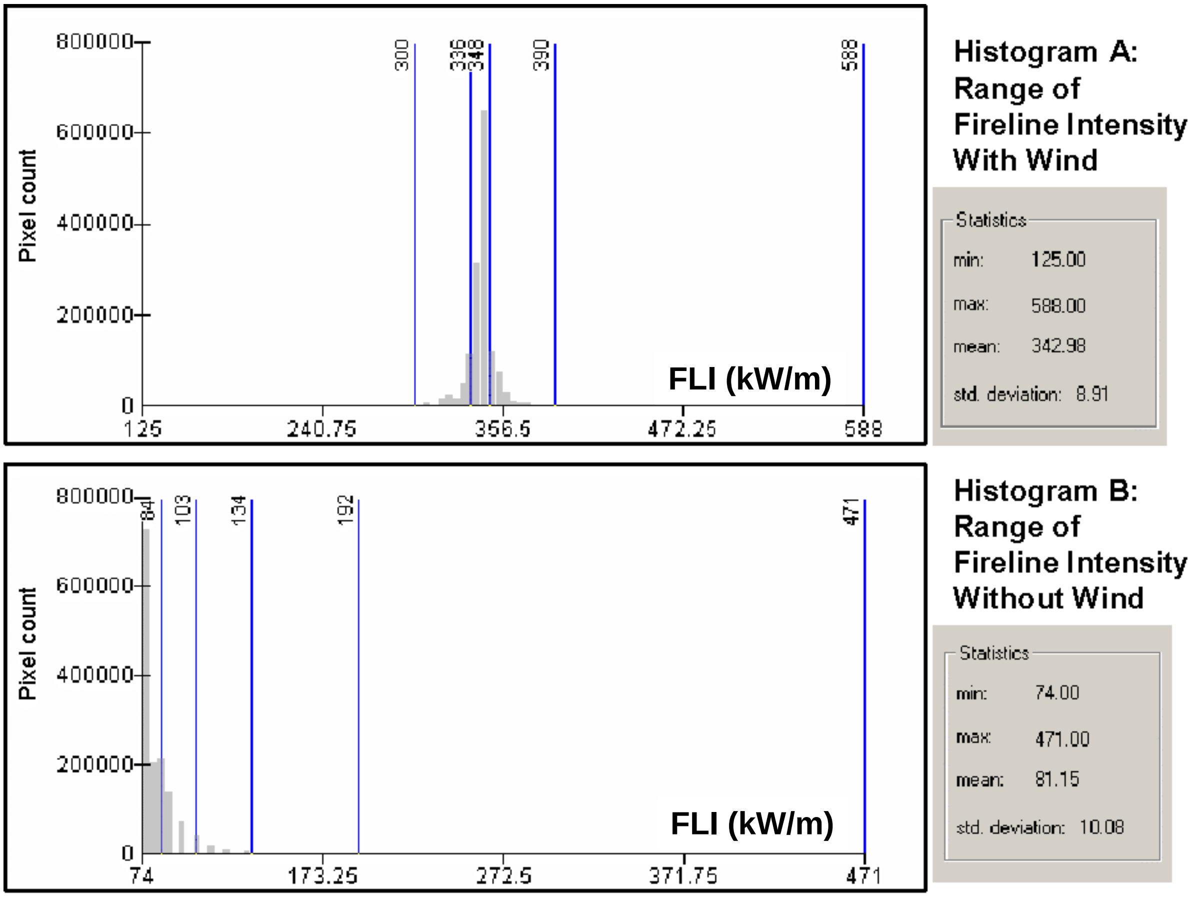

Figure 5: Ranges of fireline intensity possible with and without wind on the landscape. Histogram A shows the range of fireline intensity across the landscape on the control landscape, with the effects of wind. Histogram B shows the range of fireline intensities on the same landscape without the effects of wind. These histograms correspond to the spatial fireline intensity outputs shown on the maps in Figure 4.

Wind is an important input because its absence causes a reduced range of possible fireline intensities on any landscape. Figure 7 (Andrews et al 2004) shows the declining effects of wind speed on the range of fireline intensity outputs, along the down-slope spectrum of steepness. A steady mid-flame wind speed is represented by each curve; with values of no wind, 1.6 kilometer per hour, 4.6

kilometer per hour, and 8 kilometers per hour. With no winds, fireline intensity is relatively constant: this is the down-slope spread fireline intensity, solely impacted by slope steepness. With a 1.6 kilometer per hour wind, intensities double as wind contributes to the effects of slopes between 0-20%. A 4.6-kilometer per hour wind more than triples the range of possible intensities with wind, adding to fire behavior on slopes of 0-50%. An 8-kilometer per hour wind more than doubles, again, the range of possible intensities. It takes an 80% slope to negate the effects of a 8-kilometer per hour wind speed on intensity outputs. Wind greatly contributes to widening the range of fireline intensities possible with down-slope fire spread on the landscape.

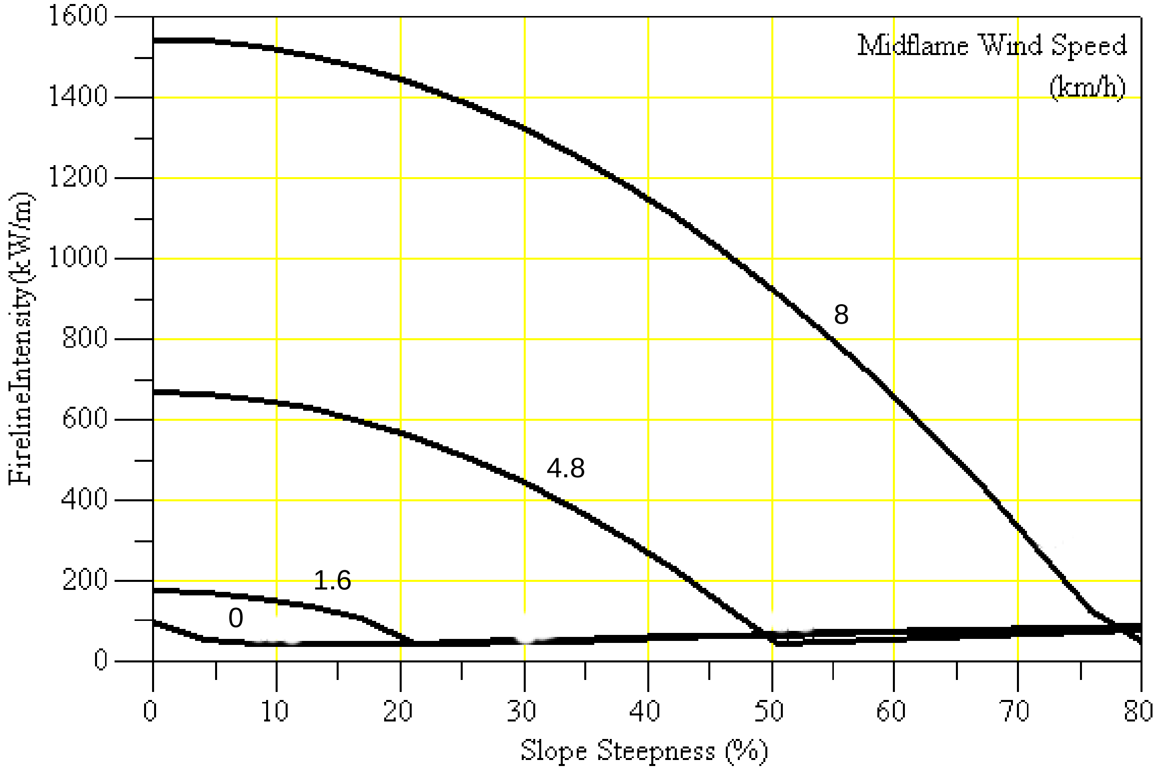

Figure 6: The effect of windspeed in increasing the potential the range of fireline intensities possible with downhill fire spread

A comparison of fireline intensities on the control landscape minus fireline intensities without the conditioning period showed fairly uniform change in the range of 63-29 kW/m increase on the landscape without conditioning. A slightly moderated range of less than 29 kW/m increase on the unconditioned landscape was seen in some of the pixels associated with our low fire behavior areas. Lack of conditioning generally elevated the range of possible fireline intensities across the landscape, but did not change the distribution pattern of intensities. There was not much change in fuel moistures across the study landscape related to conditioning period, possibly due to low terrain relief, latitude, and lack of very dry weather inputs and initial fuel moistures in our study area.

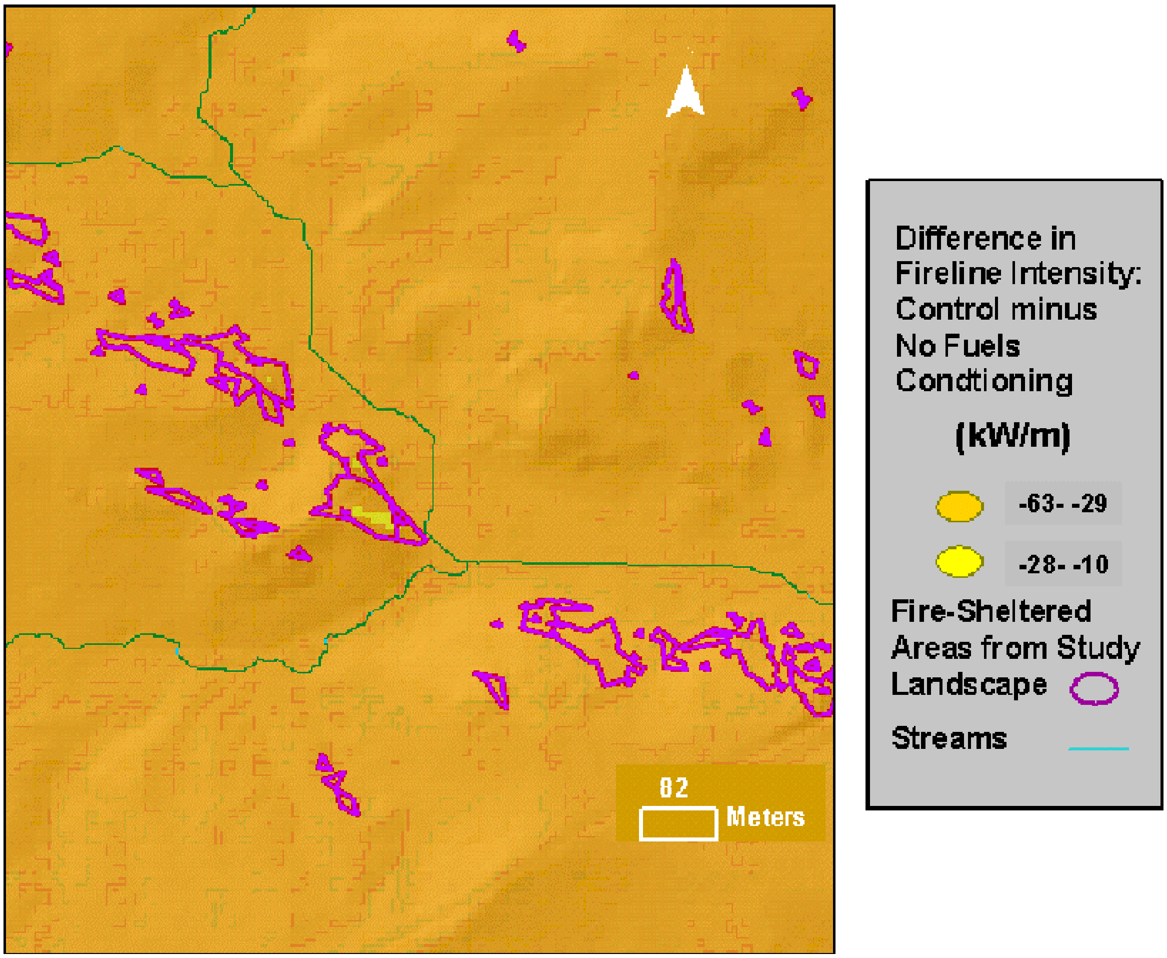

Figure 7: A portion of the study landscape showing the change in fireline intensity across the landscape when the output from a FlamMap run with no fuels conditioning period is subtracted from our initial control run with a fuels conditioning period

The comparison of the control landscape to the landscape without slope seemed to be the most significant and dramatic. No slope input resulted in a uniform fireline intensity output of 350 kW/m across the entire landscape. Both up-slope and down-slope showed fairly uniform distributions of fireline intensity changes, with the steeper slopes showing the most change. In the fire-sheltered areas, intensities were increased by lack of a slope input, with the control fireline intensity in one fire-sheltered pixel at 232 kW/m compared to the 350 kW/m possible on that pixel without slope. On very fire-exposed, steep up-slopes, intensities were significantly decreased with the control fireline intensity on a sample fire exposed pixel at 463 kW/m compared to 350 kW/m without the effect of slope. Slope appears to affect the most dramatic change on the landscape of the three factors tested, with steepest slopes showing the greatest change.

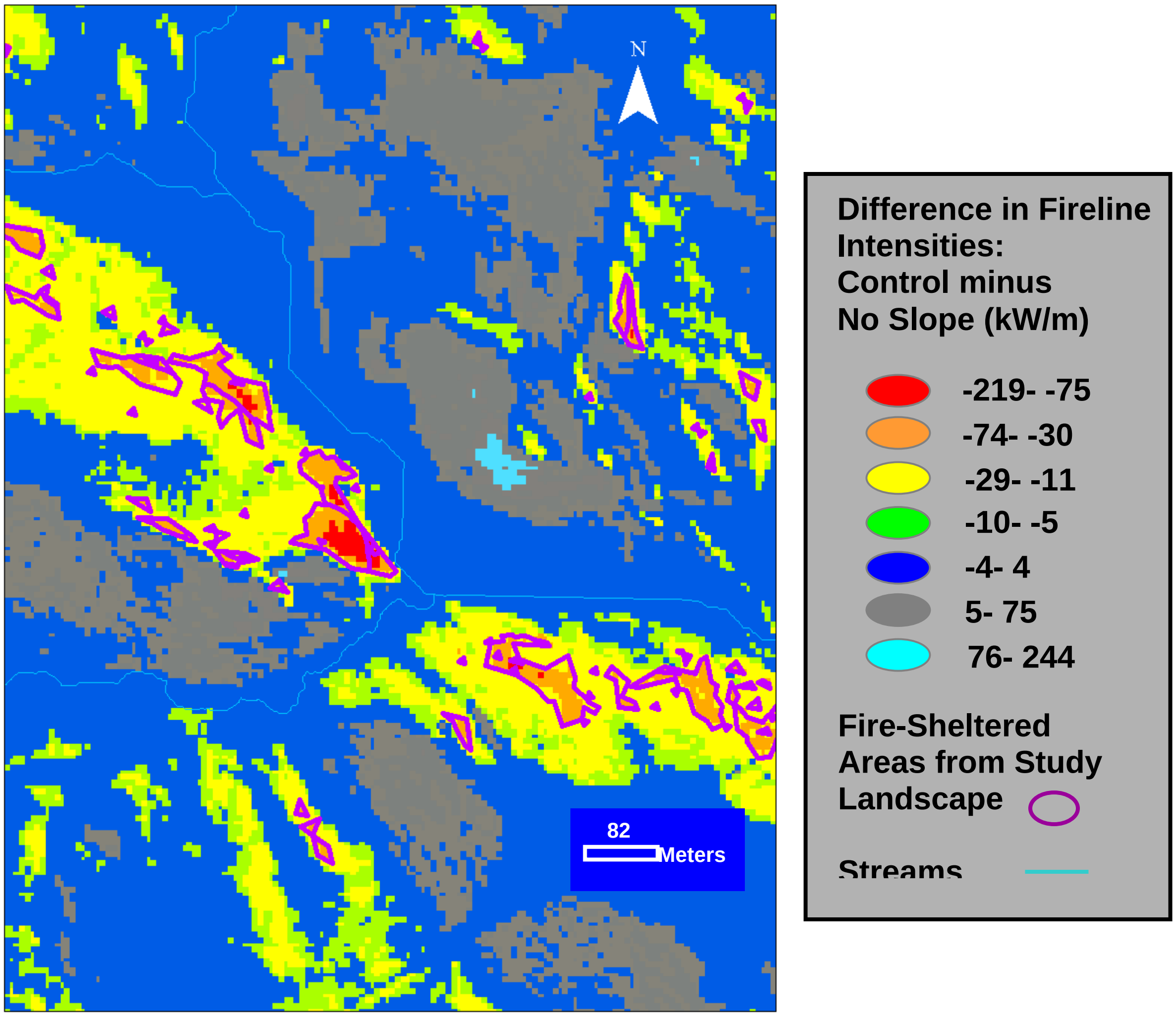

Figure 8: A portion of the study landscape showing dramatic changes in fireline intensity when the outputs generated with no slope are subtracted from the control outputs that include slope inputs

Slope affects the range of fireline intensities possible on the landscape as seen in the graph of potential fire behavior outputs in Figure 9 (Andrews et al 2004). The up-slope curve displays the effects of increase in slope steepness in increasing fireline intensities. The down-slope curve displays the effect of decline in slope in decreasing the effect of wind and overall intensities. The shaded area defines the range of fireline intensities possible across all slopes with FBPS fuel model 2, moderate fuel moistures (1hour = 5, 10hour = 7, 100hour = 13, Live Herbaceous = 30), and eight-kilometer per hour midflame wind speed.

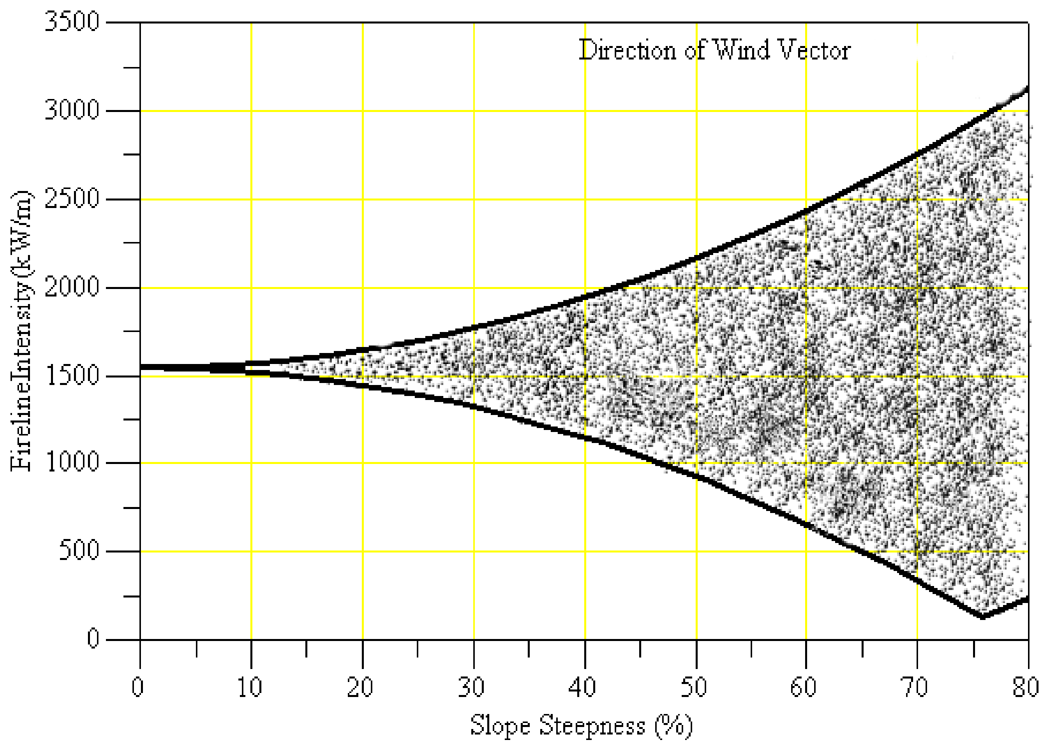

Figure 9: The effects of slope on fireline intensity outputs in the model with an 8 km/h midflame windspeed

Terrain relief is critical to the finding of fire-sheltered communities with the fire behavior model. It should be understood that this particular landscape represented very subtle terrain relief. Elevations ranged only 43-119 meters above sea level, a maximum of 76 meters between highest and lowest points, with slopes ranging from 0-47 percent. The range of the fire behavior outputs in the initial control run reflected this subtlety in terrain at about 300-390 kW/m. The absence of dramatic terrain relief and limited range of fireline intensity outputs on this landscape restricts our ability to locate more than one community type based on fire behavior outputs from the model.

The sensitivity analysis of the FlamMap model showed that, when critical inputs were changed, a difference in fireline intensities on the landscape resulted. Change in many of the inputs created no significant difference in intensity outputs; however, changes in winds and time of ignition resulted in much higher or lower intensities, fine dead fuel moistures, and flame lengths. When the lowest portions of these fire behavior outputs were placed on the landscape, however, they resulted in no significant difference pertaining to the spatial location of the lowest fire behavior areas (Figure 4). Fire-sheltering is constant across the landscape, regardless of changes in fire intensities, given a uniform fuel bed, measurable slopes, and an identifiable prevailing wind direction that determines the direction of fire spread.

Though we used a uniform fuel model in the effort to locate fire-sheltered areas, this does not, in fact, imply the true nature of actual fuel model classifications pertaining to presettlement vegetation communities. For fire behavior and spread modeling purposes, the majority of the longleaf-dominated xeric and mesic upland communities are characterized by FBPS fuel model 2. However, hardwood-dominated vegetation communities would have demonstrated lower fire intensities than those of the open, continuous grass-dominated savannas. These fire-sheltered hardwood-dominated vegetation communities are better represented by FBPS fuel model 9 (hardwood leaf litter).

Both grass fuel model 2 (FM 2) and timber litter fuel model 9 (FM 9) are primarily characterized by fine fuel (<6 millimeters diameter) driven surface fires. Though there are differences in size class distribution and loading of surface fuels, including the presence of a live fuel component only in FM 2, the critical difference between the models is the surface fuel bed depth (FM 9 at .2 ft. and FM 2 at 1ft) (Albini 1972). Physical arrangement contributes to the responsiveness of fine fuels to environmental change, thus affecting potential fire intensities. Grass is usually vertically arranged with a greater surface area to volume ratio as compared to hardwood leaf litter. The slightly lower fuel loads and physical arrangement of fine fuels produce over-all lower fire intensities on hardwood sites. It may be that hardwood-dominated vegetation communities on the historic Fort Bragg landscape both existed because of and contributed to the character of their cooler, moister fire-sheltered sites. The association of sheltered locations (because of slope, aspect, and orientation away from prevailing winds and fire spread) and physical characteristics of the vegetation discouraging higher fire intensities may have combined to encourage to the persistence of these communities on this landscape.

Conclusion

The success of this study in finding historic fire-sheltered hardwood-dominated vegetation communities on the Overhills landscape implies some potential for using fire behavior models in creating maps of vegetation distribution on similarly fire-affected landscapes. Our study was limited to the reliable spatial location of only a single fire-sheltered community type across the landscape. Factors contributing to this limitation may include lack of dramatic terrain variability and FlamMap's inability to consider the effects of the surrounding landscape on any single point when generating fire behavior outputs. Further studies of the utility of spatial fire behavior and spread models for making ecological inferences pertinent to the restoration of historic frequent-fire ecosystems could be designed for other landscapes and fire-affected systems. The partnership of fire behavior and spread modeling and ecology may benefit both immediate restoration needs and contribute to our overall understanding of the effects of fire behavior on vegetation distribution in historic fire-dependent ecosystems.

Epilogue

This analysis process was relatively simple to develop. The greatest investment was in time and the high cost of GIS software. Expertise in plant identification and local vegetation communities, the effects of fire, presettlement vegetation, GIS, fire modeling and climatology were all inherent to the success of the process. Since all of these skills are rarely found in a single person, the combined skill-sets of several people were required. Also required were the universally beneficial skills of organization, communication, persistence and creativity.

It is often difficult to find experts in the field with time to accomplish all of the fieldwork and consultation needed to complete a project such as this. It may be that invested expert hours could be reduced by training field crews to search for indicator species, enabling them to complete the bulk of the ground-truthing. This training session could be completed within a few days to a week, and greatly relieve the pressure on expert time commitment. At minimum, a consultation relationship should be maintained for the duration of the project with a botanist or ecologist familiar with local plant species, historic landscapes, and fire regimes. It may be necessary to call upon several experts to provide the skills needed for the project.

Basic operations with FARSITE or FlamMap software can be learned within a day to a week, depending on prior computer and GIS skills. Experience with fire and fuel models is valuable in determining logical inputs and understanding the effects of inputs. Knowledge of fire behavior is a plus, especially when working with fuel models and can make determining the accuracy of outputs more intuitive and less time-consuming. Again, an expert in the field of fire behavior should be retained for advice and to check data input, output, and assumptions.

Terrain relief was critical to the fire model's ability to generate variations in fire behavior outputs. Attempting to use the fire model to determine a mosaic of vegetation community distributions on flat terrain will not work. Topography is a critical input to FlamMap that contributes to calculating separate fuel moistures for each grid cell on the landscape during the fuels conditioning period. The variation in fuel moisture inputs determines variation in fire behavior outputs. The interaction between slope and fire spread direction (wind) is even more critical in affecting the range of potential fire behavior. This may not be far from the reality of how terrain affects vegetation in the real world, especially one regularly "swept clean" by fire.

The reliability of the model was greatly enhanced by the availability of high-quality LIDAR elevation data, which was readily obtainable online. Fire modeling and fire weather processing software were also available online, free of charge. Historic fire records from local weather stations were available by the same means, though historic date ranges and reliability of data collection are subject to variation. The RAWS program generally does not have data before the 1970s, and many sites have been installed more recently.

Local weather and wind information was amazingly accessible from many sources and easy to process, with the help of Fire Family Plus. Data about lightning distribution and frequencies (especially on a monthly or seasonal basis) were distinctly unavailable or difficult and expensive to acquire. The field may benefit from study and publication of lightning distribution information, especially in the southeastern U.S. where wildfire ignitions from lightning are seldom recorded on the modern landscape.

Fuels data is usually the most difficult of the FARSITE inputs to obtain. Actual vegetation data are often fraught with inaccuracies, laborious to produce and field-check, and prone to change over time. Since our process uses a uniform fuel model, in an attempt to isolate the effects of terrain and climate, a big step in the traditional fire modeling process is eliminated. This process employs a reversed concept for running the model: Instead of fuels determining fire behavior, fire behavior determines fuels. This assumes that terrain and weather are the primary determinants of vegetation (or fuels) across the landscape.

Of course, a fairly representative fuel model should be chosen. For example, modeling gradients in fire behavior outputs for stand-replacing lodgepole pine forests would not be appropriate with the use of a grass fuel model. Nor may it be appropriate to assume that vegetation given to stand-replacement fires, with infrequent fire return intervals, could be modeled in such a way. Catastrophic fires represent a less predictable, more variable range of vegetation distribution, representing successional stages of the same community type. It may be that fire models could be used to predict changes in vegetation for a certain period (say, after a single fire, given specific conditions) across such a landscape.

This process may be applied, as it is, to other areas in the Sandhills region to produce provisional presettlement vegetation layers for specific conservation areas. I reiterate that the accuracy of the output will be directly dependent on time spent in the field, the presence of some remnant vegetation, and the quality of input data. The process may be modified to work in other areas with fire-affected vegetation and changes in terrain. It would be interesting to test the success of the fire model outputs in locating high or low fire intensity related communities on other landscapes.

At 91% accuracy, the low fire behavior polygon outputs gave a good indication of where fire-sheltered hardwood-dominated communities (Oak Savanna and Woodland) actually existed on the landscape. Pyrophytic Oak-Hickory communities actually occurred directly below these communities on the landscape, instead of “in the most fire-sheltered of fire-sheltered sites” as they were defined in our model. Being already relatively uncommon on this landscape, these areas may simply be searched for in the field, in conjunction with the Oak Savanna and Woodland, and added to the map manually where they are found to occur.

Large landscapes may require the processing (intersects/buffers) of some information in GRID format. Detailed layers with many polygons or attributes may “lock up” the Geoprocessing Wizard, or take large spaces of time that renders the processing of shapefiles inefficient.

In conclusion, it is my hope that this process or the concepts outlined herein will be of use to those who are managing or restoring fire-affected landscapes. Efficient, cost effective planning processes are critical, considering the effort involved in managing with fire in the modern age. The sheer expanse of ground requiring restoration is overwhelming. Yet, significant motivation may be found for continuing to strive to understand and expand these areas considering our concern for native plant and animal species and the need to preserve the ecosystems in which they thrive.

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Appendices

Appendix 1: Hourly Weather Data for Use in FlamMap Fuels Conditioning.

Month	Day	Hour	Wind Spd (km/h)	Wind Dir (° from North)	Cloud Cov (%)
3	25	100	13	225	0
3	25	200	13	225	0
3	25	300	11	225	0
3	25	400	11	225	0
3	25	500	11	225	0
3	25	600	11	225	0
3	25	700	10	225	0
3	25	800	10	225	0
3	25	900	10	225	40
3	25	1000	10	225	20
3	25	1100	10	225	0
3	25	1200	10	225	0
3	25	1300	11	225	0
3	25	1400	13	225	20
3	25	1500	11	225	60
3	25	1600	13	225	60
3	25	1700	11	225	100
3	25	1800	11	180	0
3	25	1900	10	180	0
3	25	2000	11	180	0
3	25	2100	13	180	0
3	25	2200	13	180	0
3	25	2300	13	180	0
3	26	100	13	225	0
3	26	200	11	225	0
3	26	300	11	225	0
3	26	400	11	225	0
3	26	500	11	225	0
3	26	600	11	225	0
3	26	700	10	225	0
3	26	800	11	180	0
3	26	900	11	45 4	0

Month	Day	Hour	Wind Spd (km/h)	Wind Dir (° from North)	Cloud Cov (%)
3	26	1000	13	360	20
3	26	1100	11	225	0
3	26	1200	13	225	0
3	26	1300	14	225	0
3	26	1400	13	360	20
3	26	1500	13	360	40
3	26	1600	11	315	80
3	26	1700	13	225	100
3	26	1800	11	180	0
3	26	1900	10	225	0
3	26	2000	11	225	0
3	26	2100	10	225	0
3	26	2200	11	45	0
3	26	2300	13	45	0
3	27	2400	13	45	0
3	27	100	11	45	0
3	27	200	13	225	0
3	27	300	11	45	0
3	27	400	10	45	0
3	27	500	11	45	0
3	27	600	11	45	0
3	27	700	11	90	0
3	27	800	14	45	0
3	27	900	13	45	60
3	27	1000	11	45	20
3	27	1100	11	180	0
3	27	1200	11	90	0
3	27	1300	10	360	0
3	27	1400	11	90	20
3	27	1500	10	315	80
3	27	1600	8	90	80
3	27	1700	10	90	100
3	27	1800	8	225	0
3	27	1900	8	225	0

Month	Day	Hour	Wind Spd (km/h)	Wind Dir (° from North)	Cloud Cov (%)
3	27	2000	8	225	0
3	27	2100	10	90	0
3	27	2200	8	90	0
3	27	2300	10	90	0
3	28	2400	10	70	0
3	28	100	10	45	0
3	28	200	10	45	0
3	28	300	10	45	0
3	28	400	11	45	0
3	28	500	13	45	0
3	28	600	14	45	0
3	28	700	13	45	0
3	28	800	13	45	0
3	28	900	13	90	40
3	28	1000	13	90	20
3	28	1100	14	225	0
3	28	1200	14	90	0
3	28	1300	13	225	0
3	28	1400	16	225	20
3	28	1500	13	225	80
3	28	1600	11	225	80
3	28	1700	13	225	100
3	28	1800	11	135	0
3	28	1900	11	225	0
3	28	2000	11	90	0
3	28	2100	13	135	0
3	28	2200	13	135	0
3	28	2300	13	135	0
3	29	2400	13	135	0
3	29	100	11	45	0
3	29	200	11	45	0
3	29	300	11	45	0
3	29	400	11	45	0
3	29	500	10	180	0

Month	Day	Hour	Wind Spd (km/h)	Wind Dir (° from North)	Cloud Cov (%)
3	29	600	10	270	0
3	29	700	11	270	0
3	29	800	10	45	0
3	29	900	11	315	60
3	29	1000	11	315	20
3	29	1100	13	45	0
3	29	1200	13	315	0
3	29	1300	13	225	0
3	29	1400	13	225	0
3	29	1500	13	180	20
3	29	1600	11	180	80
3	29	1700	11	180	80
3	29	1800	10	180	0
3	29	1900	13	180	0
3	29	2000	11	180	0
3	29	2100	13	180	0
3	29	2200	11	225	0
3	29	2300	11	180	0
3	30	2400	11	180	0
3	30	100	11	225	0
3	30	200	10	225	0
3	30	300	10	225	0
3	30	400	10	90	0
3	30	500	10	90	0
3	30	600	11	90	0
3	30	700	10	90	0
3	30	800	10	90	0
3	30	900	8	45	80
3	30	1000	11	45	80
3	30	1100	8	45	40
3	30	1200	11	45	20
3	30	1300	13	225	80
3	30	1400	13	225	60
3	30	1500	8	45	80

Month	Day	Hour	Wind Spd (km/h)	Wind Dir (° from North)	Cloud Cov (%)
3	30	1600	8	90	80
3	30	1700	8	90	100
3	30	1800	8	90	0
3	30	1900	8	90	0
3	30	2000	8	90	0
3	30	2100	8	45	0
3	30	2200	8	225	0
3	30	2300	8	225	0
3	31	2400	8	45	0
3	31	100	10	45	0
3	31	200	10	225	0
3	31	300	8	225	0
3	31	400	10	225	0
3	31	500	8	225	0
3	31	600	6	225	0
3	31	700	6	45	0
3	31	800	6	135	0
3	31	900	5	180	80
3	31	1000	6	180	80
3	31	1100	8	225	80
3	31	1200	10	225	40
3	31	1300	11	270	100
3	31	1400	11	270	0
3	31	1500	11	225	20
3	31	1600	11	45	80
3	31	1700	11	180	100
3	31	1800	10	270	0
3	31	1900	8	270	0
3	31	2000	8	270	0
3	31	2100	6	270	0
3	31	2200	8	360	0
3	31	2300	8	135	0

Appendix 2: Key to Presettlement Vegetation and Fire Regimes of the Overhills Tract

Key to vegetation types and their biophysical settings for the occurrence of each type: The determinants include soils, slope, aspect and position on the fire landscape in terms of pathways for fire flow and the degree of fire exposure or shelter from fire.

The six NRCS soil drainage classes:

ED Excessively drained
SED Somewhat excessively drained
WD Well drained
SPD Somewhat poorly drained
PD Poorly drained
VPD Very poorly drained

Xeric and Dry-mesic Longleaf Pine/Wiregrass Savanna.

On convex uplands with excessively-drained or somewhat excessively-drained sand soils. The driest parts of the landscape, and, usually, the most fire exposed and fire-frequent parts of the landscape. Fire intensity (sometimes frequency) may be reduced, however, if the site is on the downwind side of a substantial firebreak such as the Lower Little River, or in the angles downwind from the confluence of two streams.
Typical soils:
LaB Lakeland sand – Coated Typic Quartzipsamments, ED, >6
Pf Pocalla loamy sand – Loamy, siliceous, Arenic Plinthic Paleudults, SED, >4
WfB Wakulla sand – Sandy, siliceous, Psammentic Hapludults, SED, >6
CaB, CaD Candor sand – sandy, siliceous Arenic Paleudults, SED, MWD, >6

Mesic Longleaf Pine/Wiregrass Savanna.

On fire-exposed landscape positions on convex or gently rolling upland, south slopes and well-drained upland flats with substrate of loamy sand and sandy loam soils.
Typical soils:
BaB, BaD, Bd (typo?), BnB, BnD Blaney loamy sand – Loamy, siliceous, Arenic Hapludults, WD, >6
NoB Norfolk loamy sand – Fine-loamy, siliceous, Typic Paleudults, WD, 4-6
VaB, VaD, VeE Vaucluse loamy sand and gravelly loamy sand – Fine-loamy, siliceous, Typic Hapludults, WD, >6
MaB Marlboro sandy loam – Clayey, kaolinitic Typic Paleudults, WD, >6
FuB, Fa (Harnett) Fuquay sand, loamy sand – Loamy, siliceous, Arenic Plinthic Paleudults, WD, 4-6
KaA Kalmia loamy sand – Fine-loamy over sandy or sandy-skeletal, siliceous, Typic Hapludults, WD, >6

GaA, GaB, GaD, GdB, GdD Gilead loamy sand – Clayey, kaolinitic, Aquic Hapludults, MWD, 1.5-2.5

Oak Savanna and Woodland (blackjack oak with post oak, mockernut hickory, and scattered stems or patches of turkey oak and longleaf pine/grass).

On any upland soil type in slightly fire-sheltered sites with an impermeable layer within 1 meter of the surface. Can occur on slopes facing in any direction, even south, if there is a sufficient topographic break in the upwind direction to create a flat or pocket.
Typical soils:
GaA, GaB, GaD, GdB, GdD Gilead loamy sand – Clayey, kaolinitic, Aquic Hapludults, MWD,
In some places on D slope classes of Candor, Blaney, Vaucluse, and E slope class of Vaucluse where an impermeable layer outcrops at or near the surface.

Pyrophytic Oak-hickory Woodland with pines (southern red oak, post oak, loblolly pine, pond pine. Fire influenced, but with reduced fire effect on more fire-sheltered lower slopes, and steep-sided ravines).

On moderately well-drained and somewhat poorly-drained soils in ravines that lie perpendicular to the prevailing wind direction. Also on lower north slopes where slope is >10% and in bottomlands on islands of higher soil that are still accessible to light surface fire but where side slopes are steep enough to prevent full access by rapidly moving fire.
Typical soils: almost any soil type where topographic and fire refugial conditions are met.

Pond Pine/Canebrake

On poorly drained and somewhat poorly drained soils. Can occur in the upper part of the landscape in gently concave streamhead depression where an impermeable layer is close enough to the surface to create a perched water table. Similarly in pockets or seepage zones on side slopes where the impermeable layer outcrops along a side slope creating a seepage zone, in midslope and lower concave or V shaped drainage sloughs. These may be so narrow as to create a string of single pond pine trees in a line, with a band of cane only 2-3 meters wide beneath them.   Cane was extensive in major and minor bottomlands where side slopes are gentle enough (<8%) to permit easy access by every passing fire.
Typical soils on slopes:
GaA, GaB, GaD, GdB, GdD Gilead loamy sand – Clayey, kaolinitic, Aquic Hapludults, MWD, 1.5-2.5
Typical soils in bottoms (occasionally on gentle slopes):
Wh Wehadkee loam – Fine-loamy, mixed, nonacid, Typic Fluvaquents, PD, 0-1
Bb Bibb loam – Coarse-loamy, siliceous, acid, Typic Fluvaquents (Harnett County), PD, 0.5-1.5
Cf Cape Fear loam – Clayey, mixed, Typic Umbraquults, VPD, 0-1.5
JT Johnston loam – Coarse-loamy, siliceous, acid, Cumulic Humaquepts (Cumberland County), VPD, +1-1.5
In many places, linear canebrakes existed in dryer soil types in wet drains too narrow to appear on soil maps.

Wet-mesic Longleaf Pine Savanna.

Mostly in large and small stream bottoms where water table remains near the surface during most of the year, either because the site is the lowest in the landscape or on slightly higher flats where there is an impermeable layer near the surface.
Typical soils: Aquults and other soils with aquic modifiers:

AaA, At Altavista fine sandy loam – Fine-loamy, mixed, Aquic Hapludults, MWD, 1.5-2.5
Pa, Pc (Harnett) Pactolus loamy sand – Coated Aquic Quartzipsamments, MWD, SPD, 1.5-3
Wo Woodington loamy sand – Coarse-loamy, siliceous, Typic Paleaquults, PD, 0.5-1
Ra, Rb, Ru Rains sandy loam – Fine-loamy, siliceous, Typic Paleaquults, PD, 0-1

Small Stream Swamp and Pyrophytic Wetland Mosaic Structured by Fire and Beaver (pond pine canebrake, hardwood canebrake, beaver ponds and marshes, bottomland hardwoods, loblolly pine, tulip poplar, sweetgum) .

Original fire frequency variable: margins and bottoms with gentle side slopes readily accessible to fire burned as frequently as adjacent uplands. Sections with steep side slopes burned less frequently.
Typical soils:

Water

None

VEGETATION STRUCTURAL DEFINITIONS for Prairie, Woodland, Savanna, Glades:

In the longleaf pine ecosystem, forest are used here means > 50% tree cover, with or without an open grassy fire-maintained understory. Dominant species range from longleaf pine on slightly fire-sheltered sites with good soil to hardwood forest and even beech on more highly fire sheltered sites.

Woodland means tree cover 25-50%. Dominant species range from pure longleaf pine to more typically longleaf in various mixtures with blackjack oak, post oak, mockernut hickory, southern red oak, white oak, loblolly pine, pond pine, and on partially fire-sheltered upper slope shoulders, shortleaf pine. There is conspicuous two-layered structure consisting of a tree canopy and species-rich grass-forb layer. Understory hardwoods and shrubs, other than fire-dwarfed shrubs such as Gaylussacia frondosa, Gaylussacia dumosa and Vaccinium tenellum, are scarce unless fire suppressed.

Savanna means tree cover < 50% with a grassy understory maintained by fire. There is conspicuous two layered structure with a tree canopy and species-rich grass-forb layer and little or no midstory. There may be a few scattered scrub oaks of which turkey oak (*Quercus laevis*) and blackjack oak (*Quercus marylandica*) are the most common at Fort Bragg.

Prairie means essentially treeless areas. Since there are many small gaps and open patches in some longleaf pine stands we could set a minimum size limit of about 2 acres before we could call it a prairie. One exception might be the small oval wet prairies such as those that occur at Apalachicola National Forest south of Tallahassee and have a geomorphological origin.

Glades: The term glades isreserved for openings in forested landscapes that are created by unusual geology such as diabase, serpentine or limestone outcropping at the soil surface. Such communities often have a shrubby pine or red cedar component. There are no known communities that should be called prairie or glades at Fort Bragg.

One citation for vegetation structural terms:
Frost, Cecil C., J. Walker and R.K. Peet. 1986. Fire-dependent savannas and prairies of the Southeast: original extent, preservation status and management problems. In: D.L. Kulhavy and R.N. Conner, eds. Wilderness and natural areas in the eastern United States: a management challenge. Nacogdoches, Texas: Center for Applied Studies, School of Forestry, Stephen F. Austin State University. p. 348-357.

Appendix 3: Comprehensive Methods and Procedures

Overview:

This analysis process was designed to map presettlement vegetation communities on a frequent fire landscape at Fort Bragg in the Sandhills area of North Carolina. The process may be used "as is" to generate preliminary presettlement vegetation maps for other Sandhills land management units, or it may be modified to fit other landscapes. The basic critical requirements for success with this process are:

1. A landscape with terrain relief. Flat landscapes will not have terrain variation required to make discerning vegetation community differences possible.
2. A GIS technician with sufficient skills to complete basic landscape analysis with raster and vector layers and the ability to operate fire behavior models. First-hand knowledge of fire behavior is a plus.

For landscapes outside of the Sandhills region, a botanist or ecologist who has experience with the local vegetation and fire regimes must first define historic vegetation community types. To do this, there must be one or more of the following:

1. Historic references describing local vegetation in detail.
2. Remnant undisturbed or only moderately disturbed vegetation on the analysis landscape from which presettlement community types can be ascertained.
3. Comparable intact systems elsewhere, from which parallels can be drawn.

The distribution of presettlement vegetation communities on the Fort Bragg landscape was influenced by soils, position on the landscape (aspect and slope) and by exposure to fire. Fire-sheltered vegetation communities found in depressions and wind-sheltered areas on the landscape were found with the FlamMap fire behavior model. Historic weather data were collected from local remote automated weather stations (RAWS) and organized with Fire Family Plus and other statistical sorting methods. Accurate terrain data were provided from satellite collected Light Detection and Ranging (LIDAR) data. A sensitivity analysis was performed in FlamMap to determine the reaction of the model to changes in individual inputs. The remaining presettlement communities were associated with terrain orientations and soils, including the fire-exposed upland communities, wetlands, and those influenced by more extreme fire behavior associated with the funneling of gradient winds.

Step One: Create an Analysis Plan

Vegetation communities at Fort Bragg were defined as detailed in the following process. For landscapes similar to Fort Bragg, these vegetation communities may be suitable for use as they are, or adapted to fit the parameters of the specific landscape. The process may also be used to model historic vegetation communities on other landscapes, as long as a good assessment has been completed concerning vegetation community description and distribution parameters. It is critical to realize that defining historic vegetation communities can be a laborious process, best accomplished by a botanist familiar with local vegetation and fire-influenced plant communities. The process of defining historic communities is only briefly outlined below, with the focus of this guide being a method to spatially locate those defined communities.

Defining Presettlement Community Types:

Presettlement vegetation communities were previously defined and delineated in an extensive 2-year study of the Fort Bragg area by Dr. Cecil Frost, an expert in local vegetation and historic fire-plant interaction (Frost 2005 in prep). He established seven communities based on comparable extant presettlement communities elsewhere, remnant vegetation on the local landscape, soils layers, and topography. These communities are similar to communities described in the Classification of the Natural Communities of North Carolina (Schafale and Weakley 1990). Historic journals and early settlement survey plats containing spatial information on indicator tree species were used to confirm the location of individual communities across the landscape. The validity of Frost's community definitions was checked extensively against remnant vegetation on the current landscape.

Table 1 presents a list of the presettlement community types defined at Fort Bragg, including a comparison to modern communities as defined by Schafale and Weakley (1990). Remnant fire indicator species include longleaf pine, wiregrass, cane (*Arundinaria gigantea*), southern red oak (*Quercus falcata*), loblolly pine (*Pinus taeda*), pond pine (*Pinus serotina*), blackjack oak (*Quercus marilandica*), post oak (*Quercus stellata*), mockernut hickory (*Carya tomentosa*), Atlantic white cedar (*Chamaecyparis thyoides*), and turkey oak (*Quercus laevis*). Presettlement vegetation communities are based on and limited to what can be verified or substantiated from early land grant surveys and other historical sources. As such, they are sometimes coarser and sometimes finer than the types described by Schafale and Weakley (1990). Because all but a few presettlement vegetation communities were influenced by fire they may differ from modern fire-suppressed communities especially as applies to the structure of vegetation. Frost's classification differs in its emphasis on fire-maintained two-layered vegetation structure (savanna and woodland) and on vegetation types whose dominants and structure are dependent on fire such as canebrake, in contrast to the modern multi-layered fire suppressed forests.

Table 1: Seven Presettlement vegetation communities at Fort Bragg

Frost Community Name *(Schafale and Weakley Community Type)*	***Community Description***
Xeric Longleaf Pine/Wiregrass Savanna. *(Pine-Scrub Oak Sandhill)*	On convex uplands with excessively drained or somewhat excessively drained sand soils. The driest parts of the landscape, and, usually, the most fire exposed and fire-frequent. Fire intensity (sometimes frequency) may be reduced, however, if the site is on the downwind side of a substantial firebreak such as the Lower Little River, or in the area downwind from the confluence of two streams.
Mesic Longleaf Pine/Wiregrass Savanna. *(Pine-Scrub Oak Sandhill)*	On fire-exposed landscape positions on convex or gently rolling uplands, south slopes, and well-drained upland flats with substrate of loamy sand and sandy loam soils.

Table 1: Seven Presettlement vegetation communities at Ft Bragg (continued)

Oak Savanna and Woodland (blackjack oak with post oak, mockernut hickory, and scattered stems or patches of turkey oak and longleaf pine/grass). *(Pine-Scrub Oak Sandhill, Blackjack-Mixed Oak Variant)*	On any upland soil type in slightly fire-sheltered sites with an impermeable layer within 1 meter of the surface. Can occur on slopes facing in any direction, even south, if there is a sufficient topographic break in the upwind direction to create a flat or pocket.
Pyrophytic Oak-Hickory Woodland (southern red oak, post oak, loblolly pine, pond pine. Fire influenced, but with reduced fire effect on more fire-sheltered lower slopes and steep-sided ravines). *(Mixed Mesic Hardwood Forest, Swamp Island Variant on the bottomlands)*	On moderately well drained and somewhat poorly drained soils in ravines that lie perpendicular to the prevailing wind direction. Also on lower north slopes where slope is >10% and in bottomlands on islands of higher soil that are still accessible to light surface fire but where side slopes are steep enough to prevent full access by rapidly moving fire.
Pond Pine/Canebrake. *(Pond Pine Woodland; Sandhill Seep; High Pocosin; Streamhead Pocosin)*	On poorly drained and somewhat poorly drained soils. Can occur in the upper part of the landscape in gently concave stream head depressions where an impermeable layer is close enough to the surface to create a perched water table. Also found in pockets or seepage zones on side slopes where the impermeable layer outcrops along a side slope, creating a seepage zone, or in mid-slope and lower concave or V- shaped drainage sloughs. These may be so narrow as to create a string of single pond pine trees, with a band of cane only 2-3 meters wide beneath them. Cane was extensive in major and minor bottomlands where side slopes are gentle enough (<6%) to permit easy access by every passing fire.

Table 1: Seven Presettlement vegetation communities at Ft Bragg (continued)

Wet-mesic Longleaf Pine Savanna. *(Pine Savanna; Wet Pine Flatwoods)*	On mineral soils in large and small stream bottoms where water table remains near the surface during most of the year, either because the site is the lowest in the landscape or on slightly higher flats where there is an impermeable layer near the surface.
Small Stream Swamp and Pyrophytic Wetland Mosaic (pond pine canebrake, hardwood canebrake, beaver ponds and marshes, bottomland hardwoods, loblolly pine, tulip poplar, sweetgum, Atlantic white cedar). *(Coastal Plain Small Stream Swamp; Cypress-Gum Swamp, Blackwater Subtype; Streamhead Atlantic White Cedar Forest; Coastal Plain Bottomland Hardwoods, Blackwater Subtype; Bay Forest; High Pocosin; Coastal Plain Semi-Permanent Impoundment)*	Original fire frequency variable: margins and bottoms with gentle side slopes readily accessible to fire burned as frequently as adjacent uplands. Sections with steep side slopes burned less frequently or not at all in the wettest swamps.

Based on these presettlement vegetation community descriptions, the following graphic was designed to guide the analysis process. A detailed description of the methods employed in the analysis process follows.

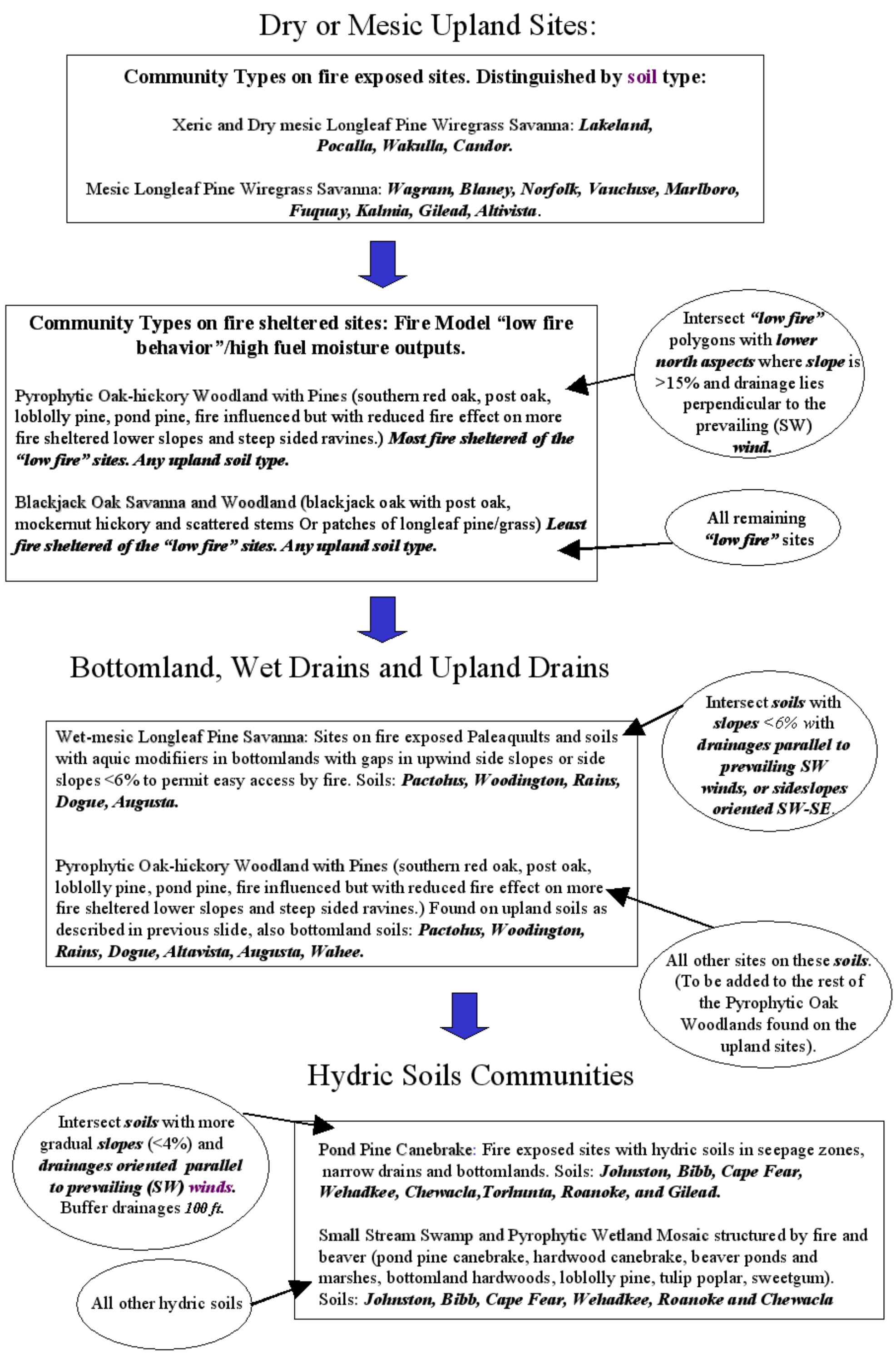


Figure 1: Analysis guide used to locate vegetation communities on the landscape

Step Two: Gather and Check Pertinent Data

Data Collection:

Overview*: In addition to the definitions of the presettlement vegetation communities, local terrain, soils and weather data and computer software must be acquired:*

Soils and stream layers were provided by the Department of Defense, Fort Bragg GIS department. All data should be checked for accuracy. This may require ground truth or GIS manipulation.

PROCEDURE: Our soils layer had some inaccuracies, due to the merging of two soils layers. The layer was cleaned with the following:

> In ArcInfo (ESRI ArcGIS version 8.3): Clean soils coverage to rid of some structural faults. (fuzzy tolerance set to 6 to get rid of line overlap, but keep integrity of polygons) Convert to polygon shapefile. Manually delete null areas and assign logical neighboring soil type to pits and dumps.

LIght Detection And Ranging (LIDAR) data obtained from the North Carolina Flood Mapping Program (www.ncfloodmaps.com). Countywide Elevation Grid format 20 foot (6-meter resolution) from:

http://www.ncdot.org/planning/tpb/gis/DataDist/GISContourMaps.html

Contour and Elevation data was generated from the LIDAR data in September 2004. Refer to Flood Mapping web site to determine the currency of the LIDAR data. The negative values could be a rock quarry or an error in the LIDAR data. All data is in North Carolina State Plane NAD83 Fips_3200 Feet. *Note that, for ease, these data are kept in the native projection (English) throughout the recorded analysis process. They may be converted to metric at any point in the procedure.*

PROCEDURE: The complete Overhills elevation grid required merging two Lidar county elevation maps

> *In ArcInfo:*
> Create boundary shapefile and convert to coverage using SHAPEARC command. BUILD topology for boundary coverage (*boundcov*).
> Harnett and Cumberland county Lidar elevation grids must be merged. Use GRIDMERGE and retain the 20-foot resolution.
> Clip merged elevation grid with *boundcov* using LATTICECLIP. Output = *ohielev*

Historic hourly weather and wind data, from local remote automated weather stations (RAWS), was accessed online at the Western Regional Climate Center's Desert Research Institute website (http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?ncNFBR). The National Wildfire Coordination Group's Fire and Aviation Management Web Applications (FAMWEB) provided historic daily RAWS data. (http://famweb.nwcg.gov/weatherfirecd/)

FARSITE and FlamMap fire modeling software and Fire Family Plus software for summarizing climatic data are available from the Rocky Mountain Research Station Fire Sciences Lab at http://fire.org.

Step Three: Generate Vegetation Communities Based on Soils and Location on Landscape

Aspect and slope grids generated for the fire behavior modeling process were used, along with a soils layer, to determine the location of the remaining communities. Basic upland communities were derived simply by selecting the soils types where they might have occurred. Xeric Longleaf occurred on Lakeland, Pocalla, Wakulla or Candor soils. Mesic Longleaf occurred on Wagram, Blaney Norfolk, Vaucluse, Marlboro, Fuquay, Kalmia or Gilead soils.

Wet-Mesic Longleaf communities occurred on Pactolus, Woodington or Rains soils, on slopes less than 6% and in drainages that are parallel to the prevailing southwest winds and on side-slopes facing southwest to southeast.

Pyrophytic Oak-Hickory Woodlands occurred in both the uplands and lowlands. The upland sites were found with the fire modeling process as described above. The lowland sites were the sites not already occupied by Wet-Mesic Longleaf on Pactolus, Woodington, Rains, Dogue, Altivista, Augusta, Wahee and Roanoke soils. The upland and lowland sites were merged to create a complete Pyrophytic Oak-Hickory Woodland layer.

Pond Pine Canebrake occurred on hydric Johnston, Bibb, Cape Fear, Wehadkee, and Torhunta and on upland Gilead soils, on flat to shallow slopes (less than 4%), and in drainages conducive to funneling of the prevailing southwest winds.

Small Stream Swamp and Pyrophytic Wetland Mosaic defines the remainder of the hydric soils areas not already occupied by Wet-Mesic Longleaf or Pond-Pine Canebrake. These sites are defined by Johnston, Bibb, Cape Fear, and Wehadkee soils.

PROCEDURE: Non fire-sheltered upland and lowland vegetation communities were derived with the following steps in ArcMap (v. 8.3):

Basic Upland communities

Xeric Longleaf:

Select Attributes: Primsoil = Lakeland or Pocalla or Wakulla or Candor (47 of 368 selected.)
Export data as polygon shapefile.

Mesic Longleaf:

Select Attributes: Primsoil = Altivista or Wagram or Blaney or Norfolk or Vaucluse or Marlboro or Fuquay or Kalmia or Gilead (234 of 368 selected)
Export data as polygon shapefile.

For *fire-sheltered upland communities*, use Select by attribute to create a layer of all of the above soils for use, later on. Layer = all_upland.shp

For Bottomland wet drains and upland drains

Wet-Mesic Longleaf:

From good soils layer:

Select Attributes: Primsoil = Pactolus, Woodington, Rains, Dogue, Augusta, Wahee (35 of 368 selected.)
Export data as polygon shapefile.

Derive slope in % file using spatial analyst from the original *harncumb* elevation file:

Select <6% from 100-foot slope raster file:
reclassify <6 to 10 and the rest to 0.
Convert Reclassified grid to a shapefile (Spatial Analyst: Convert raster to feature) based on "value"
From attribute table of new feature: Select attributes gridcode = 100
Export selected features to new shapefile: slope6.shp

Select drainages that are parallel to prevailing SW winds or sideslopes SW-SE:

From aspect grid reclassify:
0-90 to 0
90 to 180 to 100
180 – 202.5 to 0

202.5 – 247.5 to 100
247.5 – 270 to 0
270 – 360 to 100

Convert Reclassified grid to a shapefile (Spatial Analyst: Convert raster to feature) based on “value”
From attribute table of new feature: Select attributes gridcode = 100
Export selected features to new shapefile: wm_wind.shp

To create final Wet-Mesic Longleaf Polygons:

Intersect the slope, aspect and soils shapefiles using Geoprocessing Wizard.
Output = wm_int
(I actually decided that the Slope layer was detracting from the final shape of the Wet-mesic areas, so I left it out. Wet-mesic are just a buffer of aspect with soils, on my map.)

Pyrophytic Oak Hickory Woodland:

Select Attributes: Primsoil = Pactolus, Woodington, Rains, Dougue, Altivista, Augusta, Wahee, Roanoke (35 of 368 selected.)
Export data as polygon shapefile.

These areas will be all of the Pyro-oak lowland areas, not already taken by Wet-Mesic Longleaf.
Clip Wet-mesic out of low_Pyro areas using the process below:
Add Field to low_pyro_oak: Identify: 1
Union low_pyro_oak with wm_int
Select Identifier = 1.
Export selected features to new shapefile: low_pyro_final

For Hydric Soils Communities

Pond Pine Canebrake:

From good soils layer:
Select Attributes: Primsoil = Johnston, Bibb, Cape Fear, Wehadkee, Torhunta, Roanoke and Gilead (151 of 368 selected.)

Select <4% from 100-foot slope raster file:
reclassify <6 to 10 and the rest to 0.
Convert Reclassified grid to a shapefile (Spatial Analyst: Convert raster to feature) based on “value”
From attribute table of new feature: Select attributes gridcode = 100
Export selected features to new shapefile: wm_windasp2.shp

Select drainages that are parallel to prevailing SW winds:

From 100-foot aspect grid reclassify:
0-90 to 0
90 to 180 to 100
180 –270 to 0
270 – 360 to 100

Convert Reclassified grid to a shapefile (Spatial Analyst: Convert raster to feature) based on "value"
From attribute table of new feature: Select attributes gridcode = 100
Export selected features to new shapefile: ppc_aspect.shp

A buffer was created of drainages where Canebrake might be found. The streams layer did not go high enough into these drainages, so a drainage polyline was created using the following process:

Open ohielev (LIDAR elevation grid) in ArcView:

Use ArcHydro to:

Fill Sinks.

Create a "Flow Accumulation" raster (this assigns each cell a flow value, based on the number of cells that drain into it.)

Layer Properties: Symbology: Classified:

Set 2 classes and "fish" for the number that will show the drainages at the level required.

Use Spatial Analyst to:

Reclassify the flow accumulation grid (example from my values):

0-4000 → 0
4000-852,857 → 1

Convert the raster to a polyline feature

Buffer the streams layer polyline that you just created by 100 feet.

To create Pond Pine Canebrake Polygons:
Intersect the slope, aspect and soils and 100 foot Buffer shapefiles using Geoprocessing Wizard.
Output = ppc_int

Small Stream Swamp and Pyropytic Wetland Mosaic

Select Attributes: Primsoil = Johnston, Bibb, Cape Fear, Wehadkee (34 of 368 selected.)
Export data as polygon shapefile.

To remove pond pine canebrake sites from the low small stream swamp soils layer:
Add Field to sss_soils: Identify: 1
Union sss_soils with ppc_int
Select Identifier = 1.
Export selected features to new shapefile: sss_final

Step Four: Generate Vegetation Communities on Fire-Sheltered Uplands

Overview: *The location of fire-sheltered communities is best predicted with the use of the fire behavior model. These communities were influenced by soils, position on slope and gradients in fire behavior. The critical model input is prevailing wind direction, which has a direct influence on the distribution of the areas of lowest fire behavior outputs:*

Fire-sheltered communities on upland soils (Lakeland, Pocalla, Wakulla, Candor, Wagram, Blaney, Norfolk, Vaucluse, Marlboro, Fuquay, Kalmia, Gilead) were located with FlamMap. Fireline intensity outputs in Kilowatts per meter (kW/m) were generated from landscape, weather and fuels conditioning inputs and exported to ArcView. The lowest fire behavior outputs were assumed to represent "fire-sheltered" areas on the landscape where Pyrophytic Oak-Hickory and Oak Savanna and Woodland were found.

Fire Behavior Model Inputs:

FARSITE and FlamMap fire modeling software and FireFamily Plus statistical weather analysis software are available from the Rocky Mountain Research Station Fire Sciences Lab at http://fire.org.

FARSITE and FlamMap require the following basic inputs: A landscape file including aspect, slope, elevation, fuel model and canopy cover grid files; wind and weather inputs; and temporal inputs. FARSITE models fire behavior and spread spatially and temporally given heterogeneous terrain, weather and fuels conditions across a landscape (Finney 1998). FlamMap models fire behavior as if each raster cell on the landscape were ignited simultaneously. Time is only significant in FlamMap when using a fuels conditioning period. Fuels conditioning across the landscape renders dead fuel moistures variability in response to changing weather conditions and topography, as they might occur on the real landscape (Finney 2004). The FlamMap model generates fire behavior outputs from conditions found at the end of the fuels conditioning period.

Landscape:

"Bare earth" light ranging and detection (LIDAR) data were chosen over digital elevation model (DEM) cartographically digitized from 1:24000 quadrangle maps, because we considered them a more accurate representation of the actual terrain. Slope and Aspect grids were derived from the clipped LIDAR elevation grid. This provided three of the five elements required to generate a FARSITE landscape.

Fuel Models:

The final two grid files required to generate a FARSITE landscape relate to vegetation. Fire Behavior Prediction System (FBPS) [formerly National Forest Fire Laboratory (NFFL)] fuel models were designed by Rothermel (1972) and Albini (1976) to describe the properties of vegetation on the ground for use in predicting fire behavior. Each fuel model is described by fuel load and ratio of surface area to volume of the various size classes of fuel, the depth of the available vegetation, and the moisture of the fuel (Anderson 1982). There are 13 models in 4 categories: Grass, shrub, timber and slash. Grass fuel model 2, which represents surface fire spread through fine herbaceous fuels in addition to litter and dead stemwood, best describes the majority of presettlement vegetation at Fort Bragg. In order to keep the fire inputs as uniform as possible, fuel model 2 with a 50% canopy cover was held constant across the landscape.

Fuel Model 2 Loading: *1 hour: 4.5 tons (metric)/hectare*
10 hour: 2.25 tons (metric)/hectare
100 hour 1.13 tons (metric)/hectare
Live: 1.13 tons (metric)/hectare
Fuel bed depth: 0.3048 meters
Moisture of extinction of dead fuels: 15%

In order to keep the fire inputs as uniform as possible, fuel model 2 with a 50% canopy cover was held constant across the landscape. Canopy cover inputs affect the wind adjustment factor and shading effects on dead fuel moisture in the model. The elevation grid was simply reclassified in Arc Spatial Analyst to provide a uniform fuel model grid (2) and a uniform canopy cover grid (50%). This process provided the final two grid files required to generate a FARSITE landscape. The five grids (elevation, slope, aspect, fuels, and canopy cover) were combined in FARSITE and a landscape file was generated. The five grids (elevation, slope, aspect, fuels, and canopy cover) were combined in FARSITE and a landscape file was generated.

PROCEDURE: Create a FARSITE landscape and associated weather files to be used to locate fire-sheltered upland communities, using FlamMap:

Derive the five basic layers needed for use in fire models

In ArcMap (v 8.3):

Using Spatial Analyst, derive slope, aspect and hillshade files. All outputs should remain in 20-foot grids for use with FARSITE and to the same extent as *elevaton grid.* For use in other analysis, also create an aspect and slope file at 100-foot resolution.

Using Spatial Analyst, reclassify clipdem twice

- all cell values become 2 for fuel model layer.
- All cell values become 50 for canopy cover layer.

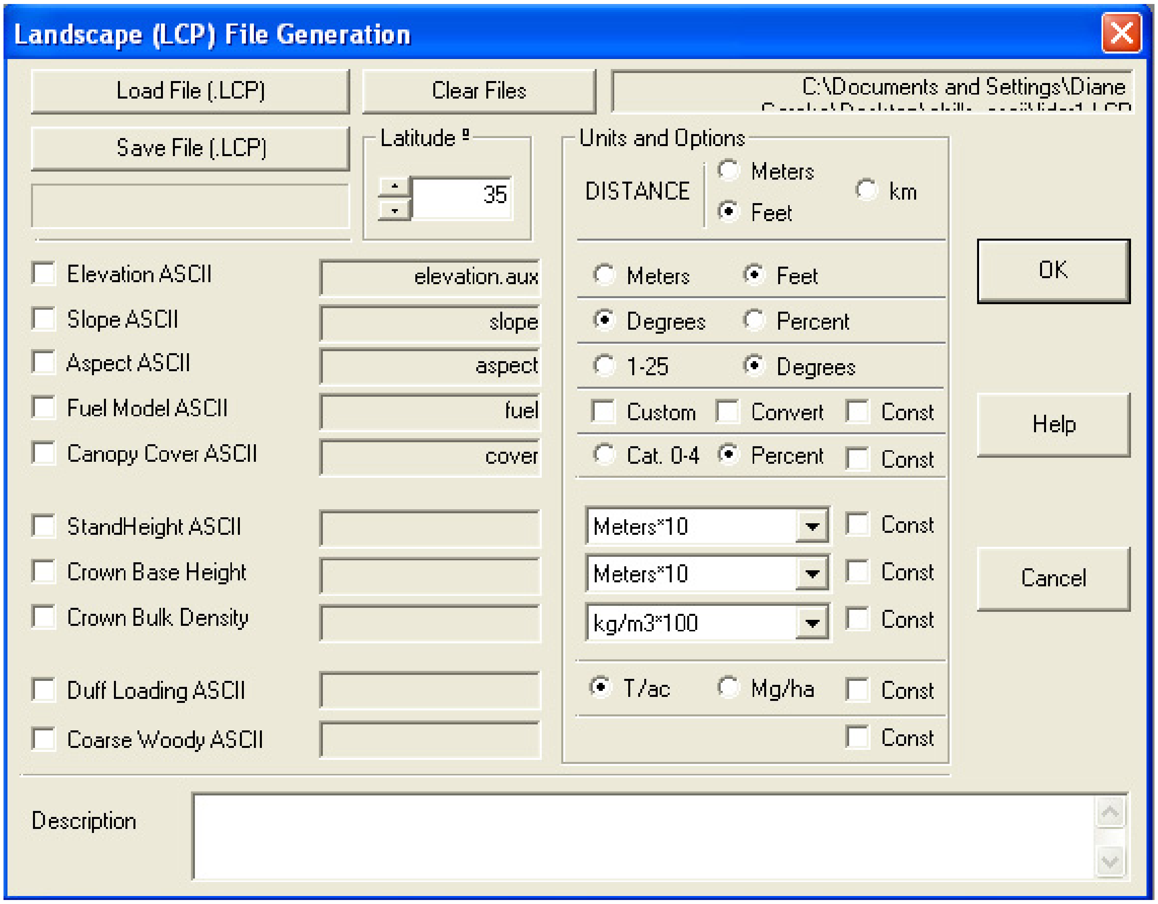
In ArcToolbox:

Convert files to ASCII format:
ohielev = elevation (feet)
ohislope = slope (degrees)
ohiaspect = aspect (degrees)
ohifuels = fuel_models (only FM 2)
ohicancov = canopy_cover (only 50%)

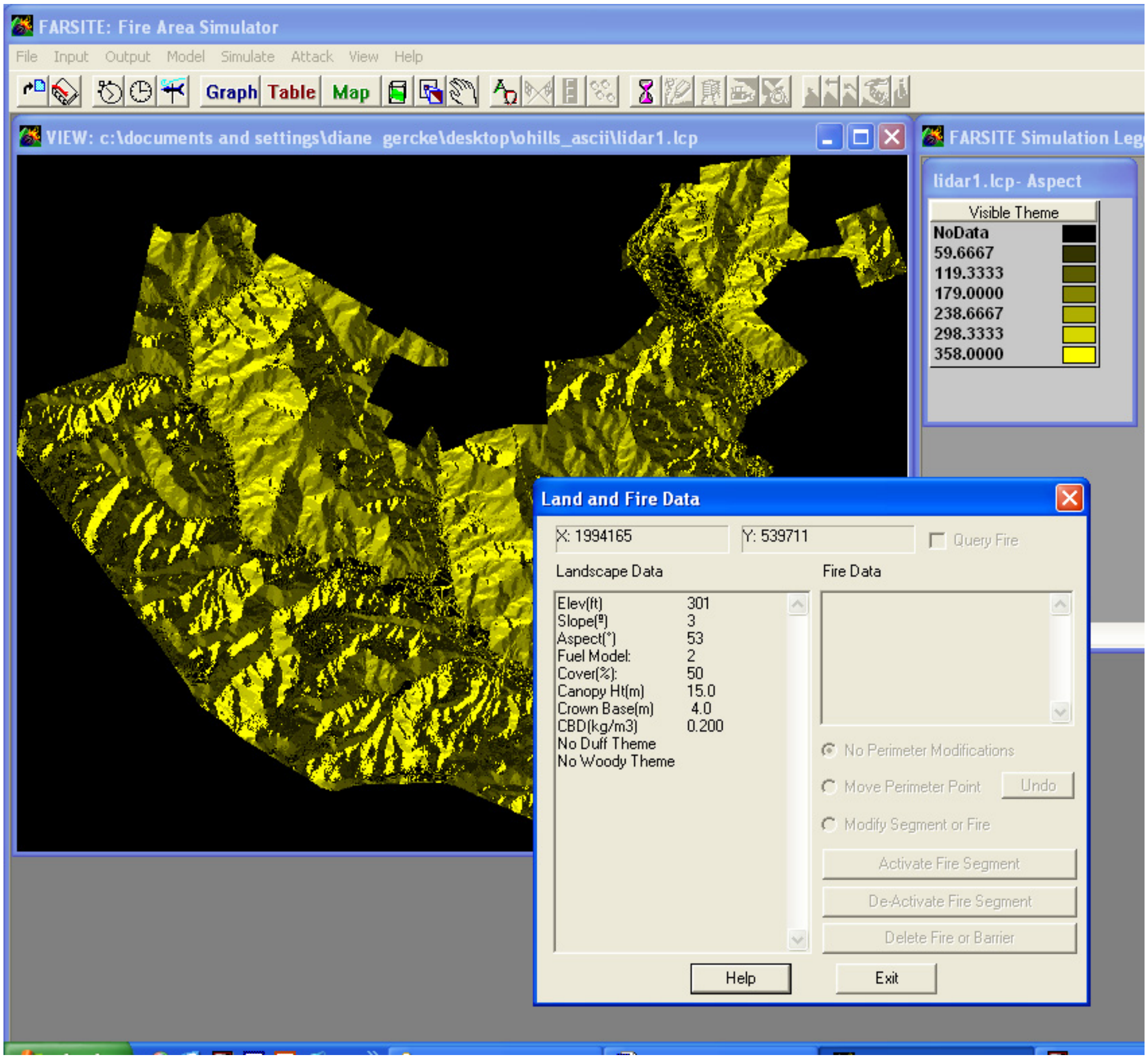
Create a FARSITE landscape file

In FARSITE v. 4 (available at http://www.fire.org/):

- Input: Landscape Utilities: Generate Landscape File:



- Load elevation ascii (feet), Slope ascii (degrees), Aspect ascii (degrees), Fuel model ascii, and Canopy Cover ascii (percent)
- Set latitude to 35 (or the latitude of your area.)
- Save as .lcp file.
- Make sure to query your landscape file to check the accuracy of your input data (View: Landscape file: 2-D window…. Simply click on the map with your selection arrow to view a table of inputs for that location.)



NOTE: It is possible that your ASCII files may be too large for FARSITE to open. If so, you must clip your original elevation grid into smaller sections:

In ArcCatalog:
- *Create a new polyline shapefile.*

In ArcToolbox:
- *Set projection of new shapefile to match that of elevation grid*

In ArcMap:
- *Add Shapefile and elevation grid*
- *Edit shapefile: Draw lines to create a grid that divides the area into smaller sections. Make sure to zoom in on the nodes to make sure the lines connect together exactly and don't overlap.*
- *Quit editing and save.*
- *Select the polygon(s) that you want to use to create the smaller areas and save the selection as a shapefile.*

In ArcCatalog:

- *Use "shapearc" to convert the selection shapefile into coverage. Clean the coverage.*
- *Use the new coverage to "latticeclip" the elevation grid. Repeat until the coverage has been sectioned into smaller sections (with edges that will line up when put back together*

(You can either re-clip all of the layers or simply take the sectioned DEM and create new slope, aspect, fuels, and canopy cover layers. This is safest, since they will be sure to be the same extent. Remember: your final outputs are ASCII files of elevation, slope, aspect, fuels, and canopy cover)

Weather and Fire Season:

Overview:

Analysis completed in this study concerning the sensitivity of the FlamMap model to changes in weather inputs has shown prevailing wind direction to be the only model input critical to locating fire-sheltered communities on the landscape. An examination of the section describing this analysis process at the end of this Guide will help you to determine how much detail you need to go into regarding weather inputs for your analysis. In the Fort Bragg area, it may be easiest to simply use the weather inputs provided in this guide. For other areas, weather inputs that are generally representative of fire season weather should be adequate, as long as assumptions about historic fire season and the associated prevailing winds are accurate.

Basic Data Sources:

Daily historic weather observations were gathered from the National Wildfire Coordinating Group's Fire and Aviation Management Web Applications (FAMWEB) website: http://famweb.nwcg.gov/weatherfirecd/

RAWS station data was available from:

- Ft Bragg (1968-1988, 2000-2004)
- Uwharrie National Forest: Troy (1968-1970, 1975-1998, 2000-2004)
- Rockingham (1986, 2000-2004)

Hourly data was found in the Western Regional Climate Institute: Desert Research Institute (DRI) RAWS archives. http://www.wrcc.dri.edu/wraws/ncF.html Hourly data was available from 2000 to the present (2005) for the Fort Bragg RAWS station.

FlamMap Weather Inputs:

Data were loaded into Fire Family Plus (software available http://fire.org)

A Special Interest Group (SIG) was created with Fort Bragg given the highest weight of 2.0 and Rockingham and Troy both rated at 0.25. This should enable missing data in the Fort Bragg set to be backed up by the other stations, while retaining the integrity of the "representative" Fort Bragg RAWS weather dataset for the analysis area.

Fuel Moisture:

Data were sorted with critical percentiles set at 90 and 97. All weather data for the months of March and April were considered. Resulting values of 1, 10, 100, live woody, and live herbaceous fuel moistures were loaded into the fuel moisture file (.fms) in FARSITE. These values should equate to a representative "fire day".

One hour	Ten hour	One Hundred Hour	Live Herbaceous	Live Woody
5	7	13	30	70

Wind:

A windrose was generated via the DRI website (http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?ncNFBR), using daytime March and April hourly wind observations from all available years. The most common wind direction was from the Southwest, with winds averaging 16 km/h at the 6-meter level. Winds speeds were doubled in the model inputs to account for an experienced exaggerated wind reduction factor. (Pat Stephen, Fire Behavior Technical Specialist, US National Park Service. pers. comm. 2005)

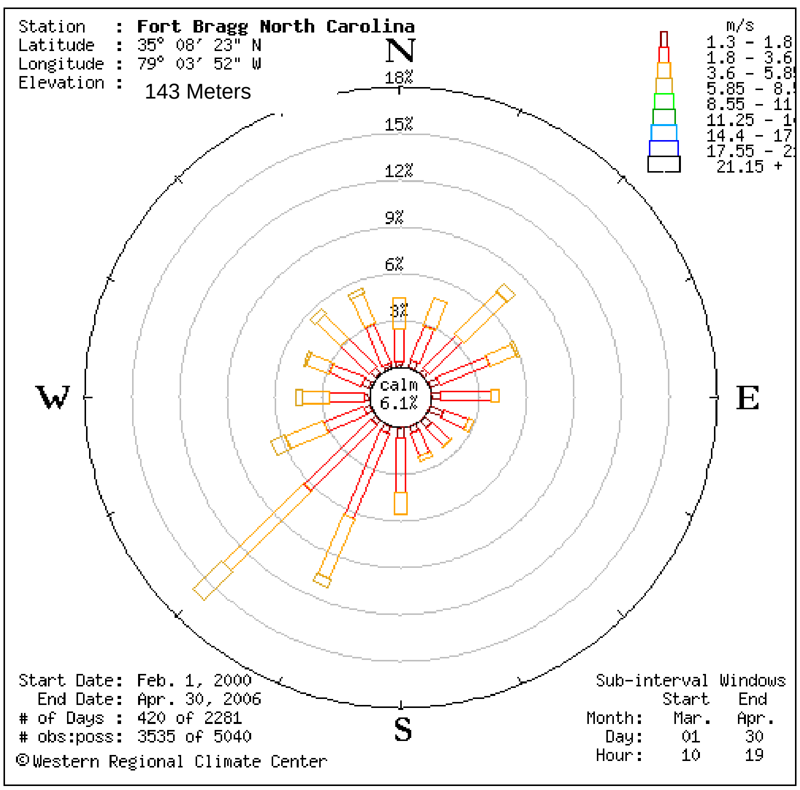


Figure 2: Wind rose for daytime March-April winds from 2000-2006 data generated at Desert Research Institute website (http://www.wrcc.dri.edu/wraws)

Fuels Conditioning Files:

It is critical to use the fuels conditioning period option for your FlamMap analysis. The fuels conditioning period is where the model creates a landscape with variation in fuels moisture, as on the actual landscape. Without this option, the simulation will be run with uniform fuel moisture inputs and will, therefore, have less variation in fireline intensity outputs. These are the critical outputs used to locate the fire-sheltered areas.

Daily 1300 weather observations, from FAMWEB RAWS files, were averaged to determine daily high and low temperatures and humidities. Maximum of high temperature, minimum of low temperature, low relative humidity, and high relative humidity columns were averaged for all data from the Ft Braggs RAWS station (1968-88 and 2000-04). Representative times of low temperature/high relative humidity and high temperature/low relative humidity were simply estimated from the DRI hourly RAWS dataset. The following data were the result:

Table 2: Historic daily weather observations for FlamMap conditioning period

Month	Day	Rain amt.	AM low	PM high	Temp. low (°F)	Temp. high (°F)	R.H. high (%)	R.H. low (%)	Elev-ation (meters)
3	25	0	600	1500	31	78	52	22	152
3	26	0	600	1500	29	82	52	23	152
3	27	0	500	1400	28	82	50	22	152
3	28	0	500	1400	30	82	48	24	152
3	29	0	500	1400	35	84	54	24	152
3	30	0	400	1300	40	86	53	27	152
3	31	0	400	1300	38	85	55	27	152

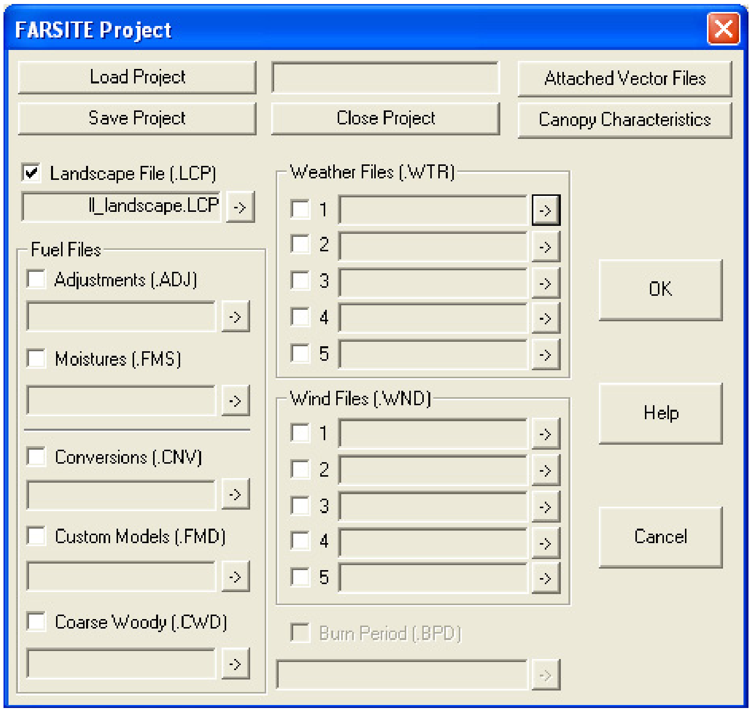
Other hourly data were organized in Microsoft Excel®. A mode of each hourly wind direction, windspeed, cloud cover [from available Fort Bragg RAWS data (2000-2005)] was taken to create the wind and weather fuels conditioning files for the dates March 25-31. A copy of these weather results is available in Appendix A.

An inverse relationship was assumed between recorded hourly solar radiation and cloud cover. The following criteria were used to determine hourly cloud cover inputs:

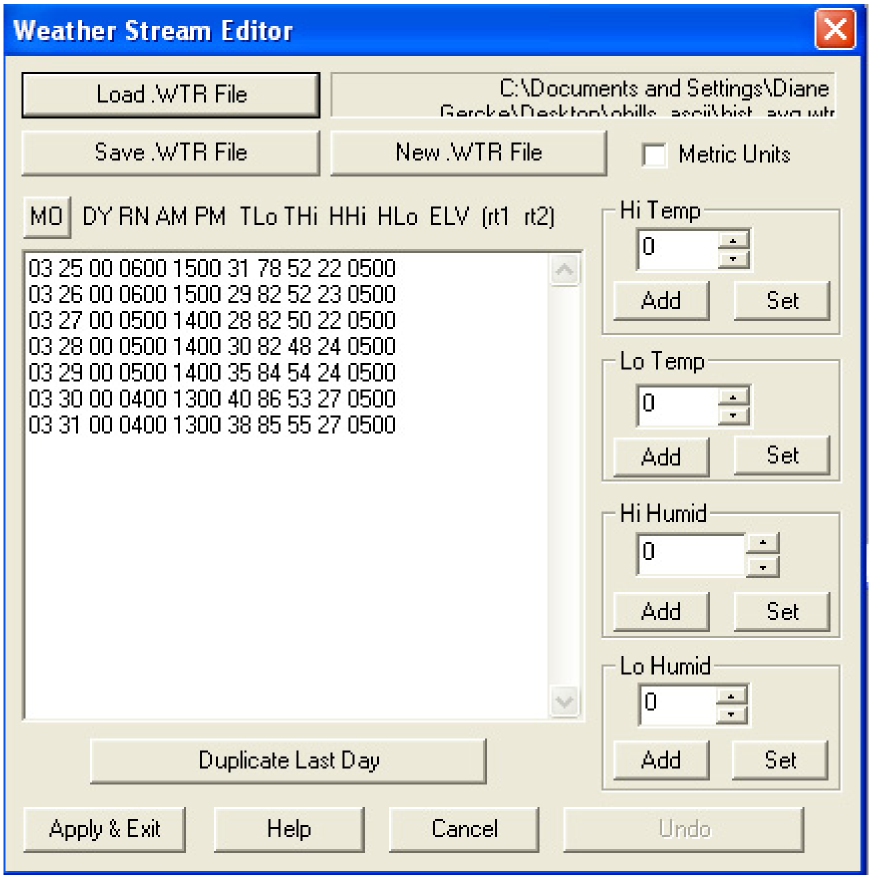
Solar Radiation °ly	**Cloud Cover %**
0-5	100
6-20	80
31-37	60
38-53	40
54-69	20
>70	0

Create Historic Fuel Moisture, Weather, and Wind Files

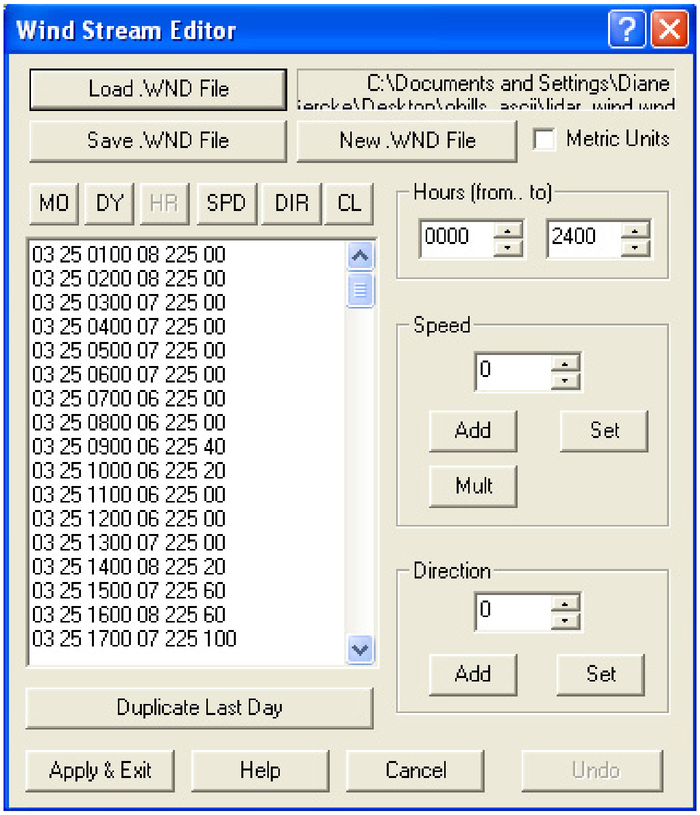
Historic weather may be accessed from local RAWS stations or the NWS. RAWS sites tend to be more representative since they are located in actual forest conditions, as opposed to being located at airports. Location of the weather station and accuracy of collected data should be verified. These weather observations may be created manually or directly copied into a text file. The weather or wind stream editors in FARSITE are accessed by clicking on the arrow to the right of the input boxes.


FARSITE Project
Load Project
Save Project
Close Project
Attached Vector Files
Canopy Characteristics
Landscape File (.LCP)
ll_landscape.LCP
Fuel Files
Adjustments (.ADJ)
Moistures (.FMS)
Conversions (.CNV)
Custom Models (.FMD)
Coarse Woody (.CWD)
Weather Files (.WTR)
1
2
3
4
5
Wind Files (.WND)
1
2
3
4
5
Burn Period (.BPD)
OK
Help
Cancel

- Make sure to use the following format: (Use FARSITE "Help" for description of inputs if you need further explanation)



- Wind files are created in the same manner, but recorded on an hourly basis (windstream)



- Save these weather and wind files. We won't use them in FARSITE, but we'll use them for fuels conditioning in FlamMap.

Completing Fire-Sheltered Upland Vegetation Layers:

A FlamMap run was completed with the standard representative fire day parameters. The fireline intensity output was exported and the lowest quarter of the fire behavior outputs were selected and saved as a shapefile. These polygon outputs were assumed to show the location of fire-sheltered Pyrophytic Oak-Hickory Woodlands and Oak Savanna and Woodland on the landscape.

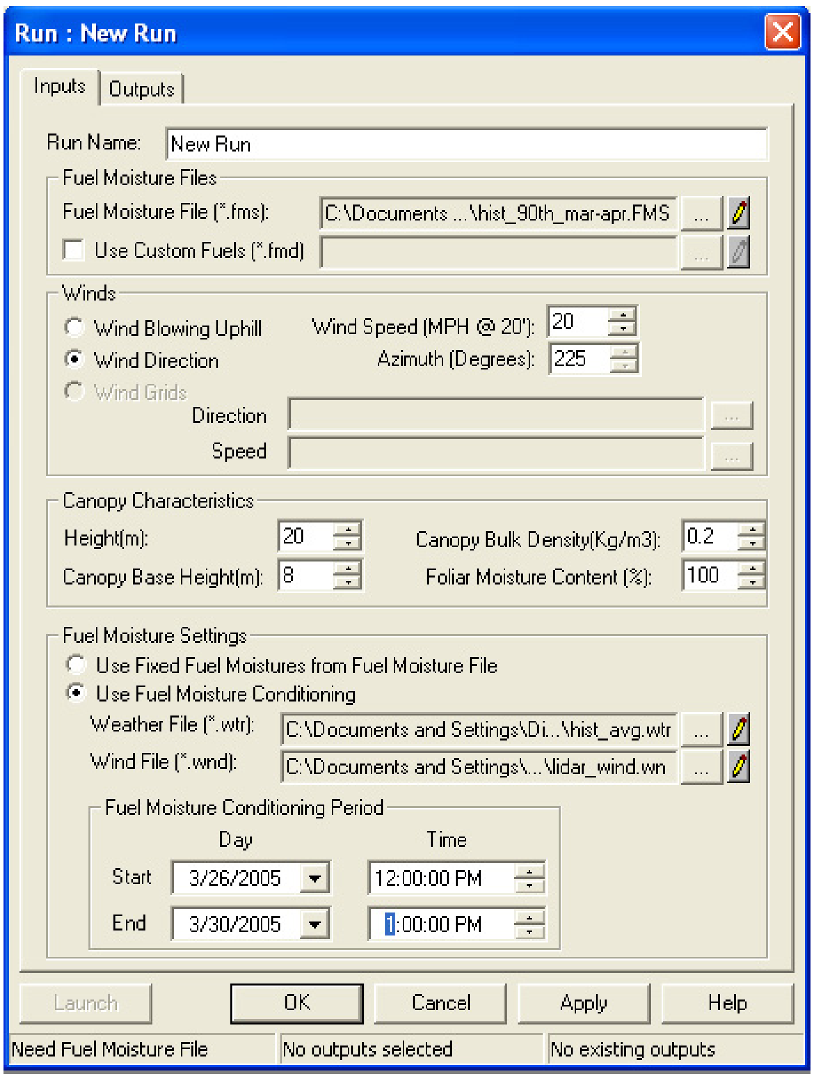
Pyrophytic Oak-Hickory Woodland areas were generated from the intersection of the low fire behavior data, upland soils (Lakeland, Pocalla, Wakulla, Candor, Wagram, Blaney, Norfolk, Vaucluse, Marlboro, Fuquay, Kalmia, and Gilead), aspects greater than 10% and drainages perpendicular to the prevailing southwest winds.

Oak Savanna and Woodland on upland soils comprised the remainder of the fire-sheltered areas on upland soils.

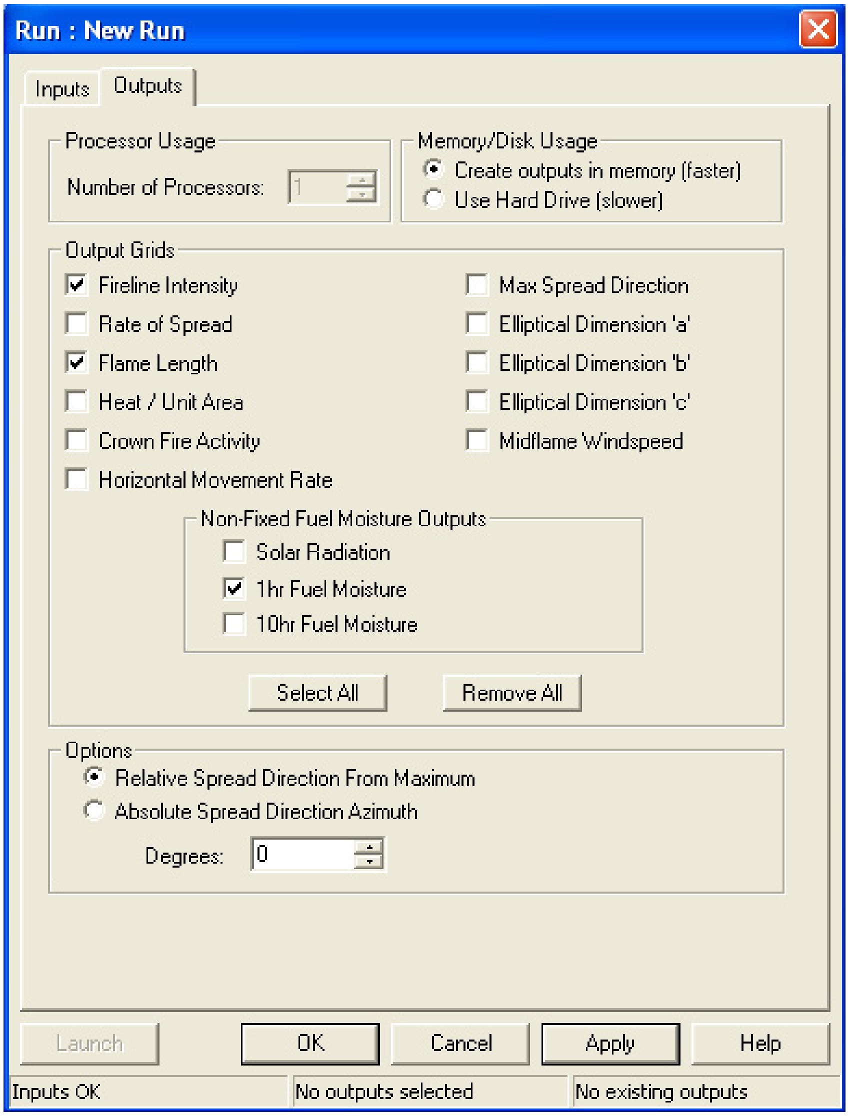
PROCEDURE: The analysis must be completed in FlamMap and outputs exported for use in the GIS. This will create the final upland fire-sheltered communities.

Create a FlamMap environment and run it

In FlamMap 2.0 (available http://www.fire.org/):
- Open FlamMap and load your landscape by double clicking in the left panel on "No Landscape file"
- Double click on "Run" below the added Landscape file Themes to open the run parameters window. Mine was filled out as follows:



- You must also specify outputs:



- “Launch” the run.
- When the run is complete, you may view the outputs by expanding the NewRun list in the left panel and clicking on the desired output.
- To export this data for use in GIS analysis, right click on output file and save-as an output file in ASCII format.

Convert ASCII output file to grid format

In ArcToolbox:

[grid type: integer (for FLI) or float (for Flame Lengths)]

Reclassify fire behavior outputs to show the range of interest

In ArcMap:

Import firebehavior output grid.
Set projection to Stateplane NAD 83 Fips 3200 Feet
Change symbology to make lower 1/16 (or the portion that best mimics the spatial extent of observed remnants on the landscape) of fire behavior outputs visible units on the map.
Properties: Symbology: Classifed: 4 classes: Classify: Manually drag breakpoints on histogram to divide into four groups: 1. Lowest flames. 2. Majority flames 3. High average flames. 4. Maximum flames.
Mark Low fire kW/m at 398-1273
Reclassify Lowfire Grid:

398-1273 to 1
1274- 2131 to 0

Convert Reclassified grid to a shapefile (Spatial Analyst: Convert raster to feature) based on "value"
From attribute table of new feature: Select attributes gridcode = 1
Export selected features to new shapefile: lowfire.shp

Deriving Specific Communities from fire behavior outputs

FOR Pyrophytic Oak-Hickory:

Soils layer: all_upland.shp
(Selected Primsoil from Good_soils.shp = Altivista, Lakeland, Pocalla, Wakulla, Candor, Wagram, Blaney, Norfolk, Vaucluse, Marlboro, Fuquay, Kalmia, Gilead (275 of 368 selected))

Select >10% from slope raster file:
Reclassify >10 to 10 and the rest to 0.

Convert Reclassified grid to a shapefile (Spatial Analyst: Convert raster to feature) based on "value"
From attribute table of new feature: Select attributes gridcode = 10
Export selected features to new shapefile: slope10.shp

Select drainages that are perpendicular to prevailing southwest winds (fire-sheltered):

From aspect grid reclassify:
0-45 = 1
45-315 = 0
315-360 = 1

Convert Reclassified grid to a shapefile (Spatial Analyst: Convert raster to feature) based on “value”
From attribute table of new feature: Select attributes gridcode = 1
Export selected features to new shapefile: lf_asp.shp

To create final Upland Pyrophytic Oak-Hickory Polygons:
Intersect the lowfire polygons with slope, aspect and upland soils shapefiles using Geoprocessing Wizard.
Output = up_pyr_oak_final

FOR Oak Savanna and Woodland:
All remaining Lowfire polygons on Upland Soils.
Intersect lowfire.shp with all_upland.shp
Add Field to intersection_output: Identifier: 1
Union up_pyr_oak_final with intersection_output
Select Identifier = 1.
Export selected features to new shapefile: bjo_final

Step Five: Combine the Data

Areas that overlap were eliminated in the above selection process. It is important to ensure that overlapping areas do not exist and that the correct dominant community should be chosen to occupy the overlap before merging the final layers. The following figure serves as a guide for intersecting the final layers, with the communities favored in the overlap decision process listed at the top.

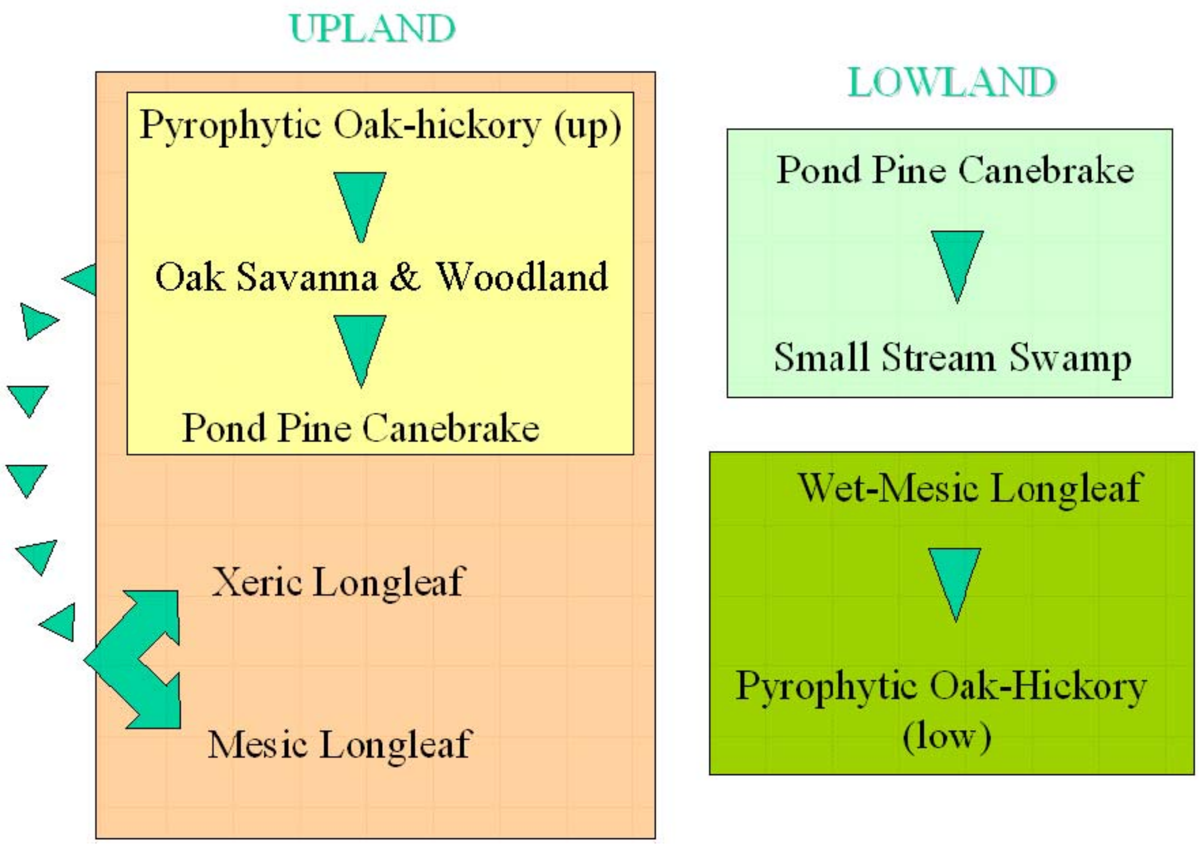


Figure 3: Guide for intersect priority of overlapping polygons

All of the resulting vegetation community polygon shapefile layers were merged into a single layer using ArcMap Geoprocessing Wizard. Unique identifiers were created to maintain the integrity of the individual vegetation types. The attribute table was then cleaned of erroneous processing fields and area and perimeter fields were updated.

PROCEDURE: All of the individual community layers must be merged to create the final layer. Special attention should be given to priorities for overlapping communities.

Joining Pyrophytic Oak Lowland and Upland Sites:

First remove Wet-Mesic sites from the low pyro soils layer:
Add Field to pyro_oak: Identify: 1
Union pyro_oak with wm_int
Select Identifier = 1.
Export selected features to new shapefile: low_pyr_oak_final

Union low_pyr_oak_final to up_pyr_oak_final
Output = pyro_oak_all_final

Creating the Final Layer:

MERGE all of the individual layers to make a complete presettlement vegetation communities layer:

Add Field to each of the individual layers' attribute table called "comm._code". Give each community type a unique number identifier. (In an edit session, use calculate field and add the value to the field: i.e. for first community: comm._code + 1 Second community: comm._code + 2, etc..

Use Geoprocessing Wizard to merge all of the individual layers. Make sure that "comm._code" fields carry over correctly by querying attribute table (numbers of polygons for each code should equal number of polygons in original file.)

Delete erroneous fields.

Update Area and Perimeter using script as available in ArcMap "Help".

Add a text field called "Hist_comm." Which will name the historic vegetation communities in the attribute table.

Step Six: Check the Data

You have now successfully created a preliminary presettlement vegetation map of your area. If you were working with Frost's presettlement community types in an area similar to that found at Fort Bragg, you might expect the accuracy to be around 78%. If you were working in a different area, your accuracy will depend on the quality of your original data defining the historic community types and the related environmental parameters used with your analysis. In both situations, field checking for remnant vegetation on your landscape will improve the accuracy of your layer.

For the purposes of our original analysis, data was checked against a pre-existing map of presettlement vegetation communities in the following manner. The final check of the data was made in ERDAS Imagine (v. 8.6). Fifty random points were generated in each of the seven community types and compared to the presettlement community map generated by Frost's extensive study. Each point was checked manually and recorded according its location on the reference layer. Communities within 50 meters of the target community were considered correct. Correct points were either lying directly within the same community type in the reference layer or within 50 meters of the correct community on the map. The Accuracy Assessment function then compared the reference points to the classified map, generating a summary sheet, an error matrix and accuracy totals.

Our ground-truth check has shown that the fire model provides approximately 91% accuracy of the model in finding fire-sheltered areas associated with this single

(Oak Savanna and Woodland) community. Ground truthing may also check the accuracy of original critical input layers like soil and digital elevation models.

PROCEDURE: The following steps are required to complete an accuracy assessment in ERDAS Imagine 8.6.

Data was reprojected to NAD 83 UTM Zone 17N Meters to match reference data from Stephanie Wilds.

Import data to Imagine:

In Spatial Analyst, convert final polygon file (classified layer) to grid (10 meter resolution) using comm_code field.
Import this grid file as an image file (.img) in Imagine.
In Import Options, pick “unsigned 8 bit”. Leave the rest at default.
Go thru the same process with and “TRUE” data layer.

True file may remain continuous, but the classified layer needs to be thematic. It’s convenient to do this in a subset window, where you may also want to clip a smaller sample of the file, to avoid sampling NULL data or insignificant areas around the edges:

To do this:

Open a view window and Load the classified image file.
Select Utility: inquirebox: Place box around the desired extent.
Data Prep: Subset. Load the classified image file. Name the output file.
Select subset button (this should recognize the inquirebox you just selected.) Select “unsigned 8 bit” and “thematic”
Close View window and open a new one to load true layer.

Start Analysis:

Classifier: Accuracy Assessment: Load file to be checked in AA window.
With Select viewer tool, select the true image in the window.
Edit: Generate random points (350): Distribution parameters: Stratified Random. Select the community types to be assigned. 50 points to each.
Begin manually labeling the points in the reference column (leave the classified column blank) by zooming to each. (Select a point in the table. Right click on the table and “show selected”. Zoom in on the map to determine location. Right click on map to zoom out again.) Save as you go!
When finished, a report is generated by clicking on the “report” button on the table. Select all options (error matrix, accuracy totals, Kappa Statistics.)

Notes on the Process

Important Considerations:

Overview:

Seasonality of historic fire spread may be an important consideration affecting vegetation distribution patterns. Local weather conditions change seasonally in most areas, with differences in temperatures, relative humidities, and precipitation causing vegetation to become more or less available to carry fire. The results of the sensitivity analysis showed that most reasonable changes in weather inputs had little effect on the distribution of the low fire behavior polygons on the landscape. The only factor that did change the location of the low fire behavior polygons was prevailing wind direction. If more than one prevailing wind direction is recorded for the area, multiple wind directions may be modeled and the resulting low fire behavior polygons added together to create fire-sheltered areas.

The model's ability to accurately predict the location of the fire-sheltered areas on the landscape is dependant upon an accurate assessment of prevailing wind direction, which may change seasonally. Ignition sources could also be an important consideration affecting the season of historic fire spread. Thorough consideration of this issue is important to quality data output.

Seasonality:

Historic data from local RAWS stations was accessed (NWCG, FAMWEB archives) and sorted. An examination of the entire dataset found that March and April were the driest weather months. This was confirmed by Uwharrie National

Forest fire records (1970-2004) showing most acres burned during the months of March and April.

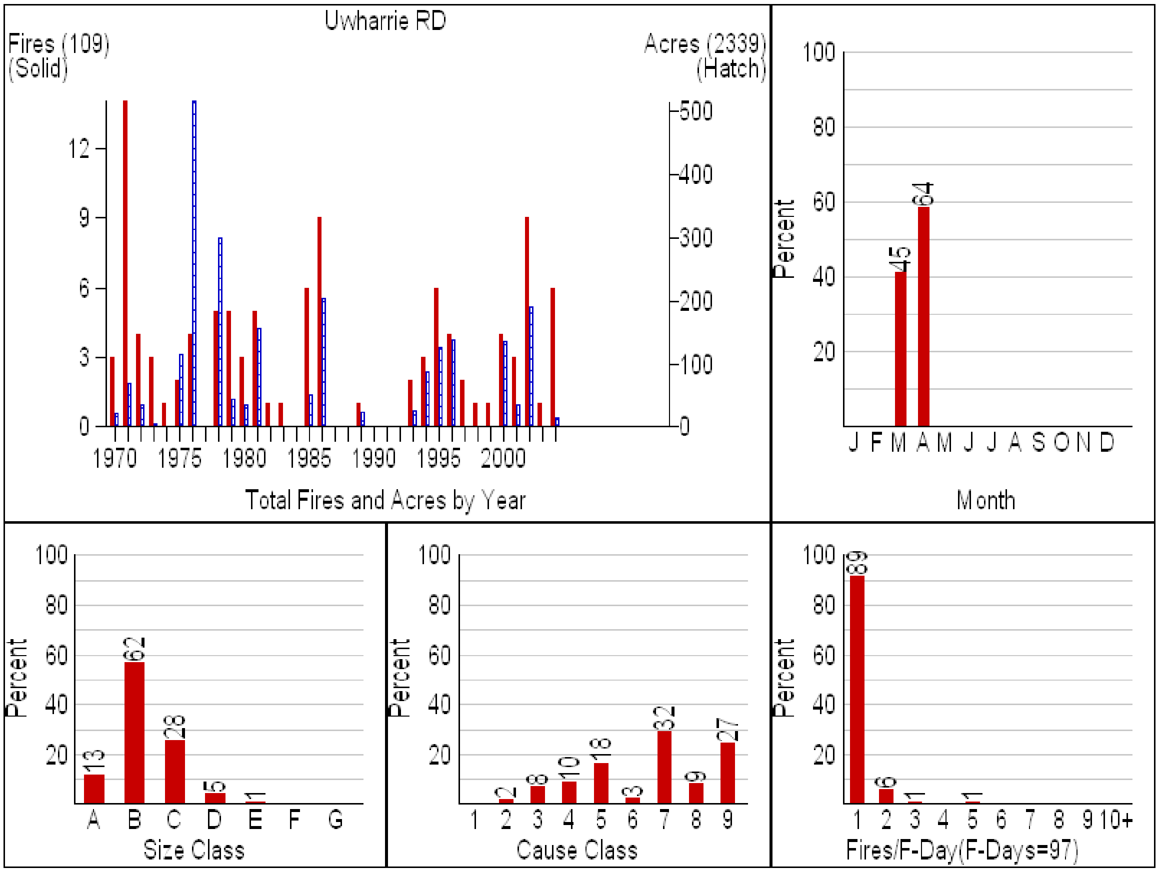


Figure 4: Fire summary output from Fire Family Plus software for the Uwharrie National Forest in North Carolina: From top/left to bottom right: Total fires and acres by year, showing the largest number of fires (at >12) in 1971 and the largest single fire (at >500) acres (>202 hectares) in 1976. Fire occurrence by month showing most fires occurred on the Uwharrie during this period in March and April. Fires by forest service size class code, showing 62% between ¼-1 acre (0.1-0.4 hectare). Fires by forest service cause class showing no recorded lighting ignitions (cause class 1). Fires by duration, showing that 89% of fires lasted no more than a day.

The Uwharrie fire records correlate with research done by Barden and Woods (1973) showing historic fire occurrence in North Carolina, in the Appalachian Mountains to have occurred in March, April and May. Because it is at a lower elevation and representing a lower elevation and warmer climate, fire season on the

Coastal Plain of North Carolina would have occurred about a month in advance of the fire season in the Mountains.

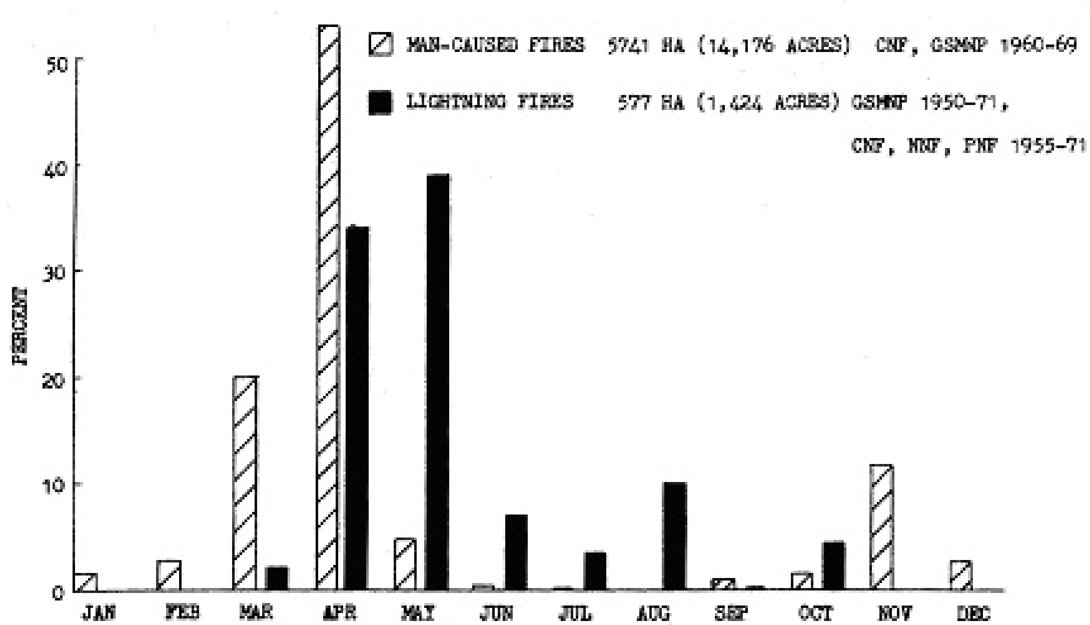


Figure 5: Lightning and man-caused fire frequencies in the Southern Appalachians (Barden and Woods 1973)

Ignition Sources:

Historically, both cultural and natural ignitions were probably common. Anthropogenic starts in eastern forests generally occur in the spring and fall, while lightning ignitions tend to happen in the summer months. Generally, lightning fires were not as intense as man caused fires. The role of lightning fires is generally to selectively remove small trees, though cases have been recorded where crowning can occur and top-kill very dense stands of trees (Barden and Woods 1973). Because thunderstorm formation requires greater than 75% relative humidity, and large fires don’t usually occur in relative humidities greater than 30-40%, lightning fires tend to stay small. More recent historic causes of fire in the East include native agricultural clearing, charcoaling for the iron industry, railroad ignitions, careless hunters, and lightning (Ruffner 1998).

The Uwharrie fire report database (Fire Family Plus v.3.0 2004) contains records from 1972 to the present, which represent ignitions on a fragmented and generally more mesic landscape than what was described in presettlement times (Lawson 1714, Brickell 1737, Schaw 1776). Brickell and Schaw described park-like stands of large timber, with a variety of wildflowers and diverse plants in the understory while Lawson described passable, though difficult travel through pocosin swamps, implying some clearing by fire. Historic journals have recorded frequent burning of the woods, year-round, by native peoples and early settlers.

No lightning caused fires were recorded in the Uwharrie database, though lightning fires surely occurred on the Coastal Plain in the historic landscape. It is probable that lightning strikes would have resulted in acres burned on a continuous, more xeric presettlement landscape. Historic savanna fuels such as wiregrass would have been available to burn within a day or two of wetting rain (Margit Bucher, Assistant Director of Science & Stewardship, NC Chapter, TNC, *pers. comm*. 2005). Weather records show that these windows existed throughout the year. Any lightning ignition in March and April would certainly have resulted in large acreage burned, while even during the wet season in July and August windows of dry weather would have occurred where many frequent lightning strikes may have resulted in some acres burned.

It is feasible that, if xeric forest and open grass savanna existed, that lightning fire acreage might have been much more significant than is commonly assumed. Studies of long-term vegetation patterns confirm the general decline of xeric communities and increase in mesic high-density brush sites in the Southeast (Carroll 2002). A drier landscape, created by climate or frequent burning, would have been more conducive to carrying lightning starts. Lightning strike frequencies are highest in Florida, but still very high into North Carolina and Virginia.

FlamMap Sensitivity Analysis:

An analysis was performed to test the sensitivity of the fire model to changes in individual inputs. The significance of inputs was determined by referencing the fuel model 2 composition in Anderson's guide and by discussion of the model with fire modeling professionals. Inputs tested include wind speed, wind direction, one-hour, ten-hour, one hundred-hour, and live herbaceous fuel moistures. Varying starting and ending times tested the conditioning period parameters. Cloud cover was also tested since it is considered to be a significant factor influencing model output (Pat Stephen, Fire Behavior Technical Specialist, US National Park Service. pers comm., 2005) A baseline run was made, using the inputs generated from the historic weather data sorting process as described previously. Then high and low inputs were substituted for each parameter as indicated in the following table.

Table 3: Weather inputs used for FlamMap sensitivity analysis

Inputs	***Standard Input***	***High Input***	***Low Input***
1 hr FM (%)	5	9	3
10 hr FM (%)	7	11	5
100 hr FM (%)	13	17	9
LH FM (%)	30	90	50
Wind Spd (km/h)	16(32)	48(97)	3(6)
Wind Dir (° from N)	225	45	135
Conditioning period			
Time Start	1200	100	2000
Time End	1300	100	2000
Cloud Cov (%)		100	0

The following represents the tabular results of the sensitivity analysis. Outputs were compared for Flame Length (meters), Fireline Intensity (kW/m), and one-hour fuel moistures (%) on the ground.

Table 4: FlamMap sensitivity analysis outputs and results. Highlighted areas specify runs exported for spatial low fire behavior accuracy assessment

	Standard Input			***High Input***			***Low Input***		
Outputs:	FL	FLI	1 hr FM	FL	FLI	1 hr FM	FL	FLI	1 hr FM
Inputs									
1 hr FM	0.6-1.5	***125-588***	6-7	0.6- 1.5	125-588	6-7	0.6- 1.5	125-588	6-7
10 hr FM				0.6- 1.5	125-588	6-7	0.6- 1.5	125-588	6-7
100 hr FM				0.6- 1.5	125-588	6-7	0.6- 1.5	125-588	6-7
LH FM				0.6-1.5	125-588	6-7	0.6- 1.5	125-588	6-7
Wind Spd				2.4- 2.7	***1706-2349***	6-7	0.6- 1.2	72-460	6-7
Wind Dir.				0.9- 1.5	170-713	6-7	0.6- 1.5	72-720	6-7
Cond. Period									
Time Start				0.6- 1.5	121-550	7-8	0.6- 1.5	125-588	6-7
Time End				0.6-0.9	***55-263***	12	0.6- 1.2	87-398	11
Cloud Cov				0.6- 1.2	111-505	9	0.6- 1.5	131-640	5-6

Three of the output files, representing high, low, and standard fireline intensity ranges, were exported in ASCII format and converted to polygon shapefiles in ArcGIS. The outputs were then classified using the same method employed in locating the "low fire behavior" polygons for the fire-sheltered vegetation communities on the landscape. These three sensitivity analysis output layers were then compared to verify the presence or absence of statistical difference between the locations of the "low fire" polygon outputs for the various ranges of fire behavior. Points were assigned to the center of the 500 largest polygons on the standard output. The high and low fire behavior outputs were then compared individually to this layer. Correct points were those with positive polygon identification at the assigned random point, or those with polygons of similar pattern or extent within 15 meters of the test layer.

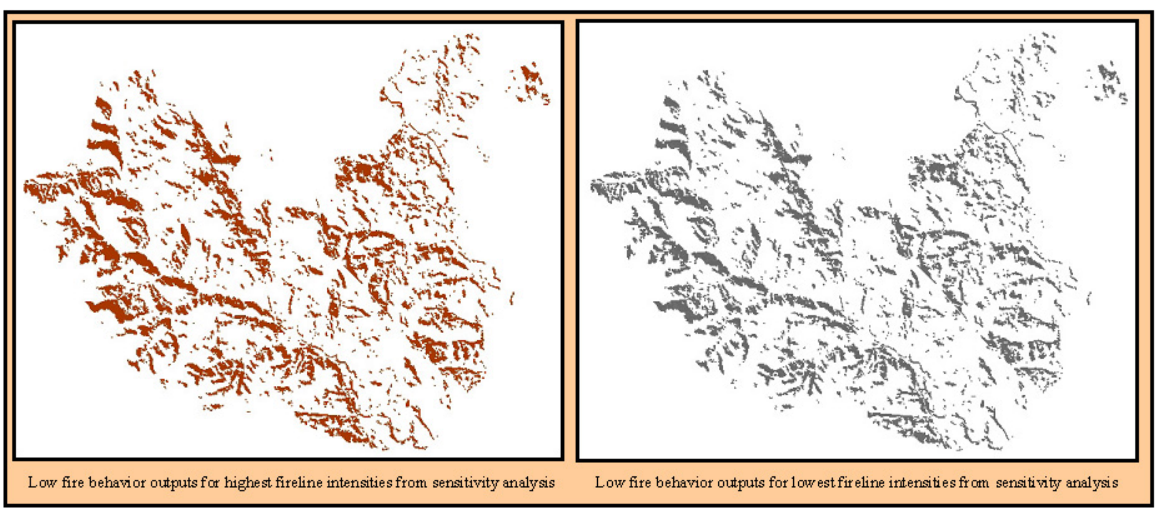


Figure 6: Lowest fire behavior polygon for high and low fireline intensities show a similar spatial pattern on the landscape

PROCEDURE: Check the similarity of the three polygon files using ArcMap.

For Standard output grid:

> Generate points: Add Area, Perimeter, an X field and a Y field to the standard (true) layer. Populate fields using Advanced field calculator. (Directions text in helpfile). Select ***Centroid***.
>
> Use Select by Attribute to find the 500 polygons with the largest area or perimeter. Export these polygons to a unique layer file.
>
> Export 500_largest layer attribute table to a .txt file (options)
>
> Tools: Add XY. Convert exported point events to a layer file.
>
> Join centroid point file for 500_largest layer with the polygon layer file to be checked.

Make sure that both layers have a unique field that identifies them. (I changed GRIDCODE to grid_code and gr_code1 respectively, in each of the 3 layers.)

Use Select by attributes to Query for areas that have both polygons and points (ex: GRIDCODE = grid_code). At this point, you will have to manually check the remainder of the points to see if the polygons occur in the same area, since some of the “centroid” points fall outside of polygons or holes may occur in a polygon layer. Your final selection over the total polygons (500) will represent your accuracy statistic.