Abstract

ROSENFELD, BRIAN JAY. Developing a New Fuel Load Mapping Strategy Using: Digital Photogrammetry; International Classification of Ecological Communities; USDA Forest Service, Forest Inventory and Analysis Protocols; and Disturbance History (Under the direction of Dr. Heather M. Cheshire).

Fire behavior models require many variables including above ground biomass or fuel load. Fuel loads include the amount of woody debris, duff, and litter that can carry a fire. The collection of these data can be very time consuming and expensive. The purpose of this project was to develop a quantitative, multi-purpose strategy for mapping fuel loads. Study sites were located in the coastal plain (Alligator River National Wildlife Refuge and Dare County Bombing Range) and the mountains (Coweeta Hydrologic Laboratory) of North Carolina. The approach was based on classifying vegetation types based on categories at the association level of the International Classification of Ecological Communities (ICEC), using digital stereo imagery. The vegetation classes were combined with field measurements of biomass volumes obtained from USDA Forest Service Forest Inventory and Analysis Phase 3 (FIA P3) plots. The methodology of using modified ICEC association level vegetation maps created from digital photogrammetry, disturbance history, and FIA P3 data, show promise as an approach to fuel mapping for the following reasons:

(1) Softcopy photogrammetry coupled with ground truthing provides a high level of accuracy for mapping to the association level of the ICEC system.

(2) Fuel loads generated from the FIA P3 plots in the field differ from fuel loads estimated by standard fire models.

(3) Fuel loads within fuel size classes vary by vegetation type, and fuel size classes for some of the modified association level classifications had distinctive fuel loads. Disturbance history appears to play a significant role in explaining why fuel loads differ within associations and will help in creating more accurate fuel maps.

The ultimate goal of this research would be to use all FIA P3 plot data from across the country to generate an index of fuel load by ICEC association level vegetation classification and disturbance history. This could lead to a valuable multi-purpose tool for both land managers and researchers to predict, prevent and manage forest biomass for wildfire.

Developing a New Fuel Load Mapping Strategy

Using: Digital Photogrammetry; International Classification of Ecological Communities; USDA Forest Service, Forest Inventory and Analysis Protocols; and Disturbance History

by

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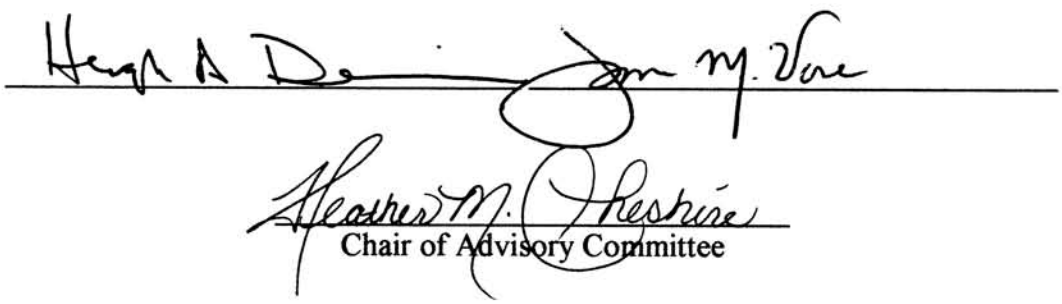

Chair of Advisory Committee

Dedication

To the journey and those who have provided direction and support and those who have made it more enjoyable and exciting.

Biography

The author was born on March 10, 1979 in Ponca City, Oklahoma of all places. He then began his tour of the sunnier parts of the United States, starting in Houston, Texas at around 9 months old, moving on to Irvine, California at age 9, then Las Vegas, Nevada at age 10, and then to West Palm Beach, Florida at age 13 where he attended Wellington High School and where his parents still reside. He went on the University of Florida where he graduated with honors and received a Bachelors of Science in Forest Resources and Conservation in 2001 before starting graduate school at North Carolina State University.

Acknowledgements

First and foremost I would like to thank my family for always being there. Additionally, I would like to thank my advisory committee and all of the CEO for all their help. Also the USDA Forest Service - Southern Global Change Program and their consultants for funding and direction. Finally, I would like to thank all of my friends who have been there to listen and give their two cents over these last few years. Your encouragement has been greatly appreciated.

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Introduction

The driving force behind fuel mapping has been the need for better fire control planning (Sandberg et al., 2001). However, as the view of fire and its role in the environment have changed from suppression to prediction to global change, mapping strategies needed to be reevaluated. From the inception of the USDA Forest Service in 1905 until the 1970s, the primary forest management focus has been fire suppression. During this time period, fuel mapping was based on a system that classified fuels by rate of spread and resistance to control on a "stand by stand" basis. The rate of spread was ranked as low, medium, high, or extreme, based on statistical analysis of fire reports for similar stand types. Resistance to control was estimated by the amount of time it would take to construct a fire line by a hand crew, using the same ranking system of low to extreme (Sandberg et al., 2001). In 1935, the USDA Forest Service's Northern Rocky Mountain Forest and Range Experiment Station and the Civilian Conservation Corps (CCC) mapped 6 million hectares in the Northern Rockies using this fuel mapping approach (Hornby, 1935). Mapping was done using field reconnaissance techniques, with the majority of the mapping being done from lookout points such as burned-over vistas (Keane et al., 2001). The only remotely sensed media used to delineate the stands and for orienteering were black and white aerial photography. Hornby's classification system was the standard to map fuels until the 1970s and is still in use today with new resistance to control classification ratings for newer methods of firefighting, such as indirect and aerial attack (Sandberg et al., 2001).

The research shift to prediction was a direct result of the mass amounts of data collected for national defense in the 1950s and 1960s. In 1972, Rothermel developed a mathematical model to predict fire spread in homogenous wildland fuels (Rothermel, 1972). Rothermel's formulas are the basis for many of the fire spread prediction programs such as Behave (Burgan and Rothermel, 1984), Nexus (Scott, 1999), Farsite (Finney, 1995) and the National Fire Danger Rating System (NFDRS) (Deeming et al., 1978). NFDRS was developed to provide a national system of fuel models and to standardize fuel models for input to fire spread models. The twenty fuel models were based on the amount and arrangement of fuel by class (Deeming, 1978). Albini (1976) used the vegetative descriptions in the fuel models and generalized them down to 13 fuel models. Anderson (1982) used these 13 fuel models to develop a guide, which could be used as an aid in determining fuel loads and fuel models. The guide also included pictures, vegetation descriptions, fuel load estimates, and a table to cross walk between the NFDRS and the Anderson's fuel models. Anderson's fuel models are one of the most widely used fuel models. These 13 fuel models, however, lack key fire inputs for predictive fire models, such as coarse woody debris (dead woody debris ≥ 3 inches in diameter x 3 feet in length), and forest floor depth (litter and duff).

The Fire and Environmental Research Application (FERA) group of the USDA Forest Service is creating the next generation of fuel models. The purpose of the proposed fuel characteristic classification (FCC) system is to "classify fuel beds and to provide numerical inputs to fire behavior, fire effects and dynamic vegetation models" (Sandberg et al., 2001). The fuel beds will be determined by eco-region, vegetation form, cover

type, structure class and disturbance agent. They will be used to create a 3–D fuelbed model for spread rate, crowning potential and fire effects, which could be cross walked back into an Anderson or NFDRS fuel model (Sandberg et al., 2001).

Remote sensing data have become a critical part of natural resources investigations. Landsat Thematic Mapper (TM) has been one of the most widely used tools to classify fuels. Examples of direct fuel mapping using Landsat TM include: Campbell et al. (1995) who classified Camp Lejeune, North Carolina to run prescribed fire simulations with the Farsite model; Van Wagtendonk (1999) who mapped fuels in Yosemite National Park using Normalized Difference Vegetation Index (NDVI) and a multi-temporal approach; and Riano et al. (2002) who assessed fire risk on a landscape level in Spain.

Another method of fuel mapping using remote sensing is the indirect mapping approach. This methodology uses ecosystem characteristics to map fuels, based on the assumption that there is a correlation between ecosystem structure (i.e. species composition, canopy height, canopy closure, etc.) and fuel loads. Some examples of this indirect method of fuel mapping include: Linear Image Self Scanning (LISS) II to create a fuel map for the Rajaji National Park in India (Jain et al., 1996); Advanced Very High Resolution Radiometer (AVHRR) to map NFDRS fuels for the continental United States (Burgan et al., 1998); and Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) data to map fuels in the State of California (Roberts et al., 1998). In these indirect mapping projects, vegetation types were first mapped and then classified into either the Anderson or the NFDRS fuel models. One of the more interesting indirect mapping methods

utilized black and white aerial photographs at 1: 80,000 viewed in stereo (Oswald et al., 1999). Forest stands were delineated by stand composition, basal area, and total crown closure and classified into NFDRS fuel model with 90% accuracy. These studies were limited by their reliance on the generalized Anderson or NFDRS fuel models. Keane et al. (2000) found multiple (3 to 10) different fuel models within the same vegetation class, while mapping fuel on the Gila National Forest in New Mexico.

Another approach to mapping fuels uses topographic, biological, geological, or biogeochemical gradients (Keane et al., 2001) to estimate fuel loads, rather than using standard values associated with specific fuel models. Mickler, et al. (2002) used climate, predicted future net primary production, FIA data and Landsat TM to estimate current and future forest biomass for fuel load mapping in the Southeastern U.S. Although this approach is not of fine enough detail for a local land manager, it does move away from the standardized fuel models.

Greater precision in estimating fuel loads will be needed to predict fire effects such as air quality and biomass consumption (Pyne et al., 1996; Sandberg et al., 2001). Recently, spatial and temporal changes in biomass have been quantified to help predict how global climate changes affect wildfire and nutrient cycling (Pyne et al., 1996). Global change analysis also includes carbon sequestration and nutrient cycling models, which use similar inputs as the fire affect models (Pyne et al., 1996). The Forest Inventory and Analysis (FIA) program ties all of these modeling programs together, since much of the data collected by FIA can be used as inputs multiple modeling efforts. The FIA Phase 3

plots in particular are used to collect fuel load data by measuring coarse woody debris, fine woody debris, litter and duff, live and dead woody shrubs, and herbaceous ground cover (Woodall, 2002).

The need for quantitative, multi-purpose mapping approaches for determining spatial distribution of fuel loads is the foundation for this project. This study investigates the potential for "fine-tuning" fuel mapping by assigning biomass values to detailed vegetation classes. These vegetation classes are based on the association level of the International Classification of Ecological Communities. The association level vegetation is identified based on the dominant species and accounts for forest structure, which is very important for fuel loading and arrangement.

This more detailed level of mapping can be achieved through the use of digital photogrammetry. The advantages of this approach are full screen stereo viewing, "zoom-in" capability, and the ability to delineate vegetation directly into a Geographic Information System (GIS). This reduces the time and error used in previous stereo classification and mapping endeavors (Millinor, 2000, Harrell, 2001 and Koch, 2001). The premise of this approach is that this classification system, coupled with disturbance history, can be correlated with the fuel load generated from the FIA Phase 3 plot data.

Objectives

Fire behavior models require many variables, including above ground biomass or fuel load. Fuel loads include the amount of downed woody debris, duff, litter and live vegetation that can carry a fire, each of which is of primary importance when predicting fire behavior. Collection of these data can be very time consuming and expensive. The purpose of this project was to develop a quantitative, multi-purpose strategy for mapping fuel loads. The general approach was based on classifying vegetation types into categories at the association level of the International Classification of Ecological Communities (ICEC) using digital stereo imagery. The vegetation classes were combined with field measurements of biomass volumes obtained from USDA Forest Service Forest Inventory and Analysis Phase 3 (FIA P3) plots. The overall goal of this study was to determine whether this classification system, coupled with disturbance history, could be correlated with the biomass volumes, and therefore be used to develop vegetation-specific fuel load models.

The specific objectives of this study were to:

(1) Determine the accuracy of softcopy photogrammetry for mapping vegetation at the association level of the ICEC system.

(2) Determine if fuel load estimates based on field data collected with FIA P3 plots were comparable to the fuel loads of standardized fuel models currently in use (Anderson's Fuel Models).

(3) Determine if the association level vegetation classifications had distinctive fuel loads.

Methodology

Study Areas

Four study sites in North Carolina were used for this project, two in the coastal plain and two in the mountains. The two eastern sites are on the border of the United States Fish and Wildlife Service's Alligator River National Wildlife Refuge (ARNWR) and the Department of Defense's (DOD) Dare County Bombing Range (Figure 1). The two coastal plain sites are each 88 acres (36 hectares). The DOD site was last disturbed in March 1980 by wildfire and the ARNWR site was last disturbed in February 2000 by a prescribed burn. Both sites are generally characterized as high pocosin and are found on Belhaven muck.

ARNWR was established in 1984 to preserve a unique wetland habitat, the pocosin. Pocosin is a Native American word meaning "swamp-on-a-hill" (U.S. Fish and Wildlife, 2002). Pocosins are located between major drainages and characterized by poorly drained organic soils. ARNWR is 152,195 acres (61,591 hectares), with the majority of the Refuge being wetlands (high and low pocosin, bogs, fresh and brackish water marshes, hardwood swamps, and Atlantic White Cedar (*Chamaecyparis thyoides*) swamps. The Refuge is probably best known for the reintroduction of endangered red wolves and as home to one of the largest populations of black bears in the Mid-Atlantic States. The Refuge also plays an important role in bird migration, including neo-tropical migrants and waterfowl (U.S. Fish and Wildlife, 2002). The DOD Dare County Bombing Range is surrounded by ARWNR and has similar ecological characteristics.

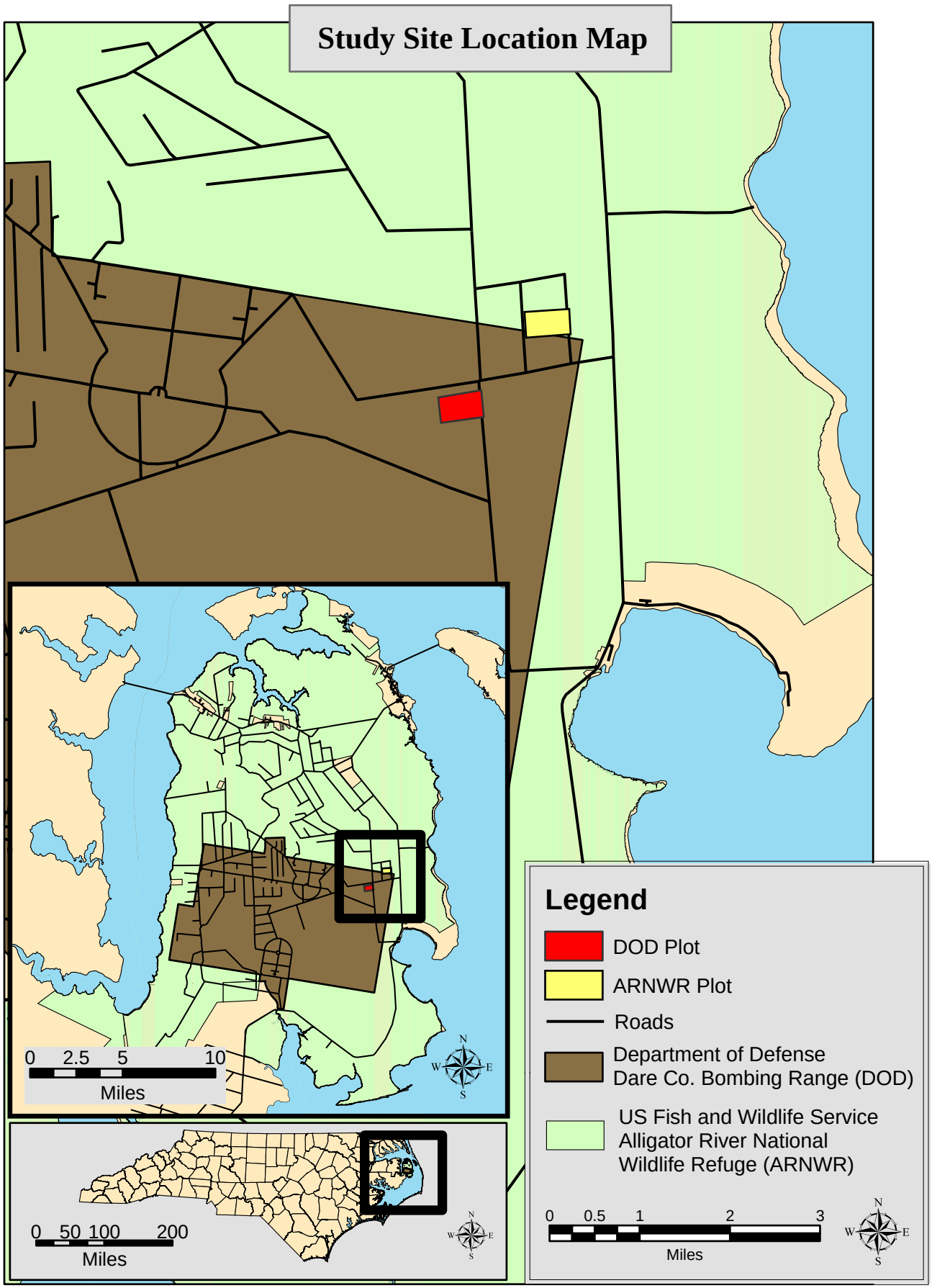

Figure 1. Location of study sites in the Pocosin Region of North Carolina.
Created by Brian Rosenfeld, 2003

The two western sites are located in the USDA Forest Service Coweeta Hydrologic Laboratory and Long Term Ecological Research Center (Coweeta). Coweeta is 5,397 acres (2,185-hectare) and located in the Southern Appalachian Mountains. It was established as a testing ground for forest hydrology projects in 1934 (Swank and Crossley, 1988). The study sites at Coweeta are identified in this study as watersheds #1 and #2 (Figure 2). Watershed #1 is a 39.5 acre (16 hectare) white pine (*Pinus strobus*) plantation planted in 1957. The watershed has a southern aspect and had a prescribed burn and herbicide application prior to planting in 1957. The soils series found in Watershed #1 are Chandler and Fannin. This watershed has never been thinned or harvested, with the only major disturbance being minor windfall damage associated with Hurricane Opal in 1995. In contrast, Watershed #2 is one of Coweeta's control watersheds, and has not been disturbed since it was clear-cut in 1927 (Swank and Crossley, 1988). It is 29.6 acres (12 hectares), with a south-southeast aspect and three distinct mixed hardwood stands. The soil series for Watershed # 2 are also Chandler and Fannin. Watershed #2 was largely unaffected by Hurricane Opal.

Vegetation Mapping

Digital stereo models were created for each site using 1: 40,000 color infrared images from the National Aerial Photography Program (NAPP) using ERDAS Imagine, Orthobase® and Stereo Analyst®. These digital stereo models allow the viewer to view photographs in three dimensions (3-D) on the computer screen with aid of polarized glasses, using the same principles of photogrammetry as a stereoscope and hardcopy

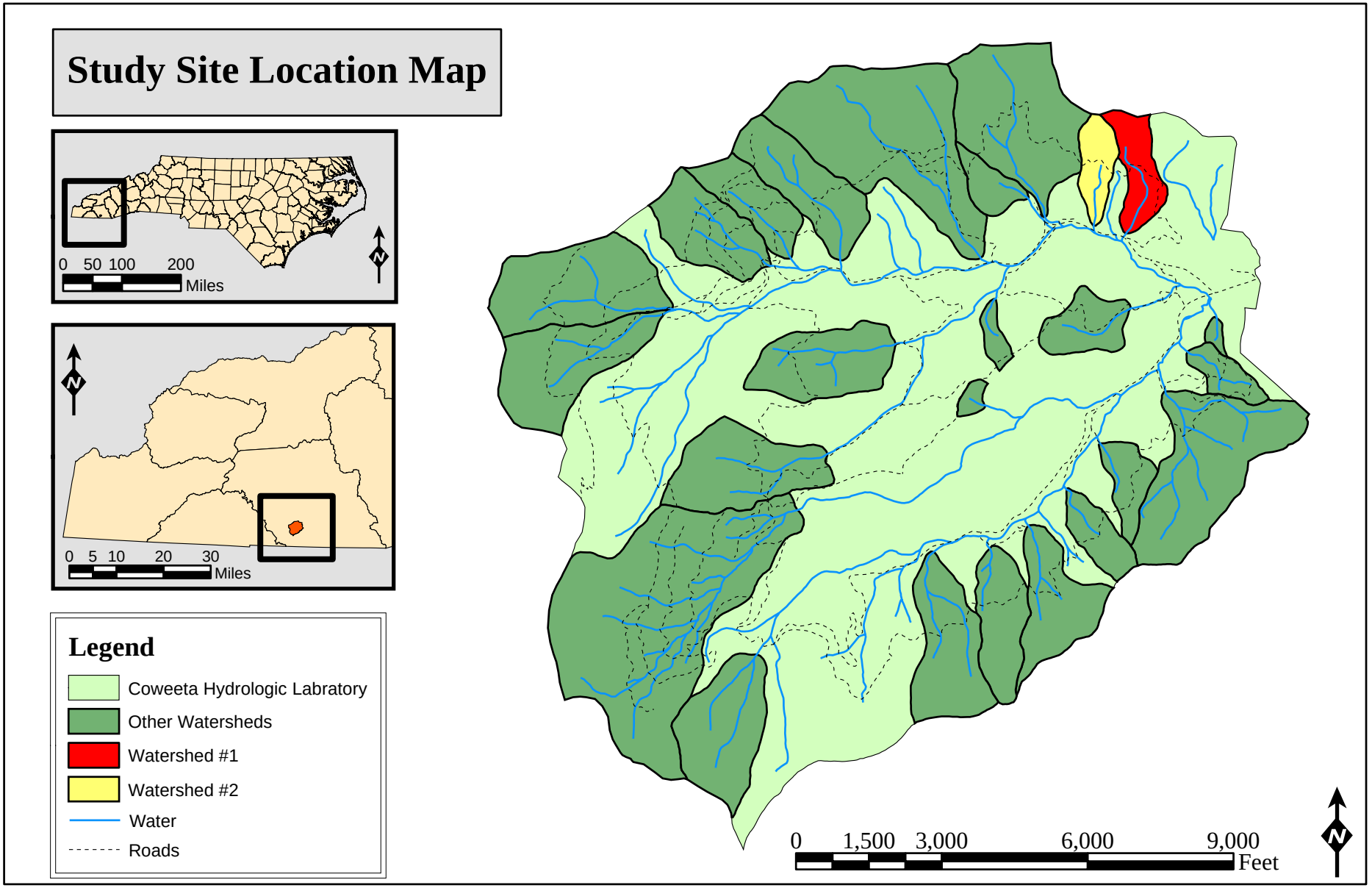

Figure 2. Location of study site in the Mountain Region of North Carolina. Created by Brian Rosnfeld, 2003.

aerial photograph stereo pairs. The NAPP images were scanned with a spatial resolution of approximately 1.4 meters (4.6 feet) per pixel. The digital images were also orthorectified and tiled to create a mosaic for each study area. Ten meter digital elevation models (DEM) resampled from USGS 30 meter DEMs and camera calibration reports from the USGS Optical Science Laboratory were used to orthorectify the images (Appendix 1).

After developing stereo models, vegetation boundaries were delineated within each study site using ERDAS Imagine Stereo Analyst®. The advantages of this method were full screen stereo viewing, zoom-in capability and direct capture of the delineation into a GIS format. These capabilities reduce time and error used in previous stereo mapping approaches (Millinor, 2000, Harrell, 2001 and Koch, 2001). Vegetation types were identified using the ICEC at the association level (Table 1). Specific associations were assigned with the aid of field data. The identification of associations was slightly modified to include disturbance history and canopy closure. Accuracy assessments were performed for the digital photogrammetry classification of each site using the FIA field data collection plots as ground reference (Appendix 1).

Biomass Field Plots

FIA P3 plots have been used nationally by the USDA Forest Service for monitoring wildfire fuels, wildlife habitat and forest condition. The FIA methodology is a statistically tested and proven method to quantify downed woody debris biomass (Chojnacky et al., in preparation). This methodology was selected because it includes

Table 1. Vegetation types identified by modified association and alliances of the International Classification of Ecological Communities.

Site	Association Name	Association ID	Alliance Name	Alliance Code	Modified Classes
ARNWR	Pond Pine/Little Gallberry/VA Chainfern Woodland	CEGL004652	*Pinus serotina* Saturated Woodland	II.A.4.N.f.9	Disturbed Open Pond Pine
ARNWR	Pond Pine-Loblolly Bay/Shining Fetterbush Woodland	CEGL003671	*Pinus serotina* Saturated Woodland	II.A.4.N.f.9	Disturbed Pine Mix (hardwood dominant)
ARNWR	Pond Pine/Little Gallberry/VA Chainfern Woodland	CEGL004652	*Pinus serotina* Saturated Woodland	II.A.4.N.f.9	Disturbed Closed Pond Pine
DOD	Pond Pine-Loblolly Bay/Shining Fetterbush Woodland	CEGL003671	*Pinus serotina* Saturated Woodland	II.A.4.N.f.9	Undisturbed Pine Mix (hardwood dominant)
DOD	Pond Pine/Little Gallberry/VA Chainfern Woodland	CEGL004652	*Pinus serotina* Saturated Woodland	II.A.4.N.f.9	Undisturbed Open Pond Pine
DOD	Pond Pine-Loblolly Bay /Shining Fetterbush Woodland	CEGL003671	*Pinus serotina* Saturated Woodland	II.A.4.N.f.9	Undisturbed Pine Mix (pine dominant)
Coweeta Watershed #1	Eastern White Pine Planted Forest	CEGL007178	*Pinus strobus* Planted Forest	I.A.8.C.x.070	White Pine Plantation
Coweeta Watershed #2	Blue Ridge Pitch Pine Woodland	CEGL007097	*Pinus rigida* Woodland	II.4.A.N.a.23	Ridge Top Pine
Coweeta Watershed #2	Appalachian Montane Oak Hickory Forest (Acidic Type)	CEGL007230	*Quercuse rubra, Carya spp* Forest	I.B.2.N.a.27	Upland Hardwood
Coweeta Watershed #2	Southern Appalachian Acid Cove Forest	CEGL007543	*Tsuga canadensis-Liriodendron tulipifera* Forest	I.C.3.N.a.33	Cove Hardwood

collection of coarse woody debris, fine woody debris, duff, litter, shrubs/herbs, slash piles, and fuel bed depths. The FIA P3 plots were installed randomly on the two pocosin sites, since vegetation types were unknown prior to plot installation. In the mountain study sites, vegetation classes were determined prior to field data collection; therefore, plots were stratified by association and then installed randomly. In all study areas, the sampling intensity was at least one plot per 2 hectares for each vegetation association (Appendix 1).

Each FIA P3 plot is centered over an area equivalent to one hectare and consists of four sub-plots arranged in a triangular formation, with one plot in the center and three sub-plots 120 feet from the center plot at specific compass directions (0, 120 and 240 degrees). Each sub-plot has three, 24 foot transects that are oriented 30, 150 and 270 degrees, respectively. These transects were used to collect information on the amount of woody debris using line intercept sampling, similar to Brown's Transects (Woodall, 2002). Along each transect, data were collected for 1000 hour fuel, 100 hour fuel, 10 hour fuel, and 1 hour fuel (Southern Research Station Field Guide, 2002). Litter and duff depths were measured at the end of each transect (Table 2).

Fuel Type	Fuel Description	Sampling Intensity by Transect
1000 Hour	Coarse woody debris ≥ 3.0 inch diameter and ≥ 3.0 ft. length	24 feet (entire transect length)
100 Hour	Fine woody debris 2.9 to 1.0 in. diameter.	10 feet (section of transect)
10 Hour	Fine woody debris 0.9 to 0.25 in diameter	6 feet (section of transect)
1 Hour	Fine woody debris 0.24 to 0 in diameter.	6 feet (section of transect)
Litter	Depth of loose plant material on the top surface of forest floor	1 point (end of transect)
Duff	Depth of organic soil horizon	1 point (end of transect)

Table 2. Descriptions of different fuel types and their sampling intensities for each transect.

All of these variables are essential to estimating downed woody debris biomass, and can be used to describe fuel characteristics and define fuel loads. The plot design is summarized on the Downed Woody Debris Fact Sheet (Figure 3; Woodall, 2002). The FIA P3 protocols for sampling woody debris can be found at URL: *http://www.fia.fs.us* (Appendix 2).

The only modification to the 2002 FIA P3 sampling procedure was to use the 2001 FIA P3 sampling protocols, which include sampling fine woody material on all three of the plots transects rather than just one. This change was made to increase the number of samples collected. Biomass values were calculated from the field data using Statistical Analysis System® (SAS) code developed by the Forest Inventory Research, Enterprise Unit of the USDA Forest Service (David Chojnacky, personal communication, 2003; Appendix 3). The data were collected from the summer of 2002 through the winter of

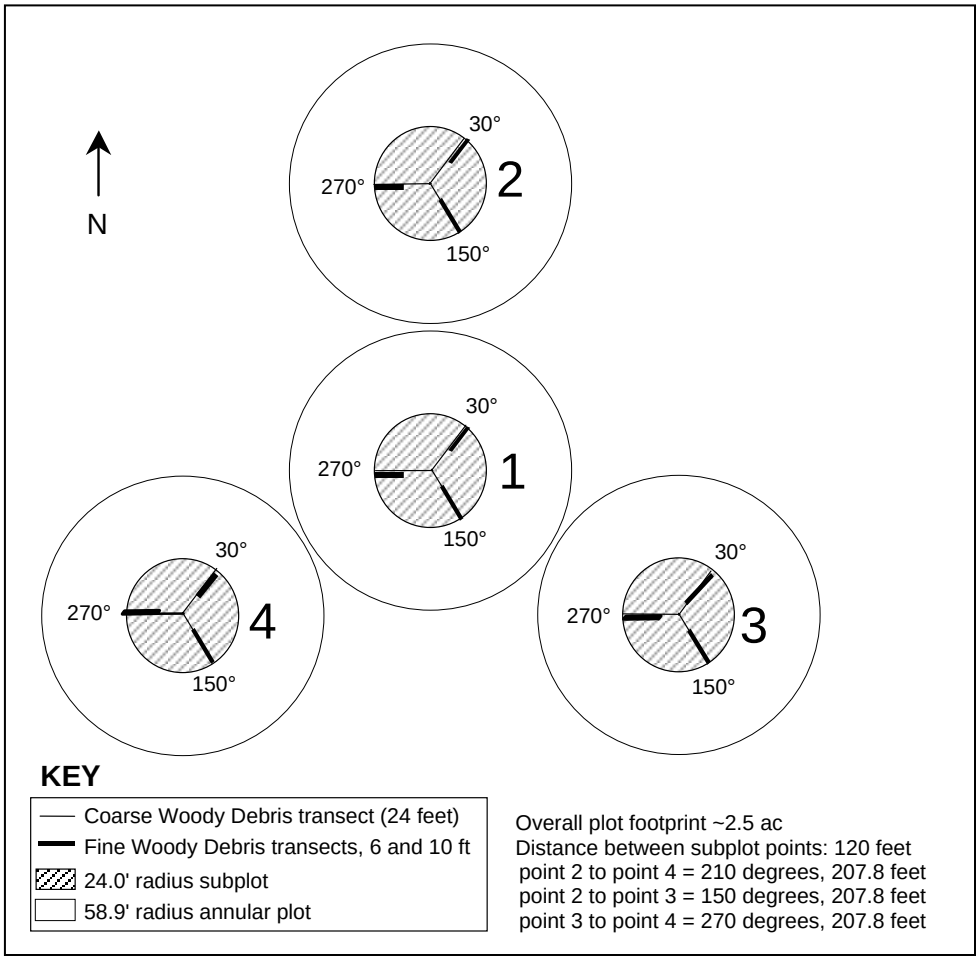

Figure 3. The FIA P3 plot design courtesy Downed Woody Debris Fact Sheet by Chris Woodall, USFS North Central Research Station, URL: *http://www.ncrs.fs.fed.us/4801/DWM* (Appendix 2)

2003, with the assistance of personnel from the USDA Forest Service Southern Global Change Program, Coweeta Hydrologic Lab, and North Carolina State University (Appendix 1).

Data Analysis

On the ARNWR study site, FIA P3 field plots were classified in the field using Anderson's *Aids to Determining Fuel Models for Estimating Fire Behavior* (1982). The Anderson fuel models identified were #4, Chaparral (6 feet) and #7, Southern Rough. The two Anderson's fuel model classes also were reclassified into other standard fuel model classification systems. The field data were then used to calculate average fuel load within each of these fuel model classes, which were compared to the standard fuel loads used by Anderson and other fuel model classification systems.

To determine if fuel loads grouped by vegetation type, disturbance history or location, a principal components analysis (PCA) was used (Ludwig and Reynolds, 1988). PCA is a type of ordination technique. The purpose of this technique is to effectively group data by expressing a many-dimensional relationship in fewer dimensions. A multiple comparison test, the protected least significant difference (LSD), was performed to look at differences between the means of fuel loads by fuel size class and vegetation classification. In a protected LSD, an analysis of variance test is first run to look for significant differences in the data. If significant differences are found, LSD is used to analyze differences between means and group those that are not significantly different (Steel et al., 1997). Five protected LSD tests were run:

(1) Total fuel load grouped by region.

(2) 1 hour, 10 hour, 100 hour, 1000 hour, and litter fuel size classes grouped by region.

(3) Total fuel load grouped by the ICEC association level vegetation classes.

(4) Total fuel load grouped by the modified association level vegetation classes.

(5) 1 hour, 10 hour, 100 hour, 1000 hour, and litter fuel size classes grouped by the modified association level vegetation classifications.

The first two tests were used to determine if there were significant regional or site differences in the fuel loading. The subsequent tests were used to find the level of classification at which the fuel loads could be considered distinctive. With these LSD tests, the mean of each group being tested is compared to all other group means. All statistical tests were conducted with and $\alpha = 0.05$ significance level.

Results

Classification Accuracy

Two ICEC associations were identified on the DOD site (Figure 4). These classifications included: (1) pond pine (*Pinus serotina*) woodland with little gallberry (*Ilex glabra*) and Virginia chain fern (*Woodwardia virginica*) understory (pond pine) and (2) pond pine – loblolly-bay woodland with shining fetterbush (*Lyonia lucida*) understory (pine mix). These were further classified on the basis of site history and canopy characteristics as: (1) undisturbed open canopy pond pine; (2) undisturbed pine mix (pine dominant); and (3) undisturbed pine mix (hardwood dominant).

The same ICEC associations were also identified on the ARNWR site (Figure 5). The modified classes included: (1) disturbed open canopy pond pine; (2) disturbed closed canopy pond pine; and (3) disturbed pine mix (hardwood dominant). Pond Pine appears only in the ICEC woodland classes, not the forest classes. Thus, open canopy pond pine (<60% canopy closure) and closed canopy pond pine (≥60%) are in the same ICEC association.

At the Coweeta site, there was one ICEC association level classification in Watershed #1, white pine (*Pinus strobus*) plantation (Figure 6). Watershed #2 was classified into three ICEC associations: (1) Southern Appalachian Acid Cove forest, which contains eastern hemlock (*Tsuga canadensis*) – tulip tree (*Liriodendron tulipifiera*) – sweet birch (*Betula lenta*) with great rhododendron (*Rhododendron maximum*) understory; (2) Appalachian

DOD Vegetation Map

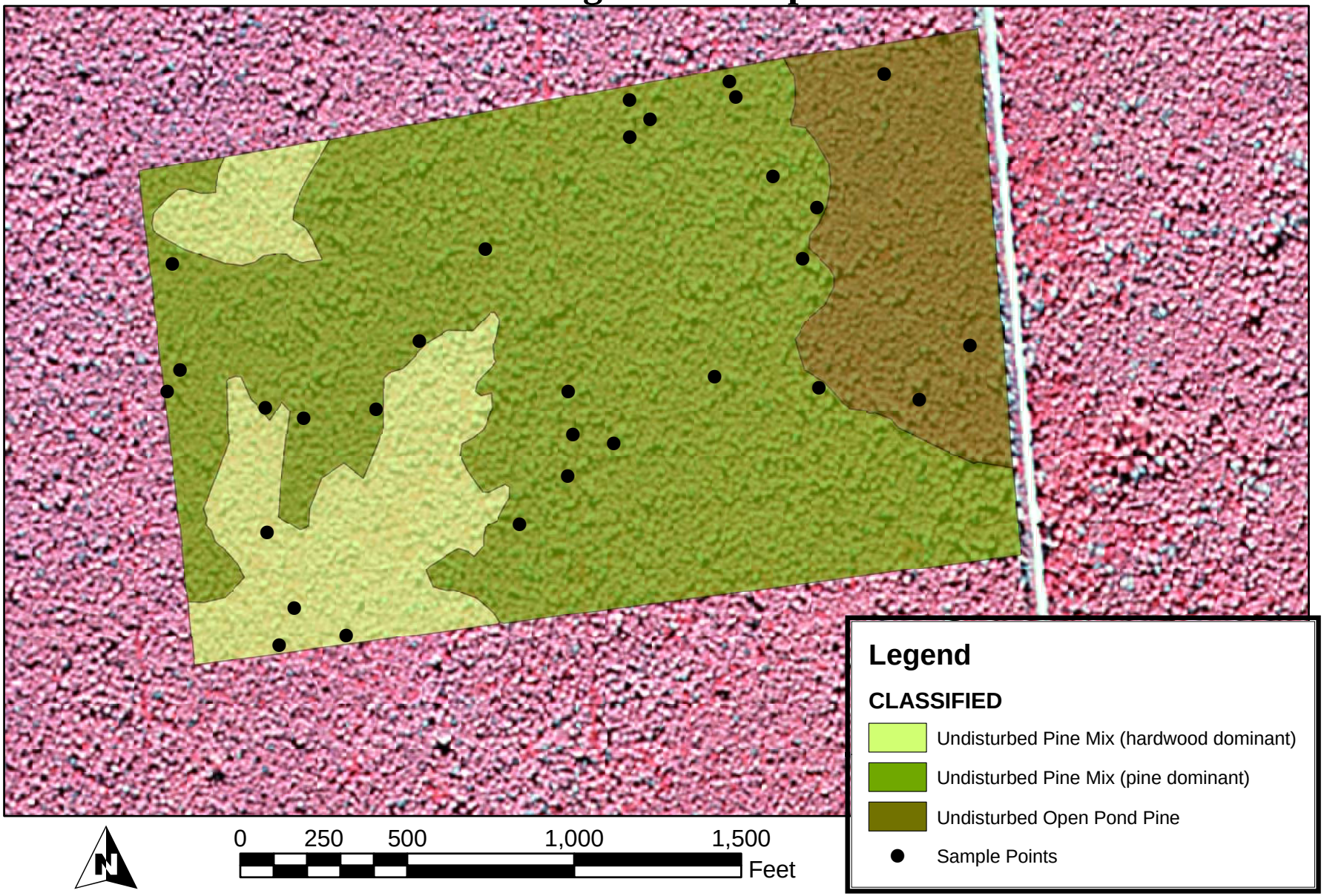

Figure 4. International Classification of Ecological Communities modified for the DOD site in the Pocosin Region. Created by Brian Rosenfeld, 2003.

ARNWR Vegetation Map

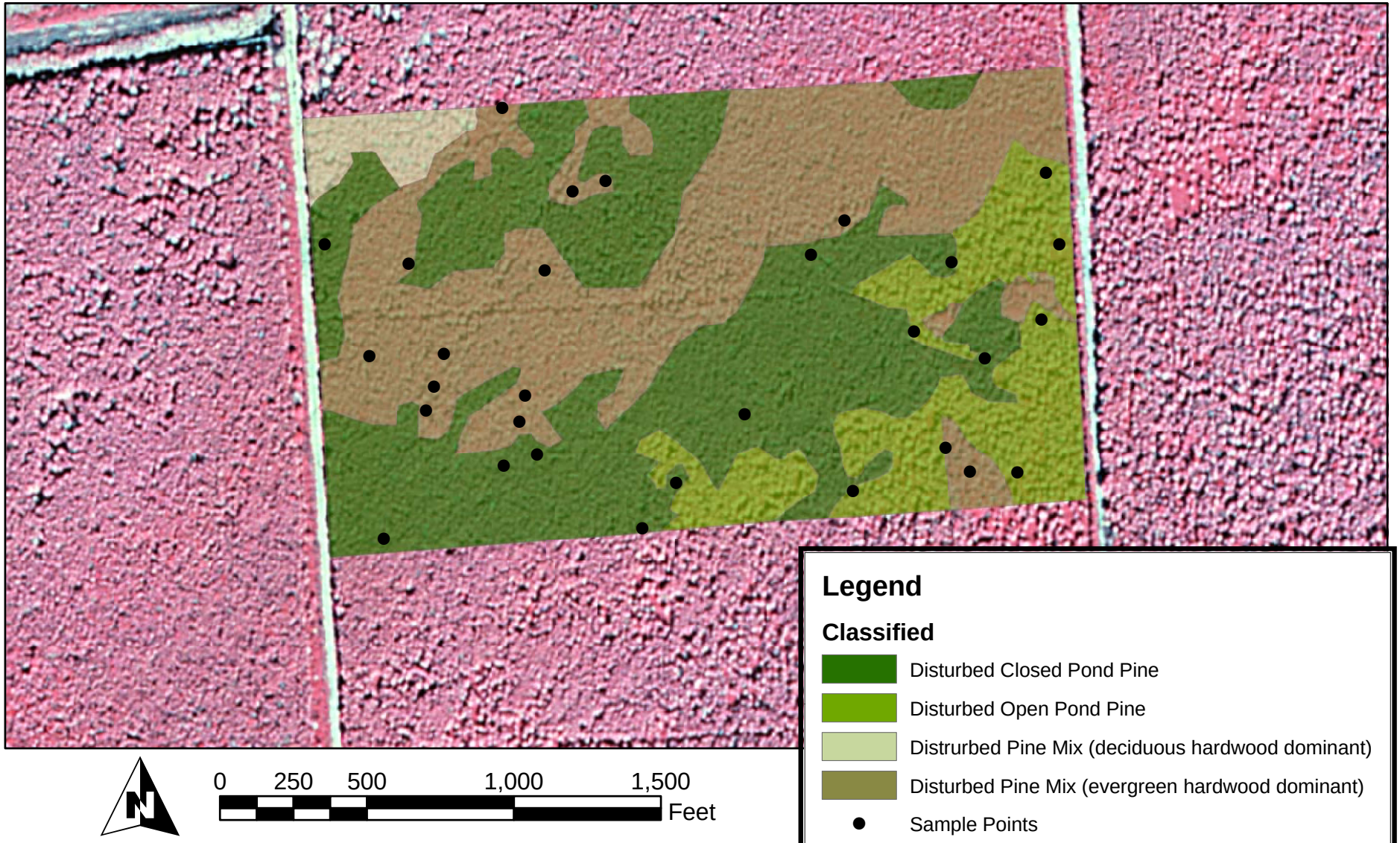

Figure 5. International Classification of Ecological Communities modified for the ARNWR site in the Pocosin Region. Created by Brian Rosenfeld, 2003.

Coweeta Vegetation Map

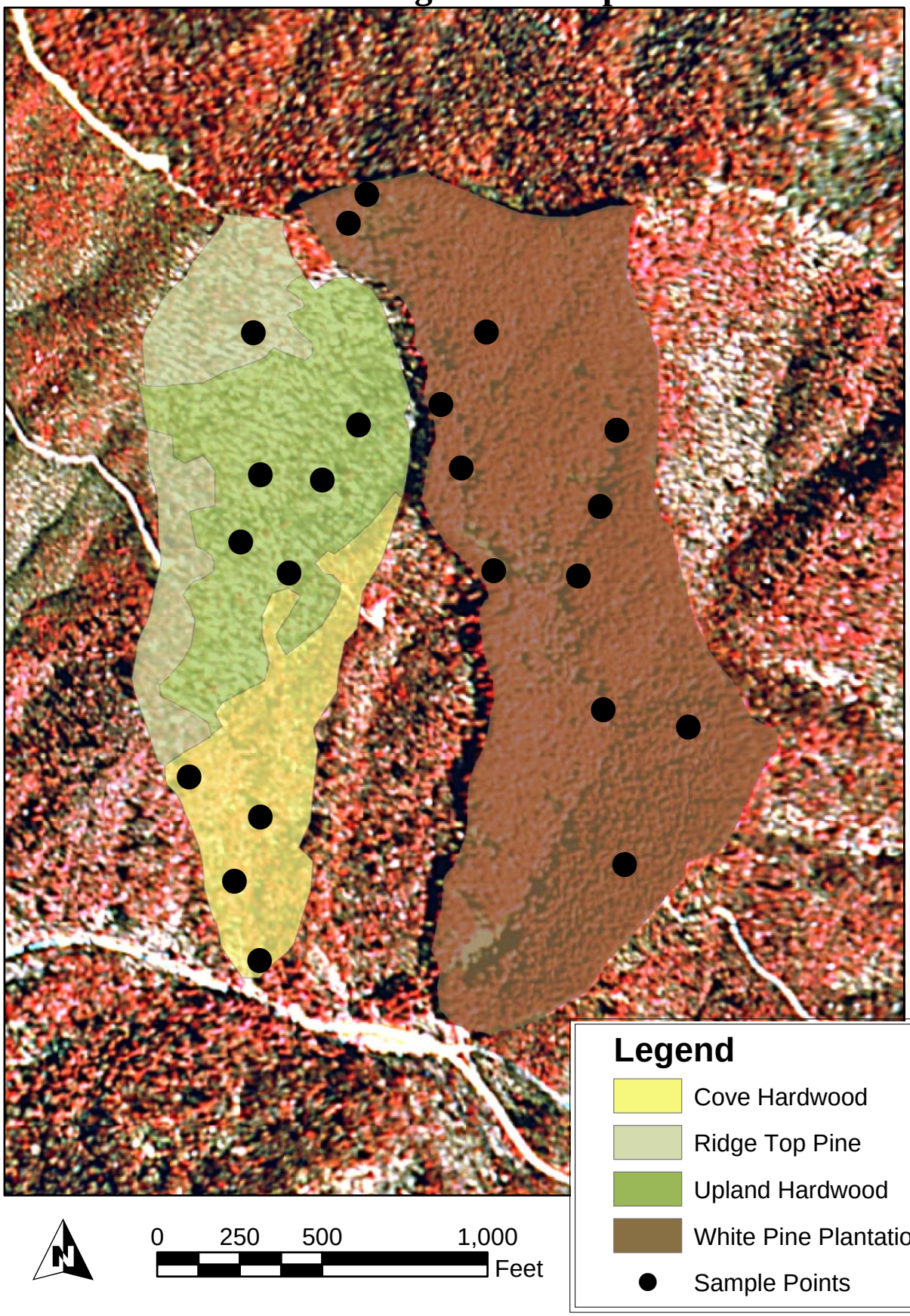

Figure 6. International Classification of Ecological Communities for the Coweeta site in the Mountatain Region. Created by Brian Rosenfeld, 2003.

Montane Oak Hickory Forest which contains white oak (*Quercus alba*) – red oak (*Quercus rubra*) with an understory of flame azalea (*Rhododendron calendulaceum*) and mountain laurel (*kalmia latifolia*); and (3) Blue Ridge Table Mountain Pine (*Pinus pungens*) – Pitch Pine (*Pinus rigida*) Woodland with an understory of mountain laurel and hillside blueberry (*Vaccinuim pallidum*). Since the same associations did not appear in both sites, these categories were not further modified and were identified as (1) white pine plantation, (2) cove hardwood, (3) upland hardwood, and (4) ridge top pine (Appendix 4).

The P3 plot locations were used to determine the accuracy of the classification identified through digital photogrammetry. The overall classification accuracies for the DOD site (83.3%), ARNWR site (96.7%), and both Coweeta watersheds (100%) are summarized in Tables 3-5.

Fire Model Fuel Loads

In order to determine if fuel loads calculated from the field data differed from generalized fuel loads provided by standard fire models, the field data were compared to the fuel loads of the following fire models for the ARNWR site:

(1) Anderson's Fuel Models # 4 and # 7, both of which are in the shrub fuel complex. Fuel Model # 4 is typified by Chaparral (6 foot) and Fuel Model # 7 is a fuel model based on Southern Rough.

(2) The National Fire - Danger Rating System (NFDRS) models *O*, High Pocosin, and *D*, also described as Southern Rough. The NFDRS models were cross walked

Table 3. Classification accuracy assessment for the Department of Defense, Dare County Bombing Range (DOD) on the pocosin site in coastal plain of North Carolina.

Accuracy Assessment of DOD Classification

			Reference Data				
			1	2	3		
Image	1	Pine mix (hardwood domintant)	4	0	0	100.0%	User's Accuracy
	2	Open pond pine	0	3	0	100.0%	
	3	Pine mix (pine domintant)	0	5	18	78.3%	
			100.0%	37.5%	100.0%	83.3%	Overall Accuracy
			Producer's Accuracy				

Table 4. Classification accuracy assessment for the Alligator River National Wildlife Refuge (ARNWR) on the pocosin site in the coastal plain of North Carolina.

Accuracy Assessment of ARNWR Classification

			Reference Data				
			1	2	3		
Image	1	Closed Pond Pine	10	0	0	100.0%	User's Accuracy
	2	Open Pond Pine	0	6	0	100.0%	
	3	Pine Mix (hardwood dominant)	1	0	13	92.9%	
			90.9%	100.0%	100.0%	96.7%	Overall Accuracy
			Producer's Accuracy				

Table 5. Classification accuracy assessment for the USDA Forest Service Coweeta Hydrologic Laboratory and Long Term Ecological Research Center (Coweeta) sites in the mountain region. Both watersheds are included in the assessment.

Accuracy Assessment of the Coweeta Classification

			Reference Data					
			1	2	3	4		
Image	1	White Pine	13	0	0	0	100.0%	**User's Accuracy**
	2	Cove Hardwood	0	4	0	0	100.0%	
	3	Upland Hardwood	0	0	4	0	100.0%	
	4	Ridge Top Pine	0	0	0	1	100.0%	
			100.0%	100.0%	100.0%	100.0%	100.0%	**Overall Accuracy**
			Producer's Accuracy					

using the Physical Descriptions Similarity Chart from Anderson's Fuel Models (Anderson, 1982).

(3) Wendel's (Wendel et al., 1962) fuel model B-20, is high brush. B-20 is described in "Forest Fuels on Organic and Associated Soils in the Coastal Plain of North Carolina."

The fuel load estimates for these standard fire model classes differed from fuel loads that were calculated from field data and calculated using the FIA procedure (Table 6). This is important to note since both the total fuel loads and the composition of the fuel loads vary. The differences in the composition from the standard fuel models is perhaps more important than the total loadings since it is the fuel load composition that is the determining factor for fire behavior.

Fuel Loads (tons/ac)						
		1hr	10hr	100hr	1000 hr	Total
Fuel Load From Field Data, by stand fire model class						
	4	0.51	3.21	2.63	1.09	7.43
	7	0.40	2.46	2.63	1.37	6.85
Anderson's Fuel Model from Anderson (1982)						
	4	5.01	4.01	2.00	n/a	11.02
	7	1.13	1.87	1.50	n/a	4.50
National Fire Danger Rating System Fuel Models from Deeming et al. (1978)						
	4 -> O	2.00	3.00	3.00	2.00	10.00
	7 -> D	2.00	1.00	--	--	3.00
Coastal Carolina Fuel Model From Wendel et. al (1962)						
	4 &7 -> B-20	n/a	n/a	n/a	n/a	5.36

Table 6. Field Data from plots on the ARNWR site grouped by Anderson's fuel models 4 (Chaparral, 6 foot) and fuel model 7 (Southern Rough) compared to standard fuel load values for those fire models. National Fire Danger Rating System fuel models *O* (High Pocosin) and *D* (Southern Rough) and Wendel *et al.* fuel model B-20 (high brush) are classes most similar to Anderson's 4 and 7.

Biomass Data

The mean total biomass measured using the FIA P3 plots ranged from 13.41 tons/acre in undisturbed pine mix, hardwood dominant to 5.24 tons/acre in ridge top pine (Table 7, Appendix 5). Principal component analysis (PCA) indicated that the first two principal components explained 70.7% (47.2% for the 1st component and 23.5% for the 2nd component) of the variability in the biomass values among all plots. The first principal component was a linear combination of the 1000 hour fuels vs. all other fuel components, and the second principal component was a linear combination of litter vs. all other fuel components. A plot of the first two components by vegetation class clearly showed differences in biomass variability by region and site (Figure 7).

The protected LSD results showed significant differences between the total biomass on sites in the pocosin and the Coweeta sites (Table 8-A). When examined by fuel size class, the LSD tests showed a significant difference between 1 hour, 10 hour, and litter fuel size classes on the ARNWR, DOD and Coweeta sites (Table 8-B). The unmodified ICEC association vegetation classes were also analyzed for differences. The Coweeta association types and the pocosin ICEC association types again grouped by their respective region (Table 9-A). The 1000 hour, 100 hour, 10 hour, 1 hour and litter fuel size classes differed by associations found in the Pocosin but generally did not differ between associations found in Coweeta (Table 9-B).

Tests of significance between the modified associations show that some of these modified association types are significantly different from the others in total biomass and in certain

Table 7. Mean tons per acre for each fuel size class and total biomass by modified ICEC vegetation class with a 95% standard error. d = Disturbed site on ARNWR, u = Undisturbed site on DOD, SE = standard error.

Vegetation Type	count	**Total**	SE
d closed pond pine	10	12.99	1.28
d pine mix (hardwood dominant)	14	11.65	1.20
d open pond pine	6	10.00	0.81
u pine mix (hardwood dominant)	4	13.41	2.35
u open pond pine	3	13.05	0.63
u pine mix (pine dominant)	23	12.61	0.98
cove hardwood	4	6.13	2.90
ridge top pine	1	5.24	n/a
upland hardwood	5	8.64	2.52
white pine	15	8.64	1.31

Vegetation Type	count	**1000 Hr**	SE	**1 Hr**	SE	**10 Hr**	SE	**100 Hr**	SE	**Litter**	SE
d closed pond pine	10	1.36	1.05	0.50	0.13	3.20	0.70	3.65	0.68	4.28	0.59
d pine mix (hardwood dominant)	14	1.49	0.57	0.32	0.10	2.09	0.34	2.61	0.49	5.14	1.15
d open pond pine	6	0.45	0.65	0.66	0.15	3.83	0.33	1.76	0.41	3.30	0.49
u pine mix (hardwood dominant)	4	1.70	0.29	0.30	0.10	1.94	0.60	1.74	0.81	7.72	2.09
u open pond pine	3	3.22	2.46	0.29	0.14	1.02	0.43	0.93	0.18	7.59	1.92
u pine mix (pine dominant)	23	2.09	0.56	0.23	0.03	1.38	0.15	1.74	0.22	7.17	0.82
cove hardwood	4	3.14	2.10	0.12	0.04	0.33	0.12	1.49	0.31	1.03	0.88
ridge top pine	1	3.46	N/A	0.12	N/A	0.32	N/A	0.76	N/A	0.57	N/A
upland hardwood	5	4.64	1.70	0.13	0.03	0.36	0.11	2.04	0.44	1.47	0.90
white pine	15	3.77	1.99	0.12	0.02	0.67	0.11	2.37	0.55	1.70	0.39

Figure 7. First two principal components derived from all fuel size classes across all plots. PCA 1 is primarily 1000 hour fuel and PCA 2 primarily is litter.

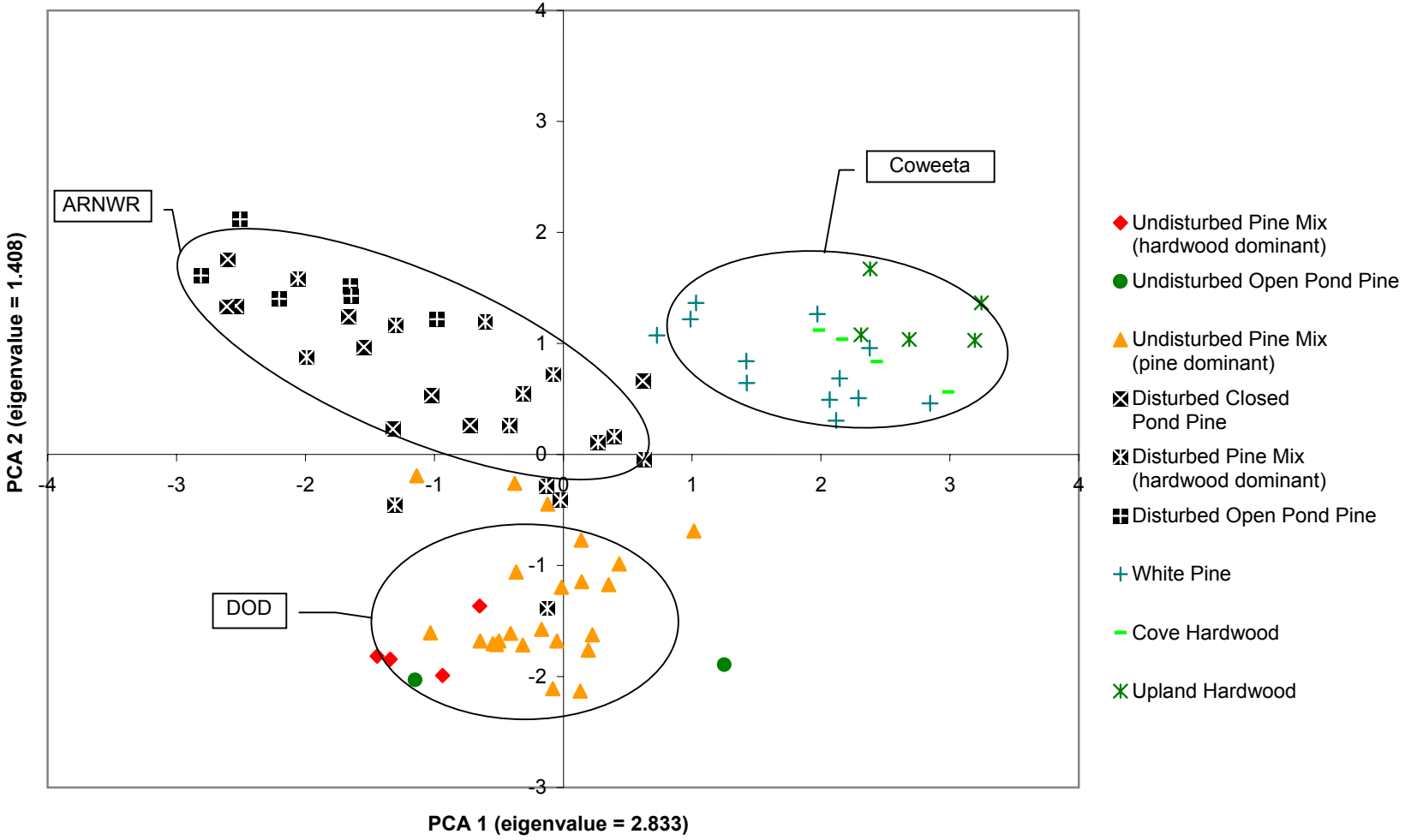

Table 8. The means and standard errors (stderr) for total biomass (A) and for fuel load size classes (B) grouped by site using the least significance difference (LSD) test. Means underscored on the same horizontal line are not significantly different at $p < 0.05$. Blue Ridge Table Mountain Pine-Pitch Pine Forest in Watershed 2 not included in test since sample size = 1.

A

Total Biomass				
Site	DOD	ARNWR	Watershed 1	Watershed 2
Mean	12.76	11.77	7.51	7.30
stderr	0.41	0.41	0.75	0.93

B

1000 Hour				
Site	DOD	ARNWR	Watershed 1	Watershed 2
Mean	2.15	1.24	2.79	3.92
stderr	0.25	0.24	0.52	0.59

C

100 Hour				
Site	DOD	ARNWR	Watershed 1	Watershed 2
Mean	1.66	2.79	2.23	1.69
stderr	0.11	0.18	0.28	0.20

D

10 Hour				
Site	DOD	ARNWR	Watershed 1	Watershed 2
Mean	2.15	1.24	2.79	3.92
stderr	0.25	0.24	0.52	0.59

E

1 Hour				
Site	DOD	ARNWR	Watershed 1	Watershed 2
Mean	2.15	1.24	2.79	3.92
stderr	0.25	0.24	0.52	0.59

F

Litter				
Site	DOD	ARNWR	Watershed 1	Watershed 2
Mean	2.15	1.24	2.79	3.92
stderr	0.25	0.24	0.52	0.59

Table 9. The means and standard errors (stderr) for total biomass (A) and fuel load size classes (B-F) grouped by the Association level of the International Classification for Ecological Communities using the least significance difference (LSD) test. Means underscored on the same horizontal line are not significantly different at $p < 0.05$. Blue Ridge Table Mountain Pine-Pitch Pine Forest was not tested since sample size = 1.

	Total Biomass					
A	Pond Pine woodland - gallberry/fern understory	Pond pine - loblolly bay woodland	White Pine Plantation	Southern Appalachian Acid Cove Forest	Appalachian Montane Oak Hickory Forest	Blue Ridge Table Mountain Pine - Pitch Pine Forest
Mean	12.06	12.36	7.51	6.13	8.64	5.24
stderr	0.49	0.37	0.75	1.48	1.29	n/a

	1000 Hour Fuel					
B	Pond Pine woodland - gallberry/fern understory	Pond pine - loblolly bay woodland	White Pine Plantation	Southern Appalachian Acid Cove Forest	Appalachian Montane Oak Hickory Forest	Blue Ridge Table Mountain Pine - Pitch Pine Forest
Mean	1.37	1.85	2.79	3.14	4.64	3.46
stderr	0.40	0.19	0.52	1.07	0.87	n/a

C	100 Hour Fuel					
	Pond Pine woodland - gallberry/fern understory	Pond pine - loblolly bay woodland	White Pine Plantation	Southern Appalachian Acid Cove Forest	Appalachian Montane Oak Hickory Forest	Blue Ridge Table Mountain Pine - Pitch Pine Forest
Mean	3.28	2.04	2.23	1.49	2.04	0.76
stderr	0.32	0.13	0.28	0.16	0.22	n/a

D	10 Hour Fuel					
	Pond Pine woodland - gallberry/fern understory	Pond pine - loblolly bay woodland	White Pine Plantation	Southern Appalachian Acid Cove Forest	Appalachian Montane Oak Hickory Forest	Blue Ridge Table Mountain Pine - Pitch Pine Forest
Mean	3.06	1.68	0.67	0.33	0.36	0.32
stderr	0.29	0.09	0.06	0.06	0.06	n/a

E	1 Hour Fuel					
	Pond Pine woodland - gallberry/fern understory	Pond pine - loblolly bay woodland	White Pine Plantation	Southern Appalachian Acid Cove Forest	Appalachian Montane Oak Hickory Forest	Blue Ridge Table Mountain Pine - Pitch Pine Forest
Mean	0.52	0.27	0.12	0.12	0.13	0.12
stderr	0.05	0.02	0.01	0.02	0.02	n/a

F	Litter					
	Pond Pine woodland - gallberry/fern understory	Pond pine - loblolly bay woodland	White Pine Plantation	Southern Appalachian Acid Cove Forest	Appalachian Montane Oak Hickory Forest	Blue Ridge Table Mountain Pine - Pitch Pine Forest
Mean	4.49	6.53	1.71	1.03	1.47	0.57
stderr	0.40	0.35	0.23	0.45	0.46	n/a

fuel size classes (Table 10). Disturbed open pond pine tended to be significantly different from all other pocosin classes in total biomass, but similar to some of the mountain classes (Table 10-A). Disturbed open canopy pond pine did not group with any other vegetation type in the 1 hour (Table 10-B) and 10 hour fuels (Table 10-C); disturbed closed canopy pond pine did not group with any other vegetation type in both the 10 hour (Table 10-C) and the 100 hour fuels (Table 10-D).

Table 10. The means and standard errors (stderr) for total biomass (A) and fuel load size classes (B-F) grouped by the modified Association level of the International Classification for Ecological Community using the least significance difference (LSD) test. Means underscored on the same horizontal line are not significantly different at $p < 0.05$. Blue Ridge Table Mountain Pine-Pitch Pine Forest was not tested since sample size = 1.

	Total Biomass									
A	Undisturbed Evergreen Hardwood	Undisturbed Open Pond Pine	Undisturbed Pine Mix	Disturbed Closed Pond Pine	Disturbed Evergreen Hardwood	Disturbed Open Pond Pine	White Pine Plantation	Southern Appalachian Acid Cove Forest	Appalachian Montane Oak Hickory Forest	Blue Ridge Table Mountain Pine - Pitch Pine
Mean	13.41	13.05	12.61	12.99	11.65	10.00	7.51	6.13	8.64	5.2
stderr	1.20	2.09	0.74	0.66	0.61	0.41	0.75	1.48	1.29	n/a

B	1000 Hour Fuel									
	Undisturbed Evergreen Hardwood	Undisturbed Open Pond Pine	Undisturbed Pine Mix	Disturbed Closed Pond Pine	Disturbed Evergreen Hardwood	Disturbed Open Pond Pine	White Pine Plantation	Southern Appalachian Acid Cove Forest	Appalachian Montane Oak Hickory Forest	Blue Ridge Table Mountain Pine - Pitch Pine
Mean	1.70	3.22	2.09	1.36	1.49	0.45	2.79	3.14	4.64	3.46
stderr	0.30	2.18	1.36	1.70	1.09	0.81	1.81	2.14	1.93	n/a

C	100 Hour Fuel									
	Undisturbed Evergreen Hardwood	Undisturbed Open Pond Pine	Undisturbed Pine Mix	Disturbed Closed Pond Pine	Disturbed Evergreen Hardwood	Disturbed Open Pond Pine	White Pine Plantation	Southern Appalachian Acid Cove Forest	Appalachian Montane Oak Hickory Forest	Blue Ridge Table Mountain Pine - Pitch Pine
Mean	1.74	0.93	1.74	3.65	2.61	1.76	2.23	1.49	2.04	0.76
stderr	0.41	0.09	0.11	0.35	0.25	0.21	0.28	0.16	0.22	n/a

D	10 Hour Fuel									
	Undisturbed Evergreen Hardwood	Undisturbed Open Pond Pine	Undisturbed Pine Mix	Disturbed Closed Pond Pine	Disturbed Evergreen Hardwood	Disturbed Open Pond Pine	White Pine Plantation	Southern Appalachian Acid Cove Forest	Appalachian Montane Oak Hickory Forest	Blue Ridge Table Mountain Pine - Pitch Pine
Mean	1.94	1.02	1.38	3.20	2.09	3.83	0.67	0.33	0.36	0.32
stderr	0.31	0.22	0.08	0.36	0.17	0.17	0.06	0.06	0.06	n/a

E	1 Hour Fuel									
	Undisturbed Evergreen Hardwood	Undisturbed Open Pond Pine	Undisturbed Pine Mix	Disturbed Closed Pond Pine	Disturbed Evergreen Hardwood	Disturbed Open Pond Pine	White Pine Plantation	Southern Appalachian Acid Cove Forest	Appalachian Montane Oak Hickory Forest	Blue Ridge Table Mountain Pine - Pitch Pine
Mean	0.30	0.29	0.23	0.50	0.32	0.66	0.12	0.12	0.13	0.12
stderr	0.05	0.07	0.02	0.07	0.05	0.08	0.01	0.02	0.02	n/a

	Litter									
F	Undisturbed Evergreen Hardwood	Undisturbed Open Pond Pine	Undisturbed Pine Mix	Disturbed Closed Pond Pine	Disturbed Evergreen Hardwood	Disturbed Open Pond Pine	White Pine Plantation	Southern Appalachian Acid Cove Forest	Appalachian Montane Oak Hickory Forest	Blue Ridge Table Mountain Pine - Pitch Pine
Mean	7.72	7.59	7.17	4.28	5.14	3.30	1.71	1.03	1.47	0.57
stderr	1.07	0.98	0.42	0.30	0.58	0.25	0.23	0.45	0.46	n/a

Discussion

Digital photogrammetry was an excellent tool for detailed classification of different vegetation types. The ability to distinguish various canopy shapes, heights and compositions in three dimensions improved the interpretation and classification of aerial photography, though there are limitations to this approach. For example, many of the ICEC associations have identical canopy characteristics, but different understory and ground vegetation components that cannot be identified directly from aerial photography. Hence, a major component of any attempt to map to the ICEC association level using digital photography will require visiting the site and ground truthing.

The comparison of fuel loads generated from the field data to fuel loads published for standard fuel models shows the limitations of using a fuel load from standard fuel models. The total fuel loads determined in this study are similar to those determined by Wendel et al. (1962), who defined and quantified fuel types on organic soils in eastern North Carolina. Although the Wendel et al. (1962) study did not include 1000 hour fuels, their study validates estimates generated from the FIA P3 plots. These results indicate that more localized, or even regionalized, vegetation types such as ICEC associations provide a better estimator of total fuel load than those provided with standard fuel models.

The principal component analysis (PCA) provided a good visual and interpretive representation of the differences in fuel loads among the vegetation types. Most of the

differences between the vegetation types were related to variations in 1000 hour fuels, and litter. These explanatory variables provide guidance for developing mapping strategies for wildland fuels, such as using vegetation types and ancillary data. For example, soil data could be used to map general litter depth (Oe horizon) based on the soil profiles defined by the USDA Soil Conservation Service and combined with high resolution imagery to identify areas with downed trees (1000 hour fuel). These ancillary data sources could aid in identifying areas with dangerous fire conditions.

PCA also showed that fuel loads clustered together by location. The pocosin sites (ARNWR and DOD) were distinguishable by disturbance history. The ARNWR site was prescribe burned in February 2000 and the DOD site was last disturbed by wildfire in March 1980. This would suggest that it is critical to consider the frequency and severity of historical disturbances when determining fuel loads, since that appears to be the only ecological difference between the two pocosin sites. This is noteworthy, since the disturbance history has a dramatic influence on the overall fuel load composition but is not included in most vegetation classifications. Disturbance history is difficult to monitor remotely and needs to be recorded over long periods of time. This would indicate that local knowledge is also an important component in developing reliable fuel load estimates.

Both the pocosin sites were significantly different than the Coweeta sites in most fuel load size classes. It is interesting to note that the sites that have not been recently been disturbed by fire (DOD, Watershed 1 and Watershed 2) are most similar. The fuel beds of

the DOD, Watershed 1 and Watershed 2 appear to have reached a common "steady – state" value, which may be related to a lack of significant disturbances over the past several years. It is important to note that disturbance can both increase a fuel load (ex. hurricane, insects, etc) as well as reduce the fuel load (ex. fire, pine straw harvest, etc). A point for further study would be to investigate how the regularity of fire and varying fire intensities, such as fires of low intensity (prescribed fire) and high intensity (wildfire), affect the composition of fuel loads.

The vegetation types on the Coweeta sites did not show significant differences (Tables 8, 9, 10). All four vegetation types at Coweeta can be classified into Anderson's #8 Fuel Model, a timber fuel model, in which the primary fuel source is either a stand with short needles with a normal downed dead wood or a stand with hardwood litter (Anderson, 1982). These similar fuel loading arrangements would also be an interesting subject for further study to determine if there is more uniformity in fuel loads in the mountains than in the coastal plain of North Carolina. There are two vegetation types that have completely unique fuel loads for four fuel size classes. The disturbed closed pond pine 10 hour and 100 hour fuel classes, and disturbed open pond pine 10 hour and 1 hour fuel classes are different from the rest of the vegetation types (Table 10).

These preliminary steps towards creating more precise multi-purpose fuel maps for land managers show promise. Researchers could also monitor forest biomass for nutrient cycling and carbon sequestration with this data. In addition this data could be used to

model smoke emissions from forest fires. The improved spatial representation of fuel loads would also help to focus fuel reduction efforts.

Conclusions

The methodology of using modified ICEC association level vegetation maps, created from digital photogrammetry, disturbance history, and FIA P3 data, shows promise as an approach to fuel mapping.

(1) Softcopy photogrammetry, coupled with ground truthing, provides a high level of accuracy for mapping to the association level of the ICEC system.

(2) Fuel loads generated from the FIA P3 plots differ from fuel loads estimated using the standard fire models. These differences could have an impact on the prediction of fire spread and behavior.

(3) Fuel loads within fuel size classes did vary between the modified association level classifications. Disturbance history appears to play a significant role in explaining why fuel loads differ and could help in creating more accurate fuel maps.

Research of this nature may lead to use of FIA P3 plot data to generate an index of fuel load by ICEC association level vegetation classification and disturbance history. This could lead to a valuable multi-purpose tool for land managers and researchers for use in predicting, preventing and managing forest biomass for wildfire.

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Appendix 1. Data Collection and Preparation

1. Creating a Digital Photogrammetric Stereo Model

1.1 Data Preparation - Raw Imagery

A total of 9 National Aerial Photography Program (NAPP) images were obtained from the Earth Resource Observation Systems (EROS) Data Center using the United States Geological Survey (USGS) Photofinder (URL: *http://edc.usgs.gov/photofinder*). NAPP imagery is flown at approximately 1:40,000 under leaf-off conditions using color infrared film. The images are centered on 1/4 sections of a 7.5-minute USGS quadrangle, and cover a ground area slightly larger than five miles on each side (approx. 30 square miles/ photo). Ground resolution is approximately 1.6 meters (4.6 ft). All NAPP imagery is cloud free and is flown to have stereoscopic coverage. The USDA Forest Service's Southern Global Change Program acquired 9 x 9 inch color infrared positive film. Film products tend to have higher resolution than prints. Six of the images were for the Coweeta site (4/2/1998) and the remaining three were for the Alligator River site (1/16/1999).

The images were scanned using a desktop scanner and Adobe Photoshop. The images were scanned at 720 dpi with 24-bit color and saved as Tagged-Image File Format (.tiff). The average file size was 128 MB. The scanning resolution (dpi) was increased compared to previous stereo models created by Millinor (2000), Harrell (2001), and Koch (2001), in order to extract more detail and make classification easier. Scanning at resolution rates

800 dpi or higher resulted in grainy images. These tiff files were then imported into ERDAS Imagine's image format.

1.2 Additional Data Required

Digital elevation models (DEM) for the two sites were acquired from the USGS EROS Data Center's Seamless Data Distribution website (URL: *http://seamless.usgs.gov/*) in Arc Interchange format (*.e00). The DEMs were resampled from 30 meters to 10 meters and reprojected from Universal Transverse Mercator (UTM) into State Plane Zone 3200 NAD 1983 meters using the ESRI Arc Toolbox. The resampled and reprojected DEMs were imported into Imagine format (*.img), in order to provide the z values used during orthorectification. The X and Y coordinates were acquired from Digital Orthophoto Quarter Quads (DOQQs). The DOQQs were acquired from the North Carolina State University Library GIS website (URL: *http://www.lib.ncsu.edu/stacks/gis/*). The DOQQs were originally produced by the USGS and the North Carolina Center for Geographic Information and Analysis (NC CGIA).

The final piece of data required is the Camera Calibration Reports from the USGS Optical Science Laboratory. The project code (ex. NAPP), film roll number, and image date and location, are needed in order to request the camera calibration report. More information about acquiring camera calibration reports can be found at the following **URL:** (*http://mac.usgs.gov/mac/tsb/osl/calreports.html*).

1.3 Orthorectification and Creation of Stereo Models

With all the necessary data in the proper formats, ERDAS Imagine OrthoBase was used to create a block file (.blk). The block file arranges and orients the individual images and then orthorectified the images as a single "block" of imagery using ground control points. Individual orthorectified images can also be created from each photograph. The DOQQs and the DEM were used to acquire X, Y and Z values for each ground control point. Two different flights lines with two different cameras were used (one for the mountains and one for the coast). Two different block files had to be created since Imagine can only handle one sensor per block.

2. Collection of Biomass and Fuel Model using Forest Inventory Analysis P3 Plots

2.1 Description of the Plots

FIA P3 plots have been used nationally by the USDA Forest Service for forest health monitoring relating to wildfire fuels and wildlife habitat. The FIA methodology is a statistically valid and proven method to quantify downed woody debris biomass (Chojnacky, in preparation). This methodology was selected for use in this project, because it includes collection of coarse woody debris, fine woody debris, duff, litter, shrubs/herbs, slash piles, and fuelbed depths. All of these variables are key to estimating downed woody debris biomass, which is needed to describe fuel characteristics and create fuel models. Each P3 plot consists of four sub-plots arranged in a triangular formation, with one plot in the center and three sub-plots 120 feet at specific compass directions (0, 120 and 240 degrees) from the center plot. Each sub-plot has three 24 foot

transects that are oriented 30, 150 and 270 degrees, respectively. The coarse and fine woody debris occurrences are recorded on these transects. At the end of each of these transects, the duff, litter, and fuelbed depths are measured. Each of these sub-plots also has a 6.8 foot radius (0.013 ac) micro-plot, where the height and percent cover of live and dead herbaceous, and shrub materials are recorded. More information about the FIA program can be found at URL: *http://www.fia.fs.us* (Appendix_2).

The P3 plots collections are adapted from Brown's Transects, which is the standard method for collecting data relating to downed woody material. Instead of going in two directions for 100 feet, the P3 plot consists of 12 - 24 foot transects covering 2.47 acres (1 hectare). The only modification from the standard P3 plot was to collect fine woody debris on all three sub-plots transects, as opposed to just one, in order to increase the number of samples collected in the sub-plots. The protocols for installation of the plot can be found in Appendix 2.

2.2 Location of Plots

Plots were located within the designated study areas using the Random Point Generator created by Jeff Jenness and made available on the ESRI webpage (URL: *http://www.esri.com*) under Free ArcScripts. The Random Point Generator is a free extension available for ArcView 3.x. The plots were placed randomly in both sites at ARNWR and watershed #1 at Coweeta. In watershed #2 at Coweeta, the plots were stratified randomly by vegetation type since this was the only area that was previously mapped and known to have multiple identified vegetation types. The field plot shapefile

was exported to a global positioning system (GPS) using another Free ArcScript created by David Kimble.

2.3 Data Collection

The data was collected from the summer of 2002 through the winter of 2003, with the assistance of the employees of the USDA Forest Service Southern Global Change Program and Coweeta Hydrologic Lab.

2.4 Data Analysis

Biomass values were calculated from the data using a Statistical Analysis System (SAS) code developed by David Chojnacky of the Forest Inventory Research, Enterprise Unit of the USDA Forest Service. Tracy Robinson, Dr. Marcia Gumpertz, and Dr. Leonard Stefnaski of the Statistics Department of North Carolina State University provided statistical consulting. Frank Koch provided help with the SAS program.

Appendix 2. USDA Forest Service Forest Inventory and Analysis

Protocols for Sampling Woody Debris

TALLY RULES FOR COARSE WOODY DEBRIS (CWD)

1. Coarse woody debris (CWD) is sampled in accessible forest land conditions only.
   Tally a piece if its central longitudinal axis intersects the transect, and the condition class is accessible forest land at the point of intersection (Figure 14-3). The entire piece is assigned to this condition.

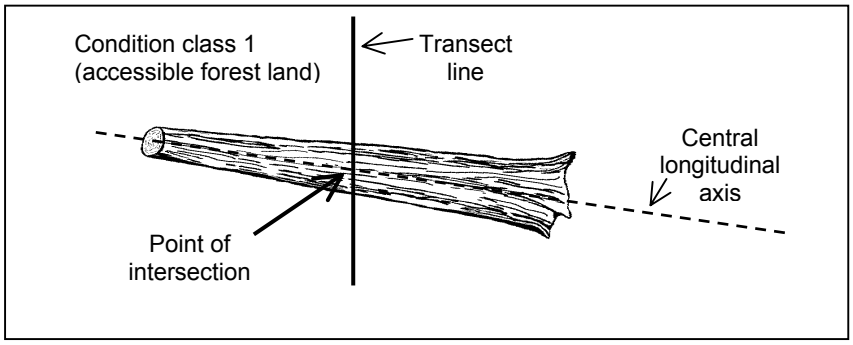

Figure 14-3. Tally rules for CWD.

2. Tally dead trees and tall stumps that are leaning > 45 degrees from vertical. Do not tally live trees or standing dead trees and stumps that are still upright and leaning < 45 degrees from vertical. Follow the same rules for down trees (LEAN ANGLE) as outlined in the 'Tree and Sapling Data' section. Most CWD will be laying on the ground.

3. The minimum length of any tally piece is 3.0 feet. When CWD pieces are close to 3 feet, measure the length to the nearest 0.1 ft to determine if it is ≥3.0 ft.

4. Tally rules depend on the decay class of the piece. (see section 14.8.9)

   For decay classes 1 to 4: tally a piece if it is ≥ 3.0 inches in diameter at the point of intersection with the transect. The piece must be ≥ 3.0 feet in length and ≥ 3.0 inches or more in diameter along that length. If the intersect diameter is close to 3.0 inches, measure the diameter to the nearest 0.1 inch to determine if the piece qualifies (Figure 14-4).

   For decay class 5: tally a piece if it is ≥ 5.0 inches in diameter at the point of intersection and **≥ 5.0 inches high from the ground.** The piece must be ≥ 3.0 feet in length and ≥ 5.0 inches or more in diameter along that length. The reason for treating decay class 5 pieces differently is because they are difficult to identify, especially when heavily decomposed. Only pieces that still have some shape and log form are tallied—humps of decomposed wood that are becoming part of the duff layer are not tallied.

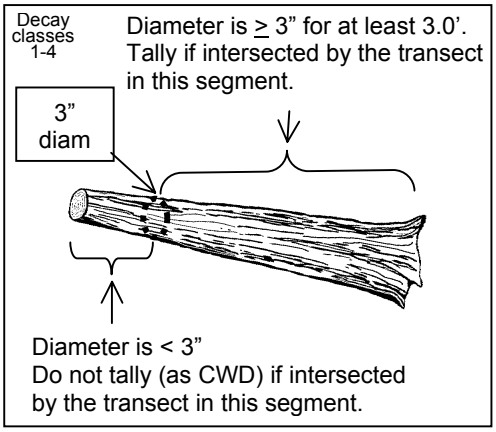

Figure 14-4. CWD tally rules for decay classes 1-4.

5. Tally pieces created by natural causes (examples: natural breakage or uprooting) or by human activities such as cutting only if not systematically machine-piled. Do not record pieces that are part of machine-piled slash piles or windrows, or that are part of a log "jumble" at the bottom of a steep-sided ravine in which individual pieces are impractical to tally separately. Instead, sample these piles according to instructions on *Sampling Residue Piles* (see section 14.12). A slash pile or windrow consists of broken logs, limbs, and other vegetative debris.

6. Tally a piece only if the point of intersection occurs above the ground. If one end of a piece is buried in the litter, duff, or mineral soil, the piece ends at the point where it is no longer visible. Measure the diameter and length at this point.

7. If the central longitudinal axis of a piece is intersected more than once on a transect line or if it is intersected by two transect lines, tally the piece each time it is intersected (uncommon situation, see Figure 14-5).

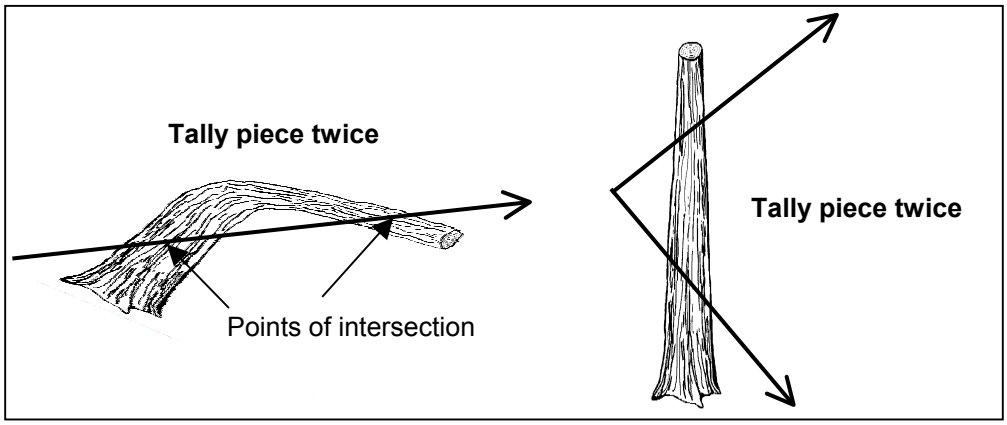

Figure 14-5. CWD tally rules: intersections.

8. Tally a piece only once if the subplot center falls directly on the central longitudinal axis of the piece. Tally the piece on the 30 degree transect and record the CWD Distance as 001.

9. If a piece is fractured across its diameter, and would pull apart at the fracture if pulled from either end, treat it as two separate pieces. If judged that it would not pull apart, tally as one piece. Tally only the piece intersected by the transect line.

10. If a piece is split along its length, would pull apart at the split if pulled from either side, and the split was due to the piece falling or to the impact of another piece or object, then treat it as two separate pieces. If judged that it would not pull apart, tally as one piece. Tally only pieces intersected by the transect line.

11. Do not tally a piece if it intersects the transect on the root side of the root collar. Do not tally roots.

12. When the transect crosses a forked down tree bole or large branch connected to a down tree, tally each qualifying piece separately. To be tallied, each individual piece must meet the minimum diameter and length requirements. In the case of forked trees, consider the "main bole" to be the piece with the largest diameter at the fork. Characteristics for this fork such as length and decay class should pertain to the entire main bole. For smaller forks or branches connected to a main bole (even if the main bole is not a tally piece), characteristics pertain only to that portion of the piece up to the point where it attaches to the main bole (see Figure 14-6).

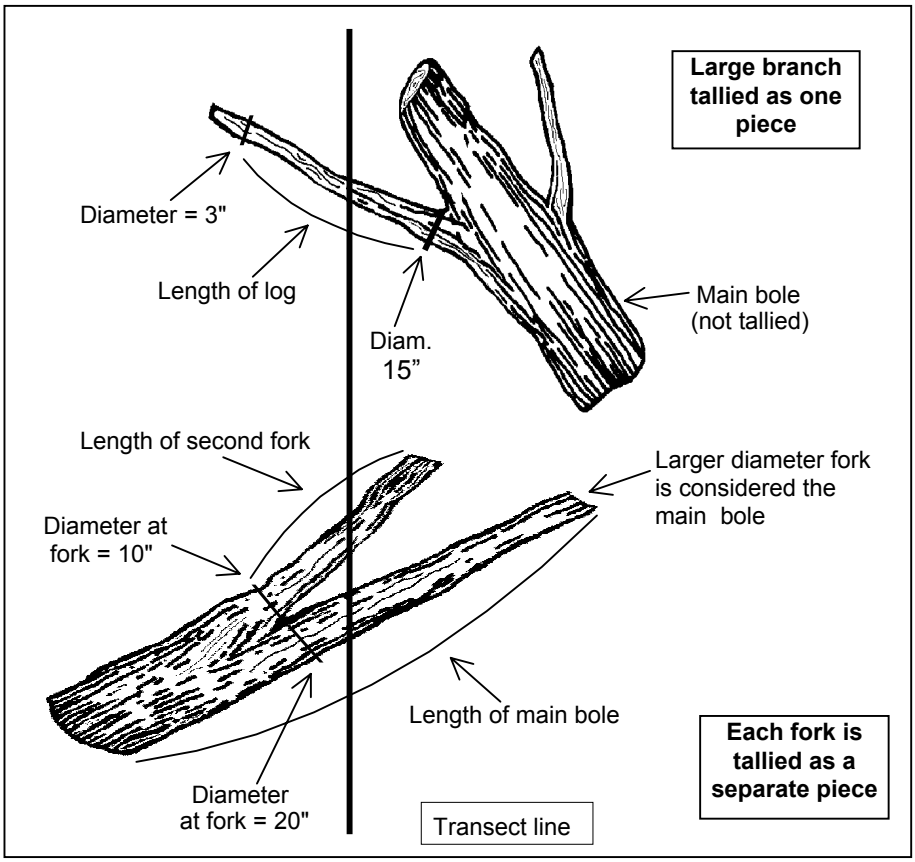

Figure 14-6. CWD tally rules for forked trees.

14.9 SAMPLING METHODS FOR FINE WOODY DEBRIS (FWD)

1. Fine Woody Debris (FWD) is sampled in accessible forest land conditions. The length of FWD transects are measured in SLOPE DISTANCE--no correction is applied to obtain a horizontal distance. The FWD transects start at 14.0 feet SLOPE DISTANCE and extend for 6.0 or 10.0 feet SLOPE DISTANCE. Estimates of FWD biomass calculated in the office, will include a slope correction factor obtained from the transect segmenting data on the subplot.

2. Only sample FWD that intersects a plane from the ground to a height of 6 feet.

3. FWD is sampled in three size classes, on the 150 degree azimuth transect. Two of the FWD size classes (0.01 to 0.24 in and 0.25 to 0.9 in) are counted on a 6 foot transect, from 14 to 20 ft. Pieces in the 3rd size class (1.0 to 2.9 in) are counted on a 10 foot transect, from 14 to 24 ft (see section 14.3 for details on transects). These transects overlap. Note: individual diameters are not recorded for FWD. Transects begin outside the subplot boundary to avoid sampling of trampled areas where numerous measurements are made on trees and understory vegetation, etc.

4. Count a piece of FWD if it intersects the transect, and the condition class is accessible forest land at the point of intersection. Only count a piece if the twig, branch, wood fragment, or shrub/tree bole are woody. Do not count pine or fir needles or non-woody parts of a tree or shrub.

5. Accumulate the number of pieces counted within each size class and enter the total count on one record for the subplot (unless there are >1 condition classes). If there is no tally on a transect, enter zero's for the count.

6. Accurate counts of FWD can be conducted efficiently up to about 50 pieces for small and medium size classes, and up to 20 pieces for the large size class. After that, crews can begin estimating counts in a systematic fashion. Transects that fall on very dense FWD where counting is nearly impossible, can be subsampled and calculated. For example, an accurate count can be conducted on a 2.0 ft-section of the transect and then multiplied by 3 to provide an estimate for the 6 foot transect, as long as the crew feels that the remaining transect has a similar density of FWD pieces.

7. If a transect intersects a large pile of material such as a wood rat's nest or a recently fallen tree (with many attached fine branches), crews should estimate a count based on #6 above, but also enter a code indicating that this is an unusual situation (see REASON_HIGHCOUNT below).

8. If rocks, logs, or other obstructions are present along the transect (14 to 24 ft section) include any FWD that is present on top of these obstructions in the respective FWD counts. If the obstructions are so large (huge boulder) that you can not see the top surface, assume the count is zero in this area, and continue counting if there is transect line beyond the boulder.

9. If a residue pile intersects the FWD transect at any point along the 14 to 24 ft section, do not measure FWD on this transect. It is too subjective determining exact boundaries of the pile, and how they relate to the exact point on the transect line.

10. If a transect crosses a condition class boundary, record the CONDITION CLASS number and enter a count for each condition on separate records. Transect lengths within each condition class will be obtained from the transect segmenting data entered for the subplot.

Appendix 3. Biomass Model Formulas

Course Woody Material Biomass Modeling
CWM = (f (vol / l) p d c) / L

f = conversion factor
vol = Smalian's Tree Volume Formula
l = log length
p = specific gravity
d = decay class
c = slope correction
L = transect length

Fine Woody Material Biomass Modeling
FWM = (f **T** dia2 p d c a) / L

f = conversion factor
T = tally of intersects
dia = mean diameter of size class
p = specific gravity
d = decay class
c = slope correction
a = orientation factor
L = transect length

Duff and Litter Biomass Modeling
B = f D p

B = duff or litter biomass
f = conversion factor
D = duff or litter depth
p = specific gravity

Appendix 4. Ecological Community Descriptions

The following International Classification of Ecological Community descriptions are from the following**:**

NatureServe. 2003. NatureServe Explorer: An online encyclopedia of life [web application]. Version 1.8. NatureServe, Arlington, Virginia. http://www.natureserve.org/explorer. (Accessed: November 12, 2003)

Note: Data presented in NatureServe Explorer at http://www.natureserve.org/explorer were updated to be current with NatureServe's central databases as of October 2002.

Modified Classes Include: disturbed open pond pine, disturbed closed pond pine, and undisturbed open pond pine
Scientific Name: *Pinus serotina* / *Ilex glabra* / *Woodwardia virginica* Woodland
Translated Scientific Name: Pond Pine / Little Gallberry / Virginia Chainfern Woodland
Unique Indentifier: CEGL004652
Classification Code: II.A.4.N.f.9
Association Summary: *Pinus serotina* is dominant or codominant with *Acer rubrum* in the canopy stratum. *Acer rubrum* and *Magnolia virginiana* are typically the most important subcanopy trees. Shrub densities are variable, from more than 80% cover to less than 50%. While not always dominant, *Ilex glabra* is a common and characteristic shrub in this type. Other common shrubs include *Lyonia lucida, Clethra alnifolia, Smilax laurifolia, Leucothoe racemosa, Gaylussacia frondosa (= var. frondosa), Vaccinium formosum,Persea palustris, Morella cerifera (= Myrica cerifera var. cerifera)*, and *Lyonia ligustrina var. foliosiflora*. Herbaceous diversity is very low, but *Woodwardia virginica* and *Osmunda cinnamomea* can be locally common. Other herbaceous plants include *Woodwardia areolata, Osmunda regalis var. spectabilis*, and *Listera australis*. Mosses, including *Sphagnum* spp., are often abundant in the saturated hummock-and-hollow microtopography. This community is variable in physiognomy, depending on fire frequency. Originally, most occurrences would have manifested themselves at most times as woodlands, with an open canopy structure. Many occurrences currently have denser canopy, up to and including a closed canopy structure. This type is closely related to the *Pinus serotina / Cyrilla racemiflora - Lyonia lucida - Ilex glabra Woodland (CEGL003670)*, which occurs farther south and has additional species, particularly *Cyrilla racemiflora*.
Ecological System Terrestrial
Formation Class II – Woodland
Formation Subclass II.A - Evergreen woodland
Formation Name II.A.4.N.f - Saturated temperate or subpolar needle-leaved evergreen woodland
Alliance Name II.A.4.N.f.9 - PINUS SEROTINA SATURATED WOODLAND ALLIANCE

Modified Classes Include: disturbed pine mix (hardwood dominant), undisturbed pine mix (hardwood dominant), and undisturbed pine mix (pine dominant)
Scientific Name: *Pinus serotina* - *Gordonia lasianthus* / *Lyonia lucida* Woodland
Translated Scientific Name: Pond Pine - Loblolly-bay / Shining Fetterbush Woodland
Unique Identifier: CEGL003671
Classification Code: II.A.4.N.f.9
Association Summary: This community occurs in Outer Coastal Plain peat domes and large peat-filled Carolina bays of eastern North Carolina and northern South Carolina. The open canopy consists of mixtures of *Pinus serotina* and *Gordonia lasianthus*, generally codominant. Various pocosin shrubs form a dense shrub stratum; typical species include *Lyonia lucida, Ilex glabra, Ilex coriacea, Smilax laurifolia, Persea palustris*, and others. The herb stratum is typically very sparse. In some areas, as in the Green Swamp, Brunswick County, North Carolina, this community occurs as islands in *Pinus serotina / Cyrilla racemiflora - Lyonia lucida* Woodland (Kologiski 1977). In other areas, it forms the landscape matrix in unbroken blocks of up to 100 square kilometers.
Ecological System Terrestrial
Formation Class II - Woodland
Formation Subclass II.A - Evergreen woodland
Formation Name II.A.4.N.f - Saturated temperate or subpolar needle-leaved evergreen woodland
Alliance Name II.A.4.N.f.9 - PINUS SEROTINA SATURATED WOODLAND ALLIANCE

Modified Classes Include: white pine plantation
Scientific Name: *Pinus strobus* Planted Forest
Translated Scientific Name: White Pine Planted Forest
Unique Identifier: ASW 8-94
Classification Code: I.A.8.C.x.070
Association Summary: Plantations, generally monospecific, dense and with little understory. Associations in North Carolina Mountains can be plantations or old field successional forests
Formation Class I - Forest
Formation Subclass I.A - Evergreen forest
Formation Name I.A.8.C - Planted temperate or subpolar needle-leaved evergreen forest
Alliance Name I.A.8.C.x.070 - PINUS STROBUS PLANTED FOREST ALLIANCE

Modified Classes Include: cove hardwood
Scientific Name: Tsuga canadensis - Liriodendron tulipifera - Betula lenta / Rhododendron maximum Forest
Translated Scientific Name: Eastern Hemlock - Tuliptree - Sweet Birch / Great Rhododendron Forest
Common Name: Southern Appalachian Acid Cove Forest (Typic Type)
Unique Indentifier: CEGL007543
Classification Code: I.C.3.N.a.33
Association Summary: This association includes hemlock-hardwood forests of lower to intermediate elevations in the Southern Blue Ridge and upper Piedmont, ranging from southwestern Virginia, south and west to northwestern Georgia. These communities occur at low to middle elevations (1300-3500 feet) in the mountains and foothills, generally in coves, gorges, or sheltered slopes, over acid soils. The canopy is usually dominated by *Tsuga canadensis* but can be comprised mainly of deciduous trees such as *Liriodendron tulipifera, Betula lenta*, and *Acer rubrum*. Other deciduous species more typical of 'rich' coves may occur as scattered individuals; *Tilia americana var. heterophylla, Fraxinus americana*, and *Fagus grandifolia*. Other canopy/subcanopy species often include *Quercus alba, Quercus rubra, Magnolia fraseri, Ilex opaca var. opaca, Calycanthus floridus, Halesia tetraptera var. tetraptera*, and *Pinus strobus*. *Rhododendron maximum* is scattered to dominant in the shrub stratum. Other typical shrubs include *Kalmia latifolia* and *Leucothoe fontanesiana*. Herbaceous cover is sparse but can be diverse and is composed of acid-loving species. Typical herbs include *Polystichum acrostichoides, Dennstaedtia punctilobula, Goodyera pubescens, Mitchella repens, Thelypteris noveboracensis, Galax urceolata, Viola rotundifolia, Hexastylis* sp., and *Tiarella cordifolia*.
Ecological System Terrestrial
Formation Class I - Forest
Formation Subclass I.C - Mixed evergreen-deciduous forest
Formation Name I.C.3.N.a - Mixed needle-leaved evergreen - cold-deciduous forest
Alliance Name I.C.3.N.a.33 - TSUGA CANADENSIS - LIRIODENDRON TULIPIFERA FOREST ALLIANCE

Modified Classes Include: upland hardwood
Scientific Name: Quercus alba - Quercus (rubra, prinus) / Rhododendron calendulaceum - Kalmia latifolia - (Gaylussacia ursina) Forest
Translated Scientific Name: White Oak - (Northern Red Oak, Rock Chestnut Oak) / Flame Azalea - Mountain Laurel - (Bear Huckleberry) Forest
Common Name: Appalachian Montane Oak Hickory Forest (Typic Acidic Type)
Unique Indentifier: CEGL007230
Classification Code: I.B.2.N.a.27
Association Summary: These forests occur in a wide elevation range (2000-4500 feet) in the Southern Blue Ridge and in the Blue Ridge/Piedmont transition, on protected sites, typically lower slopes, bottoms, and coves. Stands of this deciduous forest association are dominated or codominated by *Quercus alba*, occurring with other *Quercus* species (*Quercus rubra, Quercus prinus, Quercus coccinea*). Associated species are characteristically montane, and typical of acidic forests. This association lacks indicators of circumneutral soils and also lacks low elevation dry sites species such as *Pinus echinata, Quercus falcata, Quercus stellata*, and *Quercus marilandica*. Species other than oaks that can be important in the canopy include *Carya alba, Carya glabra, Liriodendron tulipifera, Acer rubrum*, and *Magnolia fraseri*. Common species in the subcanopy/sapling strata include *Cornus florida, Acer rubrum, Carya* spp., *Liriodendron tulipifera, Magnolia fraseri, Nyssa sylvatica, Oxydendrum arboreum, Pinus strobus*, and *Halesia tetraptera*. Shrub cover is sparse to very dense, and is often dominated by deciduous heaths. *Kalmia latifolia* and *Gaylussacia ursina* are usually present, but other shrub species can include *Euonymus americana, Rhododendron calendulaceum, Vaccinium stamineum, Vaccinium pallidum, Viburnum acerifolium, Calycanthus floridus, Pyrularia pubera, Ilex montana, Halesia tetraptera*, and *Hamamelis virginiana*. *Smilax glauca* and *Vitis rotundifolia* are common vines. The herbaceous stratum is sparse to moderate in coverage, but often rich in species, approaching the diversity but not the coverage of rich cove forests. Associated herbaceous species vary with elevation. Often there is a dominant fern stratum, with *Thelypteris noveboracensis* and *Polystichum acrostichoides* most typically dominant.
Ecological System Terrestrial
Formation Class I - Forest
Formation Subclass I.B - Deciduous forest
Formation Name I.B.2.N.a - Lowland or submontane cold-deciduous forest
Alliance Name I.B.2.N.a.27 - QUERCUS ALBA - (QUERCUS RUBRA, CARYA SPP.) FOREST ALLIANCE

Modified Classes Include: ridge top pine
Scientific Name: Pinus pungens - Pinus rigida - (Quercus prinus) / Kalmia latifolia - Vaccinium pallidum Woodland
Translated Scientific Name: Table Mountain Pine - Pitch Pine - (Rock Chestnut Oak) / Mountain Laurel - Hillside Blueberry Woodland
Common Name: Blue Ridge Table Mountain Pine - Pitch Pine Woodland (Typic Type)
Unique Indentifier: CEGL007097
Classification Code: II.A.4.N.a.23
Association Summary: This association includes mostly evergreen woodlands dominated by *Pinus pungens* and/or *Pinus rigida*, occurring over a dense ericaceous shrub stratum, on sharp ridges, mostly above 2000 feet elevation in the Southern Blue Ridge. This type is also found in limited areas of the inner Piedmont. This woodland occurs across a wide elevational range (1600-4000 feet), on exposed ridges and upper slopes with southerly and westerly exposures, over thin, excessively drained, nutrient-poor soils, and can be associated with rock outcroppings. Canopy coverage can often approach that of a forest, especially in areas where fire has been excluded and deciduous species have significant coverage. Deciduous species that can be important, particularly in the subcanopy, include *Quercus prinus, Quercus coccinea, Quercus stellata, Nyssa sylvatica, Acer rubrum*, and *Oxydendrum arboreum*. *Pinus virginiana* and *Pinus strobus* can have high coverage and even codominate on some sites. The shrub stratum is dominated by ericaceous species, typically *Kalmia latifolia* and *Leucothoe recurva* in the tall-shrub stratum and *Vaccinium pallidum* as a low shrub. Other shrub species vary with location, but include *Vaccinium stamineum, Vaccinium simulatum, Vaccinium pallidum, Vaccinium hirsutum, Vaccinium corymbosum, Rhododendron maximum, Rhododendron minus, Gaylussacia ursina, Gaylussacia baccata, Buckleya distichophylla, Pyrularia pubera*, and *Fothergilla major*. Species commonly found in the sparse herb stratum include *Chimaphila maculata, Galax urceolata, Pteridium aquilinum var. latiusculum, Xerophyllum asphodeloides, Chamaelirium luteum, Comptonia peregrina, Leiophyllum buxifolium, Gaultheria procumbens, Iris verna, Dichanthelium* spp., and *Epigaea repens*, although herbaceous species composition will vary within the range of this community. *Smilax glauca* is a common vine. Without periodic fire, this community will gradually succeed into forests dominated by *Quercus prinus* and *Quercus coccinea*, except on the most extreme sites, where this vegetation is self-perpetuating. It is thought that woodlands dominated by *Pinus pungens* are associated with more xeric conditions than woodlands dominated by *Pinus pungens* in combination with other tree species.
Ecological System Terrestrial
Formation Class II - Woodland
Formation Subclass II.A - Evergreen woodland
Formation Name II.A.4.N.a - Rounded-crown temperate or subpolar needle-leaved evergreen woodland
Alliance Name II.A.4.N.a.23 - PINUS PUNGENS - (PINUS RIGIDA) WOODLAND ALLIANCE

Appendix 5. Biomass Plot Data

			Fuel Size (tons/ac)					
Location	Site	Classified	1000 Hour	1 Hour	10 Hour	100 Hour	Litter	Total (tons/ac)
Pocosin	DOD	Undisturbed Pine Mix (hardwood dominant)	1.81	0.30	1.72	2.78	9.58	16.19
Pocosin	DOD	Undisturbed Pine Mix (hardwood dominant)	1.81	0.31	1.38	1.94	8.55	13.99
Pocosin	DOD	Undisturbed Pine Mix (hardwood dominant)	1.92	0.18	2.81	0.83	4.67	10.41
Pocosin	DOD	Undisturbed Pine Mix (hardwood dominant)	1.26	0.42	1.87	1.39	8.10	13.03
Pocosin	DOD	Undisturbed Open Pond Pine	3.37	0.27	0.80	1.11	8.13	13.68
Pocosin	DOD	Undisturbed Open Pond Pine	5.32	0.18	0.80	0.83	5.69	12.82
Pocosin	DOD	Undisturbed Open Pond Pine	0.98	0.42	1.45	0.83	8.96	12.65
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	0.33	0.20	2.08	1.67	9.04	13.32
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	0.71	0.21	1.02	2.36	6.68	10.98
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	4.72	0.22	2.11	2.08	7.27	16.39
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	1.64	0.25	0.85	1.81	7.99	12.53
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	3.55	0.22	1.04	1.67	10.03	16.51
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	2.02	0.14	1.60	2.50	9.38	15.64
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	2.39	0.32	1.33	2.22	4.52	10.78
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	2.37	0.17	1.24	1.53	4.74	10.04
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	1.72	0.12	1.62	0.83	4.63	8.92
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	2.13	0.28	1.14	0.97	7.51	12.03
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	0.57	0.22	1.24	1.81	8.85	12.68
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	1.28	0.29	1.14	1.53	8.73	12.97
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	0.70	0.44	2.01	1.94	4.55	9.64
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	0.93	0.18	1.50	0.83	5.10	8.55
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	1.34	0.13	1.26	1.11	8.96	12.79
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	2.20	0.21	0.95	1.25	7.12	11.73
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	1.24	0.27	1.26	1.53	8.73	13.03
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	1.80	0.18	1.43	2.36	9.58	15.36
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	2.76	0.22	1.43	2.22	9.58	16.22
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	2.60	0.26	1.02	0.97	7.55	12.40

Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	5.82	0.25	1.28	2.08	4.45	13.88
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	3.96	0.41	1.91	2.64	5.30	14.22
Pocosin	DOD	Undisturbed Pine Mix (pine dominant)	1.30	0.12	1.33	2.08	4.66	9.48
Pocosin	ARNWR	Disturbed Closed Pond Pine	1.65	0.43	2.74	2.36	3.74	10.92
Pocosin	ARNWR	Disturbed Closed Pond Pine	5.90	0.25	1.91	4.03	3.50	15.60
Pocosin	ARNWR	Disturbed Closed Pond Pine	1.17	0.63	3.27	4.58	5.62	15.27
Pocosin	ARNWR	Disturbed Closed Pond Pine	0.00	0.91	5.50	5.14	4.70	16.25
Pocosin	ARNWR	Disturbed Closed Pond Pine	1.27	0.52	2.57	3.47	4.08	11.92
Pocosin	ARNWR	Disturbed Closed Pond Pine	1.61	0.31	2.04	3.33	5.10	12.39
Pocosin	ARNWR	Disturbed Closed Pond Pine	0.55	0.30	3.95	3.33	2.87	11.01
Pocosin	ARNWR	Disturbed Closed Pond Pine	0.36	0.38	2.33	2.92	5.46	11.44
Pocosin	ARNWR	Disturbed Closed Pond Pine	0.96	0.73	4.27	2.08	3.20	11.24
Pocosin	ARNWR	Disturbed Closed Pond Pine	0.16	0.51	3.44	5.28	4.52	13.91
Pocosin	ARNWR	Disturbed Pine Mix (hardwood dominant)	0.33	0.32	1.55	2.36	4.42	8.98
Pocosin	ARNWR	Disturbed Pine Mix (hardwood dominant)	2.67	0.21	2.25	1.81	4.02	10.96
Pocosin	ARNWR	Disturbed Pine Mix (hardwood dominant)	2.42	0.16	1.55	2.92	4.59	11.63
Pocosin	ARNWR	Disturbed Pine Mix (hardwood dominant)	1.91	0.46	2.13	2.92	9.76	17.18
Pocosin	ARNWR	Disturbed Pine Mix (hardwood dominant)	2.25	0.10	1.07	3.19	5.16	11.77
Pocosin	ARNWR	Disturbed Pine Mix (hardwood dominant)	0.22	0.73	3.34	1.94	2.18	8.41
Pocosin	ARNWR	Disturbed Pine Mix (hardwood dominant)	0.23	0.69	2.91	1.94	4.63	10.40
Pocosin	ARNWR	Disturbed Pine Mix (hardwood dominant)	2.34	0.27	1.53	2.36	6.87	13.37
Pocosin	ARNWR	Disturbed Pine Mix (hardwood dominant)	1.53	0.23	2.08	1.67	5.61	11.12
Pocosin	ARNWR	Disturbed Pine Mix (hardwood dominant)	0.82	0.35	2.11	5.14	5.68	14.09
Pocosin	ARNWR	Disturbed Pine Mix (hardwood dominant)	0.56	0.16	1.24	1.53	9.11	12.59
Pocosin	ARNWR	Disturbed Pine Mix (hardwood dominant)	0.94	0.22	2.74	3.47	2.67	10.03
Pocosin	ARNWR	Disturbed Pine Mix (hardwood dominant)	3.77	0.39	2.33	2.64	3.68	12.80
Pocosin	ARNWR	Disturbed Pine Mix (hardwood dominant)	0.89	0.18	2.40	2.64	3.65	9.75
Pocosin	ARNWR	Disturbed Open Pond Pine	0.00	0.61	4.53	1.25	3.58	9.97
Pocosin	ARNWR	Disturbed Open Pond Pine	2.00	0.50	3.54	1.67	3.17	10.87

Pocosin	ARNWR	Disturbed Open Pond Pine	0.69	0.87	3.95	2.08	2.65	10.25
Pocosin	ARNWR	Disturbed Open Pond Pine	0.00	0.47	3.59	2.64	3.54	10.23
Pocosin	ARNWR	Disturbed Open Pond Pine	0.00	0.62	3.42	1.39	2.63	8.06
Pocosin	ARNWR	Disturbed Open Pond Pine	0.00	0.90	3.97	1.53	4.23	10.64
Coweeta	Watershed 1	White Pine Plantation	1.23	0.19	0.76	3.00	1.91	7.07
Coweeta	Watershed 1	White Pine Plantation	4.66	0.07	0.41	1.06	0.60	6.80
Coweeta	Watershed 1	White Pine Plantation	2.67	0.09	0.44	0.91	0.57	4.68
Coweeta	Watershed 1	White Pine Plantation	0.64	0.18	1.06	2.64	2.31	6.83
Coweeta	Watershed 1	White Pine Plantation	1.62	0.10	0.85	2.23	1.86	6.67
Coweeta	Watershed 1	White Pine Plantation	3.39	0.11	0.50	1.41	2.38	7.80
Coweeta	Watershed 1	White Pine Plantation	4.28	0.11	0.76	3.28	1.35	9.77
Coweeta	Watershed 1	White Pine Plantation	1.79	0.07	0.53	0.87	0.65	3.91
Coweeta	Watershed 1	White Pine Plantation	1.49	0.15	1.02	3.18	1.57	7.39
Coweeta	Watershed 1	White Pine Plantation	3.74	0.09	0.63	2.07	1.74	8.28
Coweeta	Watershed 1	White Pine Plantation	1.26	0.09	0.46	2.38	2.59	6.78
Coweeta	Watershed 1	White Pine Plantation	6.74	0.14	0.57	3.69	3.04	14.18
Coweeta	Watershed 2	Cove Hardwood	1.92	0.10	0.33	1.62	0.59	4.56
Coweeta	Watershed 2	Cove Hardwood	6.24	0.18	0.15	1.59	2.38	10.54
Coweeta	Watershed 2	Cove Hardwood	2.89	0.12	0.43	1.03	0.60	5.06
Coweeta	Watershed 2	Cove Hardwood	1.52	0.10	0.42	1.74	0.57	4.35
Coweeta	Watershed 2	Ridge Top Pine	3.46	0.12	0.32	0.76	0.57	5.24
Coweeta	Watershed 2	Upland Hardwood	5.04	0.18	0.43	1.72	2.18	9.56
Coweeta	Watershed 2	Upland Hardwood	7.04	0.15	0.17	2.56	2.86	12.78
Coweeta	Watershed 2	Upland Hardwood	3.30	0.13	0.50	2.42	0.46	6.81
Coweeta	Watershed 2	Upland Hardwood	2.15	0.12	0.34	1.35	1.27	5.22
Coweeta	Watershed 2	Upland Hardwood	5.67	0.08	0.35	2.14	0.60	8.84