

Digital Vegetation Maps for the Great Smoky Mountains National Park



Final Report

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Attachment A	Reprint of Jordan (2004), Control extension and orthorectification procedures for compiling vegetations databases of National Parks in the Southeastern United States, <i>In</i> , M.O. Altan, Ed., <i>International Archives of Photogrammetry and Remote Sensing</i> , Vol. 35, Part 4B: 422-428.
Attachment B	CRMS-NatureServe Overstory Vegetation Classification System for mapping Great Smoky Mountains National Park, by Phyllis Jackson, Rickie White and Marguerite Madden.
Attachment C	Details on the CRMS-NatureServe Overstory GRSM Vegetation Classification System, by Phyllis Jackson.
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Attachment E	Details on the CRMS GRSM Understory Vegetation Classification System, by Rick Seavey and Jean Seavey.
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Attachment H	Reprint of Madden (2004) Vegetation modeling, analysis and visualization in U.S. National Parks, <i>In</i> , M.O. Altan, Ed., <i>International Archives of Photogrammetry and Remote Sensing</i> , Vol. 35, Part 4B: 1287-1292.

Digital Vegetation Maps for the Great Smoky Mountains National Park

Summary

Detailed overstory and understory vegetation, forest fire fuels, percent canopy and understory density databases and associated maps of the 2000 km² Great Smoky Mountains National Park were developed by the Center for Remote Sensing and Mapping Science at The University of Georgia in support of resource management activities of the U.S. National Park Service. Overstory vegetation was identified to the association level and crosswalked to the finest division of the National Vegetation Classification System (NVCS) protocol for the U.S. Geological Survey (USGS) – National Park Service (NPS) Vegetation Mapping Program. Understory vegetation was identified using an association-level classification system developed in this project that included density estimates when possible. With terrain relief exceeding 1700 m and continuous forest cover over 95 percent of the Park, the requirement to use 1:12,000 and 1:40,000-scale color infrared aerial photographs as the primary data source for vegetation interpretation created a photogrammetric challenge. Challenges included lack of suitable ground control, excessive relief displacements and over 1000 photographs needed to cover the study area. In addition, Great Smoky Mountains National Park contains the world's most botanically diverse temperature zone forest and required the creation of a detailed, hierarchical classification system. For these reasons, a combination of analog photointerpretation, digital softcopy photogrammetry, geographic information system (GIS) and Global Positioning System (GPS)-assisted field data collection procedures were employed in the construction of the vegetation databases. Once complete, the overstory and understory vegetation databases were input to rule-based GIS models for analysis of forest fire fuels, percent canopy and understory density. All together, the overstory and understory vegetation data sets total 513 mb of digital data, while fire products of fuel model classes, leaf-on percent canopy, leaf-off percent canopy and understory density total 605 Mb. Hardcopy maps tiled by U.S. Geological Survey (USGS) 7.5-minute topographic quadrangle (all or portions of 25 quads are contained in GRSM) were plotted at 1:15,000 scale for overstory and understory vegetation. These maps depict the full detail of the 170 and 196 unique, association-level classes in the overstory and understory, respectively. The overstory database contains nearly 50,000 polygons (513 Mb of data) and the understory database contains nearly 25,500 polygons (605 Mb). Generalized overstory and understory vegetation data sets with approximately 24 classes each were created using GIS reclassification commands and used to produce 1:80,000-scale overview maps of the entire park. Fire fuel model, percent canopy (leaf-on and leaf-off) and understory density data sets also were used to produce park-wide maps.

Introduction

Great Smoky Mountains National Park (GRSM) encompasses approximately 2,000 km² of continuous forest cover in the southern Appalachian Mountains in southeastern United States (Figure 1). Located along the North Carolina-Tennessee border, this national park receives as many as 10 million visitors each year, yet contains one of the most diverse collections of plants

and animals in the world. It has been designated as both an International Biosphere Reserve and a World Heritage Site (Walker, 1991).

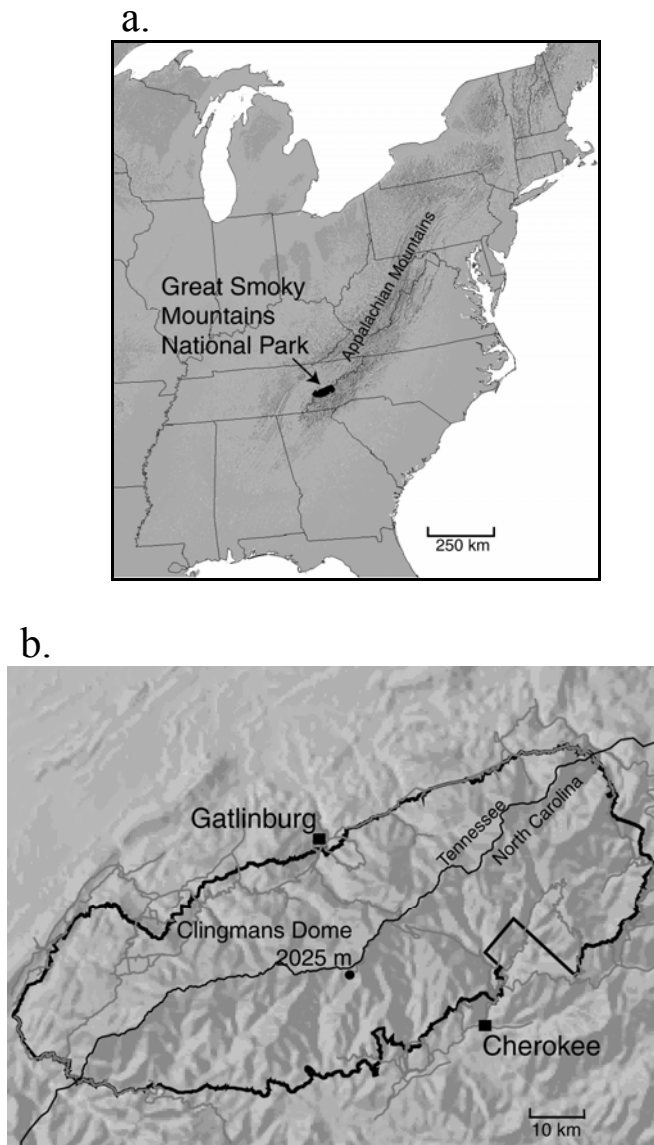


Figure 1. Location of (a) Appalachian Mountains and (b) Great Smoky Mountains National Park in eastern United States.

Although the GRSM was mapped at 1:24,000 scale by the U.S. Geological Survey (USGS) in the 1960s and 1970s, these topographic maps, while essential, do not provide the detailed information and flexibility required to manage the Park, protect it from threats due to fire and

population pressure, or to monitor changes caused by air pollution and invasive exotic plants and animals. These problems at GRSM and other parks have led the USGS and the National Park Service (NPS) to sponsor the development of detailed vegetation databases in digital format from remotely sensed data that can be used in a geographic information system (GIS) environment to create large-scale map products, conduct analyses of change and support the preservation of our national resources (USGS, 2002). The USGS-NPS National Vegetation Mapping Program aims to map all of the National Park System units using a consistent vegetation classification system and mapping protocol (Grossman et al. 1994, 1998; Maybury 1999).

The Center for Remote Sensing and Mapping Science (CRMS), Department of Geography at The University of Georgia, (www.crms.uga.edu) has been involved in vegetation mapping and database development in national parks of the southeastern U.S. for the past 10 years (Welch et al. 1995, 1999, 2002a, 2002b; Welch and Remillard 1996). As a remote sensing and mapping facility, the CRMS is unique in its combination of expertise in both technical and biological aspects of vegetation mapping projects. Scientists at the CRMS specialize in image processing, photogrammetry, GIS, air photo interpretation and field surveying, as well as botany, biology and ecology. This allows a close link between the two major components of a vegetation mapping/database project: 1) photogrammetric rectification and GIS database construction; and 2) vegetation interpretation, classification and field verification.

In addition to in-house cross training of technical and biological skills, the CRMS has developed a strong working relationship with NatureServe, a non-profit conservation organization that developed the U.S. National Vegetation Classification System and is a primary partner in the USGS-NPS Vegetation Mapping Program (www.natureserve.org). Collaboration between the CRMS and the NatureServe-Durham, North Carolina Office has resulted in the development of a detailed classification system for GRSM that maximizes the information on vegetation communities that can be gleaned from large-scale color infrared aerial photographs, while remaining compatible with the U.S. National Vegetation Classification System (Anderson et al. 1998, Jackson et al. 2002).

The objectives of this report are to: 1) demonstrate how digital photogrammetry, photointerpretation, GIS and Global Positioning Systems (GPS)-assisted field techniques were refined, adapted and integrated to permit the construction of geocoded vegetation databases from more than 1,000 large-scale aerial photographs of the rugged, high-relief GRSM; 2) discuss the CRMS-NatureServe GRSM Vegetation Classification System; and 3) present GIS analyses of the overstory and understory vegetation databases for the development of fuel models, percent cover and understory density for the management and control of forest fires. Because GRSM is considered one of the most difficult terrain areas to map in the United States, it is envisioned that the techniques discussed below can be modified as necessary and applied to rugged and remote, forested lands in other U.S. National Parks.

Study Area

Great Smoky Mountains National Park was established in 1934 in an attempt to halt the damage to forests caused by erosion and fires associated with logging activities of the 1800s and early 1900s. By the 1920s, nearly two-thirds of the lands that would become GRSM had been

logged or burned (Walker, 1991). The Park now protects 2000 km² of forestland within the southern Appalachian Mountains – among the oldest mountain ranges on earth. Elevations in GRSM range from approximately 250 m along the outside boundary of the Park to 2,025 m at Clingman's Dome (Figure 2). Rock formations in the region are sedimentary, the result of silt, sand and gravel deposits into a shallow sea that covered the area between 900 and 600 million years ago (Moore, 1988). More than 900 km of streams and rivers that flow within the Park are replenished by over 200 cm of rain per year. As of 2004, 1,637 species (1,293 native and 344 exotic) of flowering plants, 10 percent of which are considered rare, and over 4,000 species of non-flowering plants are found in GRSM (Walker, 1991). The forestlands include over 100 different species of trees and contain the most extensive virgin hardwood forest in the eastern United States (Whittaker, 1956; Kemp, 1993; Houk, 2000).

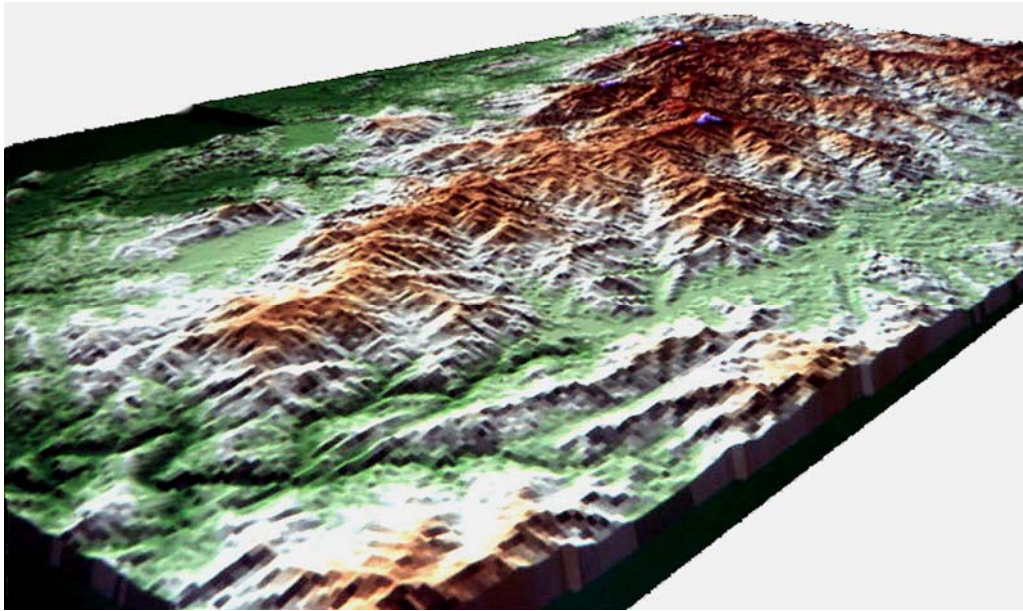


Figure 2. 3D perspective view of GRSM constructed from a mosaic of SPOT multispectral images draped over a digital elevation model. Elevations range from approximately 200 to over 2000 m above sea level.

Scientists estimate that the flora and fauna currently identified in the Park represent only 10 percent of the total species that are likely present (Kaiser, 1999). In order to discover the full range of life in GRSM, an ambitious project is underway known as the All Taxa Biodiversity Inventory (ATBI) that aims to identify every life form in the Park (possibly over 100,000 species) over the next ten to fifteen years (White and Morse, 2000). The efforts of ATBI participants rely heavily on map information in order to locate various habitats, conduct fieldwork and establish sample plots.

Natural resource managers at GRSM realized early-on the value of producing a detailed vegetation database that could be used to map habitats and aid researchers in their quest for identifying new mountain species. They also required a vegetation database for providing baseline information for future monitoring and management tasks. Facing threats by air pollution, invasive exotic plants and animals such as the hemlock woolly adelgid (*Adelges*

tsugae), large numbers of Park visitors, arson/accidental forest fires and exotic diseases (e.g., chestnut blight, dogwood anthracnose, beech bark disease, butternut canker and, potentially, sudden oak death), Park managers needed analysis tools to assist them in the preservation of valuable resources. Consequently, in 1999, the Center for Remote Sensing and Mapping Science at The University of Georgia entered into a Cooperative Agreement with the NPS to create a detailed digital database for GRSM that includes both overstory and understory vegetation and an analysis of fuels that can cause forest fires in the Park.

Methodology

The main requirement for the project was to produce a vegetation database and associated maps in vector format that contained polygons for over 150 overstory and understory plant communities plotted to within approximately ± 5 to ± 10 m of their true ground locations. Overstory vegetation was mapped using more than 1000 color infrared aerial photographs of 1:12,000 scale in film transparency format recorded with a Wild RC20 photogrammetric camera, $f = 15$ cm) in late October by the U. S. Forest Service. The fall photos were acquired when the leaves were still on the trees (leaf-on) and displayed a color diversity that allowed the vegetation communities/species to be identified (Table 1, Figure 3). Relief displacements were a major problem, in some cases reaching more than 40 mm on the 23 x 23 cm format photographs (Jordan, 2004; Attachment A).



Figure 3. An example of a large-scale color infrared aerial photograph recorded in October 1997 and used for photo interpretation of vegetation detail.

The understory vegetation was mapped from 1:40,000-scale color infrared photographs recorded (with a Wild RC30 camera, $f = 15$ cm) in the winter months as part of the USGS National Aerial Photography Program (NAPP). At that time of year, deciduous trees have lost their leaves (leaf-off) and it is possible to delineate the understory evergreen shrubs and trees that are both combustible and sufficiently dense to restrict crews combating forest fires or conducting search and rescue missions. With the dense forest cover, steep slopes, absence of ground control and relief exceeding 30 percent of the flying height for the large-scale photographic coverage, the construction of a vegetation database accurate in both the spatial and thematic context necessitated a combination of softcopy photogrammetry, photointerpretation and GIS procedures organized in parallel as shown in Figure 4. These are discussed below.

Table 1. Specifications of data sources available for map/database development of GRSM.

Data Source	Format and Type of Data	Flying Height (FH) and/or Scale	Resolution	No. Required to Cover the Park	Comments and/or Problems
Color infrared (CIR) Air Photos October 1997-1998	23 x 23 cm Analog film transparencies	FH = 1800 m 1:12,000	~ 0.4 m	~ 1,000	Terrain relief in excess of 30% of flying height. A smaller scale could alleviate this problem. Fall leaf-on conditions are ideal for mapping overstory forest communities.
USGS NAPP Air Photos March/April 1997-1998	23 x 23 cm Analog film transparencies	FH $\approx$ 6,000 m 1:40,000	~ 1m	~ 130	Scale is too small for mapping overstory vegetation. Leaf-off conditions are ideal for mapping understory vegetation.
USGS Topographic Maps	Paper maps	1:24,000	-	25	Last updated 1960-1970's.
USGS DOQQs Pan and CIR	Digital	-	1 m	80	USGS DOQQs have a planimetric accuracy of approximately ± 3 m RMS.
USGS Level 2 DEMs	Digital	1:24,000	30 m post spacing	25	USGS Level 2 DEMs have a vertical accuracy of approximately ± 3 -5 m RMS.

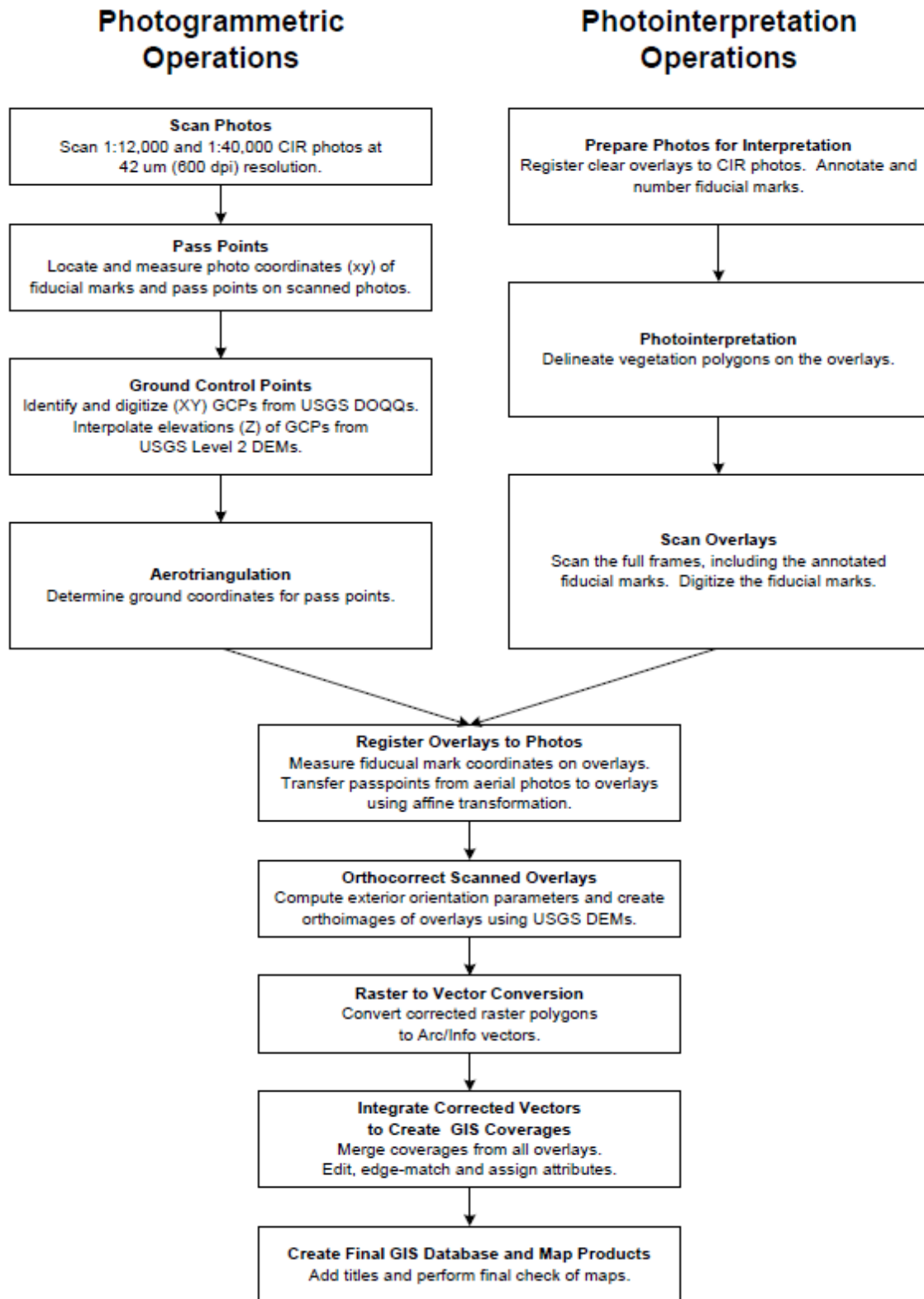


Figure 4. Diagram showing photogrammetric, photointerpretation and GIS operations used to map the vegetation of GRSM.

Photogrammetric Operations

The main objective of the photogrammetric procedure was to densify the sparse ground control in the Park by means of aerotriangulation, a photogrammetric operation whereby a relatively small number of ground control points (GCPs) are used to mathematically compute the ground coordinates of a much larger number of identified pass points (Jordan, 2002). In this way, the control network is adequately densified for the orthorectification process. At the outset, the 1:12,000-scale film transparencies were scanned at 600 dots per inch (dpi) using an Epson Expression 836xl desktop scanner to create black-and-white digital photos of 42- μ m pixel resolution, providing a file of 35 Mbytes for each photo. These digital photos were then displayed on the computer monitor and with the aid of the *R-WEL, Inc.* Desktop Mapping System (DMS) software package, the image (x,y) coordinates of pass points and GCPs were measured in the softcopy environment. This was a painstaking and time-consuming task. In the absence of cultural features and the near continuous tree canopy cover, the passpoints, in the majority of instances, were individual tree-tops that had to be identified uniquely on overlapping photographs – not an easy job in terrain of high relief recorded on large-scale photographs (Figure 5).

Ground control points were, for the most part, natural features (e.g., rock outcrops and forks in stream channels) identified on both the 1:12,000-scale color infrared transparencies and USGS Digital Orthophoto Quarter Quads (DOQQs) produced from 1:40,000-scale panchromatic aerial photographs recorded in 1993. The Universal Transverse Mercator (UTM) grid coordinates (X,Y tied to the North American Datum of 1927 or NAD 27) of these GCPs were measured directly from the DOQQs (accurate to within ± 3 m). Elevations for the GCPs were derived using CRMS custom software to interpolate the Z-coordinates to within ± 3 to ± 5 m from USGS Level 2 Digital Elevation Models (DEMs) with 30-m post spacing (Figure 6). Thus, in this project, no ground survey work was required to obtain the GCPs needed as a framework for the aerotriangulation process.

Analytical aerotriangulation was undertaken for blocks of up to 90 photos, where each block corresponded to the area covered by one of the 25 USGS 1:24,000-scale map sheets covering the Park. The PC Giant software package, in conjunction with the DMS software, was employed for the aerotriangulation process. Output from the aerotriangulation was a set of X, Y and Z coordinates in the UTM coordinate system for the nine or more pass points identified by CRMS personnel on each photo. Typical root-mean-square error (RMSE) values for these coordinates averaged ± 7 m for the XY vectors and ± 10 m for elevations (Z).

The pass points with their X, Y and Z coordinates derived from the aerotriangulation process provided the ground control required to generate orthophotos and mosaics from the scanned air photos (Figure 7). These orthophotos and mosaics, in turn, were employed in the editing and attributing operations required to build the vector database. Most importantly, however, the control provided by the aerotriangulation process was essential for rectifying vector overlays generated as part of the photointerpretation procedure described below.

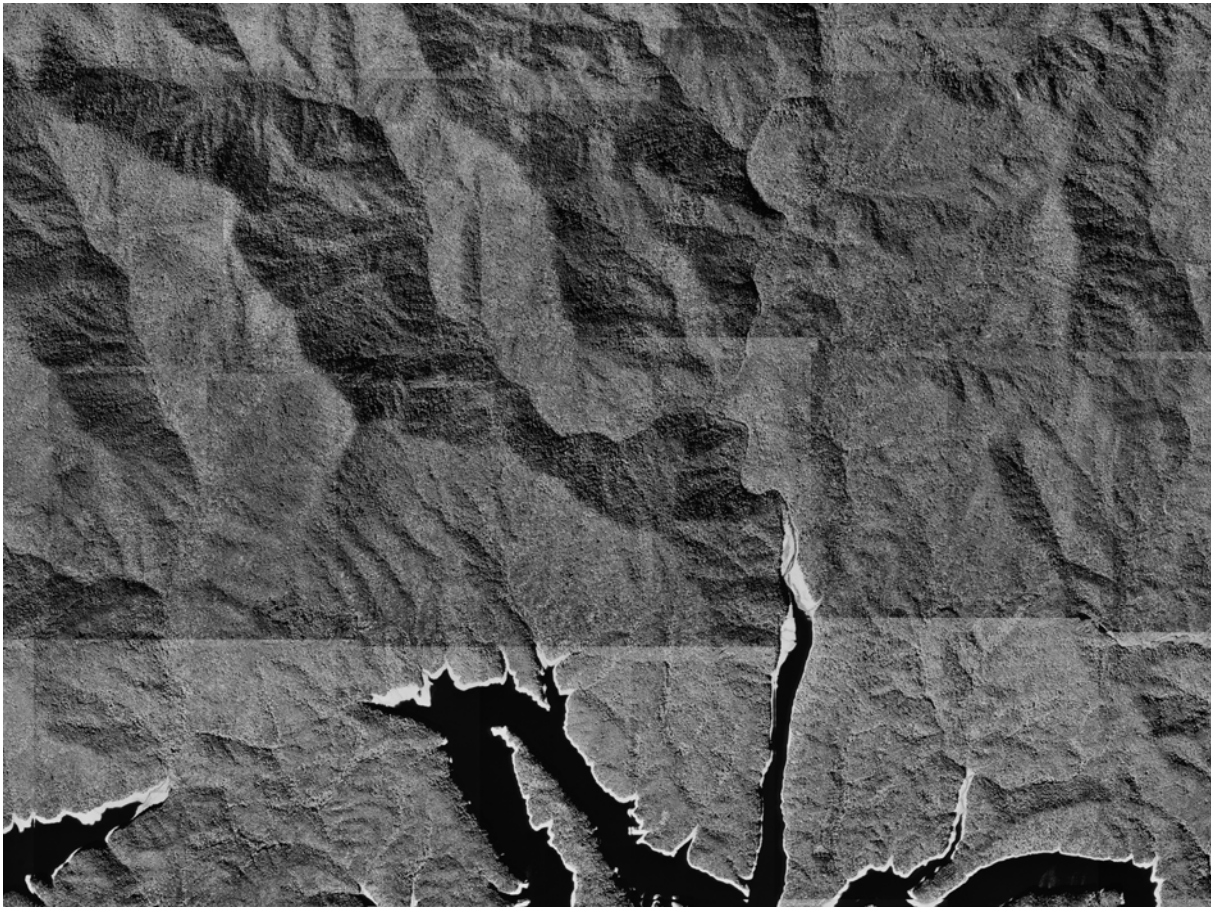


Figure 7. A mosaic of orthorectified 1:12,000-scale photographs was created for quality assurance and checking. Terrain features that are well aligned between individual photographs indicate a good overall solution. This is necessary for the rectified vegetation linework of individual photographs to edgematch correctly.

Photointerpretation Operations

The steps of the photointerpretation process listed in Figure 4 proceeded in parallel with the photogrammetric operations. Overstory vegetation was interpreted from the 1:12,000-scale leaf-on color infrared aerial photographs. On the other hand, the understory vegetation was interpreted from the 1:40,000-scale (leaf-off) transparencies.

Although it might appear desirable to scan the color infrared transparencies at high resolution and undertake the vegetation classification as an on-screen interpretation and digitizing procedure, this has proved to be exceedingly time consuming, cumbersome and expensive compared to more traditional approaches (Welch et al. 1995 and 1999; Rutchey and Vilchek 1999). Moreover, photointerpreters must view the vegetation in stereo and in color within the context of a relatively large area of terrain in order to identify the vegetation communities. This is most easily done using a stereoscope to view the analog air photos so that the vegetation

patterns can be assessed in relation to the terrain. Recognizing the need to augment manual procedures with automated techniques, the steps described below integrate conventional photointerpretation procedures with digital processing technology in an attempt to streamline the database and map compilation process.

At the beginning of the GRSM mapping project, the photointerpreters, in conjunction with NPS plant specialists, conducted field investigations to collect data on the forest communities and correlate signatures evident on the aerial photographs with ground observations. Consequently, UTM coordinates and field data were collected at over 2000 locations with the aid of a Garmin III Plus hand-held GPS receiver and a Kodak Digital Field Imaging System (FIS) 265 digital camera system. The hand-held Kodak digital camera was connected to the Garmin GPS that “stamped” the location, date and time on each image (Figure 8). These images were input to ArcView to provide a pictorial record of field observations.



Figure 8. Ground digital image of overstory and understory vegetation recorded with a Kodak FIS 265 digital camera interfaced to a Garmin III Plus GPS.

A compilation of all field information was used by Center for Remote Sensing and Mapping Science (CRMS) ecologists to organize the GRSM overstory and understory vegetation into a classification system with 170 unique association-level classes suitable for use with the large and medium-scale (1:12,000 and 1:40,000, respectively) color infrared aerial photographs (Jackson et al. 2002; Table 2). The term, association, is defined by Grossman et al. (1998) as a “plant community type of definite floristic composition, uniform habitat conditions and uniform physiognomy”. Terrestrial communities in GRSM have one to several strata of vegetation: tree canopy, sub-canopy, tall shrub, short shrub, herbaceous, non-vascular, vine/liana and epiphyte. The combination of vegetation in all of these strata present determines the community type.

The term “overstory vegetation” refers to the entire vegetation community. Communities are named and referenced by vegetation in their tallest stratum, plus abundant and/or indicator species in lower strata. Photointerpreters can see the tallest strata on color infrared photos, and may or may not be able to see through this layer to shorter layers. Sometimes a community can be determined solely by seeing its location and seeing the uppermost stratum, for example, a Hardwood Cove. In other cases, a lower stratum (or strata) must be seen because this stratum determines the community type. For example, three kinds of Montane Red Oak communities have the same canopy, but their differences are determined by an evergreen tall shrub stratum, a deciduous tall shrub stratum, or an orchard-like herbaceous stratum.

The overstory classification system was based on the USGS-NPS Vegetation Classification of GRSM for the area corresponding to the Cades Cove and Mount Le Conte USGS topographic quadrangles developed by The Nature Conservancy (TNC) as part of the USGS-NPS Vegetation Mapping Program (TNC, 1999). The full overstory CRMS/NatureServe GRSM Vegetation Classification system is provided in Attachment B with a crosswalk to NVCS Community Element Global (CEGL) code numbers for association divisions. Further details on the development and use of the CRMS/NatureServe GRSM Vegetation Classification system are provided in Attachment C.

Table 2. Sample hierarchy of alpine forest classes within the overstory vegetation classification system for GRSM cross referenced to association descriptions by CEGL numbers in the National Vegetation Classification System.

FOREST	GRSM Veg Code [CEGL Code]
A. Sub Alpine Mesic Forest	
1. Fraser Fir (above 6000 ft.)	F [6049, 6308]
a. Formerly Fraser Fir	(F) [6049, 6308]
b. Fraser Fir/Deciduous Shrub-Herbaceous	F/Sb [6049]
c. Fraser Fir/ <i>Rhododendron</i>	F/R [6308]
2. Red Spruce – Fraser Fir	S-F*, S/F, F/S [7130, 7131]
a. Red Spruce – Fraser Fir/ <i>Rhododendron</i>	S-F/R [7130]
b. Red Spruce – Fraser Fir/Low Shrub-Herb	S-F/Sb [7131]
3. Red Spruce	S [7130,7131]
a. Red Spruce/ <i>Rhododendron</i> (5000-6000 ft.)	S/R [7130]
b. Red Spruce/Southern Mountain Cranberry-Low Shrub/Herbaceous (5400-6200 ft.)	S/Sb [7131]
4. Red Spruce – Yellow Birch – Northern Hardwood	S/NHxB [6256]
5. Exposed Northern Hardwood/Red Spruce	NHxE/S [3893]
6. Beech Gap	NHxBe [6246, 6130]
a. North Slope Tall Herb Type	NHxBe/Hb [6246]
b. South Slope Sedge Type	NHxBe/G [6130]

* Symbols: (-) designates a equal mix and (/) designates the first class listed is dominate (> 50 percent) over the second class listed.

In order to accommodate the complex vegetation patterns found in GRSM and generally maintain a minimum mapping unit of 0.5 ha, a three-tiered scheme was developed for attributing vegetation polygons, similar to that developed for an earlier project in the Everglades of south Florida (Madden et al. 1999). The three-tiered scheme allowed photointerpreters to annotate each polygon in the database with a primary or dominant vegetation class accounting for more than 50 percent of the vegetation in the polygon. Where appropriate, secondary and tertiary vegetation classes are added to describe mixed-plant communities within the polygon. Secondary and tertiary classes were especially useful for describing ecotones, and for polygons with a patchwork of communities below the minimum mapping unit size. See Attachment C for further explanation of the three-tiered polygon attribution procedure.

A separate classification system containing over 196 unique association-level classes was developed by CRMS photointerpreters in consultation with NPS resource managers to map the understory vegetation (Table 3).

Table 3. Sample classes within the understory vegetation classification system for GRSM.

Pine overstory with Kalmia understory	
a. Pine dominant over high density Kalmia	(PI/Kh)
b. Pine dominant over medium density Kalmia	(PI/Km)
c. Pine dominant over low density Kalmia	(PI/Kl)
d. Pine dominant over possible Kalmia	(PI/Kp)
e. Pine dominant over implied Kalmia	(PI/Ki)

* Symbols: (/) designates the first class listed is dominate (> 50 percent) over the second class listed.

The term “understory” denotes woody vegetation of medium height (3 to 5 m) that does not reach the forest canopy level. Understory classes of particular interest to fire managers included two evergreen, broad-leaf shrubs: rhododendron (*Rhododendron* spp.) and mountain laurel (*Kalmia latifolia*). Information on the location and density of these understory shrubs is important for modeling fire fuels, assessing fire behavior and determining accessibility for research, resource management and search and rescue activities. Interpretation of these understory vegetation strata from the air photos, therefore, included further classification according to the density of the shrub as light (l), medium (m) or heavy (h). Additional subclasses were added for these shrub areas of interest to qualify uncertainty in their interpretation and identification when the understory was obscured by overstory vegetation. In these cases, the evergreen forest community (e.g., “T” for hemlock) and the probable understory shrub (e.g., “R” for rhododendron) are combined in a single label of T/R with an indicator of “i” to denote “implied” or “p” to denote “possible” rhododendron, in place of a density symbol (i.e., T/Ri). **Implied** is defined to mean the conditions are right for the presence of the species and it is believed to be found there. On the other hand, **possible** is defined as the conditions are only marginally right for the presence of the species. The full understory classification system is

provided in Attachment D, and further details on the development of the understory classification system and the interpretation of understory communities can be found in Attachment E.

Once the overstory community and understory vegetation classification systems were established, the photointerpretation proceeded by taping transparent plastic overlays to the film transparencies, and transferring the photo numbers and fiducial marks to the overlays by means of a Rapidograph technical pen. The film transparencies, with plastic overlays, were then placed on a high intensity light table and the polygons corresponding to the vegetation classes outlined on the overlay using the Rapidograph pen while viewing the photographs through a stereoscope. This is a simple, fast, inexpensive and flexible method of creating a vegetation overlay that can be scanned to create a raster file.

Following recommendations by Welch and Jordan (1996), the scanning process involved the use of the desktop Epson 836xl scanner, at a resolution of 42 μm (600 dpi). All annotated point, line and polygon information on the overlay was converted to raster format. The parameters derived from the differential rectification of the scanned 1:12,000-scale photos were applied to the scanned overlay files via registration with the transferred fiducial marks. Figure 9 illustrates the magnitude of polygon displacement, as well as distortion in polygon shape and size, due to variable relief displacements across the photograph.

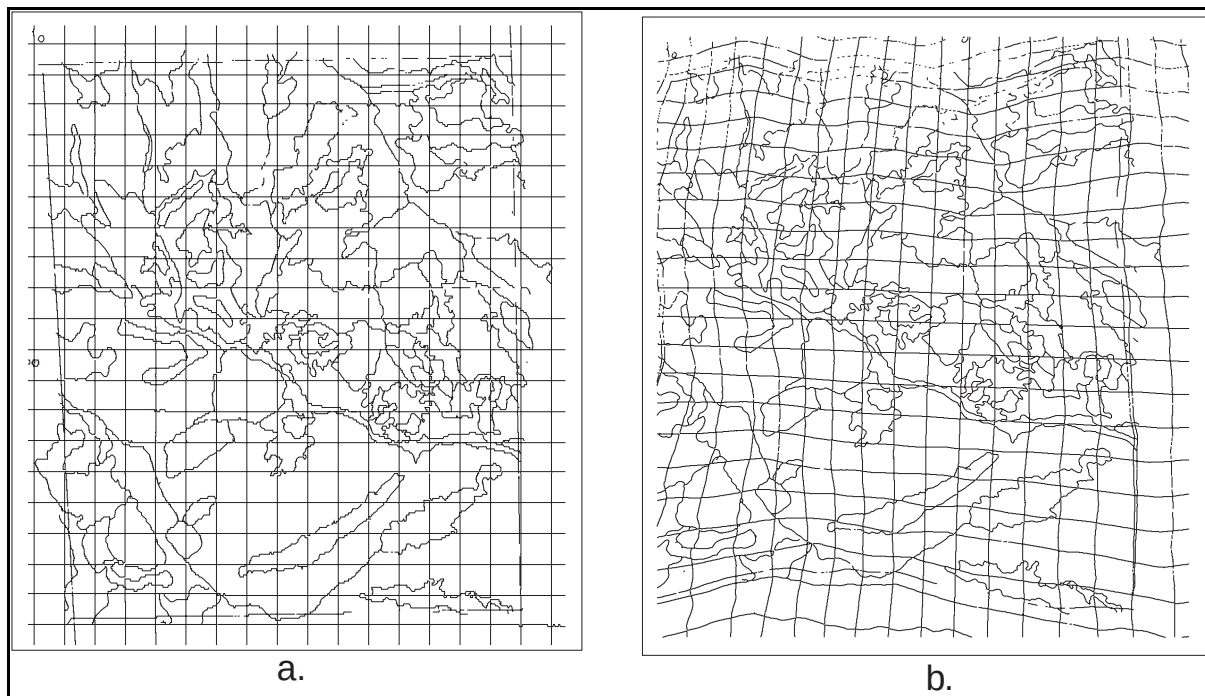


Figure 9. (a) Original photo overlay depicting vegetation polygons and a 1-cm grid before corrections for relief displacement. (b) Overlay and grid after orthorectification showing the extreme corrections required to accommodate the large range of relief in the area.

Overstory and Understory Vegetation Database and Map Products

Upon differential rectification of the scanned raster overlay files, these files are converted to vector format with the software package R2V by Able Software Company (Cambridge, Massachusetts) and saved in ArcInfo line format. Vector files from approximately 45 photographs must be edited, edgematched and incorporated into a single ArcInfo coverage to produce one vegetation map corresponding to the area covered by a single USGS topographic quadrangle (Figure 10). A typical coverage for the area corresponding to a USGS 1:24,000-scale map can contain over 4,500 polygons that must be attributed with a dominant vegetation class, and possibly secondary and tertiary vegetation classes. More than 700 man-hours are required to produce a single quad-sized vegetation map from the 1:12,000-scale photos, including quality control checks of labels/line work within and between adjacent maps. Understory maps, produced from the smaller scale NAPP air photos, require approximately 100 man-hours to prepare. Although limited funds available for the project precluded a thorough check of thematic classification accuracy, maps were taken into the field as they were completed to assess the general agreement between map information and observations on the ground.

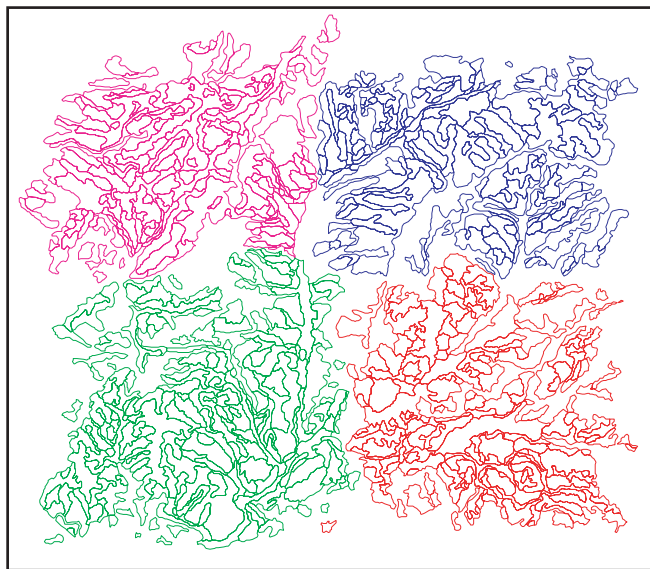


Figure 10. Individual vector files from four adjacent photos that have been edited and edge matched.

Final products included a seamless GIS database in Arc/Info coverage and ArcView shapefile formats of detailed overstory and understory vegetation communities for the entire park, along with hardcopy maps plotted at 1:15,000 scale corresponding to the area covered by 25 individual USGS 7.5-minute topographic quadrangles (Figures 11 and 12). Each map sheet contains a color-coded legend and brief description of all vegetation classes found in GRSM. A demonstration of additional digital/hardcopy products that can be created for particular areas of interest as a result of the vegetation database development include color orthophoto mosaics and drapes of maps/images on the DEM to enhance visualization of vegetation patterns with respect

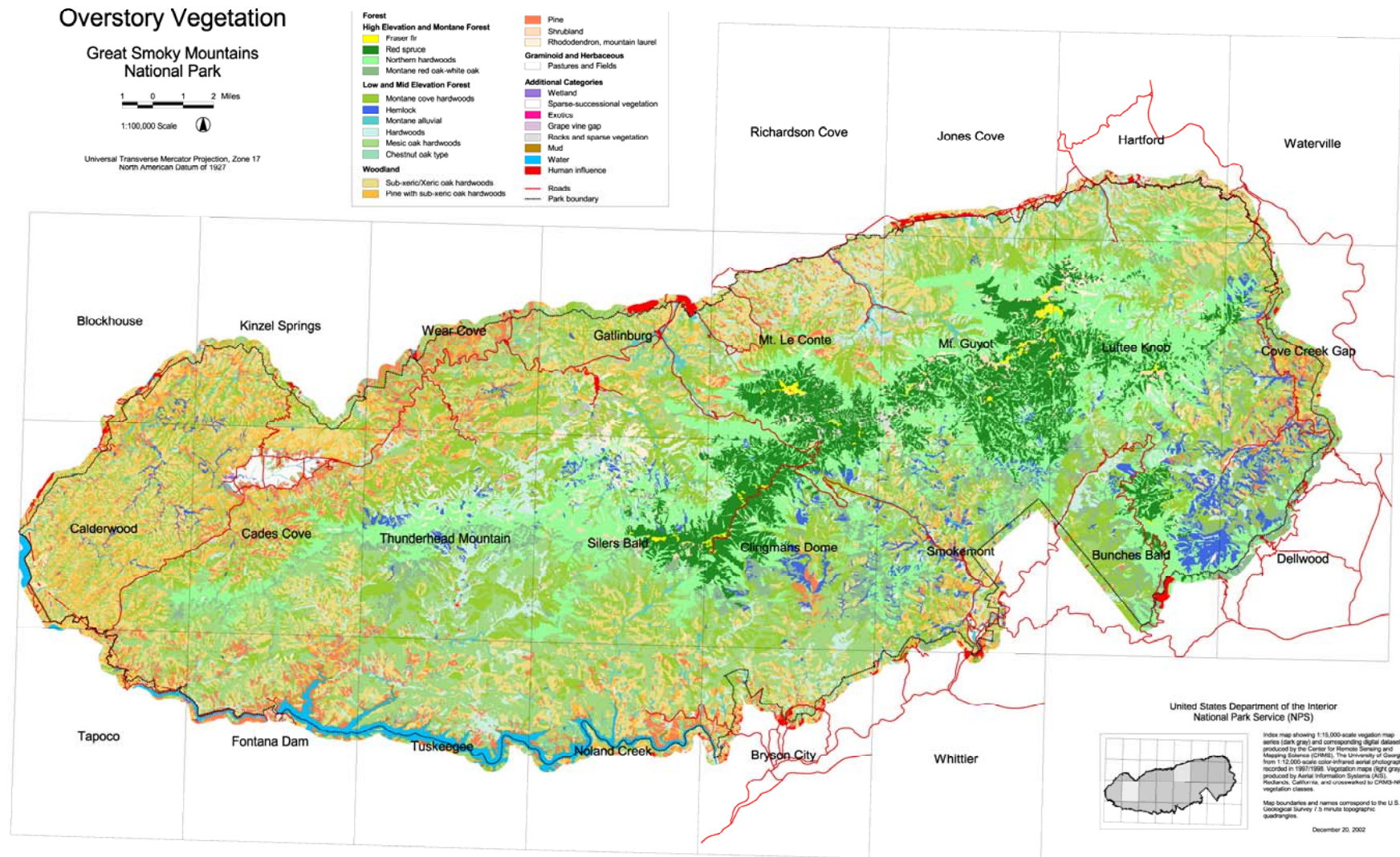


Figure 11. Hardcopy vegetation maps plotted at 1:15,000 scale correspond to the area covered by 25 individual USGS 7.5-minute topographic quadrangles in GRSM, as outlined on this generalized overview map of GRSM overstory vegetation.

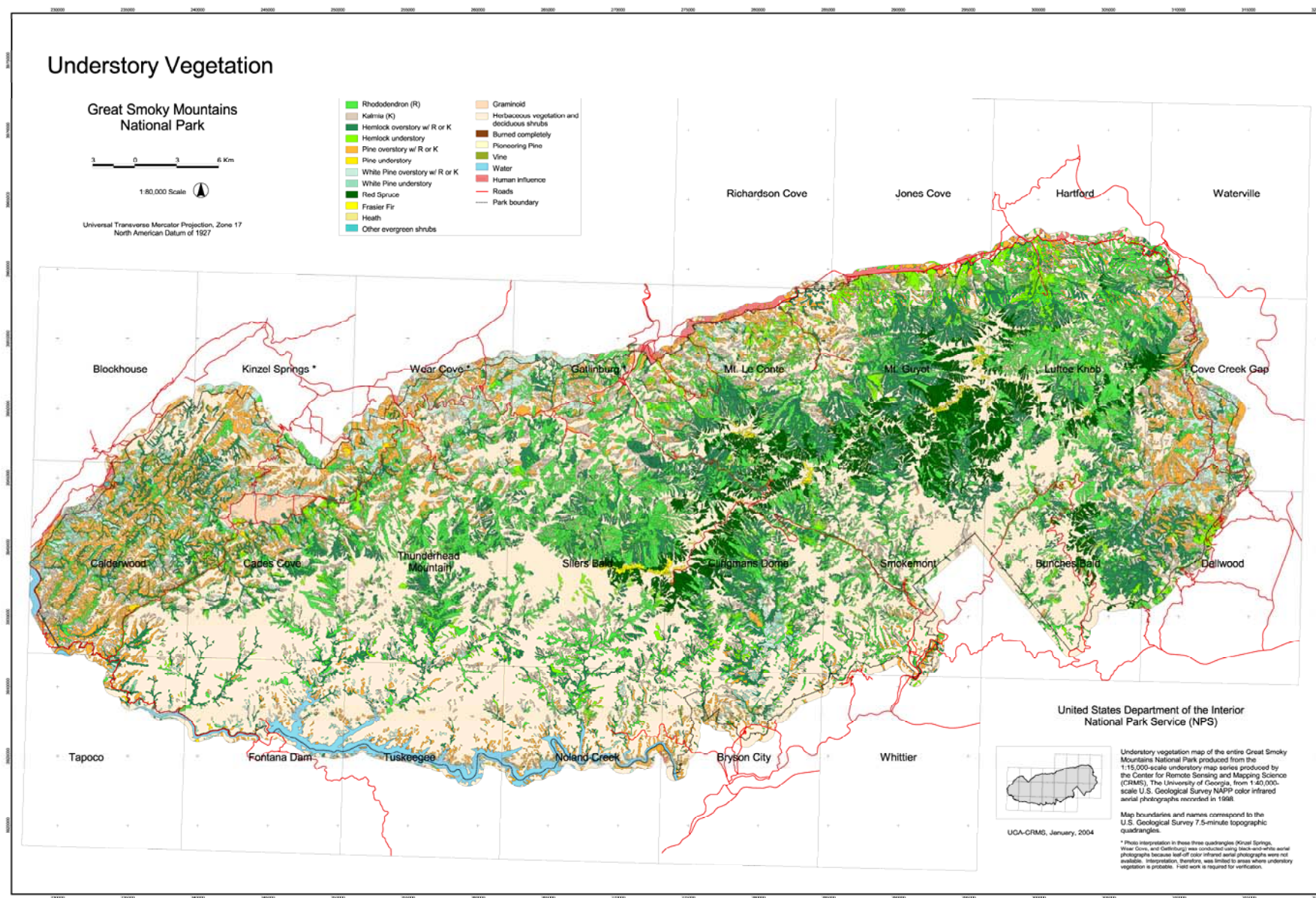


Figure 12. Generalized overview map of GRSM understory vegetation.

to the terrain. Applications of the GRSM map/database products include: 1) vegetation assessment for general resource management tasks; and 2) utilization of the overstory and understory vegetation structure for classifying fuels and the associated risk of forest fire.

The overstory and understory databases provide a basis for park-wide resource management decisions. Basic information that is required by all managers includes a spatial inventory of existing vegetation communities and summary statistics indicating the total area covered by each community. These data can be quickly tallied in a GIS environment once the database has been developed. Attachments F and G contain a comprehensive list of all overstory and understory vegetation classes in the database and their respective areas within the park.

Detailed information at the association-level is often needed to address management problems that target individual species. For example, the overstory vegetation database can be queried to locate pure stands of high elevation table mountain pine (*Pinus pungens*) requiring controlled burning to eliminate hardwood invasion. Polygons containing Eastern hemlock (*Tsuga canadensis*) also can be reselected to identify areas susceptible to die-off and damage caused by the non-native hemlock woolly adelgid.

Other management questions may require a broader-perspective. Given the complexity of vegetation diversity in GRSM, it is difficult for managers to assess general trends in vegetation patterns when posed with management questions on a Park-wide level. The hierarchical structure of the GRSM Vegetation Classification System allows this to be easily accomplished. To this end, 170 association-level overstory vegetation classes were collapsed to 24 classes that approximate the alliance level of the National Vegetation Classification System (Table 4). A lookup table was used to reclassify the overstory attributes of polygons to the more general forest type classes and the Arc/Info Dissolve command was used to create new polygon boundaries surrounding the forest types (See attached CD for lookup table files). A composite map depicting generalized forest types for the entire park was created and plotted at 1:80,000 scale (see Figure 11). This map and digital data set provides an overview of forest types and can be used to highlight the distribution of particular communities of interest such as pines, high elevation spruce-fir or cove hardwoods. A tally of the area covered by each of these forest types also provides useful baseline information for resource inventory and assessing changes over time (Figure 13; also see Attachments F and G).

Table 4. Generalized overstory vegetation and area statistics for GRSM.

Overstory Vegetation	Overstory	Area (Ha)	Percent
Submesic to Mesic Oak/Hardwood Forest	OmH	45,499.9	20.7
Southern Appalachian Cove Hardwood Forest	CHx	31,844.2	14.5
Southern Appalachian Early Successional Hardwood Forest	Hx	14,081.4	6.4
Subxeric to Xeric Chestnut Oak/Hardwood Forest/Woodland	OzH	32,928.4	15.0
Xeric Pine Woodland	PI	19,551.3	8.9
Southern Appalachian Northern Hardwood Forest	NHx	31,248.4	14.2
Montane Northern Red Oak Forest	MO	8,489.0	3.9
Southern Appalachian Eastern Hemlock Forest	T	6,381.4	2.9
Red Spruce Forest	S	14,654.9	6.7
Fraser Fir Forest	F	437.5	0.2
<i>Kalmia latifolia</i> Shrubs	K	525.8	0.2
<i>Rhododendron</i> spp. Shrubs	R	516.0	0.2
Mixed <i>Kalmia</i> and <i>Rhododendron</i> Shrubs, Heath	R-K	2,219.0	1.0
Montane Alluvial Forest	MAL	2,674.3	1.2
Rock with Sparse Vegetation	SV	311.4	0.1
Shrubland	Sb	859.0	0.4
Pasture, Forbs, Graminoids, Grassy Balds and Vines	P	1,551.6	0.7
Dead Vegetation	Dd	135.5	0.1
Cobble-Gravel-Sand-Mud Bar	Grv	495.2	0.2
Wetland	Wt	43.6	0.0
Water	W	3,035.6	1.4
Road	RD	492.5	0.2
Human Influence	HI	1,462.1	0.7
Exotics	E	0.5	0.0
Total		219,438.2	100.00

With reference to Table 4 and Figure 12, Submesic to Mesic Oak/Hardwood Forests (CRMS label “OmH” and Cegl Code 6192, 7692, 7230 and 6286) are the most prevalent forest type in the park covering over 45,000 ha (or 21% of the total area). The next three most prevalent forest types, each covering approximately 15% or 30,000 ha, are Southern Appalachian Cove Hardwood Forests (CHx, 7710, 7543, 7693, 7695 and 7878), Subxeric to Xeric Chestnut Oak/Hardwood Forests (OzH, 6271 and 7267) and Southern Appalachian Northern Hardwood Forest (NHx, 6256, 7861, 7285, 4973, 4982, 6124, 6246, 3893 and 6130). These four general forest types account for 64% of the park area. Of the remaining types, Xeric Pine Woodlands (PI and PIs, 7097, 7119, 7078, 2591, 3590, 7100, 7944 and 7519) cover almost 9% of the park (over 19,500 ha) and Southern Appalachian Early Successional Hardwood Forests (Hx, 8558, 7219, 7879 and 7543) cover 6.4% or over 14,000 ha. Red Spruce dominant forests (S, 7130, 7131, 6256, 6152 and 6272) are most prevalent at high elevations covering approximately 14,600 ha (6.7%), while Fraser Fir dominant forests (F, 6049 and 6308) cover only 437 ha or 0.2%. Although there are approximately 6,400 ha (2.9%) of Eastern Hemlock dominant Forest (T, 7861 and 7136), it should be noted that there is a hemlock component of numerous other GRSM forest associations as defined by NatureServe in the National Vegetation Classification System.

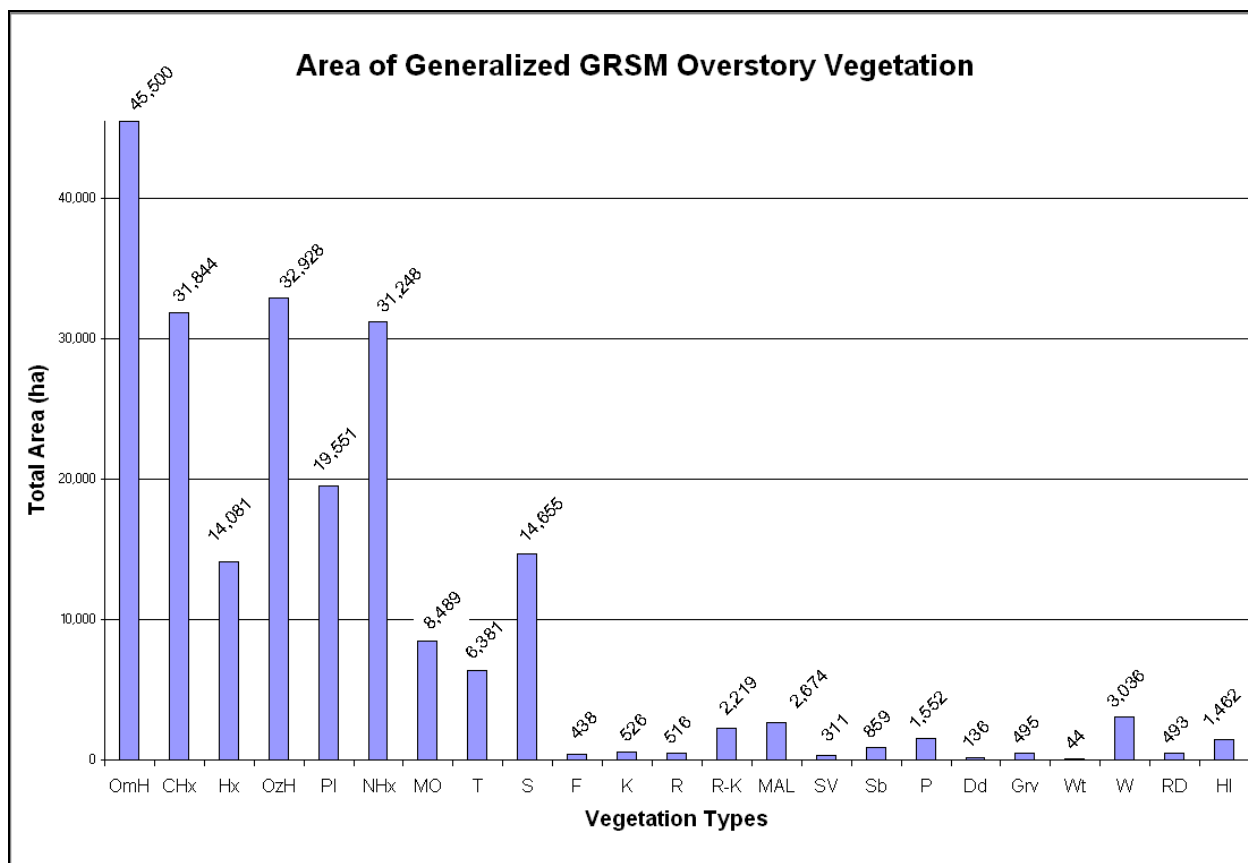


Figure 13. Total area (hectares) of generalized overstory vegetation classes in GRSM.

A total of 196 understory association-level classes, some with species density information, were generalized to 14 classes (Table 5, Figure 14). As stated in Appendix D, the targeted understory species to be mapped in GRSM were evergreen shrubs such as rhododendron (R) and mountain laurel (K). These species, together, covered nearly 50% of the total park area, or 101,275 ha either as shrub-dominated areas (e.g., Rh or Kh) or as understory components of areas dominated by an overstory such as hemlock (e.g., T/Rh or PI/Kh). Approximately 102,000 ha were covered by herbaceous and deciduous understory shrub species (HD) and the remaining evergreen understory coverage consisted of evergreen tree species (e.g., hemlock, white pine, yellow pines, Fraser fir and red spruce) less than 2 m in height.

Table 5. Generalized Understory Vegetation and Area Statistics for GRSM.

Understory Vegetation	Understory Label	Area (Ha)	Percent Cover
Herbaceous and Deciduous Understory	HD	102,739.1	46.8
<i>Rhododendron</i> – Heavy Density	Rh	18,850.3	9.3
<i>Rhododendron</i> – Medium Density	Rm	26,761.1	13.2
<i>Rhododendron</i> – Light Density	RI	20,711.8	10.2
<i>Rhododendron</i> – <i>Kalmia</i> Mixed	RK	4,635.5	2.3
<i>Kalmia</i> – Heavy Density	Kh	4,114.6	2.0
<i>Kalmia</i> – Medium Density	Km	13,375.1	6.6
<i>Kalmia</i> – Light Density	KI	12,826.3	6.3
Heath Understory	Hu	1,248.7	0.6
Other Evergreen Understory (e.g., Eastern White Pine)	Ou	33,276.0	15.2
Burned Completely	BC	16.1	0.0
Graminoid	G	926.2	0.4
Road	RD	60.7	0.0
Water	W	2,751.1	1.3
Human Influence	HI	1,230.6	0.6
Total		219,438.2	100.0

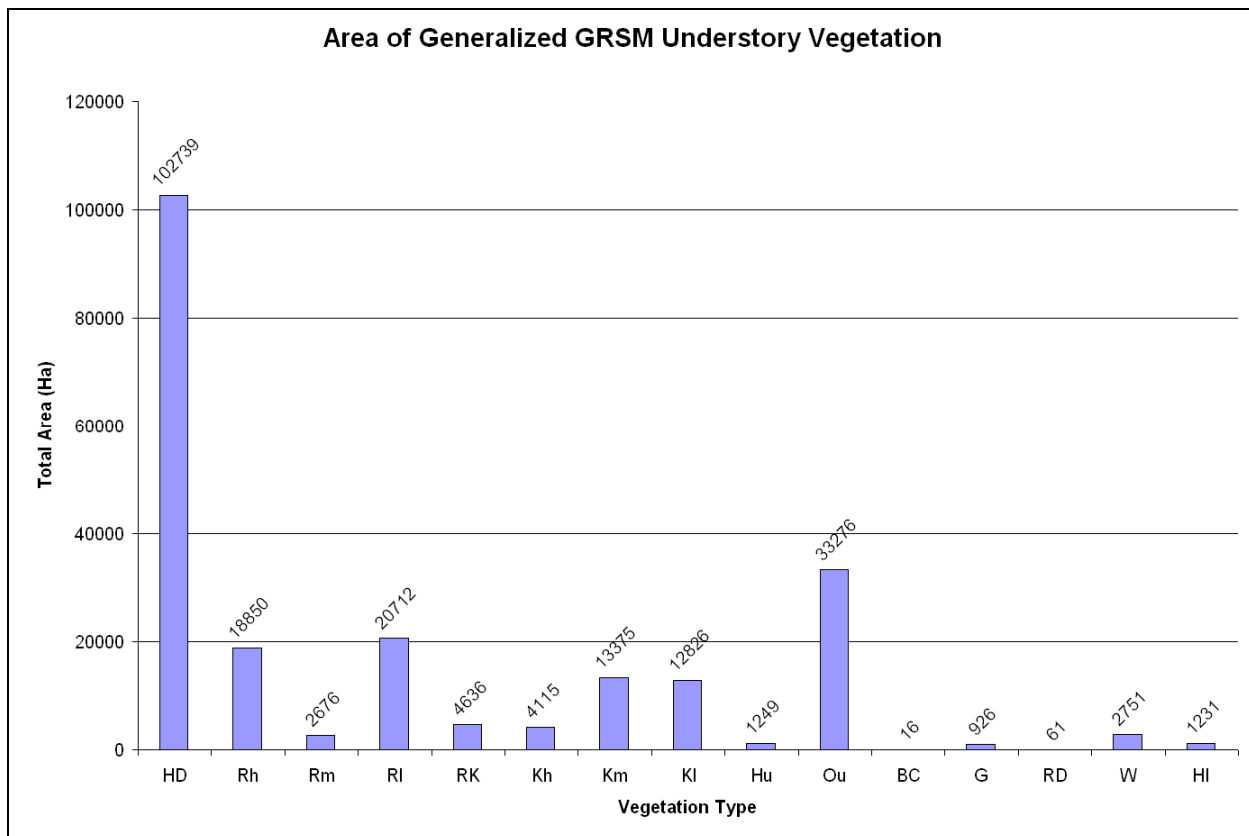


Figure 14. Total area (hectares) of generalized understory vegetation classes in GRSM.

Modeling Applications

In addition to providing an overview of the distribution and total area covered by overstory and understory vegetation types, the generalized vegetation classes are useful for conducting modeling analyses such as fire fuel assessment and spatial correlation of vegetation types with environmental parameters such as elevation, slope and aspect (Madden and Jordan 2001; Madden 2003, 2004; Madden and Welch 2004; Attachment H). The customized GIS reclassification programs can be adapted to reclassify detailed vegetation attributes to derive secondary databases such as percent canopy and understory density maps. The GRSM vegetation database also has been used to create geovisualizations that depict 3D perspective views and explore the use of 3D visualizations to assess vegetation patterns and conduct quality control checks on the finalized vegetation database (Madden and Giraldo 2005; Madden et al. 2006). Examples of some of these applications are provided below.

Fire Fuel Modeling

Fire managers in GRSM are especially interested in assessing the overstory and understory vegetation in terms of fuels for potential forest fires. Historically, the majority of forest fires in the Park have been suppressed, resulting in the accumulation of flammable woody debris and the potential for intense wild fires. In the past few years, however, the benefits of allowing naturally occurring wildfires to burn and/or using prescribed fires to reduce fuel loads and maintain fire-dependent vegetation communities has been recognized within the entire National Park system. Although arson fires and those that endanger life or property are still suppressed, other natural fires are now allowed to burn under careful observation. Prescribed fires are also set in particular areas to preserve ecosystem health.

In order to perform effective and safe controlled burns, fire managers require detailed and comprehensive spatial data on vegetation structure, terrain conditions and fuel loads. Geographic information systems are used in many aspects of fire management such as fuel management, fire prevention, fire fighting dispatch, suppression and wild fire management (Salazar and Nilsson, 1989). In this instance, GIS modeling techniques were used to assess overstory and understory vegetation related to fuels for potential forest fires in the Park (Dukes, 2001).

In the United States, a well-tested and popular fuel classification system, known as the Anderson Fuel Classification System, contains 13 fuel classes that were originally defined for fire behavior prediction as applied to the vegetation of the western United States (Rothermel, 1972; Albini, 1976; Anderson, 1982). With close consultation with NPS fire managers, the overstory and understory vegetation classes were related to the Anderson fuel classes to create fire fuel maps of the Park.

The basic steps in the GIS modeling analysis of fuels begins with a simplification of the overstory and understory vegetation classes to reduce the number of classes to be considered for reclassification as fire fuels. This procedure was facilitated by the hierarchical structure of the overstory and understory vegetation classification systems that enabled generalization of the mapped classes and assignment to preliminary fuel classes (numbered 1 through 13). Since the fuel classification system was originally created for vegetation in the more xeric western United

States, fuel classes were reevaluated to relate fire behavior and overstory vegetation of eastern deciduous forests. Fieldwork was conducted to determine which Anderson Fuel Model Classes would be assigned to particular GRSM overstory and understory communities. Resource and fire experts familiar with GRSM vegetation advised CRMS personnel of Anderson Fuel Model classes that could be assigned to vegetation classes (Figures 15 and 16). This information was used to create a rule-based model with the structure, “if this overstory and this understory of a particular density, then that fuel model class.” The model was written in Arc Macro Language (AML) operational in Arc/Info and provided on the attached CD.

The density and structure of understory vegetation are important in fire fuel analysis. Dense evergreen understory vegetation tends to shade the ground and help maintain moist conditions on the forest floor, while a light density of evergreen shrubs allows sunlight to reach the ground and dry out the accumulated leaf litter. To address the influence of understory vegetation on fuels, GIS overlay commands were employed to create composite data layers of preliminary fuel classes and understory vegetation. The rule-based GIS model in Arc/Info AML format was then run to assign Anderson Fuel Model classes to polygons in the composite overstory/understory data set. A particular combination of overstory and understory was assigned a particular fuel model class as integer values of 1 through 13 (Table 6). A decimal value, indicative of the



Figure 15. National Park Service resource/fire managers Mike Jenkins and Leon Konz, along with CRMS research assistant, Robin (Dukes) Puppa, determine the Anderson Fuel Model associated with a particular vegetation community in GRSM.



Fuel Class 1 *Short Grass*



Fuel Class 5 *Brush*



Fuel Class 2 *Timber (Grass and Understory)*



Fuel Class 6 *Dormant Brush, Hardwood Slash*



Fuel Class 4 *Shrub*



Fuel Class 8 *Closed Timber Litter*

Figure 16. Examples of GRSM vegetation communities associated with Anderson Fuel Models



Fuel Class 9 *Hardwood Litter*



Fuel Class 10 *Timber (Litter and Understory)*



Fuel Class 12 *Medium Logging Slash*

Figure 16 (continued). Examples of GRSM vegetation communities associated with Anderson Fuel Models.

understory type and density, was then added to the fuel class (Table 7). For example, polygons with an understory of light density *Kalmia latifolia* (mountain laurel), an evergreen understory shrub that usually grows on dry, south-facing slopes, were assigned a decimal value of 0.1 and medium density mountain laurel a value of 0.3. The overstory-based fuel class integer value (1 through 13) added to the understory-based decimal value provides fire managers with a maximum amount of information on fuel conditions that considers both overstory and understory vegetation (Figure 17).

Table 6. Level I - Rules for assigning fuel classes in GRSM.

Group	Fuel Class	Description	General Overstory Vegetation Type	Understory Vegetation Type
Non-Flammable	0	Non-flammable/Wet	W, Wt, MAL, RD	W
Grasses	1	Short Grass	P, HI, (:6)	BC,G, HI
	2	Timber (Grass and Understory)	SV	SV
	3	Tall Grass	N/A	N/A
Shrubs	4	Shrub (6 feet tall)	K, R, R-K (:7)	PP
	5	Brush (2 feet tall)	SU, Sb	Sb, Ou
	6	Brush/Hardwood Slash	Wd	No Understory
	7	Southern Rough	MO/Hth	No Understory
Timber	8	Closed Timber Litter	PI, OzHf	No Understory
	9	Hardwood Litter	CHx, OmH, NHx, Hx, etc.	HD
	10	Timber (Litter and Understory)	F, S	F, S
Slash	11	Light Logging Slash	N/A	N/A
	12	Medium Logging Slash	Dd, (:9)	N/A
	13	Heavy Logging Slash	N/A	N/A

Table 7. Example of Level II rules for assigning decimal values to fuel classes.

Group	Fuel Class	Description	General Overstory Vegetation Type	Understory Vegetation
Shrubs	6.0	Brush/Hardwood Slash	Wd	No Understory
Shrubs (<i>Kalmia</i>)	6.1			Kl, Kp
	6.3			Km, Ki
	6.5			Kh
Shrubs (<i>Rhododendron</i>)	6.2			Rl, Rp
	6.4			Rm, Ri
	6.6			Rh
Shrubs (<i>Kalmia</i>- <i>Rhododendron</i> Mix)	6.7			R-K
Shrubs (Other Understory)	6.9			Ou

The final step in the GIS analysis procedure involved the development of refinement rules for changing the assignment of fuel classes to reflect influences on fire behavior due to unique combinations of particular overstory and understory vegetation (see Attachment I). For instance, a polygon in the overstory vegetation data layer that is classified as pine is normally assigned a fuel class of 8. If further examination of the understory data layer reveals spatial coincidence with medium density mountain laurel that sufficiently shades the litter so it remains moist, then the model assigns a final fuel class of 8.3. If, however, a polygon is classified as pine with light density mountain laurel shrubs, the model determines that a fire in this area will be hotter and more dangerous than that of a class 8 due to dry leaf litter, then polygons of this unique combination are assigned a final fuel class of 9.1. In this way, resource managers are able to assess not only the fire fuel class but the relative density of important shrub communities that might influence fire ignition risk and fire behavior. Future improvement of the model might involve allowing rule-based decisions to change fuel conditions for different seasons and account for particularly wet or dry weather conditions.

The results of the Level I and Level II rule-based model was a fuel model data set for the entire GRSM. This data set can be used to assess risk of fire ignition and general fire behavior for assistance in making fire management plans.

Percent Canopy Data Layers

In addition to fire fuel classes, leaf-on and leaf-off percent canopy data sets also were derived from the overstory vegetation database since these data layers are required for the GRSM fire modeling efforts. Field work was conducted with NatureServe botanists to determine estimates of percent canopy “openness” that could be associated with individual forest types under both leaf-on and leaf-off conditions (Figure 18, Table 8).

Table 8. Percent Canopy Classes

Percent Canopy Class	Field-Estimated Percent of Canopy Closure
1	0 – 25 %
2	> 25% - 50 %
3	> 50% - 75%
4	> 75%

A lookup table was created to crosswalk overstory vegetation classes with percent canopy classes for both leaf-on and leaf-off conditions (See Attachment G). Digital data sets and maps of these two data sets, leaf-on and leaf-off percent canopy for the entire park, were then created and plotted at 1:80,000 scale. Figure 19 depicts percent canopy data sets for a portion of GRSM corresponding to the Gatlinburg USGS topographic quadrangle.

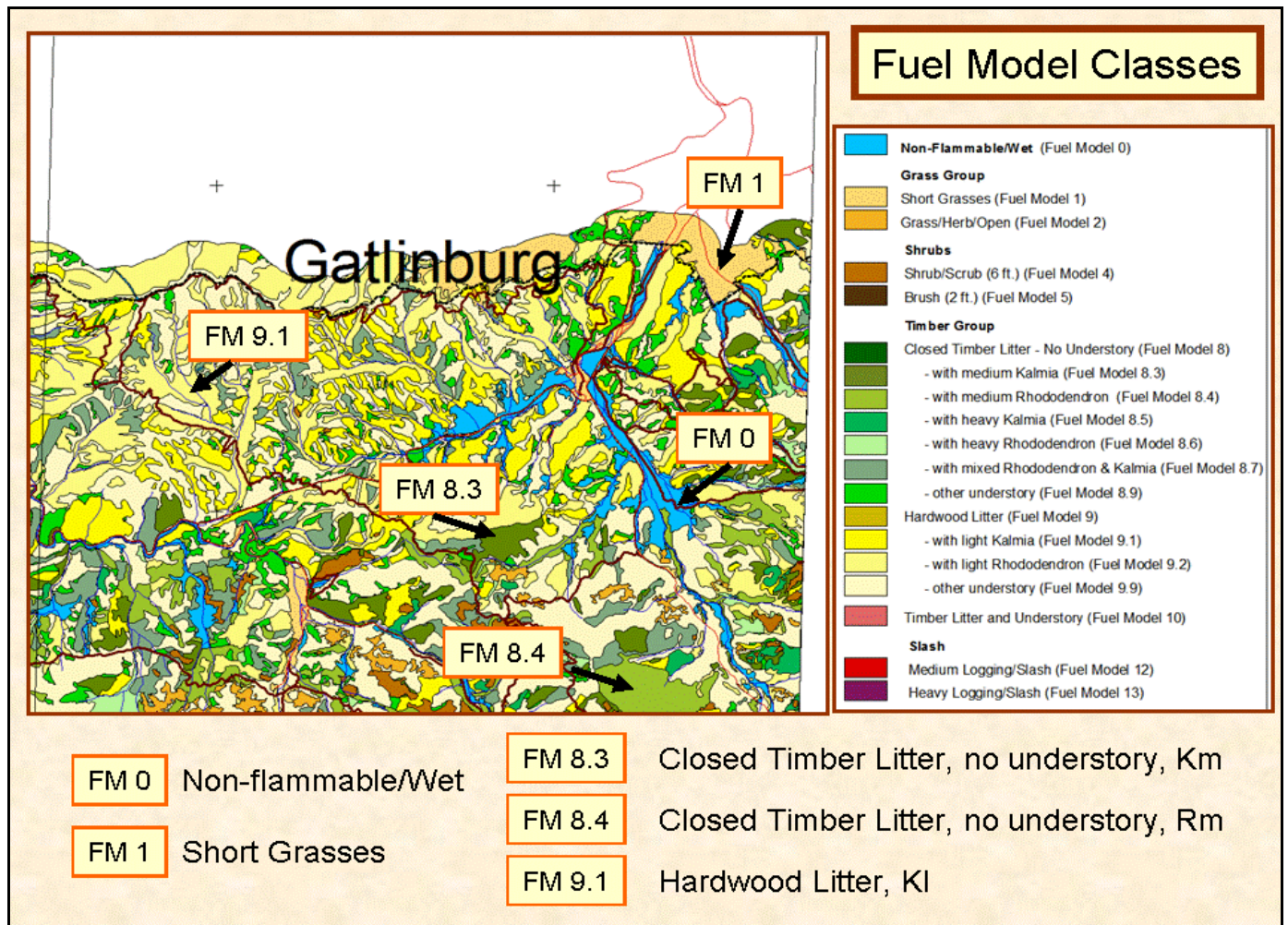


Figure 17. A sample of the fire fuel model data set with fuel model values based on unique combinations of overstory/understory vegetation classes (integer values) and understory density (decimal values).



Figure 18. CRMS photo interpreter Phyllis Jackson and NatureServe botanists Alan Weakly and Rickie White assess the vegetation community and percent canopy in the field.

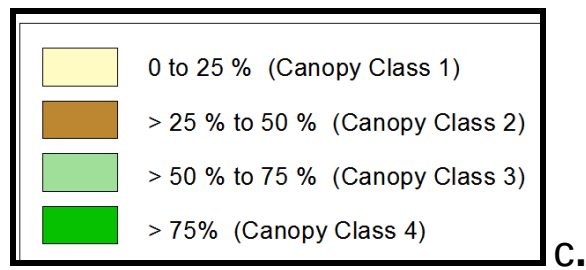
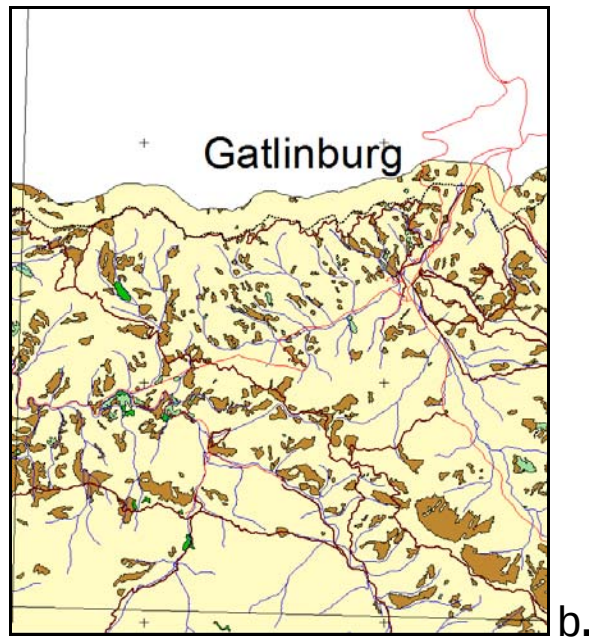
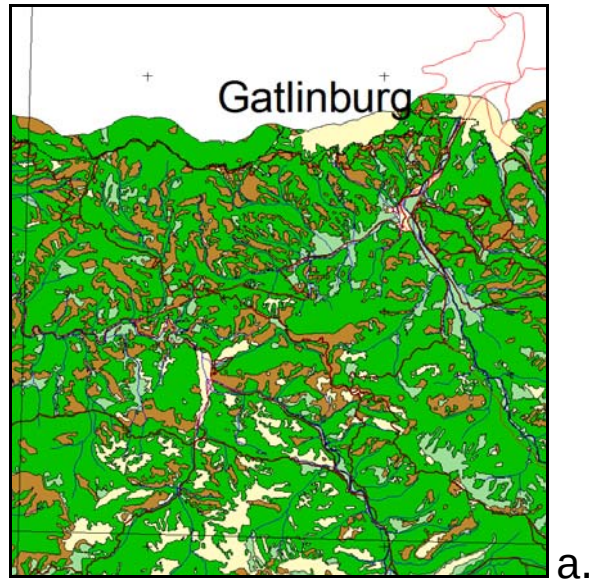


Figure 19. Percent canopy within the Gatlinburg quadrangle in leaf-on (a) and leaf-off (b) conditions color-coded according to canopy classes based on percent of canopy closure (c).

The fuel class and percent canopy data layers and associated maps provide fire managers with information that can be quickly assessed to determine general patterns of fire ignition and spread. In the event of a forest fire within the Park, these data also can be used as input, along with percent canopy cover derived from the overstory vegetation data layer and terrain characteristics, to a fire behavior prediction model called FARSITE Fire Area Simulator (Finney, 1998). Output from the FARSITE spatial model predicts the spread, intensity and behavior of forest fires. Managers can determine if fires should be observed or controlled, optimize their deployment of control measures and estimate the impact of fires on Park facilities and adjacent private lands.

Understory Density

The understory vegetation data set contains information on the density of *Rhododendron* and *Kalmia*. Since these two evergreen shrubs can often grow in dense thickets and are nearly impossible to traverse, information on the location of particularly dense stands is useful for field scientists, rescue workers and resource managers who must travel off-trail to access remote areas of the park. In response to the need of park managers to identify new sample plot locations for the ATBI research effort, GIS reclassification procedures were used to derive a simplified version of the understory vegetation data set in which approximately 190 unique classes were collapsed to 11 classes (Figure 20). Understory density classes included: herbaceous and deciduous understory (HD); 2) light, medium and heavy *Rhododendron* (Rh, Rm and Rl, respectively); 3) light, medium and heavy *Kalmia* (Kh, Km and Kl); 4) light, medium and heavy mixed *Rhododendron* and *Kalmia* (RKh, RKm and RKl); and 5) other understory (Ou). The geographic locations of future randomly located sample plots were overlaid on this understory density data set by GRSM resource managers to determine the accessibility of the samples. If a plot, for example, was found to be located in the middle of a high density *Rhododendron* thicket, then an assessment would be made concerning the level of effort needed to reach the plot and the suitability of the particular plot location for the study. A decision could then be made to keep the location or discard it and select an alternate site.

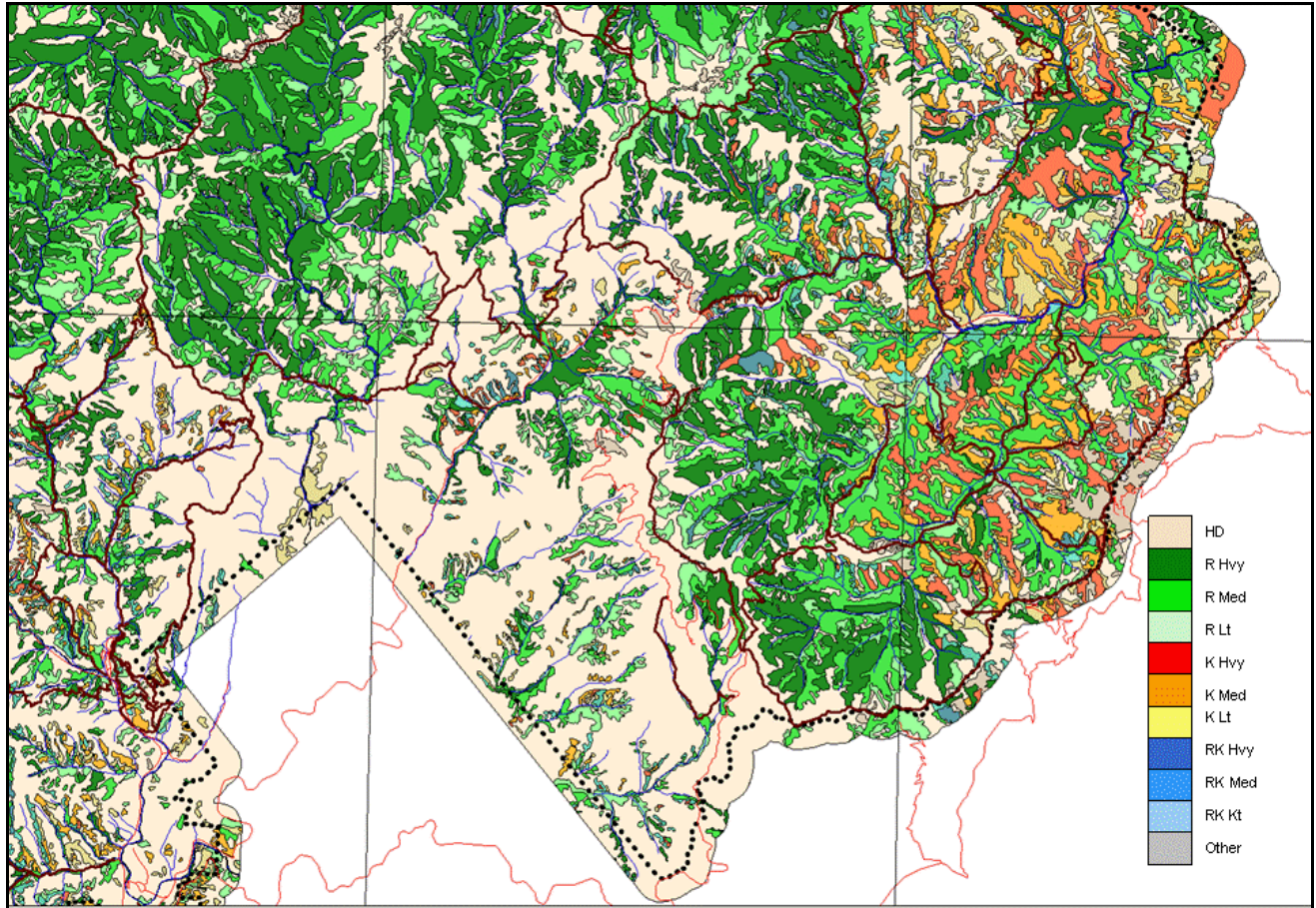


Figure 20. A portion of the GRSM understory density data set depicting light, medium and heavy densities of *Rhododendron* (R), *Kalmia* (K) and mixed *Rhododendron/Kalmia* (RK).

Conclusion

Experience gained from conducting this five-year study to develop detailed overstory and understory vegetation, fire fuel model and leaf-on and leaf-off percent canopy cover databases for GRSM can be used to make recommendations on the best source materials and procedures for mapping vegetation in remote and mountainous areas. First, there should be careful consideration of the aerial photographs or image data source to insure a high level of detail in identifying vegetation composition is balanced with photogrammetric and mapping requirements. The construction of vegetation databases over extensive areas of mountainous terrain should focus on the acquisition and use of aerial images recorded by a standard 23 x 23 cm format photogrammetric film camera system (or the newer digital photogrammetric cameras) equipped with a lens of not less than 15 cm focal length and, preferably, 30.5 cm. While this longer focal length camera necessitates an aircraft operating at higher altitudes for a given scale or pixel resolution, the greater flying height significantly reduces displacements due to terrain relief – a most serious problem when attempting to create detailed GIS databases from large numbers of aerial photographs. Furthermore, if at all possible, the camera system should be

interfaced to auxiliary data systems (e.g., inertial guidance and GPS) at the time of photo acquisition so that exterior orientation parameters are available for input to softcopy photogrammetric software. This will minimize the requirements for ground control and aerotriangulation over rugged, forested terrain, and reduce the time required to complete the project by as much as 30 to 50 percent.

The spatial accuracy requirements for constructing GIS databases and mapping vegetation polygons are appropriately based on the reliability to which the photointerpreters can delineate individual vegetation community boundaries and the smallest polygons to be mapped in rough terrain – that is the minimum mapping unit. In general, the coordinate accuracy requirements for GIS database and/or thematic maps of vegetation in rugged, forested terrain should not be as stringent as those for low relief areas with a good distribution of readily identifiable features and where it is possible to pre-mark control points. Thus, when planning a vegetation mapping project, it is appropriate to note that photogrammetrists can use photographs of relatively small scale and/or coarse pixel resolution for acceptable control generation tasks, whereas the photointerpreters may insist on photographs of larger scale and/or higher resolution more suitable for the extraction of thematic detail. In order to preclude burdening photogrammetrists and the GIS personnel responsible for editing, edge matching and attributing polygons with excessive numbers of large-scale photographs having extraordinary displacements due to relief, or crippling the photointerpreters with photos of insufficient scale or resolution to permit the extraction of thematic detail, close coordination is required between the project planners, photogrammetrists, photointerpreters and GIS specialists. Failure to communicate on the above issues will likely result in data acquisitions that will prove cumbersome, causing the project to be greatly extended at a significantly higher cost.

The construction of vegetation databases can be facilitated by integration of traditional analog and newer digital data processing techniques. For example, in this instance softcopy photogrammetric techniques offered significant advantages for control extension, generation of orientation parameters for individual photographs and the production of digital orthophoto mosaics employed in the editing process to finalize vegetation polygons delineated by the photointerpretation. Traditional analog photointerpretation techniques permitted interpreters to view the false color aerial photographs in color and in 3D under magnification, all requirements for the identification of individual tree species and forest associations. To date, automated classification techniques do not match human interpreters in their ability to assess the colors, pattern, texture, context, height, shape, size and location that together make up the signature of a plant community. While scanning air photos or using images from digital cameras for viewing/interpreting on-screen and performing heads-up digitizing to create the digital database is adequate in many cases, the magnitude of this project precluded using these procedures.

In order to identify association-level vegetation detail from nearly 1200 aerial photographs, it was necessary to view the positive transparencies under a magnifying stereoscope and delineate vegetation polygons on transparent overlays registered to the film transparencies. These overlays were then scanned, and in raster digital format, rectified based on known camera orientation parameters and an available DEM, to place the polygons in the UTM coordinate system. The rectified polygons were converted to digital vector format for input to ArcInfo GIS

software, where editing, edge matching and attributing operations were conducted to form a vegetation database.

Once a vegetation database is in place, it provides baseline information on community/species distributions and heterogeneity that can be employed with GIS software for a variety of inventory and analysis tasks, including the production of large-scale thematic maps, assessment of growth patterns and changes over time, and the quantification of fuels and fire risk. The ability to drape maps and images over DEMs is useful in planning search and rescue missions and for depicting the changes in vegetation patterns as a function of elevation. Terrain visualization is also an attractive mechanism for displaying the beauty of the natural environment to visitors and tourists.

In summary, this study integrated traditional feature extraction and new digital data processing techniques to produce vegetation databases and associated large-scale map products of high spatial and thematic detail for the rugged, forested GRSM. It is anticipated that the methodologies established for this project can be adapted to meet the requirements of vegetation mapping efforts in other National Park units of the United States.

With respect to the previously mentioned ATBI project, the selection of the ATBI sample plots representing the diversity of GRSM environments will be based on GIS data layers that document environmental, historical and geologic variations in the Park. The overstory and understory vegetation databases should play a useful role in stratifying the Park's diverse habitats and ensuring sampling efforts are thorough and cost effective. They also provide a basis for further spatial analysis, modeling and management scenarios. It is hoped that these databases will continue to be updated and contribute to the preservation of the biologically diverse GRSM.

Acknowledgments

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Control Extension and Orthorectification Procedures for Compiling Vegetation Databases of National Parks in the Southeastern United States

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KEYWORDS: vegetation mapping; softcopy photogrammetry; GIS; mountainous terrain; national parks

ABSTRACT:

Vegetation mapping of national park units in the southeastern United States is being undertaken by the Center for Remote Sensing and Mapping Science at the University of Georgia. Because of the unique characteristics of the individual parks, including size, relief, number of photos and availability of ground control, different approaches are employed for converting vegetation polygons interpreted from large-scale color infrared aerial photographs and delineated on plastic overlays into accurately georeferenced GIS database layers. Using streamlined softcopy photogrammetry and aerotriangulation procedures, it is possible to differentially rectify overlays to compensate for relief displacements and create detailed vegetation maps that conform to defined mapping standards. This paper discusses the issues of ground control extension and orthorectification of photo overlays and describes the procedures employed in this project for building the vegetation GIS databases.

INTRODUCTION

The Center for Remote Sensing and Mapping Science (CRMS) at The University of Georgia has been engaged for several years in mapping vegetation communities in national parks in southeastern United States (Welch, et al., 2002). In this project, vegetation polygons delineated on overlays registered to large-scale (1:12,000 to 1:16,000 scale) color-infrared (CIR) aerial photographs are converted to digital format and integrated into a GIS database. To maximize vegetation discrimination, the aerial photographs are acquired during the autumn (leaf-on) season when the changing colors of the leaves provide additional indicators for species and vegetation community identification. It is critical that the polygons transferred from overlay to GIS database be accurate in terms of position, shape and size to ensure that analyses that depend on the interaction of layered data sets, such as fire fuel modelling and data visualization, can be performed with confidence (Madden, 2004). As many of these parks are located in remote and rugged areas where conventional sources of ground control are lacking, streamlined aerotriangulation procedures have been developed to extend the existing ground control and permit the production of orthophotos and corrected overlays for incorporation into the GIS database.

STUDY AREA AND METHODOLOGY

The overall project area encompasses much of the southeastern United States and includes U.S. National Park units located in the states of Kentucky, Tennessee, North Carolina, South Carolina, Virginia and Alabama (Figure 1). The parks differ greatly in size, location, relief and origin. Some of the smaller (100-400 ha) historical battlefield parks and national home sites in the project are located in or near urban areas with little relief and ample roads, field boundaries and other features that can be

used for ground control. In these cases, ground control coordinates are extracted from U.S. Geological Survey (USGS) Digital Orthophoto Quarter Quadrangles (DOQQ) and simple polynomial techniques are applied to create corrected photos. Interpretation is then performed directly on the rectified CIR photographs and the polygons transferred into the GIS.

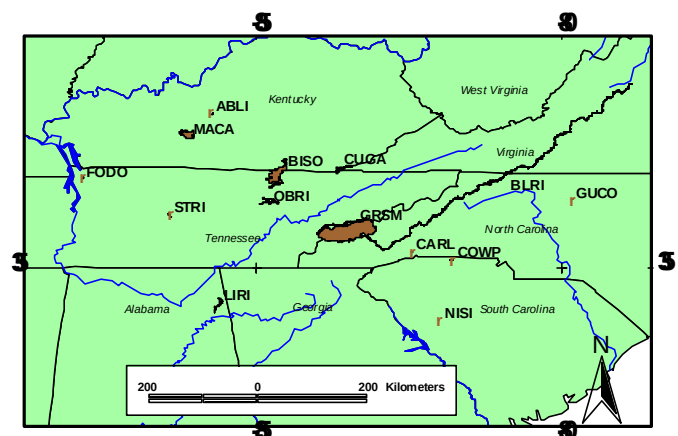


Figure 1. U.S. National Park units being mapped by the UGA-CRMS. See Table 1 below for park name abbreviations.

Many of the parks, however, are set aside to protect natural areas ranging from 80 to over 2000 sq. km in size and require a large number of aerial photographs for complete coverage (Table 1). In the more remote areas, a recurring problem is the lack of cultural features suitable for use as the ground control required to restitute the aerial photographs and associated overlays. This issue is frequently exacerbated by the presence of extensive forest cover and high relief. The result is that the locations and shapes of vegetation polygons interpreted for

Table 1: U.S. National Parks being mapped by the UGA-CRMS

Park Name	Abbreviation	Location	Size (Ha)	# Photos	Photo Scale
Abraham Lincoln National Historic Site	ABLI	Kentucky	140	3	12,000
Big South Fork National Recreation Area	BISO	Kentucky/Tennessee	50,733	309	16,000
Blue Ridge Parkway	BLRI	North Carolina/Virginia	37,408	768	16,000
Carl Sandburg Home National Historic Site	CARL	North Carolina	107	1	12,000
Cowpens National Battlefield	COWP	South Carolina	341	4	12,000
Cumberland Gap National Historical Park	CUGA	Kentucky	8,285	76	16,000
Fort Donelson National Historic Site	FODO	Tennessee	223	3	12,000
Great Smoky Mountains National Park	GRSM	Tennessee/North Carolina	209,000	1,200	12,000
Guilford Courthouse National Military Park	GUCO	North Carolina	93	1	12,000
Little River Canyon National Preserve	LIRI	Alabama	5,519	89	12,000
Mammoth Cave National Park	MACA	Kentucky	21,389	124	16,000
Ninety-Six National Historic Site	NISI	South Carolina	400	2	12,000
Obed Wild and Scenic River	OBRI	Tennessee	2,156	106	16,000
Stones River National Battlefield	STRI	Kentucky	288	3	12,000

these areas tend to be more highly influenced by geometric errors caused by improper rectification techniques or poor control. A full photogrammetric solution and orthorectification is required in these instances.

Control Extension

Extension and simplification of ground control identification and aerotriangulation procedures developed for mapping Great Smoky Mountains National Park has dramatically improved the speed and accuracy with which aerial photographs and overlays can be prepared for use in building the GIS database (Jordan, 2002). These methods permit the use of non-traditional features such as tree tops to be used for ground control. In addition, the procedures can be undertaken by non-photogrammetrists to achieve accuracies required to meet the project goals and deadlines that would be difficult under normal circumstances. Using low cost softcopy photogrammetry tools provided by the DMS Softcopy 5.0 software package and standard aerotriangulation point distribution and numbering practises, pass points are identified on scanned (42 μ m) color infrared aerial photographs (R-WEL, Inc., 2004). Although well-defined cultural features are chosen as pass points whenever possible, it is frequently the case that natural features such as corners of clearings or even tree tops must be employed when the tree canopy is extremely dense.

Well-defined features suitable for use as ground control points (GCPs) are identified on USGS DOQQs and the scanned aerial photos. Their X,Y Universal Transverse Mercator (UTM) planimetric coordinates are measured directly from the DOQQ. Elevation values for GCPs are extracted from USGS digital elevation models (DEMs) using a bilinear interpolation algorithm. In general, the accuracy of the GCP coordinates recovered from these data sets is on the order of ± 3 -5 m in XY and ± 4 -7 m in Z.

Photo coordinates are organized into flight line strips within DMS Softcopy 5.0 and automatically employed with the AeroSys 5.0 for Windows aerotriangulation (AT) package to

compute map coordinates for the pass points (Stevens, 2002). The process is quick and typical errors are comparable in magnitude to the GCP coordinate errors. Experience has shown that a person familiar with aerial photographs and the fundamental concepts of photogrammetry quickly can be trained to do productive aerotriangulation work with this system in just one or two days. This is a vast improvement on previous AT software which required weeks of experience and a strong photogrammetric background to achieve adequate results.

Rectification of Overlays

Overlays first must be scanned and rectified to the map coordinate system before the vegetation polygons can be incorporated into the GIS database. It is difficult, however, to accurately transfer ground and image coordinates directly from the aerial photographs to the overlays using manual methods. Therefore, the fiducial marks on the photos and scanned overlays are employed as registration points. Image coordinates identified during the AT process are transformed into the overlay coordinate system and used with an appropriate rectification algorithm to create a corrected overlay that is in register with the underlying GIS database. The raster polygons are converted to vector format using R2V program from Able Software, Inc. (Cambridge, Massachusetts, USA) and imported to ESRI ArcGIS for editing.

In areas of little relief, it is appropriate to apply simple polynomial correction techniques to create rectified photographs. For smaller parks, these rectified photos are tiled, overlaid with coordinate grids and printed on a high quality color printer for use in the field. Interpretation is performed on overlays registered to the hard copy prints. The overlays are scanned and converted to vector format for input to the GIS. There the polygons representing vegetation communities are edited and assigned attributes. The vegetation map of Guilford Courthouse National Military Park was created in this manner (Figure 2). In the Guilford Courthouse map product, the top portion in a rectified color infrared aerial photograph annotated with the park boundary. In the bottom section of the product, the detailed vegetation map is presented at the same scale and area coverage as the aerial photograph.

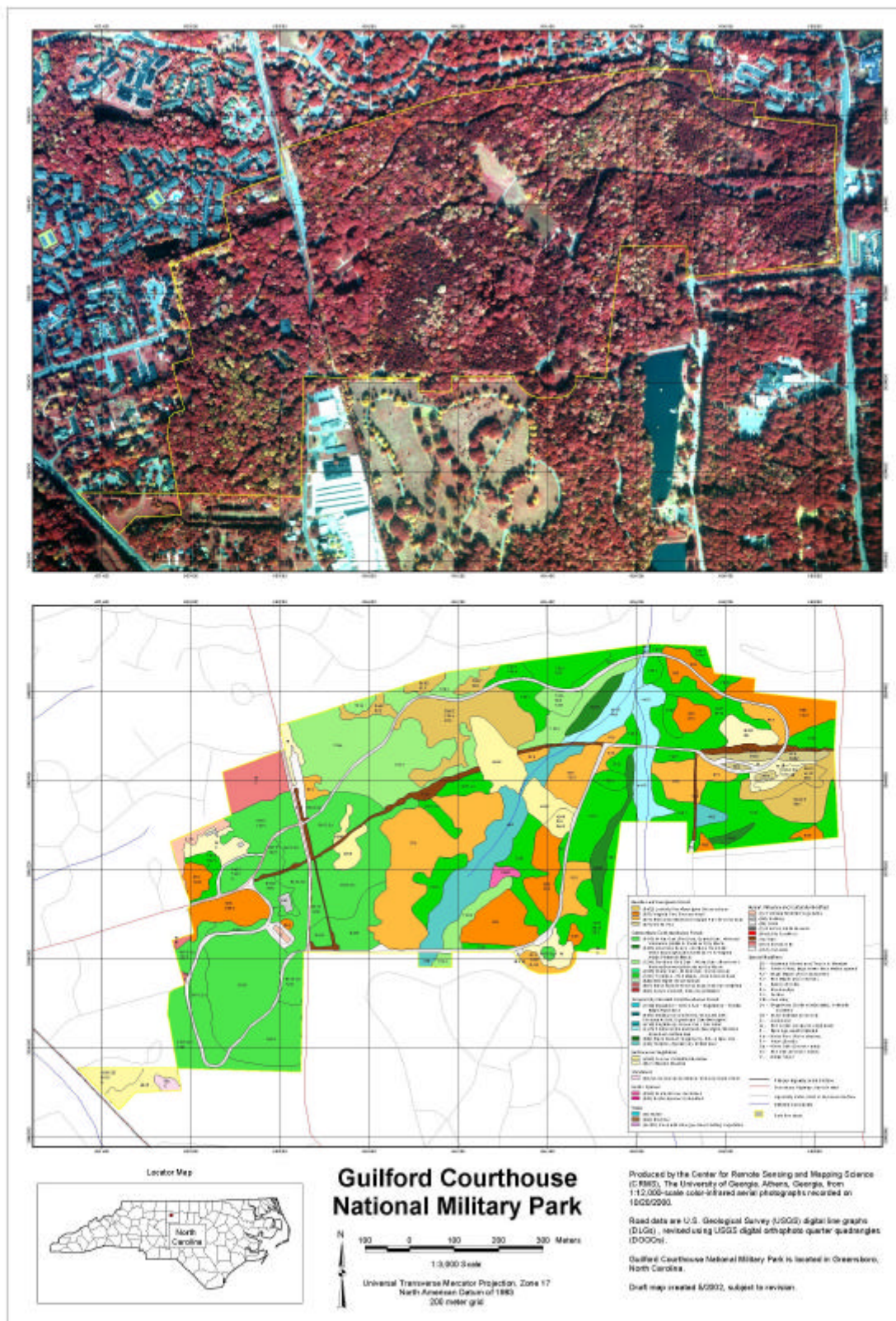


Figure 2. The vegetation map product of Guilford Courthouse National Military Park.

For areas of high relief such as Great Smoky Mountains National Park, Blue Ridge Parkway and Cumberland Gap, the overlays must be differentially rectified using a DEM to remove the effects of relief displacement, which at times can be quite significant (see Jordan, 2002). Improper corrections can lead to major difficulties in edge matching detail in the overlap areas of adjacent photographs along a flight line. The mountainous terrain in Great Smoky Mountains National Park is the source of major relief displacements in the large (1:12,000) scale aerial photographs. These relief effects greatly influence the apparent shapes of objects appearing on adjacent photos as well as their map positions and areas. Thus, it is important that the polygons are corrected properly in shape and position to facilitate edge matching during its incorporation into the GIS database. For example, a distinct area appearing on the aerial photographs in the Thunderhead Mountain area in the central portion of the park near the Appalachian Trail occurs on a steeply sloping mountainside. Elevation ranges from 1549 m in the lower left corner of the image chip to 1214 m in the upper right – a range of 335 m over a distance of about 600 m. When viewed on the three overlapping photographs, the area appears to be vastly different sizes and shapes (Figure 3). Thus, mapping the area from each of the three uncorrected photos would potentially give different results.

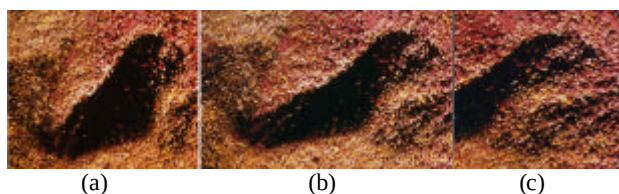


Figure 3. The dark shadowed area in the above image chips appears to be very different in shape and size in these three overlapping photographs. The image chip (a) is from the lower right corner of Photo 10063; b) near the bottom center of Photo 10062; and c) lower left edge of Photo 10061.

COMPARISON OF RECTIFICATION METHODS

There are a number of well-known image rectification methods available that can be used for converting vegetation overlays in raster format to a vector map base. Three of these are 1) polynomial (affine) based on a least-squares fit to two-dimensional GCPs; 2) single-photo projective rectification referenced to a mean datum elevation using a photogrammetric solution and 3-D GCP coordinates; and 3) rigorous differential correction (orthorectification) using the photogrammetric solution and a DEM (Novak, 1992; Welch and Jordan, 1996). To compare the effectiveness of the techniques, Photo 10063 from Thunderhead Mountain was rectified using each of the three methods and then overlaid with the completed vegetation map (Figures 4a-d). In the following examples, the darker shadowed area and corresponding vegetation polygon indicated by the black arrow in Figure 4a will be used to illustrate the

effects of the different rectification methods. In the GIS database, this polygon has an area of 5.97 ha (Table 2).

After aerotriangulation, 14 GCPs were available for Photo 10063. The affine transformation coefficients were computed using the method of least squares and resulted in an RMSE at the 14 GCPs of 106 pixels or 53 m. Most of this error is due to relief displacements in the image. The aerial photograph was then rectified using the polynomial method. The resulting image is approximately in the correct geographical location but relief displacements have not been corrected (Figure 4a). Although the general correspondence between the vegetation polygons and the underlying image can be seen (point A on the photo), it is clear that the overall registration accuracy is poor: the lines from the vegetation coverage do not fit this rectified air photo well and the shape distortions in the image are clearly visible. In this case, the dark shadowed area in the photo corresponding to the polygon (indicated by the arrow) appears to be longer, wider and in a different position than the actual polygon in the vegetation coverage. In this figure, the polygon measured directly from the image has an area of 8.34 ha, which is 2.4 ha (40 per cent) greater than the actual area of the polygon taken from the GIS database.

The overall geometry of the image rectified using the single photo projective transformation was not improved significantly over the polynomial rectification (Figure 4b). The photogrammetric solution used to determine the exterior orientation parameters, however, was excellent and yielded a RMSE of 3.34 pixels or 1.67 m at the 14 GCPs. The image was then rectified to an elevation datum value of 1380 m using a method which enforces the scale at the datum and corrects for tilt but does not correct for relief effects. Note that although the vegetation polygons generally do not fit the image exactly, there is a good fit in the areas near the 1380 m contour (shown in yellow) where scaling is exact using the photogrammetric solution. Overall, the shapes of the target polygon and other features are still distorted and this solution is not satisfactory. The area of the sample polygon measured from this image is 7.9 ha.

Orthorectification was performed on the photo using the same exterior orientation parameters computed above, but this time using the USGS DEM to provide elevation values to correct for relief displacement at each pixel location (Figure 4c). Polygons in the completed vegetation coverage are aligned perfectly with the underlying orthophoto (see point A) and the shadowed area indicated by the arrow has an area of 5.98 ha which corresponds well with the value in the GIS database for the polygon. This high level of correspondence clearly demonstrates the requirement for a full softcopy photogrammetric solution to rectifying vegetation overlays.

Finally, as a logic check, the vegetation vectors were overlaid on the USGS DOQQ (Figure 4d). It is reassuring to see that the GIS database created by orthorectification techniques described in this paper lines up very well with the USGS DOQQ product of the same area.

Table 2. Results of different image rectification methods on Photo 10063 (Great Smoky Mountains: Thunderhead Mountain Quadrangle).

Rectification Method	# GCPs	RMSE (pix)	RMSE (m)	Area of Target Polygon (ha)	Difference
DOQQ (Reference Image)	N/A	N/A	N/A	5.97	--
Affine Polynomial	14	106.3	53.1	8.34	40%
Single Photo Projective	14	3.34	1.67	7.90	32%
Orthorectification	14	3.34	1.67	5.98	0.2%

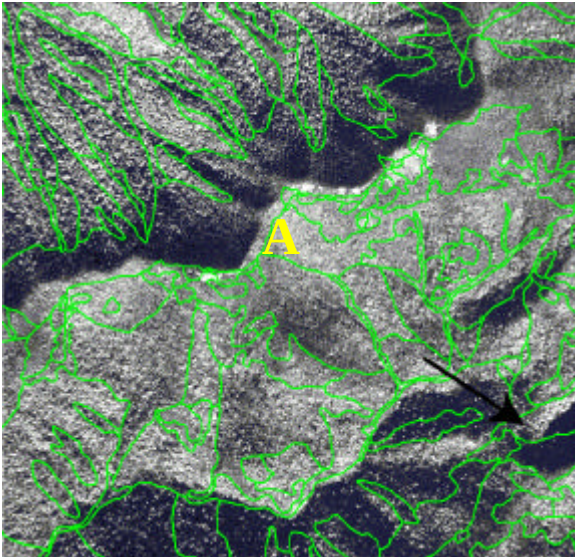


Figure 4a. Portion of Photo 10063 resulting from the polynomial rectification. Polygons in the completed vegetation coverage are shown in green. The sample polygon in the lower right portion of the photo (indicated by the black arrow) has an area of 5.97 ha according to the GIS database but 8.34 ha when measured directly from the image.

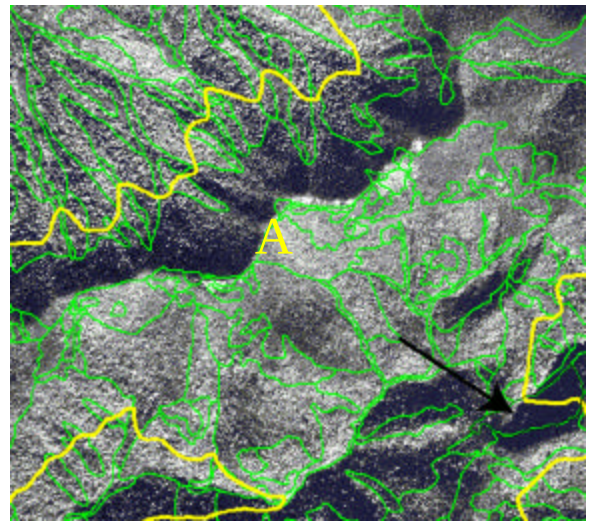


Figure 4b. Photo 10063 rectified using the single photo projective transformation. In this image, the contour representing the datum elevation of 1380 m employed for the rectification is shown in yellow.

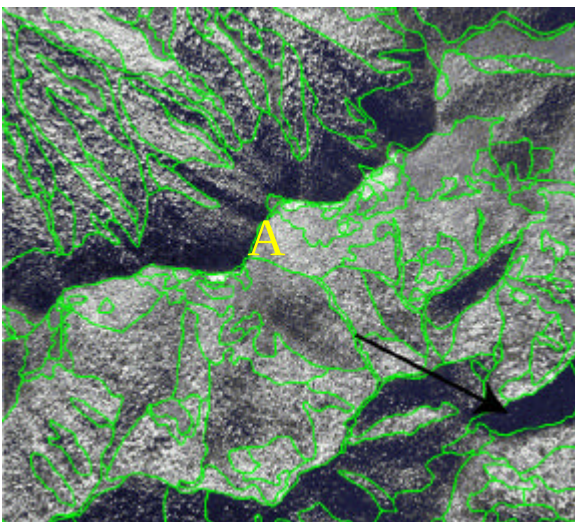


Figure 4c. The digital orthophoto created by from Photo 10063 and the USGS DEM.

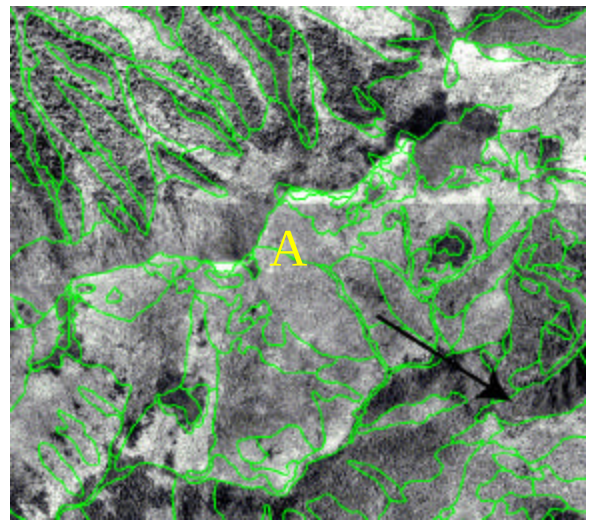


Figure 4d. A portion of the USGS DOQQ corresponding to the area covered by Photo 10063.

CONCLUSION

Experience with mapping vegetation communities in national parks units in the southeastern United States has led to the development of streamlined methods for the extension of ground control in remote areas using softcopy photogrammetry and analytical aerotriangulation techniques. Basic ground control extracted from standard USGS digital orthophoto quarterquads (DOQQs) and digital elevation models (DEMs) provide the framework with which a large number of aerial photographs of areas that have nearly continuous tree canopy cover can be controlled. Although a number of rectification methods are available, it was found that for areas of high relief, overlays delineating vegetation polygons are more accurately transferred to a GIS database if they are first orthorectified using photogrammetric differential rectification techniques. This method improves not only positional accuracy but also ease of editing and edge matching polygons from adjacent photographs. In a test polygon, area calculation was in error by as much as 40% when simple polynomial rectification was performed on an area with very high relief.

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Attachment B
Vegetation Classification System for Mapping
Great Smoky Mountains National Park

Developed by:
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Vegetation Classification System for Mapping Great Smoky Mountains National Park

CEGL Code¹ **CRMS Code**

I. FOREST

A. Sub-Alpine (5000-6643 feet)

Sub-Alpine Mesic Forests

1. Fraser Fir (above 6000 ft.) ²	6049, 6308	F
a. Formerly Fraser Fir	6049, 6308	(F), (F)S
b. Fraser Fir/Deciduous Shrub-Herbaceous	6049	F/Sb ³
c. Fraser Fir/Rhododendron	6308	F/R
2. Red Spruce - Fraser Fir	7130, 7131	S(F), S/F, S-F
a. Red Spruce- (Fraser Fir)/ Highbush Cranberry- Deciduous Shrub-Herbaceous (5400-6200 ft.)	7131	S-F/Sb
b. Red Spruce- (Fraser Fir)/ Rhododendron (5000-6000 ft.)	7130	S-F/R
3. Red Spruce	7130, 7131	S
a. Red Spruce/Southern Mountain Cranberry- Low Shrub/Herbaceous (5400-6200 ft.)	7131	S/Sb
b. Red Spruce/Rhododendron (5000-6000 ft.)	7130	S/R
4. Red Spruce-Yellow Birch - (Northern Hardwood)	6256	
a. Red Spruce - Birch- (Northern Hardwood) / Shrub/ Herbaceous (4500-6000 ft.)	6256	S/NHxB, S-NHxB, NHxB/S, S/NHx, S-NHx, NHx/S
b. Red Spruce - Birch/Rhododendron (rare)	4983	S/NHxB, S-NHx
5. Beech Gap	6246, 6130	NHxBe
a. North (also East) Slope Tall Herb Type	6246	NHxBe/Hb
b. South (also West) Slope Sedge Type	6130	NHxBe/G

¹ Cross-reference to association descriptions by CEGl numbers in the National Vegetation Classification System (Grossman, et al. 1998; Anderson et al. 1998; and NatureServe 2002) and the USGS BRD/NPS Vegetation Mapping Program Vegetation Classification System for Cades Cove and Mt. LeConte Quadrangles (The Nature Conservancy, 1999).

² Elevation range: For example, elevation 3500/4000 – 5500 ft. means most communities will be located within the elevation range 4000 - 5500 ft., some will be at 3500/4000 ft. and extremes may be outside the stated limits.

³ Symbols: (-) designates an approximately equal mix of evergreens and deciduous hardwoods; (/) indicates the first class listed is dominant over the second class (i.e., > 50% cover); and (:) indicates additional modifiers to the class will follow. Within class names, (x) = mixed, (m) = mesic to submesic, (z) = xeric to subxeric

Sub-Alpine Woodland

6. Exposed, Disturbed Northern Hardwood Woodland /(Spruce) 3893 NHxE, NHxE/S
(burned, formerly S-F or F lands, now High Elevation
Rubus spp.) Shrubland (CEGL 3893) with woodland stature
canopy of minor species of NHxY: *Sorbus americana*,
Prunus pensylvanica, *Amelanchier laevis*; also scattered
Picea rubens and *Betula allegheniensis*

B. High Elevation Forests (3500/4000 - 5500 feet)**High Elevation Mesic to Submesic Forests**

- | | | |
|---|--------------|--|
| 1. Red Spruce/Southern Mountain Cranberry-Low Shrub/
Herbaceous (also at sub-alpine elevations) | 7131 | See I.A.3 above |
| 2. Red Spruce-Yellow Birch- (Northern Hardwoods)/ Shrub/
Herbaceous (also at sub-alpine elevations) | 6256 | See I.A.4 above |
| 3. Red Spruce-Hemlock/Rhododendron (4000-5000 ft.) | 6152, 6272 | S/T, S-T, T/S,
S-T/R |
| 4. Southern Appalachian Northern Hardwoods
(4000-5500/6000 ft.) | 6256, 7861 | NHx, T/NHx,
NHx/T, NHx-T |
| a. S. Appalachian Northern Hardwoods, Yellow Birch Type
(The hardwood component of S/NHxB (6256) at
higher elevation (4800-6000 ft.); or of
T/NHxB (7861) at mid-high elev. (3500-4000/4800 ft.) | 6256
7861 | NHxB, NHxB/S,
NHxB-S
NHxB, NHxB/T,
NHxB-T, T/NHxB |
| b. Southern Appalachian Northern Hardwoods,
Typic Type (4000-6000 ft.) | 7285 | NHxY, NHxY/T |
| c. Southern Appalachian Northern Hardwoods,
Rich Type (3500-5500 ft.) | 4973 | NHxR, NHxR/T,
NHxR-T (T/NHxR) ⁴
T/NHxR |
| d. S. Appalachian Northern Hardwoods, Beech dominant | 7285 | NHx:Fg |
| e. Southern Appalachian Forested Boulder Fields | 4982, 6124 | NHx:Bo ⁵ |

⁴ Although hemlocks are usually absent or only a minor component of rich coves, T/NHxR (and also T/CHxR and T/CHx) forests with giant hemlocks occur in Dellwood and eastern Bunches Bald quadrangles in coves. In these areas, hardwoods were cut but hemlocks were apparently left standing due to low commercial value at the time of logging. In other areas T/CHx cross-references to Acid Cove Hardwood Forest, CEGL 7543.

⁵ Boulders often cannot be seen on the photos and such areas may be labeled NHxB or NHx.

5. Southern Appalachian Mixed Hardwood Forest, Acidic		
a. Southern Appalachian Mixed Hardwoods/ Rhododendron, Acid Type (3500-5000 ft.) (At mid-elevation, see I.C.6.a)	8558	NHxA, NHxA/T, NHxA-T
b. Southern Appalachian Sweet Birch/ Rhododendron (2500-5000 ft.) (At mid-elevation see I.C.6.b)	8558	HxBI/R, (NHxBI/R) ⁶
6. Eastern Hemlock/ Yellow Birch- (Northern Hardwoods)/ Rhododendron (3500-4000/4500 ft.)	7861	T/NHxB, T/NHx
7. E. Hemlock / S. Appalachian Mixed Mesic Acid Hardwoods	7861	T/NHxA
8. Eastern Hemlock/Rhododendron (1700-5000 ft.) (More common at mid elevation, see I.C.2 below.)	7136	T, T/R
9. Montane Northern Red Oak (3500-5000 ft.) (7300, 7298)	7299	MOr
a. Northern Red Oak/Rhododendron-Kalmia	7299	MOr/R-K
i.) Northern Red Oak/Rhododendron	7299	MOr/R
ii.) Northern Red Oak/Kalmia	7299	MOr/K
b. Northern Red Oak/Deciduous Shrub-Herbaceous	7300	MOr/Sb
c. Northern Red Oak/Graminoid-Herbaceous	7298	MOr/G
High Elevation Xeric Woodlands		
10. Montane Xeric Northern Red Oak-Chestnut Oak- (White Oak) / Kalmia Woodland	7299	MOz, MOz/K
11. Montane Xeric White Oak/ Kalmia-Deciduous Ericaceous Woodland	7295	MOa, MOa/K
12. Southern Appalachian Xeric Mixed Hardwood/Kalmia Woodland, Acid Type (with Hemlock; also at mid elevation, see I.C.12)	8558	NHxAz, NHxAz/T
C. Low and Mid Elevation Forests (900/1000 - 2500 ft. is low elev.; 2500 - 3500/4000 ft. is mid elev.)		
Low and Mid Elevation Mesic to Submesic Forests		
1. Southern Appalachian Cove Hardwood Forests (2000-4000/4500 ft.)	7710	CHx
a. S. Appalachian Cove Hardwoods, Typic (with Hemlock)	7710	CHx, CHx/T, CHx- T, T/CHx
b. S. Appalachian Cove Hardwoods, Liriodendron dominated, lower slope (with Hemlock)	7710	CHxL, CHxL/T, CHxL-T

⁶ NHxBI/R was originally distinguished from a lower elevation HxBI/R community. The two types were found to be contiguous and designated HxBI/R.

c. S. Appalachian Cove Hardwoods, Acid Type (usually with Hemlock)	7543	CHxA, CHxA/T, CHxA-T, T/CHxA, T/CHx ⁷ , T/HxL
d. Southern Appalachian Cove Hardwoods, Silverbell- Hemlock Type	7693	CHx-T:Ht, CHx/T:Ht
e. Southern Appalachian Cove Hardwoods, Rich Type (with Hemlock)	7695	CHxR, CHxR/T
f. Northern Red Oak Cove Forest (3000-3800 ft.)	7878	CHxO
2. Submesic to Mesic Oak/Hardwoods (1000-3500/4000 ft.) (with White Pine, with Yellow Pine, with Hemlock)	6192	OmH (OmH/PIs, OmH/PI, OmH/T)
a. Red Oak-(White Oak, Chestnut Oak, Scarlet Oak)- Hardwoods /Herbaceous, Rich Type (1800-3800 ft.)	7692	OmHR
b. Red Oak-Red Maple-Mixed Hardwoods Type (below 3500 ft.)	6192	OmHr, (OmHr/PIs) (OmHr/PI, OmHr/T)
c. Red Oak-Red Maple Type, Liriodendron co-dominant	6192	OmHL
d. White Oak-(Red Oak-Chestnut Oak)-Hickory, Acid Type (1200-4200/4400 ft.)	7230	OmHA, (OmHA/PIs) (OmHA/PI, OmHA/T)
e. Chestnut Oak-(Red Maple-Red Oak)/ tall Rhododendron (was rarely found)	6286	OmHp/R
f. Chestnut Oak Type (7267),	7230 ⁸	OcH
g. Chestnut Oak-Red Maple/Sourwood/Herbaceous Forest (2000-3000 ft.)	7267	OzHf, OzHf/PI
h. White Oak-Red Maple-Hardwood/Herbaceous	7267	OzHfA
3. Southern Appalachian Eastern Hemlock/ Rhododendron Forest, Typic Type ⁹ (1700-5000 ft.)	7136	T/R, T, T/K
4. Eastern Hemlock-Eastern White Pine /Rhododendron (below 2500 ft.)	7102	PIs/T, PIs-T, T/PIs
5. Eastern White Pine – Mesic Oak Forest (below 3000 ft.)	7517	PIs-OmH, PIs/OmH
a. Eastern White Pine-White Oak-(Red Oak-Black Oak-Hickory) Mesic Hardwood Forest	7517	PIs-OmHA, PIs/OmHA
b. Eastern White Pine- Red Oak-Red Maple-Hardwoods	7517	PIs-OmHr, PIs-OmH

⁷ See footnote 4.

⁸ May also be cross-referenced with 7298, 7299, 7300 and 8558 (HxBI/R).

⁹ May be labeled as T if R cannot be seen in the understory on the photos.

6. Southern Appalachian Mixed Hardwood Forest, Acidic (sub-mesic, at mid elevation, without oaks)		
a. Red Maple-Sweet, Yellow Birch-Fraser Magnolia- Blackgum-Sourwood / Rhododendron Submesic Acid Type (Hemlock) (HxA at 2500-3500+ ft.; NHxA at 3500-5000+ ft.)	8558	HxA, HxA/T, HxA-T
b. Southern Appalachian Sweet Birch/Rhododendron (2500-5000 ft.)	8558	HxBI/R
7. Southern Appalachian Early Successional Hardwoods	7219	Hx
a. Tuliptree-Red Maple-Sweet Birch -(Black Locust), Liriodendron Successional Type (may have Hemlock) (below 2800/3000 ft.)	7219 7543	HxL, HxL/T, HxL-T T/HxL
b. Black Walnut Successional Type	7879	HxJ
c. Broad Valley Sweet Birch Type (may have Hemlock) Shared association with Southern Appalachian Acid Cove Hardwoods CEGl 7543 (below 2800 ft.)	7543	HxBI, (also HxB) ¹⁰ HxBI/T, HxBI-T HxB/T, HxB-T
d. Rich Broad Valley Type (Fraser magnolia-Sweet Birch-Tuliptree-Red Oak-Mesic Hardwoods / dense sapling Hemlock (t) - Rhododendron	7543	HxF, HxF/T, HxF/t
8. Montane Alluvial Forest	4691	MAL MAL/T, MAL-T
a. Sycamore-Tuliptree-(Yellow, Sweet Birch)/ Alder-American Hornbeam; Large River Type	4691	MALt
b. American Hornbeam Thicket	4691	MALc
c. Sweetgum-Tuliptree (Sycamore)/ American Hornbeam-Silverbell; Sweetgum Flat	7880	MALc:Ls
d. Black Walnut / Shingle Oak /Butternut Type	7339	MALj
e. Hemlock/ Montane Alluvial Hardwoods and Broad Valley Acid Cove Hardwoods	7543	T/MAL

Low to Mid-elevation Subxeric to Xeric Forests and Woodlands

9. Chestnut Oak/Hardwoods (with Eastern White Pine, PIs; yellow pine species, PI)	6271	OzH, OzH/PI OzH/PIs
a. Chestnut Oak-Red Maple-Scarlet Oak/Mountain Laurel Xeric Ridge/Slope Woodland (below 4000 ft.)	6271	OzH, OzH/PI, (OzH/PIs)
b. Chestnut Oak-Red Maple / Sourwood/Herbaceous Forest (2000-3000 ft.)	7267	OzHf, ¹¹ OzHf/PIs

¹⁰ Originally named HxB; was changed to HxBI to indicate the dominant birch is *Betula lenta*. HxBI is not to be confused with HxBI/R, CEGl 8558.

¹¹ OzHf, OzHf/PI and OzHfA were regrouped with sub-mesic oak-hardwoods, Section I.C.2.

10. White Oak-Red Maple/Hardwood/Herbaceous Forest (In Calderwood quadrangle, uncommon.)	7230	OzHfA ¹²
11. Eastern White Pine and Mixed Eastern White Pine - Dry Oak		
a. Southern Appalachian White Pine/Mountain Laurel Woodland (below 2400 ft.)	7100	PIs PIs/K
b. Eastern White Pine Successional	7944	PIs
c. Appalachian White Pine- (Chestnut Oak-Scarlet Oak) Xeric Forest/Woodland	7519	PIs/OzH, PIs-OzH
d. Appalachian White Pine- Chestnut Oak- Red Maple-Red Oak Dry Forest	7519	PIs/OzHf, PIs-OzHf
Low and Mid Elevation Xeric Woodlands		
Southern yellow pine species (listed below) in xeric woodlands		PI
Virginia Pine (<i>Pinus virginiana</i>)	2591, 7119	PIv
Shortleaf Pine (<i>Pinus echinata</i>)	7078, 3560	PIe
Pitch Pine (<i>Pinus rigida</i>)	7097	PIr
Table Mountain Pine (<i>Pinus pungens</i>)	7097	PIp
12. Southern Appalachian Xeric Mixed Hardwoods, Acidic Red Maple-Sweet Birch-Fraser Magnolia- Black gum- Sourwood/ Kalmia (HxAz at 2500-3500+ ft.; NHxAz at 3500-4800 ft.	8558	HxAz
13. Blue Ridge Pitch Pine-Table Mountain Pine Woodland (1800-2500/3000 ft, without PIp; 2500/3000-4500 ft. with PIp)	7097	PIp, PIr, PIp/OzH, PIp-OzH, PI/OzH PI-OzH
14. Low Elevation Mixed (Virginia-Pitch-Shortleaf) Pine and Mixed Pine-Xeric Oak/ Hardwood Woodland/Forest (Pines at least 50% of canopy; below 2300/2500ft.)	7119	PI/OzH, PI-OzH, OzH/PIr
15. Appalachian Shortleaf Pine-(Xeric Oak)/Mountain Laurel- <i>Vaccinium</i> spp. Woodland (below 2400 ft.)	7078	PIe, PI/OzH, PI/OzH K K
16. Virginia Pine Early Successional Woodland/Forest (below 2000 ft.)	2591	PIv:5, PIv/OzH, PIv-OzH, OzH/PIv, PI/OzH
17. Appalachian Shortleaf Pine/ Little Bluestem Woodland (Uncommon)	3560	PIe; PI/OzH, PI/OzH G
18. <i>Paulownia tomentosa</i> Disturbed Woodland (Exotic sp.)	3687	No mapping unit

II. Shrublands or Shrub Understory	3893	Sb
A. Southern Appalachian Heath Balds	7876, 3814	Hth
1. Southern Appalachian High Elevation Heath Bald (>5500ft.) (<i>R. catawbiense</i> - <i>R. carolinianum</i>)	7876	Hth:R, Hth
2. Southern Appalachian Mid Elevation Heath Bald (<5500 ft.)		
a. <i>R. maximum</i> , <i>R. catawbiense</i> , small trees/shrubs	7876	Hth:R, Hth
b. <i>Kalmia latifolia</i> , small trees/shrubs	3814	Hth:K, Hth
3. Southern Alppalachian Sand Myrtle Heath Bald (above 5800 ft.)	3951	No mapping unit
B. High Elevation Successional Blackberry Thicket <i>Rubus</i> spp./ Lady Fern/Skunk Goldenrod; may have tree canopy of sparse woodland stature; disturbance related.	3893	Sb:Rc
C. Montane Grape Vine Opening (<i>Vitis aestivalis</i>) (2000-3500 ft.)	3890	V (= modifier :8)
D. Shrub Understory (May include spares overstory vegetation)		
1. <i>Rhododendron</i> sp., generally <i>R. maximum</i>	7876	R
2. <i>Kalmia latifolia</i> (mountain laurel)	3814	K
III. Graminoid and Herbaceous		
A. Appalachian High Elevation Grassy Bald, Mountain Oatgrass- Mountain Cinquefoil-Herbaceous	4242	Gb
B. Cultivated Meadow, Old Field, Graminoid, Herbaceous	4048	G, Hb
Forbs (non-Graminoid Herbaceous), Low to Mid Elevation	4048	Fb
IV. Rock Outcrops and Summits	4394	RK
A. Rock with Sparse Vegetation; Road Cut; Road Fill Rubble	4394	RK; RK:6
B. Landslide Scars; Rocky Cliffs; Rock Outcrops; Rocky Summits (May include sparse overstory vegetation)	4278	RK, SV
C. Appalachian Felsic Cliff Sparse Vegetation, Mountain Spleenwort-Rock Alumroot	4980	RK, SV, RK G
D. Montane Calcerous Cliff Sparse Vegetation, <i>Asplenium</i> spp.-Purple Cliffbrake	4980, 4394	RK, SV, RK Fb

E. Southern Blue Ridge Spray Cliff, Appalachian Shoestring Fern-
Cave Alumroot-Appalachian Bluet/ Liverwort-Herbaceous 4302 SV, RK

F. Southern Appalachian High Elevation Rocky Summits:

- | | | |
|---|------|--------|
| 1. Cliff Saxifrage-Wretched Sedge-Cain's Reedgrass-Herbaceous | 4278 | SV, RK |
| 2. Cliff Saxifrage-Wretched Sedge-Skunk Goldenrod-Herbaceous | 4277 | SV, RK |

V. Non-Alluvial Wetlands (Beaver Ponds, Marshes, Seeps)

A. High Elevation Herbaceous Seeps

- | | | |
|---|------|------------------------|
| 1. Rich Montane Cove Shaded Seep, ¹²
<i>Diphylleia- Saxifraga- Laportea</i> | 4296 | Seep: D-S |
| 2. High Elevation Rich Montane Seep,
<i>Rudbeckia-Monarda-Impatiens</i> | 4293 | Seep: R-M
Seep:4293 |

B. *Sphagnum* –(Graminoid-Herbaceous) Seepage Slopes

- | | | |
|--|------|-----------------------|
| 1. High Elevation Mountain Fringed Sedge-Wood Orchid-
Roundleaf Sundew/ <i>Sphagnum</i> spp. Seepage Slope | 7697 | Seep:G
Seep: 7697 |
| 2. High Elevation Cain's Reedgrass (<i>Calamagrostis cainii</i>)/
<i>Sphagnum</i> spp. Seepage Slope | 7877 | Seep: Cc
Seep:7877 |
| 3. Low Elevation Southern Appalachian Fowl Mannagrass-
Sedge- Mountain Fringed Sedge-Turtlehead-Forbs/
<i>Sphagnum</i> spp. Wet Seepage Meadow | 8438 | Seep: 8438
Wt: G |

C. Wetlands; Graminoid-Herbaceous, Forbs

- | | | |
|--|------|--|
| 1. <i>Juncus effusus</i> -Herbaceous Seasonally Flooded Marsh | 4112 | Wt |
| 2. Southern Blue Ridge Beaver Pond <i>Juncus effusus</i> -
Herbaceous Marsh | 4112 | Wt:Je, Wt: 4112 |
| 3. Smartweed-Cutgrass-Perennial Forb Beaver Pond
(in Kinzel Springs) | 8433 | Wt:Je, Wt:8433 |
| | 4290 | Wt: Fb, Wt:G ¹³
Wt: 4290 |

D. Montane Low-Elevation Smooth Alder-Spicebush/Mad-dog
Skullcap-New York Fern Seep

3909 Seep:Sb
Seep: 3909

E. Sweet Gum/*Sphagnum* spp. Seasonally Flooded Swamp
(in Cades Cove)

7388 Wt:Ls, Hx:Ls
Wt: 7388

VI. Alluvial Habitats, Non-Forested

4103, 3895 AL

A. Montane Alluvial Canebrake (*Arundinaria gigantea*)

3836 AL:Ag

¹² Generally shaded and cannot be seen on the air photos

¹³ 4290, 843, 4112 and 8433 may be listed as Wt:G if not field checked.

B. Black willow thicket	3895	AL:Sn
C. Cobble-Gravel-Sand-Mud Bar, Twisted Sedge Type (Riverscour vegetation)	4103	AL:G
D. Cobble-Gravel-Sand-Mud Bar, Alder-Yellowroot Shrub Type (Riverscour vegetation)	3985	AL:Sb
E. Fontana Lake Drawdown Zone	3910	Mud

VII. Additional Categories

HI	Human Influence (Disturbed environs of old home site or other human influence)
RD	Road
W	Water
Dd	Dead Vegetation
SV	Sparse Vegetation
SU	Successional Vegetation
E	Exotic Vegetation
Mud	Cobble, Gravel, Sand, Mud

VIII. Special Modifiers

:1	Damage, cause undetermined
:2	Damage by landslides
:3	Damage by insects
:4	Damage by wind
:5	Post disturbance recovery (e.g., young or mid-age even-age stand)
:6	Human Influence (Disturbed environs of old home site or other human influence)
:7	Abandoned agriculture
:8	Grape vines (Grape hole)
:9	Logged recently
:10	Burned recently
:11	Old home site
:12	Agricultural field, cultivated meadow
:13	Row planted
:Bol	Boulder field
:P	Pasture
:Sb	Shrub

Species designation, indicating that a species is particularly dominating in the association:

:A	<i>Acer rubrum</i>
:Af	<i>Aesculus flava</i>
:B	<i>Betula allegheniensis</i>
:Fg	<i>Fagus grandifolia</i>
:Fs	<i>Festuca</i> spp. (now, <i>Lolium</i> spp.)

:G Graminoid spp.
:Ht *Halesia tetraptera* var. *monticola*
:Je *Juncus effuses*
K: *Kalmia latifolia*
:Ls *Liquidambar styraciflua*
:L *Liriodendron tulipifera*
:Mf *Magnolia fraseri*
:Ox *Oxydendron arboretum*
:Pr *Picea rubens*
:Ps *Prunus serotina*
:Qf *Quercus falcata*
:Qi *Quercus imbricaria*
:Qp *Quercus prinus*
:Qr *Quercus rubra*
:Qv *Quercus velutina*
:R *Rhododendron* spp.(usually *R. maximum*)
:Rc *Rubus canadensis*
:S Spruce, *Picea rubens*
:Sn *Salix nigra*
:T *Tsuga canadensis*
:t *Tsuga canadensis*, young even age subcanopy

Attachment C

Notes on the Overstory Vegetation Classification System for Great Smoky Mountains National Park

by Phyllis Jackson

Introduction

This document contains notes on GRSM overstory vegetation classes including: 1) descriptions of air photo signatures and interpretation of particular classes; 2) characteristic species of forest communities; and 3) typical habitats, growth conditions and disturbance regimes associated with overstory vegetation classes.

Classification of GRSM Plant Communities

Large-scale (1:12,000) color infrared (CIR) aerial photographs and data collected from fieldwork were used to identify overstory vegetation associations, i.e., plant community types, as described by the U.S. National Vegetation Classification System (NVCS) protocol for the U.S. Geological Survey-National Park Service (USGS-NPS) Vegetation Mapping Program (Anderson et al. 1998). The unit of *association* is defined as a “plant community type of definite floristic composition, uniform habitat conditions and uniform physiognomy” (Grossman et al. 1998). The association is the finest division in the NVCS classification system with each association assigned a unique Community Element Global (CEGL) code number. About a year after the mapping project was underway, we began coordinating our fieldwork and vegetation classification more closely with NatureServe (formerly ABI, a research unit of The Nature Conservancy). Cooperation in conducting joint fieldwork and exchanging data with NatureServe’s plant ecologists greatly benefited the mapping project, as well as NatureServe’s classification as they continued to sample vegetation cover types, describe new classes and refine existing classes.

At the onset of the GRSM database/mapping project, a classification of GRSM vegetation conducted by The Nature Conservancy was available to UGA-CRMS photo interpreters (Drake et al. 1999; TNC 1999). Based upon many existing reports and studies such as Cain (1943), Whittaker (1956), Campbell (1977), Schmalzer (1978), Schafale and Weakley (1990), Bryant et al. (1993), Kemp and Voorhis. (1993), Skeen et al. (1993) and others, as well as over 400 vegetation samples collected in areas corresponding with the Cades Cove and Mount Le Conte USGS topographic quadrangles and quantitative data analysis using ordination techniques, a GRSM classification for the Cades Cove and Mont Le Conte area that includes 42 alliances and 68 associations was described. Since it focuses on the two-quad area, it was not considered a comprehensive vegetation classification for the entire park. It did, however, cover the major vegetation types expected to be found in the park.

Photointerpreters from UGA-CRMS evaluated this classification system to determine if the classes could be identified on the aerial photographs. Over five years of interpreting aerial photographs and field work resulted in an expansion of the TNC classification for GRSM and the organization of plant community information into a hierarchical reference outline (Jackson et al. 2002). (See Attachment B for the Vegetation Classification System for Mapping Great Smoky Mountains National Park.) The classification system had to be open-ended, flexible and allow additions, modification and refinement as we progressed throughout the project. We believe this classification system serves as a good overview and reference guide to the vegetation of GRSM.

Organization of the GRSM overstory vegetation classification system is based on the ecological location of forest communities with respect to elevation and moisture gradients. A graph with elevation (900 to +6000 ft.; 274 to 1829 m) along the vertical y-axis, and moisture from mesic to xeric along the horizontal x-axis is presented in Figure B-1. Environmental factors such as relief, degree of slope and slope position, slope aspect, geology and soils, hydrology, local and prevailing wind patterns and location south vs. north of the spine of the Appalachians interact to determine the mesic to xeric gradient within the overall elevation gradient. Rainfall, snow and ice, clouds, fog, rime ice and edaphic conditions are factors accounting for available moisture. Natural breaks in plant community groups occurred along the elevation gradient: lowlands, about 900 to 2,500 ft. (274 to 762 m); mid-elevation at 2,500 to 4,000 ft. (762 to 1,219 m); high elevation from 4,000 to 5,000 ft. (1,219 to 1,524 m); sub-alpine from 5,000 ft. (1,524 m) to the highest peak, Clingman's Dome, at 6,643 ft. (2,025 m).

Next, we placed forest communities on this graph in the elevation-moisture gradient space where they typically grow (Figure C-1). We added communities to this graph as the mapping project progressed and adjusted their locations as we continued fieldwork. We also added non-forest communities such as shrublands, graminoid, herbaceous, rock outcrop and others. Some communities spanned a relatively large vertical or horizontal space on the graph. Others occupied a small and very specific space. Some communities overlapped while others were disjunctive. At highest elevations, of course, all the forests are mesic unless they cover a substrate that cannot retain water. This graph was used to organize overstory classes in the GRSM vegetation classification outline (see Attachment B).

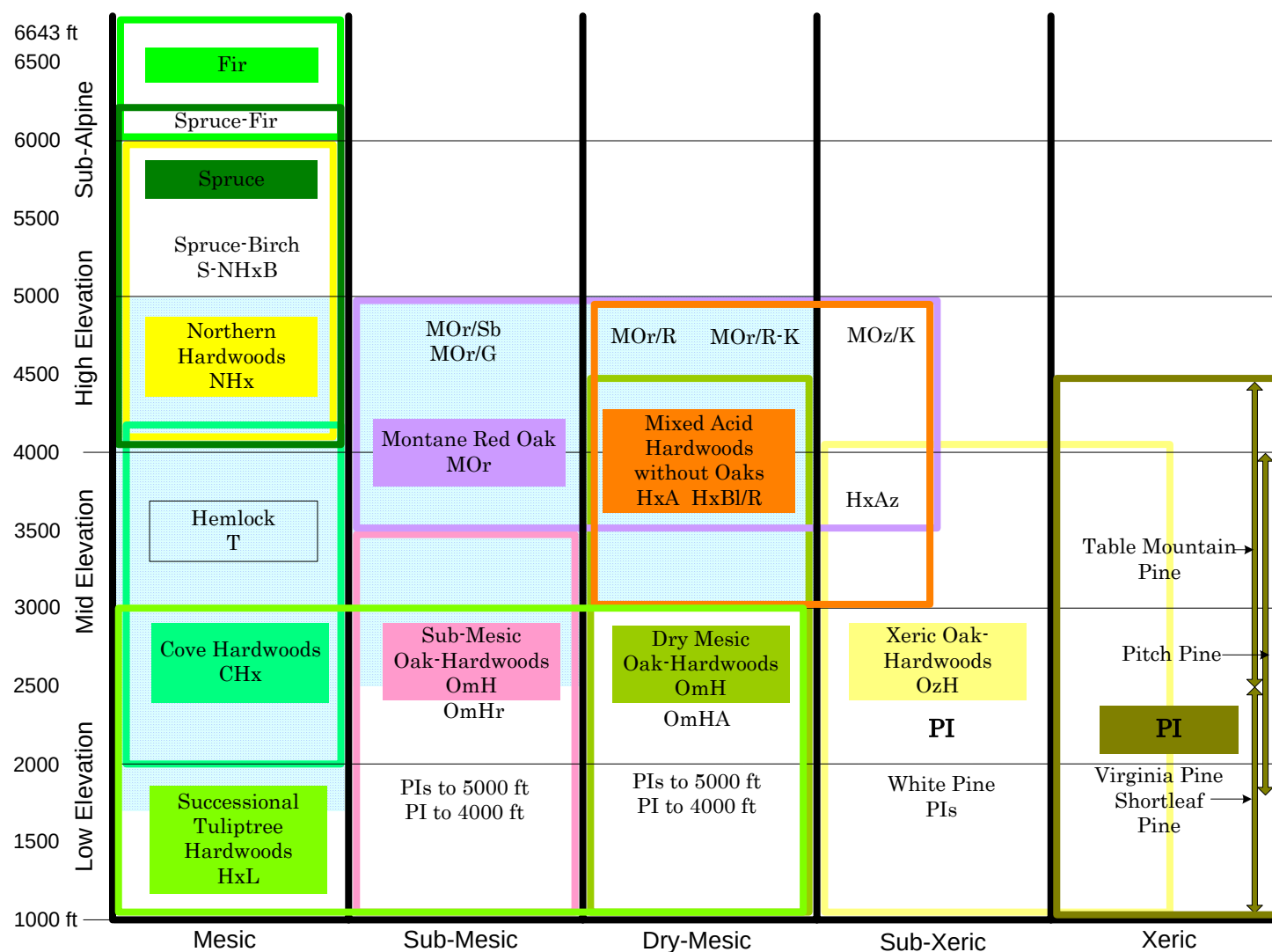


Figure C-1. Ecological location of forest communities in Great Smoky Mountains with respect to elevation and moisture gradients. (Abbreviations are explained in Jackson et al. (2002), Vegetation Classification System for Mapping Great Smoky Mountains National Park, Appendix B.)

Our ecologically based classification outline is thus structured from sub-alpine to low elevations and from mesic to xeric conditions, while all classes are floristically defined. It differs at the top levels in the hierarchy from the National Vegetation Classification System (NVCS) since the first five levels of NVCS are physiognomic and the lower two levels—Alliance and Association—are floristic. For example:

Physiognomic NVCS levels:

- I. = Forest
- I.A = Evergreen forest
- I.A.8 = Temperate or sub-polar needle-leafed evergreen forest
- I.A.8.N = Natural/semi-natural forest
- I.A.8.N.c = Conical-crowned temperate or sub-polar natural/semi-natural needle-leaf evergreen forest

Floristic NVCS levels:

- I.A.8.N.c.1 = *Abies fraseri* – *Picea rubens* Forest Alliance
- CEGL 7130 = *Picea rubens* – (*Abies fraseri*)/ *Rhododendron catawbiense* or *R. maximum* Forest Association

The CRMS – NatureServe Classification arrives at the same association (plant community) level by a different route, for example:

- I. = Forest
- A. = Sub-Alpine Forest (+ 4800/5000 ft.)
 - Mesic Forests
 - 3. = Red Spruce (*Picea rubens*) Sub-Alpine Forests
 - a. = Red Spruce/Rhododendron Forest; (S/R = CEGL 7130)

The CRMS – NatureServe Vegetation Classification System for Mapping GRSM cross-references CRMS letter codes with CEGL number codes designated by the NVCS (see Attachment B). The reasons for the divergence from the NVCS are: 1) the GRSM mapping project was initiated before the NVCS classes for GRSM were complete or finalized; and 2) the letter codes and less complex floristic-based hierarchy were felt to be more straight forward, easier to understand and better-suited for photointerpretation.

Although most overstory vegetation polygons were interpreted at the association level, some polygons had to be mapped at the next higher (i.e., more general) level in the hierarchy and some were mapped at the next level finer (i.e., more detailed) than the association. Reasons for these and other variations are discussed below.

Use of Dominant, Second and Third Vegetation Classes and Modifiers

Each vegetation polygon attributed in the database and labeled on the hardcopy map uses up to three levels of dominance denoted as dominant, second and third vegetation (Welch et al. 2002). Using three vegetation tiers of classes allowed information on transitions between communities

and/or complex patterns to be incorporated in the vegetation database. Further, we added modifiers to indicate additional influences on the vegetation such as recent disturbances, land use histories and tree species of particular prominence within the polygon. Additional categories included non-vegetative features such as roads, old homesites, dead vegetation and others. For example, a polygon at sub-alpine elevation labeled S-F/Sb:3 // S-F :5 // Sb:Rc (in this text, // separates dominant, second and third vegetation levels) describes a dominant Spruce-Fir / Highbush Cranberry-Shrub-Herbaceous Forest (CEGL 7130) with modifier :3 indicating damage by insects (meaning that standing and/or fallen dead trees can be seen on the CIR photos and the causal agent “insects” was either inferred or determined from field observation). The second level describes areas of this same spruce-fir forest regenerating within the matrix, as indicated by modifier :5. The third level indicates areas of High Elevation Blackberry Thicket (*Rubus canadensis* shrubland, Sb:Rc, CEGL 3893) in the matrix. Had the regenerating spruce-fir or the blackberry thicket in this example been polygons above minimum map unit size, they would have been delineated and mapped separately.

The goal of the photointerpreters was to document for each one of the approximately 50,000 vegetation polygons as much ecologically meaningful information as possible. In this way, the database/map user can better understand the composition of mixed vegetation associations, transitions between associations, and the relationship of vegetation patterns to other spatial data such as topography.

Nomenclature

The system we developed for naming and classifying each community type (association) is intuitive and hierarchical. CHx, for example, is the abbreviation for mixed Cove Hardwoods. (Note: m = mesic, x = mixed, z = xeric.) This class, denoted the default group, can be further classified as a particular type of Cove Hardwood. For example:

Cove Hardwoods (low to mid elevations):

- CHx = Southern Appalachian Cove Hardwoods, Typic Type (the default group)
- CHxL = Southern Appalachian Cove Hardwoods, Tuliptree (*Liriodendron tulipifera*) dominated
- CHxA = Southern Appalachian Acid Cove Hardwoods
- CHxR = Southern Appalachian Rich Cove Hardwoods
- CHxO = Southern Appalachian Red Oak (*Quercus rubra*) Cove Hardwoods.

Northern Hardwoods (high elevation):

- NHx = Northern Hardwoods (the default group)
- NHxY = Typic Northern Hardwoods (Y is from Typic, as T was already used.)
- NHxB = Northern Hardwoods, Yellow Birch (*Betula alleghaniensis*) dominated
- NHxR = Rich Northern Hardwoods
- NHxE = Exposed and disturbed Northern Hardwoods
- NHxBe = Beech (*Fagus grandifolia*) gaps, a special northern hardwood type at high elevations, further divided into NHxBe/Hb (the north slope tall herbaceous type) and NHxBe/G (the south slope graminoid type).
- NHx:Fg = Northern Hardwoods, Beech dominant

Mesic Oak-Hardwoods (low to mid-elevations):

OmH = Mesic Oak-Hardwoods (the default group)

OmHr = Mesic Northern Red Oak-Red Maple / Mixed Hardwoods (the r is from *Quercus rubra* and *Acer rubrum*)

OmHA = Mesic Oak-Hardwoods, Acidic Type

OmHR = Mesic Oak-Hardwoods, Rich Type

Why did we use community name abbreviations instead of CEGL numbers? First, alpha abbreviations were selected to intuitively represent vegetation association names vs. learning numerical codes. Second, the CRMS/NatureServe hierarchical system provides flexibility in interpretation. Using a CEGL number to label a map polygon is an “either/or” decision. If photointerpreters could not discern between certain associations, for example the mesic oak-hardwoods OmHr vs. OmHA photographed before their leaves had changed color in autumn, they could move up one level in the ecological hierarchy and label the polygon OmH. Thus OmH becomes the default group, and is assigned the CEGL number of the association most common of the possible choices. The default groups (e.g., CHx, NHx, Hx, OmH, OzH, MOr, etc.) are apparent in the GRSM Vegetation Classification System, Attachment B.

Many associations differ according to their understory, which can be readily discerned in the field but not necessarily seen through the canopy on CIR photos. For example, the Montane Red Oak (MOr) associations differ ecologically as indicated by their understory: orchard-like *Carex* (graminoid)-herbaceous (MOr/G, CEGL 7298); or *Rhododendron maximum-Kalmia latifolia* (MOr/R-K, CEGL 7299); or, deciduous shrub-herbaceous (MOr/Sb, CEGL 7300.) MOr was the default group if we could not discern the understory, and was cross-referenced to the most common MOr type, CEGL 7299.

Using a CEGL number would have required a choice of either one CEGL number or another, and indicated certainty when there was uncertainty, thereby introducing a source of error. Further, the number of communities in GRSM resulted in a very large classification system. Remembering so many CEGL numbers, or looking them up, is time consuming and tedious (therefore, prone to mistakes) for both those who construct the database and use the maps.

Why are some Additional Categories (e.g., HI = human influence) also assigned Special Modifier numbers (e.g., 6 = human influence)? HI could be a stand alone polygon label, but in a more complex polygon, the modifier could be added to indicate evidence of human influence. Similarly, Dd = dead vegetation is a stand alone label when the trees are all dead and the species/forest and cause are undetermined. Dd: 2 would indicate an undetermined species killed by landslides. A label F: 3 indicates a known species, Fraser Fir (*Abies fraseri*) Forest, damaged by a known agent, insects.

Use of (-) and (/) Symbols to Indicate Mixed Evergreens and Deciduous Hardwoods; and Other Mixed Vegetation

The symbol (-) indicates an approximately equal mix of evergreens and deciduous hardwoods, while (/) indicates the first group is dominant in the mix. For example, PI/OzH indicates the relative percentage of yellow pines to xeric oak and hardwoods is greater than 50%, whereas PI-OzH indicates an approximately 50:50 mix.

In the NVCS Classification outline:

- I.A = Forest, evergreen
- I.B = Forest, deciduous
- I.C = Forest, mixed evergreen-deciduous
- II.A = Woodland, evergreen
- II.B = Woodland, deciduous
- II.C = Woodland, mixed evergreen-deciduous

Originally we intended for communities mapped with (-) and (/) symbols to correspond to I.C or II.C, mixed evergreen-deciduous forest or woodland community types in the NVCS classification outline. However, all four of the yellow pine forest communities we found in GRSM that are in Evergreen Forest category I.A of the NVCS were actually most often mixed pine and oak species, and often the oaks were 50% or greater. (Also, they were sometimes more a woodland than a forest.) Thus, we used the (-) and (/) symbols in naming yellow pine-xeric oak forest /woodland communities to indicate the relative composition of evergreen and deciduous trees.

We also used (-) and (/) in naming the three mixed evergreen-evergreen communities. For a mix of hardwoods (and almost always they were mixed) we used Hx in the name. In addition, we used the (/) symbol to separate canopy and understory in those associations where a rhododendron, deciduous shrub, or graminoid understory are a key factor determining classification. For example, S/Sb (Spruce/ Shrub) or S/R (Spruce/ Rhododendron) indicates spruce dominant over shrubs and rhododendron, respectively.

NVCS classified seven forests in GRSM as I.C, Mixed Evergreen-Deciduous. They are:

Spruce/Yellow Birch-(Northern Hardwood).....	CEGL 6256, 4983
White Pine- Mesic Oak	CEGL 7517
White Pine- Dry Oak	CEGL 7519
Yellow Birch- (Northern Hardwood)/ Hemlock.....	CEGL 7861
Acid Cove Hardwoods (Tuliptree-Sweet Birch-Hemlock) ..	CEGL 7543
Acid Cove Hardwoods, Silverbell-Hemlock Type.....	CEGL 7693

Yellow Pine- Xeric Oak forest and woodlands classified as Evergreen (category I.A) by the NVCS, but often indicated in our naming system as Mixed Evergreen-Deciduous are:

Mixed (Virginia-Pitch-Shortleaf) Pine/ Xeric Oak.....	CEGL 7119
Shortleaf Pine/ Xeric Oak.....	CEGL 7078
Virginia Pine/Xeric Oak Successional.....	CEGL 2591
Pitch Pine-Table Mountain Pine/ Xeric Oak Woodland.....	CEGL 7097
Shortleaf Pine/ Xeric Oak/ Little Bluestem.....	CEGL 3560

Three forests are Mixed Evergreen-Evergreen Forests:

Spruce-Fir.....	CEGL 7130, 7131
Spruce-Hemlock.....	CEGL 6272, 5152
Hemlock-White Pine	CEGL 7102

When communities are defined as “mixed” by the NVCS standard, the relative evergreen-deciduous hardwood mix present is not necessarily indicated in their CEGL description. The CRMS-NatureServe classification goes a step further and describes the approximate mix in each polygon. Several examples follow:

Hemlocks are defined in the NVCS as a component of acidic cove hardwoods (CEGL 7543). In GRSM, hemlocks may or may not be present in acid coves, or they may dominate. We labeled acid coves with hemlocks as CHxA-T, CHxA/T or T/CHxA, all of which crosswalk to CEGL 7543. We also labeled hemlocks in other communities such as rich northern hardwood coves (NHxR/T) where they are not listed as present in the NVCS description (CEGL 4973). Now, with the arrival at GRSM of the devastating woolly hemlock adelgid (*Adelges tsuga*), valuable information about the location of hemlocks is retrievable. Hemlock information can be extracted from dominant, second and third vegetation levels to identify hemlock distributions.

The low to mid-elevation mixed pine (may be *Pinus echinata*, *P. rigida*, *P. pungens* or *P. virginiana*) and xeric oak-hardwood woodlands are mapped as PI/OzH, PI-OzH or OzH/PI. In some polygons the pines are very dominant (PI/OzH), but in areas with heavy mortality from past pine beetle infestations, and with suppression of fires in recent years, these woodlands are becoming *Quercus prinus*-*Q. coccinea* dominated sub-xeric to xeric woodlands (OzH/PI).

Our original intent was to use (-) or (/) as a way to list both the evergreen and hardwood components of a community so it would correspond to an NVCS mixed class. Sometimes, however, the evergreen or deciduous component may be listed as the second vegetation, particularly if the secondary vegetation is less than 20% of the canopy.

We almost hesitate to specify the percentages that would indicate use of (-), (/), or second vegetation category. For several important reasons, these percentages are not cast in stone. We used (-) to indicate an evergreen and deciduous mix from approximately 50-50% to 60-40%; (/) indicates approximately a mix from 60/40 to 80/20. At less than 20 % canopy coverage, the component was generally placed in the next lower level. However, when the polygon was complex and much information had to be entered into a 3-line label, the label might read: CHx/T // OmHA/PIs // HxL. In this case, premium space for information was not used up by listing

CHxA and T, or OmHA and PIs, on separate lines as a second or third vegetation, even if they were less than 20% of the canopy. Also, in this example, it was the photointerpreter's decision to list PIs with the OmHA instead of the HxL.

The percent canopy cover of a species or association is approximate for several reasons. For example, photointerpreters may differ in their estimations. On photos acquired when hardwood leaves had fallen, as many had at higher elevations, conifers appear to have a greater significance in the CIR images than the leafless hardwoods, so interpreters must interpolate the percentages.

Other variations in the use of (-) and (/) occurred during the labeling process as the data editors processed information written on the interpreted overlays and assigned labels for the 50,000 polygons in the GRSM overstory vegetation database. Also, if polygons were substantially smaller than the minimum map unit size of 0.5 ha, they had to be collapsed and combined with adjacent polygons, and the attributes and percentages adjusted accordingly. Compare the attributing process to cooking with a recipe for potato soup and having to occasionally make changes. Overall, the substitutions may vary somewhat but the process is consistent, and the result is potato soup and not clam chowder.

Interpreting the CIR Air Photos

The majority of CIR air photos were acquired in late October (10-28-1997 and 10-27-1998) to record the vegetation condition of mid to high elevation forests in GRSM at the peak of their autumn leaf color. Overall, these photos were optimal for photointerpretation and the large scale (1:12,000) captured considerable detail in tree color, shape and height. Unfortunately, however, the highest elevation northern hardwood forests were already over half leaf-off by the time of both flights. Ultimately this was not a serious problem because these forests are mainly birch dominated. Conversely, senescence had barely begun in the low elevation mesic deciduous forests, making these CIR photos more difficult to interpret, while senescence was well underway in the drier oak and pine-oak forests at low and mid-elevations. A subset of CIR photos for the northeast section of the park were acquired in May 1998. With little variation in leaf color at this time of year, interpretation at the association level was more difficult and required extra fieldwork.

In mapping the canopy, we also referred to medium-scale (1:40,000) National Aerial Photography Program (NAPP) CIR air photos and some NAPP black and white (B/W) air photos in Tennessee where CIR was not available. These NAPP photos were acquired in late winter and provided information on vegetation communities in leaf-off conditions to discern the understory in deciduous hardwood forests and better see the evergreen component of mixed forests. We also used these NAPP CIR photos to assess understory vegetation for the fire fuel map project.

The signature of a vegetation association will vary on CIR photos may vary from roll to roll with differences in exposure settings, developing and printing. Color and tone also will vary from top to bottom, and center to periphery of the same frame due to position of the sun at the time of exposure (angle and direction) and fall off (differential darkening of the photo away from the center). Further information on factors affecting the appearance of CIR air photos can be found in Paine and Kaiser (2003). Original film diapositives are preferred over second generation

prints for greatest discrimination of color and photo detail. The type of light used to viewing the diapositives is also critical. We have experimented with lighting and found 5000° Kelvin (daylight) fluorescent light is best for discriminating the many nuances of colors with the human eye.

In addition to differences in CIR film, lighting, photography and development, Mother Nature contributes her own far greater influence to signature variations. A forest's autumn leaf color palette can change dramatically over just a few days, hence its CIR signature may depend precisely on the date of the photo. Mixed oak-dominated signatures can be amongst the most challenging to interpret from CIR photos. The ideal time for flying air photos is to catch the oaks at mid-senescence, when the scarlet oaks have already turned fully scarlet, the white and chestnut oaks are peanut butter brown to golden yellow, and the red oaks are still green or just beginning to change color. Of course, the perfect timing for all elevations, all aspects, and all landforms does not occur entirely on the same day in GRSM.

Windstorms are another of Mother Nature's events that can greatly affect a CIR signature overnight at the time of senescence. The colored leaves can be blown off and there is little chance of discerning any differences in CIR signatures of bare branches. The first hard frost will also bring about a rapid change in leaf color, and may cause leaves to quickly turn "dead brown" instead of progressing through their expected fall colors.

Photos of the same community taken the same date in different years may differ. A prime example is the CIR signature of HxBI/R in the 1997 and 1998 photos. Certain HxBI/R communities on slopes above the Sweet Creek Valley on the border between Clingmans Dome and Silers Bald quadrangles were photographed in overlapping flight lines from the two different years. One year, the signature was a buckskin-white color, with even-age tree crowns packed like palisades of white pinheads. These were the sweet birches (*Betula lenta*), having turned to their autumn yellow leaf color. The next year, that same community had a rough brick-red signature. Careful examination revealed barely visible (under high power of the stereoscope) branches above the brick-red patches. We were seeing the dense *Rhododendron maximum* understory beneath the already leafless sweet birches. Interestingly, this was not the usual smooth, bright red or pink-red signature of *R. maximum* on balds or in the understory elsewhere in GRSM. This rough textural brick-red signature was consistent in HxBI/R throughout GRSM.

Leaf physiology affects leaf pigmentation, and in turn, alters the CIR signature. For example, tree pigments vary with soil minerals, such as iron and aluminum, and with stress, such as drought stress in summer. Some trees, sweet birches and the tuliptrees in low elevation valleys, in particular, shut down their photosynthetic system and their green chlorophyll stocks during a dry summer. Their anthocyanin pigments, no longer masked by the chlorophylls, show themselves as the leaves turn blueish during this still relatively early-season time when cell contents have a basic pH. The CIR signature also becomes blueish¹. In fall, when chlorophylls decline and late season cell conditions are acidic, these very same water-soluble anthocyanins will give the leaves their rose-red, blood-red, orange-red, pink and deep purple colors. The lesser xanthophylls, also water-soluble, will impart yellow and tan colors. The oil-soluble carotenoids

¹ Forest ecologist Kim Coder (pers. comm. 1998) likens the summer shut down to the lyrics of a Pink Floyd song: the trees go "comfortably numb."

are tougher and less fleeting than the water-soluble anthocyanins and xanthophylls. Carotenoids are collectively over 60 pigments, each imparting a slightly different color mostly in the brilliant yellow to orange to red spectrum (Coder 1997). Combine the banquet of possible pigments influenced by the array of possible environmental conditions and events, and the resulting nuances of fall leaf colors are enormous.

A single species may consistently turn a different leaf color during fall in different parts of the park. For example, red maples in Dellwood and Bunches Bald quadrangles on the east side of GRSM always turned dazzling yellow during the years we were in the field, giving a brilliant white CIR signature. On the west side of the park, however, red maples conformed to their typical red leaf color and resulted in a yellow CIR signature.

Several different species growing in the same area may have nearly identical CIR signatures. In some cases, the dazzling yellow tuliptrees and red maples of Dellwood quadrangle both produce a bright white CIR signature. The yellow-green sweet birches and yellow-green tuliptrees in the broad valleys of Wear Cove have light white to pink-white CIR signature. The red maples, scarlet oaks, black gums (*Nyssa sylvatica*) and sourwoods (*Oxydenndrum arboretum*) in the xeric oak communities of Thunderhead Mountain quadrangle all turn orange-red to scarlet to blue-red and they will appear yellow to dense, goldenrod-yellow in CIR.

Many of Mother Nature's trees have a mind of their own, so to speak with Northern red oaks among the more unpredictable. Timing of senescence will vary considerably from red oak to red oak in the same neighborhood, and even from leaf to leaf of the same tree. Leaf color, reflecting timing of the senescence process, varies with changing aspect, and from concave and protected slopes, to convex, exposed slopes. Most red oaks in a low elevation cove in late October in GRSM were unfrosted and green with their chlorophyll factories still in production, but a few flamboyant individuals were decked out in full color, while some individuals had just a percentage of their leaves changing. Some red oaks will have entire limbs with green leaves and other limbs entirely with orange-red leaves. On convex, exposed slopes at mid elevation and higher, the red oaks and also the chestnut oaks were already "dead brown" following hard and early frosts.

The Physical Environment--Relationship of Slope, Aspect and Location to Vegetation Distribution

In the course of our fieldwork and while conducting stereoscopic interpretation of aerial photographs, we observed how slope, aspect and the sun's energy influence the distributions of plant communities. We mention here some observations about slope, aspect and location on the north or south side of the Southern Appalachian ridge in order to both help and caution those who will use the vegetation database and maps.

Changes from one aspect to another, especially on the north side of the Great Smoky Mountains, can be abrupt and dramatic. At an elevation of 3000 ft. (914 m) in the Thunderhead Mountain quadrangle, for example, a person can hike on a summer afternoon through the cool shade and shelter of a north-facing, cove hardwood forest, and then round the bend and abruptly tangle in

the inhospitable smilax and mountain laurel of a southwest-facing, hot, chestnut oak-scarlet oak-red maple-black gum sub-xeric woodland.

The Great Smoky Mountains, in the Unaka Range, are part of the Blue Ridge Province of the Southern Appalachians. The Blue Ridge Range lies to the southeast of the Unaka Range and both ranges run parallel to each other from southwest to northeast, with important connecting cross-ridges, e.g., Balsam Mountain in GRSM. The long, snaking and relatively level-crested ridge of the Smokies is the state border between Tennessee to the north and North Carolina to the south. Due to their position relative to the Eastern Continental Divide, river drainage for these mountains is entirely to the northwest into the Great Valley of the Tennessee River, and then onward to the Ohio River. The Great Smoky Mountains rise between the two gorges cut by the major rivers that drain them: the Little Tennessee River on the southwest, and the Big Pigeon River on the northeast.

At any particular place along the generally southwest-northeast axis of the Great Smoky Mountains, the climate close to the ground will vary with differences in exposure to oceanic and continental air masses, latitude, slope and exposure, and elevation. High elevations in the Smokies are cooler and moister than the valleys below. Temperature decreases about 2.23° F per 1000 ft. (about 0.4° C per 100 m) increase in elevation, while high summits in summer average 10 to 15 °F cooler than lands in the valleys. The summer climate of high summits in GRSM is approximately similar to that at sea level in northern Maine and New Brunswick, 1000 miles (1,609 km) to the northeast (Shanks 1954).

North facing mountain slopes north of the spine of the Great Smoky Mountains (Tennessee side) intercept prevailing westerly winds. The winds are forced abruptly upward along crests of the mountains into a cooler atmosphere, causing their moisture to condense as rain, snow, clouds and the famous haze that named the Great Smoky Mountains. Wind blown clouds, fog and mist are estimated to add another 50-100% to the total annual precipitation for the sub-alpine spruce-fir forests, with their needles so efficient at collecting wind blown droplets (White et al. 1993).

Winds at high elevations are also important. Winds reach velocities of 100 km./hr. on 20 to 25 days of the year and occasionally exceed 200 km./hr. on exposed summits. Intense rainstorms are frequent and can produce debris avalanches on steep slopes. Debris avalanches and windstorms are probably the most important natural climatic disturbances on the steep, high elevation slopes (White et al. 1993).

Slopes on the north side receive considerable protection from the sun's radiation. In general, on the north side, we found the gradation from the most mesic to the most xeric slope aspects seems to follow this order: North, NE, East, NW, SE and West, South, SW. The great mesic cove hardwoods are on this north side since there are so many opportunities here to face north. See Madden (2003) and (2004) for GIS analysis of GRSM vegetation in relation to aspect.

We observed southwest facing slopes in summer in GRSM to be hotter and drier than south and southeast facing slopes. Incident solar radiation here is about the same before and after midday, but the Great Smoky Mountains are altogether a humid place. So much of the morning sun's energy is spent to evaporate the previous night's accumulation of dew and transpired moisture

that the east slopes lag in drying out and heating up. There are many nice, east facing mesic coves. By afternoon, when the sun is around to the southwest, leaves and air have dried, and the afternoon rains have not yet arrived, the exposed, southwest slopes take a beating from solar radiation.

The generally drier south (North Carolina) side of the Great Smoky Mountains lies between two high ridges: the crest of the Smokies to the north-northwest shelters it from prevailing westerly winds, and the Blue Ridge Range to the south-southeast intercepts southeasterly winds coming from the subtropical Bermuda High in summer. The relation of aspect and moisture gradient is not so predictable here as on the north side. Some northeast to northwest facing slopes, for example, will be drier than some slopes facing southeast.

The western half of the south side of GRSM is drier and hotter than the north side in summer, with an abundance of sub-mesic oak and xeric pine-oak communities. As the prevailing westerly winds cross over the high crest of the Great Smoky Mountains and descend downslope, they have already unloaded much of their moisture. In general, the south side also has much more surface area facing southeast to southwest, soaking up solar radiation and making it hotter.

Topography of the eastern half of the south side of the Great Smoky Mountains gets more complicated due to four high ridges and their valleys lying to the south of the spine of the Smokies. Thomas Ridge runs approximately south from the crest at Newfound Gap in the Clingmans Dome Quadrangle. Near Mt. Guyot in the Mt. Guyot quadrangle, the spine splits, with one fork continuing northeast through Cosby Knob. The other fork is the Balsam Mountain ridge which runs southeast through Luftee Knob in the Luftee Knob quadrangle, then joins the Mt. Sterling Ridge at Big Cataloochee Mountain. The Mt. Sterling ridge turns back to follow an east-northeast path to Mt. Sterling, just into the Cove Creek Gap quadrangle. The Balsam Mountain ridge continues south from Big Cataloochee Mountain, into Bunches Bald quadrangle. At Whim Knob the Cataloochee Divide ridge runs northeastward from Balsam Mountain, and into the Dellwood quadrangle. Great coves and convex mountainsides of all aspects lie in this southeast section of GRSM, divided by its major cross-ridges. There are many opportunities here for coves to face north and have ecological conditions similar to the north side of GRSM

We offer a word of caution to anyone using the digital vegetation database and maps for research on GRSM plant communities. Be aware that ecological conditions on the north side, the southwest, and the southeast are not the same. Be wary of combining data from across the divides.

CRMS/NatureServe Codes Cross-referenced to Two or More CEGL Codes, and CEGL Codes Crossed to Multiple CRMS/NatureServe Codes

If CIR signatures of different communities (having different CEGL codes) look the same, the CRMS code will cross-reference to each of them. For example, Red Spruce /Deciduous Shrub (S/Sb, CEGL 7131) and Red Spruce/Rhododendron (S/R, CEGL 7130) have CIR signatures that are difficult to distinguish from one another if the understory cannot be seen through the dense spruce canopy under the stereoscope. We can label the polygon with the default code, S, which is cross-referenced to both CEGLs 7131 and 7130.

An NVCS association (assigned one CEGL code) may have several variations that we can distinguish on CIR images and cross-reference each variation to its own CRMS code. See, for example, Attachment B, MOr/R-K, MOr/R, MOr/K, MOz and MOz/K are all cross-referenced to CEGL 7299.

Several NVCS associations are “shared associations,” with possible components that are distinctly different from each other. For example, HxBI is a shared association with CHxA below 2,800 ft. (853 m), both are CEGL 7543. Pending further study, NHxE also is a shared association with Sb:Rc (CEGL 3893, and HxBI/R is shared with HxA (CEGL 8558). In these cases, although the vegetation composition is similar, CIR signatures of the CRMS/NatureServe classes are distinctly different and therefore were mapped separately and cross-referenced to the same CEGL code.

GRSM Vegetation Classification System

A researcher should be able to study the GRSM Vegetation Classification System (Attachment B) and have a reference framework to understand the plant ecology of the Great Smoky Mountains. We listed in the outline some non-alluvial wetlands, and some rock outcrop and summit communities that we did not map because they were too small or too obscured to be seen on the CIR photos. These classes are listed so they can be mapped in the future, and so the Vegetation Classification Outline will provide the most complete representation of vegetation of GRSM.

Notes on Certain Communities and their Cross-reference to CEGL Codes

Low to Mid-Elevation Protected Cove and Valley Forests

Coves (located on concave, protected slopes) support the most mesic of the mixed deciduous hardwood communities. Most of the splendid cove hardwood forests, including the northern hardwood rich coves (NHxR) are on north facing slopes on the north and more mesic side of the main high spine of the Great Smoky Mountains. Another group of nice coves lies in the southeast section of the park where there are major high cross-ridges and their great valleys. (See Figure B-1 and the previous section on Physical Environment—Relation of Slope, Aspect and Location to Vegetation Distribution) At higher elevations with more mesic conditions, the range in aspect for coves was from northwest to north to east.

1. CHx, Southern Appalachian Typic Cove Hardwood Forests (CEGL 7710), were the most common cove hardwoods. They were the cove hardwood default group if there was uncertainty in distinguishing the type of coves.
2. CHxL, Cove Hardwood Forests (CEGL 7710), are dominated by tuliptree (*Liriodendron tulipifera*) and often cover the lower, flatter slopes of coves. CHxL grades into CHx as elevation increases and the slope becomes steeper. CHxL and CHx are cross-referenced to

the same CEGL 7710. We separated them because CHxL predictably occurs on the low slope position with low gradient (although CHx can also occupy this position), the species composition differs, and the CIR signature of tuliptree in coves is so distinct. Some Successional Tuliptree (HxL) forests appeared to be borderline CHxL and may be labeled either.

3. CHxA and CHxA-T, Southern Appalachian Acid Cove Hardwood Forests (CEGL 7543), are broadly defined by the NPS-NVCS. We generally applied a more restricted definition for acid coves: relatively narrow, V-shaped coves and valleys co-dominated by hemlock (but sometimes entirely lacking hemlock), with tuliptrees and usually sweet birch, over a *Rhododendron maximum* understory, associated with small to medium streams, but not a wetland.

“Acid cove” as defined by CEGL 7543 adds to our more restricted “classic acid cove” definition (above) some forests in the broad valleys of GRSM that often also include mesic oak species, occasional rich cove species, and even white pines. We occasionally even found pitch pines growing in the broader and flatter valleys. If mesic oaks (OmHA and OmHr) and pines were significantly present they are listed in the 2nd and 3rd vegetation classes. Most, if not all, of the broad valleys had been logged and are in middle stages of successional tree wars. We attributed vegetation in these valleys as we saw it in the CIR images, for example, HxL // OmHA // T; or, HxL/T // OmHA/PIs // OmHr:PI; or, HxBI; or numerous other variations. These would cross-reference to CEGL 7219, successional tuliptree-red maple-hardwood forests. Note: (//) separates dominant, 2nd and 3rd vegetation.

4. HxBI, Successional Sweet Birch Forest (CEGL 7543), was classed as a shared association with CHxA. HxBI covers broad, non-alluvial valleys, and is not to be confused with HxBI/R (CEGL 8558). HxBI seems similar to Successional Tuliptree, HxL (CEGL 7219) in valleys, but with sweet birch and little to no tuliptree. We suggest HxBI “needs more work.” In the beginning we labeled HxBI as HxB. Later we distinguished between the birch species and assigned “B” to yellow birch and “BI” to sweet birch. Care was needed in order to distinguish between the very similar white signatures of HxBI and HxL in valleys.
5. CHxR, Southern Appalachian Rich Cove Forests (CEGL 7695), generally grade upslope, as the cove becomes more protected and mesic, from a CHx forest below. The transition appears to be gradual both in the field and on CIR images. At the late October dates when most of our CIR images were taken, the higher elevation rich cove forests had advanced to their fall color palette. Photointerpreters distinguished CHxR from CHx based mainly on the more colorful and varied CIR signature of CHxR, large tree crowns with some natural gaps, and elevation. CHxR coves made a gradual transition to NHxR coves if the cove formation continued to yet higher elevation before it broadened and flattened as it approached a ridge and was no longer a protected, concave land formation.
6. CHxO, Southern Appalachian Red Oak Cove Forest (CEGL 7878), could have been grouped with the mesic oak-hardwood forests and named OmHC instead. (We originally did so.) However, the CIR signature of this red oak- (basswood, *Tilia americana* - silverbell, *Halesia tetraptera*) community was almost indistinguishable from the CHx signature, and it occurs

only in protected coves. If photointerpreters were to mistake CHxO for any other forest, it would be the default, CHx. Therefore, red oak coves were grouped with cove hardwoods. CHxO was uncommon, and distinguished by its canopy of 75-90% northern red oak where we found it. The red oaks themselves were also distinguished by their architecture, much like that of the “structural oaks” of MOr (Montane Red Oak) forests. Some examples had 20% large yellow birch and Fraser magnolia (*Magnolia fraseri*), which are not in the CEGl description. We found CHxO on the upper slopes of coves. CHxO graded into MOr further upslope as the valley broadened and flattened, and was no longer protected by the concave land formation. In the few examples we saw, CHxO graded downslope to CHx.

Low to Mid-Elevation Mesic to Sub-mesic Oak-Hardwood Forests

See Bryant, McComb and Fralish (1993) and Van Lear and Brose (2002) for further information on the ecology of oak-hardwood forests.

7. OmH, Submesic to Mesic Oak/Hardwood Forest (CEGL 6192), was the default group when the identity of a mesic to sub-mesic oak forest was in question. These forests are by far easier to distinguish from each other on CIR images when the leaves are about midway through senescence. (See previous discussion on Interpreting CIR Air Photos.) OmH is cross-referenced to CEGl 6192, OmHr.
8. OmHr, Northern Red Oak - Red Maple - Hickory / Sweet Shrub – Buffalo-nut (*Pyrularia pubera*) Forest (CEGL 6192), was common at low and mid-elevations on the more mesic north side of GRSM. In the field someone asked, “If this is an oak-hickory forest, where are the hickories?” There aren’t many. OmHr in GRSM might more accurately be called a red oak-red maple-tuliptree- mixed hardwood forest. The CIR signature of OmHr was quite variable due to the considerable variations in species composition, past logging and farming, the variability in fall leaf color of northern red oaks, and the percentage of *L. tulipifera*. One photointerpreter working in GRSM quadrangles where *Liriodendron* was so commonly co-dominant in OmHr did label these polygons OmHL, which was cross-referenced to CEGl 6192. Such polygons may also be labeled OmHr // HxL.
9. OmHA, Submesic White Oak-(Northern Red Oak-Chestnut Oak)- Hickory/ *Rhododendron calendulaceum* Acid Type Forest (CEGL 7230), was a common submesic oak community at low and mid-elevations on the drier, south side of GRSM. At higher elevations, about 3500 ft. up to 4400 ft. (1067 – 1341 m), white oaks often became less numerous, northern red and chestnut oaks increased in numbers, and OmHA graded into one of the Montane Red Oak forests, MOr. The transition between OmHA and MOr was gradual and the borders between these classes somewhat arbitrary both on the vegetation maps and in the field.
10. OmHR, Northern Red Oak – (White Oak, Chestnut Oak, Scarlet Oak)- Hickory / Herbaceous, Rich Type Forest (CEGL 7692), was the richest and most mesic of the oak forests on slightly concave to slightly convex slopes at mid-elevation. OmHR was magnificent but uncommon. The CIR signature was almost identical to the cove hardwoods, but the land formations where OmHR forests lie are not as protected as coves. A good example of OmHR in the Thunderhead Mountain quadrangle is on a steep and slightly

convex slope facing north-northwest above the Finley Cove trail, after the trail crosses Hickory Tree Branch.

11. OmHp/R, Chestnut Oak- (Red Maple-Red Oak)/ tall Rhododendron Forest (CEGL 6286), was an association we seldom saw in GRSM. (The “p” is from *Q. prinus*.) The few examples we identified as CEGL 6286 were not a good fit. Chestnut oak and tall *R. maximum* were dominant but white oaks and other deciduous hardwoods were also present, and these places perhaps were an unusual variation of OmHA (CEGL 7230). Polygons we attributed as OmHp in GRSM were not the same as the good-fit OmHp we later saw at Carl Sandburg Home National Historic Site, with a canopy of 95% chestnut oak (5% red oak) over a 90-95% tall *R. maximum* understory.
12. OzHf (and OzHf/PI), Chestnut Oak-Red Maple/ Sourwood Forest (CEGL 7267), is borderline between sub-mesic and sub-xeric, but OzHf is probably better grouped with the sub-mesic oaks. We first saw this community on the east side of Fodderstack Mountain in the Wear Cove quadrangle in CIR photos before we saw it in the field. The yellow-and-white, “salt-and-pepper” signature was similar to the OzH woodland signature, except this was a closed canopy forest, and it did not appear to have an ericaceous understory. (The defining *K. latifolia* understory of OzH is readily visible in CIR photos.) Thus, we first named this signature OzHf, adding the “f” for forest, but it would be several months before we would go to the mountain and find out what it was. In many OzHf examples elsewhere in GRSM, leaf senescence was less advanced and resulted in a CIR signature very similar to that of OmHA.
13. OcH, Sub-mesic Chestnut Oak/Hardwood Forest (CEGL 7230 and CEGL 7267), was a designation used at the beginning of the GRSM vegetation mapping project, before we had made many observations about woodlands and forests where chestnut oak can be a significant component, and before we began working more closely with NatureServe to match communities, when possible, to the NVCS being refined and developed for GRSM concurrently with our project. The dry-mesic to dry OcH forest most often cross-references to CEGL 7230 (= OmHA), Appalachian White Oak-(Northern Red Oak-Chestnut Oak)/Hickory, Acid Type. When chestnut oaks are numerous in the canopy, OcH best cross-references CEGL 7267, Chestnut Oak-Red Maple/Sourwood /Herbaceous Dry Forest (= OzHf). Photointerpreters differed in their use of the OcH category. Some photointerpreters used the OcH label throughout the project for dry-mesic oak ridge and top slope communities with a high percentage of chestnut oak, while another senior photointerpreter did not use OcH, but did take longer to interpret the photos. Thus, the presence or absence of OcH polygons in different quadrangles is due, in large part, to a difference in photointerpreters. It should be noted that Oak communities and their signatures are the most variable and complex of GRSM groups for photointerpreters to discern. (See section on Interpreting CIR Air Photos.) The overlap of OcH with OmHA (CEGL 7230) and OzHf (CEGL 7267), should be recognized when users of the vegetation database assess Park-wide distributions of OcH.

Under dry-mesic to sub-xeric conditions on exposed slopes, chestnut oak will change to a golden-yellow fall leaf color, like many other trees in GRSM. The CIR signature of various yellow leaves is a nuance of creamy-white. A ground truth assessment of polygons labeled OcH showed that most were OmHA or OzHf. Some were also MOR/G (CEGL 7298),

MOr/R-K (CEGL 7299) and HxBI/R (8558). These communities all have creamy-white components in their CIR signatures.

Mixed Hardwoods without Oaks

14. HxA and HxA/T, Southern Appalachian Mixed Hardwood (Acidic) Forest (CEGL 8558), along with higher elevation variation NHxA and NHxA/T, is a spectacular forest, especially in autumn, with a CIR signature we called the “coat of many colors.” This forest jewel—although common from eastern Thunderhead Mountain to eastern Bunches Bald quadrangles—is new to the NVCS, requiring a new CEGL 8558. Not only was this a new association, it was also a new alliance (*Acer rubrum*–*Nyssa sylvatica* – *Magnolia fraseri* Forest Alliance), documented for the first time in GRSM and in the world. Notably also, this is the only association and only alliance in GRSM where red maple is a dominant and identifying member, not playing its usual role as the ubiquitous and successional intruder.

We hope further research will shed light on how HxA came to be. This collection of hardwoods, distinctly without oaks, covers slopes where oak forests would be expected. So many species share dominance that there was no room for all of them to be designated as nominals in the CEGL description: red maple, sweet birch, and/or yellow birch, depending on elevation, Fraser magnolia, black gum, sourwood, and usually silverbell and giant hemlock. *R. maximum*, hobblebush (*Viburnum lantanoides*), greenbrier (*Smilax rotundifolia*) and holly (*Ilex* spp.) occupy the shrub understory. American beech also occurred in the canopy and understory of some HxA polygons. The birches are a constant and defining member of this community, but they were left out as a nominal in NatureServe’s official CEGL description for the NVCS. We hope the name will be amended.

Dry-mesic HxA forests cover moderate to steep terrain on mid to upper convex slopes of all aspects, and most often stop abruptly at a heath bald on the ridgetop which HxA surrounds. Many HxA forests appear to be old growth with the size of tree crowns rivaling those in rich coves. Giant American chestnut sawed stumps were found in some old growth HxA forests.

15. NHxA, NHxA/T, Southern Appalachian Mixed Hardwoods / Rhododendron (Acidic) Forest (CEGL 8558), is the higher elevation version of HxA (CEGL 8558). Here, *B. alleghaniensis* replaces *B. lenta*. Giant fire cherries (*Prunus pensylvanica*) join the canopy with their show of flower corymbs. Red spruce joins or replaces the big hemlocks. NHxA also covers convex slopes of all aspects and predictably surrounds a heath bald on the ridge top.
16. HxAz, Southern Appalachian Mixed Hardwood (Acidic and Xeric) Forest (CEGL 8558), is a xeric variation of HxA (CEGL 8558). Found on mid-elevation, south to southwestern slopes only, HxAz is a woodland with short stature trees co-dominated by four of the HxA deciduous hardwood species: red maple, sweet birch, black gum and Fraser magnolia. Sassafras (*Sassafras albidum*) and sourwood were sometimes abundant. Hemlocks were absent except as saplings. The shrub understory has *Kalmia latifolia* replacing *R. maximum*, and no shortage of *Smilax*.

17. HxBI/R, Southern Appalachian Sweet Birch / Rhododendron Forest (CEGL 8558), is another community we found that was not previously documented in GRSM or in the NVCS. NatureServe plant ecologists tentatively cross-referenced HxBI/R to CEGL 8558 (same CEGL as HxA, NHxA, HxAz and HxAz), due in considerable part to time constraints for sufficient study. There is no mistaking an HxBI/R type specimen: 95% sweet birch packed densely in the even-age 50-60 foot canopy, with 5% silverbell, red maple and yellow birch. Understory is 95-100 % *R. maximum* and can be nearly impenetrable. HxBI/R occurs mostly north of and protected by high ridges, such as the spine of the Smokies. Much of the Luftee Knob quadrangle is HxBI/R.

At high elevations HxBI/R will lie on gently concave, somewhat protected, north facing top slopes. At mid-high elevation, this forest will cover convex slopes of all aspects, with a rhododendron “bald” on the ridge. We never made it over or under the dense *R. maximum* understory in HxBI/R to actually field check these balds. In a mid-elevation HxBI/R polygon in the northeastern Thunderhead Mountain quadrangle, where the bridle path trail to Mt. Davis cut through a knoll of HxBI/R lying between Indian Flats Prong and a branch to the west, the thick rhododendron opening at the center of HxBI/R was entirely *R. maximum*. HxBI/R appears to be an even-age successional community. We have found it where there was evidence of past logging. The question is, what community did it succeed, and why? And, with continuing succession, what will it become?

We believe that with increasing red maple, Fraser magnolia and yellow birch, HxBI/R grades into HxA or NHxA, depending on elevation. In the Smokies, yellow birch is considered the high elevation birch and sweet birch the low elevation species. But in HxBI/R, the sweet birch, not yellow birch, was dominant at high elevation. We hope this most interesting community will be worthy of further study, and perhaps its own CEGL recognition and description. We expect it will also be found along the Blue Ridge Parkway.

Low to Mid-Elevation Successional Hardwood Forests:

18. HxBI, Southern Appalachian Early Successional Hardwoods - Broad Valley Sweet Birch Type Forest (CEGL 7543), was another forest new to the NVCS that we found from its unique CIR signature. (It should not to be confused with HxBI/R, CEGL 8558.) NatureServe ecologists cross-referenced it to Southern Appalachian Acid Cove Forest, CEGL 7543. They added sweet birch as a nominal in CEGL 7543 (*Liriodendron tulipifera*-*Betula lenta*-*Tsuga canadensis* /*Rhododendron maximum*) forest description and changed CEGL 7543 to a “shared association.” CEGL 7543 has a potpourri of variations. HxBI is a low and mid-elevation approximate ecological equivalent of Successional Tuliptree Forest, HxL (CEGL 7219) in broad valleys, with sweet birch dominant and very little or no tuliptree.
19. HxF, Southern Appalachian Early Successional Hardwoods - Rich Broad Valley Type Forest (CEGL 7543), is cross-referenced to the same CEGL 7543 as HxBI, but it was not well documented and “needs work.” The best examples lie in formerly settled Bone Valley on the North Carolina side of Thunderhead Mountain quadrangle. The “F” is for the Fraser magnolia that gives this community a distinct CIR signature, and also for “Full of

everything”: Fraser magnolia, sweet birch, tuliptree, ash (*Fraxinus* sp.), red oak, white oak, and other deciduous hardwood species associated with coves. HxF is characterized by a CIR signature of small, even-age tree crowns and a very dense sapling hemlock and *R. maximum* understory.

20. HxL, Southern Appalachian Early Successional Hardwoods - Tuliptree Forest (CEGL 7219), was abundant on formerly disturbed lands. Succession on toe slopes in coves was often borderline between HxL and CHxL, and could have been labeled either way. Fortunately, the CIR signature of tuliptrees is one of the least variable and easiest to identify: pink when the leaves are their usual yellow-green color, ranging to pinkish-white (also light lavender-white) at mid-senescence, to white after the leaves turn light lemon yellow.

Montane Oak Forests:

21. MOr, Montane Northern Red Oak Forest, the default group, was cross-referenced to the most common CEGL 7299. NVCS recognized three montane red oak forest types distinguished by their understory, and also one montane white oak forest. On CIR photos, the crown structure of MOr forests is usually open enough that the understory can be seen in places and CEGL 7299 distinguished from the other two MOr types: MOr/Sb with deciduous shrub – herbaceous understory (CEGL 7300) and MOr/G (CEGL 7298) with graminoid – herbaceous understory. With a closed canopy of oaks, CEGLs 7298 and 7300 could not necessarily be distinguished from each other and we often we used the default label MOr because of time constraints in determining the understory.
22. MOr/R-K, Montane Red Oak/Rhododendron-Kalmia Forests (CEGL 7299), has four variations all cross-referenced to CEGL 7299. They are the most acidic and also most common of the montane red oak forests. These forests varied along a moisture gradient from sub-mesic Northern Red Oak/Rhododendron (MOr/R), to a drier MOr/R-K, to a sub-xeric Northern Red Oak/Kalmia (MOr/K), to a xeric Northern Red Oak-Chestnut Oak-(White Oak)/ Kalmia woodland (MOz). These forests and woodlands grew under different environmental conditions and had CIR signatures distinct from each other. MOr/R at one end of the spectrum barely resembled MOz at the other end, neither on CIR photos nor in the field. Thus, we mapped CEGL 7299 variations at divisions finer than the NVCS association level. Except for MOz, they were notably abundant on the south facing, high, convex slopes on the North Carolina side of GRSM. There they gradually graded downslope to OmHA forests.
23. MOr/G, Montane Red Oak / Graminoid – Herbaceous Forest (CEGL 7298), has an open, orchard-like *Carex pensylvanica* graminoid-herbaceous understory beneath old oaks with spreading crowns. From Hwy 441, when the high elevation trees of the Smokies are bare of leaves, these MOr/G forests can be spotted on the ridgetops as far as the eye can see by looking for the oaks’ towering, wind-shaped architecture. They became fondly called the “structural oaks.”

24. MOr/Sb, Montane Red Oak / Deciduous Shrub – Herbaceous (CEGL 7330). has a deciduous ericaceous shrub-herbaceous understory best determined by field checking since it is often difficult to discern the understory beneath the closed canopy on the CIR photos.
25. MOz, High Elevation Xeric Northern Red Oak – Chestnut Oak – (White Oak) / *Kalmia* Woodland (CEGL 7299), has trees of short stature over a dense and inhospitable shrub cover of *K. latifolia*, and was uncommon.
26. MOa and MOa/K, Montane White Oak and Montane Xeric White Oak / *Kalmia* -Deciduous Ericaceous Woodland (CEGL 7295), with a *Kalmia* understory was not common. A more mesic montane white oak forest with a deciduous ericaceous understory was also cross-referenced to CEGL 7295.

High Elevation and Sub-alpine Forests:

27. NHx, Northern Hardwood forest, was the default group for NHxY or NHxB if there was uncertainty distinguishing one from another on the CIR image. NHx was cross-referenced to the more common CEGL 7861 (NHxB).
28. NHxB, Southern Appalachian Northern Hardwood Forest (CEGL 6256 and 7861), Yellow Birch Type, was the most common Northern Hardwood community, far more common than the designated “Typic” Northern Hardwood forest, NHxY. (NHxB has an acidic understory with rhododendron. NHxY is characterized by an herbaceous understory.) However, for some time no CEGL code was cross referenced for NHxB. It was not until the very last day of GRSM field work, after marching Tom Govus and Milo Pyne of NatureServe through an assortment of NHxB type specimens in the Clingmans Dome quadrangle, that we stopped for a late lunch and came to some understanding of the ubiquitous, but illusive NHxB.

At higher elevations of + 4800/5000 ft. (1463/1524 m) the composition of NHxB corresponds approximately to the yellow birch dominated hardwood component of CEGL 6256, Red Spruce-Yellow Birch- (Northern Hardwood)/Herbaceous forest. At lower elevations of 4000-4800 ft. (1219-1463 m), it corresponds approximately to the hardwood component of Hemlock-Yellow Birch forest, CEGL 7861. Thus, NHxB should be cross-referenced to either the Spruce-Birch or Hemlock–Birch forests, depending on elevation, even though the conifers are not significantly present.

With increasing Fraser magnolias and red maples (and increasing sweet birches at the lower elevations) in the NHxB mix, it seems to make a transition to HxA or NHxA. The NHxB association most definitely “needs work” and should be fodder for an interesting study.

29. NHxY, Typic Northern Hardwood Forests (CEGL 7285), were not so common or “typical” as the name might suggest (see NHxB, above). NHxY is distinguished by its “3-B canopy” (birch-beech-buckeye) and its herbaceous understory. Yellow birch is most often over 60% of the canopy, buckeyes are occasional, and beeches are absent in many NHxY areas. The “Y” is from the “y” in Typic, since T was already taken for hemlock.

30. NHx:BoI, Southern Appalachian Boulderfield Forests (CEGL 4982 and 6124). Forested boulderfields are located in upper ravines in Northern Hardwood zones, with a canopy dominated by yellow birches that germinated on the mossy boulders. Boulderfields are generally remote and cannot be discerned from air photos with certainty unless field checked because the boulders are not usually evident on the photos. The canopy may be interpreted as NHxB from CIR photos, and as such, would be cross-referenced to CEGL 7861.
31. NHx:Fg, Southern Appalachian Northern Hardwood Forests - Beech (*Fagus grandifolia*) Type (CEGL 7285), was common in the Bunches Bald quadrangle in the southeast part of GRSM. In Northern Hardwood areas west of the Bunches Bald quadrangle, mature beeches were infrequent or absent in the Typic Northern Hardwood forests. These NHx:Fg forests are not beech gaps (see below) and cover convex slopes. Beeches here are tall and as of July, 2002, showed some infestation by beech scale, but appeared much healthier than the beeches in beech gap forests. NHx:Fg is cross-referenced to CEGL 7285, "Typic" Northern Hardwoods.
32. NHxBe, Sub-Alpine Mesic Forest Beech Gaps (CEGL 6246 and 6130), occur with few exceptions in the sub-alpine spruce-fir and spruce zone. It seemed that every beech gap had at least one or several large buckeyes, and all beeches were in decline due to heavy beech scale insect infestation and the necrotic fungus the insects introduced. Beech gaps were nearly always on gently concave upper slopes, in saddles at high ridges. In the Bunches Bald quadrangle along the lower Flat Creek Trail, there were a number of broad and atypical, west-facing beech gaps below sub-alpine elevation on slightly convex slopes protected by higher ridges. (Some huge *Amelanchier laevis* also grew here, perhaps a North American record). Nearly all beech gaps we found were the South (also West) Slope Sedge (*Carex*) Type, NHxBe/G (CEGL 6130). (The "G" indicates graminoid.) The North (and East) Slope Tall Herbaceous Type Beech Gaps, NHxBe/Hb (CEGL 6246), were rare.
33. NHxR, Southern Appalachian Northern Hardwood Rich Type Forests, (CEGL 4973), grade upslope from CHxR forests below, occurring in the north facing, very mesic, upper coves and draws. These CHxR and NHxR communities overlap in their elevation range, and the gradual transition from one to the other can be hard to distinguish both in the field and on CIR photos because their multi-colored CIR signatures are similar. We found CHxR up to 4000 ft. (1219 m), and rarely, to 4500 ft. (1372 m). We found NHxR as low as 3500 ft. (1067 m), but usually ranging from 4000 to 5000+ ft. (1219 – 1524 m). At the late October dates when most of our CIR photos were taken, the yellow birches that are so common in NHxR forests had lost half or more of their leaves and the buckeyes were all leafless. In the field, we marked the transition from CHxR to NHxR when the basswoods "dropped out" with increasing elevation and the yellow birches became the most dominant canopy tree.

Scattered beeches in NHxR appeared to be the most healthy beeches anywhere in GRSM. In old growth coves it was interesting to note that beeches were usually shorter than their neighboring trees, which accounts for some of the dips in the uneven NHxR canopy. Beeches may spend years waiting in deep shade for a canopy opening, but once stake a claim to their place in the sun, they seem able to defend it.

34. NHxE and NHxE/S, Sub-Alpine Exposed/Disturbed Northern Hardwood Woodlands (CEGL 3893), (sometimes with spruce), is a new and uncommon community we located from its CIR signature. Those we found were in the sub-alpine zone and seemed to occur on burned, former spruce-fir lands. The canopy is composed of the minor species of the Typical Northern Hardwoods, NHxY: mountain ash-fire cherry-serviceberry, and sometimes also yellow birch and spruce. The trees are of short stature, like a woodland. The understory is tall herbaceous and deciduous shrub, with *Vaccinium* spp. numerous. We speculated that these were places where old slash piles were set to intense fires and burned down to mineral soil.

Hopefully this community will warrant further study of its origin and future. If the soil is so altered, is it permanently changed? Is the NHxE community permanent? It seemed to be an unusually good, sub-alpine songbird habitat in the summer. NatureServe plant ecologists cross-referenced NHxE and NHxE/S to CEGL 3893, High Elevation Blackberry Thicket, based on the closest match of the understory in their NHxE field plot. They added to the CEGL 3893 description, the possibility of a sparse cover by these tree species scattered in the thicket. Still, CEGL 3893 does not seem a very “good fit,” and it is a bit of a stretch to envision NHxE as a blackberry thicket. An excellent NHxE example can be seen along the Forney Ridge Trail a short distance from the Clingmans Dome parking lot.

35. Sub-Alpine Mesic Forest Spruce-Fir (S/F, S-F, S(F); S-F/Sb; S-F/R) and Spruce Forests (S; S/Sb; S/R) all were cross-referenced to CEGLs 7130 or 7131. These are former mixed spruce-fir forests where some to nearly all the firs have been killed by the balsam woolly adelgid. On CIR photos, firs and spruces are difficult, if not impossible, to distinguish from one another in a mixed stand. Determining the mix required field checking.

Standing dead conifers at sub-alpine elevation showed up readily in CIR photos. These were either fir or spruce. Although the majority of firs are well known to be dead, we probably encountered as many dead spruce as dead fir.

36. Sub-Alpine Mesic Fraser Fir Forests (F, F/Sb and F/R) (CEGLs 6049 and 6308), exist in small patches within the Spruce-Fir and Spruce-formerly Fir Forests and could be identified by their very dense crowns and relatively lower stature. We field checked these areas, when possible, to confirm that they were living firs and not even-age, dense spruce claiming an opening created by a past disturbance.

37. High Elevation Mesic to Submesic Red Spruce-Eastern Hemlock / Rhododendron Forest (S/T, S-T, T/S, S-T /R) (CEGLs 6152 and 6272). When mixed, it can be hard to distinguish spruce from hemlock on CIR photos. It also can be hard to distinguish this forest type from several other spruce or hemlock forest types. Hemlocks begin to look like spruce in CIR photos at the highest elevations of their range where they are closer to being off-site and grow shorter than the spruce. Because their crowns are lower, they will always be somewhat in shadow and therefore appear to have a slightly darker red CIR signature, just like the CIR signature of spruce. The forest might be spruce-hemlock, or simply uneven height spruce. At the lower elevation, where spruce are closer to being off-site and hemlocks at optimum

elevation, the hemlocks are taller, and when in sunlight, show a slightly lighter red CIR signature. When these conifers are photographed on a slope not in full sun (e.g., a north slope), they are problematic to distinguish from one another at any elevation. During the interpretation of spruce vs. hemlock, we made inferences based on elevation and surrounding polygons, and expect some error.

38. Sub-Alpine Mesic Red Spruce Low Shrub / Herbaceous (S/Sb) (CEGL 7131) was similar to Red Spruce Low Shrub / Rhododendron S/R (CEGL 7030) when the canopy was dense and the understory obscured in the air photos, which was often the case. Further, what appears to be rhododendron in the understory could occasionally be regenerating spruce. Rhododendron and dense, young spruce in a shaded understory will both have a dense, dark red CIR signature. When the understory was not field checked or determined with certainty from air photos, we labeled S/Sb and S/R polygons as the Red Spruce group (S), cross-referenced to the somewhat more common CEGL 7030.
39. High Elevation Mesic to Submesic Eastern Hemlock / Southern Appalachian Mixed Mesic Acid Hardwood Forest (T/NHxA) (CEGL 7861), is a new variation in the NVCS and at present is cross-referenced to the same CEGL as Hemlock-Yellow Birch- (Northern Hardwoods)/ Rhododendron (T/NHxB or T/NHx). The hardwood component of T/NHxA has yellow birch, red maple, Fraser magnolia, and often fire cherry and silverbell. The NVCS description for CEGL 7861 lists the hardwood component as yellow birch dominant and it has been noted that this description is in need of further regional and national assessment.

Sub-Xeric to Xeric Oak and Pine-Oak Forests and Woodlands:

40. Low and Mid Elevation Xeric Woodlands (PI, PI/OzH, and PI-OzH) (CEGLs 7097, 7119, 7078, 2591 and rarely 3560) are xeric mixed pine and mixed pine-oak communities. On CIR photographs, Eastern white pines (*Pinus strobus*, PIs) can be distinguished from the yellow pines (*P. pungens*, Pip; *P. rigida*, PIr; *P. echinata*, Pie; *P. virginiana*, PIV) at GRSM. Yellow pine species, however, are hard to distinguish from each other without field checking, especially when mixed. There are elevation differences among yellow pine species, but also considerable overlap in elevation. If the species of pine was known, it was indicated as PIP (CEGL 7097), PIR (CEGL 7097), PIE (CEGL 7078 and 3560) or PIV (CEGL 2591 and 7119).

PI, PI-OzH and PI/OzH should be cross-referenced to these common woodlands:

Blue Ridge Pitch Pine-Table Mountain Pine/ (Oak) Woodland (CEGL 7097), (2000-4500 ft., 610 - 1372m). Note, table mountain pine is absent in CEGL 7097 below about 2500 ft. (762 m), present above about 2500 ft. (762 m), and common from 3000 to 4500 ft. (914 - 1372 m). Pitch pine ranges up to 4000 ft. (1219 m) in CEGL 7097. Table mountain will be the only yellow pine species at a higher elevation.

Southern Appalachian Low Elevation Mixed (Virginia – Pitch – Shortleaf) Pine (PIv, PIr, PIe) (CEGL 7119), and Mixed Pine- Xeric Oak/ Hardwood Woodland or Forest. Pines are at least 50% of the canopy. Found below 2300-2500 ft, 701 - 762 m.

Southern Appalachian Shortleaf Pine- (Xeric Oak) / *Kalmia* - *Vaccinium* spp. Woodland. (CEGL 7078) (below 2400 ft., 732 m.)

The ranges of CEGLS 7119, 7097 and 7078 overlap below 2500 ft. (762 m). Above this elevation, the woodland will likely be CEGL 7097. Pines in these pine-oak communities have been in decline, and the oaks increasing (especially chestnut oak), due to fire suppression and mortality from pine beetle infestations. The NatureServe definition for CEGL 7119 says pines are at least 25% of the canopy, but we used a definition of pines approximately half or more. Otherwise, the community was attributed as mixed oak/pine, OzH/PI. Several uncommon pine and pine-oak woodlands (e.g., CEGL 3560) listed in the GRSM Vegetation Classification System (Attachment B) could also have been assigned PI and PI-OzH labels.

40. Low to Mid-elevation Subxeric to Xeric Oak – Hardwood / *Kalmia* Woodlands (OzH, OzH/PI and OzH/PIs) (CEGL 6271) were easily identified by their CIR signature. See discussions above about classifying pine-oak forests and woodlands.

Non-Forested Communities -- Balds, Seeps and Grape Vine Holes:

41. Southern Appalachian High to Mid-elevation Heath Balds (Hth, Hth:R or Hth:K) (CEGLs 7876 and 3814) are the two heath bald communities recognized by NPS-NVCS at GRSM. We did not distinguish between the two types on the air photos. The difference can be determined from their elevation.

The higher elevation Southern Appalachian Heath Balds (CEGL 7876) occur on ridges, rock outcrops and landslides at elevations usually above 5500 ft. (1670 m). The rhododendron species here are *R. catawbiense* and *R. carolinianum*.

The lower elevation Southern Appalachian Heath Balds (CEGL 3814) occur on exposed ridges and also on south to southwest exposed, steep slopes, in the range of 4000 to 5000 ft. (1219 – 1524 m). Common heath species listed in the NVCS description are *R. catawbiense* and *Kalmia latifolia*. However, we found *R. maximum* to be dominant on many of these lower elevation ridgetop balds. *Kalmia* was dominant when the bald was on a very steep, exposed slope. We distinguished between *Kalmia* (mountain laurel) dominated and *Rhododendron* dominated CEGL 3814 balds when possible. Photointerpreters working in different high elevation quadrangles did have differences of opinion about the CIR signatures of the ridgetop balds (whether Hth: K or Hth: R). We could not field check most of them because they are many and remote.

42. Non-alluvial Wetlands High Elevation Seeps (CEGLs 4293, 4296), were a treat to come upon during the course of fieldwork, but were difficult to identify on the air photos because

the surrounding tree canopy often obscures the small seeps. Gaps with a seep are hard to distinguish from gaps resulting from natural tree mortality. Some spectacular High Elevation Rich Montane *Monarda-Rudbeckia-Impatiens* Seeps (Seep: R-M) (CEGL 4293) are to be found in the boulder strewn, steep ravines along the Heintooga Ridge road in the Bunches Bald quadrangle. Out the Forney Ridge trail from the Clingmans Dome parking lot, a path passes through Andrews Bald where there is the small graminoid seep (see 43, below), and on into Silars Bald through a broad and spectacular Seep:4293 that was in full flower on July 27 the year we visited.

43. Non-alluvial Wetlands *Sphagnum* – Graminoid - Herbaceous Seepage Slopes (CEGL 7697), are seeps that are hard to find on aerial photographs and must be identified in the field. There is a nice Seep: G (or Seep:7697) on Andrews Bald in the Clingmans Dome quadrangle.
44. Shrublands or Shrub Understory Montane Grape Vine Openings (*Vitis aestivalis*), or “grape holes,” designated by “V” or modifier “:8” (CEGL 3890), were found only in cove hardwood forests, or very uncommonly, at the transition from an OmHr forest adjacent to a CHx forest. Some of the small vine openings we found in the field were actually pipevine (*Aristolochia macrophylla*) openings. They were below minimum map unit size of 0.5 ha and on CIR photos, looked like gaps in the canopy resulting from natural tree mortality.

Field Work Acknowledgements

It was a privilege to map vegetation in Great Smoky Mountains National Park. The work put me in the field in the company of outstanding plant taxonomists and ecologists with whom it was a pleasure and honor to work. They are repositories of knowledge. We put in long and fabulous days, and stopped for many a lunch with a view.

Mike Jenkins, GRSM Park Ecologist and dendrologist got us oriented and underway. He once forecast the weather up at the beech gaps on the high slopes. Henceforth I carried a raincoat, no matter how sunny the forecast.

Mark Whited, Biological Science Technician at GRSM for several summers, knows and loves the flora of the Great Smoky Mountains. In the winter season he was a photo-interpreter for CRMS on the GRSM mapping project. If born a century or two earlier, Mark would have been a “mountain man,” and we would be reading about him in historical accounts.

Walt West, then Park Ranger in the Cataloochee Valley, welcomed me to stay in the old bunkhouse. It had a version of every upscale amenity, including an item once reputed to be a radio. Its little wood stove warmed the mornings and toasted perfect marshmallows at night. After we trapped out the mice we were living at the Ritz!

Karen Patterson, Regional Vegetation Ecologist with NatureServe (formerly ABI), worked with us in the field before she moved from the Southeastern Regional Office. Karen was a force putting together a tome of vegetation classification standards for Cades Cove and Mount LeConte quadrangles of GRSM. She always wanted to get it right. Once we got hold of “The Tome,” we were operating on a higher plane.

Alan Weakley, plant taxonomist nonpareil, was fun in the field and a wonderful teacher. He showed us so many things, like the lamellate interior architecture of the pipevine that allows it to twist in the wind without breaking. His taxonomic musings are spare and clear. Alan worked with us first as southeastern Regional Vegetation Ecologist, and then Chief Ecologist with NatureServe. Alan is now Curator of the University of North Carolina Herbarium at Chapel Hill, a department of the North Carolina Botanical Garden. He continues writing his *Flora of the Carolinas, Virginia and Georgia*.

Rickie White worked with us as southeastern Regional Vegetation Ecologist with NatureServe. He is the organized coordinator-of-things. In the field he was dependably first up in the morning and attending to details that facilitated everyone else’s work. Rickie is never one to lodge or eat generic if a local joint can be ferreted out.

Milo Pyne, Senior Ecologist at NatureServe, offered good company and conversation about some of his passions in life, in addition to plants. Someday, I hope he’ll bring me a yellowwood sapling from his stomping grounds in Tennessee.

How does NatureServe find all these good people?

Tom Govus should be along on every trip to entertain with his wit. He's a taxonomist, plant ecologist and good teacher. NatureServe, the Georgia Natural Heritage Program, the Chattahoochee National Forest, and others have sought Tom's expertise. Somewhere between our discourses on taxonomy and tupelo honey, Tom told the story of his trip to South Carolina one night to check out a good dog and a good woman, in that order. He got them both, the dog first, and eventually his wife.

Jeff Jackson, retired Wildlife Specialist for the Georgia Cooperative Extension Service and Professor of Wildlife Management at the University of Georgia, also my husband and the best wildlife biologist I've ever known, was good company and photographer on a number of treks to distant places of splendor in GRSM. He claims some treks were forced marches. Jeff enjoyed fieldwork with the NatureServe crew who even laughed at his lame puns, and were not fooled for a minute by the *Limnobia* from Florida he slipped into their daily collection bag.

Roy Welch, recently retired Director of CRMS and redoubtable pioneer in the field of remote sensing, made my opportunity to work in the Great Smoky Mountains possible. I thank R. W. and Marguerite Madden, now Director of CRMS, for asking me to join the CRMS crew on the Everglades and Big Cypress mapping project. Marguerite was happiest when she could squeeze in some fieldwork. Our motto: If you don't know where you are, but you can get back, you're not lost.

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Attachment D

CRMS Understory Vegetation Classification System for Mapping Great Smoky Mountains National Park

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Introduction to the Classification System

The targeted understory evergreen species to be mapped in Great Smoky Mountains National Park (GRSM) were Rhododendron (*Rhododendron* spp.), mountain laurel (*Kalmia latifolia*), hemlock (*Tsuga canadensis*), white pine (*Pinus strobus*), yellow pine species (*Pinus* spp.), Fraser fir (*Abies fraseri*) and red spruce (*Picea rubens*). The symbols used to denote these species in the understory database are R, K, Tu, PIsu, PIu, Fu and Su, respectively. When polygons contained a mixture of these species, especially in transition zones, the symbol “/” was used to separate the mixed classes. For example, the class for a mix of Rhododendron and mountain laurel is R/K. A mix containing three species would be denoted as PI/PIsu/Kl (i.e., pine, white pine and light density mountain laurel).

Understory interpretation included the designation of density classes if they could be determined from the aerial photographs. Species name abbreviations are followed by an “l” (light), “m” (medium) or “h” (heavy) density. Heavy density indicated 0 to 20% of ground surface was visible through the target species, medium less than 50% and light greater than 50% of the ground surface was visible through the vegetation. It should be noted that a density class used with mixed communities implies neither species being dominant, but rather the density of the polygon as a whole.

Frequently, an evergreen overstory obstructed the view of the understory. In such cases the understory classification begins with a symbol to indicate the overstory evergreen species. This serves to alert the user that the interpreter’s view was at least partially obstructed. These symbols include PI (pine), PIs (white pine), T (hemlock), S (spruce), F (fir) and S/T (mixed spruce/hemlock). Following this symbol will normally be an “R” (rhododendron) or a “K” (mountain laurel) to designate the understory species density (e.g., PI/Kl).

When the overstory is sufficiently thin to permit at least a partial view of the forest floor, the overstory/understory string is followed by a density designation (described above). In many cases, however, the overstory is extremely dense and obstructs the view of the understory. In these instances the density class is eliminated and the symbols “i” (implied) or “p” (possible) are used in their place. “Implied” is defined to mean the conditions are right for the presence of the

species and it is believed that it will be found there. On the other hand, “possible” is defined as conditions only marginally right for the presence of the species and it is not believe that it will be found there. Occasionally other factors such as shadow prevented an absolute identification of rhododendron or mountain laurel even though there was no overstory. In these cases, "K" or "R" are followed by an "i" or "p".

Shadows in the aerial photographs were common and could completely or partially obscure the vegetation. Where the shadow resulted in a relatively large, black area on the photo, "Sd" was used to note this area is in shadow and no interpretation is possible. More frequently, however, the shadows were small or not completely black and at least some of the polygon's attributes could still be detected. In such cases, the "i" or "p" designation was used after the appropriate understory class, followed by "Sd" This serves to alert the user of the conditions under which the polygon was interpreted and attributed. With minor exceptions, the only time this combination was utilized was in the case of rhododendron, which yielded Ri/Sd, Rp/Sd, Rl/Sd and Rm/Sd combinations.

GRSM Understory Vegetation Mapping Classification System

Rhododendron (*Rhododendron* spp.)

Rhododendron heavy density	Rh
Rhododendron medium density	Rm
Rhododendron light density	Rl
Rhododendron implied	Ri
Rhododendron possible	Rp
Rhododendron light density in shadow	Rl/Sd
Rhododendron medium density in shadow	RmSd
Rhododendron implied in shadow	Ri/Sd
Rhododendron possible in shadow	Rp/Sd
Rhododendron high density with hemlock understory	Rh/Tu
Rhododendron medium density with hemlock understory	Rm/Tu
Rhododendron light density with hemlock understory	Rl/Tu
Rhododendron medium density with spruce implied	Rm/Si
Rhododendron medium density with white pine and hemlock	Rm/PIs-T

Mountain Laurel (*Kalmia latifolia*)

<i>Kalmia</i> heavy density	Kh
<i>Kalmia</i> medium density	Km
<i>Kalmia</i> light density	Kl
<i>Kalmia</i> implied	Ki
<i>Kalmia</i> possible	Kp
<i>Kalmia</i> with pine	Kh/PI
<i>Kalmia</i> with rhododendron possible	K/Rp

Mixed *Rhododendron* (*Rhododendron* spp.) and Mountain Laurel (*Kalmia latifolia*)

<i>Rhododendron</i> and <i>Kalmia</i> (R dominant)	R/K
(equal dominance)	R-K
<i>Rhododendron</i> and <i>Kalmia</i> heavy density	RKh ¹
<i>Rhododendron</i> and <i>Kalmia</i> medium density	RKm
<i>Rhododendron</i> and <i>Kalmia</i> light density	RKl
<i>Rhododendron</i> and <i>Kalmia</i> implied	RKi
<i>Rhododendron</i> and <i>Kalmia</i> possible	RKp
<i>Rhododendron</i> and <i>Kalmia</i> high density with hemlock understory	RKh/Tu
<i>Rhododendron</i> and <i>Kalmia</i> medium density with hemlock understory	RKm/Tu
<i>Rhododendron</i> and <i>Kalmia</i> light density with hemlock understory	RKl/Tu

Heath Bald Species (mixture of rhododendrons and mountain laurel)

Heath bald understory	Hth ²
Heath understory heavy density	Hu
Heath understory medium density	Huh
Heath understory light density	Hum
	Hul

Eastern Hemlock (*Tsuga canadensis*)

Hemlock ³ with <i>Rhododendron</i> heavy density	T/Rh
Hemlock with <i>Rhododendron</i> medium density	T/Rm
Hemlock with <i>Rhododendron</i> light density	T/Rl
Hemlock with <i>Rhododendron</i> implied	T/Ri
Hemlock with <i>Rhododendron</i> possible	T/Rp
Hemlock with <i>Rhododendron</i> implied in shadow	T/Ri/Sd
Hemlock with <i>Kalmia</i> medium density	T/Km
Hemlock with heath bald species medium density	T/Hum
Hemlock with heath bald species light density	T/Hul
Hemlock with heath bald species implied	T/Hui
Hemlock with white pine	T/PIs
Hemlock with white pine and light <i>Rhododendron</i>	T/PIs/Rl
Hemlock with white pine and <i>Rhododendron</i> implied	T/PIs/Ri
Hemlock with white pine and <i>Rhododendron</i> possible	T/PIs/Rp
Hemlock with mixed pine and <i>Rhododendron</i> implied	T/PIx/Ri
Hemlock with mixed pine and shadow	T/PIx/Sd
Hemlock with Spruce and <i>Rhododendron</i> medium density	T-S/Rm
Hemlock understory	Tu ⁴
Hemlock understory with <i>Rhododendron</i> heavy density	Tu/Rh
Hemlock understory with <i>Rhododendron</i> medium density	Tu/Rm
Hemlock understory with <i>Rhododendron</i> light density	Tu/Rl
Hemlock understory with <i>Rhododendron</i> implied	Tu/Ri
Hemlock understory with <i>Rhododendron</i> possible	Tu/Rp

¹ RKh denotes heavy density for the RK mix, not K alone.

² Hth and Hu are equal and can be combined.

³ Class names of evergreen species refer to overstory, unless “understory” is specified.

⁴ Evergreen understory is indicated in class name by “u”.

Hemlock understory with <i>Kalmia</i> possible	Tu/Kp
Hemlock understory with heath bald species	Tu/Hu
Hemlock understory with white pine understory	T/PIsu
Hemlock understory, white pine understory, <i>Rhododendron</i> implied	Tu/PIsu/Ri
Hemlock understory with white pine understory	T/PIsu
Hemlock understory implied	Tui
Hemlock understory implied with spruce understory implied	Tui/Sui

Eastern White Pine (*Pinus strobus*)

White pine with <i>Rhododendron</i> heavy density	PIs/Rh
White pine with <i>Rhododendron</i> medium density	PIs/Rm
White pine with <i>Rhododendron</i> light density	PIs/RI
White pine with <i>Rhododendron</i> implied	PIs/Ri
White pine with <i>Rhododendron</i> possible	PIs/Rp
White pine with <i>Kalmia</i> heavy density	PIs/Kh
White pine with <i>Kalmia</i> medium density	PIs/Km
White pine with <i>Kalmia</i> light density	PIs/Kl
White pine with <i>Kalmia</i> implied	PIs/Ki
White pine with <i>Kalmia</i> possible	PIs/Kp
White pine with <i>Rhododendron</i> and <i>Kalmia</i> medium density	PIs/RKm
White pine with <i>Rhododendron</i> and <i>Kalmia</i> light density	PIs/RKI
White pine with <i>Rhododendron</i> and <i>Kalmia</i> implied	PIs/RKi
White pine with <i>Rhododendron</i> and <i>Kalmia</i> possible	PIs/RKp
White pine with yellow pine and <i>Kalmia</i> implied	PIs/PI/Ki
White pine with yellow pine and <i>Kalmia</i> possible	PIs/PI/Kp
White pine, mixed yellow pines and <i>Kalmia</i> medium density	PIs/PIx/Km
White pine, mixed yellow pines and <i>Kalmia</i> possible	PIs/PIx/Kp
White pine, mixed yellow pines and <i>Rhododendron</i> possible	PIs/PIx/Rp
White pine, mixed yellow pines, <i>Rhododendron</i> <i>Kalmia</i> mix possible	PIs/PIx/RKp
White pine and hemlock mix with <i>Rhododendron</i> heavy density	PIs-T/Rh
White pine and hemlock mix with <i>Rhododendron</i> medium density	PIs-T/Rm
White pine and hemlock mix with <i>Rhododendron</i> light density	PIs-T/RI
White pine and hemlock mix with <i>Rhododendron</i> possible	PIs-T/Rp
White pine understory	PIsu
White pine understory with <i>Rhododendron</i> medium density	PIsu/Rm
White pine understory with <i>Rhododendron</i> implied	PIsu/Ri
White pine understory with <i>Rhododendron</i> possible	PIsu/Rp
White pine understory with <i>Rhododendron</i> implied and hemlock	PIsu/Ri/Tu
White pine understory with hemlock understory	PIsu/Tu
White pine understory, hemlock understory and <i>Rhododendron</i> possible	PIsu/Tu/Rp
White pine understory with <i>Kalmia</i> high density	PIsu/Kh
White pine understory with <i>Kalmia</i> medium density	PIsu/Km
White pine understory with <i>Kalmia</i> light density	PIsu/Kl
White pine understory with <i>Kalmia</i> implied	PIsu/Ki
White pine understory with <i>Kalmia</i> possible	PIsu/Kp
White pine understory with yellow pine understory	PIsu/PIu

White pine understory with yellow pine understory and <i>Kalmia</i> possible	PIsu/PIu/Kp
Yellow pine⁵	
Pine with <i>Kalmia</i> heavy density	PI/Kh
Pine with <i>Kalmia</i> medium density	PI/Km
Pine with <i>Kalmia</i> light density	PI/Kl
Pine with <i>Kalmia</i> implied	PI/Ki
Pine with <i>Kalmia</i> possible	PI/Kp
Pine with <i>Rhododendron</i> light density	PI/RI
Pine with <i>Rhododendron</i> possible	PI/Rp
Pine with white pine and <i>Kalmia</i> light density	PI/PIs/Kl
Pine with white pine and <i>Kalmia</i> possible	PI/PIs/Kp
Pine with white pine understory	PI/PIsu
Pine with white pine understory and <i>Kalmia</i> light density	PI/PIsu/Kl
Pine with white pine understory and hemlock understory	PI/PIsu/Tu
Pine understory	PIu
Pine understory and <i>Kalmia</i> heavy density	PIu/Kh
Pine understory and <i>Kalmia</i> possible	PIu/Kp
Mixed pine	PIx ⁶
Mixed pine with <i>Kalmia</i> heavy density	PIx/Kh
Mixed pine with <i>Kalmia</i> medium density	PIx/Km
Mixed pine with <i>Kalmia</i> light density	PIx/Kl
Mixed pine with <i>Kalmia</i> implied	PIx/Ki
Mixed pine with <i>Kalmia</i> possible	PIx/Kp
Mixed pine with <i>Rhododendron</i> medium density	PIx/Rm
Mixed pine with <i>Rhododendron</i> light density	PIx/RI
Mixed pine with shrubs	PIx/Sb
Mixed pine with white pine and <i>Kalmia</i> medium density	PIx/PIs/Km
Mixed pine with white pine and <i>Kalmia</i> implied	PIx/PIs/Ki
Mixed pine with white pine and <i>Kalmia</i> possible	PIx/PIs/Kp
Mixed pine with white pine and <i>Rhododendron</i> possible	PIx/PIs/Rp
Mixed pine with white pine and mixed <i>Rhododendron-Kalmia</i> possible	PIx/PIs/RKp
Mixed pine with white pine understory and <i>Kalmia</i> implied	PIx/PIsu/Ki
Mixed pine with white pine understory and <i>Kalmia</i> possible	PIx/PIsu/Kp
Pioneering pine (even aged pine regrowth especially after fire)	PP
Red Spruce (<i>Picea rubens</i>)	
Spruce with <i>Rhododendron</i> heavy density	S/Rh
Spruce with <i>Rhododendron</i> medium density	S/Rm
Spruce with <i>Rhododendron</i> light density	S/RI
Spruce with <i>Rhododendron</i> implied	S/Ri
Spruce with <i>Rhododendron</i> possible	S/Rp
Spruce with heath bald species	S/Hth

⁵ Species include short-leaf pine (*Pinus echinata*), pitch pine (*P. rigida*), Virginia pine (*P. virginiana*) and table mountain pine (*P. pungens*).

⁶ PI indicates dominance by a single yellow pine species. PIx indicates a mix of two or more yellow pine species.

Spruce with heath bald species medium density	S/Hum
Spruce with Fir understory	S/Fu
Spruce with shrubs	S/Sb
Spruce with hemlock and <i>Rhododendron</i> heavy density	S/T/Rh
Spruce with hemlock and <i>Rhododendron</i> medium density	S/T/Rm
Spruce with hemlock and <i>Rhododendron</i> light density	S/T/Rl
Spruce with hemlock and <i>Rhododendron</i> implied	S/T/Ri
Spruce with hemlock and <i>Rhododendron</i> possible	S/T/Rp
Spruce implied with <i>Rhododendron</i> heavy density	Si/Rh
Spruce implied with <i>Rhododendron</i> medium density	Si/Rm
Spruce implied with fir <i>medium</i> density	Si/Fum
Spruce implied with hemlock and <i>Rhododendron</i> possible	Si/T/Rp
Spruce understory	Su
Spruce understory with <i>Rhododendron</i> heavy density	Su/Rh
Spruce understory with <i>Rhododendron</i> medium density	Su/Rm
Spruce understory with <i>Rhododendron</i> light density	Su/Rl
Spruce understory with <i>Rhododendron</i> implied	Su/Ri
Spruce understory with <i>Rhododendron</i> possible	Su/Rp
Spruce understory with hemlock understory	Su/Tu
Spruce understory with fir understory	Su/Fu
Spruce understory light density with fir understory light density	Sul/Ful
Spruce understory implied	Sui
Spruce understory implied with fir understory implied	Sui/Fui
Spruce understory implied with hemlock understory implied	Sui/Tui
Spruce understory possible	Sup
Fraser Fir (<i>Abies fraseri</i>)	
Fir implied with spruce implied and shadow	Fi/Si/Sd
Fir understory	Fu
Fir understory heavy density	Fuh
Fir understory medium density	Fum
Fir understory light density	Ful
Fir understory with <i>Rhododendron</i> heavy density	Fu/Rh
Fir understory with <i>Rhododendron</i> medium density	Fu/Rm
Fir understory with <i>Rhododendron</i> light density	Fu/Rl
Fir understory with spruce understory	Fu/Su
Fir understory light density with <i>Rhododendron</i> light density	Ful/Rl
Fir understory light density with spruce implied	Ful/Si
Fir understory light density with spruce understory light density	Ful/Sul
Fir understory medium density with spruce implied	Fum/Si
Fir understory medium density with <i>Rhododendron</i> implied	Fum/Ri
Additional Categories	
Deciduous shrubs	Sb
Deciduous shrubs with mixed yellow pines	Sb/PIx
Shadow	Sd

Burned completely	BC
Graminoids	G
Graminoids with shrubs	G/Sb
Herbaceous and deciduous understory	HD
Human influence	HI
Road	RD
Vines	V
Water	W

Attachment E

Notes on the Interpretation of the Understory Vegetation of Great Smoky Mountains National Park

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The interpretation of understory vegetation of Great Smoky Mountains National Park (GRSM) was accomplished, for the most part, using 1:40,000-scale color infrared (CIR) aerial photographs acquired in 1998 as part of the U.S. Geological Survey (USGS) National Aerial Photography Program (NAPP). In the northwest corner of the park where 1998 CIR NAPP photos were not available, panchromatic NAPP photos acquired in 1997 were used. The use of panchromatic photographs is not optimal for identifying vegetation to the association or community level. This limitation, as well as other factors that may have affected the accuracy of the interpretation and details on the interpretation of understory density classes, are described below.

Limitations to Interpretation

Presence of Evergreen Overstory

Many of the vegetation communities of GRSM include an evergreen overstory which creates, to varying degrees, a visual barrier to the understory vegetation. These culprit overstory species are Eastern white pine (*Pinus strobus*), hemlock (*Tsuga canadensis*), red spruce (*Picea rubens*), Fraser fir (*Abies fraseri*) and yellow pines such as short-leaf pine (*P. echinata*), pitch pine (*P. rigida*), Virginia pine (*P. virginiana*) and table mountain pine (*P. pungens*). The density of these evergreens varied considerably, sometimes completely obscuring the view below. Conversely, in other cases, it was sufficiently sparse to permit reasonable visibility of whatever understory existed.

In the case of dense evergreen overstory, it was necessary to take into consideration many external factors before interpreting and attributing such polygons. These considerations included, first and foremost, a knowledge of what generally grows in a particular location based on field experience. Additional considerations were the overstory community, aspect, geographical position (ridge, valley or slope), elevation and nearby polygons with visible understory vegetation having similar characteristics. Using these clues, the vegetation could be interpreted and the polygon would receive an attribute label. At the inception of the project, many of these polygons were field checked and were found to be sufficiently accurate to retain this method of classification.

Map scale

The scale of the leaf-off photos available for this project was 1:40,000. This intrinsically places a limit on the amount of detail and positional accuracy of the various plant communities during the interpretation of the understory. For example, at this scale, the width of the line drawn by the interpreter to delineate a polygon, although only .18 mm wide, represents approximately 7 meters on the ground. Such a scale requires the interpreter to be extremely accurate in the drawing and placing of each polygon as even a fraction of a millimeter error (seemingly insignificant on the transparencies) leads to a large error at ground level. Additionally, some of the very small polygons detected by the interpreter could not be depicted on the maps due to editing tolerances of the map making process. Map users should be aware of these limitations, especially when taking the maps to the field.

Shadows

Occasionally, areas of the high relief photos were in deep shadow which prohibited visibility. In such cases, much the same method was used to determine the likely understory as described above. When this was considered to be too arbitrary, the polygon was simply labeled "Sd" to indicate shadow.

Elevational Gradients

Severe elevational gradients are common in GRSM. When the aerial photo is taken directly overhead of a steep slope, polygons on such slopes are viewed at a very low angle with the effect of compressing the polygon into a smaller area than it is in real life. Although the photogrammetric process used by the University of Georgia rectifies distortions and displacements caused by photographic tip, tilt and elevational gradients, the danger is that the interpreter might overlook such polygons as being below the minimum mapping unit when in reality it is larger than he/she perceives. Therefore, it is possible that some understory may have gone undetected in such areas.

Panchromatic Aerial Photographs

The area corresponding to three USGS 7.5-minute topographic quadrangles in GRSM, namely, Kinzel Springs, Wear Cove and Gatlinburg, were interpreted using panchromatic (i.e., black and white) air photos. These photos lacked the color component of an interpretation signature which is very important for vegetation identification. To compensate for this limitation, the panchromatic photos were interpreted last in order to make use of experience gained from interpreting understory vegetation from surrounding color infrared photos. Vegetation communities were attributed with classes that are inherently uncertain such as Ri and Kp, *Rhododendron* implied and *Kalmia* possible, respectively. Interpretation was performed while viewing the photos in stereo to use information on slope, aspect and elevation to help discern the vegetation class. In any event, it is likely that the accuracy of these quadrangles (Kinzel

Springs, Wear Cove and Gatlinburg) will be lower than the rest of the understory database. Additional field checking of these quad areas is advised.

Kalmia vs. White Pine Saplings

Early in this project, GRSM fire cache personnel noted that we might be confusing our interpretation of white pine saplings with low density mountain laurel (*Kalmia latifolia*) in the extreme western portion of the park (mainly within the Calderwood quadrangle). This proved to be the case. Subsequent fieldwork and consequent editing of the database has, hopefully, eliminated as many of these mistakes as possible. However, the interpretive characteristics of these two understory communities are very similar and difficult to separate. There still may be misinterpretations present mostly in the extreme western side of the Park where white pine occurs more frequently. Fortunately, (with the exception of Dellwood) this species mainly occurs below 2500 feet (762 meters) elevation and most of the Park exceeds that elevation.

Density Classes

At the initiation of this project, interpreters felt they could see a clear density difference in the various *Rhododendron* and mountain laurel polygons. Accordingly, density classifications of light, medium and heavy were applied to polygons containing these two species whenever possible. Ground truthing has shown that the heavy and medium designations are reasonably accurate. Polygons classified as being light were somewhat less accurate, sometimes being confused with hemlock in the case of *Rhododendron* and white pine in the case of mountain laurel. At the outset, the density classes were designed to be flexible and collapsible. If the light polygon designation in the future is found to be of limited value, it can be modified or eliminated without affecting the rest of the system.

In only rare instances was a density class given for hemlock since, in most cases, understory hemlock could not be reliably detected. This may have been due to the feathery nature of its foliage and/or to the relatively small scale of the photos. In any case, it seemed that one of two conditions had to be met before it became clearly visible. The first requirement was that the community had to be extremely dense. The second required the photo to be taken at a low angle, which gave the illusion of a high concentration. In most cases hemlock understory polygons found on the maps were more than likely encountered during the ground truthing process and incorporated into the database by that method. Users of the maps can be assured that there is far more understory hemlock in the Park than is delineated.

In view of the impending non-native hemlock woolly adelgid (*Adelges tsugae*) threat, all hemlock which were visible on the transparencies were interpreted and incorporated into the final database and maps as part of this project. This could not be accomplished on the companion overstory maps, as any hemlock below the broadleaf canopy was not visible to the interpreter.

In determining the density of *Rhododendron* and mountain laurel, we used the following density classes after discarding several others which proved to be too detailed and inaccurate due to the scale of the photos. If 0 to less than 20% of ground surface, usually indicated by a black background, was visible in the polygon through the target species, it was designed as heavy density. Medium density was used when 20% to less than 50% of the ground surface was visible and light density when greater than 50% of the ground was visible through the *Rhododendron* or mountain laurel. We realized this demarcation of the classes would make the medium designation the most ambiguous with 50 to 80% foliage cover from the aerial perspective, yet none of the other criteria (including using 4 or 5 density classes) provided sufficiently accuracy as to be meaningful.

At the inaugural meeting for this project we were asked if we could translate our density classes into more useful information at ground level. Subsequent ground truthing showed that in the case of *Rhododendron*, the densities actually encountered in the field were slightly less than indicated by the photo interpretation. This is probably due to the sprawling nature of the plant as well as its large and abundant foliage. However, in the case of the *Rhododendron* heavy density class (Rh), the difference in most cases was not very significant and, unless extenuating circumstances prevail, these are areas that one would probably want to avoid. Conversely, the *Rhododendron* light density class (Rl) encountered during field verification was usually easily negotiated. The main error with this classification (Rl) was not with the density but that it was occasionally confused with hemlock. As previously mentioned, the medium density class (Rm) provides a wider range of possibilities concerning one's ability to negotiate through these vegetation patches on the ground. When ground truthing this class, we concentrated on those Rm polygons with highest ground cover. Fieldwork showed that about 10% of the Rm designations should have been Rh and were so changed. The ease of navigation through Rm density polygons varied considerably. However, all such areas traversed during field work slowed travel time markedly, which may be of interest when more rapid passage through the Park is desired.

In the case of the mountain laurel polygons, light density classifications (Kl) again proved to be least accurate, but were still greater than 80%. Conversely, the medium (Km) and heavy (Kh) classes were shown to be very accurate when ground truthed, after adjusting for the white pine problem mentioned earlier. Frequently, Km polygons ringed Kh zones especially in the central and, even more commonly, eastern parts of the Park. Users of these maps should note that the delineation line between the two classes (Km and Kh) was not always clear and may vary considerably when compared with actual field conditions.

In the field, the Kl class was normally no impediment to human travel - at least from the standpoint of the presence of mountain laurel. Conversely, Kh polygons could only be traversed on hands and knees. As with *Rhododendron*, Km polygons varied the most and on the whole were much less negotiable than Rm areas. This is due to the smaller leaf size of mountain laurel. In comparison to *Rhododendron*, a much larger

number of leaves are necessary to equal a greater than 50% ground cover. The larger quantity of leaves requires a much larger number of twigs and branches, making mountain laurel a considerably more densely branched entity than *Rhododendron* and accounting for the increased difficulty in traversing Km polygons. It should also be mentioned here, for those not familiar with the Southern Appalachians, that mountain laurel communities frequently have various species of thorny greenbriers (*Smilax* spp.) associated with them, even in Kl designated polygons. During ground truthing several Km polygons were revised to Kh, but none were found to be Kl.

Finally, the CIR signature of Kh polygons (monotypic mountain laurel stands normally seen on southern aspect slopes, ridges and peaks) was extremely similar to that of heath balds (a mix of *Rhododendron* species with associated mountain laurel seen mostly on north trending ridges). The heath (Huh, Hum, Hul) communities, in general, that were chosen for ground truthing proved difficult to access and exhausted large blocks of time. Consequently, a smaller proportion of these were field checked and it is possible that some of these were misinterpreted. If so, it is more likely that heath balds were identified as mountain laurel rather than the reverse.

Attachment F

Summary of Park-wide Statistics for Overstory Vegetation of Great Smoky Mountains National Park

(See Attachment B for class descriptions)

Overstory Dominant Vegetation	Number of Polygons	Average Polygon Size (ha)	Minimum Polygons Size (ha)	Maximum Polygon Size (ha)	Total Area (ha)
(F)	10	1.4	0.3	3.1	14.5
(F)S	3	3.2	0.4	7.5	9.7
AL	11	0.7	0.1	1.4	7.3
CHx	2453	4.9	0.0	205.9	11947.0
CHx/T	93	10.5	0.1	91.9	979.8
CHxA	728	4.6	0.1	128.7	3379.1
CHxA/T	74	7.7	0.3	115.9	571.3
CHxA-T	364	5.1	0.1	73.0	1852.0
CHxL	662	6.7	0.0	117.7	4448.5
CHxL/T	18	6.0	0.9	20.3	107.9
CHxO	348	4.0	0.2	36.2	1404.0
CHxR	627	7.5	0.1	201.1	4731.2
CHxR/T	23	15.1	0.5	102.8	347.6
CHxR-T	8	40.7	7.0	160.5	325.2
CHx-T	228	7.7	0.3	81.1	1750.5
Dd	112	1.2	0.1	14.5	135.5
E	2	0.3	0.2	0.4	0.5
F	141	2.7	0.1	71.5	382.9
F/S	10	4.0	0.4	19.6	40.2
Fb	8	1.0	0.4	2.6	8.0
G	78	2.0	0.0	17.2	157.8
Gb	12	1.3	0.1	4.8	15.9
Grv	114	4.3	0.0	87.2	495.2
HI	532	2.7	0.0	163.1	1462.1
Hth	1395	1.6	0.1	61.0	2217.5
Hx	330	2.0	0.1	33.7	645.8
HxA	396	4.8	0.3	82.2	1910.0
HxA/T	96	5.4	0.4	23.9	515.7
HxA-T	31	3.8	0.6	12.9	119.1
HxAz	141	6.7	0.7	126.7	946.3
HxBI	307	4.3	0.1	59.8	1320.8
HxBI/R	186	5.8	0.2	138.9	1083.2
HxF	25	6.6	0.5	26.7	166.2
HxF/T	5	19.9	2.3	56.3	99.6
HxJ	15	2.4	0.3	15.5	35.9

HxL	1403	4.9	0.0	141.1	6846.8
HxL/T	53	5.4	0.4	58.4	288.8
HxL-T	12	8.6	0.7	24.5	103.2
K	220	2.1	0.1	16.4	467.4
K/R	7	6.0	0.2	28.0	41.8
K/T	14	1.2	0.2	4.1	16.7
MAL	351	3.6	0.1	50.4	1275.3
MAL/T	23	2.1	0.3	12.6	47.5
MALc	205	3.2	0.1	40.3	659.0
MALc-T	20	1.7	0.2	6.5	34.4
MALj	10	5.2	0.4	25.1	52.2
MALt	108	3.7	0.2	34.9	399.3
MAL-T	38	5.2	0.3	31.5	199.1
MOa	41	8.2	0.7	45.3	336.4
MOr	376	7.4	0.0	143.5	2792.9
MOr/G	43	10.3	0.6	172.3	442.3
MOr/K	70	5.2	0.2	39.3	362.8
MOr/R	81	4.0	0.3	35.3	320.4
MOr/R-K	83	6.6	0.0	33.8	548.7
MOr/Sb	318	9.6	0.0	176.4	3044.7
MOz	147	4.4	0.1	31.9	640.8
NHx	2299	4.5	0.1	178.7	10424.2
NHx/S	3	1.8	1.1	2.4	5.4
NHx/T	247	3.2	0.3	22.7	778.1
NHxA	633	5.3	0.2	67.4	3358.7
NHxA/T	152	5.4	0.3	61.2	826.5
NHxA-T	46	2.7	0.5	11.6	124.7
NHxAz	50	7.1	0.2	36.6	357.2
NHxAz/T	1	1.0	1.0	1.0	1.0
NHxB	546	5.9	0.0	389.4	3225.8
NHxB/S	79	6.5	0.4	63.1	512.2
NHxB/T	26	6.0	0.2	40.0	155.8
NHxBe	85	2.3	0.1	41.3	196.1
NHxBe/G	6	0.9	0.1	2.5	5.4
NHxBe/Hb	1	0.2	0.2	0.2	0.2
NHxBI/R	133	5.0	0.4	37.6	670.4
NHxB-T	2	0.7	0.4	0.9	1.3
NHxE	27	2.7	0.4	21.8	73.8
NHxR	796	8.0	0.0	120.3	6401.0
NHxR/T	56	10.6	0.4	117.6	593.5
NHxR-T	14	9.5	0.2	71.6	132.4
NHx-T	428	4.0	0.3	38.9	1714.9
NHxY	359	4.7	0.1	220.4	1689.4
NHxY-T	1	0.4	0.4	0.4	0.4

OcH	492	7.5	0.1	151.8	3709.9
OmH	3714	3.9	0.0	215.0	14634.8
OmH/T	183	1.5	0.2	13.9	279.0
OmHA	2032	5.9	0.1	217.6	11986.4
OmHA/PI	11	2.5	0.2	9.6	27.6
OmHA/PIs	63	6.1	0.1	72.3	381.3
OmHA/T	43	4.7	0.4	22.7	202.3
OmHA-PI	13	1.9	0.0	7.2	25.3
OmHA-T	9	1.9	0.5	3.3	17.4
OmHL	526	3.6	0.2	27.9	1891.8
OmHp/R	714	3.0	0.1	64.0	2177.0
OmHr	2083	4.8	0.1	96.8	9901.0
OmHr/PIs	68	3.9	0.1	19.8	265.9
OzH	3159	4.5	0.0	354.7	14241.0
OzH/PI	1556	3.2	0.0	211.2	4930.2
OzH/PIp	41	3.4	0.5	11.2	140.6
OzH/PIr	4	4.5	2.3	7.2	18.1
OzH/PIs	15	3.6	0.4	6.9	53.6
OzH/PIv	32	2.0	0.2	8.5	62.8
OzHf	2788	4.2	0.0	93.4	11661.9
OzHf/PIs	23	5.0	0.5	24.3	114.7
OzHfA	311	3.5	0.1	51.0	1084.0
OzH-PI	7	5.1	1.2	10.2	35.5
OzH-PIs	374	1.6	0.2	12.8	585.9
P	74	12.1	0.1	238.5	897.6
PI	2308	2.5	0.0	155.2	5688.0
PI/OzH	1497	3.3	0.0	60.7	4947.2
PI-OzH	1019	2.6	0.0	32.6	2638.9
PIp	214	1.9	0.1	14.5	408.1
PIp/OzH	68	3.8	0.2	22.0	260.1
PIp-OzH	45	2.8	0.2	13.8	124.7
PIr	227	3.6	0.0	30.9	815.1
PIs	1069	2.5	0.1	52.2	2687.4
PIs/OmH	34	2.1	0.4	13.4	71.9
PIs/OmHA	45	3.3	1.0	12.3	150.0
PIs/OzH	406	2.3	0.2	28.7	952.2
PIs/OzHf	42	3.5	0.3	26.1	147.7
PIs/T	30	2.3	0.3	12.0	69.8
PIs-T	214	1.7	0.1	18.4	362.4
PIv	78	1.5	0.1	10.0	117.3
PIv/OzH	32	3.0	0.1	8.9	94.5
PIv-OzH	8	2.0	0.4	4.4	16.1
R	154	2.6	0.1	20.5	403.5
R/K	9	5.6	0.2	16.7	50.5

R/T	26	2.4	0.4	6.8	62.0
RD	85	5.8	0.0	58.4	492.5
RK	190	1.1	0.1	31.6	213.8
R-K	3	0.5	0.4	0.6	1.4
S	941	3.1	0.0	65.5	2893.7
S(F)	46	11.2	0.2	182.9	513.6
S/F	153	4.4	0.1	82.6	678.4
S/NHx	536	5.0	0.1	98.6	2687.7
S/NHxA	22	11.3	0.4	51.4	249.5
S/NHxB	445	10.8	0.1	347.0	4797.5
S/R	171	5.5	0.2	151.0	946.4
S/Sb	16	5.3	0.4	26.8	84.8
S/T	170	6.2	0.1	62.2	1053.9
Sb	309	2.5	0.1	22.2	773.5
Seep	1	0.0	0.0	0.0	0.0
S-F	9	4.1	0.2	12.8	37.0
S-F/Sb	7	5.1	0.6	10.8	35.8
S-NHx	8	2.1	0.3	4.9	16.4
S-NHxB	19	15.1	0.2	87.7	287.2
S-R	3	2.3	0.5	4.9	6.9
S-T	22	7.1	0.9	53.1	155.6
S-T/R	32	6.3	0.2	27.6	200.7
SU	31	2.8	0.1	11.4	85.5
SV	125	0.8	0.0	5.9	97.6
T	553	3.0	0.1	58.5	1678.2
T/CHx	47	13.0	0.4	61.4	609.0
T/CHxA	70	10.6	0.6	119.2	741.6
T/CHxR	3	4.6	1.0	6.3	13.7
T/HxA	64	6.0	0.5	44.4	383.7
T/HxBI	4	3.7	2.5	5.6	14.8
T/HxF	3	1.6	1.2	2.2	4.7
T/HxL	3	2.2	0.3	5.1	6.6
T/K	8	2.4	0.5	7.8	19.3
T/MAL	2	1.8	1.0	2.5	3.5
T/NHx	26	3.4	0.1	19.3	87.2
T/NHxA	98	5.5	0.4	65.6	536.6
T/NHxAz	1	1.2	1.2	1.2	1.2
T/NHxB	22	2.5	0.1	8.6	54.9
T/NHxR	16	3.9	0.4	17.2	62.6
T/OmH	28	3.0	0.3	9.6	83.7
T/OmHA	11	6.2	0.9	18.2	68.5
T/PIs	58	6.5	0.3	103.8	375.6
T/R	159	9.9	0.2	504.9	1570.6
T/S	14	4.7	0.7	15.7	65.4

V	288	1.6	0.1	20.7	472.2
W	63	48.2	0.1	2259.8	3035.6
Wt	27	1.6	0.1	12.6	43.6
Total/Average	49971	4.9	0.4	72.6	219438.2

Attachment G

Summary of Park-wide Statistics for Understory Vegetation of Great Smoky Mountains National Park

(See Attachment D for class descriptions)

Understory Dominant Vegetation	Number of Polygons	Average Polygon Size (ha)	Minimum Polygons Size (ha)	Maximum Polygon Size (ha)	Total Area (ha)
BC	7	2.3	0.7	9.3	16.1
Fi/Si/Sd	1	4.0	4.0	4.0	4.0
Fu	45	1.8	0.2	19.3	78.9
Fu/Rh	4	1.4	1.0	1.7	5.4
Fu/RI	2	1.3	1.1	1.6	2.7
Fu/Rm	3	2.2	1.7	2.7	6.7
Fu/Su	1	0.6	0.6	0.6	0.6
Fuh	56	2.4	0.2	13.9	135.2
Ful	41	1.7	0.4	11.5	69.3
Ful/RI	4	3.7	2.3	6.0	14.7
Ful/Si	7	9.8	1.7	29.6	68.4
Ful/Sul	2	5.9	0.9	10.8	11.7
Fum	53	2.1	0.5	19.1	109.8
Fum/Ri	2	2.4	1.9	3.0	4.9
Fum/Si	4	4.8	0.6	15.1	19.2
G	16	57.9	0.4	823.2	926.2
G/Sb	1	1.8	1.8	1.8	1.8
HD	2207	46.6	0.0	59716.4	102739.1
HI	95	13.0	0.3	340.8	1230.6
Hth	72	2.6	0.2	15.2	187.9
Hu	2	1.6	1.2	2.0	3.2
Huh	323	2.9	0.3	20.1	952.4
Hul	7	1.4	0.5	2.4	9.8
Hum	35	2.5	0.4	9.8	88.6
K/Rp	18	5.5	0.9	17.0	98.5
Kh	844	2.9	0.2	48.6	2459.1
Kh/PI	2	23.4	20.3	26.5	46.8
Ki	22	4.2	0.3	38.8	91.4
Kl	1556	2.6	0.0	71.5	3991.6
Km	1189	3.0	0.1	38.4	3517.8
Kp	99	4.4	0.5	31.1	439.3
Ou	20	1.7	0.1	9.8	34.4
PI/Kh	165	6.3	0.3	94.9	1034.5
PI/Ki	763	5.0	0.1	90.0	3794.9
PI/Kl	284	4.8	0.0	56.8	1356.5

PI/Km	371	6.5	0.2	79.6	2417.7
PI/Kp	725	3.7	0.1	50.6	2652.7
PI/PIs/Kl	1	9.5	9.5	9.5	9.5
PI/PIs/Kp	15	22.2	3.8	160.5	333.4
PI/PIsu	4	8.4	3.1	11.8	33.4
PI/PIsu/Kl	3	44.2	5.2	96.2	132.7
PI/PIsu/Tu	2	2.8	1.7	3.9	5.6
PI/Rl	3	6.9	4.2	10.5	20.8
PI/Rp	1	27.0	27.0	27.0	27.0
PIs/Kh	13	8.5	0.2	30.8	111.1
PIs/Ki	216	4.5	0.0	48.0	967.8
PIs/Kl	64	5.9	0.6	44.4	374.4
PIs/Km	53	6.7	0.9	50.2	353.1
PIs/Kp	230	3.4	0.1	69.0	793.1
PIs/PI/Ki	1	3.5	3.5	3.5	3.5
PIs/PI/Kp	3	5.4	2.9	8.1	16.2
PIs/PIx/Km	2	12.4	11.6	13.2	24.8
PIs/PIx/Kp	10	13.6	2.8	35.5	136.3
PIs/PIx/RKp	6	15.1	1.5	45.1	90.5
PIs/PIx/Rp	23	14.2	0.3	54.3	325.5
PIs/Rh	3	7.3	0.5	17.7	21.9
PIs/Ri	78	4.0	0.4	25.3	313.5
PIs/RKi	1	8.3	8.3	8.3	8.3
PIs/RKl	2	8.0	2.1	13.9	16.0
PIs/RKm	11	6.1	0.7	15.7	67.4
PIs/RKp	8	6.8	1.6	21.5	54.6
PIs/Rl	23	5.3	0.0	12.8	121.8
PIs/Rm	19	5.6	0.0	22.7	106.5
PIs/Rp	169	7.4	0.0	97.9	1251.6
PIs/Tu	1	18.7	18.7	18.7	18.7
PIs-T/Rh	9	35.2	7.6	139.0	316.8
PIs-T/Rl	16	14.6	1.9	79.2	233.0
PIs-T/Rm	27	25.9	0.9	182.6	698.8
PIs-T/Rp	5	15.8	4.3	33.1	79.2
PIsu	251	3.5	0.4	24.3	870.7
PIsu/Kh	2	3.3	2.4	4.1	6.5
PIsu/Ki	54	4.3	0.5	19.5	231.2
PIsu/Kl	88	5.1	0.4	31.9	450.8
PIsu/Km	15	5.0	0.8	14.7	74.7
PIsu/Kp	49	4.0	0.6	14.0	197.7
PIsu/PIu	7	4.7	1.7	9.3	33.0
PIsu/PIu/Kp	3	3.8	2.2	5.2	11.3
PIsu/Ri	2	3.1	2.0	4.3	6.2
PIsu/Ri/Tu	2	8.2	5.2	11.2	16.4

PIsu/Rm	1	11.0	11.0	11.0	11.0
PIsu/Rp	9	8.6	1.2	23.0	77.8
PIsu/Tu	40	5.7	0.6	19.1	228.7
PIsu/Tu/Rp	7	4.5	2.2	10.1	31.8
PIu	39	3.3	0.0	24.1	130.6
PIu/Kh	1	2.2	2.2	2.2	2.2
PIu/Kp	8	6.0	0.4	22.5	48.3
PIx	8	2.4	0.6	4.2	18.8
PIx/Kh	35	13.0	0.9	77.8	454.4
PIx/Ki	223	5.5	0.2	57.9	1229.6
PIx/Kl	44	6.0	0.7	31.8	264.8
PIx/Km	65	9.3	0.6	40.0	601.9
PIx/Kp	384	3.6	0.0	26.8	1392.2
PIx/PIs/Ki	1	7.0	7.0	7.0	7.0
PIx/PIs/Km	2	11.1	8.1	14.2	22.3
PIx/PIs/Kp	17	12.3	1.1	31.9	208.7
PIx/PIs/RKp	6	14.3	6.1	29.2	85.8
PIx/PIs/Rp	5	14.5	2.7	28.6	72.4
PIx/PIsu/Ki	1	33.8	33.8	33.8	33.8
PIx/PIsu/Kp	7	9.5	2.4	22.6	66.7
PIx/RI	2	3.9	2.3	5.6	7.9
PIx/Rm	4	4.2	1.3	7.2	16.9
PIx/Sb	7	4.2	2.6	7.5	29.7
PP	11	3.9	0.8	16.4	43.0
R/K	28	1.6	0.4	3.7	45.0
RD	8	7.6	0.6	24.0	60.7
Rh	1601	7.0	0.1	371.0	11201.1
Rh/Tu	3	3.4	2.4	4.6	10.3
Ri	6	4.3	0.4	12.4	25.6
Ri/Sd	253	6.8	0.4	47.8	1722.6
R-K	61	2.1	0.3	8.1	129.2
RKh	253	3.4	0.0	46.8	852.7
RKh/Tu	1	3.4	3.4	3.4	3.4
RKi	12	3.9	0.7	15.5	46.9
RKl	450	2.8	0.3	28.4	1267.3
RKl/Tu	1	8.2	8.2	8.2	8.2
RKm	559	2.9	0.3	34.8	1600.5
RKm/Tu	1	2.3	2.3	2.3	2.3
RKp	83	4.8	0.4	21.7	402.3
RI	2144	3.7	0.0	132.3	7861.0
RI/Sd	154	4.7	0.0	43.4	727.9
RI/Tu	6	6.2	1.6	20.8	37.2
Rm	1939	3.5	0.1	75.0	6848.3
Rm/PIs-T	1	24.3	24.3	24.3	24.3

Rm/Sd	1	4.9	4.9	4.9	4.9
Rm/Si	3	2.7	1.1	5.3	8.1
Rm/Tu	4	9.4	2.1	22.9	37.5
Rp	141	5.6	0.4	64.1	790.4
Rp/Sd	144	10.8	0.2	72.2	1561.5
S/Fu	1	33.5	33.5	33.5	33.5
S/Hth	1	6.8	6.8	6.8	6.8
S/Hum	2	5.7	4.3	7.2	11.4
S/Rh	291	11.2	0.6	241.3	3253.2
S/Ri	206	7.0	0.6	99.5	1434.3
S/RI	68	6.5	0.8	41.6	443.0
S/Rm	88	4.7	0.5	27.8	416.8
S/Rp	128	7.6	0.9	75.9	967.6
S/Sb	3	13.1	8.4	19.2	39.4
S/T/Rh	126	7.3	1.2	39.6	917.2
S/T/Ri	95	5.7	0.7	29.6	545.1
S/T/RI	9	6.4	2.3	19.9	57.8
S/T/Rm	27	5.7	1.3	27.3	155.2
S/T/Rp	45	4.4	0.8	16.6	197.9
Sb	4	2.0	0.3	3.2	8.2
Sb/PIx	1	1.3	1.3	1.3	1.3
Sd	6	1.7	0.8	2.5	10.0
Si/Fum	2	5.9	3.5	8.4	11.9
Si/Rh	1	14.7	14.7	14.7	14.7
Si/Rm	3	6.2	1.4	9.0	18.6
Si/T/Rp	1	0.9	0.9	0.9	0.9
Su	22	4.8	0.6	20.2	105.4
Su/Fu	10	6.8	0.6	43.6	68.1
Su/Rh	13	14.0	1.7	58.5	182.3
Su/Ri	6	7.5	1.7	14.9	44.9
Su/RI	14	7.2	0.5	45.5	101.3
Su/Rm	10	2.9	1.1	5.0	29.3
Su/Rp	1	2.8	2.8	2.8	2.8
Su/Tu	2	4.1	3.8	4.4	8.2
Sui	15	14.8	0.2	57.5	221.3
Sui/Fui	2	14.8	14.6	15.0	29.6
Sui/Tui	4	6.5	3.3	11.0	26.1
Sul/Ful	1	16.9	16.9	16.9	16.9
Sup	4	5.7	2.8	10.9	23.0
T/Hui	1	2.3	2.3	2.3	2.3
T/Hul	2	3.0	2.7	3.3	6.0
T/Hum	4	5.1	1.6	8.6	20.4
T/Km	1	3.5	3.5	3.5	3.5
T/PIs	4	5.4	1.1	12.3	21.5

T/PIs/Ri	53	6.6	0.7	31.9	351.9
T/PIs/Rl	1	7.7	7.7	7.7	7.7
T/PIs/Rp	84	6.9	0.1	164.0	577.2
T/PIx/Ri	1	3.3	3.3	3.3	3.3
T/PIx/Sd	1	13.1	13.1	13.1	13.1
T/Rh	479	11.1	0.3	271.4	5321.6
T/Ri	1207	8.9	0.3	197.2	10718.9
T/Ri/Sd	7	15.3	2.3	34.8	107.4
T/Rl	310	4.6	0.1	34.6	1418.5
T/Rm	373	8.3	0.1	223.4	3109.9
T/Rp	529	4.4	0.1	86.0	2338.0
T-S/Rm	2	64.7	59.0	70.3	129.3
Tu	164	5.0	0.1	156.6	827.6
Tu/Hu	1	3.2	3.2	3.2	3.2
Tu/Kp	3	3.5	1.0	7.5	10.6
Tu/PIs/Ri	2	2.0	1.5	2.6	4.1
Tu/PIs/Rp	1	2.0	2.0	2.0	2.0
Tu/PIsu	35	4.8	1.0	22.7	168.3
Tu/PIsu/Ri	1	8.4	8.4	8.4	8.4
Tu/PIsu/Rp	10	8.2	2.3	27.9	81.5
Tu/Rh	62	10.0	0.9	83.0	622.7
Tu/Ri	81	8.9	0.3	78.2	722.5
Tu/Rl	258	5.2	0.2	53.4	1336.1
Tu/Rm	199	5.6	0.1	74.7	1109.2
Tu/Rp	41	5.6	0.5	15.9	228.5
Tui	6	4.2	1.6	8.1	25.2
Tui/Sui	2	2.7	2.0	3.3	5.3
V	7	3.4	0.4	9.3	23.5
W	20	167.0	0.5	2680.8	2751.1
Totals	24491	1710.3	592.9	70372.0	219438.2

Attachment H

Vegetation Modeling, Analysis and Visualization In U.S. National Parks

by
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Vegetation Modeling, Analysis and Visualization In U.S. National Parks

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Commission IV, Working Group IV/6

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ABSTRACT:

Researchers at the Center for Remote Sensing and Mapping Science (CRMS) at The University of Georgia have worked with the U.S. Department of Interior National Park Service (NPS) over the past decade to create detailed vegetation databases for several National Parks and Historic Sites in the southeastern United States. The sizes of the parks under investigation vary from Everglades National Park and Big Cypress National Preserve in south Florida (10,000 km²) and Great Smoky Mountains National Park located in the Appalachian mountains of Tennessee and North Carolina (2,000 km²) to small national battlefields and historic sites of less than 100 ha. Detailed vegetation mapping in the parks/historic sites has required the combined use of Global Positioning System (GPS), softcopy photogrammetry and geographic information system (GIS) procedures with digital elevation models (DEMs) to construct large scale digital orthophotos and vector-based vegetation databases. Upon completion of the vegetation databases, 3D visualization and spatial analyses were conducted and rule-based models constructed to assist park managers with a variety of environmental issues such as terrain influence on vegetation, fire fuel assessment and vegetation patterns related to interpreter differences and human influence on vegetation.

1. INTRODUCTION

The Center for Remote Sensing and Mapping Science (CRMS) at The University of Georgia has worked cooperatively with the National Park Service (NPS) over the past decade to create digital vegetation databases for 17 National Park units of the southeastern United States (Madden et al., 1999; Welch et al., 1995; 1999; 2000; 2002a). In all of these parks, overstory vegetation detail was interpreted and compiled from large- and medium-scale color infrared (CIR) aerial photographs (1:12,000 to 1:40,000-scale). In one park, Great Smoky Mountains National Park, an understory vegetation database also was compiled using leaf-off aerial photographs of 1:40,000 scale. The method of photo rectification varied from simple polynomial solutions in relatively flat areas such as the Everglades in south Florida to full photogrammetric solutions, aerotriangulation and orthorectification in high relief areas such as the Great Smoky Mountains National Park (Jordan 2002; 2004).

In order to accommodate the complex vegetation patterns found in national parks, classification systems suitable for use with the aerial photographs were created jointly by CRMS, NPS and NatureServe ecologists (Madden et al., 1999; Welch et al., 2002b). These classification systems are based on the U.S. Geological Survey (USGS)-NPS National Vegetation Classification System (NVCS) developed by The Nature Conservancy (TNC) (Grossman et al., 1998). Extensive Global Positioning System (GPS)-assisted field investigations also were conducted to collect data on the vegetation communities and correlate signatures on the air photos with ground observations. Based on this field work, manually interpreted vegetation polygons were attributed with NVCS classes to create vegetation databases in Arc/Info, ArcView and ArcGIS formats, depending on the time the database was developed and the size of the park.

Upon completion of the vegetation databases, geographic information system (GIS) analyses were conducted to assist park managers with a variety of environmental issues. Specific objectives of this paper include: 1) demonstrate GIS analysis of the Great Smoky Mountains National Park overstory vegetation database for assessing environmental factors related to vegetation distributions; 2) utilize rule-based modeling techniques to assess forest fire fuels and fire risk; and 3) examine vegetation patterns using landscape metrics to address interpreter differences, human influences and hemlock distributions threatened by exotic insects.

2. GIS ANALYSIS OF OVERSTORY VEGETATION

The analysis of environmental factors such as terrain characteristics that are associated with each forest community type provides national park botanists with information that can be used to better understand, manage and preserve natural habitats. A portion of the Great Smoky Mountains National Park database, namely the area corresponding to the Thunderhead Mountain (THMO) 7.5-minute USGS topographic quadrangle, was selected for assessing vegetation and terrain characteristics (Fig. 1).

Overlay analysis of vegetation polygons with elevation range and slope provided mean, range and variance statistics that can be associated with individual forest and shrub classes (Fig. 2 and 3). Overlay analysis of vegetation polygons with aspect indicated the probability of locating forest community types in particular microclimates controlled largely by aspect. (Fig. 4). For example, cove hardwood forests prefer moist environments and are found mainly on north, northeast and northwest aspects, while xeric oak hardwoods are found predominantly on south, southeast and southwest facing slopes.

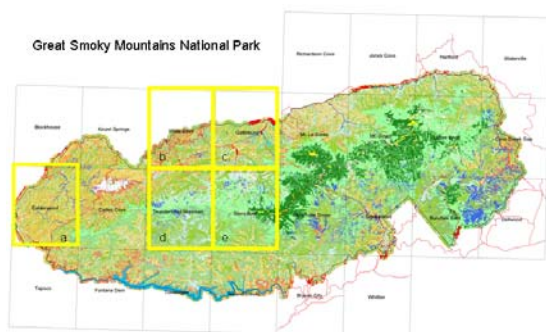


Figure 1. Great Smoky Mountains National Park and the area corresponding to: (a) Calderwood (CALD); (b) Wear Cove (WECO); (c) Gatlinburg (GATL); (d) Thunderhead Mountain (THMO); and (e) Silers Bald (SIBA) 7.5-minute U.S. Geological Survey (USGS) topographic quadrangles.

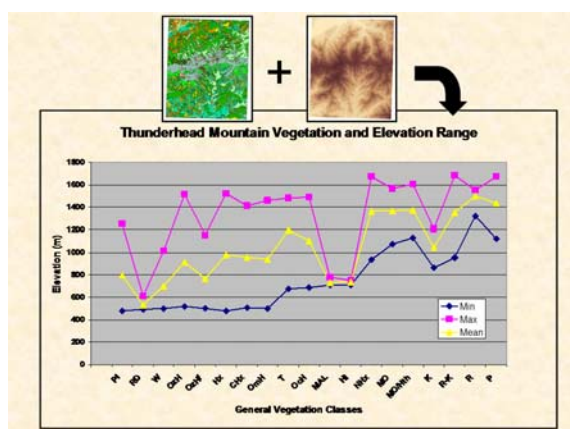


Figure 2. Spatial correlation of elevation range and overstory vegetation classes.

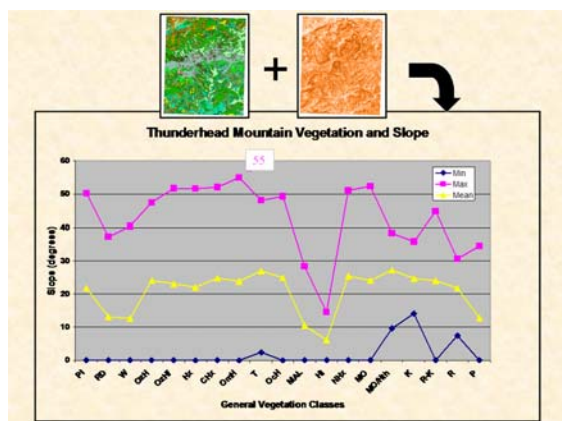


Figure 3. Spatial correlation of slope and overstory vegetation classes.

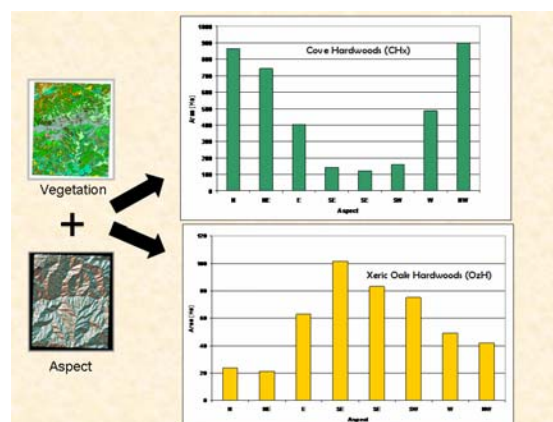


Figure 4. Spatial correlation of aspect and overstory vegetation classes: cove hardwood and xeric oak hardwood forests.

Developing elevation range, slope and aspect characteristics for each forest community type better defines the community description and can be used to model the probability of locating similar communities outside of the national park, but within the southern Appalachian Mountains. Visualization techniques, such as 3D perspective views and drapes of orthorectified images related to mapped vegetation are also useful for conveying information on terrain-vegetation relationships (Fig. 5).

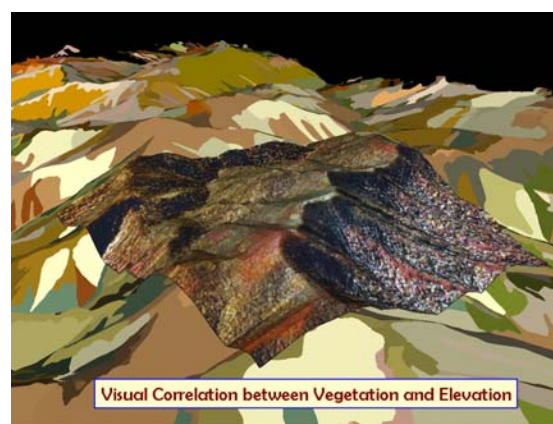


Figure 5. A 3D perspective view of an orthorectified color infrared air photo and overstory vegetation polygons.

3. RULE-BASED MODELING TECHNIQUES TO ASSESS THE RISK OF FOREST FIRES

There has been an increased interest in finding new tools for fire management and prediction in U.S. national parks due to recent dry summers and devastating forest fires. To this end, rule-based GIS modeling procedures were used to classify fire fuels for Great Smoky Mountains National Park based on overstory and understory vegetation (Dukes, 2001; Madden and Welch 2004).

Through field work and consultation with NPS fire experts, fire fuel model classes originally defined by the U.S.

Department of Agriculture for forest types of the western United States were adapted for use with the eastern deciduous forest communities that occur in Great Smoky Mountains National Park (Anderson, 1982). Extensive experience in fire management, long-term observation of fire behavior in vegetation communities of the park and familiarity with the Anderson fire fuel classification allowed NPS fire managers to correlate the 13 Anderson fire fuel classes with forest communities of the southern Appalachian Mountains. Classes were assigned based on characteristics such as the overstory community, the type and density of understory shrubs and the type and amount of leaf litter. This information was then used to develop a set of rules for fuel model classification given the combination of particular overstory and understory classes of the vegetation database.

Figures 6 and 7 depict overstory and understory vegetation within a portion of Great Smoky Mountains National Park corresponding with the Calderwood (CALD) USGS topographic quadrangle (See location “a” in Fig. 1). Detailed vegetation classes of both overstory and understory were collapsed to generalize forest and shrub communities originally mapped as associations of individual species with over 170 classes to more general forest types containing approximately 25 classes. This facilitated the definition of rules for the assignment of fire fuel model classifications (Fig. 8). Level 1 rules assigned intersected polygons a whole number fuel class (0 to 13) according to the spatial coincidence of general overstory and understory vegetation types. For example, an intersected polygon consisting of a dry oak hardwood overstory with no appreciable understory vegetation was assigned a fuel model class of 8 – Closed Timber Litter, while a more moist hardwood overstory forest community coincident with a deciduous shrub understory was assigned a fuel model 9 – Hardwood Litter (Madden and Welch 2004).

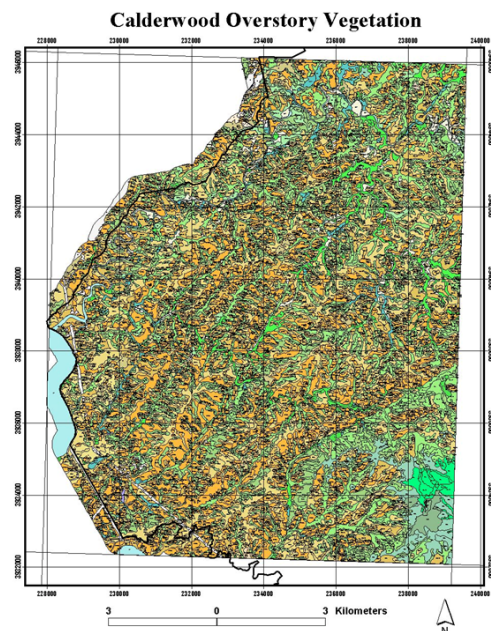


Figure 6. A portion of the overstory vegetation in Great Smoky Mountains National Park corresponding to the USGS 7.5-minute Calderwood topographic quadrangle.

Level 2 rules further refined the fire fuel classification system by accounting for the density of mountain laurel (*Kalmia latifolia*.) and Rhododendron (*Rhododendron* spp.), two prominent broadleaf evergreen shrubs found in the park. An intersected polygon containing scattered hardwoods in the overstory and light density mountain laurel shrubs in the understory would be assigned a Level 2 fuel model class of 6.1, while the same overstory polygon with heavy density Rhododendron would be assigned a class of 6.6. Fire managers can thus distinguish both understory type and density from the assigned fire fuel classes which may prove useful for determining how to suppress a wild fire or when it might be appropriate to conduct a prescribed burn (Fig. 9).

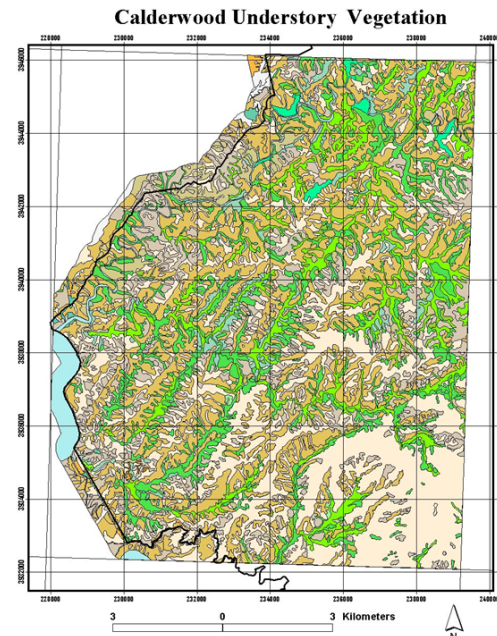


Figure 7. A portion of the understory vegetation in Great Smoky Mountains National Park corresponding to the USGS 7.5-minute Calderwood topographic quadrangle.

GIS/Cartographic Model to Produce Fuel Class Map

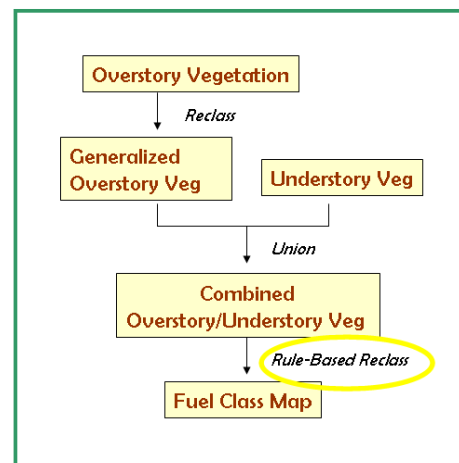


Figure 8. A schematic diagram of the GIS cartographic model used to produce the fuel class data sets.

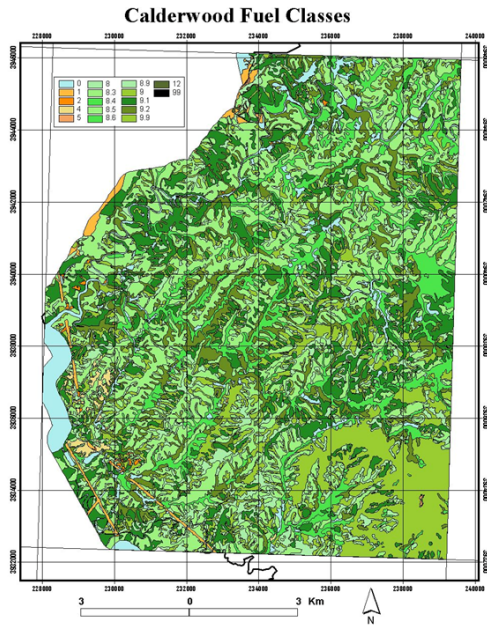


Figure 9. A portion of the fuel class database in Great Smoky Mountains National Park corresponding to the USGS 7.5-minute Calderwood topographic quadrangle.

The fire fuel class maps and GIS data sets for Great Smoky Mountains National Park are being used for fire management decisions and long-term planning for the protection of park resources. As a demonstration of the use of the fuel maps for further fire analysis, Dukes (2001) assigned risk factors based on fuel classes, topography (isolating relatively dry slopes, aspects and elevations) and ignition sources (e.g., distance to roads, campsites and areas of potential lightning strikes). Since ignition risks were found to be important predictors of 24 previous forest fires located in the Calderwood quad area, this risk data layer was given a weight of 2x in the model. A combination of all risk factors resulted in an overall map of fire ignition risk ranked as high medium and low (Fig. 10). An overlay of six withheld fire locations indicted all previous fires corresponded with designations of medium and high risk.

4. LANDSCAPE METRICS RELATED TO VEGETATION PATTERNS

Landscape metrics comparing vegetation patterns due to interpreter differences and human influence were derived using the Patch Analyst, an ArcView extension that interfaces grids and shapefiles with Fragstats Spatial Pattern Analysis program (McGarigal and Maraks, 1995; Elkie et al., 1999). An area corresponding to four 7.5-minute USGS topographic quadrangles was selected to examine differences in landscape metrics. Overstory vegetation in the Wear Cove (WECO) and Thunderhead Mountain (THMO) quadrangles was mapped by Interpreter #1, while the vegetation in the Gatlinburg (GATL) and Silers Bald (SIBA) quadrangles was mapped by Interpreter #2 (Fig. 11). (Also indicted by “b”, “c”, “d” and “e”, respectively, in Fig. 1). In addition to interpreter differences, WECO and GATL quadrangles are located on the outside boundary of the park and the vegetation in these quads is subject to greater human

influence than the interior quads, THMO and SIBA (Fig. 12). These four quads, therefore, provide a good test for whether interpreter differences or human influence is having a greater impact on vegetation patterns as measured by landscape metrics (Madden 2003).

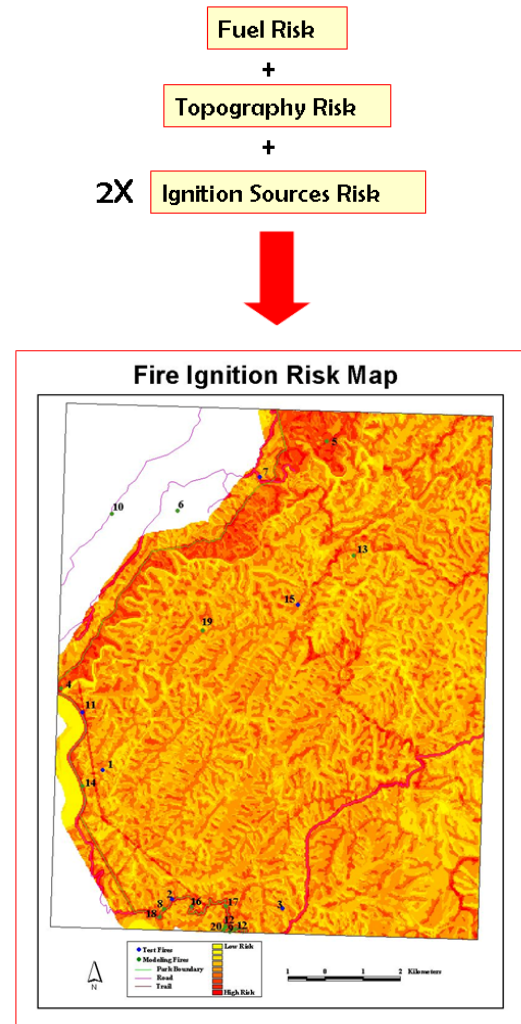


Figure 10. A schematic diagram of the GIS data layers combined in a cartographic model to assess the risk of forest fire and a map of fire ignition risk in the Calderwood area of Great Smoky Mountains National Park (Dukes, 2001).

Landscape metrics, such as Shannon's Diversity Index, computed at the landscape level (i.e., considering all pixels in the grid) indicate that there is very little difference that can be attributed to the two interpreters (Fig. 13). Exterior quads (WECO and GATL) showed a slight decrease in diversity compared to interior quads: SIBA and THMO. Groups of adjacent pixels with the same overstory vegetation class were then identified using an 8N-diagonals clumping method of the Patch Analyst (Fig. 14). Since resource managers in Great Smoky Mountains National Park are extremely interested in preventing wide-spread destruction of old growth forests due to an infestation of an exotic insect known as the hemlock wooly adelgid (*Adelges tsugae*), patches representing areas containing Eastern hemlock were

isolated from the overstory vegetation database and analyzed using the Patch Analyst (Fig. 15). Forest polygons containing hemlock were reclassified to pure hemlock and hemlock mixed with other tree species. Patch-level landscape metrics calculated using hemlock polygons show interpreter differences were minimal, while edge density and mean shape index metrics were significantly lower for exterior quads (WECO and GATL) having more human influence compared to interior quads (THMO and SIBA) (Fig. 16 and 17).

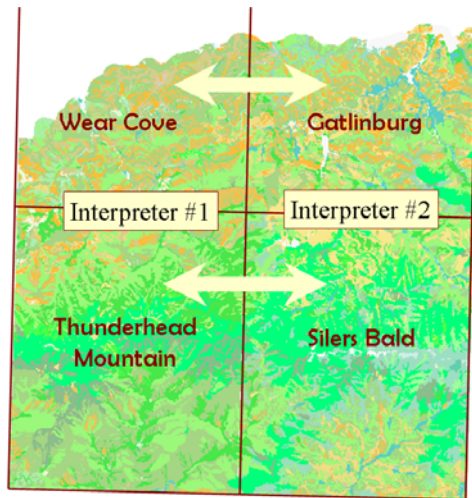


Figure 11. Overstory vegetation in the Wear Cove and Thunderhead Mountain quadrangles of Great Smoky Mountains National Park were mapped by Interpreter #1, while Interpreter #2 mapped vegetation in Gatlinburg and Silers Bald.

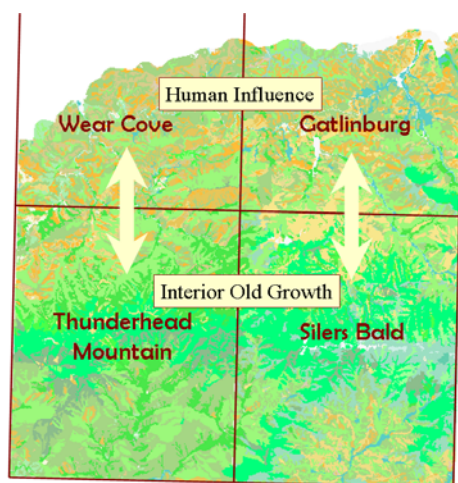


Figure 12. Overstory vegetation in the Wear Cove and Gatlinburg quadrangles of Great Smoky Mountains National Park are subject to greater human influence because they are located at the edge of the park boundary, while vegetation in the interior Thunderhead Mountain and Silers Bald quads is more protected from human impacts.

Landscape Level Landscape Metrics

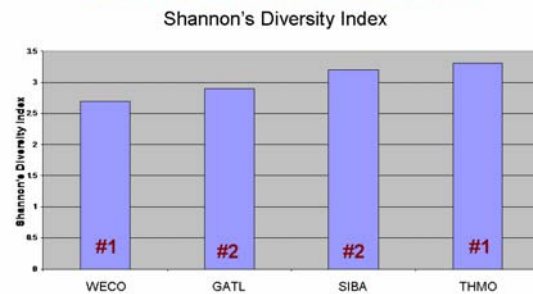


Figure 13. At the landscape level, the Shannon's Diversity Index was slightly lower for exterior quads (WECO and GATL). Interpreter differences were not significant.

Patch Level Landscape Metrics

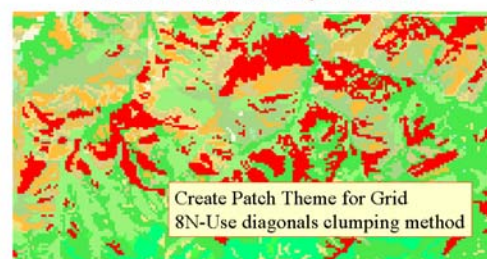


Figure 14. Overstory vegetation polygons in vector format were converted to patches in a raster grid for computation of patch level landscape metrics.

Reclass to Isolate Hemlock

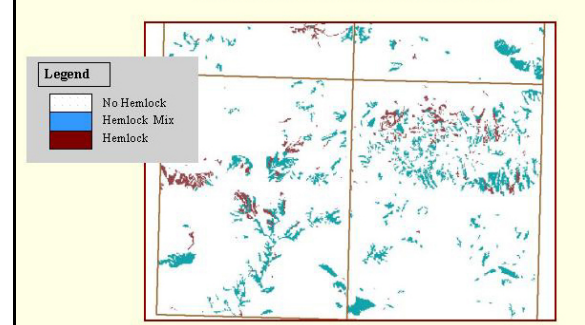


Figure 15. Reclassification of overstory vegetation isolated forest patches containing pure hemlock stands and mixed hemlock/hardwood communities.

4. SUMMARY

In summary, GIS analyses and visualization techniques were used to assess vegetation patterns in Great Smoky Mountains National Park vegetation community distributions. Overlay analyses of vegetation, elevation, slope and aspect resulted in range and variance statistics that define vegetation distributions related to terrain factors. Rule-based modeling of overstory and understory vegetation produced fuel class data sets for the park that, in turn, can be used to model fire behavior, plan fire management tactics and assess the risk of future fires. Landscape metrics also were used to investigate patch characteristics of diversity, shape and edge density.

Results indicated differences in photo interpreters were not as important as the degree of human influence on the landscape. This information provides resource managers with information that can be used in the development of management plans for preserving forest communities in national parks.

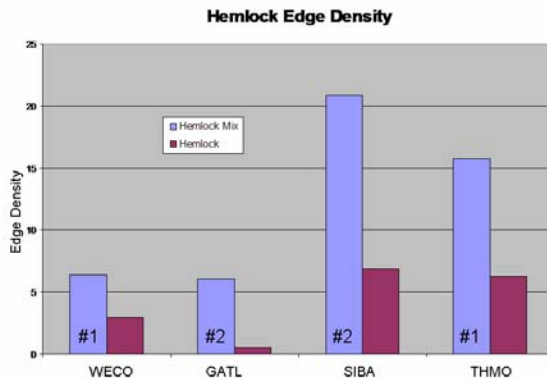


Figure 16. Edge density for hemlock patches was significantly lower for exterior quads (WECO and GATL), while interpreter differences were not significant.

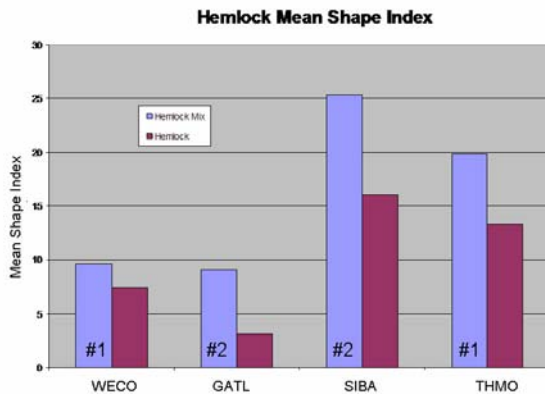


Figure 17. Shape index for hemlock patches was significantly lower for exterior quads (WECO and GATL), while interpreter differences, again, were not significant.

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