

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.
Attachment D	CRMS Understory Vegetation Classification System for mapping Great Smoky Mountains National Park, by Rick Seavey and Jean Seavey.
Attachment E	Details on the CRMS GRSM Understory Vegetation Classification System, by Rick Seavey and Jean Seavey.
Attachment F	Summary of Park-wide statistics for overstory classes.
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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).

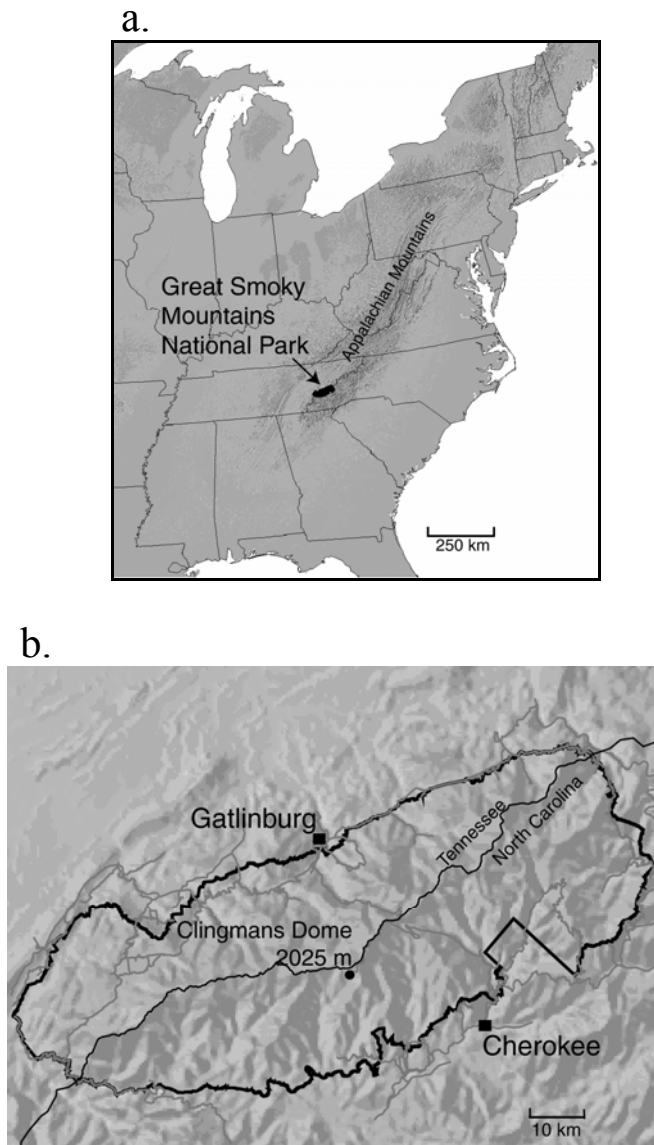


Figure 1. Location of (a) Appalachian Mountains and (b) Great Smoky Mountains National Park in eastern United States.

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).

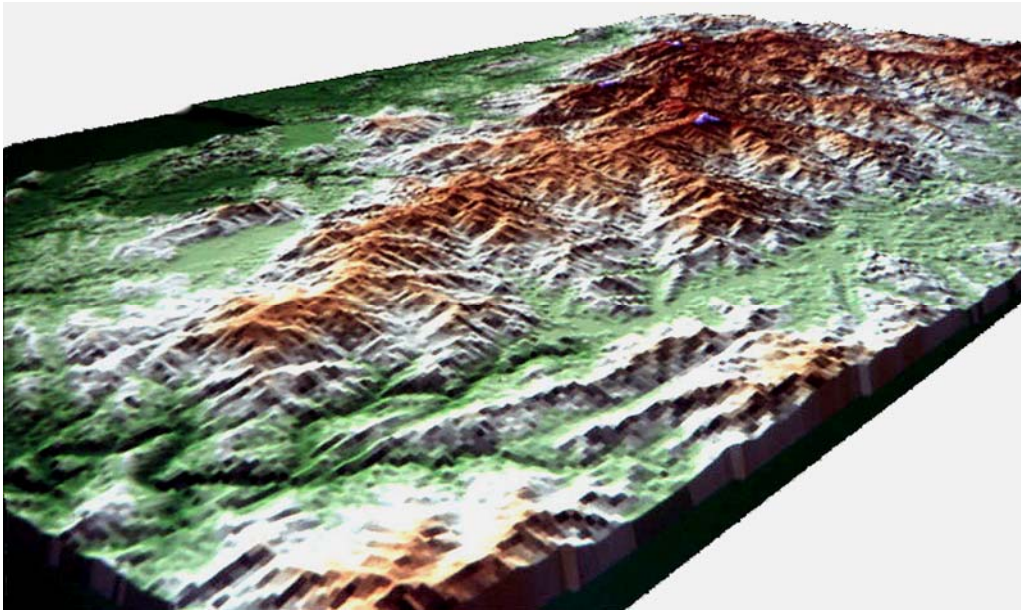


Figure 2. 3D perspective view of GRSM constructed from a mosaic of SPOT multispectral images draped over a digital elevation model. Elevations range from approximately 200 to over 2000 m above sea level.

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.

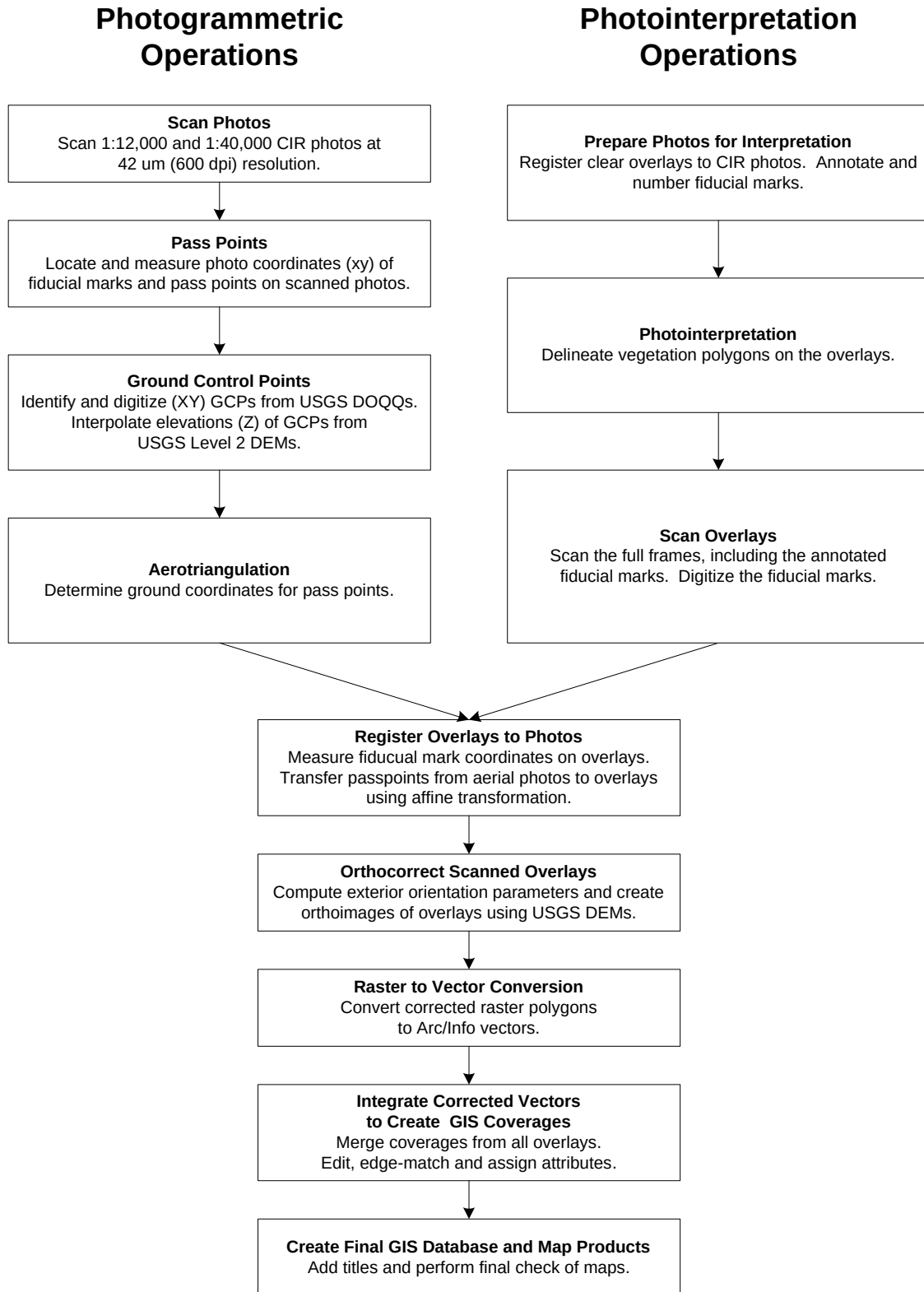


Figure 4. Diagram showing photogrammetric, photointerpretation and GIS operations used to map the vegetation of GRSM.

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.

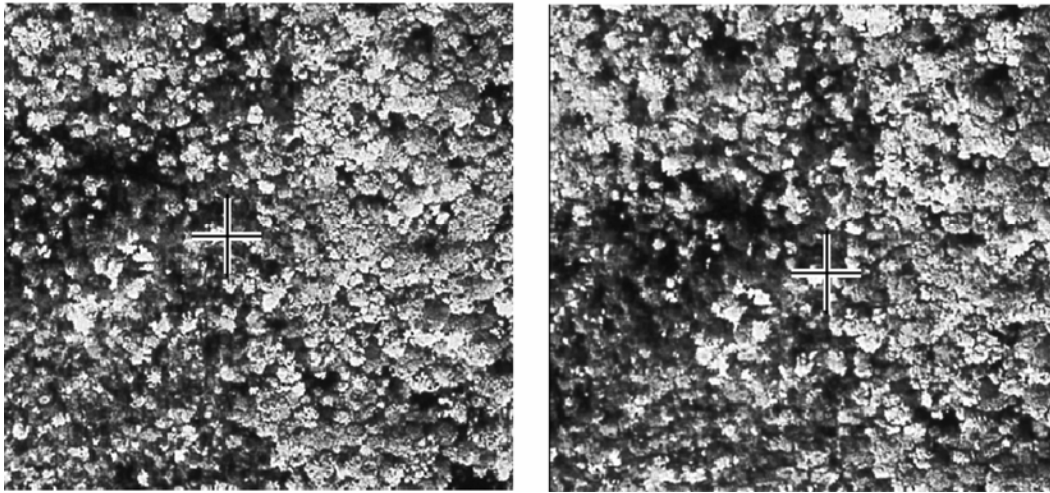


Figure 5. Tree tops were used as pass points in overlapping images in the heavily forested GRSM.

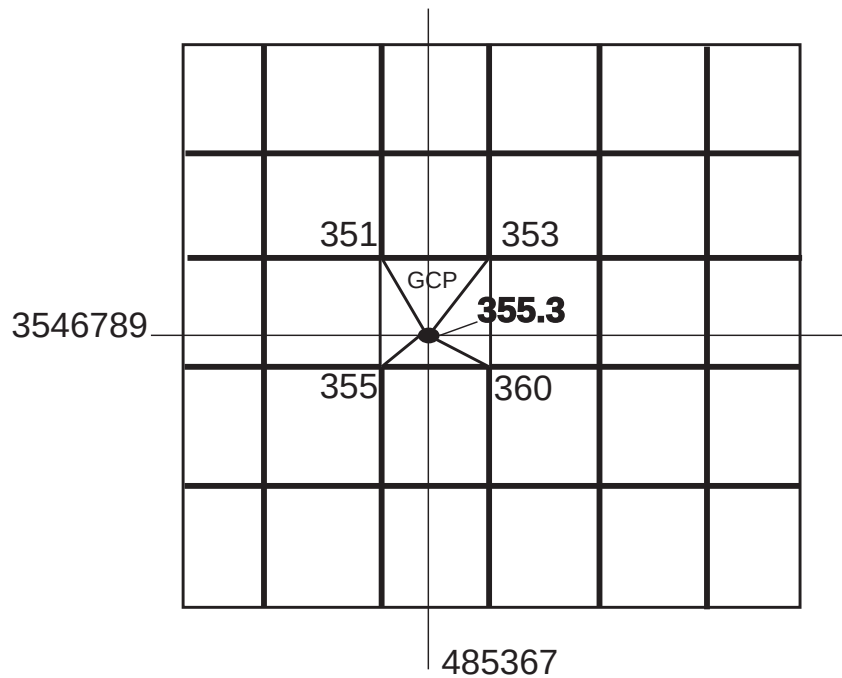


Figure 6. The elevations of ground control points (GCPs) were determined from the 30-m digital elevation model (DEM) using a bilinear interpolation algorithm.

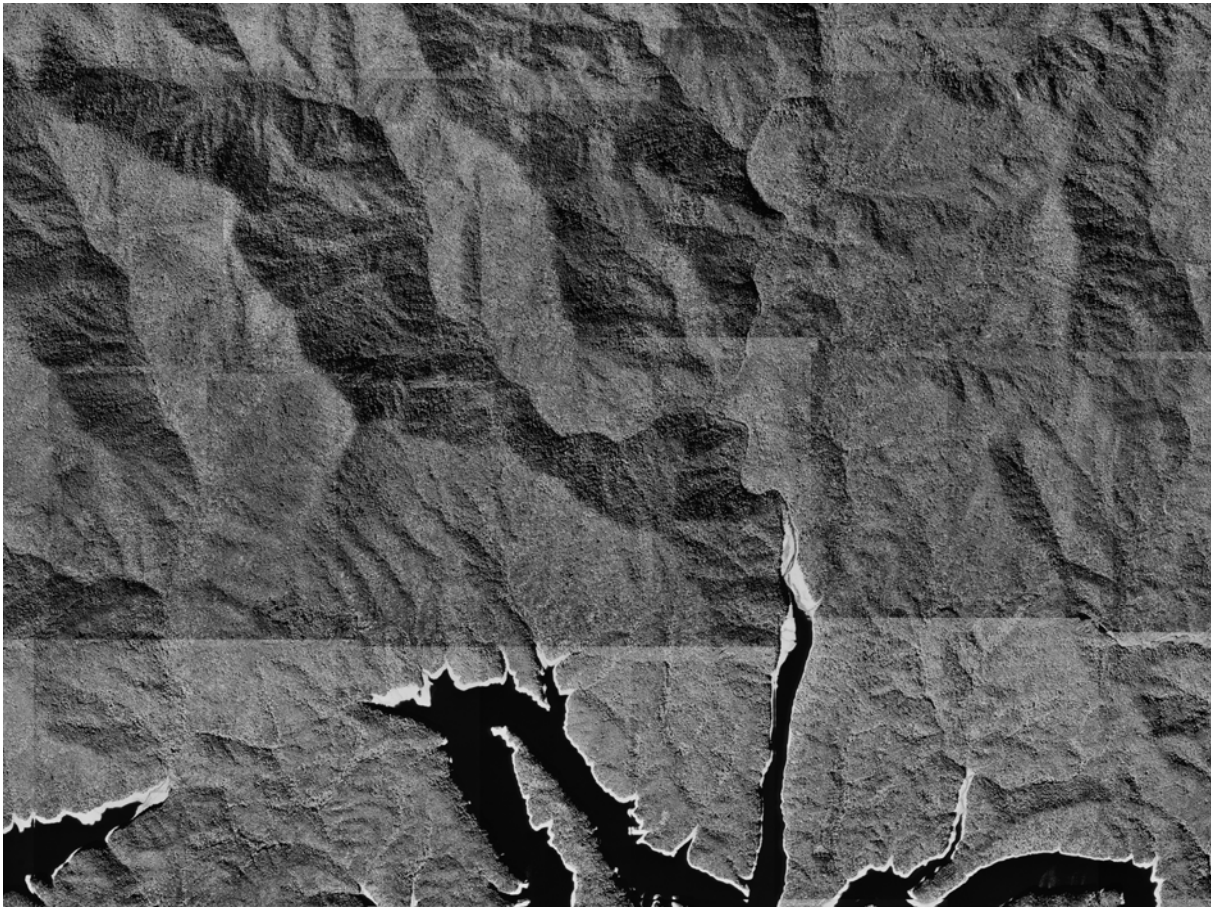


Figure 7. A mosaic of orthorectified 1:12,000-scale photographs was created for quality assurance and checking. Terrain features that are well aligned between individual photographs indicate a good overall solution. This is necessary for the rectified vegetation linework of individual photographs to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

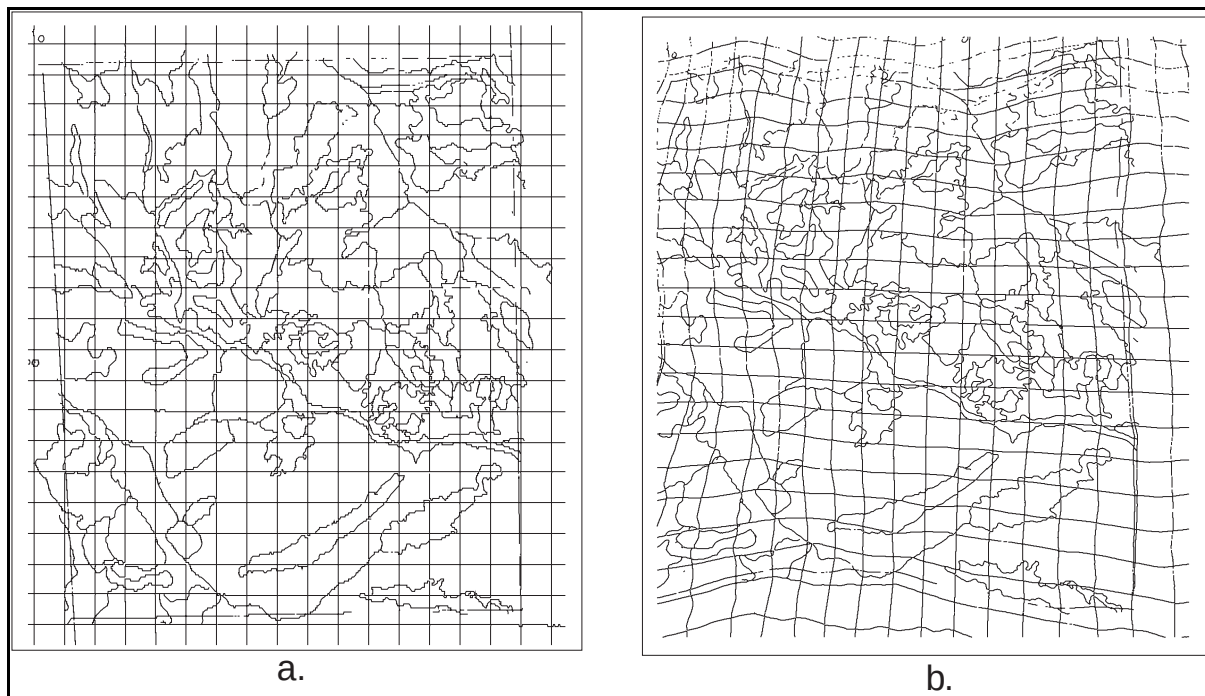


Figure 9. (a) Original photo overlay depicting vegetation polygons and a 1-cm grid before corrections for relief displacement. (b) Overlay and grid after orthorectification showing the extreme corrections required to accommodate the large range of relief in the area.

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.

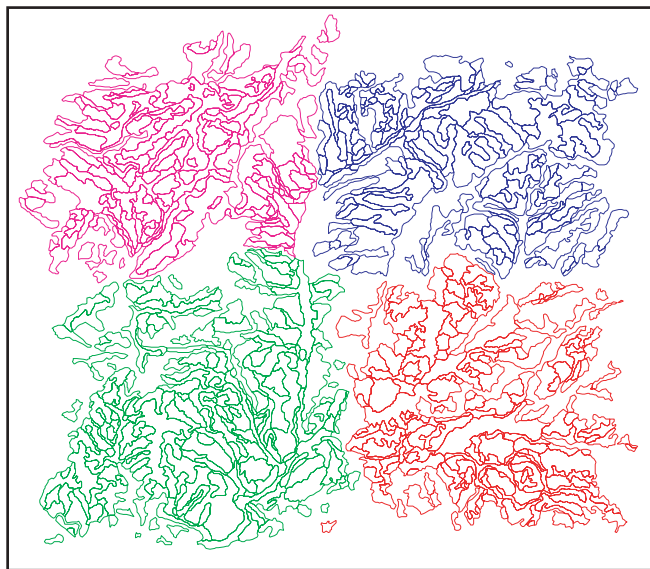


Figure 10. Individual vector files from four adjacent photos that have been edited and edge matched.

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

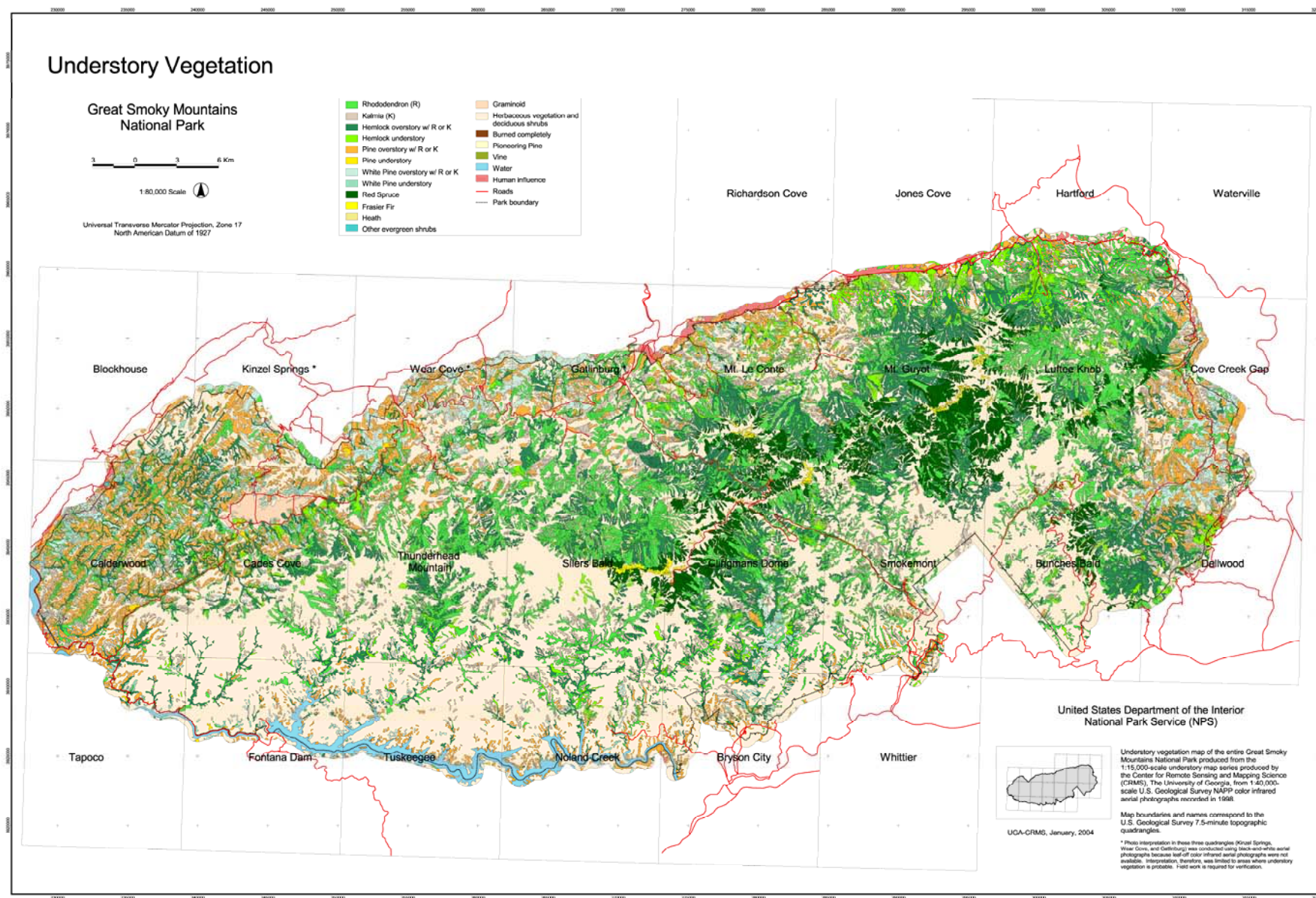


Figure 12. Generalized overview map of GRSM understory vegetation.

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.

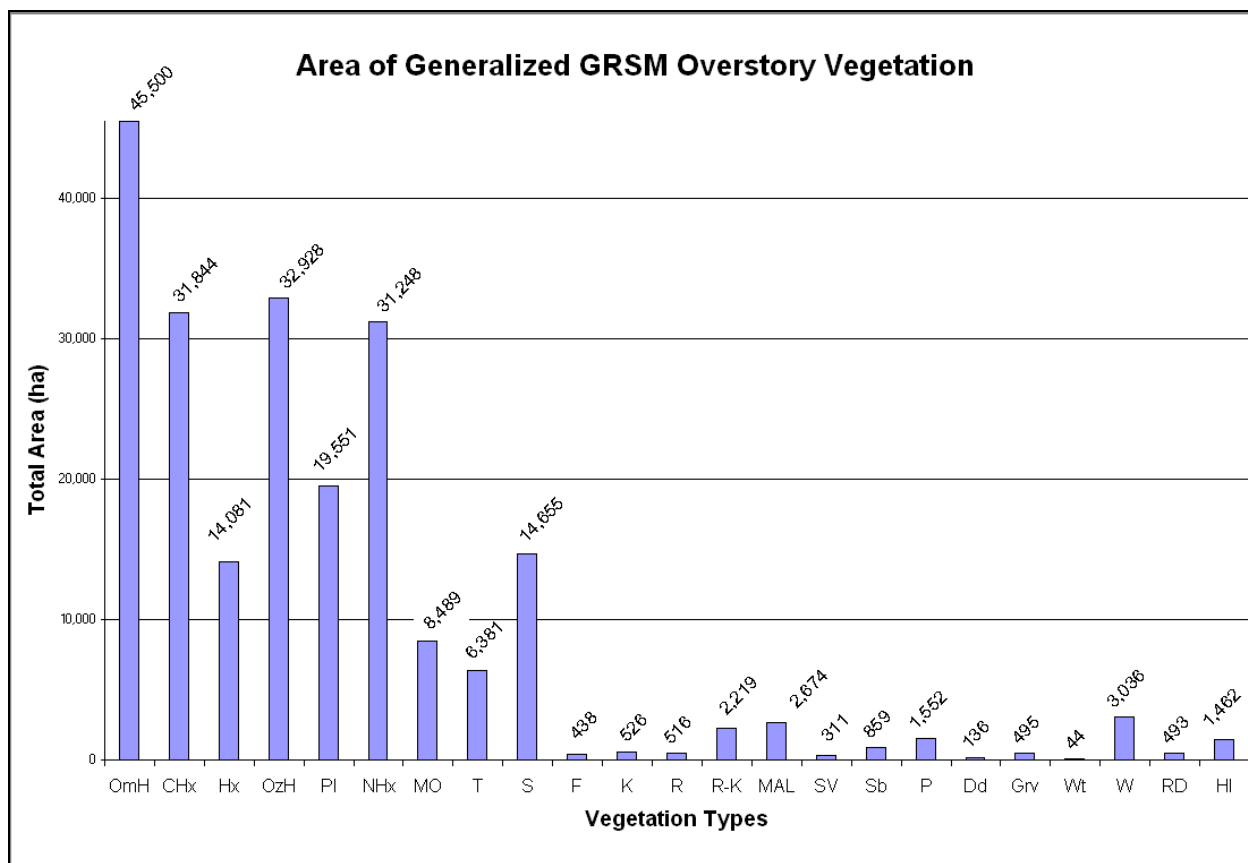


Figure 13. Total area (hectares) of generalized overstory vegetation classes in GRSM.

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

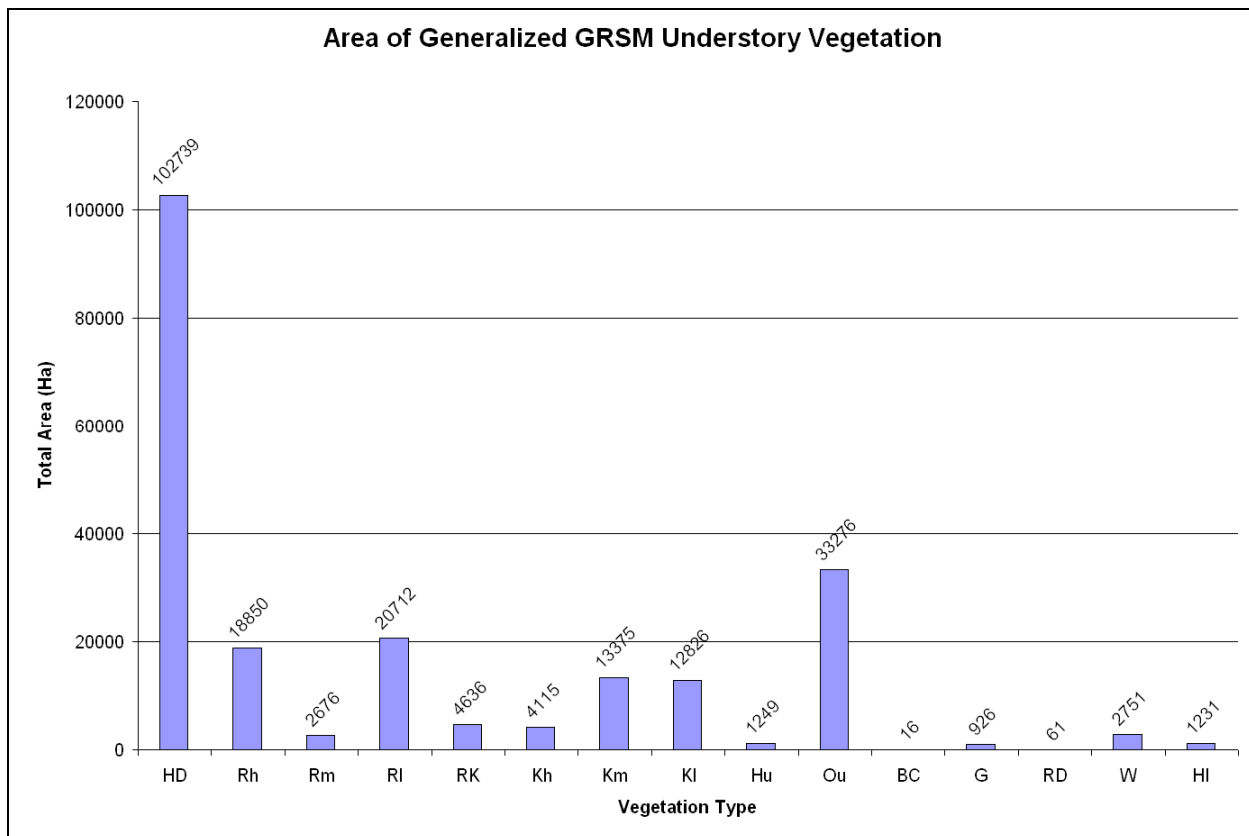


Figure 14. Total area (hectares) of generalized understory vegetation classes in GRSM.

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.

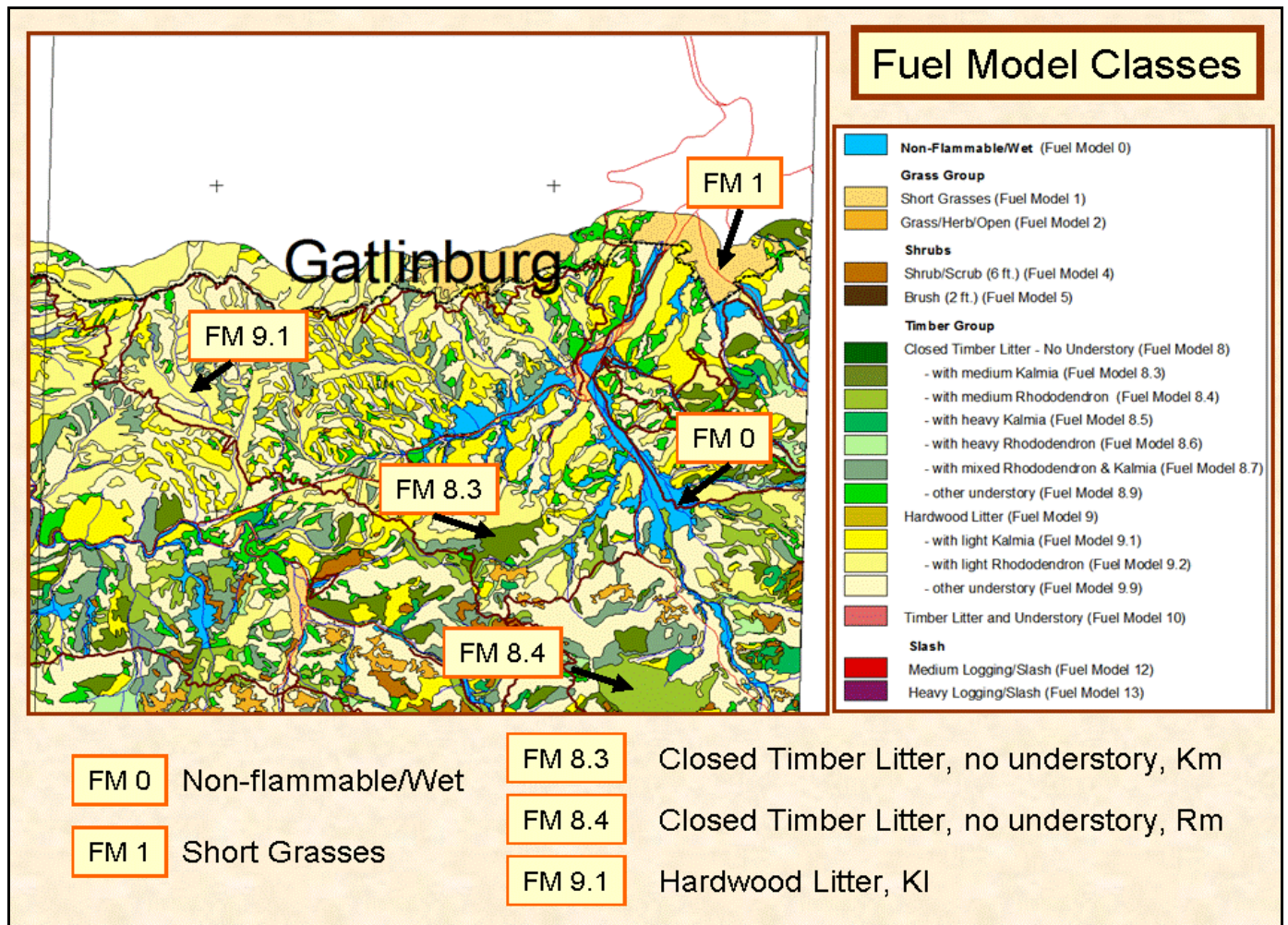


Figure 17. A sample of the fire fuel model data set with fuel model values based on unique combinations of overstory/understory vegetation classes (integer values) and understory density (decimal values).



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.

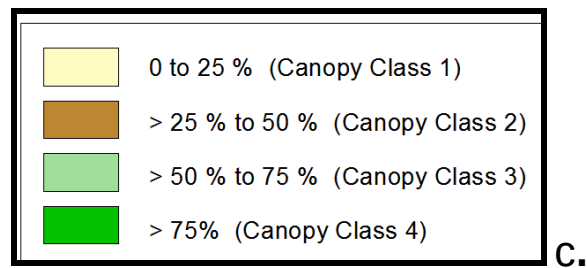
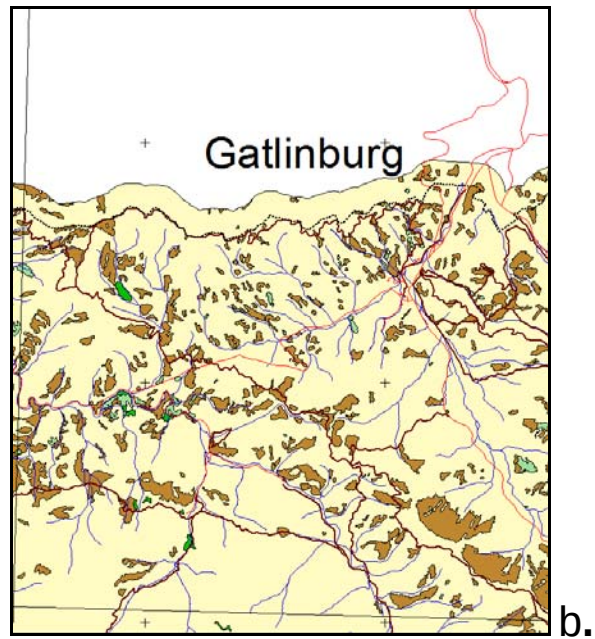
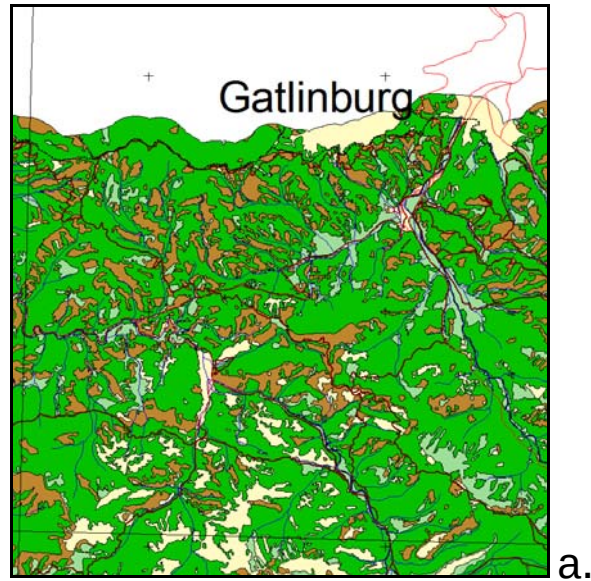


Figure 19. Percent canopy within the Gatlinburg quadrangle in leaf-on (a) and leaf-off (b) conditions color-coded according to canopy classes based on percent of canopy closure (c).

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.

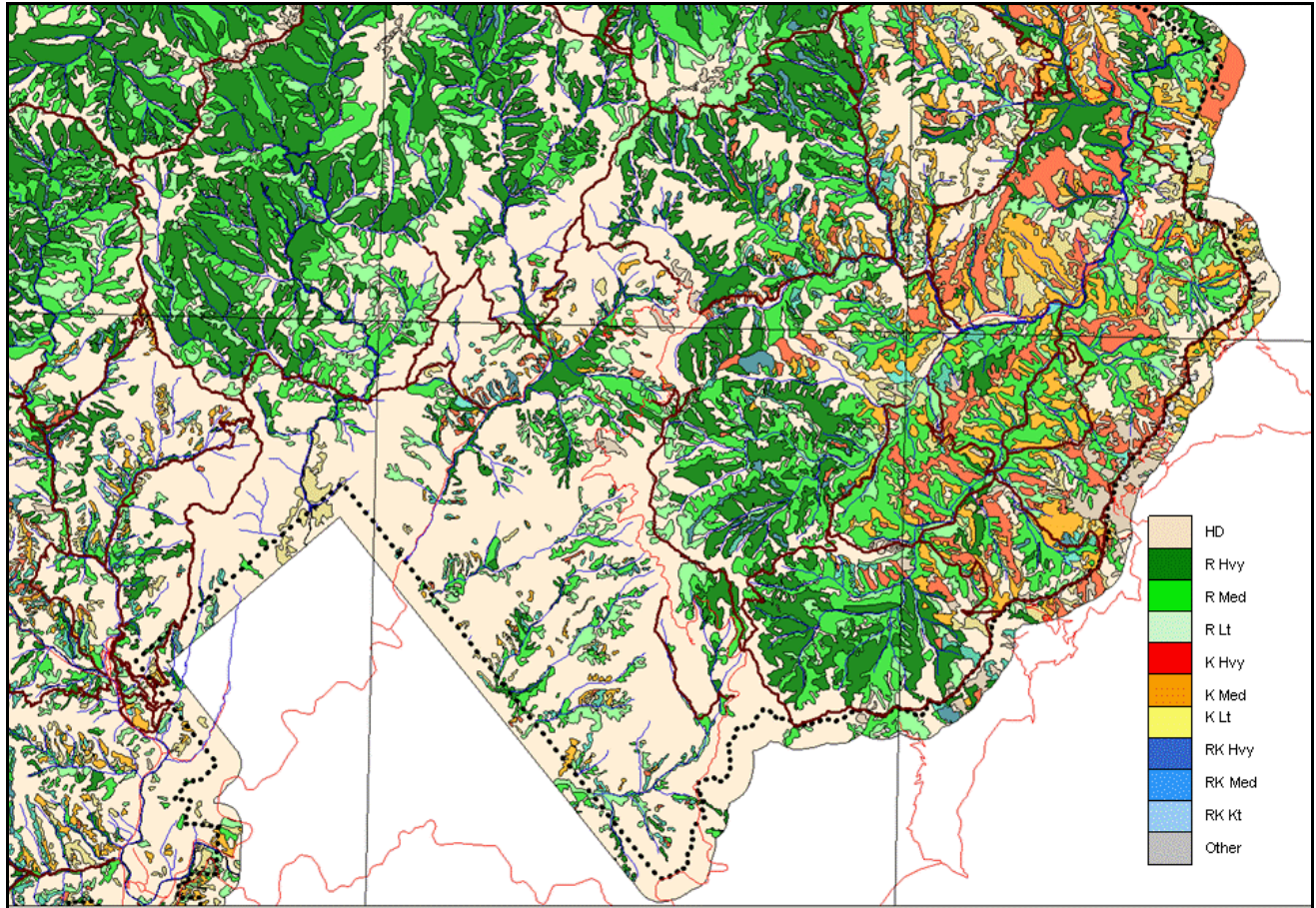


Figure 20. A portion of the GRSM understory density data set depicting light, medium and heavy densities of *Rhododendron* (R), *Kalmia* (K) and mixed *Rhododendron/Kalmia* (RK).

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.

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