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

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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
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 Battleground | 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 | GU CO | 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 practices, pass points are identified on scanned (42 μm) 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 (orthocorrection) 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.

Orthocorrection 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 orthocorrection 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).

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

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 orthocorrected 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.

REFERENCES


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

I. FOREST

A. Sub-Alpine (5000-6643 feet)

Sub-Alpine Mesic Forests

1. Fraser Fir (above 6000 ft.)$^2$
   a. Formerly Fraser Fir
   b. Fraser Fir/Deciduous Shrub-Herbaceous
   c. Fraser Fir/Rhododendron

2. Red Spruce - Fraser Fir
   a. Red Spruce- (Fraser Fir)/ Highbush Cranberry-Deciduous Shrub-Herbaceous (5400-6200 ft.)
   b. Red Spruce- (Fraser Fir)/ Rhododendron (5000-6000 ft.)

3. Red Spruce
   a. Red Spruce/Southern Mountain Cranberry-Low Shrub/Herbaceous (5400-6200 ft.)
   b. Red Spruce/Rhododendron (5000-6000 ft.)

4. Red Spruce-Yellow Birch - (Northern Hardwood)
   a. Red Spruce - Birch- (Northern Hardwood) / Shrub/Herbaceous (4500-6000 ft.)
   b. Red Spruce - Birch/Rhododendron (rare)

5. Beech Gap
   a. North (also East) Slope Tall Herb Type
   b. South (also West) Slope Sedge Type

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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


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.) 7861

   b. Southern Appalachian Northern Hardwoods, Typic Type (4000-6000 ft.) 7285

   c. Southern Appalachian Northern Hardwoods, Rich Type (3500-5500 ft.) 4973 NHxR, NHxR/T, NHxR-T (T/NHxR)4
   d. S. Appalachian Northern Hardwoods, Beech dominant 7285 NHx:Fg
   e. Southern Appalachian Forested Boulder Fields 4982, 6124 NHx:Bol5

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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.) 8558 NHxA, NHxA/T, 
      NHxA-T
      (At mid-elevation, see I.C.6.a)
   b. Southern Appalachian Sweet Birch/
      Rhododendron (2500-5000 ft.) 8558 HxBl/R, (NHxBl/R)\textsuperscript{6}
      (At mid-elevation see I.C.6.b)

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.) 7136 T, T/R
   (More common at mid elevation, see I.C.2 below.)

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 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

\textsuperscript{6} NHxBl/R was originally distinguished from a lower elevation HxBl/R community. The two types were found to be contiguous and designated HxBl/R.
c. S. Appalachian Cove Hardwoods, Acid Type (usually with Hemlock) 7543 CHxA, CHxA/T, CHxA-T, T/CHxA, T/CHx, 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 6286 (was rarely found)

f. Chestnut Oak Type (7267), 72308 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 Type9 (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 Pls-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

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7 See footnote 4.
8 May also be cross-referenced with 7298, 7299, 7300 and 8558 (HxBl/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  HxB/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.)  7543  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  HxBl, HxBl/T, HxBl-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
   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
   a. Chestnut Oak-Red Maple-Scarlet Oak/Mountain Laurel Xeric Ridge/Slope Woodland (below 4000 ft.)  6271  OzH/PIs
   .
   b. Chestnut Oak-Red Maple / Sourwood/Herbaceous Forest (2000-3000 ft.)  7267  OzHf, OzHf/PIs

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

11 OzHf, OzHFPI and OzHf/A were regrouped with sub-mesic oak-hardwoods, Section I.C.2.
10. White Oak-Red Maple/Hardwood/Herbaceous Forest
(In Calderwood quadrangle, uncommon.)

   a. Southern Appalachian White Pine/Mountain Laurel Woodland (below 2400 ft.) 7100 Pls
   b. Eastern White Pine Successional 7944 Pls
   c. Appalachian White Pine- (Chestnut Oak-Scarlet Oak) Xeric Forest/Woodland 7519 Pls/OzH, Pls-OzH
   d. Appalachian White Pine- Chestnut Oak- Red Maple-Red Oak Dry Forest 7519 Pls/OzHf, Pls-OzHf

Low and Mid Elevation Xeric Woodlands
Southern yellow pine species (listed below) in xeric woodlands
Virginia Pine (P{	extit{inus virginiana}) 2591, 7119 Plv
Shortleaf Pine (P{	extit{inus echinata}) 7078, 3560 Ple
Pitch Pine (P{	extit{inus rigida}) 7097 Plr
Table Mountain Pine (P{	extit{inus pungens}) 7097 Plp

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 Plp; 2500/3000-4500 ft. with Plp) 7097 Plp, Plr, Plp/OzH,
   Plp-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/Plr

15. Appalachian Shortleaf Pine-(Xeric Oak)/Mountain Laurel-
    \textit{Vaccinium} spp. Woodland (below 2400 ft.) 7078 Plr, PI/OzH, PI/OzH

16. Virginia Pine Early Successional Woodland/Forest
    (below 2000 ft.) 2591 Plv:5, Plv/OzH, Plv-OzH, OzH/Plv, PI/OzH

17. Appalachian Shortleaf Pine/ Little Bluestem Woodland
    (Uncommon) 3560 Plr; PI/OzH, PI/OzH

18. \textit{Paulownia tomentosa} Disturbed Woodland (Exotic sp.) 3687 No mapping unit
II. Shrublands or Shrub Understory 3893 Sb

A. Southern Appalachian Heath Balds 7876, 3814 Hth
2. Southern Appalachian Mid Elevation Heath Bald (<5500 ft.)
   a. R. maximum, R. catawbiense, small trees/shrubs 7876 Hth:R, Hth
   b. Kalmia latifolia, 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 3893 Sb:Rc
   Rubus spp./ Lady Fern/Skunk Goldenrod; may have tree canopy of sparse woodland stature; disturbance related.

C. Montane Grape Vine Opening (Vitis aestivalis) (2000-3500 ft.) 3890 V (= modifier :8)

D. Shrub Understory (May include spares overstory vegetation)
   1. Rhododendron sp., generally R. maximum 7876 R
   2. Kalmia latifolia (mountain laurel) 3814 K

III. Graminoid and Herbaceous

A. Appalachian High Elevation Grassy Bald, Mountain Oatgrass- 4242 Gb
   Mountain Cinquefoil-Herbaceous

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, Asplenium spp.-Purple Cliffbrake 4980, 4394 RK, SV, RK Fb
E. Southern Blue Ridge Spray Cliff, Appalachian Shoestring Fern-Cave Alumroot-Appalachian Bluets/ 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,\textsuperscript{12}  
      \textit{Diphylleia- Saxifraga- Laportea}  
      4296    Seep: D-S
      4293    Seep: R-M

B. \textit{Sphagnum} –(Graminoid-Herbaceous) Seepage Slopes
      7697    Seep:G
      Seep: 7697
   2. High Elevation Cain’s Reedgrass (\textit{Calamagrostis cainii})/ \textit{Sphagnum} spp. Seepage Slope  
      7877    Seep: Cc
      Seep:7877
   3. Low Elevation Southern Appalachian Fowl Mannagrass-Sedge- Mountain Fringed Sedge-Turtlehead-Forbs/ \textit{Sphagnum} spp. Wet Seepage Meadow  
      8438    Seep: 8438
      Wt: G

C. Wetlands; Graminoid-Herbaceous, Forbs
   1. \textit{Juncus effusus} -Herbaceous Seasonally Flooded Marsh  
      4112    Wt
      4112    Wt:Je, Wt: 4112
   2. Southern Blue Ridge Beaver Pond \textit{Juncus effusus} -Herbaceous Marsh  
      8433    Wt:Je, Wt:8433
   3. Smartweed-Cutgrass-Perennial Forb Beaver Pond  
      (in Kinzel Springs)  
      4290    Wt: Fb, Wt:G\textsuperscript{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/\textit{Sphagnum} spp. Seasonally Flooded Swamp  
   (in Cades Cove)  
   7388    Wt:Ls, Hx:Ls
      Wt: 7388

VI. Alluvial Habitats, Non-Forested

A. Montane Alluvial Canebrake (\textit{Arundinaria gigantea})  
   3836    AL:Ag

\textsuperscript{12} Generally shaded and cannot be seen on the air photos
\textsuperscript{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 Acer rubrum
:Af Aesculus flava
:B Betula allegheniensis
:Fg Fagus grandifolia
:Fs Fustuca spp. (now, Lolium spp.)
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<th>Code</th>
<th>Species</th>
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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
- NHxB = Beech (Fagus grandifolia) gaps, a special northern hardwood type at high elevations, further divided into NHxB/Hb (the north slope tall herbaceous type) and NHxB/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:
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 HxBl/R in the 1997 and 1998 photos. Certain HxBl/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 HxBl/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 photosyntheticic 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 blueish\(^1\). 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

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\(^1\) 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 (Oxydendrum 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, MO/R-K, MO/R, MO/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, HxBl 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 HxBl/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:Pl; or, HxBl; 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. HxBl, Successional Sweet Birch Forest (CEGL 7543), was classed as a shared association with CHxA. HxBl covers broad, non-alluvial valleys, and is not to be confused with HxBl/R (CEGL 8558). HxBl seems similar to Successional Tuliptree, HxL (CEGL 7219) in valleys, but with sweet birch and little to no tuliptree. We suggest HxBl “needs more work.” In the beginning we labeled HxBl as HxB. Later we distinguished between the birch species and assigned “B” to yellow birch and “Bl” 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 tetraphylla) 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 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 HxB/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. Sassafrass (*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. HxBl/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 HxBl/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 HxBl/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. HxBl/R occurs mostly north of and protected by high ridges, such as the spine of the Smokies. Much of the Luftee Knob quadrangle is HxBl/R.

At high elevations HxBl/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 HxBl/R to actually field check these balds. In a mid-elevation HxBl/R polygon in the northeastern Thunderhead Mountain quadrangle, where the bridle path trail to Mt. Davis cut through a knoll of HxBl/R lying between Indian Flats Prong and a branch to the west, the thick rhododendron opening at the center of HxBl/R was entirely R. maximum. HxBl/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, HxBl/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 HxBl/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. HxBl, 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 HxBl/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. HxBl 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 HxBl, 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 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:Bol, 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 nectria 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 *Amalanchier 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 Typic 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, Plr, PLe) (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 Limnobium 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.
References


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, Plsu, Plu, 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/Plsu/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), Pls (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

Attachment D

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

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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: Ri/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)**
- Kalmia heavy density: Kh
- Kalmia medium density: Km
- Kalmia light density: Kl
- Kalmia implied: Ki
- Kalmia possible: Kp
- Kalmia with pine: Kh/Pl
- Kalmia with rhododendron possible: K/Rp
Mixed Rhododendron (*Rhododendron* spp.) and Mountain Laurel (*Kalmia latifolia*)

*Rhododendron* and *Kalmia* (R dominant)  
(equal dominance)  
*Rhododendron* and *Kalmia* heavy density  
*Rhododendron* and *Kalmia* medium density  
*Rhododendron* and *Kalmia* light density  
*Rhododendron* and *Kalmia* implied  
*Rhododendron* and *Kalmia* possible  
*Rhododendron* and *Kalmia* high density with hemlock understory  
*Rhododendron* and *Kalmia* medium density with hemlock understory  
*Rhododendron* and *Kalmia* light density with hemlock understory

Heath Bald Species (mixture of rhododendrons and mountain laurel)

Heath bald understory  
Heath understory heavy density  
Heath understory medium density  
Heath understory light density

Eastern Hemlock (*Tsuga canadensis*)

Hemlock with *Rhododendron* heavy density  
Hemlock with *Rhododendron* medium density  
Hemlock with *Rhododendron* light density  
Hemlock with *Rhododendron* implied  
Hemlock with *Rhododendron* possible  
Hemlock with *Rhododendron* implied in shadow  
Hemlock with *Kalmia* medium density  
Hemlock with heath bald species medium density  
Hemlock with heath bald species light density  
Hemlock with heath bald species implied  
Hemlock with white pine  
Hemlock with white pine and *Rhododendron*  
Hemlock with white pine and *Rhododendron* implied  
Hemlock with white pine and *Rhododendron* possible  
Hemlock with mixed pine and *Rhododendron* implied  
Hemlock with mixed pine and shadow  
Hemlock with Spruce and *Rhododendron* medium density  
Hemlock understory  
Hemlock understory with *Rhododendron* heavy density  
Hemlock understory with *Rhododendron* medium density  
Hemlock understory with *Rhododendron* light density  
Hemlock understory with *Rhododendron* implied  
Hemlock understory with *Rhododendron* possible

---

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”.

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Attachment D
Hemlock understory with *Kalmia* possible  
Tu/Kp

Hemlock understory with heath bald species  
Tu/Hu

Hemlock understory with white pine understory  
T/Plsu

Hemlock understory, white pine understory, *Rhododendron* implied  
Tu/Plsu/Ri

Hemlock understory with white pine understory  
T/Plsu

Hemlock understory implied  
Tui

Hemlock understory implied with spruce understory implied  
Tui/Sui

**Eastern White Pine (Pinus strobus)**

- White pine with *Rhododendron* heavy density  
  PIs/Rh
- White pine with *Rhododendron* medium density  
  PIs/Rm
- White pine with *Rhododendron* light density  
  PIs/Rl
- White pine with *Rhododendron* implied  
  PIs/Ri
- White pine with *Rhododendron* possible  
  PIs/Rp
- White pine with *Kalmia* heavy density  
  PIs/Kh
- White pine with *Kalmia* medium density  
  PIs/Km
- White pine with *Kalmia* light density  
  PIs/Kl
- White pine with *Kalmia* implied  
  PIs/Ki
- White pine with *Kalmia* possible  
  PIs/Kp
- White pine with *Rhododendron* and *Kalmia* medium density  
  PIs/RKm
- White pine with *Rhododendron* and *Kalmia* light density  
  PIs/RKl
- White pine with *Rhododendron* and *Kalmia* implied  
  PIs/RKi
- White pine with *Rhododendron* and *Kalmia* possible  
  PIs/RKp
- White pine with yellow pine and *Kalmia* implied  
  PIs/PI/Ki
- White pine with yellow pine and *Kalmia* possible  
  PIs/PI/Kp
- White pine, mixed yellow pines and *Kalmia* medium density  
  PIs/Plx/Km
- White pine, mixed yellow pines and *Kalmia* possible  
  PIs/Plx/Kp
- White pine, mixed yellow pines, *Rhododendron* possible  
  PIs/Plx/Rp
- White pine and hemlock mix with *Rhododendron* heavy density  
  PIs-T/Rh
- White pine and hemlock mix with *Rhododendron* medium density  
  PIs-T/Rm
- White pine and hemlock mix with *Rhododendron* light density  
  PIs-T/Rl
- White pine and hemlock mix with *Rhododendron* possible  
  PIs-T/Rp
- White pine understory  
  Plsu
- White pine understory with *Rhododendron* medium density  
  Plsu/Rm
- White pine understory with *Rhododendron* implied  
  Plsu/Ri
- White pine understory with *Rhododendron* possible  
  Plsu/Rp
- White pine understory with *Rhododendron* implied and hemlock  
  Plsu/Ri/Tu
- White pine understory with hemlock understory  
  Plsu/Tu
- White pine understory, hemlock understory and *Rhododendron* possible  
  Plsu/Tu/Rp
- White pine understory with *Kalmia* high density  
  Plsu/Kh
- White pine understory with *Kalmia* medium density  
  Plsu/Km
- White pine understory with *Kalmia* light density  
  Plsu/Kl
- White pine understory with *Kalmia* implied  
  Plsu/Ki
- White pine understory with *Kalmia* possible  
  Plsu/Kp
- White pine understory with yellow pine understory  
  Plsu/Plu
White pine understory with yellow pine understory and *Kalmia* possible  PIu/Plu/Kp

**Yellow pine**

- Pine with *Kalmia* heavy density  PI/Kh
- Pine with *Kalmia* medium density  PI/Km
- Pine with *Kalmia* light density  PI/Kl
- Pine with *Kalmia* implied  PI/Ki
- Pine with *Kalmia* possible  PI/Kp
- Pine with *Rhododendron* light density  PI/Rl
- Pine with *Rhododendron* possible  PI/Rp
- Pine with white pine and *Kalmia* light density  PI/Pls/Kl
- Pine with white pine and *Kalmia* possible  PI/Pls/Kp
- Pine with white pine understory  PI/Plsu
- Pine with white pine understory and *Kalmia* light density  PI/Plsu/Kl
- Pine with white pine understory and hemlock understory  PI/Plsu/Tu
- Pine understory  PIu
- Pine understory and *Kalmia* heavy density  PIu/Kh
- Pine understory and *Kalmia* possible  PIu/Kp
- Mixed pine  PIx
  - Mixed pine with *Kalmia* heavy density  PIx/Kh
  - Mixed pine with *Kalmia* medium density  PIx/Km
  - Mixed pine with *Kalmia* light density  PIx/Kl
  - Mixed pine with *Kalmia* implied  PIx/Ki
  - Mixed pine with *Kalmia* possible  PIx/Kp
  - Mixed pine with *Rhododendron* medium density  PIx/Rm
  - Mixed pine with *Rhododendron* light density  PIx/Rl
  - Mixed pine with shrubs  PIx/Sb
  - Mixed pine with white pine and *Kalmia* medium density  PIx/Pls/Km
  - Mixed pine with white pine and *Kalmia* implied  PIx/Pls/Ki
  - Mixed pine with white pine and *Kalmia* possible  PIx/Pls/Kp
  - Mixed pine with white pine and *Rhododendron* possible  PIx/Pls/Rp
  - Mixed pine with white pine and mixed *Rhododendron-Kalmia* possible  PIx/Pls/RKp
  - Mixed pine with white pine understory and *Kalmia* implied  PIx/Plsu/Ki
  - Mixed pine with white pine understory and *Kalmia* possible  PIx/Plsu/Kp
  - Pioneering pine (even aged pine regrowth especially after fire)  PP

**Red Spruce (*Picea rubens*)**

- Spruce with *Rhododendron* heavy density  S/Rh
- Spruce with *Rhododendron* medium density  S/Rm
- Spruce with *Rhododendron* light density  S/Rl
- Spruce with *Rhododendron* implied  S/RI
- Spruce with *Rhododendron* 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  
Spruce with Fir understory  
Spruce with shrubs  
Spruce with hemlock and *Rhododendron* heavy density  
Spruce with hemlock and *Rhododendron* medium density  
Spruce with hemlock and *Rhododendron* light density  
Spruce with hemlock and *Rhododendron* implied  
Spruce with hemlock and *Rhododendron* possible  
Spruce implied with *Rhododendron* heavy density  
Spruce implied with *Rhododendron* medium density  
Spruce implied with *Rhododendron* possible  
Spruce implied with *Rhododendron* implied  
Spruce implied with *Rhododendron* possible  
Spruce implied with hemlock and *Rhododendron* possible  
Spruce understory  
Spruce understory with *Rhododendron* heavy density  
Spruce understory with *Rhododendron* medium density  
Spruce understory with *Rhododendron* light density  
Spruce understory with *Rhododendron* implied  
Spruce understory with *Rhododendron* possible  
Spruce understory with hemlock understory  
Spruce understory implied  
Spruce understory implied with *Rhododendron* implied  
Spruce understory implied with hemlock understory implied  
Spruce understory possible  

**Fraser Fir (Abies fraseri)**

Fir implied with spruce implied and shadow  
Fir understory  
Fir understory heavy density  
Fir understory medium density  
Fir understory light density  
Fir understory with *Rhododendron* heavy density  
Fir understory with *Rhododendron* medium density  
Fir understory with *Rhododendron* light density  
Fir understory with spruce understory  
Fir understory light density with *Rhododendron* light density  
Fir understory light density with spruce implied  
Fir understory light density with spruce understory light density  
Fir understory medium density with spruce implied  
Fir understory medium density with *Rhododendron* implied  

**Additional Categories**

Deciduous shrubs  
Deciduous shrubs with mixed yellow pines  
Shadow
Burned completely
Graminoids
Graminoids with shrubs
Herbaceous and deciduous understory
Human influence
Road
Vines
Water

BC
G
G/Sb
HD
HI
RD
V
W
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)

<table>
<thead>
<tr>
<th>Overstory Dominant Vegetation</th>
<th>Number of Polygons</th>
<th>Average Polygon Size (ha)</th>
<th>Minimum Polygon Size (ha)</th>
<th>Maximum Polygon Size (ha)</th>
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attachment g

summary of park-wide statistics for understory vegetation of great smoky mountains national park
(see attachment d for class descriptions)

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Attachment H

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

by
Marguerite Madden

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

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Commission IV, Working Group IV/6

KEY WORDS: GIS, Analysis, Visualization, Aerial Photographs, Vegetation, Landscape

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.
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).

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

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

**Figure 8.** A schematic diagram of the GIS cartographic model used to produce the fuel class data sets.
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 Mararks, 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 Siers 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).

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 reclassed 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.

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.

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

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.

REFERENCES


