VEGETATION MODELING, ANALYSIS AND VISUALIZATION IN U.S. NATIONAL PARKS

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ABSTRACT:

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

1. INTRODUCTION

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

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

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

2. GIS ANALYSIS OF OVERSTORY VEGETATION

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

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

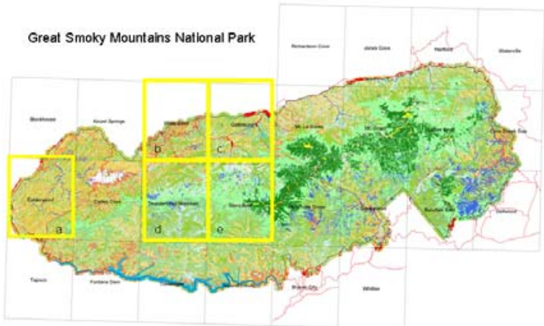

Figure 1. Great Smoky Mountains National Park and the area corresponding to: (a) Calderwood (CALD); (b) Wear Cove (WECO); (c) Gatlinburg (GATL); (d) Thunderhead Mountain (THMO); and (e) Silers Bald (SIBA) 7.5-minute U.S. Geological Survey (USGS) topographic quadrangles.

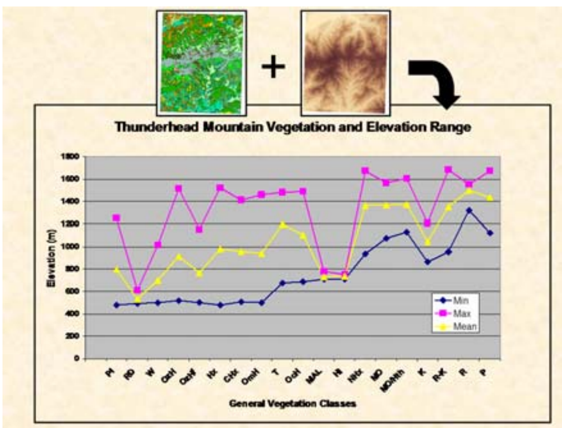

Figure 2. Spatial correlation of elevation range and overstory vegetation classes.

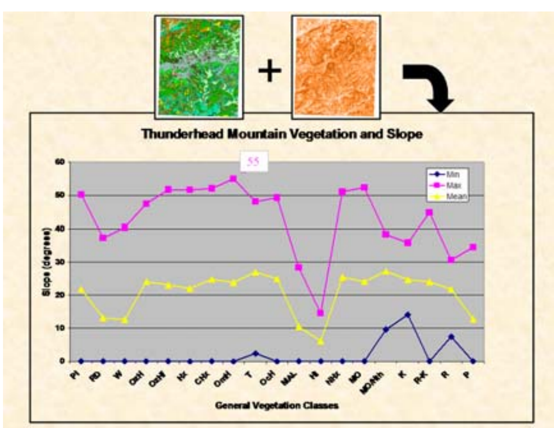

Figure 3. Spatial correlation of slope and overstory vegetation classes.

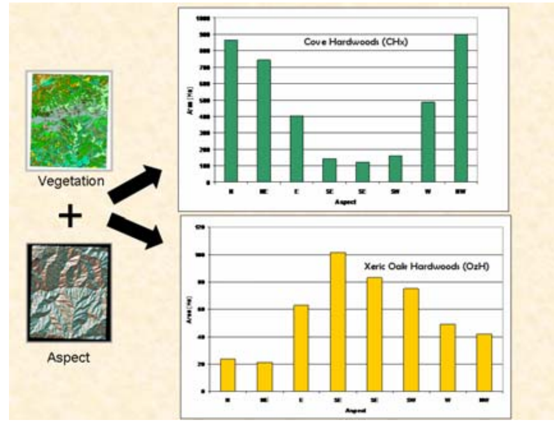

Figure 4. Spatial correlation of aspect and overstory vegetation classes: cove hardwood and xeric oak hardwood forests.

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

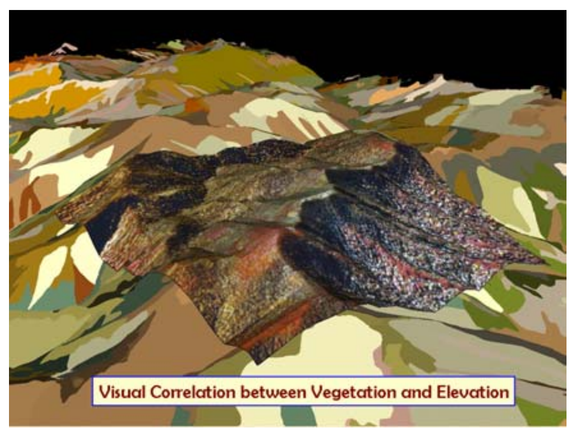

Figure 5. A 3D perspective view of an orthorectified color infrared air photo and overstory vegetation polygons.

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

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

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

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

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

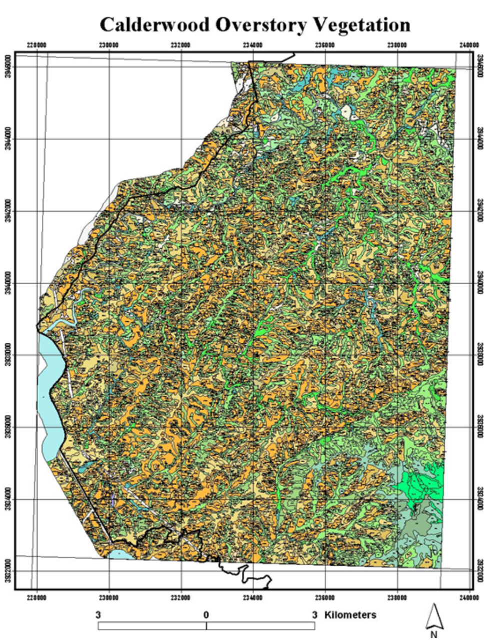

Figure 6. A portion of the overstory vegetation in Great Smoky Mountains National Park corresponding to the USGS 7.5-minute Calderwood topographic quadrangle.

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

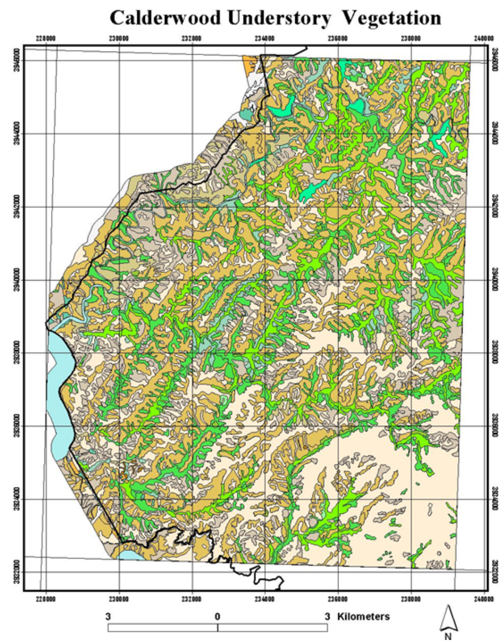

Figure 7. A portion of the understory vegetation in Great Smoky Mountains National Park corresponding to the USGS 7.5-minute Calderwood topographic quadrangle.

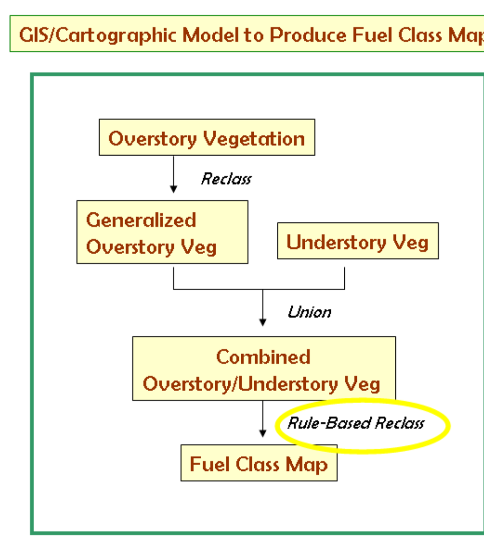

Figure 8. A schematic diagram of the GIS cartographic model used to produce the fuel class data sets.

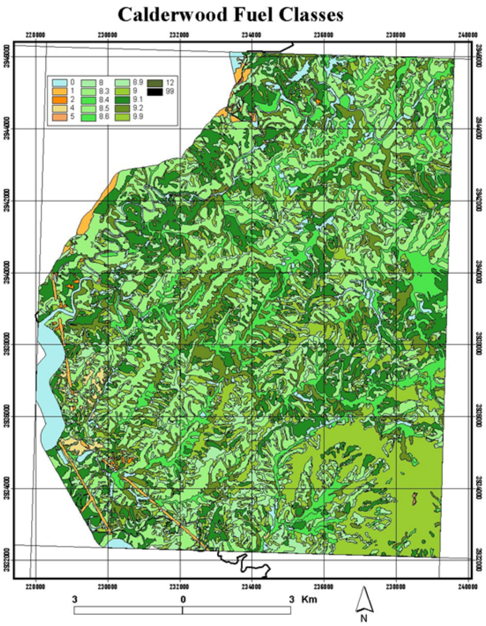

Figure 9. A portion of the fuel class database in Great Smoky Mountains National Park corresponding to the USGS 7.5-minute Calderwood topographic quadrangle.

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

4. LANDSCAPE METRICS RELATED TO VEGETATION PATTERNS

Landscape metrics comparing vegetation patterns due to interpreter differences and human influence were derived using the Patch Analyst, an ArcView extension that interfaces grids and shapefiles with Fragstats Spatial Pattern Analysis program (McGarigal and Maraks, 1995; Elkie et al., 1999). An area corresponding to four 7.5-minute USGS topographic quadrangles was selected to examine differences in landscape metrics. Overstory vegetation in the Wear Cove (WECO) and Thunderhead Mountain (THMO) quadrangles was mapped by Interpreter #1, while the vegetation in the Gatlinburg (GATL) and Silers Bald (SIBA) quadrangles was mapped by Interpreter #2 (Fig. 11). (Also indicted by "b", "c", 'd" and "e", respectively, in Fig. 1). In addition to interpreter differences, WECO and GATL quadrangles are located on the outside boundary of the park and the vegetation in these quads is subject to greater human influence than the interior quads, THMO and SIBA (Fig. 12). These four quads, therefore, provide a good test for whether interpreter differences or human influence is having a greater impact on vegetation patterns as measured by landscape metrics (Madden 2003).

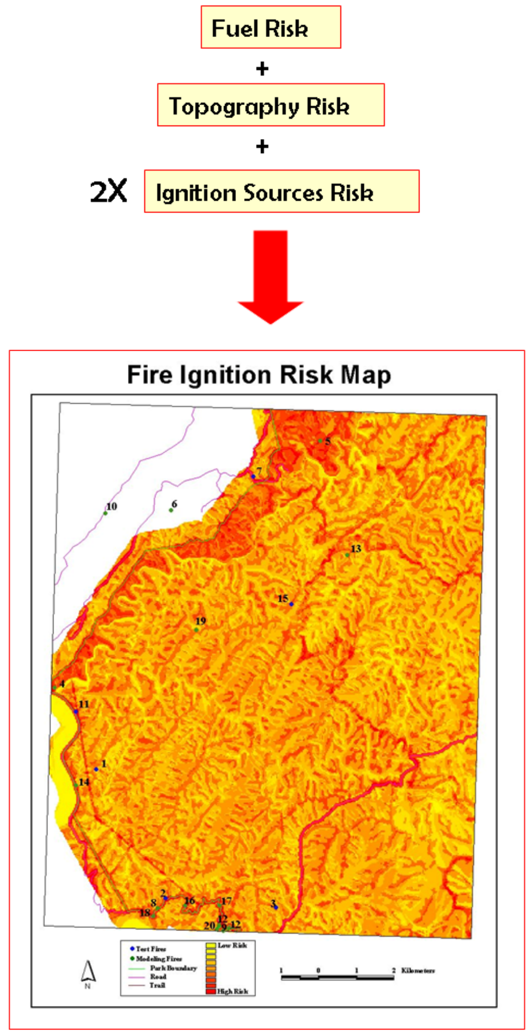

Figure 10. A schematic diagram of the GIS data layers combined in a cartographic model to assess the risk of forest fire and a map of fire ignition risk in the Calderwood area of Great Smoky Mountains National Park (Dukes, 2001).

Landscape metrics, such as Shannon's Diversity Index, computed at the landscape level (i.e., considering all pixels in the grid) indicate that there is very little difference that can be attributed to the two interpreters (Fig. 13). Exterior quads (WECO and GATL) showed a slight decrease in diversity compared to interior quads: SIBA and THMO. Groups of adjacent pixels with the same overstory vegetation class were then identified using an 8N-diagonals clumping method of the Patch Analyst (Fig. 14). Since resource managers in Great Smoky Mountains National Park are extremely interested in preventing wide-spread destruction of old growth forests due to an infestation of an exotic insect known as the hemlock wooly adelgid (*Adelges tsugae*), patches representing areas containing Eastern hemlock were isolated from the overstory vegetation database and analyzed using the Patch Analyst (Fig. 15). Forest polygons containing hemlock were 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).

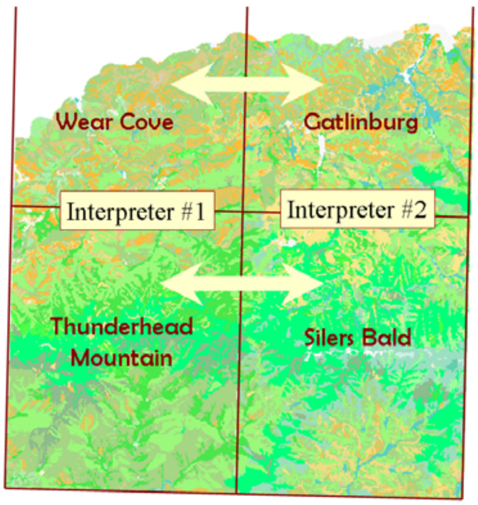

Figure 11. Overstory vegetation in the Wear Cove and Thunderhead Mountain quadrangles of Great Smoky Mountains National Park were mapped by Interpreter #1, while Interpreter #2 mapped vegetation in Gatlinburg and Silers Bald.

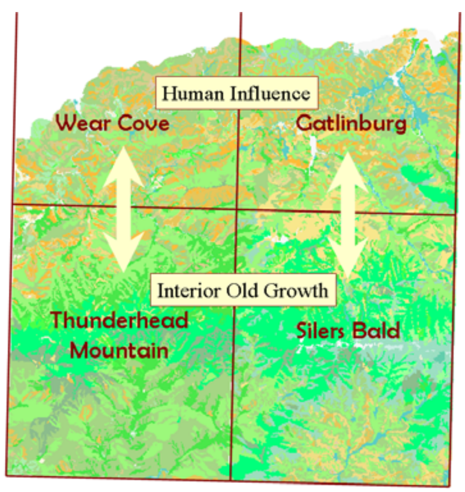

Figure 12. Overstory vegetation in the Wear Cove and Gatlinburg quadrangles of Great Smoky Mountains National Park are subject to greater human influence because they are located at the edge of the park boundary, while vegetation in the interior Thunderhead Mountain and Silers Bald quads is more protected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

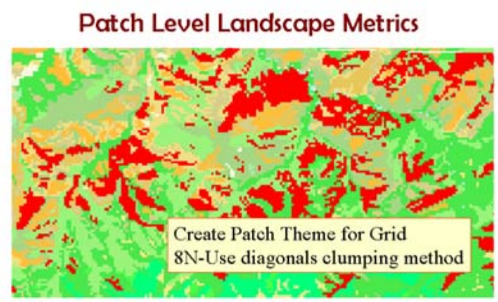

Figure 14. Overstory vegetation polygons in vector format were converted to patches in a raster grid for computation of patch level landscape metrics.

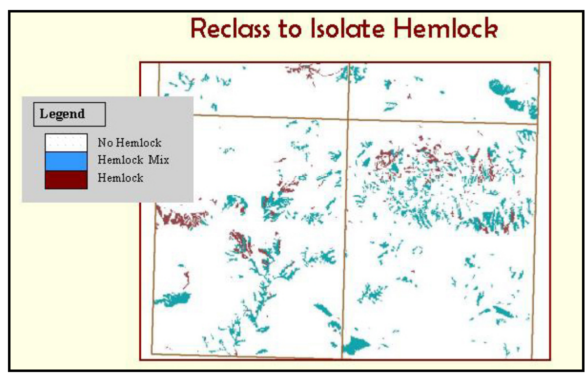

Figure 15. Reclassification of overstory vegetation isolated forest patches containing pure hemlock stands and mixed hemlock/hardwood communities.

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.

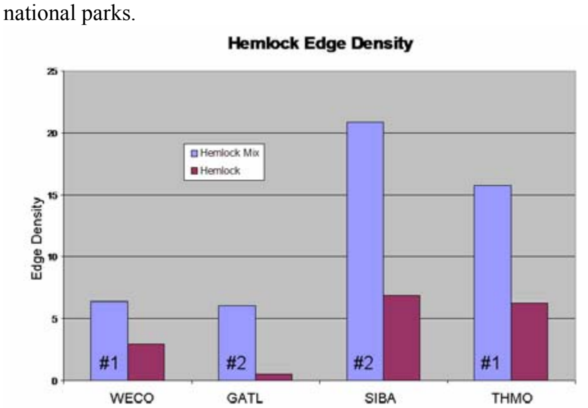

Figure 16. Edge density for hemlock patches was significantly lower for exterior quads (WECO and GATL), while interpreter differences were not significant.

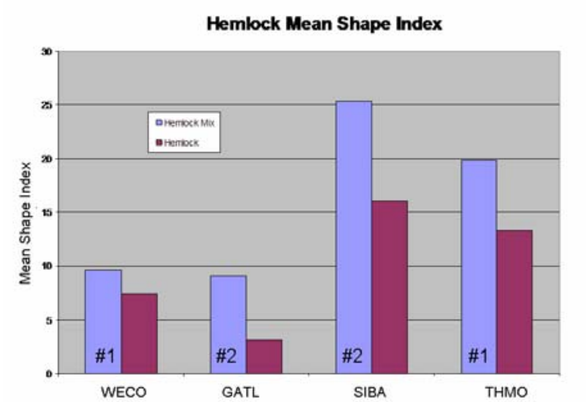

Figure 17. Shape index for hemlock patches was significantly lower for exterior quads (WECO and GATL), while interpreter differences, again, were not significant.

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