

# **MARYLAND COMPREHENSIVE STATE FOREST ASSESSMENT**

## **Creating Forest Stand Inventories Via Definiens Developer 7.0<sup>TM</sup> Image Segmentation and ERDAS Imagine Software**

Report for:  
Harry R. Hughes Center for Agro-Ecology, Inc.  
College of Agriculture and Natural Resources  
University of Maryland  
College Park, MD

Submitted by:  
Jack L. Perdue  
Maryland Department of Natural Resources  
Forest Service  
Annapolis, MD

February 10, 2011

## **PROJECT CONTRIBUTORS**

### **Harry Kahler**

U.S. Fish and Wildlife Service  
2800 Cottage Way, Rm W-2605  
Sacramento, CA 95825-1846  
harry\_kahler@fws.gov

### **Alexander Clark**

Maryland Department of Natural Resources  
Chesapeake Forest  
6572 Snow Hill Road  
Snow Hill, MD 21863  
aclark@dnr.state.md.us

### **Jack L. Perdue**

Maryland Department of Natural Resources  
Forest Service  
580 Taylor Ave, E-1  
Annapolis, MD 21401  
jperdue@dnr.state.md.us

### **Francis Zumbrun**

Maryland Department of Natural Resources  
Green Ridge State Forest  
28700 Headquarters Dr, NE  
Flintstone, MD 21530  
fzumbrun@dnr.state.md.us

### **Andrew Lister**

USDA Forest Service, Northern Research Station  
National Inventory and Monitoring Applications Center  
Forest Inventory and Analysis Unit  
11 Campus Blvd, Suite 200  
Newtown Square, PA 19073  
alister@fs.fed.us

### **Clair L. Patterson, III “Pat”**

Maryland Department of Natural Resources  
Forest Service  
580 Taylor Ave, E-1  
Annapolis, MD 21401  
ppatterson@dnr.state.md.us

Funding for this report was provided by the U.S. Department of Agriculture, Cooperative State Research, Education and Extension Services – Special Projects

## TABLE OF CONTENTS

<b>CHAPTER I - INTRODUCTION.....</b>	<b>7</b>
OBJECTIVES .....	8
<b>CHAPTER II - METHODS.....</b>	<b>13</b>
STUDY AREA .....	14
<i>Green Ridge State Forest.....</i>	<i>15</i>
<i>Potomac-Garrett State Forest.....</i>	<i>17</i>
<i>Savage River State Forest.....</i>	<i>17</i>
ECOLOGICAL COMMUNITY GROUPS .....	18
CONTINUOUS FOREST INVENTORY .....	18
STRATIFICATION VIA IMAGE SEGMENTATION .....	19
<i>Imagery and Layers Used in the Segmentation.....</i>	<i>20</i>
<i>Delineating and Classifying the Stands .....</i>	<i>21</i>
<i>Incorporating Existing Boundaries.....</i>	<i>27</i>
<i>Exporting the Segmented Objects and Preparing for Classification .....</i>	<i>27</i>
CLASSIFICATION METHODOLOGY.....	28
<i>Definiens Developer's "nearest neighbor" classification .....</i>	<i>28</i>
<i>Leica Geosystems ERDAS Imagine's "maximum likelihood" classification scheme .....</i>	<i>31</i>
<i>WEKA Data Mining "IBk nearest neighbor" classification .....</i>	<i>37</i>
<b>CHAPTER III - RESULTS AND DISCUSSION.....</b>	<b>39</b>
COMPARISON OF METHODS .....	39
<i>Accuracy Assessments.....</i>	<i>39</i>
CHOSEN CLASSIFICATION METHOD(S) .....	41
INCORPORATING THE OUTPUT WITH EXISTING SYSTEMS .....	42
<b>CHAPTER IV - CONCLUSIONS.....</b>	<b>44</b>
<b>LITERATURE CITED .....</b>	<b>45</b>

## LIST OF FIGURES

FIGURE 2.1 FLOW CHART DEMONSTRATING THE MOVEMENT OF DATA THROUGH THE SYSTEM. ....	13
FIGURE 2.2 THE STATE OF MARYLAND WITH THE WESTERN STATE FORESTS IN ENLARGED VIEW. ....	15
FIGURE 2.3 A SAMPLE OF CFI PLOTS AT GREEN RIDGE STATE FOREST. ....	19
FIGURE 2.4 AN EXAMPLE OF A PROCESS TREE WITH MULTIPLE NESTED PROCESSES. ....	20
FIGURE 2.5 EXAMPLES OF SEGMENTATIONS PERFORMED USING A SHAPE VALUE OF 0.1 (LEFT) AND 0.5 (RIGHT). ....	23
FIGURE 2.6 EXAMPLE OF A MULTIREOLUTION SEGMENTATION ON A SUBSECTION OF GREEN RIDGE STATE FOREST ..	24
FIGURE 2.7 IMAGE OBJECTS SMOOTHED USING THE MORPHOLOGY ALGORITHM ON A SUBSECTION OF GREEN RIDGE STATE FOREST. ....	25
FIGURE 2.8 AN EXAMPLE OF SMOOTHED AND MERGED IMAGE OBJECTS ON A SUBSECTION OF GREEN RIDGE STATE FOREST, USING THE “MULTIREOLUTION SEGMENTATION REGION GROW” AND “REMOVE OBJECTS” ALGORITHMS FOR MERGING . ....	26
FIGURE 2.9 AN EXAMPLE OF IMAGE OBJECTS CLIPPED BY THE GREEN RIDGE STATE FOREST BOUNDARY TO CREATE A FINAL SHAPEFILE PRODUCT. GREEN RIDGE STATE FOREST LAND IS COLORED YELLOW, WHILE NON-STATE LANDS ARE COLORED GREEN. ....	27
FIGURE 2.10 THE CLASSES USED FOR CLASSIFICATION IN DEFINIENS DEVELOPER. ....	29
FIGURE 2.11 A FEW EXAMPLES OF SAMPLES USED IN THE CLASSIFICATION PROCEDURE FOR DEFINIENS DEVELOPER. ....	30
FIGURE 2.12 IMAGE OBJECTS CLASSIFIED USING DEFINIENS DEVELOPER’S FEATURE SPACE OPTIMIZATION. ....	31
FIGURE 2.13 PIXEL MAP USING ERDAS IMAGINE’S MAXIMUM LIKELIHOOD SUPERVISED CLASSIFICATION. ....	32
FIGURE 2.14 POLYGONS CLASSIFIED USING PIXEL-BASED MAXIMUM LIKELIHOOD SUPERVISED CLASSIFICATION AND ZONAL ATTRIBUTES IN ERDAS IMAGINE. ....	33
FIGURE 2.15 THE HIERARCHAL SYSTEM USED FOR GREEN RIDGE STATE FOREST. ....	34
FIGURE 2.16 AN EXAMPLE OF SIGNATURE PLOT MEANS AND ELLIPSES PLOTTED IN A FEATURE SPACE IMAGE SHOWING AREAS OF OVERLAP AND UNIQUENESS. ....	35
FIGURE 2.17 PIXEL MAPS SHOWING THE CFI FOREST TYPE CLASSIFICATION (LEFT) AND THE RESULT OF CLASSIFYING ECGs FROM EXTRACTED “MIXED OAK” AREAS (RIGHT). ....	37
FIGURE 2.18 RASTER MAP SHOWING EXAMPLE OF PIXEL MAP CREATED USING WEKA DATA MINING SOFTWARE. ....	38
FIGURE 3.1 EXAMPLE OF CELL ARRAY OUTPUT FROM THE ACCURACY ASSESSMENT. ....	40
FIGURE 3.2 EXAMPLE ACCURACY ASSESSMENT RESULTS WITH KAPPA STATISTICS. ....	41
FIGURE 3.3 GEODATABASE QUERYING AND POLYGONS. ....	42

## LIST OF TABLES

TABLE 1.1 SUSTAINABLE FORESTRY INITIATIVE (SFI) STANDARD PRINCIPLES FOR SUSTAINABLE FORESTRY, 2005-2009 EDITION. ....	10
TABLE 1.2 FOREST STEWARDSHIP COUNCIL (FSC) PRINCIPLES AND CRITERIA FOR FOREST MANAGEMENT THAT ARE APPLICABLE TO ALL FSC-CERTIFIED FORESTS. ....	11
TABLE 1.3 OBJECTIVES FOR SUSTAINABLE FORESTRY INITIATIVE (SFI) STANDARD, 2005-2009 EDITION.....	12
TABLE 2.1 IMAGE LAYER WEIGHTS USED FOR GREEN RIDGE STATE FOREST. ....	22

## **EXECUTIVE SUMMARY**

The State Forests administered by the Maryland Department of Natural Resources are truly investments in the current and long term health of the state. These lands contain some of the largest blocks of contiguous forest cover remaining in the state, provide key habitats and refuge for wildlife and native plants, and are critical to protecting the water quality of nearby streams, rivers and the Chesapeake Bay. They also are important to local economies, benefiting local businesses that cater to a public seeking recreation opportunities and also raw materials for forest product companies.

Managing these lands for these multiple benefits has become more critical as surrounding lands have become fragmented and parcelized from development and changing demographics due to an aging private forest landowner population. At the same time, tightening budgets and reduced staffs have made the leveraging of emerging technologies even more important. The use of Geographic Information Systems (GIS), Global Positioning Systems (GPS), high definition satellite imagery have become common tools for natural resource managers, but other sophisticated computer applications are being developed to extend and expand how even these tools can be used.

On three State Forests in western Maryland, one such system was developed and implemented to delineate management units through a process called image segmentation. This process also would take known associated information from field data collection such as forest type and ecological community types and apply them to similar areas as determined by the computer applications. This automated digital image segmentation and analysis was determined to be extremely useful as a supplemental tool for creating stand delineations and mapping.

With the use of Definiens Developer, ESRI ArcGIS, and ERDAS Imagine, large areas can be accurately segmented and classified in as little as a few weeks with the help of suitable data and preexisting knowledge in the use of these programs.

With sufficient planning and effort, this system can be both efficient and accurate. When used in conjunction with ground verification, automated image analysis and classification can be a very effective way to manage and maintain a working, dynamic system for the use of forest management.

The goal of this project was to collect, compile, analyze, classify and manage the data necessary for the sustainable management of 200,000 acres of public forestland. This data and the data management system created for it will be used to seek and retain third party forest management certification of Maryland's four State Forests and Chesapeake Forest and to create a model for the sustainable management of other forestlands in Maryland.

## CHAPTER I - INTRODUCTION

From its inception, the State of Maryland has played a vital significance in balancing the agenda of disparate objectives and ways of life. Much of this responsibility emanates from its geographic location, traditionally the core of the United States. Furthermore, the ecological face of Maryland, ranging from the Allegheny Mountain forests in the west, through the ridge-and-valley and piedmont regions in the center to the Chesapeake Bay and Atlantic Slope regions of the east, has inevitably generated a myriad of challenges to leaders and resource managers throughout the state.

One such current challenge facing state forest managers in Maryland is maintaining forest ecological function and sustainable working forests in the face of rapid urban development, deforestation and parcelization. Currently, about 41% of Maryland's land is covered by forest, whereas over 46% of Maryland was forested in 1950. The ever-growing population, which has more than doubled since 1950, has inherently increased demands on our forestlands. Rapid development and forest deforestation negatively impact the ecological sustainability of Maryland's forest landscape in several ways – from fragmentation and internal patch effects to complete removal of forested acreage (Zipperer 1993).

Additionally, the \$2.2 billion forest and wood products industry is the sixth largest in the state. Furthermore, as multiple-use lands, recreation on state forests also is a large factor in determining the management strategies on these lands. Green Ridge State Forest alone, for example, contributes nearly \$2 million in recreational day-use fees to the state budget (Wieland et al, 2008). The pressures of economic feasibility, ecological sustainability and other uses are only likely to increase over the coming years. Nowhere in Maryland will these diverse pressures be more acute than on state forestlands, typically the largest unbroken forest tracts in the state.

Managing dynamic equilibria among distinct consumptive and non-consumptive uses of natural resources are not issues that are unique to Maryland State Forests. In recent years such issues have prompted the development of many non-regulatory conservation tools designed to evaluate and standardize responsible and sustainable forest management practices. Losses of Northern Spotted Owl habitat in the northwestern United States (Lande 1988; Montgomery et al, 1992), and the loss of Amazonian Rainforest acreage (Skole and Tucker, 1993; Laurance et al, 1998), are two examples of such issues that have gained attention both nationally and globally.

In 2004, a governor's executive order (Executive Order 01.01.2004.21) charged the Department of Natural Resources with the task of seeking, obtaining and managing the State Forests under the independent third party Sustainable Forestry Initiative (SFI) and Forest Stewardship Council (FSC) principles and certification standards. As with many U.S. National Forests (Sample et al, 2007), Maryland State Forests may already meet many of the existing FSC and SFI requirements. However, the SFI and FSC standards and principles have been developed at continental and global scales respectively, such that all forests, regardless of location and forest condition, are held to the same code. An assessment of Maryland State Forests is necessary to evaluate the current position of State Forests with regard to certification.

## Objectives

To acquire certification, forest management plans must meet and adhere to principles and criteria set forth by SFI and FSC. SFI objectives focus on maintaining responsible and sustainable forestry practices while protecting forest, soil and water resources as well as managing and monitoring for continual improvement (Table 1.1). Similarly, FSC principles seek the efficient use of the forest's multiple products and services while lessening the impact on communities, indigenous peoples, and forest workers as well as maintaining biological diversity and high conservation value forests through continual monitoring and assessment (Table 1.2).

The goal of this project proposal is to collect, compile, analyze, classify and manage the data necessary for the sustainable management of 200,000 acres of public forestland. The data collected, analyzed and classified, and the data management system created, will be used to seek and retain forest certification of Maryland's four State Forests and Chesapeake Forest to create a model for the sustainable management of other forestlands in Maryland.

Specifically, our aim is to identify forest types and stratify the forest into distinct forest stands on Green Ridge, Potomac-Garrett, and Savage River State Forests:

1. We conduct a comprehensive analysis of existing Continuous Forest Inventory (CFI) data to begin the process of forest stand level stratification and to identify current data gaps.
2. We develop classification methodologies for using existing remote sensed data and aerial photography to further stratify forest stands and enhance existing forest data sets. We develop additional methodologies and analysis techniques to determine forest stand characteristics using sets of remote sensed imagery products.
3. We overlay existing historic timber sale data to assist with forest stand level classification and to further refine recently digitized data.
4. We use field inventory procedures to further enhance the accuracy of stand descriptions and stand boundary locations on the ground.

The main product of our assessment is a Geographic Information System (GIS) data base that contains information on every discrete forest stand or management unit, its typology, description and spatial location, to aid in sustainable management and monitoring, and to develop models for sustainable management of key forest components over time.

Additionally, we collect original and supplemental forest inventory data from forest plots to compile and analyze information on forest type, past management history, age, volume, economic potential, forest structure, plant and animal diversity and water resources that can be used in support of third party forest certification and sustainable forest management. Finally, we complete an accuracy assessment of our stand level characterization and determine the applicability of these techniques for use on other forestlands throughout Maryland.



In summary, our objectives were to provide and institute an inventory and assessment of forest conditions that can be continually updated and used to aid in meeting objectives of independent third party certification, such as those outlined by SFI in Table 1.3.

The main product of our assessment is a Geographic Information System (GIS) data base that contains information on every discrete forest stand or management unit and each stand's typology, description, and spatial location. The database will be used to aid in sustainable management and monitoring, and to develop models for sustainable management of key forest components over time. This process occurred in three steps:

- A. Collect original and supplemental forest inventory data from forest plots to compile and analyze information on forest type, past management history, age, volume, economic potential, forest structure, plant and animal diversity and water resources that can be used in support of third party forest certification and sustainable forest management.
- B. Use this forest stand analysis to create and run a pilot growth and yield model to guide sustainable forest management on one of the four Maryland State Forests.
- C. Complete an accuracy assessment of stand level characterization using these techniques. Determine applicability of these techniques for use on other forestlands throughout Maryland.

**Table 1.1 Sustainable Forestry Initiative (SFI) Standard Principles for sustainable forestry, 2005-2009 edition.**

<b>Principle</b>	<b>Criteria</b>
1. Sustainable Forestry	To practice sustainable forestry to meet the needs of the present without compromising the ability of future generations to meet their own needs by practicing a land stewardship ethic that integrates reforestation and the managing, growing, nurturing, and harvesting of trees for useful products with the conservation of soil, air, and water quality, biological diversity, wildlife and aquatic habitat, recreation, and aesthetics.
2. Responsible Practices	To use and to promote among other forest landowners sustainable forestry practices that are both scientifically credible and economically, environmentally, and socially responsible.
3. Reforestation and Productive Capacity	To provide for regeneration after harvest and maintain the productive capacity of the forestland base.
4. Forest Health and Productivity	To protect forests from uncharacteristic and economically or environmentally undesirable wildfire, pests, diseases, and other damaging agents and thus maintain and improve long-term forest health and productivity.
5. Long-Term Forest and Soil Productivity	To protect and maintain long-term forest and soil productivity.
6. Protection of Water Resources	To protect water bodies and riparian zones.
7. Protection of Special Sites and Biological Diversity	To manage forest and lands of special significance (biologically, geologically, historically or culturally important) in a manner that takes into account their unique qualities and to promote a diversity of wildlife habitats, forest types, and ecological or natural community types.
8. Legal Compliance	To comply with applicable federal, provincial, state, and local forestry and related environmental laws, statutes, and regulations.
9. Continual Improvement	To continually improve the practice of forest management and also to monitor, measure and report performance in achieving the commitment to sustainable forestry.

Source: The Sustainable Forestry Initiative Inc. Sustainable Forestry Initiative Standard (SFIS) 2005-2009 standard, 2004 (September 2008).

**Table 1.2 Forest Stewardship Council (FSC) Principles and Criteria for forest management that are applicable to all FSC-certified forests.**

<b>Principle</b>	<b>Criteria</b>
1. Compliance with Laws and FSC Principles	Forest management shall respect all applicable laws of the country in which they occur, and international treaties and agreements to which the country is a signatory, and comply with all FSC Principles and Criteria.
2. Tenure and Use Rights and Responsibilities	Long-term tenure and use rights to the land and forest resources shall be clearly defined, documented and legally established.
3. Indigenous Peoples' Rights	The legal and customary rights of indigenous peoples to own, use and manage their lands, territories, and resources shall be recognized and respected.
4. Community Relations and Worker's Rights	Forest management operations shall maintain or enhance the long-term social and economic well being of forest workers and local communities.
5. Benefits from the Forest	Forest management operations shall encourage the efficient use of the forest's multiple products and services to ensure economic viability and a wide range of environmental and social benefits.
6. Environmental Impact	Forest management shall conserve biological diversity and its associated values, water resources, soils, and unique and fragile ecosystems and landscapes, and, by so doing, maintain the ecological functions and the integrity of the forest.
7. Management Plan	A management plan – appropriate to the scale and intensity of the operations – shall be written, implemented, and kept up to date. The long-term objectives of management, and the means of achieving them, shall be clearly stated.
8. Monitoring and Assessment	Monitoring shall be conducted – appropriate to the scale of the forest – to assess the condition of the forest, yields of forest products, chain of custody, management activities and their social and environmental impacts.
9. Maintenance of High Conservation Value Forests	Management activities in high conservation value forests shall maintain or enhance the attributes which define such forests. Decisions regarding high conservation value forest shall always be considered in the context of a precautionary approach.
10. Plantations	Plantations shall be planned and managed in accordance with Principles and Criteria 1-9, and Principle 10 and its Criteria. While plantations can provide an array of social and economic benefits, and can contribute to satisfying the world's needs for forest products, they should complement the management of, reduce pressures on, and promote the restoration and conservation of natural forests.

Source: Forest Stewardship Council A.C., FSC principles and criteria for forest stewardship, 1996 (amended 2002).

**Table 1.3 Objectives for Sustainable Forestry Initiative (SFI) Standard, 2005-2009 edition.**

<b>SFI Objectives for Land Management</b>
1. To broaden the implementation of sustainable forestry by ensuring long-term harvest levels based on the use of the best scientific information available.
2. To ensure long-term forest productivity and conservation of forest resources through prompt reforestation, soil conservation, afforestation, and other measures.
3. To protect water quality in streams, lakes, and other water bodies.
4. To manage the quality and distribution of wildlife habitats and contribute to the conservation of biological diversity by developing and implementing stand- and landscape-level measures that promote habitat diversity and the conservation of forest plants and animals, including aquatic fauna.
5. To manage the visual impact of harvesting and other forest operations.
6. To manage program participant lands that are ecologically, geologically, historically, or culturally important in a manner that recognizes their special qualities.
7. To promote the efficient use of forest resources.
<b>SFI Objectives for Procurement</b>
8. To broaden the practice of sustainable forestry through procurement programs.
<b>SFI Objective for Forestry Research, Science, and Technology.</b>
9. To improve forestry research, science, and technology, upon which sound forest management decisions are based.
<b>SFI Objective for Training and Education</b>
10. To improve the practice of sustainable forest management by resource professionals, logging professionals, and contractors through appropriate training and education programs.
<b>SFI Objective for Legal and Regulatory Compliance</b>
11. Commitment to comply with applicable federal, provincial, state, or local laws and regulations.
<b>SFI Objective for Public and Landowner Involvement in the Practice of Sustainable Forestry</b>
12. To broaden the practice of sustainable forestry by encouraging the public and forestry community to participate in the commitment to sustainable forestry and publicly report progress.
<b>SFI Objective for Management review and Continual Improvement</b>
13. To promote continual improvement in the practice of sustainable forestry and monitor, measure, and report performance in achieving the commitment to sustainable forestry.

Source: The Sustainable Forestry Initiative Inc. Sustainable Forestry Initiative Standard (SFIS) 2005-2009 standard, 2004 (September 2008).

## CHAPTER II - METHODS

To address our objectives we used several sources of forest data along with multiple remote images to create our initial assessment and inventory. Because the initial database will not be static, we developed a system that can continually be modified and regulated over time. The process involves several key steps, each of which can be adjusted with the accumulation and acquisition of additional data (Figure 2.1).

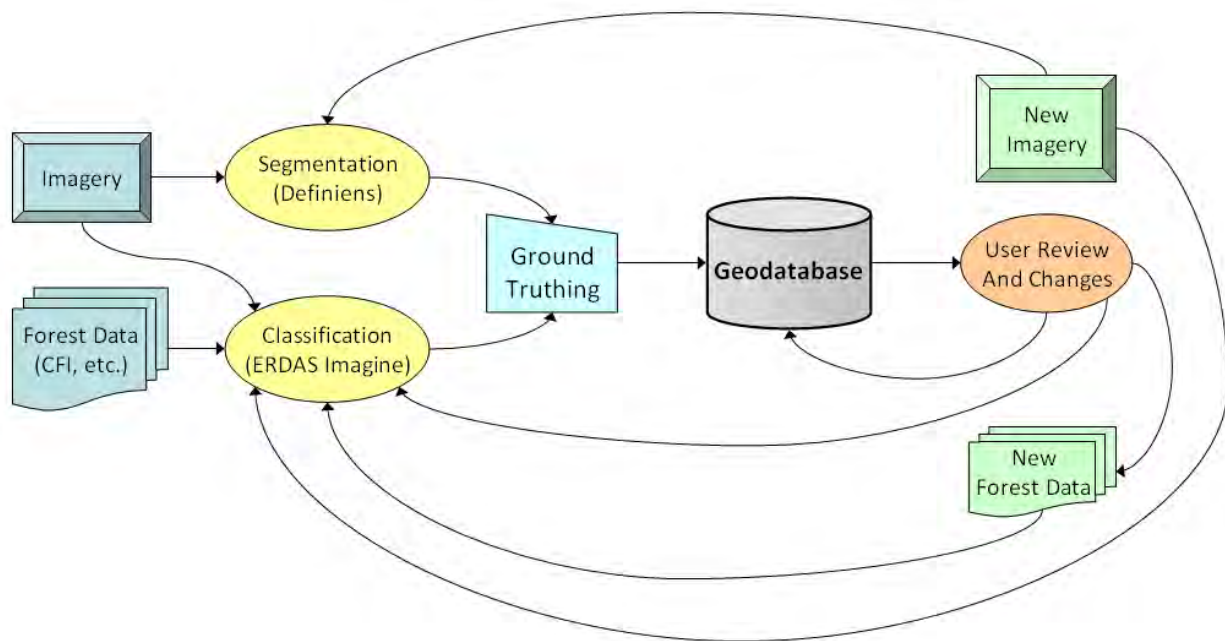


Figure 2.1 Flow chart demonstrating the movement of data through the system.

A flow chart demonstrating the movement of data through the system shows the general process involving 5 main steps.

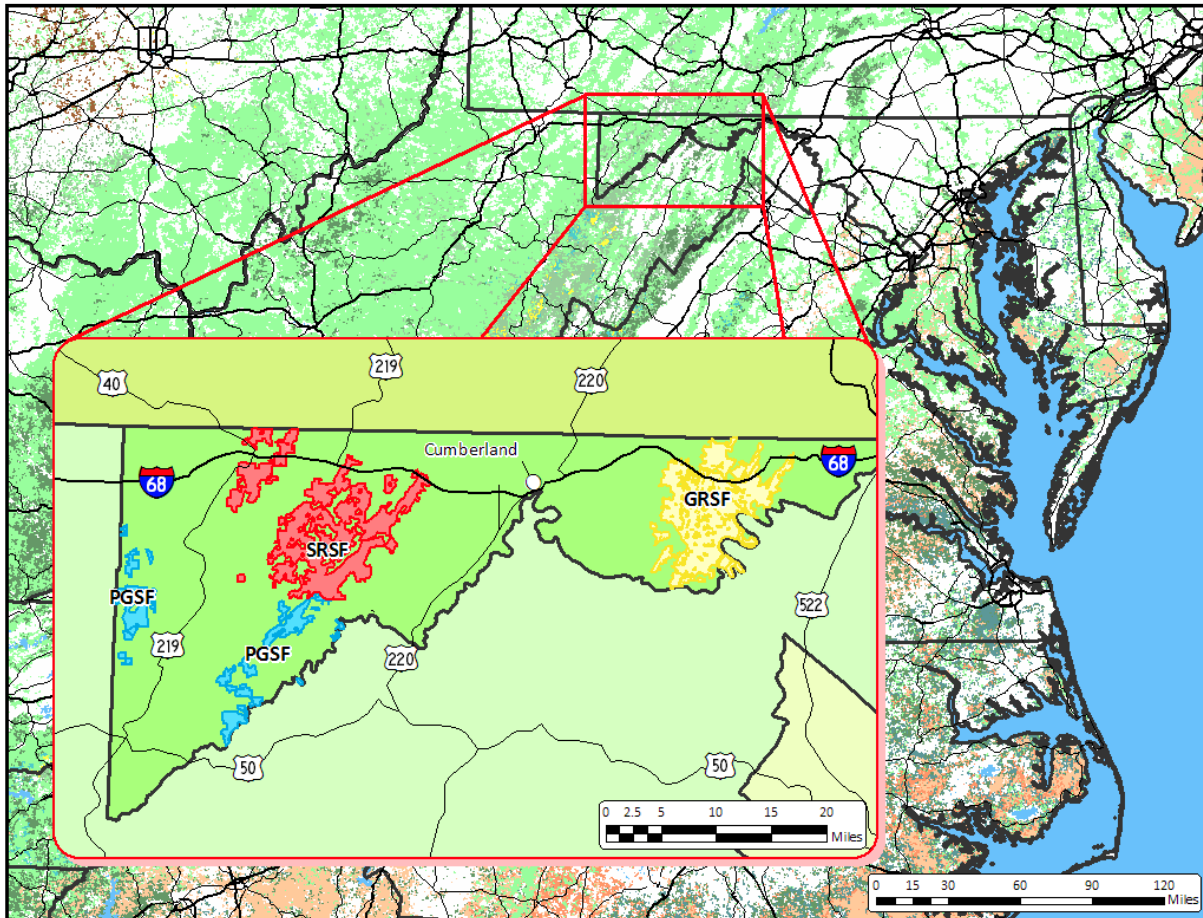
1. Imagery is segmented using Definiens Developer/eCognition.
2. Then, the imagery is classified using Erdas Imagine.
3. The segmented layer and the classified layers are evaluated using both statistical and ground truthing methods.
4. When an acceptable accuracy is achieved, the layers are stored in a geodatabase. Changes to the geodatabase can be made at any time.
5. Finally, data and imagery released in the future can be used to resegment and/or reclassify forest stands.

## Study Area

Of the five Maryland State Forests managed for timber, recreation, and conservation values, we used the three western state forests as assessment projects: Green Ridge State Forest, Potomac-Garrett State Forest and Savage River State Forest (Figure 2.2). Together, these forests comprise nearly 60% of the working state-owned forestlands in Maryland. All three forests are within the central hardwood region of the United States (Braun 1950).

Green Ridge State Forest (GRSF) is located in Allegany County within the Ridge and Valley physiographic province of the eastern United States (Fenneman 1938). Braun (1950) characterizes the region as traditionally Oak-Chestnut in forest cover. Elevation generally ranges from 140 m to 545 m, with many slopes greater than 65%. Because the general atmospheric flow across North America is from west to east, the Allegheny Plateau manifests a rainshadow effect on the Ridge and Valley Province (Stone and Matthews 1977). Average annual precipitation reported from Cumberland in Allegany County, the driest county per annum in Maryland, is 94.5 cm (Owenby and Ezell 1992). The average daily mean temperature reported from Cumberland is 12°C (Owenby and Ezell 1992).

Both Potomac-Garrett and Savage River State Forests are located in Garrett County, in far western Maryland. Garrett County is situated atop the Glaciated Allegheny Plateau (Fenneman 1938), and plateau forests are generally considered within the Mixed Mesophytic cover region (Braun 1950). The National Weather Service Station in Oakland, Garrett County, reports an average annual temp of 9°C and an average annual precipitation of 119cm (Owenby and Ezell 1992) (Figure 2.2).



**Figure 2.2 The State of Maryland with the western State Forests in enlarged view. Green Ridge State Forest is outlined in yellow, Potomac-Garrett State Forest in blue, and Savage River State Forest in red.**

### ***GREEN RIDGE STATE FOREST***

Green Ridge State Forest is located in eastern Allegany County and is the only State Forest located in the Ridge and Valley province. Green Ridge receives the least amount of rainfall in Maryland, averaging 36 inches annually. Consisting of over 18,615 hectares (46,000 acres), Green Ridge is the largest contiguous block of forestland in Maryland within the Chesapeake Bay watershed. It accounts for about 30% of the State Forest System and approximately 12% of all DNR land in Maryland.

The general geographic boundaries of Green Ridge are Town Creek to the west and Sideling Hill Creek to the east. The northern boundary extends to the Mason-Dixon Line. The southern boundary parallels the Potomac River. Elevations range from 152 meters (500 feet) above sea level on the Potomac River to 610 meters (2,000 feet) on Town Hill. Three Major highways traverse the forest in an east to west direction: Route 144, Maryland Route 51, and Interstate 68.

In the early 1800's, Richard Caton and William Carroll in partnership owned much of the land that is Green Ridge State Forest today. Richard Caton was the son-in-law to Charles Carroll of

Carrollton, a signer of the Declaration of Independence. William Carroll was the grandson of Daniel Carroll of Rock Creek, a framer of the United States Constitution. The land was originally patented from vacant lands from 1820 to 1840 for inclusion into various timber and mining interests, primarily the Town Hill Mining, Manufacturing, and Timber Company. This business venture was financed by the estate of Charles Carroll of Carrollton. The crumbling stone structure known as the Carroll Chimney, part of the steam-powered sawmill built in 1836, is the only known surviving structure of that period.

From 1880-1912, most of the remaining virgin forest was cut and a period of neglect resulted in numerous wildfires. During the early 1900's the Mertens family of Cumberland attempted to convert the forest into apple orchards and promoted it as "The Largest Apple Orchard in the Universe." The orchard was subdivided into 4.04 hectare (10 acre) parcels and sold to individuals as investment properties. 2.02 hectares (5 acres) of each property parcel was cleared, burned, and planted into apple trees. The remaining five acres had the best trees cut and the poorer trees were left standing. The orchard company went into bankruptcy in 1918. The interests of the corporation were acquired by the State Department of Forestry in 1931. Apple cages can still be found throughout the forest and serve as remnants of the historic apple orchards.

The first forest management activities at Green Ridge were performed by the Civilian Conservation Corps (CCC) in the 1930's. Their main focus was fire control. Other work consisted of building roads, trails, recreation enhancements, and the management of existing forest for its future timber and wildlife potential. During World War II, the CCC camp at Fifteen Mile Creek housed German prisoners of war who were required to cut pulpwood in the forest. As the forest grew it became popular with outdoor enthusiasts, especially hunters. It also contributed more and more to the local wood products industry.

Today, Green Ridge is a diverse forest consisting primarily of a 110 year old even-aged mixed oak forest, mixed with a wide variety of age classes resulting from various silviculture activities beginning in the late 1960's. The oak consists of a variety of species, including black oak, white oak, red oak, scarlet oak and chestnut oak. Five native pines grow at Green Ridge: white pine, Virginia pine, pitch pine, table-mountain pine and shortleaf pine. Flowering dogwood, redbud, and serviceberry are common understory trees. Wildflowers such as mayapple, coltsfoot, spring beauty, trillium, bloodroot and spiderwort flourish at Green Ridge.

Upland animals found in abundant numbers in the forest are white-tailed deer, fox and gray squirrel, raccoons, red fox and cottontail rabbits. Other animals include muskrat, beaver, mink, chipmunks, mice, flying squirrels, weasels, skunks, opossums, bobcat, and black bear. Wild turkey, ruffed grouse, and woodcock are popular game birds on Green Ridge. Other birds include the pileated woodpecker, red-tailed hawk, and the barred owl. A wide variety of neo-tropical migrants and songbirds also occur on the forest (Maryland Department of Natural Resources Green Ridge State Forest Annual Work Plan Fiscal Year 2010, 2008).



### ***POTOMAC-GARRETT STATE FOREST***

The Potomac-Garrett State Forest, situated in southwestern Garrett County in Western Maryland, has the distinction of being the birthplace of forestry conservation in Maryland. The generous donation of 775.8 hectares (1,917 acres) by the Garrett Brothers in 1906 not only serves as the foundation of the Garrett State Forest, but is the root of both Maryland's present Public Lands system and Forest Service. Mountain forests, streams and valleys make up the nearly 7,689 hectares (19,000 acres) of this State Forest. The forest cover is predominantly a second growth mixed hardwood forest dominated by mixed oaks, sugar and red maples, black cherry, basswood, ash and birch. The geography of this area provides for a wide range of growing conditions from the harsh, wind and ice swept ridge tops of Backbone Mountain to the deep rich slopes above the North Branch of the Potomac River. Much of the state forestland contains excellent quality hardwoods (Maryland Department of Natural Resources Potomac-Garrett State Forest Annual Work Plan Fiscal Year 2010, 2008).

### ***SAVAGE RIVER STATE FOREST***

Savage River State Forest is approximately 22,033 hectares (54,446 acres) in size and is situated in the northeastern quadrant of Garrett County of Western Maryland. It is a second growth mixed hardwood forest dominated by oak species, sugar and red maple, black cherry, hickory and ash. Owing to high rainfall and certain geographic and/or topographic features, Savage River State Forest contains many excellent quality growing sites stocked with superior quality trees. The forest contains approximately 1,619 hectares (4,000 acres) of conifer plantations, which were established in the 1940's following state acquisition. Red pine is the dominant tree species within these plantations but other conifers include white pine, Norway spruce, larch and Scotch pine. These plantations were established as nurse crops to rehabilitate abandoned and depleted farm fields, with the long-term goal of conversion back to native hardwoods as appropriate.

Savage River State Forest has been intensively managed for over 60 years. Forest harvest and grooming operations are undertaken to thin overstocked stands, effectively deal with public safety concerns, harvest mature or diseased/dying trees, improve habitat for certain wildlife species, assist and provide for certain research needs, address aesthetic concerns and increase the proportion of age/height diversity of forested stands. The benefits of these treatments are self-evident and are substantial – including improved wildlife habitat, abundant mast yields, and a forested landscape that is healthier, more biologically diverse, and more resistant to disease and insect attack.

Gypsy Moth defoliations were heavy in 2006 and very heavy in 2007, denuding approximately 10,117 hectares (25,000 acres) which is half the forest. The spray suppression program was boosted to over 12,141 hectares (30,000 acres) in 2008 and a very wet spring and summer assisted via fungal infections of the caterpillars to apparently wipe this destructive insect out. In the aftermath of these defoliations, tree mortality among the preferred species was very high in those areas which were defoliated two consecutive years. The areas of heaviest tree mortality are

the Middle Fork Wildland, Big Savage Wildland, Parts of Meadow Mountain, Fairview Road vicinity, and the upper slopes above Monroe Run and Poplar Lick. Salvage of dead trees will take place where practical and permissible. Much of the heaviest tree mortality has occurred in areas restricted from timber harvest administratively or in areas of steep and restrictive terrain. Accessible areas will be salvaged as markets permit. It is anticipated that fuelwood cutters will aggressively harvest dead trees which are accessible from the roadsides, and in fact this trend has already begun (Maryland Department of Natural Resources Savage River State Forest Annual Work Plan Fiscal Year 2010, 2008).

## Ecological Community Groups

As a basis for forest stratification, our assessment used Maryland Natural Heritage Program document “The Natural Communities of Maryland: Draft” (Harrison 2007). We classified to the Ecological Community Group (ECG) level. Although drafting on this classification continues, these units are based on combinations of topographic, edaphic, physiognomic and gross floristic similarities (Harrison 2007). The Maryland system was developed in concordance with classification systems used worldwide by Natureserve, such as the United States National Vegetation Classification (USNVC).

For Forest Management Certification, SFI (2004) now requires that program participants use the Natureserve or equivalent systems to aid in identifying and protecting species and communities that have imperiled conservation status. Also, FSC (1996) requires assessments that include data regarding the vulnerability of common as well as rare plants, animals, and habitats are in accordance with Natural Heritage Programs and Natureserve standards.

## Continuous Forest Inventory

Since 1976, each State Forest has undergone a Continuous Forest Inventory (CFI) at regular intervals in coordination with 10-year planning processes. CFI data collected during the last interval, from 1999 through 2001, were used to link our current mapping efforts to actual forest conditions.

CFI points were established throughout each state forest on a grid system such that each point by design was separated by 482.8 meters (0.3 miles). At each point, data was collected on an 809.4 m<sup>2</sup> (1/5 acre) circular plot. Data was collected on 450 plots at Green Ridge State Forest between June and August of 2000 and 2001. At Potomac-Garrett State Forest 274 plots were collected in summer months of 1999 and 2000. Savage River State Forest plots totaled 518; data was collected in the summers of 1999 and 2000. A global positioning system (GPS) was used to record the latitude and longitude of the center of each plot. About 40% of these position points were re-measured between 2007 and 2008 to verify and improve accuracy and correct any issues.

Collected data used for our assessment described site conditions such as Site Class (i.e., productivity), Site Index and Forest Type, as well as data on size and composition collected from all trees within plots. We used this information to further describe our stratification units.



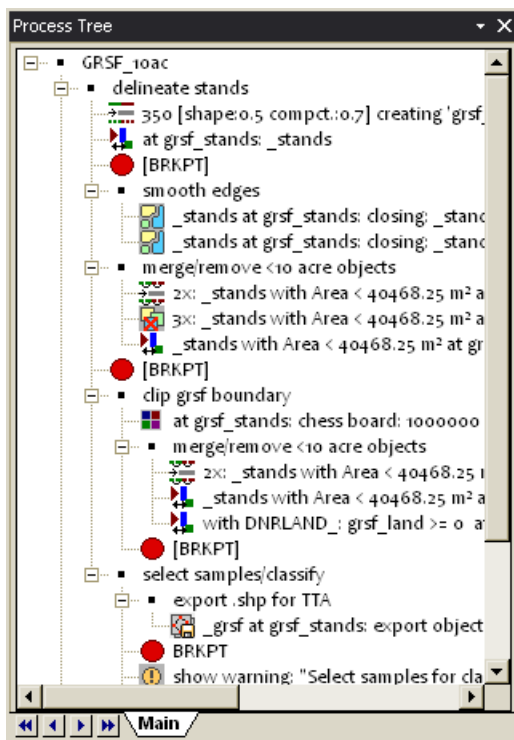
**Figure 2.3** A sample of CFI plots at Green Ridge State Forest.

### Stratification Via Image Segmentation

The stratification of forests into distinct stands involved the use of Definiens Developer image segmentation software. Definiens Developer is a computer-based program that assists in image segmentation and classification based on an image's spectral information. Developer is one part of an entire suite of an image analysis platform called Definiens Enterprise Image Intelligence. The client used for development, called Definiens Developer, provides all available tools for developing, testing and analyzing rulesets and results. There are also versions of the Definiens software that are designed specifically to be user-friendly for end users. These versions take away some of the initialization features that come with Developer, but still allow for customization. As an option, these programs can be connected to a server-based system, which allows for batch processing and greater data management (Definiens AG 2008-A).

Definiens Developer uses specific and unique terminology to define various functions of the program. The program contains a variety of processes that the user can select and manipulate, which allows nearly limitless customizability to the user. Each process consists of specialized

algorithms suited for various purposes. Multiple sequential processes are referred to as a process tree. Polygons or shapes that are created by an executed process are called image objects. Those image objects can be classified into different classes based on various criteria. A process tree can be exported with the classes, which is called a ruleset. This ruleset can then be transferred to other computers for further analysis or alteration (Definiens AG 2007, 2008). Figure 2.4 is an example of a process tree with various processes.



**Figure 2.4** An example of a process tree with multiple nested processes.

A ruleset in Definiens Developer is a schematic plan that contains multiple algorithms used in image segmentation. The ruleset used for this analysis contains three main steps:

- A. delineate, smooth, and merge image objects
- B. identify and incorporate the boundary into the segmentation
- C. export a shapefile of the final product

### ***IMAGERY AND LAYERS USED IN THE SEGMENTATION***

This project used a composite image that contains National Land Cover Database (NLCD), Landsat 7 Enhanced Thematic Mapper (ETM) + imagery, National Agriculture Imagery Program (NAIP) photography, and multiple digital elevation model (DEM) raster derivations. Landsat 7 ETM+ includes near-infrared and infrared imagery along with visible spectral data. The Landsat imagery was used to create tasseled cap transformed images that contain brightness, greenness, and wetness transformations (Huang, 2002). A boundary line shapefile for Green



Ridge State Forest acquired in 2008, which excludes in-holdings, was used as the thematic data layer.

The image raster bands used in this project are as follows:

1. spring bright
2. spring green
3. spring wet
4. leaf on bright
5. leaf on green
6. leaf on wet
7. leaf off bright
8. leaf off green
9. leaf off wet
10. slope
11. aspect
12. elevation
13. positionid
14. areasol/insolation

Raster bands 1-9 are derived from a 1-meter NAIP that was merged with tasseled cap transformed 30-meter Landsat 7 ETM+ imagery using ERDAS Imagine (ERDAS, Inc. 1999). The NAIP image was rescaled from 1 meter, its native resolution, to 5 meters before it was merged with 5-meter rescaled Landsat imagery. Bands 10-14 are 30-meter DEM raster files rescaled to 5 meters. The slope, aspect, and elevation layers were derived from the DEM, also using ERDAS Imagine. “Position ID” refers to the pixel’s location in the landscape, where a value is assigned based on various factors including slope, elevation, and aspect. “Areasol” or “insolation” refers to how much time and amount of sunlight reaches a pixel in the landscape based on elevation, landscape position, and aspect. This can be used as a way to predict the amount of available soil moisture at a certain pixel. The resulting imagery is a 5-meter resolution 14 band image.

### ***DELINEATING AND CLASSIFYING THE STANDS***

First, a “multiresolution segmentation” algorithm is selected. Definiens’ description of this algorithm is “...an optimization procedure which locally minimizes the average heterogeneity of image objects for a given resolution” (Definiens AG 2007, 2008). In simpler terms, this algorithm looks at each individual pixel and decides if its neighbors are similar enough to group together. There are many variables associated with a “multiresolution segmentation” that affect the segmentation in various and unique ways. All of these variables can be changed to generate an optimal segmentation of the image.

The first variables are the image layers weights. These weights can be changed on a scale of 0 (no weight) to 1 (full weight) to influence how much or little the user feels the image layer should be used in the segmentation process. Layers with high spectral differences are the most useful in segmentation, thus they were assigned the highest weight. Topographic layers are generally less indicative of differences; therefore those weights were adjusted slightly

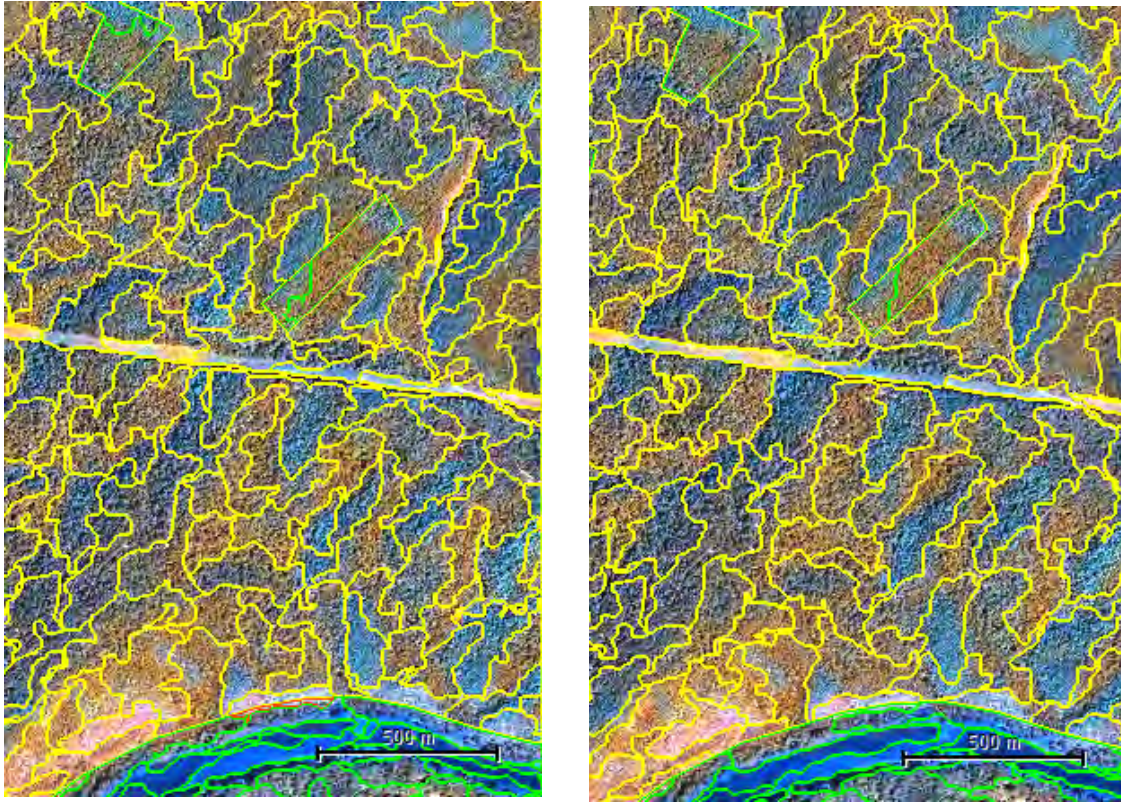
downward. Since the weights need to be on a scale of 0 to 1, if there are no values equal to 1 (either less than or greater than), the weights are scaled up or down in order to have the highest weight value equal to 1 (Definiens AG 2007, 2008, Hamilton 2007). The best results for GRSF were achieved with the weights in Table 2.1.

**Table 2.1 Image layer weights used for Green Ridge State Forest.**

Layer	Weight
01 spring bright	0.8
02 spring green	0.7
03 spring wet	1.0
04 leaf on bright	0.8
05 leaf on green	1.0
06 leaf on wet	0.4
07 leaf off bright	0.9
08 leaf off green	0.5
09 leaf off wet	1.0
10 slope	0.3
11 aspect	0.4
12 elevation	0.4
13 positionid	0.7
14 areasol	0.5

The scale parameter relates to the area of the resulting image objects. Through trial and error, it seems that there is an inverse relationship between the scale parameter and the pixel size of the image in use. For this project, using a scale parameter in the range of 250 to 350 for images with 5-meter resolution produces the best results. This project uses a scale parameter of 250. The scale parameter also is affected by the shape and compactness criterion. For an image with 30-meter resolution we tested, a scale parameter of 9 created sized image objects that were large enough in acreage as to be unmanageable, but small enough to be in compliance with FSC Appalachia Regional Indicator 6.3.g.1.a (FSC, 1996).

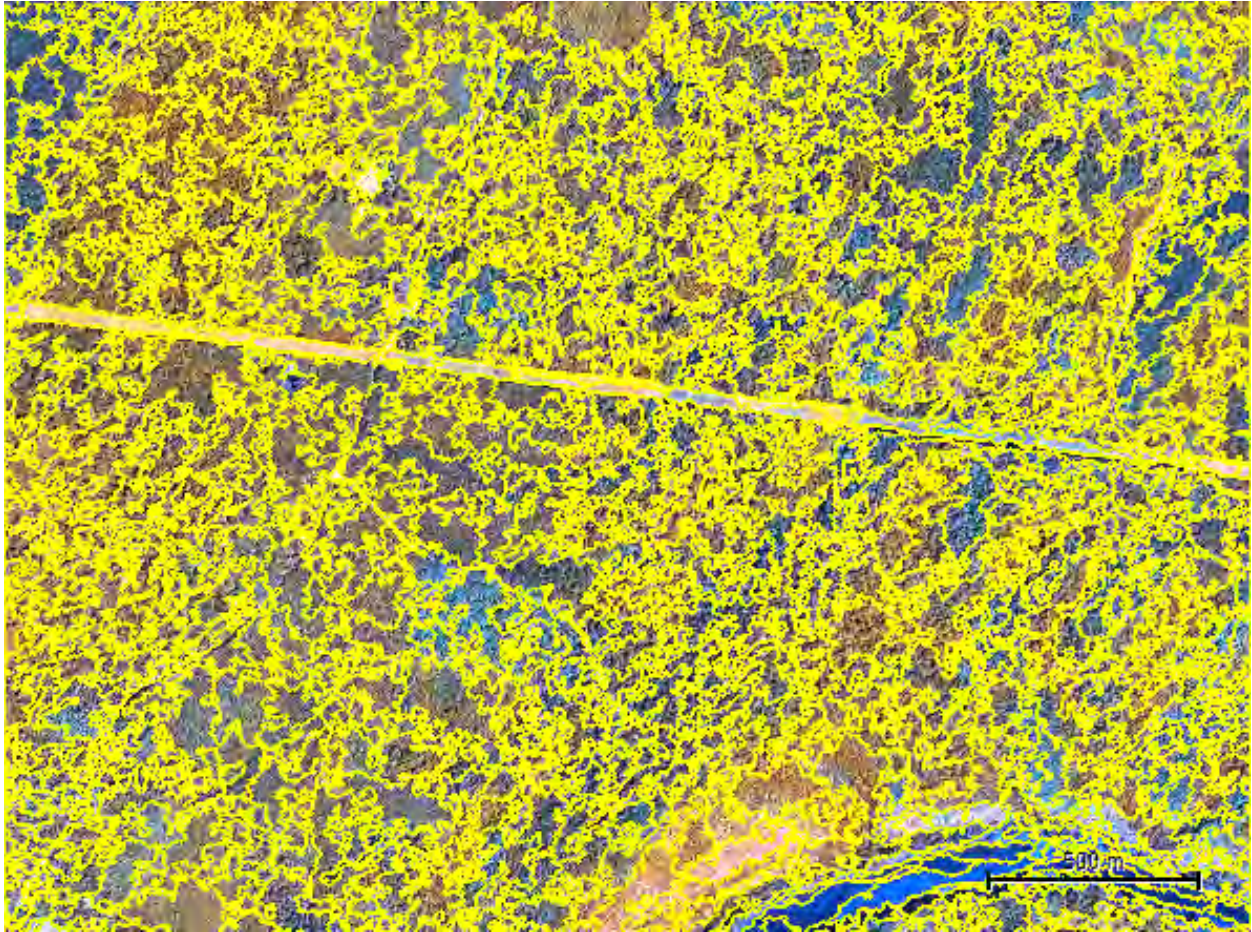
The next two variables are under the heading of “Composition of homogeneity criterion”. The first variable is the shape criterion, which is described as “The higher its value, the lower the influence of color on the segmentation process” (Definiens AG 2007, 2008). Choosing a lower value here uses more of the spectral/color component, which can create irregular and fragmented image objects. A higher value will create smoother and more usable image objects, but will incrementally decrease the amount of spectral or color information used in the segmentation process. Therefore, an optimum value for the shape criterion will allow the use of as much color information as possible (Hamilton 2007). When the image contains little discernable color information, such as a compressed and rescaled NAIP image, pushing the shape criterion to the lower bounds would yield the best results. Since this project uses tassled cap imagery, there is a high amount of color information present, so the shape criterion can be pushed to a more central number. This project uses a value of 0.5. Using a lower value with the tasseled cap imagery tends to yield a higher number of image objects that are more segmented, whereas the shape value of 0.5 will provide image objects more suited towards management activities (Figure 2.5). The differences may be subtle, but the effect on visual and ground accuracy is considerable.



**Figure 2.5** Examples of segmentations to the same geographic area performed using a shape value of 0.1 (left) and 0.5 (right).

The other homogeneity criterion is compactness. As the name suggests, this affects how compact image objects may be (Definiens AG 2007, 2008). A low compactness value will yield irregularly shaped image objects, while a high value will create more compact image objects. A “perfect” regular object would best be described as a circle. For this project, a value of 0.7 is used to achieve the best results (Figure 2.6).



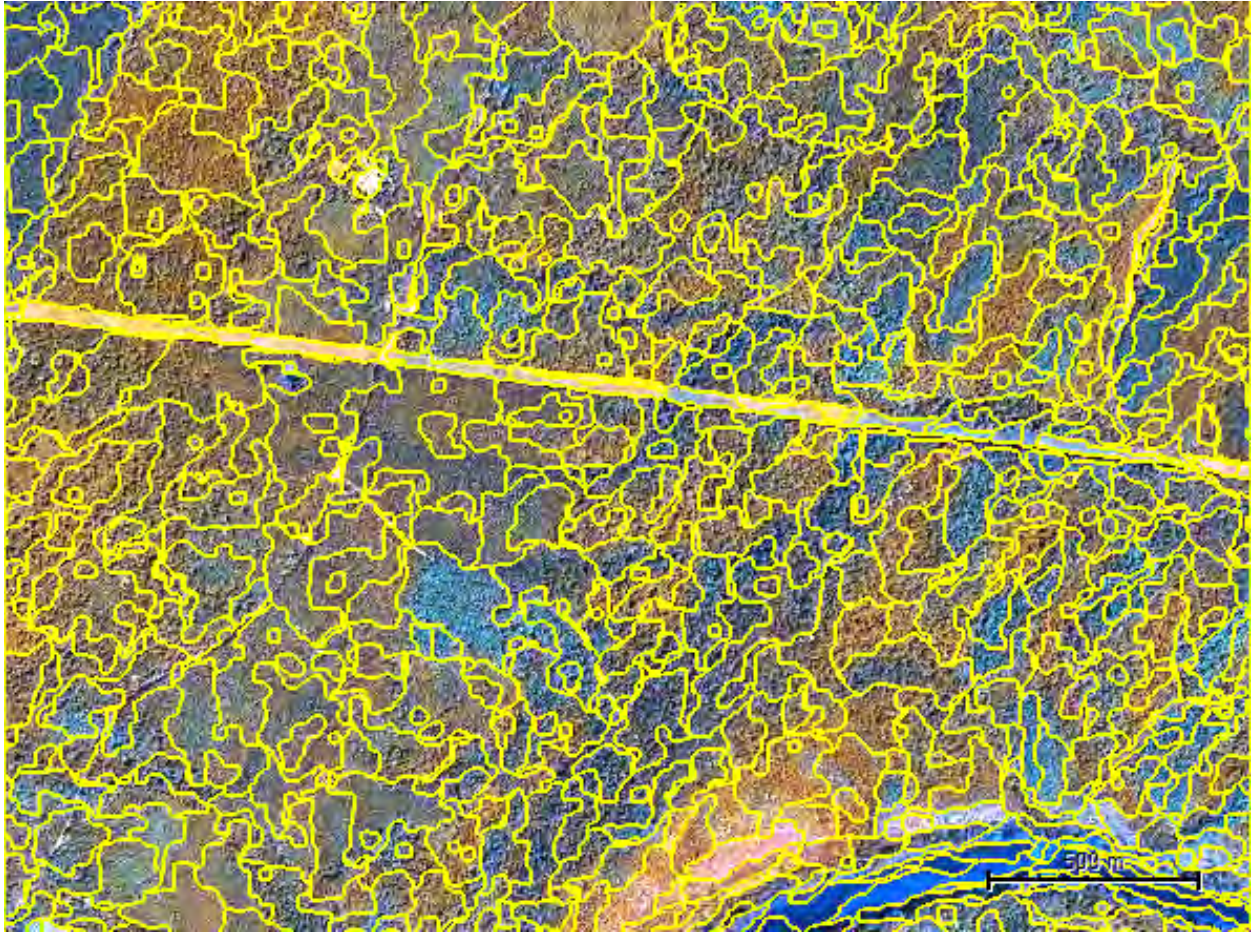


**Figure 2.6** An example of a multiresolution segmentation on a subsection of Green Ridge State Forest.

Following the multiresolution segmentation, the output is assigned to a class. In this project, it is called “stands”. It is important to classify the output of the segmentation because this initial classification will be used in the subsequent steps.

The next step for delineating the stands is to use the “morphology” algorithm to smooth the edges of the segmented image objects (Figure 2.7). This algorithm cuts and fills the jagged edges of the segmented image objects (Definiens AG 2007, 2008), which makes the final product appear more like a hand drawn map. This also makes it more useable for land management purposes. Two separate passes are used to achieve the best smoothing results.





**Figure 2.7 Image objects smoothed using the morphology algorithm on a subsection of Green Ridge State Forest.**

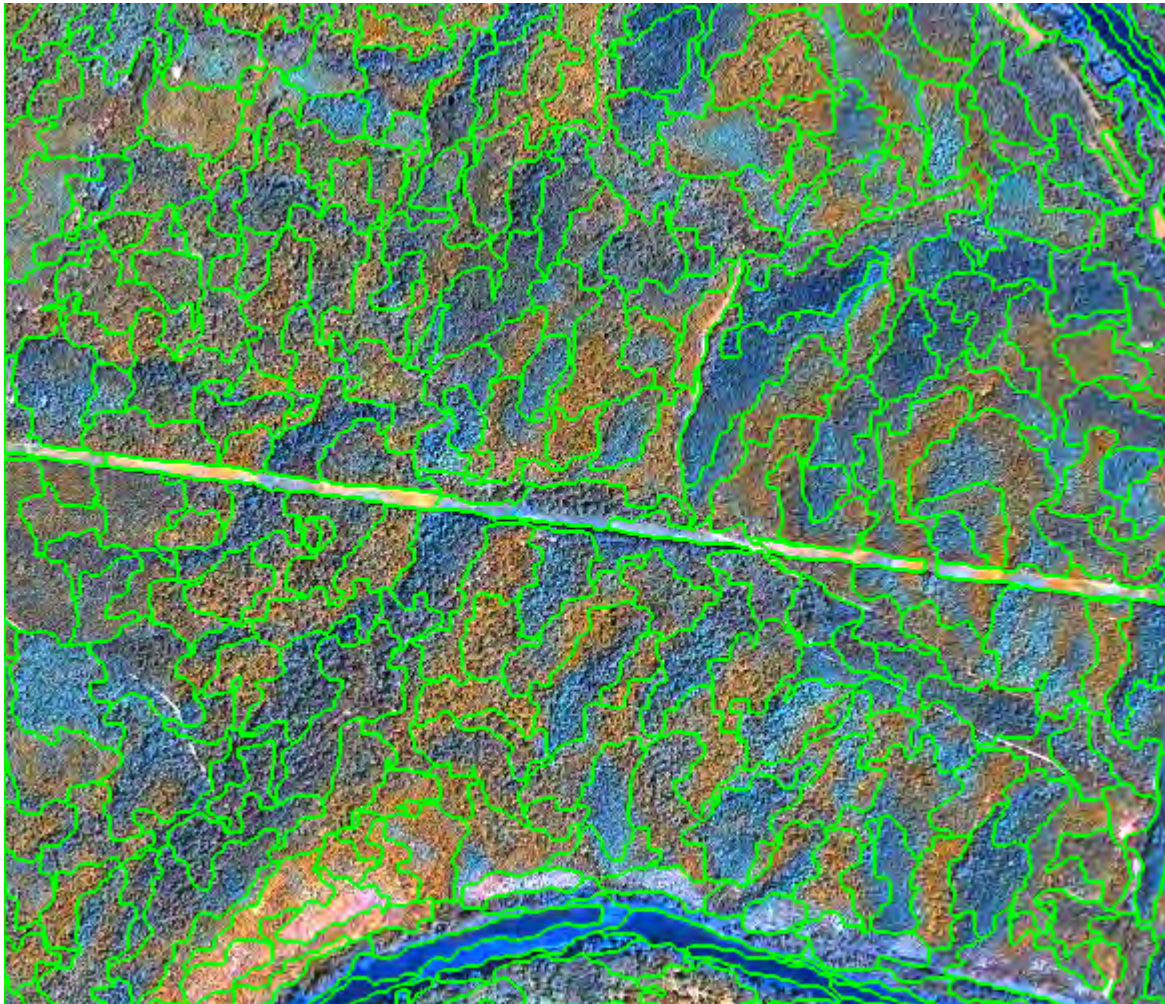
Closing the image object will fill the “jagged” areas of image objects by encompassing and incorporating surrounding pixels and, sometimes, smaller image objects. This results in somewhat larger, but smoothed, image objects. The other option, open image object, allows pixels that are already inside the object to become their own image objects. This option leads to many small image objects that would not be useful for management, and therefore is not used for this project.

A lower number pixel mask yielded image objects that were smoothed in areas with a lot of jagged edges, but did not produce visually significant results in areas that were smooth prior to the smoothing process. Additionally, smaller sized circle masks tend not to incorporate pixels that are encompassed by other, larger image objects. On the other hand, a higher number pixel mask would smooth nearly all of the edges, with exception to image objects that have a smaller area. Also a larger sized mask may cause areas that are not spectrally similar to each other to join together, thus defeating the purpose of the initial image segmentation. Five-pixel circle and square masks are used because it was found to be the best balance between too little and too much smoothing.

Finally, image objects that are less than the minimum threshold are removed using two algorithms. First, the “multiresolution segmentation result grow” algorithm is used to merge and



remove image objects using spectral information. A larger scale parameter is used in this algorithm, which allows the image objects to grow. The multiresolution segmentation result grow algorithm helps keep the image objects spectrally pure, while still meeting the minimum size threshold. However, there were still some image objects that were below the minimum threshold, so the “remove objects” algorithm was used to merge and remove those objects. The “remove objects” algorithm merges image objects that meet certain conditions with neighboring objects with which they share the most bordering pixels (Definiens AG 2007, 2008). Criteria used in this algorithm is setting the target class and setting a condition (Area < 4.046863 hectares (10 acres)). Each algorithm was set to cycle multiple times to ensure no image objects smaller than the minimum threshold remained (Figure 2.8).



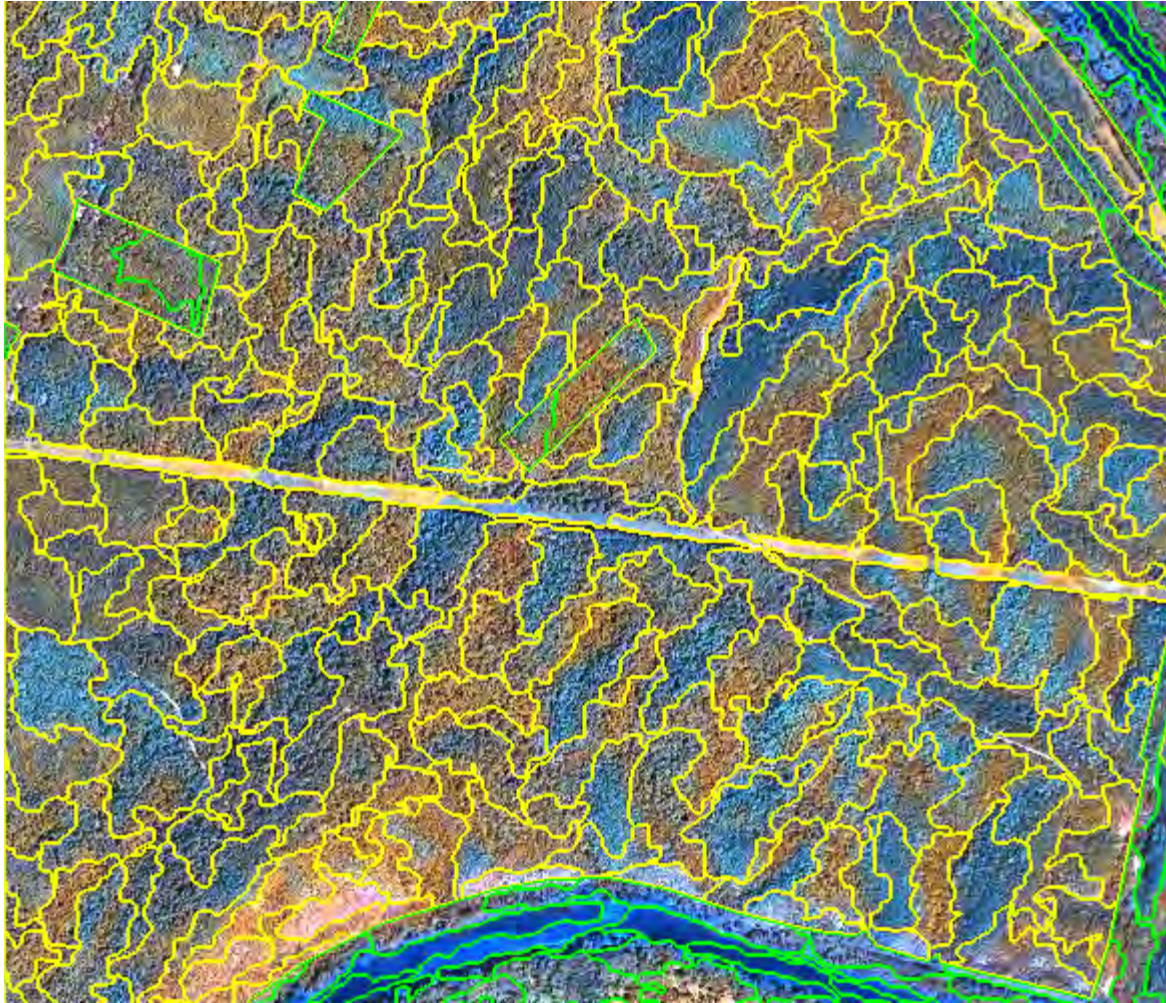
**Figure 2.8** An example of smoothed and merged image objects on a subsection of Green Ridge State Forest, using the “multiresolution segmentation region grow” and “remove objects” algorithms for merging, respectively.

Additional merging or segmentation can be performed manually at this point in Definiens using the “Merge Objects Manually” or “Cut Objects Manually” tools, respectively, or can be performed in ESRI ArcMap following a shapefile export.



### ***INCORPORATING EXISTING BOUNDARIES***

The Green Ridge State Forest (GRSF) boundary was created using a “chess board segmentation” that “split[s] the pixel domain or an image object domain into square image objects” (Definiens AG 2007, 2008). A very coarse “chess board segmentation” is used to make the boundary layer “visible” to both the program and the user. The next process assigned the GRSF level to a class based on its association with DNR lands. This classification will be used during the export process (Figure 2.9).



**Figure 2.9** An example of image objects clipped by the Green Ridge State Forest boundary to create a final shapefile product. Green Ridge State Forest land is colored yellow, while non-state lands are colored green.

### ***EXPORTING THE SEGMENTED OBJECTS AND PREPARING FOR CLASSIFICATION***

When the image objects were successfully segmented, smoothed and merged, they were exported into shapefiles. The exported shapefile was used both for the classification process using Definiens Developer and for classifications involving ERDAS Imagine and WEKA Data Mining software. In Definiens Developer, classification can be performed using a Training and Test

Area (TTA) mask and a Definiens Developer tool called feature space optimization. The next section contains more detailed information about how those programs were used for classification.

## Classification Methodology

There are a multitude of programs and methods available to perform suitable classifications. This project tested and chose between three different programs to determine the best solution. The three programs tested were Definiens Developer, ERDAS Imagine, and WEKA Data Mining. Within each program, various classification schemes were evaluated.

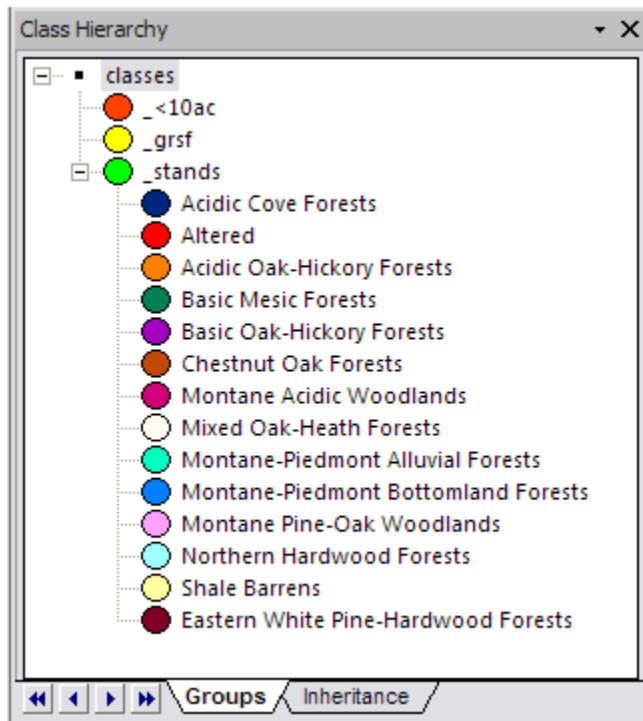
### *DEFINIENS DEVELOPER'S "NEAREST NEIGHBOR" CLASSIFICATION*

Definiens Developer uses a nearest neighbor algorithm to perform its classification (Definiens AG 2007, 2008). There are five main steps involved with Definiens Developer's classification process: loading and creating classes, defining sample image objects, running a feature space optimization, classifying the image objects, and reviewing the results. Sampling is used to "teach" the program how to classify the image objects. The image objects used as samples are then extrapolated for all image objects based on the underlying image layers. A benefit to this system is that only a small number of samples for each class are needed for classification.

First, new classes for each of the ecological community groups found in the forest were created in the class hierarchy (Figure 2.10). Next, samples were either created using a "training and test area" (TTA) mask, chosen manually, or a combination of the two. The locations of the training point data were derived from Continuous Forest Inventory (CFI) plots and additional plots taken throughout the forest. The first step in creating a TTA mask was exporting the segmented image objects into a shapefile. At this point, exporting any additional information with the shapefile was unnecessary. Each record in the training point data was then given a unique ID number that related to its ecological community group (ECG). CFI forest types and ECGs were matched up directly to the appropriate ECG. There was a 1:1 match for all types in Potomac-Garrett and Savage River State Forests, but some forest types in Green Ridge State Forest did not have a 1:1 match for CFI forest type and ECG. An example is the CFI forest type "Mixed Oak", which could be an Acidic Oak-Hickory, Basic Oak-Hickory, Chestnut Oak, or Mixed Oak-Heath ECG. In these cases, CFI forest types were related to ECGs by matching collected CFI tree and understory species plot data to species listed in the Natural Communities of Maryland report (Harrison 2007). If there was any doubt about the forest type or ECG, the plot was either discarded or a field visit was made to verify and correct the typing.

Both the exported shapefile and the training data point layer were then loaded into ArcMap. Polygons from the exported shapefile that contained the training points were selected, and a new layer was created from those selected polygons. The new "selected" polygon layer was spatially joined to the points layer to associate the community group from the points layer with its associated polygon. This new spatially joined layer was converted from a shapefile polygon to a

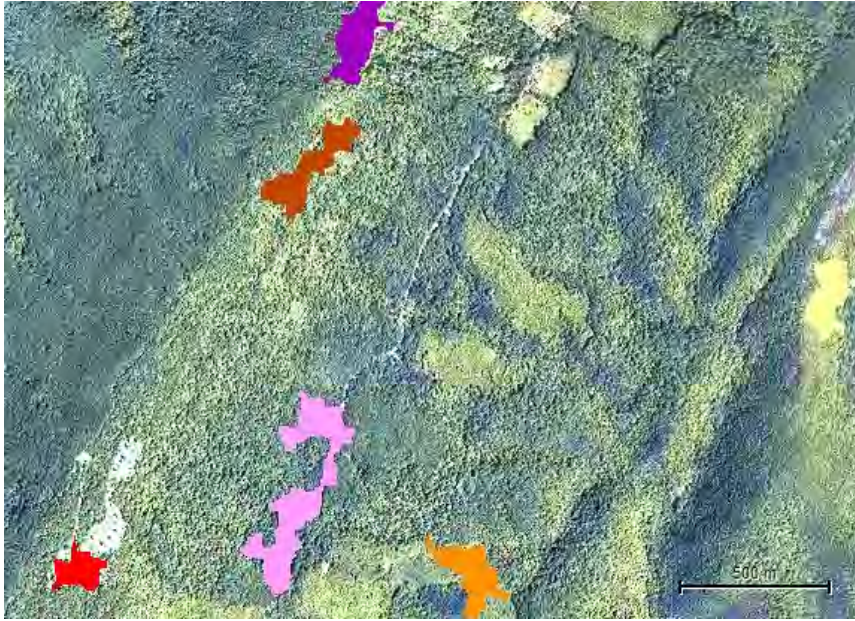
GeoTIFF raster dataset. The specific ID number associated with each community type was used to define the pixels in the raster dataset.



**Figure 2.10** The ecological community group classes used for classification in Definens Developer.

The resulting GeoTIFF image was loaded into Definens Developer as a TTA mask to become samples that the program could use for classification (Figure 2.11). Next, “feature space optimization” was run to create an optimized nearest neighbor classification process. Feature space optimization helps find the combination of features that are suitable for separating classes in conjunction with a nearest neighbor classifier (Definens AG 2007, 2008). For this project, the mean values of all the layers, including brightness and maximum difference, were selected in the feature space optimization. The optimized feature space was then calculated and these optimized values were applied to the classes using the advanced settings. These optimized feature values were stored in each class to be used in the classification process.

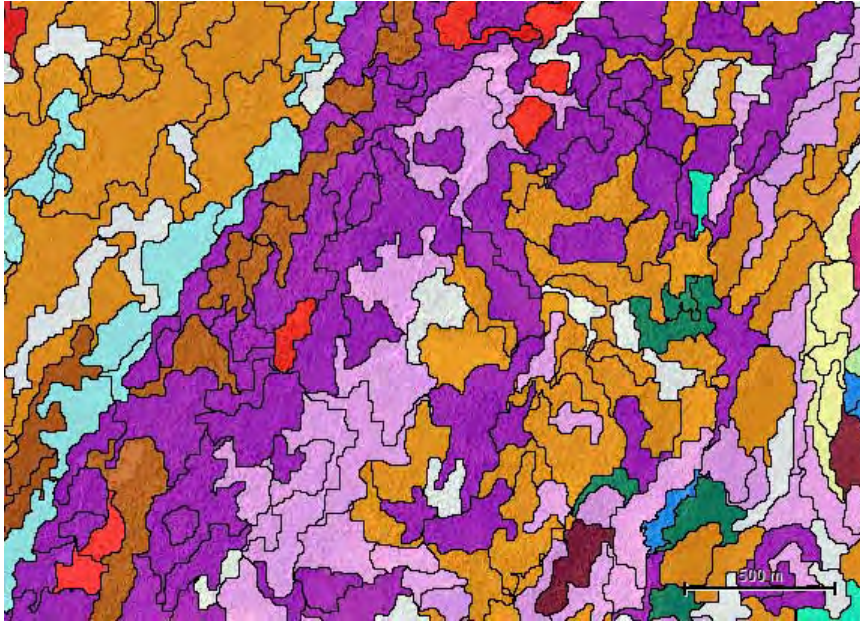




**Figure 2.11 A few examples of samples used in the classification procedure for Definiens Developer**

The “classify” algorithm is used for the actual classification process. Once this process is run, the results were reviewed. In areas where the classification was not correct, samples were either added or removed using the available CFI plots to attempt to correct and improve the classification. When these new samples were created the classification process was run again. This procedure was repeated as many times as was felt necessary until the optimal results based on an accuracy assessment were achieved (Definiens AG 2007, 2008).

Additionally, significant areas that were not classified correctly based on field and ground verification or were left unclassified were manually classified (Figure 2.12). Areas that were not classified include non-forested areas, recent harvests, or any area without an associated ecological community group.



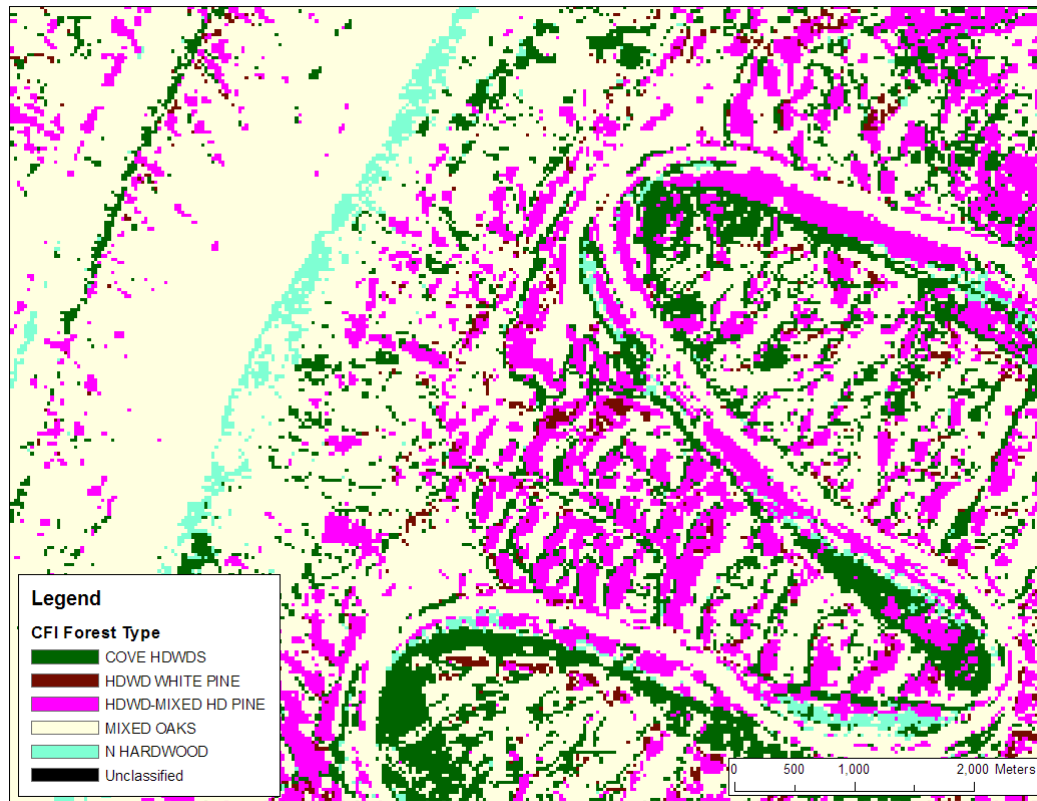
**Figure 2.12** Image objects classified using Definiens Developer’s feature space optimization. The colors represent the ecological community group, while the stand lines delineate differences in age, stocking, or other forest characteristics interpreted by the Definiens Developer segmentation process.

The Definiens nearest neighbor/feature space optimization method has both positive and negative qualities. First, this method is the simplest to apply of all the methods we attempted. Adding and removing points was a very simple process, but the accuracy achieved was less than the baseline of 80%. One of the reasons we presume the accuracy may not be the most effective is because the classifier relies on the segmented image objects for classification rather than the base imagery. This led to problems when the imagery was segmented too coarsely, which caused more than one sample point to fall into a single image object. Classification at the forest or ECG level is not a problem if there are multiple plots in an image object. It does complicate assigning any additional CFI data to the plots in later steps. Therefore, this method was not applied to the final classified maps, but was instead used as a faster method for testing different combinations and evaluating the quality of both sample and withheld points.

#### ***LEICA GEOSYSTEMS ERDAS IMAGINE’S “MAXIMUM LIKELIHOOD” CLASSIFICATION SCHEME***

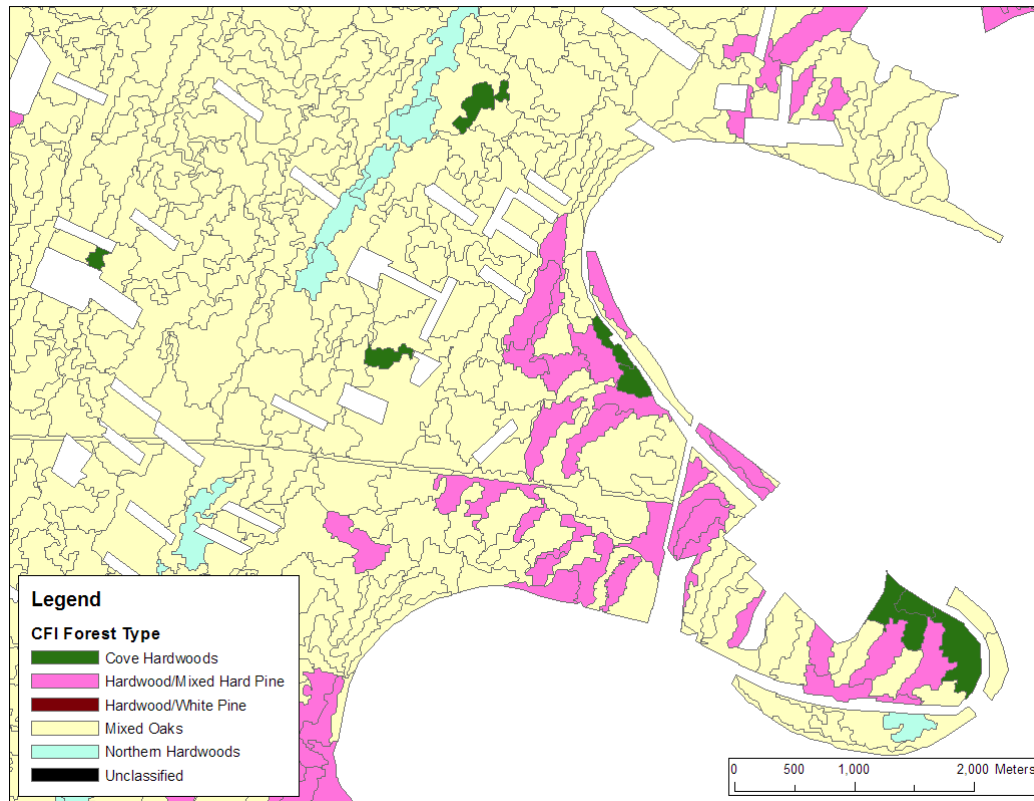
ERDAS Imagine offers a variety of unique classification methods that create accurate and practical classified images. This project experimented with using the supervised classification methods of minimum distance and maximum likelihood and the ISODATA unsupervised method. After experimenting with the different methods, it was determined that the maximum likelihood method suited this project the best.

In a maximum likelihood classification, the probability that a pixel belongs to a certain class is calculated, and assigned (ERDAS, Inc. 1999) (Figure 2.13). The resulting pixel map was combined with the segmented polygons using the zonal statistics “majority” tool. This created a “final” stand map that utilizes the community types (Figure 2.14).



**Figure 2.13 Pixel map generated using ERDAS Imagine's maximum likelihood supervised classification.**



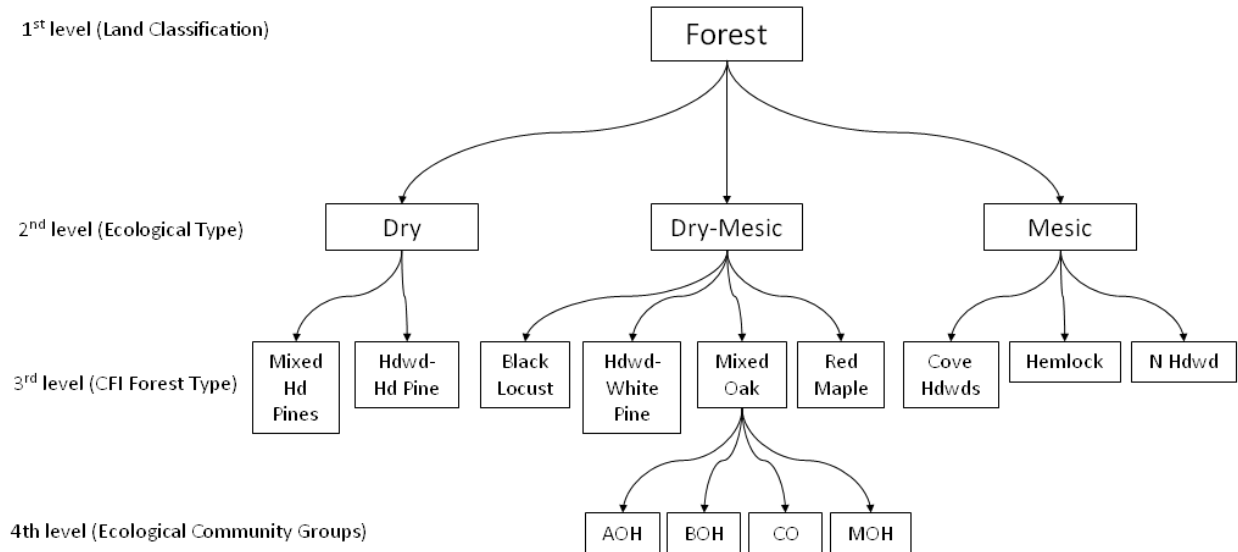


**Figure 2.14 Polygons classified using the pixel-based maximum likelihood supervised classification and zonal attributes in ERDAS Imagine.**

One of the main issues encountered using the 30-meter imagery was that the date that the satellite imagery had taken was different than the date the aerial imagery was taken, and therefore numerous landscape changes were not attributed for. Also, ground data points (CFI and others) were taken at different times, so careful inspection of each point as it related to the imagery had to be taken into account. The best and most common example of this is in areas where harvests had occurred in between the plot data and the imagery acquired.

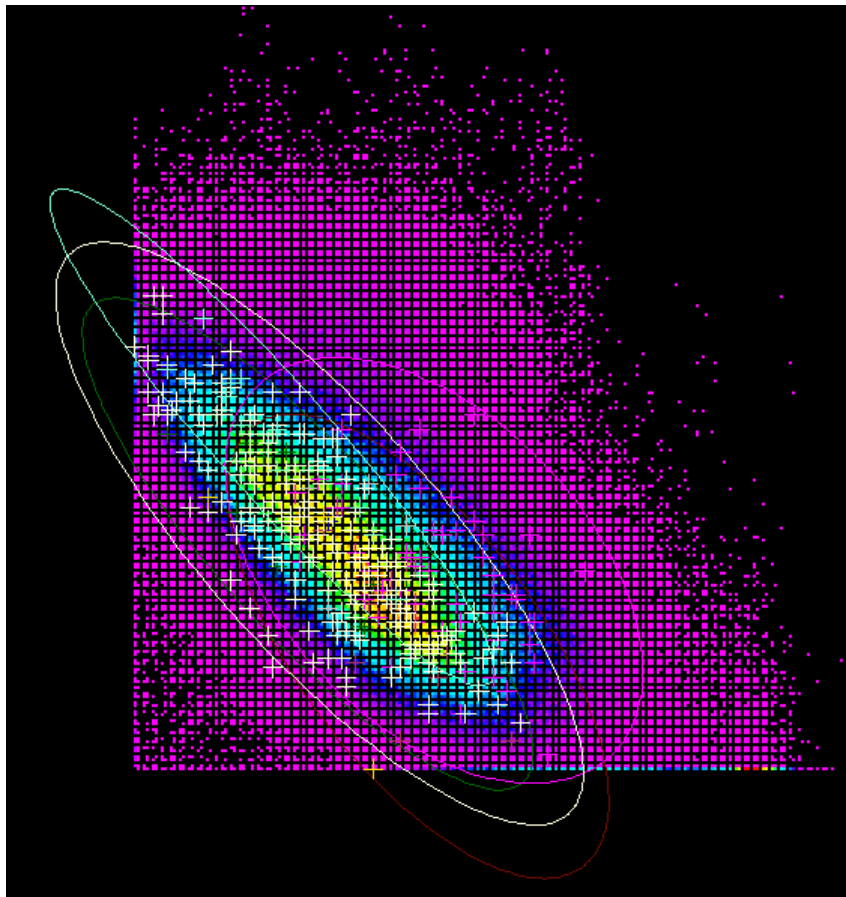
After experimenting with different methods and classes, it was determined that the best means was to use a hierarchical method of classification. This project uses the CFI plots for primary and secondary classes which are the ecological class and the CFI forest type. At Green Ridge State Forest, a tertiary class is used to differentiate the different “Mixed Oak” forest types by using an ecological community group (Figure 2.15). Using primary, secondary and tertiary classes the classification accuracy was improved dramatically, and more importantly the data gleaned from the classification has a potentially wider scope.

This project uses the CFI plots for the primary and secondary classes, which are the ecological class and the CFI forest type. At Green Ridge State Forest, the tertiary class is the ecological community group (Figure 2.15).



**Figure 2.15 The hierarchal system used for Green Ridge State Forest.**

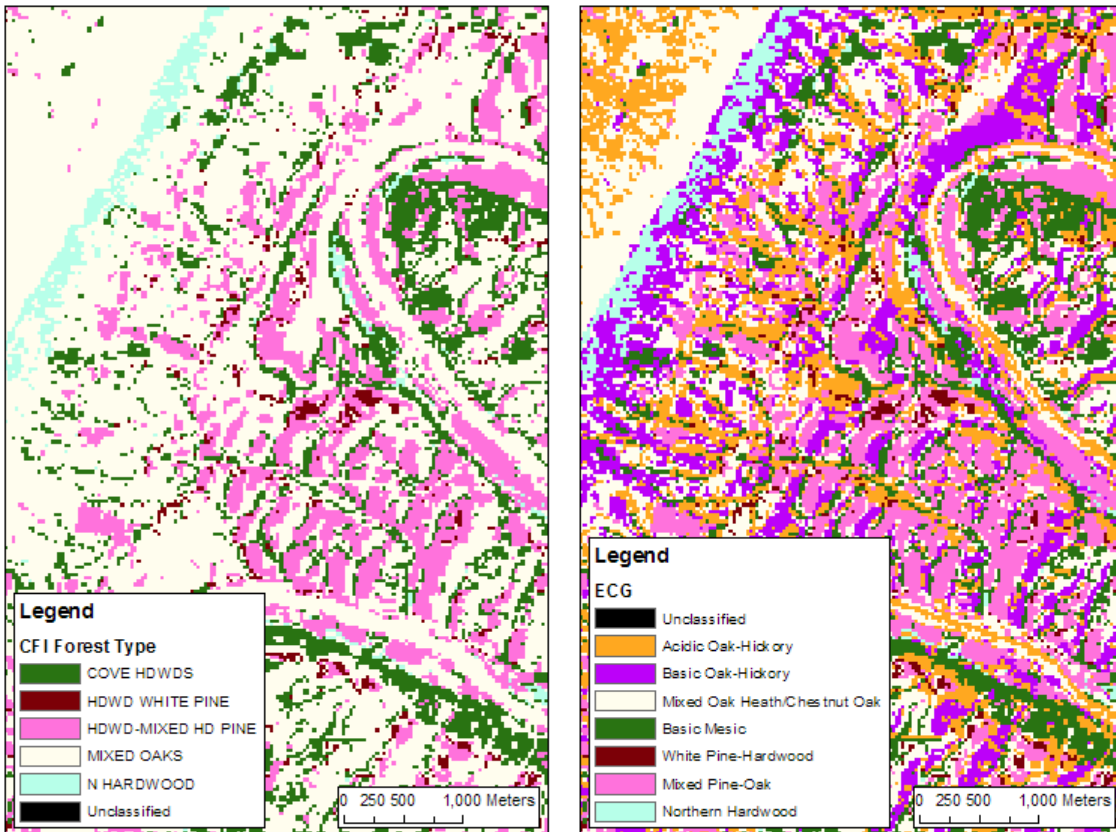
The plots used as samples, or signatures, are tweaked and evaluated based on various criteria, including examinations of signature separability and visual inspection in feature space images. Feature space images are created from the imagery used for classification (ERDAS, Inc. 1999). Feature space images are created using two layers from the classification imagery to display the density of points. The classification imagery used has 14 layers, which yields 91 unique feature space images. The two axes of the feature space image are the pixel values from the layers (0-x). The signatures can be overlaid on the feature space image to show areas of overlap and uniqueness (Figure 2.16). Feature space images combined with signature overlay can be useful in determining which layers from the imagery are the best for separating the signatures as well as determining which signatures are the most unique and best representatives of a particular class.



**Figure 2.16** An example of signature plot means and ellipses plotted in a feature space image showing areas of overlap and uniqueness. This feature space image shows overlap between the cove hardwoods (green +) mixed oak (white +), northern hardwood (light blue +), and white pine-hardwood (maroon +) signatures, with some overlap with the mixed hardwood-pine (pink +) signatures. Brighter colors in the feature space image represent a higher density of points from the selected image layers.

Once the signatures were evaluated as being the most similar or unique, the best image band combination was determined using a mean plot evaluation across all bands. A minimum distance supervised classification was performed as a test of initial classification quality. Classes of the same forest type were then merged together to create a single merged class that still contained all the original points. This is necessary for the maximum likelihood classification. Probabilities are adjusted where appropriate to account for differences in the number of signatures available for different forest types. For example, the Mixed Oak class may have over 100 signatures while the Northern Hardwood class may only have 15 signatures. In this case a Mixed Oak signature has a higher likelihood of being classified when compared with a spectrally similar Northern Hardwood signature. A supervised, maximum likelihood parametric rule was used as the classifier. Different combinations of layers and class probabilities were tested and used to achieve the highest statistical accuracy possible based on the built-in ERDAS accuracy assessment that uses withheld signatures. More details on the accuracy assessment process and results are located in the results section.

To account for the third level in the hierarchy, a model that extracts only certain parts of imagery based on its pixel value or classification is used. For example, areas classified as “Mixed Oak” in the secondary level can be extracted and reclassified using the ECG classes of Acidic Oak-Hickory (AOH), Basic Oak-Hickory (BOH), Chestnut Oak (CO), and Mixed Oak Heath (MOH). This accounts for the much coarser classification that came using solely the ECG classes across the entire image, in turn preserving the classification scheme of the higher levels. This method of extracting certain classes was also used to alleviate issues concerning inaccurate classification caused by using the ECG classes outright (Figure 2.17).



**Figure 2.17 Pixel maps showing the CFI forest type classification (left) and the result of classifying ECGs from extracted “Mixed Oak” areas (right).**

In addition to increasing the overall accuracy of the classification,, this method also expands the usefulness of the output data. For instance, a forest manager may be interested in the overall classifications across a large 200-acre area, but not necessarily down to the ECG level. The implemented system allows for the forest manager to view the area as a landscape unit (forest ecology/type), but still let the forest manager see the details that may be important for making management decisions.

Using the maximum likelihood classifier with merged signatures yields a very similar result to using minimum distance with unmerged signatures. The only issue is how to account for classes that only contain a handful of signatures (not enough to meet the requirements for a maximum likelihood classification). One solution may come with using the best band combination, which

potentially could only use a fraction of the current bands, therefore lowering the required number of signatures. The best bands can be determined using feature space images. Another issue is setting the probabilities correctly as to adjust for the differences seen in the total number of signatures per class. For example, the Dry-Mesic signature set contains roughly 2/3 of all signatures in the ecological class, and over half of the signatures in the CFI forest types are Mixed Oak. On the other end of the spectrum, the Mesic ecological class only has approximately 1/10 of the total signatures, and Hemlock, Red Maple, and Black Locust account for less than 5% of the signatures. Simply discounting their significance would be a major oversight, as these forest types are somewhat unique (which eliminates merging or removing the signatures altogether). The only viable solutions are to either use a fraction of the bands in order to use those classes, or to eliminate the classes.

At Green Ridge State Forest, the number of CFI classes was reduced to 5 out of a previous total of 9. The Hardwood-Hard Pine and Mixed Hard Pine classes were combined due to their proximity in feature space. Hemlock, Red Maple and Black Locust types did not show any discernable patterns in feature space images, therefore were deemed not viable for classification and were not used in the final classification.

#### ***WEKA DATA MINING “IBK NEAREST NEIGHBOR” CLASSIFICATION***

A third method of classification is using WEKA Data Mining software to use a nearest neighbor classification developed by Andrew Lister (Lister, 2008) of the U.S. Department of Agriculture Forest Service, Northern Research Station. Due to various time constraints, this method could not be evaluated across all three forests. Only a small portion of Green Ridge was used as a test area for a subset of the software’s capabilities. There are still plans to experiment with this method in the future, however.

This program uses the values obtained from the CFI and additional plot points to assign each pixel a unique value. The first step in this process was to convert a single band of the 14-band raster image to an ASCII text matrix using ERDAS Imagine. Then the WEKA Data Mining Software model was applied to the text matrix. The classified ASCII text matrix was then converted back into a single band raster image (Figure 2.18). Using zonal statistical tools, the summarized distribution of any of the plot attributes can be enumerated, and the statistics can be attached to the polygon to create a final map.





**Figure 2.18** Raster map showing an example of a pixel map created using WEKA Data Mining software. This map shows the likelihood of deciduous species at a site, where green is high, and pink or red is none.

The CFI data that can be incorporated using WEKA Data Mining software includes volume, number of stems, average diameter, age, site index, basal area, and an estimate of species likelihood. As with other similar databases, the database created from the WEKA models can be used for a multitude of complex queries, such as determining acceptable allowable harvest levels.

## CHAPTER III - RESULTS AND DISCUSSION

### Comparison of Methods

The three different methods of classification were compared to one another both visually and statistically to determine which type yielded the best and most usable result. Statistical approaches included performing accuracy assessments. Visual inspection was only used as a secondary means to improve upon existing methodology and results.

### *ACCURACY ASSESSMENTS*

Approximately 20% of the sample points from each forest (with equal distribution across all classes or forest types) were set aside prior to the classification process to be used in the accuracy assessment for the ERDAS Imagine and WEKA classifications. The Definiens Developer accuracy assessment uses its own accuracy assessment based on the TTA mask that was previously used. Although each program has its own built in accuracy assessing algorithms, their functions are very similar. ERDAS Imagine's accuracy assessment can use either random points the program chooses or pre-determined user points. The latter were used for this project to allow for known points (most commonly CFI points) to be used as the ground truthing locations.

ERDAS Imagine's accuracy assessment contains various options that can change the way pixels are reviewed. Each ground truthed point is subject to at least a 3x3 pixel (9 pixel total) area assessment, with either a clear majority or a majority threshold (minimum number of pixels) classified correctly (Figure 3.1). If neither of those criteria are met, then either the value of the center pixel is used for the accuracy assessment or the window is discarded (Figure 3.2). User and producer accuracy percentages are both returned to show where possible errors may have occurred.

```

Imagine - ClassAcc (Classification Accuracy Assessment)
-----
Random Points Cell Listing
-----
Options Used in this run:
-----
Number of Points      : 0
Window Size          : 3
Window Majority Rule  : Clear Majority
No Majority Action    : Use Center Value

CELL 1 (1)           CELL 2 (4)           CELL 3 (4)           CELL 4 (3)
4  1  4              4  4  4              4  4  4              1  3  3
1  1  1              4  4  4              4  4  4              4  3  3
1  4  4              4  4  2              4  4  4              4  3  3

CELL 5 (2)           CELL 6 (3)           CELL 7 (3)           CELL 8 (3)
2  3  3              3  3  3              3  3  3              3  3  3
4  2  2              2  3  3              4  3  3              3  3  3
1  4  2              3  3  3              4  3  3              3  3  3

CELL 9 (4)           CELL 10 (3)          CELL 11 (4)          CELL 12 (4)
4  4  1              4  4  2              4  4  4              4  4  4
4  4  3              2  3  3              4  3  3              3  4  4
4  4  3              4  3  3              4  4  4              3  4  4

CELL 13 (4)          CELL 14 (4)          CELL 15 (3)          CELL 16 (3)
4  4  3              4  4  4              3  3  3              4  2  2
1  4  4              4  3  3              3  3  3              3  3  3
1  4  1              4  4  3              3  3  3              3  3  3

CELL 17 (3)          CELL 18 (4)          CELL 19 (3)          CELL 20 (3)
2  2  3              3  4  3              3  3  4              3  3  4
3  3  3              3  4  4              3  3  4              3  3  4
3  3  3              4  4  4              3  3  4              3  3  4

CELL 21 (4)          CELL 22 (4)          CELL 23 (4)          CELL 24 (4)
4  4  3              3  3  4              1  1  1              1  1  1
4  4  4              4  4  4              4  4  1              4  4  4
3  4  4              4  2  4              4  4  4              4  4  4

```

**Figure 3.1** Example of cell array output from the accuracy assessment.



ACCURACY TOTALS					
Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	0	0	0	---	---
COVE HDWDS	3	2	1	33.33%	50.00%
HDWD WHITE PINE	2	3	1	50.00%	33.33%
HDWD-MIXED HD P	15	13	9	60.00%	69.23%
MIXED OAKS	51	55	45	88.24%	81.82%
N HARDWOOD	3	1	1	33.33%	100.00%
Totals	74	74	57		
Overall Classification Accuracy = 77.03%					
----- End of Accuracy Totals -----					
KAPPA (K^ ) STATISTICS					
Overall Kappa Statistics = 0.4888					
Conditional Kappa for each Category.					
	Class Name	Kappa			
	Unclassified	0.0000			
	COVE HDWDS	0.4789			
	HDWD WHITE PINE	0.3148			
	HDWD-MIXED HD PINE	0.6141			
	MIXED OAKS	0.4150			
	N HARDWOOD	1.0000			
----- End of Kappa Statistics -----					

**Figure 3.2 Example accuracy assessment results with kappa statistics.**

Accuracy levels reached and exceeded 80% for the Ecological Type class at all three forests, but failed to reach the minimum requirement for the lower levels in the hierarchy. However, the accuracy was still greater than 70% for those lower levels.

#### Chosen Classification Method(s)

The final choice for the best result was to use ERDAS Imagine to classify based on forest and ecological types, and use the IBk nearest neighbor classifier to add selected CFI plot data to the polygons. This decision was based on the original guidelines set forth in the grant proposal, as well as additional goals that were deemed important to the project. There are three specific goals that needed to be met with the grant proposal as it relates to forest management certification. First, the grant required that existing datasets were to be used, including Continuous Forest Inventory (CFI) plots, aerial and satellite imagery, and historic harvest data. Second, a spatial data base (GIS) management system that contains information on every discrete forest stand or management unit, its typology, description, and spatial location, to aid in sustainable management and monitoring needed to be developed. Third and finally, supplemental forest inventory data must be incorporated into the stands.

## Incorporating The Output With Existing Systems

There were also a few criteria that we felt would help make this project's data more useful for the forest managers and workers. First, the information available in the database had to be made accessible and understandable. Second, the data available in each polygon had to be robust to allow for maximum flexibility. And finally, it was important that the final dataset could be easily and quickly updated to adjust for errors in the data, as well as to allow new data to be integrated into the system.

Using the chosen methods will assist in achieving forest management certification and sustainable forest management goals. CFI data and existing aerial and satellite imagery were the basis of all of the classification schemes. The chosen method made the transition into a GIS database using the existing CFI plots very simple. Also, the supplemental data that were collected was integrated into the stands alongside the CFI data. Using these methods, all of the necessary data is kept well organized and easy to query.

Theoretically, the general process for querying the data involves only a few simple steps. First, the user would load the shapefile layer into a GIS program (or in a web-based GIS system). Second, the user would visually locate the area of interest. And third, the user would query the appropriate stand(s). At this point, all of the data associated with the queried stand(s) is displayed to the user in a simple, easy to comprehend, tabular format. Nearly every piece of data that was or has been collected can be included in this stand map database (Figure 3.3). This allows for a fully comprehensive dataset that is practical for many applications. One of the main benefits of using the geodatabase system is that it is a wholly contained product that can be stored and updated in one location and transferred to the end user at another location.

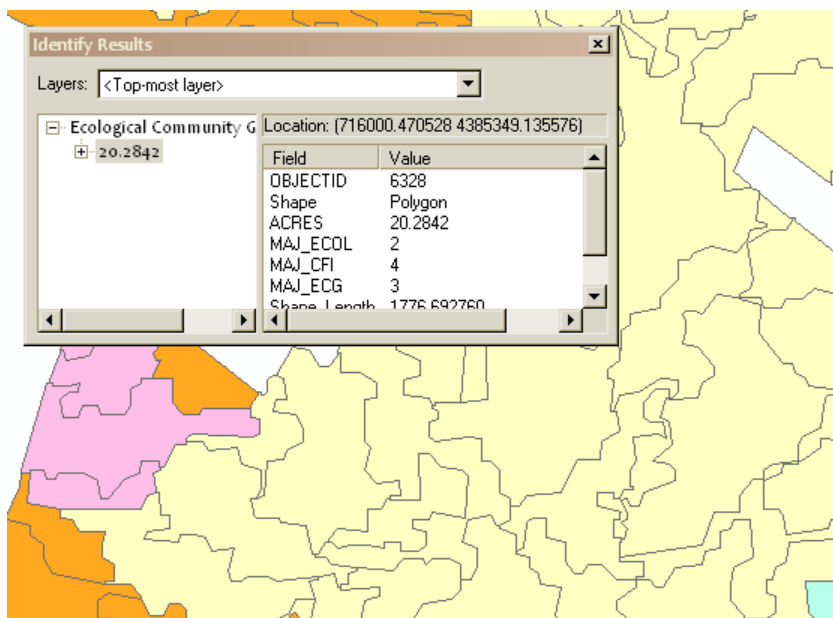


Figure 3.3 Geodatabase querying and polygons.

Also, the geodatabase allows for simple and instantaneous additions of new data using GIS software as well as database programs. For example, future harvests can be immediately added to the database by editing the data associated with those areas using initialized harvest data and if necessary, editing the polygon shape itself. Future inventory data can also be added to this database for immediate retrieval and analysis. However, it is recommended that the segmentation and classification processes be repeated with updated imagery and the new inventory data as to reflect the changes that surely have occurred since the previous survey.

## CHAPTER IV - CONCLUSIONS

The goal of this project was to delineate and classify forest management units in an efficient and cost effective method, leveraging current technology and available data as much as possible. This project would collect, compile, analyze, classify and manage the data necessary for the sustainable management of 200,000 acres of public forestland. The data and subsequent data management system will be used to gain and maintain third party forest management certification of Maryland's four major State Forests and Chesapeake Forest and to create a model for the sustainable management of other forestlands in Maryland.

Using automated image segmentation and analysis is extremely helpful and useful as a supplemental tool for creating stand mapping and delineation. At this point, it is still important for the user to supplement this tool with pre and post-classification ground data.

Chronological anomalies are the main problem with relying solely on this technology as imagery may be too old due to harvests or simply stand age. Also, imagery that is tainted by cloud cover or other natural anomalies can disrupt and spoil segmentation. Additionally, the monetary costs of obtaining and maintaining a good segmentation and classification system may deter some potential users from the ultimate benefits of its use, especially if it will only be used in a small area.

The differences in time spent using traditional methods of delineation and using Definien Developer is substantial. For example, a 200 hectare (494 acre) compartment potentially could take over a week to execute a full delineation and typing using aerial photographs, soil maps, and manual, ground-based mapping techniques. With Definien Developer, ESRI ArcGIS, and ERDAS Imagine, areas that are 100 times larger can be accurately segmented and classified in as little as a few weeks with the help of suitable data and preexisting knowledge of how to use the programs. Automated image analysis and classification also allows for more time to conduct additional, and more accurate, ground verification and correction.

Any forest manager that has been involved in a large scale inventory knows that getting crews to the field for data collection is a major portion of the overall budget. It is difficult to accurately state what the financial savings of this system would provide an organization or company since much of the initial project work was involved in learning the software applications and necessary procedures. Even after the formal project was completed, the technical staff was continuing to learn the numerous intricacies of the applications and fine tune the procedures. There currently are so few forest management organizations using this process that to find training and knowledgeable people to discuss procedures was difficult. However, with sufficient guidance, planning and effort, this system can be both efficient and accurate. As with most sophisticated software applications, it is critically important to maintain a certain level of activity and knowledge of its use or that expertise can be lost. More than a year after the initial study, the inventory work continues and the Definien application is utilized to update the stand classification predictions. When used in conjunction with ground verification, automated image analysis and classification can be a very effective way to manage and maintain a living database of a forest management program.

## LITERATURE CITED

- Braun, E.L. 1950. *Deciduous Forests of Eastern North America*. Blakiston Co., Philadelphia, PA, 596 pp.
- Definiens AG. 2007. Definiens Developer 7 Reference Book Version 7.0.2.936. München, Germany. Definiens AG. 197 p.
- Definiens AG. 2008. Definiens Developer 7 User Guide Version 7.0.5.968. München, Germany. Definiens AG. 506 p.
- Definiens AG. 2008-A. "Definiens Enterprise Image Intelligence™ Suite"  
[http://www.definiens.com/definiens-enterprise-image-intelligence-suite\\_44\\_7\\_8.html](http://www.definiens.com/definiens-enterprise-image-intelligence-suite_44_7_8.html) Last visited: Jan 8 2009.
- ERDAS, Inc. 1999. ERDAS Field Guide, Fifth Edition, Revised and Expanded. Atlanta, GA. ERDAS, Inc. 698 p.
- Fenneman, N.M. 1938. *Physiography of the Eastern United States*. McGraw-Hill, New York, NY, 372pp.
- Forest Stewardship Council A.C. 1996. FSC principles and criteria for forest stewardship, FSC-STD-01-001 version (4-0) EN (amended 2002), Bonn, Germany.
- Hamilton, R., K. Megown, T. Mellin, and I. Fox. 2007. Guide to automated stand delineation using image segmentation. RSAC-0094-RPT1. Salt Lake City, UT: USDA Forest Service, Remote Sensing Applications Center.
- Harrison, J.W. 2007. The Natural Communities of Maryland: Draft. Maryland Department of Natural Resources, Wildlife and Heritage Services, Annapolis, MD. Unpublished report. July 2007. 36pp
- Huang, C., Wylie, B., Yang, L., Homer, C., Zylstra, G. 2002. Derivation of a tasseled cap transformation based on Landsat 7 at-satellite reflectance. *International Journal of Remote Sensing* 23(8): 1741-1748.
- Lande, R. 1988. Demographic models of the northern spotted owl (*Strix occidentalis caurina*). *Oecologia* 75(4): 601-607.
- Laurance, W.F., Ferreira, L.V., Rankin-De Merona, J.M., and S.G. Laurance. 1998. Rain forest fragmentation and the dynamics of Amazonian tree communities. *Ecology* 79(6): 2032-2040.
- Lister, A. 2008. Imputing Forest Inventory Data to Stands Formed by Image Segmentation in Maryland's Green Ridge State Forest. In Proceedings of the 6th Southern Forestry and Natural Resources GIS Conference (2008), P. Bettinger, K. Merry, S. Fei, J. Drake, N. Nibbelink, and J. Hepinstall, eds. Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA. p. 48-59.
- Maryland Department of Natural Resources, Forest Service. 2008. Green Ridge State Forest Annual Work Plan, Fiscal Year 2010. 18p.
- Maryland Department of Natural Resources, Forest Service. 2008. Potomac-Garrett State Forest Annual Work Plan, Fiscal Year 2010. 36p.
- Maryland Department of Natural Resources, Forest Service. 2008. Savage River State Forest Annual Work Plan, Fiscal Year 2010. 20p.
- Montgomery, C.A., G.M. Brown, G.M. and D.M. Adams. 1992. The Marginal Cost of Species Preservation : The Northern Spotted Owl, Working Papers 92-13, University of Washington, Department of Economics.
- Owenby, J.R., and D.S. Ezell. 1992. Monthly station normals of temperature, precipitation, heating and cooling degree days 1961-1990. Climatography of the United States No. 81, U.S.

- Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC, 18pp.
- Sample, V.A., W. Price, J.S. Donnay, and C.M. Mater. 2007. National forest certification study: an evaluation of the applicability of Forest Stewardship Council (FSC) and Sustainable Forest Initiative (SFI) standards on five national forests. Pinchot Institute for Conservation.
- Skole, D., and C. Tucker. 1993. Tropical deforestation and habitat fragmentation in the Amazon: satellite data from 1978 to 1988. *Science* 260(5116): 1905-1910.
- Stone, K.M., and E.D. Matthews. 1977. Soil Survey of Allegany County, Maryland. U.S. Department of Agriculture Soils Conservation Service, 134pp.
- The Sustainable Forestry Initiative Inc. 2004. Sustainable Forestry Initiative Standard (SFIS) 2005-2009 standard (September 2008).
- Wieland, R.C., J. Horowitz, and D.E. Strebel. 2008. Estimating timber and non-market values of Maryland's state-owned forestland: a summary of three research papers. Harry R. Hughes Center for Agro-Ecology, HRHCAE Publication 2008-01-A, Queenstown, MD.
- Zipperer, W.C. 1993. Deforestation patterns and their effects on forest patches. *Landscape Ecology* 8(3):177-184.