Ecological Zones on the George Washington National Forest First Approximation Mapping

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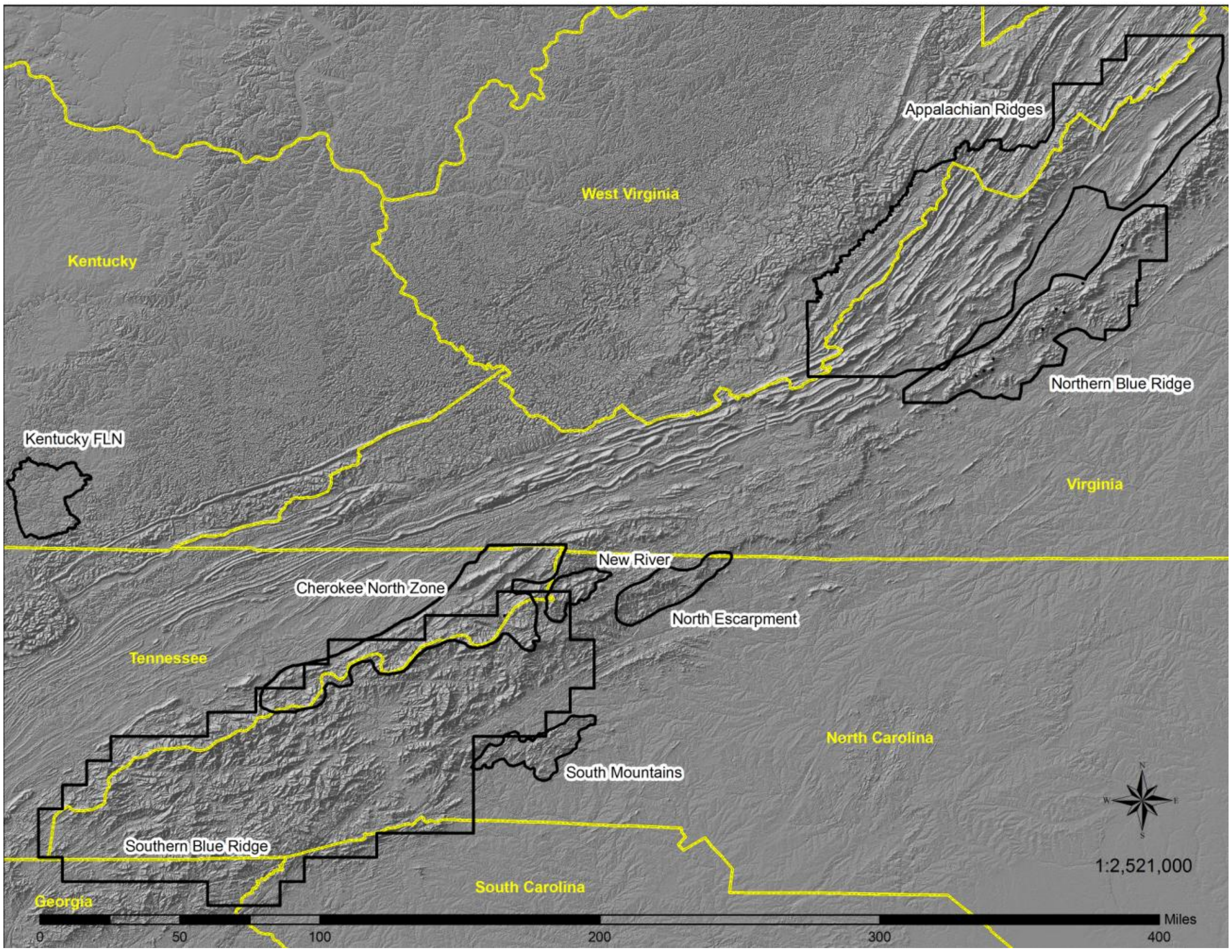
INTRODUCTION

Ecological Zones are units of land that can support a specific plant community or plant community group based upon environmental factors such as temperature, moisture, fertility, and solar radiation that control vegetation distribution. They may or may not represent existing vegetation, but instead, the vegetation that could occur on a site with historical disturbance regimes. They are equivalent to LANDFIRE's Biophysical Settings (2009) which "represent the vegetation that may have been dominant on the landscape prior to Euro-American settlement, based on both the current biophysical environment and an approximation of the historical disturbance regime".

Ecological Zones in the Southern Appalachian Mountains, identified from intensive field data that defined plant communities, were associated with unique environmental variables characterized by digital models (Simon et. al., 2005). These zones were mapped on over 5 million acres by applying logistic regression coefficients to digital terrain models using a geographic information system. In that study, Ecological Zones subdivided the forested landscapes in the Southern Appalachian Mountains into homogeneous units for natural resource planning at a range of scales. Since that study, Ecological Zones have been mapped in Kentucky, and in the South Mountains, Northern Escarpment, and New River Fire Learning Network (FLN) landscapes in North Carolina, and most currently in Virginia, centered on the George Washington National Forest (Figure 1). This report documents the methods and results of the most recent effort to model and map Ecological Zones on the George Washington National Forest in Virginia and West Virginia.

Figure 1. Location of Ecological Zone mapping in the Southeastern U.S.



Ecological Zones - background and uses: This term, developed in 2001, was used to define units of land that can support a specific plant community or plant community group based upon environmental and physical factors that control vegetation distribution, i.e., the past and potential landscapes based upon measurable environmental factors, such as climate, topography, and geology. Prior to this, comparable environmental models used for ecological classification in the Southeastern U.S. were called "plant association predictive models", "potential vegetation", or "pre-settlement vegetation".

The Chattooga River Ecosystem Management Demonstration Project started in 1993 in South Carolina, Georgia, and North Carolina, was the first attempt at applying environmental models, like those used for developing Ecological Zones, to predict 'potential' plant community distribution across extensive landscapes in the Southeastern U.S. One of the primary goals of this project was to produce an ecological classification that would provide the information for implementing ecosystem management tied to the National Hierarchical Framework of Ecological Units, "a regionalization, classification and mapping system for stratifying the Earth into progressively smaller areas of increasingly uniform ecological potential for use in ecosystem management" (ECOMAP, 1993). What are now termed Ecological Zones were then called "plant association predictive models" or "Potential Vegetation". In the Chattooga project, plant association predictive models were developed, under the guidance of Henry McNab - Southern Forest Service Experiment Station, based upon the relationships between field locations of example plant association types and digitally derived landform factors such as elevation, landform index, and relative slope position (McNab 1991). These models were used in combination with soil maps to develop ecological units at different resolutions, i.e., Landtype Associations, Landtypes, and Landtype Phases.

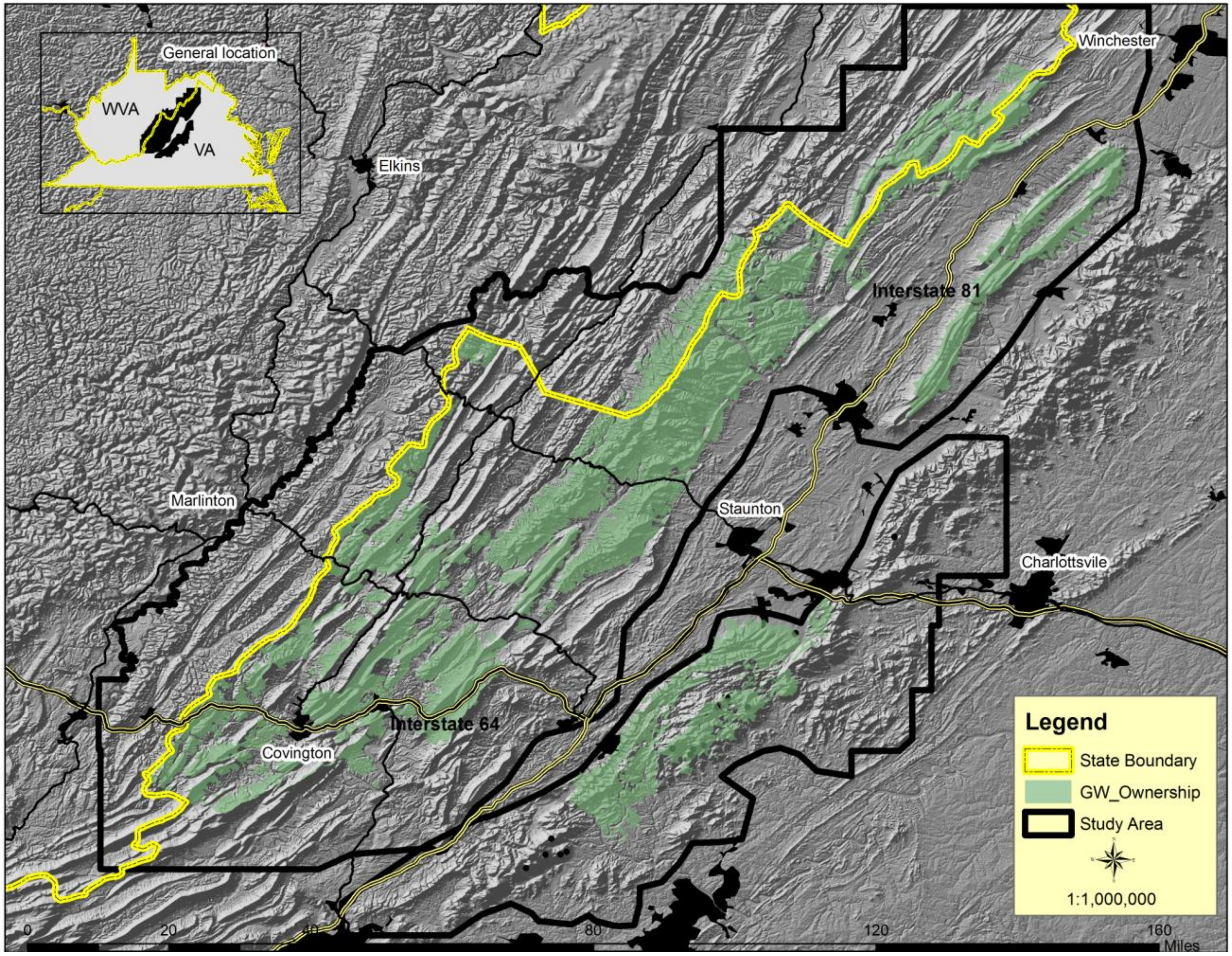
In 1999, as part of the forest planning process on the Croatan National Forest, pre-settlement vegetation maps, equivalent to Ecological Zones (Frost 1996), were used to develop an Ecological Classification that included: Landtype Associations, Landtypes, and Landtype Phases, "A new tool that needed to be incorporated into the revised Plan" (USDA 2002). An ecological classification system was developed for the Croatan National Forest that provided a basis for ecologically based land management decisions. This classification organized the landscape into "units having similar topography, geology, soil, climate, and natural disturbance regimes" (USDA 2002) and was used to define management areas, management prescription boundaries, standards, and to set forest-wide objectives. Similarly, in 2001, the Forest Service in cooperation with the Department of Defense (DOD), Camp Lejeune Marine Corps. Base, developed an Ecological Classification System (ECS) to guide conservation management decisions for their Integrated Natural Resource Management Plan (INRMP). The ECS was based, in part, on a report titled "Presettlement Vegetation and Natural Fire Regimes of Camp Lejeune" by Cecil Frost, January 24, 2001, a map analogous to Ecological Zones. In DOD's most current INRMP, Camp Lejeune continues to refer to the ECS for overall guidance on the desired future condition for specialized habitat areas, i.e., natural areas (DOD 2006).

In 2001, the staff of the National Forests of North Carolina conducted a status review of management indicator species (MIS) habitats and population trends using Ecological Zone mapping to quantify the amount and distribution of plant community types on the Nantahala and Pisgah National Forests (USDA 2004). Ecological Zones were also used to identify sites capable of supporting eastern and Carolina hemlock plant communities as part of a conservation area design to prioritize areas for Hemlock Woolly Adelgid control. This conservation area is currently being used to maintain, on portions of the Forests, important hemlock ecosystem functions and to serve as a genetic reserve to maintain a diverse hemlock gene pool 'in situ' (USDA 2005). Ecological Zones were used in the Uwharrie National Forest plan revision process to develop a map of the potential extent of Nature Serve Ecological Systems. This mapping provided the basis for the Ecological Sustainability Analysis and was used to define management areas, restoration areas, and desired conditions, and to help set objectives and guidelines (USDA, 2009). Ecological Zones were used in a Plan amendment to evaluate the appropriateness of various management indicator species on the Nantahala and Pisgah National Forests (USDA, 2005), and were combined with satellite imagery to map existing vegetation on the Nantahala National Forest in a multi-year, USFS Southern Region pilot project to demonstrate a process for mid-level existing vegetation mapping suitable in the hardwood dominated forests of the Southern Region (USDA 2006).

From 2008 to 2009, Ecological Zones were mapped in the Cumberland Plateau of Kentucky, and in the South Mountains, Northern Escarpment, and New River Fire FLN landscapes within the Southern Blue Ridge (SBR) in North Carolina to evaluate locations and extent of fire-adapted plant communities.

General description: The George Washington National Forest in Virginia and West Virginia (GW Study area) is primarily (60%) within the Appalachian Ridges subsection, an area that consists of long mountainous ridges and intervening valleys with primarily sedimentary rock. It also includes the Northern Blue Ridge Mountains subsection (20%), an area that consists of narrow mountains from 1,000 to 4,000 feet with primarily metamorphic, meta-sedimentary, and igneous rock. Also, the Massanutten Mountains, included within the Great Valley of Virginia subsection (10%), an area dominated by a broad valley with low hills and mountains having elevations of 700 to 3,000 feet with primarily meta-sedimentary rock, and the Northern High Allegheny Mountains of West Virginia (10%), a dissected plateau with primarily sedimentary rock. The study area is bounded to the east by the Southern Appalachian Piedmont and to the west by the Greenbrier River. The closest cities are Staunton, Marlinton, and Covington (Figure 2).

Figure 2. Location of the GW Study Area



METHODS

"Spatial models built with geographic information systems (GIS) provide a means to interpolate between data points to provide spatially explicit information across broad scales. By accounting for variation in environmental conditions across these broad scales, GIS models can predict the location of ecological communities within a landscape using relationships between vegetation and topography (e.g., Fells 1994, Bolstad et. al. 1998, Phillips

2000) derived from field data" Pearson and Dextraze (2002). The process of interpolating between field data points involves applying coefficients from predictive equations, developed through statistical analyses, to geospatial data that characterize terrain and environmental variables for the target landscape. Care must be taken not to extrapolate to landscapes far away from data points or to landscapes having very different environmental characteristics. Most of the data was collected on the GW National Forest and therefore Ecological Zone predictions outside of this area are likely less accurate.

A multi-stage process was used to model Ecological Zones in the project area that included: 1) data acquisition, i.e., identifying Ecological Zones at field locations, 2) creating a digital terrain GIS database and extracting environmental data, 3) statistical analysis, 4) spatial modeling, 5) post-processing of digital model outputs, and 6) evaluating the accuracy of Ecological Zone map units.

Data acquisition: Approximately 5 months during the 2009 and 2010 growing seasons were spent in the field documenting (through GIS, notes, and photos) the location of plant community types and Ecological Zones that occur across the project area. A laptop computer attached to a Global positioning system (GPS), to enable real-time locational tracking in the field, was used in conjunction with ArcGIS 9.3.1 to document on-site observations of ecological characteristics and to access resource data layers for each site. Sample sites predominantly in forested stands >60 years of age and not recently disturbed, were subjectively selected to represent uniform site conditions, i.e., similar aspect, landform, and species composition. Specifically, these reference sites for plant community types described in the literature for the Southeastern U.S. were targeted for sampling especially if they were in 'good condition' and therefore easily recognized. Of equal importance, was the evaluation of where these types occurred, i.e., their pattern on the landscape. Good condition plant community types found repeatedly within the same environments were therefore more heavily sampled. Quality control included a nightly review of individual plot photos, and Ecological Zone "calls", and a weekly review of these relationships based upon Nature Serve Ecological Systems and Virginia Natural Heritage Program plant community descriptions.

Ecological Zones were identified at over 3,700 sample areas by evaluating overstory and understory species composition, growth form, stand density, and site factors. A portion of the Pine-Oak Heath sample sites, (less than 10 plots and each well over 10 acres in size), were identified using a combination of 1-meter color Digital Ortho Photos, high powered binoculars, and topographic map data. Data from nearly 800 plots, collected within the project area during the past 15 years by the Virginia and West Virginia Natural Heritage programs (VA_WVA NHP 2009), were used in this sample. This generous contribution to the project included data for less common Ecological Systems such as Central and Southern Appalachian Spruce-Fir Forests, Southern Ridge & Valley / Cumberland Dry Calcareous Forests, and Appalachian Shale Barrens and provided the author a means of evaluating local ecological interpretations by visiting established plots within the area.

Ecological Zone classification units are relatively coarse and fairly easy to recognize in the field. They do not include most rare types such as barrens (except Shale barrens), bogs, cliff-talus, fens, glades, seepage swamps, small wetlands, or white cedar because the digital data needed to model these unique environments, such as rock outcrops and wetlands, are incomplete or at too coarse a resolution. The 25 different Ecological Zones identified in the study area, arranged from wet to xeric moisture regimes, are cross-walked below with George Washington National Forest ESE Tool Systems, Nature Serve Ecological Systems (NatureServe 2010) and Virginia Natural Heritage Natural Communities (Fleming and Patterson 2010) to help in describing the composition of types observed in the field and mapped across the study area (Table 1). More detailed site and species composition descriptions for Ecological Zones, Nature Serve Ecological Systems, and Virginia Natural Heritage Community groups are in Appendix I. This cross-walk reflects the author's ongoing adjustment of Ecological Zone concepts to fit local landscapes based upon work between 2008 and 2009 evaluating Biophysical Setting (BpS) map units (LANDFIRE 2009), in the Southern Blue Ridge Mountains in North Carolina, South Carolina, Tennessee, and Georgia, and modeling Ecological Zones in the Cumberland Plateau in Kentucky, in North Carolina's South Mountains and Northern Blue Ridge Escarpment, and in the VA_WVA FLN.

Table 1. Crosswalk between Ecological Zones, GW ESE Tool Systems, Nature Serve Ecological Systems, and Virginia Natural Heritage Program Ecological Groups or Community Types

Ecological Zone	map code	GW ESE Tool Systems (Forest Plan)	map code	NatureServe Ecological System	map code	Virginia Heritage Program Ecological Groups or Community Types
Spruce	1	Spruce Forest	1	Central and Southern Appalachian Spruce-Fir Forest	1	Spruce-Fir Forests
Northern Hardwood Slope	2	Northern Hardwood Forest	2	Appalachian (Hemlock)-Northern Hardwood, Southern Appalachian Northern Hardwood	2	Central App. Northern Hardwood Forests App. Hemlock-Northern Hwood. Forests
Northern Hardwood Cove	3	Cove Forest	3			High Elevation Rich Cove Forests
Acidic Cove	4			Southern and Central Appalachian Cove Forest	4	Acidic Cove Forests High Elevation Acidic Cove Forest
Spicebush Cove	25					Appalachian Rich Cove Forest
Rich Cove	5					Central and S.App. Rich Cove Forests Basic Mesic Forests
Alluvial Forest	6	Floodplains, Wetlands, and Riparian Areas	4	Central Appalachian River Floodplain, Central Appalachian Stream and Riparian	6	Piedmont / Mt. Alluvial Forests
Floodplain Forest	23					Piedmont / Mt. Floodplain Forests
High Elevation Red Oak	8	Oak Forests and Woodlands	5	Central and Southern Appalachian Montane Oak	8	Northern Red Oak Forests
Montane Oak-Hickory (Rich)	24			Central and Southern Appalachian Montane Oak (using a broader concept), Southern Appalachian Oak Forest (in part)	9	Central Appalachian Montane Oak-Forest (Rich Type)
Montane Oak-Hickory (Cove)	15					Montane Mixed Oak and Oak-Hickory Forests
Montane Oak-Hickory (Slope)	9					
Colluvial Forest	7			Northeastern Interior Dry-Mesic Oak Forest (mostly) Southern Appalachian Oak Forest (in part)	13	Montane Mixed Oak and Oak-Hickory Forests
Dry Mesic Oak	13					Acidic Oak-Hickory Forests
Dry Mesic Calcareous Forest	14			S. Ridge & Valley / Cumberland Dry Calcareous Forest	14	Dry-Mesic Calcareous Forests
Dry Oak Evergreen Heath	10			Central Appalachian Dry Oak-Pine Forest	10	Oak / Heath Forests
Dry Oak Deciduous Heath	11					
Low Elevation Pine	16	Pine Forests and Woodlands	6	Southern Appalachian Low-Elevation Pine	16	Pine-Oak / Heath Woodlands (in part) Oak / Heath Forests (in part)
Pine-Oak Heath (eastside ridge)	17			Southern App. Montane Pine Forest and Woodland, Central Appalachian Pine-Oak Rocky Woodland (in part)	18	Central and Southern Appalachian Pine-Oak / Heath Woodlands
Pine-Oak Heath (westside ridge)	18					
Pine-Oak Heath (ridgetop)	19					
Pine-Oak Shale Woodlands	22			Central Appalachian Pine-Oak Rocky Woodland (in part), Appalachian Shale Barrens	22	Central Appalachian Xeric Shale Woodland
Shale Barren	21	Cliff, Talus and Shale Barrens	7	Appalachian Shale Barrens	21	Central Appalachian Shale Barrens
Alkaline Woodland	12	Mafic Glade and Barrens and Alkaline Glades & Woodlands	8	Central Appalachian Alkaline Glade and Woodland	12	Montane Dry Calcareous Forest & Wdls.
Mafic Glade and Barren	26			Southern and Central Appalachian Mafic Glade and Barrens	26	Low Elevation Basic Outcrop Barrens, High Elevation Outcrop Barrens Central Appalachian Basic Woodlands

Creating a digital terrain database: Development of the individual Ecological Zone models began with the creation of a spatial database that described the study area environment using landform and environmental variables. Site conditions for each field plot were extracted these 32 landform / environmental models (DTMS) used to characterized these variables (Table 2) in a GIS. For statistical analyses, data were stored in a database that included plot number, Ecological Zone, and digital landform / environment values for each plot. The methods used for developing DTMs are described in detail in Appendix III.

Table 2. Environmental variables evaluated for Ecological Zone model inclusion

Aspect (slope direction in degrees)
Aspect (slope direction in cosine of radian degrees)
Curvature of land all directions
Curvature of land in the direction of slope
Curvature of land perpendicular to slope
Distance to stream
Distance to river
Elevation
Distance to carbonate-bearing rocks
Distance to mafic-silicate rocks
Distance to siliciclastic rocks
Distance to carbonaceous-sulfidic rocks
Distance to very acid carbonaceous-sulfidic rocks (Brallier Formation)
Landform index (from McNab 1993)
Average annual precipitation
Local relief
River influence
Difference in elevation from nearest river
Surface curvature roughness
Relative slope position (from Wilds 1997)
Slope length
Slope steepness
Distance to high snowfall zones
Distance to the Great Lakes (influence of lake effect snow)
Solar radiation (yearly)
Solar radiation (growing season)
Difference in elevation from nearest stream
Terrain relative moisture index (from Iverson et.al. 1997)
Terrain shape index (from McNab 1993)
Valley position
Distance to high snowfall zones
Distance to river

3) Statistical analysis: The relationship between Ecological Zone and environments, characterized by DTMs, were analyzed and predictive equations developed at this stage of the process. Ecological Zone field locations were used to train habitat suitability models using MAXENT 3.2.1 (Phillips and Dudik 2004). MAXENT (maximum entropy) is a relatively new modeling approach (Phillips, et. al. 2004, 2006) that emphasizes the ecological characteristics of a location where a target species is observed (an Ecological Zone in our case) as the primary focus while presuming nothing about locations where these condition are not observed. MAXENT, unlike logistic regression, is therefore a “presence only” modeling approach; it used only Ecological Zone presence (the field data points) to estimate individual Ecological Zone models across the project area. MAXENT works by finding the largest spread (maximum entropy) in a geographic dataset of Ecological Zone presences in relation to a set of environmental predictors for these same locations and 100,000+ randomly selected points / pixels within the project area. The MAXENT logistic

outputs are continuous estimates of habitat suitability (probability) for each Ecological Zone ranging from zero to one for each pixel within the project area. This analysis process is described in Appendix IV.

4) Spatial modeling / creating final Ecological Zone maps: To produce a final Ecological Zone (Zone) map, all Zone models were merged and each pixel in the project area was first assigned to the Zone having the highest probability for that pixel. In the event of a "tie", preference was given to the less extensive Zone(s) by using the ArcGrid 9.3.1 Merge command preference of order. Although MAXENT works well to predict the distribution of individual Zones, merging the models in this fashion did not always reflect the true field condition because of different model 'strengths'. To better balance individual Zone model strengths, a 'sensitivity analysis' based upon accuracy evaluations (Appendix V), was used to adjust probability levels across the project area for some models. For example, the High Elevation Red Oak Ecological Zone had lower probability levels relative to all Zones found at similar elevations and slope positions, especially Montane Oak-Hickory (rich) and Pine-Oak Heath (ridgetop). By increasing High Elevation Red Oak probability levels by just .03 across the project area, the distribution of this Zone based upon field plots, local knowledge, and the overall accuracy of this type, was improved significantly.

The Mafic Glades model was processed separately from the other types until the final mapping. A probability of .31 was chosen as the threshold value to define the type and was based an accuracy of 60% for the 23 plots documented in the project area (most of which were outside of the GW ownership).

5) Post-processing of digital model outputs: Post-processing was used to reduce "data noise" i.e., the number of isolated single 10x10 meter pixels (about 1/40th of an acre in size) within the combined Ecological Zone model area and to improve processing time for converting pixels to polygons. This post-processing included 1 ArcGrid Majority filter command which replaces cells in a raster based on the majority of their contiguous neighboring cells. An additional ArcGrid Majority filter was used to produce the Nature Serve Ecological Systems and GW ESE Tools System grids. If there is a desire to produce maps having a defined minimum map unit size, then further processing is recommended using the ESRI "eliminate" command, however this tends to overemphasize the size of major types at the expense of less common types.

6) Assessing the accuracy of Ecological Zone map units: Field plots were used as reference data to evaluate the accuracy of the final Ecological Zone maps. Although this is a biased measure of accuracy because these were the same data used to produce the predictive equations, MAXENT does not force a classification upon a sample plot based upon its location, rather, environmental data from that location is used to model the **entire** landscape with no bias to where a plot is located. Also, using field plots as reference data is a reasonable means of objectively comparing different analysis methods and does indicate how well map composition reflects the plot data composition in these landscapes in comparison to other areas where Ecological Zones have been identified.

RESULTS and DISCUSSSION

The location, extent, accuracy, and usefulness of Ecological Zones modeled in the project area were evaluated from the following:

1) Field observations
2) Relative importance of environmental factors in predicting Ecological Zones (Tables 3 to 6)
3) Accuracy of map units relative to field sample plot information (Table 7 and Appendix V)
4) Location and extent of Ecological Zones based on acreage of map units (Table 8), Nature Serve Ecological Systems (Table 9), GW ESE Tool Systems (Table 10), and displays relative to topography (Figures 3 to 7) and,
5) The extent of fire-adapted plant communities within Ecological Zones and their mapped accuracy (Tables 6-9, Appendix V). Two fire-adaptation classes, less-adapted and more-adapted, were evaluated using the same classes assessed in North Carolina and Kentucky for FLN Ecological Zone mapping projects (Simon 2008, 2010). These two classes are based on target communities identified by the SBR Fire Learning Network in 2008 for restoring fire regimes (http://www.tncfire.org/training_usfln SBRfln.htm).

They include pine-oak heath, shortleaf pine-oak, dry-mesic oak-hickory, and high-elevation red oak forests (and their equivalent Ecological Zones); the assumption was made that more mesic zones (alluvial forests and wetter) were less fire-adapted. A refinement of these groups is possible, and may follow methods described in "*Rule-based Mapping of Fire-adapted Vegetation and Fire Regimes for the Monongahela National Forest*", (Tomas-Van Gundy et. al. 2007).

1) <u>Field Observations</u>: The most common Ecological Zones observed in the GW study area were those that support oak-dominated communities, especially Dry Oak and Dry-Mesic Oak. Dry Oak sites were dominated by chestnut oak and had three distinct stand and understory conditions; open woodlands on broader ridges especially on limestone, woodlands to forests with a dense mountain laurel understory most often associated with Pine-Oak heath at mid to higher elevations, and forests or woodlands with a dense to sparse huckleberry and blueberry understory and only occasional mountain laurel at mostly mid to lower elevations. Dry-Mesic oak sites were dominated by white oak with a sparse understory and were situated in concave portions of the landscape or associated with broader floodplains on colluvial surfaces; dry-mesic to sub-mesic oak sites in the later situation were labeled 'Colluvial Forests'. Highly dissected slopes on the northwest-facing side of major ridges were dominated by Pine-oak heath on west-facing slopes, and Dry Oak or Dry-Mesic Oak on northwest to north facing slopes. Table mountain pine was the predominant species in this Pine-oak heath. This striking pattern of alternating Pine-Oak and Oak Ecological Zones repeated itself across these landscapes throughout the project area but were more subtle in the Blue Ridge. A much weaker but similar pattern was observed on the southeast-facing slopes of major ridges in the Appalachian Ridges portion of the study area. There, the Pine-Oak Heath occurred in much smaller patches confined to south-facing slopes and pitch pine was more common than table mountain pine. Pine-Oak heath was also observed on high ridges where it mixed with High Elevation Red Oak types. Patch sizes were typically small in these situations.

Except for areas closest to the Allegheny Plateau, Northern Hardwood types were confined to more concave landscapes on the northwest-face of major ridges where they mixed with Montane Oak-Hickory and High Elevation Red Oak types. Differentiating between these latter two types was difficult because they formed a very broad transition zone along most high ridges and often included Dry Oak types intermixed on the most exposed sites. Along broader ridges and near saddles, Montane Oak-Hickory (rich) types occurred especially in the Blue Ridge associated with mafic rock. Spruce was observed only in the northwest portion of the study area and patterns in this area have been highly altered from farming and pasturing. Only along cold air drainages below higher ridges was a distinct Spruce Ecological Zone discernable. However, some of the highest ridges had remnant spruce stands or were planted extensively to Red spruce, presumably based on historical evidence / local knowledge that these areas once supported spruce. Rich Cove Forests were uncommon except in limestone lithology and most of these areas have likely had multiple timber harvests and were highly disturbed and therefore hard to interpret. Spicebush Coves were common in these same environments in the Blue Ridge but small and less extensive in the Appalachian Ridges. Very distinctive Virginia pine dominated woodlands were observed at low elevations on west-facing slopes mostly on loose, friable, shale. Trees on these steep sites were stunted and gnarled and the understory was very sparse and often lichen dominated. These types did not seem to fit the typical shale barren description where continual undercutting of weak shale strata by a river maintains a poorly vegetated hillside. Instead, they seem to fit the description for Mountain / Piedmont Acidic Woodlands (VA Natural Heritage program 2009) and were placed in the Pine-Oak Shale Woodlands Ecological Zone. Recognition of vegetation / landform patterns was most difficult in limestone areas and on lower elevation gently sloping broad ridges where apparently continual management has occurred on these productive sites. However, a distinct pattern was observed on some broad low ridges on sandstones and metasediments where occasional shortleaf pine was observed. These sites and species composition looked similar to extensive pine types observed in Kentucky, North Carolina, and Georgia, and to what has been described historically in lower elevation forests in Virginia. They therefore warranted recognition and fit well with the description for the Nature Serve Southern Appalachian Low Elevation Pine Ecological System. Photo examples for most of these types are included in Appendix II.

<u>2) Relative importance of environmental factors</u>: The relationship between plant community types and the environments in which they occur (the Ecological Zone) can be evaluated by examining the relative importance of environmental variables found by MAXENT to be the best predictors of Ecological Zone location (Tables 3-5). Some of these relationships are fairly straight-forward, others are not. For example, MAXENT identifies elevation as the primary environmental factor to define the distribution of Spruce, Northern Hardwood, High Elevation Red Oak, Pine-Oak Heath (ridges), and Montane Oak-Hickory (rich) (Tables 3-4), and for Shale Barrens and Pine-Oak Shale Woodlands – their association with very acidic carbonaceous-sulfidic rocks (or their distance away from carbonate-bearing rocks) primarily and secondarily with aspect and slope (Pine-Oak Shale Woodlands) and distance to rivers or river influence (Shale Barrens). Similarly, the primary environmental factor that drives the distribution of Pine-Oak heath, on both sides of major ridges in the Appalachian Ridges, is aspect and for Alluvial Forests is slope, and secondarily the distance above rivers, distance to streams, and valley position. Geologic substrate strongly influences the distribution of Rich Cove and Dry-mesic calcareous forests, i.e., both are centered on carbonate-bearing rock.

Table 3: Relative contribution (%) of environmental variables used for Ecological Zone models in the Appalachian Ridges study area. The variable making the highest contribution for each type is highlighted in yellow.

EZONE	SF	NhW	NhC	Acov	Rcov	Allu	Fld	Hero	MonR	MonS	MonC	Collu	Dmok	Dmcal	DryE	DryD	LowP	PohW	PohE	PohRd	POshl	ShaleB	AlkW
Code / DTM	1	2	3	4	5	6	23	8	24	9	15	7	13	14	10	11	16	17	18	19	22	21	12
Asp_r	-	-	-15	-	-4	-3	-	-		-	-		1	-	6	2	-	+23	6	2	+4	-	3
Asp_c	-	-	-	-	-	3	-	-		-	+5		-	2	-	2		7	-21	3	-11	2	2
Curve		-	-	-						-	-		-		-					-			-
Curpl		-		1	-	-	-	-	-	-	-5		2	-	+4	2		-	-	-	-		-
Curpr			-	-		6	2			-	-				-	-	-	-	-			1	-
Dstrm	3			-16	1	-11	1	-	2	-	+10	-	-	2	-	-	+4		+4	+4	1	-	-
Driver	+10	-	2	+11	-	1	2	1	2	2	+5	2	2	1	3	1	1	+4	-	-	2	-21	
Elev	+59 [1/]	+53	+47	-	2		-	+29	+7	+7	-	-	-8	1	3	2	-12	-4	-	+48	3	3	1
Geo1	+4	+19	3	-	-15	6	3	1	-	2	1		+5	-38	1	8	-21	-	+2		18	3	-32
Geo2	2	3	-7	-	9		-	-	3	6	+5		+5	10	9	5		4	-10	+5	-	2	
Geo3	2	-	-	-3	2	2	1	-	-	-10	-10	2	-10	+5	3	-7	-	-7		-11	-7	1	+17
Geo4	- [2/]	-	3	-	-		-	-		-	-		1	2	2	1	+9	-		1	-	-	1
Geo6	+5	1	1	+6	+5		-	+6	2	5	6	-16	2	-	+9	+14	+3	-3	-6	2	+14	-20	1
Lfi	-	-	-	+17	+17	2	2		1	-		2	-	1	-	-			1				1
Prec		3	2	1	-	+5		-	2	-			-	1	-	-	-	-			-8		-
Relief	2	2		+10	-		7	3	1	20	2	+6	+8		+32	5		+9	4		-	-	-
Rivinfl		-		-	-	-4	1	-	-	-		-	-	+12	-	-	-	1	1		-	18	+32
Rivdiff		3	-	-4	1		-56	27	31	16	+18	-26	-7	2	-8	10	+11	+3		+16	-	2	
Rough	2	-		-	2	+4	-	-	-	-	-	+4	3	-	1	2	2	2		-	2		-
Rsp		3	+7	-3	3	-4	-	-	-7	-	+25	3	-	-	3	3	-	-2	-8		-6	2	2
Slength	-			-	-		-	-	2	-	-		-	+4	-	1	-	-	1		-		-
Slope	-4	1	-8	-	2	-29	-10	-	-	-	1	-12	3	+5	-	1	-21	-			+13	+8	+4
Snow1		-5	-	3	8	-	-	2	+4	4	3		14	2	8	10	2	2	7		2	2	-
Snow2	-7	-	3	-	-	1	3	+4	-	6		3	5		4	11	+11	+9	4		6	-	
Solyr		-	-	-	3		-	3		1			-	-	-	-		-	-	-		-	--
Solgw		-	-	-	-			-	+7	2			1	-	-	-		-	-				
Stmdiff		-	-	-13		3	-	1	1	-	-	4	2		1	+5	1	+11	+16	1	2	-	
Trmi			-	-	-	3	-	-	1	-			-	-	-	-						-	-
Tsi		1		-	-18			-		-		-	-11	-	-	-		-2		-		2	
Vpos		-		-	4	+16	4	-17	-25	-12	-	-10	3	7	1	5	-	-	7	6		+4	-
n	28	97	26	187	100	15	74	166	17	243	43	13	293	62	377	204	39	215	81	22	79	41	26

[1/] The + or – sign that precedes the variable value (for variables having at least a 5% contribution) indicates the relational direction of the variable. For example, elevation in Spruce-fir (SF) is +59 which indicates that as elevation increases, so does the 'gain' in the model prediction for this type. No sign indicates either that the gain is not linear or that there is confusion in interpreting the relationship. [2/] less than 1% but included in the prediction equation, blank indicates a variable that was not included in the prediction equation.

These relationships were all obvious in the field and from viewing digital terrain data in comparison to individual Ecological Zone models. Not so obvious in the field was the influence of high snowfall areas and the distribution of Northern Hardwood Coves or why multiple rock types contribute information for so many Zones. This latter relationship, however, is likely due to the fact that the influence of rock types was analyzed as a continuous "distance to" variable and not a class variable. Also, relationships between Ecological Zones and environmental variables get confusing because many variables used in this analysis provide redundant information and are therefore correlated. Elevation, relative slope position, distance to stream, and solar radiation, for example, can all have an influence on temperature and moisture. Although MAXENT "finds" the variable or combination of variables that contribute most to predicting each type, care must be taken in interpreting these relationships because of the complexity of variable interactions and the statistics used in 'fitting' models. In addition, MAXENT unfortunately does not provide a negative or positive sign for the important variables which further complicates interpretation, but this can be evaluated by viewing variable frequency distributions (Table 6).

Table 4: Relative contribution (%) of the environmental variables used for Ecological Zone models in the Blue Ridge study area. The variable making the highest contribution for each type is highlighted in yellow.

EZONE	NhW	NhC	Acov	Scov	Rcov	Allu	Hero	MonR	MonS	Dmok	DryE	DryD	LowP	Poh	Mafic
Code / DTM	2	3	4	25	5	6	8	24	9	13	10	11	16	17	26
Asp_r			-	-5	-4	-	-	-	-	-	-	-		+10	-
Asp_c	6		2	2	-	-	-	-	-	-	2	-	2	2	3
Curve			2				-			3	-	-			-
Curpl	-		-		-			-	-	-	3	-	-	+4	-
Curpr			2	-			-		-	-	-	-	2	-	
Dstrm	3		3	-12	1	-11	-	-	-	-	-	-	-	-	-
Driver	-		+10	2	-	7	-		2	-	2	2	2	-	
Elev	+39	+70 [1/]	-5	-	2	-	+67	+64	+25	10	+15	-	10	+13	-
Geo1	2	- [2/]	4	11	-15	-5	-	-	2	14	7	3	-9	7	2
Geo2	3	2	-7	-19	9	-4	-	-17	-6	1	2	2	-9	-11	-
Geo3	+35	-	1	8	2	-	-	2	2	2	2	-8	-17	-	2
Geo4	-	3	-	-	-	-3	2	-	2	9	5	6	-	14	-
Geo6			-		+5		-		-	-	-	-		-	-
Lfi	-		+10	+11	+17	+4			-	-	-	-	-4	-	-
Prec		-11	-	16	-	2		2	2	11	+12	-12	-10	2	3
Relief	-	-	3	3	-	-	+5	1	13	7	5	+8	-	3	+6
Rivinfl			1	-	-	-	-	-	-	1	-	-	-4	-	3
Rivdiff	-	2	-	-	1	-15	3	3	-	-	-	-	-6	-	
Rough			-		2	+15	-		-		-	-	2	-	2
Rsp	1	+7	+15		3	1	-	2	-	2	-	1	-7	1	-
Slength	-		-	-	-	1	-	-	1	-	-	-			+12
Slope		-	-	-	2	-28	-	-	1	1		-	7	-	+22
Snow1		-	5		8		2	-	16	-	5	-8		1	1
Snow2	-		15	2	-		-6	2	-19	29	31	26	2	-13	3
Solyr	-		-	-	3		-			-	-	2		-	
Solgw			-		-		-		-	-		-		-	2
Stmdiff	-		2	1			3	-	-		2	+7	-	11	+33
Trmi		3	-		-	-	-	-	-		-	-		-	
Tsi	7	-	7	-	-18	-	-				-	-		-	-
Vpos	-		1	-	4	2	2	-4	1	3	-	1	+6	3	-4
n	21	12	81	21	100	31	122	78	199	136	233	115	11	151	23

[1/] The + or – sign that precedes the variable value (for variables having at least a 5% contribution) indicates the relational direction of the variable. For example, elevation in Northern Hardwood Cove (NhC) is +70 which indicates that as elevation increases, so does the 'gain' in the model prediction for this type. No sign indicates either that the gain is not linear or that there is confusion in interpreting the relationship. [2/] less than 1% but included in the prediction equation, blank indicates a variable that was not included in the prediction equation.

The importance of environmental and landform factors that control Ecological Zone distribution in the project area can also be evaluated by looking at those variables that were used most often in the models (Table 5). Elevation and the distance to carbonate-bearing rocks had at least a 5% contribution in more models than all other variables. Four of the top seven variables were associated with lithologic type, an indication of the effect that fertility has on plant community distribution in the project area. Local relief, distance to high snowfall zones, elevation above rivers, and valley position, also within the top seven variables used, reflect the broader scale influence of landscape configuration and topography, so important in the area, while slope steepness, relative slope position, and elevation above the nearest stream helped to define finer-scale variation in Ecological Zone distribution. These finer scale variables along with elevation have a strong effect on temperature and moisture regimes. On the other hand, solar radiation, terrain relative moisture index, and most surface curvature variables used to describe the finest-scale land surface configuration, made little contribution to the models. This is probably due to redundancy within the environmental variable set, i.e., other variables were better able to explain these same factors. For example, slope steepness, relative slope position, and terrain shape index individually were perhaps better able to explain moisture regime than terrain relative moisture index which combines these same variables into one value (Appendix III).

Table 5: Environmental variables having at least a 5% contribution to the Ecological Zone models

Environmental variable	% of all models	% of models App. Ridges	% of models Blue Ridge
Elevation	50	39	67
Distance to carbonate-bearing rocks	45	44	47
Distance to mafic-silicate rocks	45	44	47
Local relief	37	35	40
Distance to high snowfall zones	37	30	47
Distance to very acidic shales	34	52	7
Difference in elevation from the nearest river	34	48	13
Distance to siliciclastic rocks	34	39	27
Slope steepness	29	35	20
Distance to the Great Lakes	29	26	33
Valley position	26	39	7
Average annual precipitation	21	9	40
Relative slope position	18	17	20
Difference in elevation from the nearest stream	18	17	20
Aspect in degrees	16	17	13
Distance to closest river	16	17	13
Aspect cosine	13	17	7
Distance to closest stream	13	13	13
Landform index	13	9	20
Terrain shape index	13	9	20
Distance to carbonaceous-sulfidic rocks	13	4	27
River influence	8	13	-
Surface curvature perpendicular to slope direction	3	4	-
Surface curvature in the direction of slope	3	4	-
Solar radiation during the growing season	3	4	-
Surface curvature roughness	3	-	7
Slope length	3	-	7
Surface curvature	-	-	-
Solar radiation during the entire year	-	-	-
Terrain relative moisture index	-	-	-

Table 6: Median Ecological Zone map unit values for environmental variables that describe temperature, fertility, moisture, and radiant energy gradients among Zones within the project area (values are rounded). Highest and lowest values (or most informative) in bold.

		Temp.	Fertility (Distance to Geologic Type, in meters)[1/]				Moisture, Temperature, Radiant Energy, and Fertility[2/]						
ap code	Ecological Zones	ELEV. ft.	GEO1	GEO2	GE03	GEO4	SLOPE	VPOS	RPOS	ASP	LFI	TSI	DRIV
1	Spruce	3,730	**4,080**	9,500	490	**0**	19	33	31	199	11	-6	**2,180**
2	Northern Hardwood Slope	3,290	3,580	11,910	1,330	**0**	36	40	30	212	17	**3**	1,210
3	Northern Hardwood Cove	3,380	2,890	11,620	1,060	**0**	**46**	48	46	**77**	**24**	**-74**	1,050
4	Acidic Cove	1,950	3,090	9,190	440	464	26	68	**66**	209	**21**	-48	480
25	Spicebush Cove	1,200	3,380	**80**	440	**13,440**	27	66	**70**	**82**	**21**	-16	810
5	Rich Cove	1,650	**0**	16,230	1,580	530	25	57	58	**90**	19	**-96**	940
6	Alluvial Forest	1,130	1,220	12,200	920	1,140	**3**	78	60	**90**	10	-15	**310**
23	Floodplain Forest	1,420	730	17,260	660	**40**	**5**	**84**	40	135	12	-19	**60**
8	High Elevation Red Oak	3,450	1,730	6,070	**0**	490	30	**12**	**12**	228	11	29	**2,040**
24	Montane Oak (rich)	3,070	**4,210**	**80**	660	**14,650**	29	16	**12**	146	**9**	13	1,750
9	Montane Oak Slope	2,710	2,180	13,530	70	380	39	30	27	153	17	**5**	1,430
15	Montane Oak Cove	2,260	1,090	23,390	130	140	31	49	76	135	**21**	**-241**	1,760
7	Colluvial Forest	1,450	1,080	**25,220**	1,050	270	7	**82**	21	135	12	**2**	**200**
13	Dry Mesic Oak	1,620	1,280	13,600	570	720	20	58	37	153	13	-14	800
14	Dry Mesic Calcareous	1,470	**0**	18,040	**3,760**	740	16	51	23	162	10	11	580
10	Dry Oak Evergreen Heath	2,340	1,950	13,120	130	270	32	47	20	237	15	38	1,230
11	Dry Oak Deciduous Heath	1,680	1,840	12,100	270	340	30	47	17	135	13	39	1,050
16	Low Elevation Pine	**1,110**	2,570	3,880	**0**	2,600	10	51	17	156	**8**	8	860
17	Pine-Oak Heath (eastside ridges)	2,310	1,150	**23,080**	760	**0**	34	47	13	**195**	15	172	1,090
18	Pine-Oak Heath (westside ridges)	2,060	1,970	13,590	**0**	1,430	32	43	17	**264**	15	34	1,260
19	Pine-Oak Heath (ridgetops)	**4,010**	2,520	21,800	**0**	230	28	**12**	13	243	10	65	**2,320**
22	Pine-Oak Shale Woodland	1,660	2,520	20,580	1,960	190	34	51	21	214	15	93	640
21	Shale Barren	1,280	1,270	21,360	2,400	900	26	61	22	164	12	37	**64**
12	Alkaline Forest and Woodland	1,250	**0**	16,460	**3,660**	1,900	19	45	24	214	**9**	51	370
26	Mafic Glade and Barren	2,630	3,380	**476**	490	**15,570**	**61**	23	18	177	**22**	10	1,380
	average median	2,160	1,900	13,370	970	2,260	27	48	32	168	15	3	1,050

[1/] Geo1 = Carbonate-bearing rock, Geo2 = Mafic-silicate rock, Geo3 = Siliciclastic rock, Geo4 = Carbonaceous-sulfidic rock. [2/] Slope in percent, VPOS = valley position (100 = valley bottom, 0 = major ridge top), RPOS = relative slope position (100 = bottom of slope, 0 = top of secondary or major ridge), LFI = landform index (larger numbers indicate more sheltered sites), TSI = terrain shape index (land surface shape, negative numbers are degree of concavity, positive numbers are degree of convexity), DRIV = distance to the closest 4th order or greater stream in meters.

3) <u>Map unit accuracy</u>: The following discussion is based on intersecting 3,765 field plots with the first approximation Ecological Zone and Nature Serve Ecological Systems maps. Details of this accuracy evaluation are included in Appendix V. Overall accuracy within the project area for Ecological Zones is 77% and for Nature Serve Ecological Systems map units is 83%. This compares favorably with other Ecological Zone modeling within the Southern Blue Ridge and in the Kentucky FLN (Table 5), especially given the size of the GW project area and the number of zones modeled. More Ecological Zones were modeled in the GW project area than in other areas; this allowed for a finer breakdown of the Dry Oak and Pine-Oak Heath types. Most plots misclassified by type occur in the correct fire-adapted group therefore the 97-98% overall accuracy for more fire-adapted types is greater than for individual Ecological Zones (Table 5).

Northern Hardwood Cove had the highest accuracy by zone (89 to 100%) and 13 other types (Spruce-fir, Northern Hardwood Slope, Acidic Cove, Rich Cove, High Elevation Red Oak, Dry-Mesic Oak, Dry-Mesic Calcareous Forest, Low Elevation Pine, Pine-Oak Heath (east), Pine-Oak Shale Woodland, Shale Barren, Alkaline Woodland, and Mafic Glade and Barren) exceeded 80% accuracy. Five types had accuracy levels below 70%, four in the Appalachian Ridges (Alluvial Forest, Dry Oak Evergreen Heath, Dry Oak Deciduous Heath, and Pine-Oak Heath ridges) although accuracy exceeded 70% in the Blue Ridge for these types, and one in the Blue Ridge (Montane Oak-Hickory rich) although accuracy was nearly 80% in the Appalachian Ridges. The Pine-Oak Heath ridge zone had the poorest accuracy of all types and was confused primarily with High Elevation Red Oak, a type occurring in close proximity (Appendix V, Table 1). The two types form a true mosaic of conditions likely due more to disturbance regime than environment.

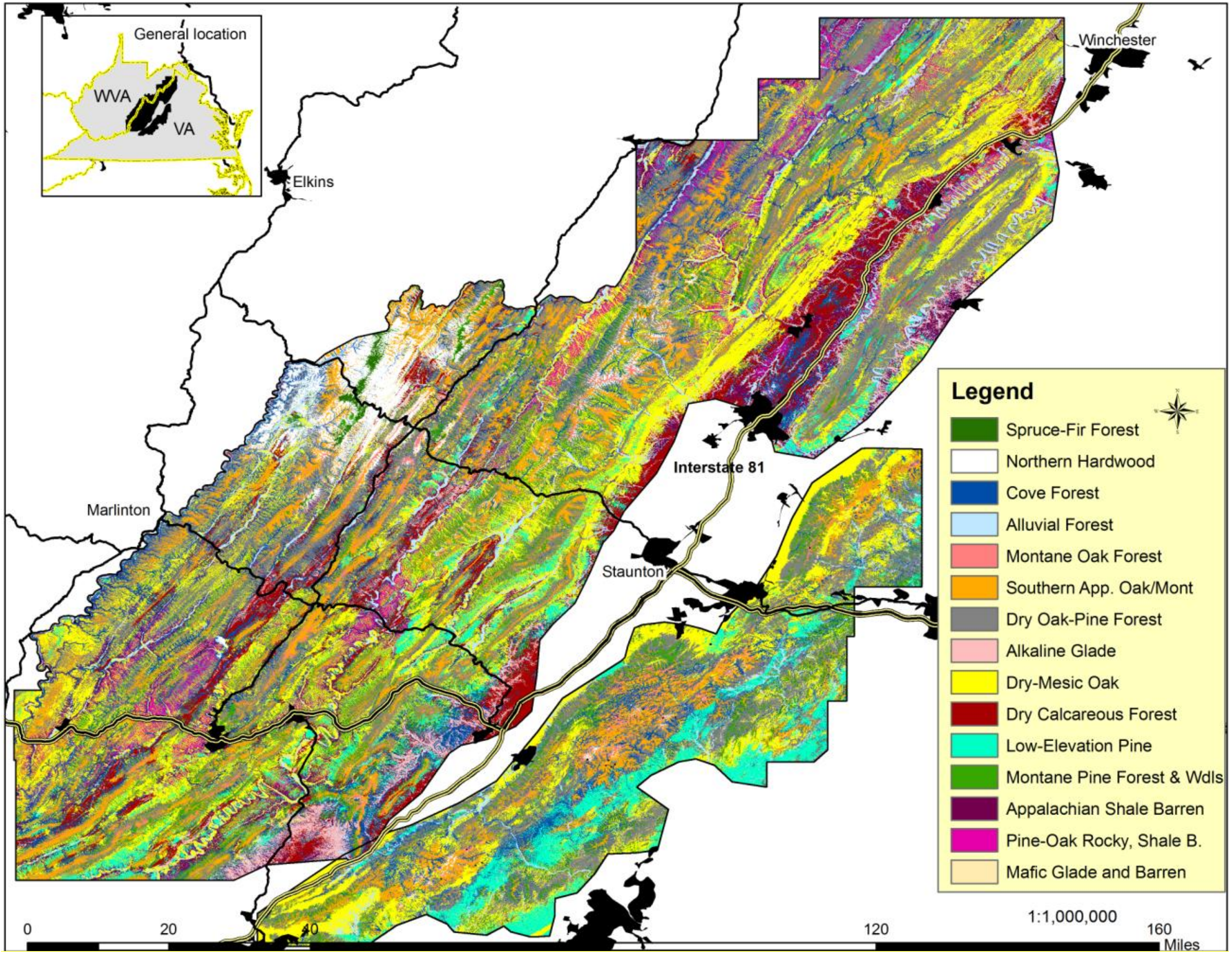
Table 7: Comparison of Ecological Zone accuracy across the GW, Kentucky FLN, and the Southern Blue Ridge (SBR) study areas

Ecological Zone	GW Appalachian Ridges	GW Northern Blue Ridge	Kentucky FLN	Northern Escarp. SBR	South Mts. SBR	Other SBR
Size of area (acres-rounded)	3,761,700	1,026,200	278,000	233,000	217,000	5,600,000
	Percent correct					
Grassy Bald	-	-	-	-	-	30
Heath Bald	-	-	-	-	-	19
Spruce-Fir	89	-	-	-	-	53
N. Hardwood Slope	86	81	-	-	-	70
N. Hardwood Cove	89	100	-	-	-	23
Acidic Cove	83	90	87	93	63	66
Spicebush Cove	-	71				
Rich Cove [1/]	82	82	92	100	-	51
Alluvial Forest	67	94	81	91	100	56
Floodplain	78	-				
High Elevation Red Oak	86	84	-	73	-	75
Montane Oak Rich	77	68				
Montane Oak Cove	79	-	-	-	-	-
Montane Oak Slope [2/]	72	80	-	83	67	43
Colluvial Forest	70	-	-	-	-	-
Dry-Mesic Oak	84	90	77	73	62	27
Dry-Mesic Calcareous Forest	81	-	-	-	-	-
Dry Oak Evergreen Heath [3/]	66	73	83	-	59	27
Dry Oak Deciduous Heath	65	71	-	-	-	-
Mixed Oak Heath	-	-	-	83	-	36
Low Elevation Pine [4/]	90	91	80	-	100	66
Shortleaf P-O Heath	-	-	-	-	-	58
Pine-Oak Heath (eastside)	82	-	-	-	-	-
Pine-Oak Heath (westside)	77	83	-	93	-	58
Pine-Oak Heath (ridges) [5/]	59	-	79	-	-	-
Pine-Oak Shale Woodland	89	-	-	-	-	-
Shale Barren	83	-	-	-	-	-
Alkaline Woodland	92	-	-	-		
Mafic Glade and Barren	-	91				
OVERALL	77	80	82	86	64	52
Most fire-adapted group	97	98	95	98	89	83

[1/] Mesic Forest" in Kentucky, [2/] Montane Oak Slope in VA_WVA, [3/] Chestnut Oak in SBR, [4/] Shortleaf Pine-Oak in SBR, [5/] "Xeric Pine-Oak" in Kentucky.

4) <u>Ecological Zone location and extent</u>: In general, the model based on MAXENT appears to represent both the location and extent of predicted Ecological Zones observed in the field. An overall-project area view of Nature Serve Ecological Systems (Figure 3), an aggregation of Ecological Zones based on the crosswalk between types (Table 1 and Appendix I), shows Central Appalachian Dry Oak-Pine Forests (dark grey) and Northeastern Interior Dry-Mesic Oak Forests (yellow) as the dominant types on the landscape covering about 1,101,000 acres and 1,040,000 acres respectively (Table 9). Northern Hardwood types (white) are common in the central-western portion of the study area closest to the Allegheny Plateau where they mix with Spruce-fir (dark green) in cold air drainages but they also occur in small patches along major ridges throughout the project area (Figures 4 and 7). The distribution of the Montane Oak Forest (High Elevation Red Oak Ecological Zone) and their transition to a broader Montane Oak concept combined with Southern Appalachian Oak can also be seen in these figures (orange).

Figure 3: Nature Serve Ecological Systems in the GW Study Area



The strong pattern of alternating Pine-Oak Heath and Dry Oak, Dry-Mesic Oak Ecological Zones is evident throughout the Appalachian Ridges study area and exemplified east of the Calfpasture River and north of Ramsey Gap (Figure 5). In this area, west-facing slopes (on the NW-facing side of major ridges) and south-facing slopes (on the SE side of major ridges) are dominated by Pine-Oak Heath (westside ridge) zones, while the adjacent north and northeast convex slopes are dominated by Dry Oak Deciduous Heath. These two Ecological Zones comprise approximately 8% and 13% of the GW National Forest respectively (Table 8). Concave draws provide environments for a third Ecological Zone, Dry-Mesic oak (or occasionally Rich Cove) that further highlight this pattern. Also distinctive is the Shale Barren zone (purple) found on steep slopes bordering the river and extending up major drainages. They cover about 1% of the GW National Forest (Tables 8 and 10).

In the Blue Ridge, these strong patterns are less evident but Ecological Zones are still closely aligned with topographic features that influence temperature, moisture, and fertility gradients. For example, on slopes west of Highco and Coleman Mountain (Figure 6), Pine-Oak Heath dominates the most exposed landscape positions forming a repeated landscape pattern with more mesic types (Dry-Mesic Oak, Acidic Cove, Rich Cove) but at higher elevations is replaced by the Dry-Oak Evergreen Heath type on similar sites. At even higher elevations and on more east-facing slopes, Montane Oak-Hickory is more dominant and the vegetation pattern is more subdued. At the highest elevations in the Blue Ridge such as at Bald Knob and Fletcher Mountain, Pine-Oak Heath is entirely absent (Figure 7). In this area, High Elevation Red Oak occurs along narrow ridges, Montane Oak-Hickory (rich) on broader ridges, and Northern Hardwood Coves on the highest elevation concave landforms. Mid to lower elevation concave areas are dominated by Rich Cove and Acidic Cove, most slopes are dominated by Montane Oak-Hickory, and Dry Oak Evergreen Heath occupies narrow convex tertiary ridges.

Figure 4: Ecological Zones in the Flagpole Knob area (Appalachian Ridges Study Area)

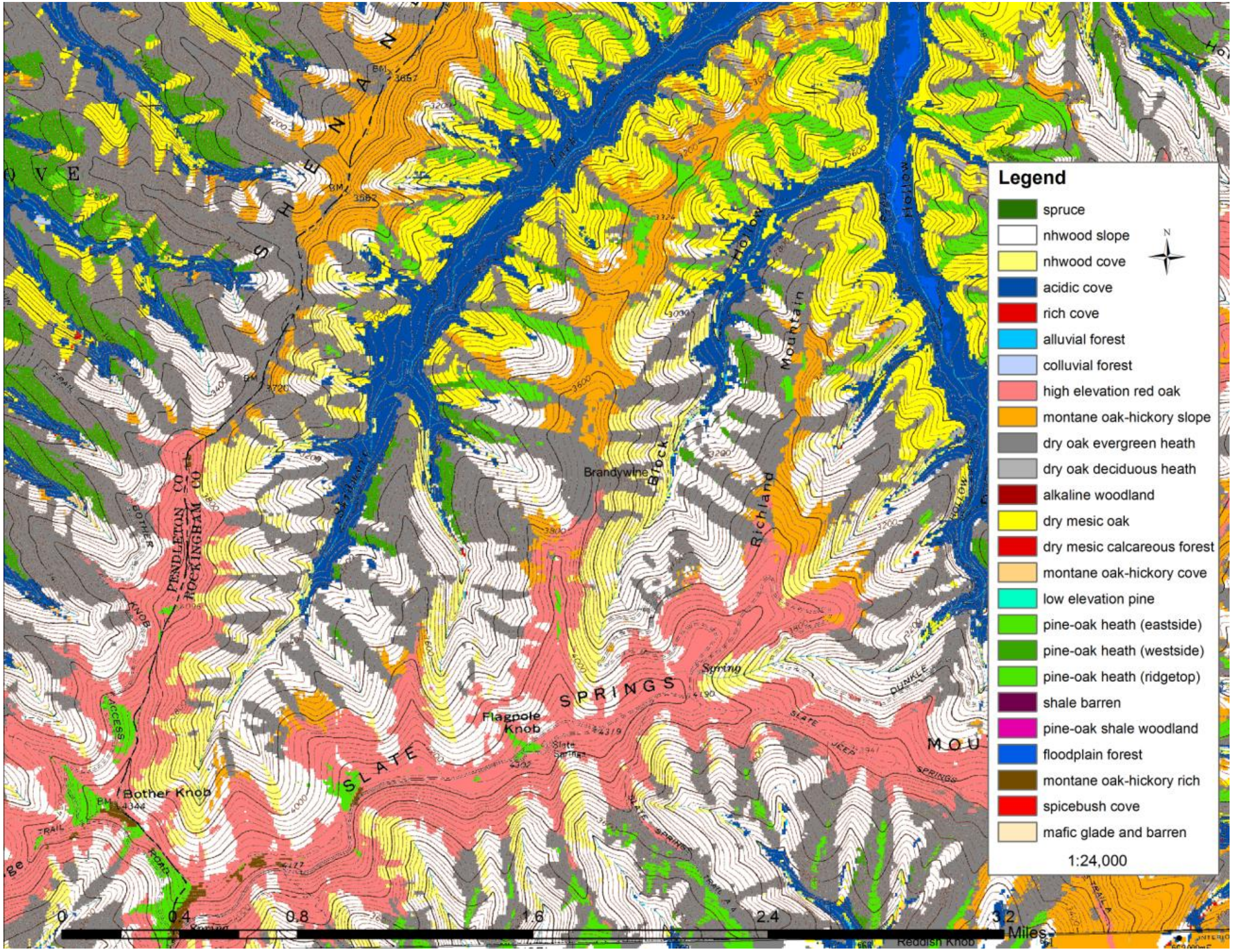


Table 8. Extent of Ecological Zones in the project area and within the GW National Forest

map code	Ecological Zones	Total acres	% of total	accuracy allplots[/1]	GW acres	% of total
1	Spruce	16,268	0.3	89%	2,241	0.2
2	Northern Hardwood Slope	97,633	2.0	85%	21,818	2.0
3	Northern Hardwood Cove	36,826	0.8	92%	8,675	0.8
4	Acidic Cove	316,808	6.6	78%	59,974	5.6
25	Spicebush Cove	13,481	0.3	71%	1,803	0.2
5	Rich Cove	190,319	3.7	83%	35,232	3.3
6	Alluvial Forest	177,413	1.2	85%	7,428	0.7
23	Floodplain Forest	99,317	2.1	78%	5,341	0.5
8	High Elevation Red Oak	31,546	0.7	85%	13,126	1.2
24	Montane Oak (rich)	46,453	1.0	70%	14,566	1.4
15	Montane Oak Cove	66,120	1.4	79%	20,038	1.9
9	Montane Oak Slope	377,052	7.9	76%	126,471	11.9
7	Colluvial Forest	72,270	1.5	69%	5,841	0.5
13	Dry Mesic Oak	965,303	20.2	86%	200,604	18.8
14	Dry Mesic Calcareous	274,857	5.7	81%	21,791	2.0
10	Dry Oak Evergreen Heath	613,430	12.8	69%	194,763	18.3
11	Dry Oak Deciduous Heath	484,790	10.1	67%	139,845	13.1
16	Low Elevation Pine	249,350	5.2	90%	26,338	2.5
17	Pine-Oak Heath (eastside ridges)	56,551	1.2	82%	24,871	2.3
18	Pine-Oak Heath (westside ridges)	220,491	4.6	80%	84,155	7.9
19	Pine-Oak Heath (ridgetops)	6,085	0.1	59%	1,447	0.1
22	Pine-Oak Shale Woodland	125,007	2.6	89%	30,748	2.9
21	Shale Barren	159,863	3.3	83%	13,869	1.3
12	Alkaline Forest and Woodland	86,710	1.8	92%	3,244	0.3
26	Mafic Glade and Barren	3,133	0.1	91%	757	0.1
	TOTAL	4,787,076	100.0	77%	1,064,986	100.0

[1/] accuracy based on plot pixel (10 meter) intersection

Table 9. Extent of TNC Ecological Systems in the project area and within the GWNF ownership

map code	NatureServe Ecological System	Total acres	% of total	accuracy allplots[/1]	USFS acres	% of total
1	Central and Southern Appalachian Spruce-Fir Forest	16,218	0.3	89%	2,237	0.2
2	Appalachian (Hemlock) – Northern Hardwood	134,796	2.8	90%	30,538	2.9
4	Southern and Central Appalachian Cove Forest	520,998	10.9	89%	97,046	9.1
6	Central Appalachian River Floodplain, Stream and Riparian	275,172	5.7	88%	12,352	1.2
8	Central and Southern Appalachian Montane Oak	31,444	0.7	85%	13,084	1.2
9	Southern Appalachian Oak Forest	489,520	10.2	80%	161,035	15.1
13	Northeastern Interior Dry-Mesic Oak Forest	1,039,662	21.7	85%	206,698	19.4
14	Southern Ridge and Valley / Cumberland Dry Calcareous Forest	274,587	5.7	81%	21,724	2.0
10	Central Appalachian Dry Oak-Pine Forest	1,100,972	23.0	77%	335,674	31.5
16	Southern Appalachian Low-Elevation Pine	248,793	5.2	90%	26,148	2.5
18	Southern Appalachian Montane Pine Forest and Woodlands , Central Appalachian Pine-Oak Rocky Woodland (in part)	281,430	5.9	80%	109,984	10.3
22	Central Appalachian Pine-Oak Rocky Woodland (in part), Appalachian Shale Barrens	124,451	2.6	89%	30,695	2.9
21	Appalachian Shale Barrens	159,469	3.3	83%	13,806	1.3
12	Central Appalachian Alkaline Glade and Woodland	86,480	1.8	92%	3,219	0.3
26	Southern and Central Appalachian Mafic Glade and Barrens	3,088	0.1	91%	740	0.1
	TOTAL	4,787,080	100.0	83%	1,064,980	100.0

[1/] accuracy based on plot pixel (10 meter) intersection

Figure 5: Ecological Zones in the Calfpasture River below Ramsey Gap (Appalachian Ridges Study Area)

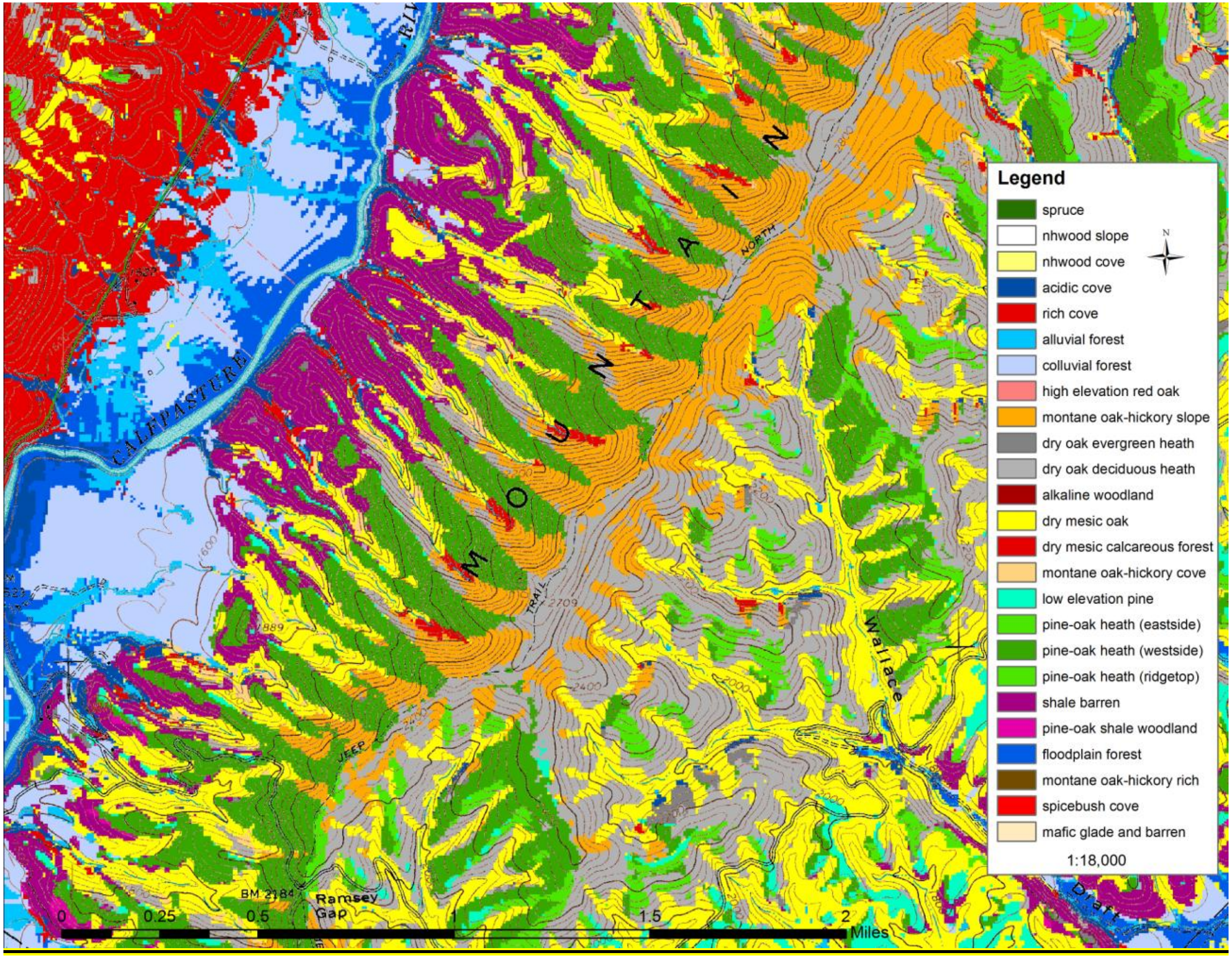


Table 10. USFS ESE Tool Systems in project area compared to GWNF ownership

Code	**ESE System**	Total acres	% of total	accuracy all plots[1]	USFS acres	% of total
1	Spruce Forest	16,213	0.3%	89%	2,239	0.2%
2	Northern Hardwood Forest	96,936	2.0%	85%	21,545	2.0%
3	Cove Forest	552,757	11.5%	89%	103,898	9.8%
4	Floodplain, Wetlands and Riparian areas	274,052	5.7%	88%	11,982	1.1%
	Total LEAST FIRE ADAPTED	939,958	19.6%	91%	139,664	13.1%
5	Oak Forest and Woodlands	2,948,183	61.6%	93%	742,454	69.6%
6	Pine Forest and Woodlands	651,259	13.6%	85%	165,371	15.6%
7	Cliff, Talus, and Shale Barrens	158,562	3.3%	83%	13,599	1.3%
8	Mafic Glades and Barrens, and Alkaline Glades and Woodlands	89,121	1.9%	92%	3,883	0.4%
	Total MOST FIRE ADAPTED	3,847,125	80.4%	98%	925,307	86.9%
	TOTAL	4,787,082	100.0%	90%	1,064,971	100.0%

[1] accuracy based on plot pixel (10 meter) intersection

Figure 6: Ecological Zones around Coleman and Highco Mountain (Blue Ridge Study area)

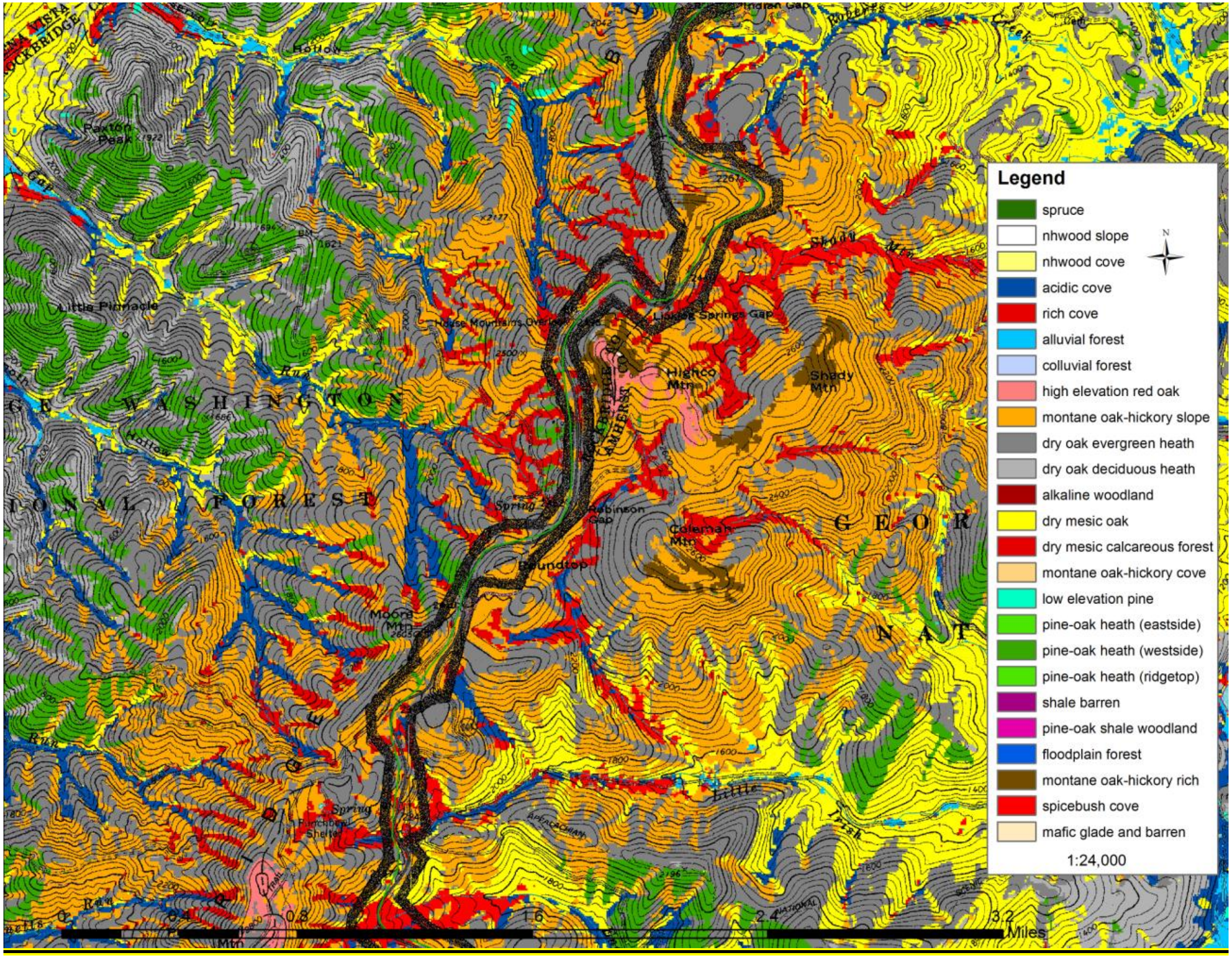
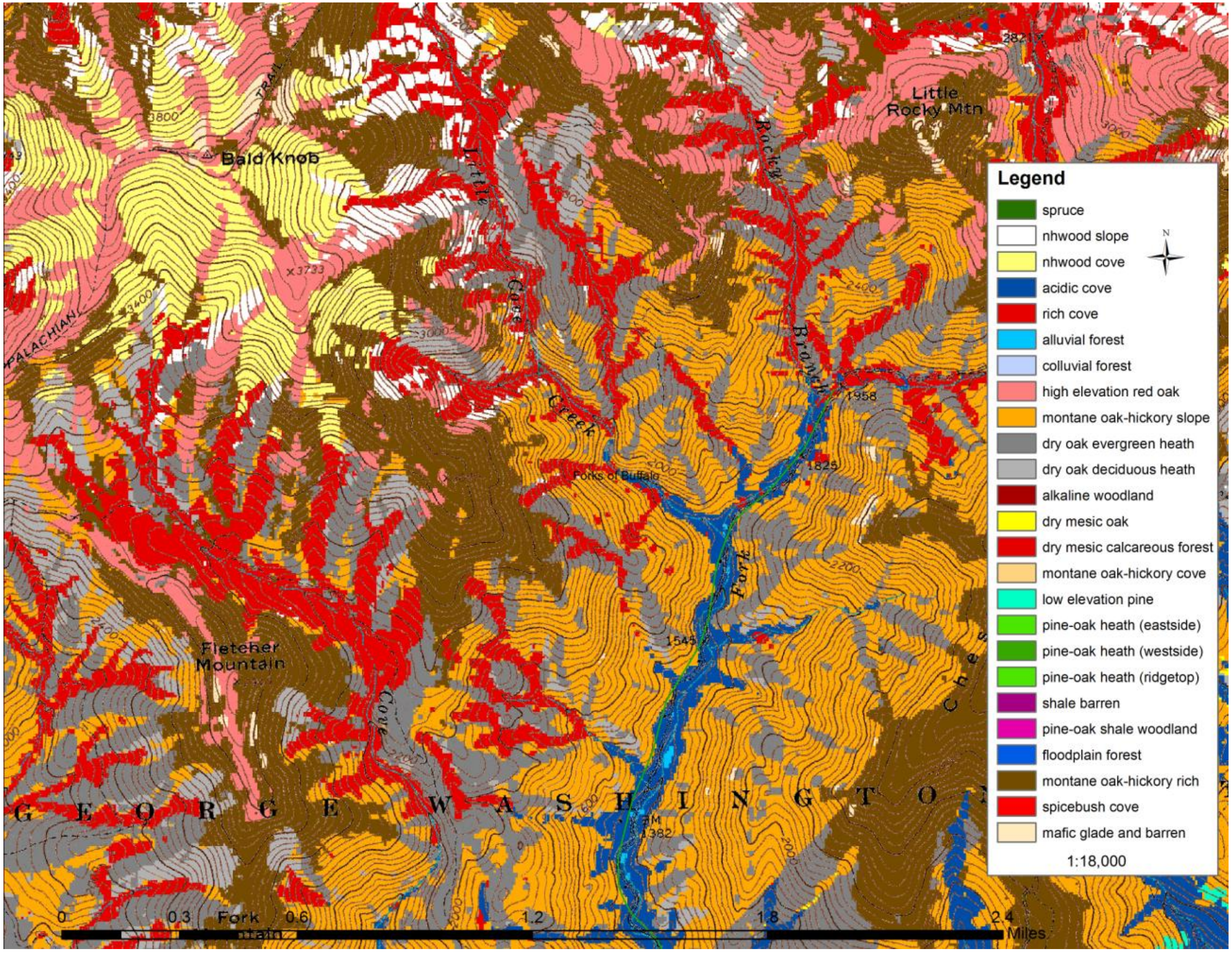


Figure 7: Ecological Zones around Bald Knob and Fletcher Mountain (Blue Ridge study area)



5) <u>Extent and location of fire-adapted plant communities</u>: Ecological Zone maps for the GW project area can be used to identify landscapes that support fire-adapted plant communities. Clearly well over 90% of the reference plot data occurring in types considered as more fire-adapted, are found within Ecological Zones correctly modeled as fire-adapted (Table 7 and Appendix V). Only 7 of the types have fire-adapted group accuracy below 95%. They include (from least to most accurate), Colluvial Forest (69%), Spicebush Cove (71%), Rich Cove 87%), Acidic Cove (88%), Northern Hardwood Slope (90%), Alluvial Forest (91%), and Pine-Oak Heath ridge (91%).

Ecological Zone and Nature Serve Ecological System maps can also be used to evaluate fire restoration needs in different areas (Tables 10-12, and Appendix VI), for example, on Federal Land, State Land, TNC land, or other conservation land within the project area. Although Federal land, because of its greater proportion in the project area obviously has the greatest number of acres that may need restoration through the use of controlled burning, the relative proportion of a type within an ownership may indicate differences in priorities. For example, Central Appalachian Dry-Oak Pine Forest, Northeastern Interior Dry-Mesic Oak Forest, and Southern Appalachian Oak Forest / Central and Southern Appalachian Montane Oak (expanded concept) account for the largest proportion, respectively, of TNC lands, Federal lands, State lands, and other conservation lands. In addition, there is a larger percent of TNC lands (88.4) and other conservation lands (91.9) in the most fire-adapted types than there are on Federal (83.5) or State (83.5) lands which may also indicate different needs or priorities within these ownerships.

Table 11. Extent of Nature Serve Ecological Systems in the project area and within conservation ownerships

Code	Ecological System	Total Study Area		Conservation Land		Private Land	
		acres	%	acres	%	acres	%
1	Central and Southern Appalachian Spruce-Fir Forest	16,218	0.3	9,265	57.1	6,953	42.9
2	Appalachian (Hemlock) Northern Hardwood	134,796	2.8	81,605	60.5	53,191	39.5
4	Southern and Central Appalachian Cove Forest	520,998	10.9	176,065	33.8	344,933	66.2
6	Central Appalachian River Floodplain, Stream, Riparian	275,172	5.7	23,330	8.5	251,842	91.5
8	Central and Southern Appalachian Montane Oak	31,444	0.7	26,788	85.2	4,656	14.8
9	Southern Appalachian Oak Forest (in part), Central and Southern Appalachian Montane Oak (expanded)	489,520	10.2	314,461	64.2	175,059	35.8
13	Northeastern Interior Dry-Mesic Oak Forest	1,039,662	21.7	327,028	31.5	712,634	68.5
14	S.Ridge&Valley /Cumberland Dry Calcareous Forest	274,587	5.7	35,539	12.9	239,048	87.1
10	Central Appalachian Dry Oak-Pine Forest	1,100,972	23.0	500,645	45.5	600,327	54.5
16	Southern Appalachian Low-Elevation Pine	248,793	5.2	37,252	15.0	211,541	85.0
18	Southern App. Montane Pine Forest and Woodland	281,430	5.9	171,225	60.8	110,205	39.2
22	Central Appalachian Pine-Oak Rocky Woodland (in part), Appalachian Shale Barrens	124,451	2.6	36,798	29.6	87,653	70.4
21	Appalachian Shale Barren	159,469	3.3	29,749	18.7	129,720	81.3
12	Central Appalachian Alkaline Glade and Woodland	86,480	1.8	6,705	7.8	79,775	92.2
26	Southern and Central App. Mafic Glade and Barrens	3,088	0.1	2,999	97.1	89	2.9
	TOTAL	4,787,080	100.0	1,779,454	37.2	3,007,626	62.8
	Most fire-adapted [1/]	3,839,896	80.2	1,489,189	83.7	2,350,707	78.2
	Least fire-adapted	947,184	19.8	290,265	16.3	656,919	21.8

Table 12. Extent of Ecological Zones on conservation lands in the study area

Map Code	Ecological Zone	Federal Land & Appalachian Trail		State Land		TNC Land		Other Conserv. Land	
		acres	%	acres	%	acres	%	acres	%
1	Spruce	7,281	0.5	44	0.0	3	0.0	-	-
2	Northern Hardwood Slope	46,882	3.2	764	0.7	260	2.5	-	-
3	Northern Hardwood Cove	19,237	1.3	108	0.1	93	0.9	-	-
4	Acidic Cove	95,459	6.5	7,611	7.1	229	2.2	40	1.0
25	Spicebush Cove	4,321	0.3	9	0.0	16	0.2		-
5	Rich Cove	48,829	3.3	6,354	5.9	597	5.7	93	2.2
6	Alluvial Forest	12,763	0.9	1,627	1.5	20	0.2	102	2.5
23	Floodplain Forest	7,474	0.5	1,222	1.1	-	-	99	2.4
8	High Elevation Red Oak	18,069	1.2	1,382	1.3	1,091	10.4	111	2.7
24	Montane Oak (rich)	28,347	1.9	586	0.5	234	2.2	-	-
15	Montane Oak Cove	26,471	1.8	3,246	3.0	247	2.4	155	3.7
9	Montane Oak Slope	193,864	13.2	13,357	12.4	3,338	31.9	98	2.4
7	Colluvial Forest	8,165	0.6	1,063	1.0	5		-	-
13	Dry Mesic Oak	276,496	18.9	19,254	17.9	756	7.2	907	21.9
14	Dry Mesic Calcareous	28,791	2.0	5,284	4.9	358	3.4	626	15.1
10	Dry Oak Evergreen Heath	228,623	15.6	26,038	24.2	1,982	18.9	412	9.9
11	Dry Oak Deciduous Heath	176,719	12.1	6,955	6.5	343	3.3	352	8.5
16	Low Elevation Pine	33,286	2.3	3,046	2.8	4	0.0	312	7.5
17	Pine-Oak Heath (eastside ridges)	30,229	2.1	2,288	2.1	98	0.9	50	1.2
18	Pine-Oak Heath (westside ridges)	106,517	7.3	3,628	3.4	458	4.4	129	3.1
19	Pine-Oak Heath (ridgetops)	2,564	0.2	22	0.0	271	2.6		
22	Pine-Oak Shale Woodland	32,132	2.2	838	0.8	37	0.4	101	2.4
21	Shale Barren	25,571	1.7	1,181	1.1	24	0.2	238	5.7
12	Alkaline Forest and Woodland	4,598	0.3	1,780	1.7	3	0.0	319	7.7
26	Mafic Glade and Barren	2,187	0.1	15	0.0	1	0.0		
	TOTAL	1,464,875	100.0	107,702	100.0	10,468	100.0	4,144	100.0
	Most fire-adapted [1/]	1,222,629	83.5%	89,963	83.5%	9,250	88.4%	3,810	91.9%
	Least fire-adapted	242,246	16.5%	17,739	16.5%	1,218	11.6%	334	8.1%

Improving Map Unit Accuracy

The accuracy of the 1st approximation Ecological Zone map is good In comparison to other similar Ecological Zone modeling efforts in the Southeastern U.S. (Table 7), but can be improved. Model accuracy can be affected by several major factors: 1) plot location accuracy, 2) Ecological Zone identification, 3) DTM accuracy, and 4) modeling methods.

1) Plot location accuracy: Incorrect plot locations from poor GPS readings or inaccurate topographic map interpretations can lead to erroneous data and therefore models that do not reflect reality. Furthermore 'ecotone' samples can and may have contributed to modeling errors in the project area. This reality was confirmed by results of the post-processing procedures used to reduce data noise and produce a cleaner product in 2009 within the VA-WVA FLN. Using just 3 majority filters of the 'raw' model, 52 of the 1,321 reference plots (about 4%), shifted into different Ecological Zone map units; 17 of these moved to incorrect classes and thus reduced the overall accuracy by about 2% points. The majority filter command merely replaces *individual 1/40th acre cells* in a grid based on the majority of their *contiguous* neighboring cells, a change that would only occur on the edges or interior of a type. These changes observed in plot accuracy indicate the close proximity of these 'shifted' plots to the narrow moisture-temperature-fertility gradients that occur between many Ecological Zones, i.e. the ecotone which is certainly largest around sample sites near ecotones. Although difficult to capture in GIS modeling, this variability in environmental conditions over short distances is common in the study area where numerous Ecological Zones may be encountered while traversing along only a 100 meter transect in highly dissected landscapes.

2) Ecological Zone field identification: The identification of reference condition (the Ecological Zone) at individual site locations is of equal or greater importance as plot location accuracy in developing a truer representation of landscapes that may have existed prior to Euro-American settlement. Ecological Zone models are evaluated from a sample of plot locations in a project area and from the interpretation of data collected from these areas that describe existing vegetation and often only remnant site indicator species. Incorrect identification of the Ecological Zone can therefore have a major impact on the outcome of map unit extent and accuracy especially for those zones that are hard to recognize because of past disturbance or because of lack of experience in the area by the observer.

3) DTM accuracy: The accuracy of DTMs used to reflect temperature, moisture, and fertility gradients, especially geologic / lithologic type in the project area, have a significant impact on Ecological Zone map unit accuracy. Lithology in the project area influences soil fertility, (also slope and aspect), thus having a major influence on the distribution of Ecological Zones across the complex background of temperature and moisture regimes described by other DTMs. Although lithologic map units were aggregated into just five distinct groups, there were still differences between these grouped map units across State lines; not only map line differences but also map unit labeling differences. An improvement in map unit accuracy could be possible by correlating lithologic map units between among the State-wide maps and those acquired from the GW-Jeff and Shenandoah Park.

4) Modeling methods. The 1st approximation Ecological Zones are based on merging 25 individual Ecological Zone models into one map based upon the zone having the highest probability of occurrence. Although this seems to be a reasonable approach, other techniques might be evaluated. For example, choosing a threshold probability value for each type that maximizes the correct plot inclusion and minimizes inclusion of plots representing other types could be used to map the location of individual zones having their greatest probability of occurrence. This coverage could then be merged with the 1st approximation to fill areas where these conditions are not met.

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appendixes for this
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