WESTERN NORTH CAROLINA ALLIANCE

An Assessment of the Ecosystems of Nantahala-Pisgah National Forest & Surrounding Lands

A Synthesis of the eCAP Methodology and LiDAR Vegetation Analysis

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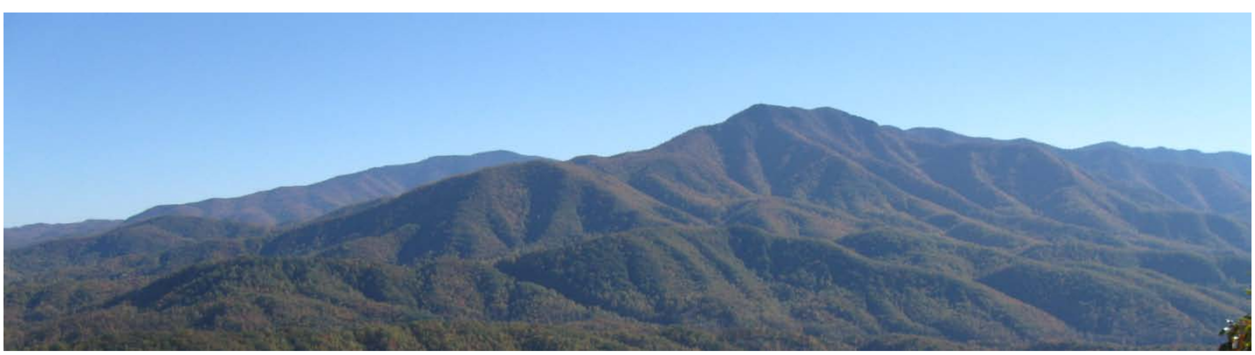


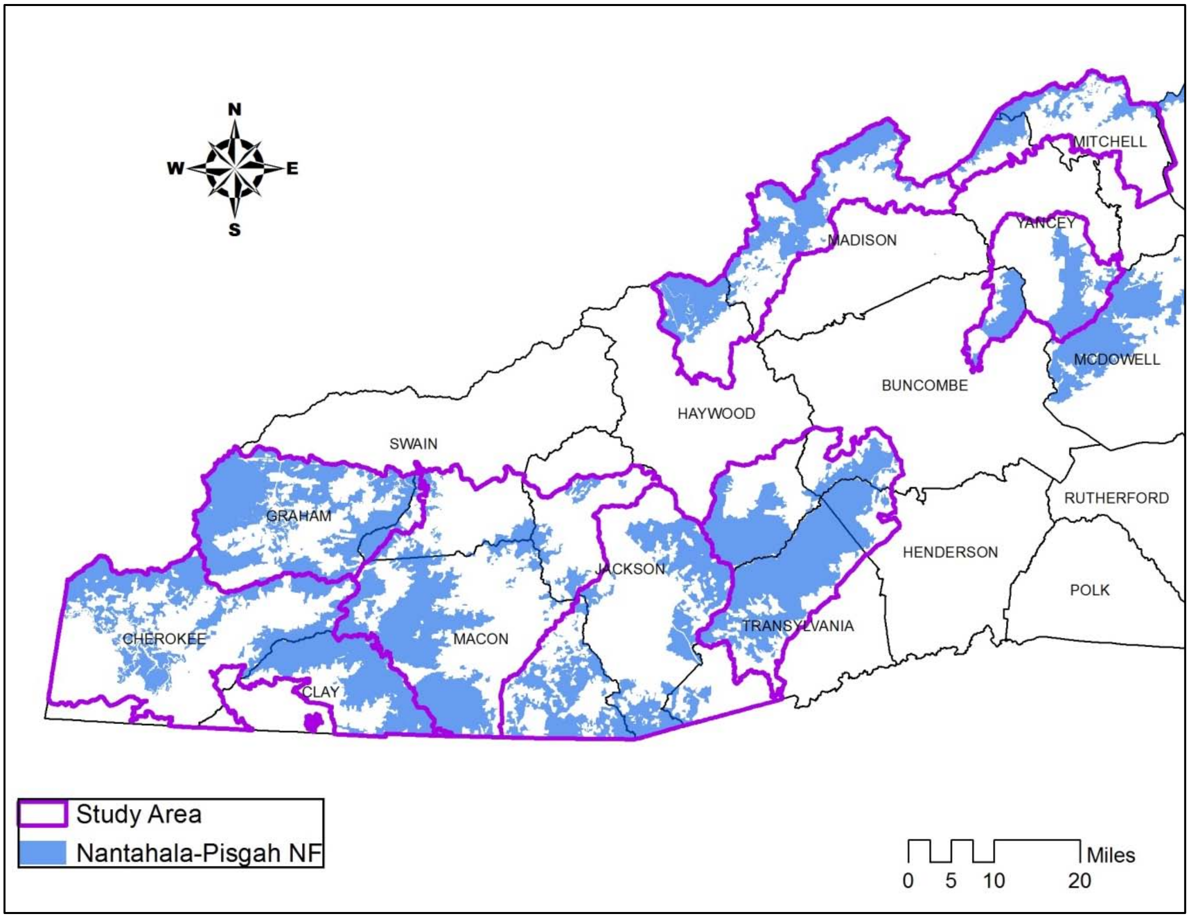
Abstract

Ecological restoration has become one of the guiding principles of National Forest management. However, it can be difficult to identify a reference or desired condition as a restoration goal, and furthermore, accurately assessing ecosystem condition is dependent of the quality of the data available. LANDFIRE Biophysical Settings are computer models that combine scientific research, historical information, and expert opinion to describe the disturbance probabilities of ecosystems and simulate a Natural Range of Variation as a restoration target. Ecological zone maps are the most accurate ecosystem maps available for the Southern Blue Ridge Ecoregion and can be cross-walked to LANDFIRE Biophysical Settings. Light Detection and Ranging (LiDAR) data are recognized as one of the most comprehensive and accurate data for measuring vegetation structure. A study area including the overlap of the 2005 Phase III North Carolina LiDAR data and the proclamation boundary of Nantahala-Pisgah National Forest was analyzed with the use of ecological zone maps, LANDFIRE Biophysical Settings, and LiDAR vegetation models. In total, over 700,000 hectares (1,760,000 acres) of forest were evaluated using LiDAR measured height and US Forest Service stand records to estimate forest age. LiDAR measurements of canopy cover and shrub density were used to evaluate canopy closure. Of 11 forest ecosystems evaluated, five were found to be highly departed from reference conditions. In general, ecosystems with a more frequent historical fire return interval were more departed from reference conditions than mesic forests and ecosystems with greater timber value were more disturbed than ecosystems with less economic value. For oak, cove and spruce ecosystems the Natural Range of Variation included a much higher proportion of old forests than the 2005 conditions, while the converse was true for shortleaf pine and pine-oak/heath ecosystems. Both oak and pine ecosystems had canopies that were much more closed than the reference models, while the canopies of cove ecosystems were more open than the reference models. This study indicates that increased fire management and the continued restoration of old-growth conditions on public land would be ecologically beneficial.

Introduction

The Southern Blue Ridge Ecoregion has long been appreciated as an area of great scenic beauty and unique biodiversity. Nantahala-Pisgah National Forest totals nearly 1.1 million acres in the Southern Blue Ridge Mountains of North Carolina and includes all of the representative ecosystems of the region. National Forest management has been the subject of vigorous debates since at least the 1980's with environmental concerns typically countering timber industry demand for tree cutting (Newfont 2012). In 2012, Nanthala-Pisgah National Forest began a three year process of Forest Plan Revision, which could be an opportunity for either further conflict between interest groups, or for groups to work together to identify common interests that meet the needs of a broad constituency. Ecological restoration has emerged as a strategy for land management that can improve the health and resilience of ecosystems, identify situations in which timber cutting could be beneficial and pursue management activities that align with environmental interests, thus providing hope of decreasing conflict over management of these important conservation lands.

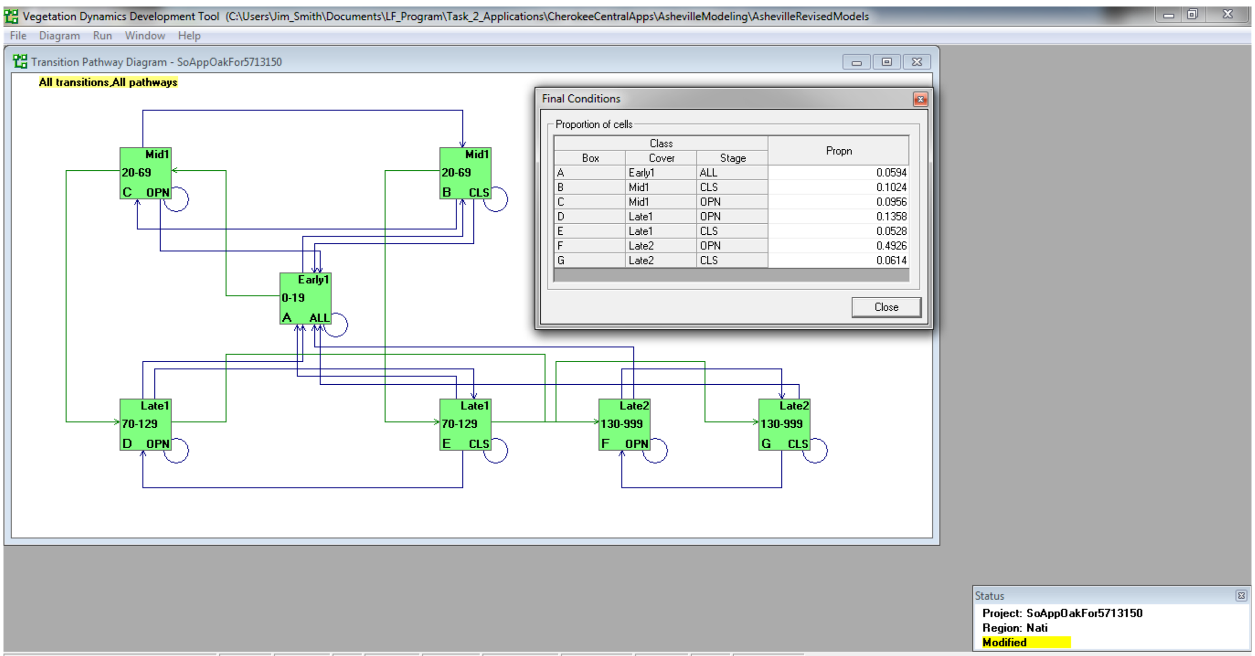
Figure 1: Study area defined by the overlap of the Nanthala-Pisgah National Forest Proclamation Boundary and Phase III LiDAR data from North Carolina



One difficulty in ecological restoration can be identifying a condition or set of conditions to restore ecosystems to. This can be especially challenging in areas in which it is believed that human influence has caused significant and, in some cases undesired, change in ecosystems such as in much of eastern North America. LANDFIRE Biophysical Setting models are viable options for addressing the challenges associated with choosing a reference condition. Biophysical Setting models have been developed for each ecosystem in the U.S. by regional panels of experts that define the probabilities of disturbances such as fire, wind, ice, insects, disease, and other natural dynamics. The disturbances are used as "transitions" between S-classes - successional and structural conditions defined in the models as "states". After the state and transition framework of the model has been created and probabilities entered into Vegetation Dynamics Development Tool software, the models are run through a thousand year simulation that predicts the percentages of the various S-classes that would be expected for each ecosystem, which becomes the reference, or natural range of variation for each ecosystem (Landfire 2013).

LiDAR technology has emerged as perhaps the most precise and accurate way to measure the physical structure of large forested areas and has been used to accurately measure tree height, canopy closure, basal area, and even coarse woody debris (Hopkins et al. 2009; Lefsky et al. 1999; Suarez et al. 2004; Wulder et al. 2012; Zimble et al. 2003). The acquisition of raw LiDAR data by the state of North Carolina between 2001 and 2005 provides the opportunity for analyzing the condition of vegetation over a large area at a resolution not previously possible. The Phase III data, acquired in 2005, have four times the density of points per unit area as the Phase II data from 2003, allowing especially fine-scale analysis of forests.

Figure 1: The seven box (S-class) state and transition model for Southern Appalachian Oak Forest viewed in the Vegetation Dynamics Development Tool. **Image credit: Jim Smith**



Analyzing the physical structure of ecosystems requires a reliable map of where ecosystems occur. Fortunately, Nantahala-Pisgah National Forest and the Southern Blue Ridge Fire Learning Network have invested substantial resources into mapping the ecological zones of the study area, not once, but three times (Simon et al. 2007; Simon 2011). The resultant map products are accurate, consistent over millions of hectares, and facilitate the analysis of vegetation across a gradient of productivity in which each ecosystem has a discreet potential for tree growth and height.

The eCAP methodology developed by The Nature Conservancy uses Biophysical Settings, ecosystem mapping, an assessment of current ecosystem conditions, and scenario forecasting to guide land management - all but the scenario forecasting are included in this study, producing a measure of ecological departure for the ecosystems in question (Low et al. 2010). Ecological departure is calculated by comparing the current percentage of s-classes to the reference condition in each ecosystem. By identifying the most departed ecosystems and the S-classes leading to the departure of each ecosystem, land managers can prioritize activities so as to decrease the departure of ecosystems from the natural range of variation. The intent of this study is to help identify a "need for change" in the Nantahala-Pisgah Forest Plan Revision and to facilitate ecologically sound management on National Forest and other lands.

Methodology

LiDAR Processing

Raw LiDAR data covering the purchase boundary of Nantahala-Pisgah National Forest were acquired from the Click website (http://lidar.cr.usgs.gov/). LiDAR point clouds were processed into canopy height, canopy cover, and shrub density models with the use of Fusion© Software, a free software package from the University of Washington and the USFS Northwest Research Station. The LiDAR data from the USGS are projected in NC State Plane FIPS 3200(feet), so all LiDAR models are in units of feet. Canopy height models were produced at 20' pixel size with values <0' and >190' being excluded from analysis as the tallest known tree in the ecoregion is 192' tall (http://www.ents-bbs.org/viewtopic.php?f=74&t=2423). Canopy cover and shrub density models were produced at 40' pixel size. Canopy cover was defined as occurring above 15' in height and shrub density was calculated below 15' in height. LiDAR models created in Fusion© were imported into ArcMap as ASCI files and converted to raster format.

GIS Analysis

Ecozones were first lumped into broader types that could be cross-walked to Biophysial Settings (see Table 1). A total of 11 ecosystems were then evaluated separately. Agricultural and developed areas were excluded from the analysis using GAP land cover data. LiDAR vegetation models were extracted to the boundaries of each ecosystem, reclassified into broad categories, and intersected. The intersected master file was then clipped to a layer of Forest Service ownership, creating master files for Forest Service and "All Lands".

Taking inspiration from previous studies, LiDAR canopy height models were reclassified to serve as a surrogate for height (Weber & Boss 2009). This analysis includes lands other than Forest Service lands, and those ownerships have no systematic age data. Additionally, even Forest Service data often overlooks natural disturbances like wind throw, landslides, insect outbreaks, disease, or individual tree mortality if they occur at a scale smaller than the stand level. Broad categories of height were defined for Early, Mid, and Late S-Classes for each ecosystem. As a first attempt, site-index growth curves were selected for each ecosystem as a guide for choosing height breaks. For example, the break between early and mid S-classes occurs at 20 years and the break between mid and late S-classes occurs at 70 years in the Southern Appalachian Oak BpS (Dry Mesic Oak Ecozone). Tracing a growth curve for white oak at site index 70, the site index most often listed for this forest type, yields a height of just over 30' at 20 years and approximately 85' at 70 years (Carmean 1971). However, the results of this methodology grossly underestimated the quantity of the late successional S-class on National Forest, where fairly reliable age data are available.

Table 1: Crosswalk between LANDFIRE Biophysical Settings and Ecozones analyzed in this study.

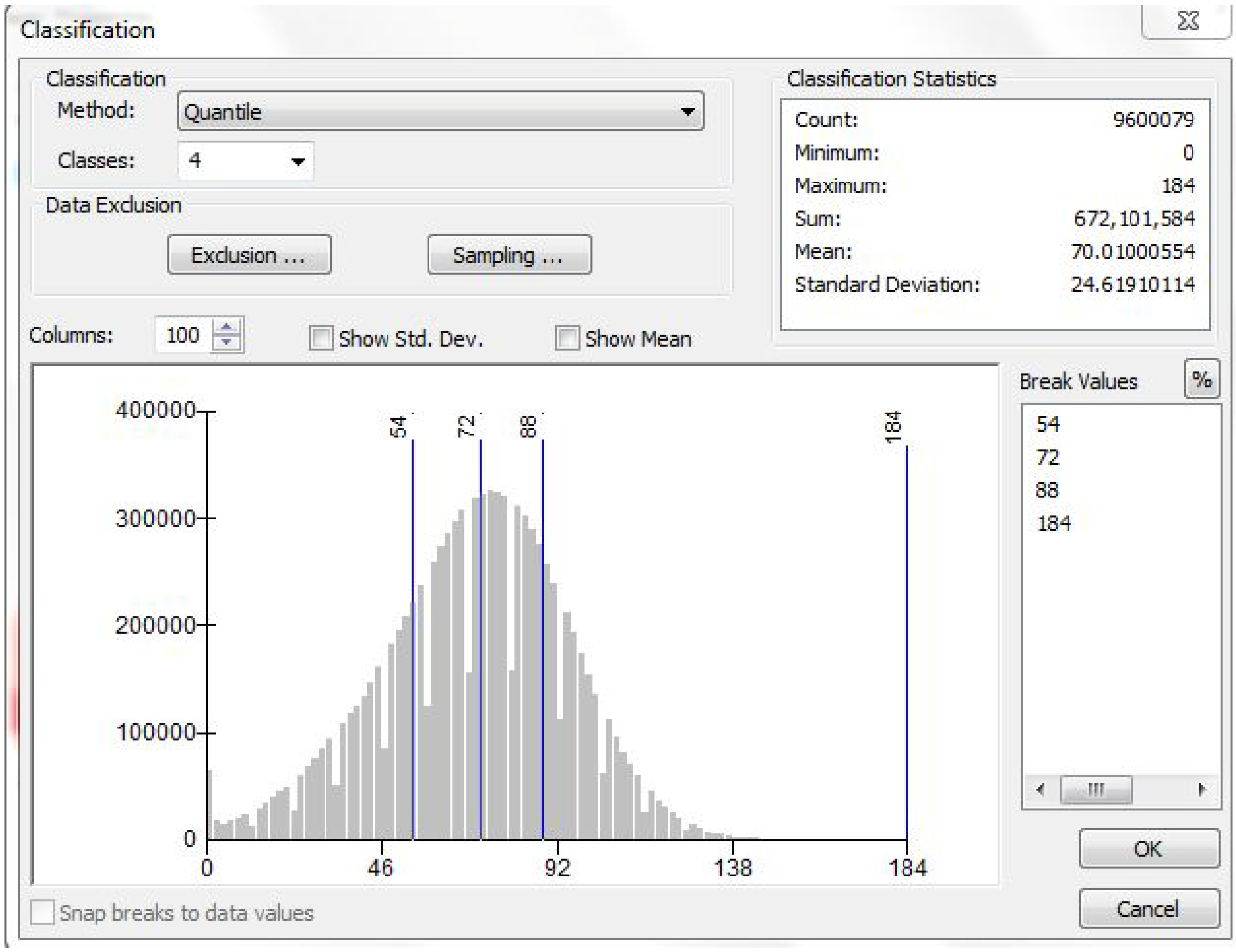
Biophysical Setting	Ecozone(s)	Gridcode
Central and Southern Appalachian Spruce-Fir Forest	Spruce-Fir	1
Southern Appalachian Northern Hardwoods Forest	Northern Hardwoods Slope Northern Hardwoods Cove	2 3
Southern Blue Ridge Cove Forest	Acidic Cove Forest Rich Cove Forest Oak Rhodo	4 5 29
Southern Appalachian Mesic Oak Forest*	High Elevation Red Oak*	8
Southern Appalachian Mesic Oak Forest	Montane Oak-Hickory Slope Montane Oak Rich Montane Oak-Hickory Cove	9 24 28
Allegheny Cumberland Dry Oak-Pine Forest	Dry Oak Evergreen Heath Dry Oak Deciduous Heath	10 11
Southern Appalachian Oak Forest	Dry Mesic Oak Forest	13
Southern Appalachian Low Elevation Pine Forest	Low Elevation Pine Shortleaf Pine-Oak/Heath	16 31
Southern Appalachian Montane Pine Forest & Woodland	Pine-Oak/Heath	18

* High Elevation Red Oak Forest lacks an acceptable LANDFIRE Biophysical Setting, so Mesic Oak was used as its reference.

There are many logical reasons why the site index approach failed. First, the pixel size for the LiDAR canopy height model employed is smaller than the crown of a large tree. So, while the tree may reach the height predicted, not all the pixels of the crown would be classified as the correct age. Second, not all of the species making up the canopy of the forest grow as rapidly as the site index species. Species like black gum and sourwood would tend be older than the site index height approach would indicate. Third, not all of the forests sampled are even aged. Old growth forest and forest approaching old growth conditions will in most cases have all age classes and an uneven canopy. Many stands also have been high-graded, leaving deformed trees and less-than-ideal growing conditions for the residual trees. Ecosystem mapping errors may also contribute because while the mapping products used are the best available, they are still incorrect in approximately 20% of all locations.

The method finally adopted was to examine the distribution of LiDAR heights within each ecosystem on National Forest Land. Because age data are available for Forest Service ownership, the percentage of late successional and old-growth forest within an ecosystem was compared with the distribution of LiDAR points. So, for Dry Mesic Oak Hickory Forest, where Forest Service stand data record 74% of the stands being greater than 70 years in age, the height break chosen was 55’ (See Figure 2). An obvious consequence of this methodology is that it will overestimate the age of some trees. Height is what is actually being measured, after all. However, concentrated areas of consistently tall canopy are classified correctly, and the percentages of late-seral and old-growth forest on Forest Service Land are within 5% of Forest Service stand data in all ecosystems when using this method.

Figure 2: The quantile distribution of heights within National Forest ownership in the Dry-Mesic Oak-Hickory ecosystem. Because 74% of Forest Service ownership is >70 years of age, 55' was used as the height associated with age ≥70 in this ecosystem.



Old-growth forest was analyzed in systems in which LANDFIRE BpS models have been revised to include old-growth S-classes. Ecosystems not yet modeled for old-growth S-Classes are: Southern Appalachian Montane Pine Forest and Woodland, Southern Appalachian Low Elevation Pine Forest, Southern Appalachian Northern Hardwoods Forest, and Southern Appalachian Spruce Forest. Old-growth was not detected by LiDAR, but by Forest Service stand age. The age used for the old-growth threshold was 130 years for oak forests and 140 years for Cove Forests; both ages consistent with and informed by the "Guidance for Conserving and Restoring Old-Growth Forest Communities in the Southern Region" (USDA Forest Service 1998). Because no records for age are available for other lands, no old-growth was indentified on those lands.

For each ecosystem, the LiDAR canopy height raster reclassified into Early, Mid, and Late S-Classes was intersected with the canopy cover raster re-classified as open (≤60%) or closed (> 60%) and a shrub density raster re-classified as low (≤50%) or high (>50%). The result was the creation of at least 5 different condition classes for each ecosystem, and up to 13 condition classes for ecosystems where shrub density was analyzed and old-growth s-classes were modeled.

Table 2: Physical Metrics used to define S-classes in this analysis

Ecozone/Ecosystem	Max Early-Seral Height	Max Mid-Seral Height	Old-Growth Age	Canopy Cover Classes	Shrub Density Classes
Spruce	23’ (<35 yrs.)	60’ (65 yrs.)	No BpS Model	<60% = Open	Not Analyzed
NH Cove	33’ (<25 yrs.)	59’ (75 yrs.)	No BpS Model	<60% = Open	Not Analyzed
NH Slope*	25’ (<25 yrs.)	55’ (75 yrs.)	No Bps Model	<60% = Open	Not Analyzed
High Elevation Red Oak	20’ (<20 yrs.)	42’ (70 yrs.)	130 years	<60% = Open	>50% = High Shrub Cover
Acidic Cove**	33’ (<10 yrs.)	97’ (100 yrs.)	140 years	<60% = Open	>50% = Acidic Cove
Rich Cove**	33’ (<10 yrs.)	97’ (100 yrs.)	140 years	<60% = Open	<50%= Rich Cove
Mesic Oak	33’ (<20 yrs.)	60’ (70 yrs.)	130 years	<60% = Open	>50% = High Shrub Cover
Dry Mesic Oak	33’ (<20 yrs.)	55’ (70 yrs.)	130 years	<60% = Open	>50% = High Shrub Cover
Dry Oak	25’ (<20 yrs.)	49’ (70 yrs.)	130 years	<60% = Open	>50% = High Shrub Cover
Shortleaf Pine	27’ (<20 yrs.)	57’ (70 yrs.)	No BpS Model	<60% = Open	>50% = High Shrub Cover
Pine-Oak Heath	20’ (<20 yrs.)	40’ (70 yrs.)	No BpS Model	<60% = Open	>50% = High Shrub Cover

* Modeled separately from NH Cove Forest because of productivity differences in these ecosystems.

** Acidic Cove and Rich Cove were separated in this analysis by shrub density; high shrub density being defined as Acidic Cove.

After ecosystems were analyzed and acreage of each condition class was tabulated, the 2005 condition – the time of LiDAR acquisition – of each ecosystem was compared to the respective LANDFIRE Biophysical Setting model to calculate a departure from the Natural Range of Variation. Because Biophysical Setting (BpS) models do not have specific S-classes for shrub density, areas of high shrub density were aggregated with closed canopied S-classes. High shrub density generally corresponds to areas of evergreen shrubs in the genera *Rhododendron*, *Kalmia*, and *Luecothoë* . These evergreen shrubs tend to exclude many herbs and shade intolerant tree seedlings and such environments are considered to be ecologically analogous to a closed canopy in this study. The percentages of S-classes measured with LiDAR were compared with the percentages of S-classes from the Natural Range of Variation described by BpS models to calculate ecological departure with the following equation:

$$100\% - \sum_{i=1}^{n} \min\{Current_i, NRV_i\}$$

Ecosystems with a departure scores ≤33% were considered to be in good condition, those with scores 33% ≥ and ≤ 66% are considered to be in fair condition, and scores > 66% reflect poor ecosystem conditions.

Results

Five of 11 ecozones/ecosystems analyzed were found to be > 66% departed from reference conditions. The most departed ecosystem analyzed was Dry Oak Forest and the least departed ecosystem was Northern Hardwoods Forest. The most common cause of departure was too much of an ecosystem falling into one age class, generally either the middle or late age classes. Coincident with the overabundance of those age classes was an under-abundance of old-growth in every ecosystem where it was modeled. Six of the eight most departed ecosystems also had much less open canopied forest than their reference conditions.

Table 3: Ecological Departure of Ecosystems in the Nantahala-Pisgah National Forest and surrounding lands by ownership

Ecosystem	National Forest	Other Lands	All Lands	Drivers of Departure
Dry Oak Forest	84%	80%	80%	Too much closed canopy, lacks old-growth
Pine-Oak/Heath*	83%	74%	79%	Too much closed canopy, too much late-seral
Shortleaf Pine-Oak*	83%	63%	71%	Too much closed canopy, too much late-seral, lacks early-seral
Dry Mesic Oak-Hickory	70%	71%	71%	Too much closed canopy, lacks old-growth
Mesic Oak-Hickory	70%	74%	72%	Too much closed canopy, lacks old-growth
High Elevation Red Oak Forest	63%	75%	65%	Too much closed canopy, lacks old-growth
Rich Cove Forest	54%	56%	55%	Lacks old-growth
Acid Cove Forest	55%	57%	56%	Lacks old-growth
Spruce-Fir Forest*	34%	43%	39%	Too much mid-seral, too little late-seral; questions about species composition
Northern Hardwoods Cove*	6%	14%	10%	No significant departure, but old-growth not modeled
Northern Hardwoods Slope*	3%	7%	4%	No significant departure, but old-growth not modeled

* Old-Growth S-classes not included in these models

There were consistent differences in the departure of ecosystems across land-ownership. All ecosystems had a greater proportion of closed canopy and were generally older (or, at least, taller) on National Forest land than on other lands, the majority of which are private. So, for dry oak and pine ecosystems in which woodland conditions make up a substantial portion of the reference models, other lands generally had a lower departure from the reference than Forest Service land because of a greater percentage of open canopied forest. For ecosystems in which woodland conditions are less common in the reference models National Forest lands are less departed from the reference than other lands. In every ecosystem, National Forest lands contain a greater percentage of late-seral and old-growth than on other lands, which led to lower departures in Rich Cove, Acidic Cove, High Elevation Red Oak, Mesic-Oak Hickory, and Spruce-Fir ecosystems.

Despite some differences in the proportion of S-classes between National Forest and other lands, the basic trend of ecological departure between land ownerships is remarkably consistent. Ecosystems that are departed on National Forest also tend to be similarly departed on other lands. Only three ecosystems differ by more than 10% in the departure metric between National Forest and Other Lands: Shortleaf Pine-Oak, Pine-Oak/Heath, High Elevation Red Oak. In Pine-Oak/Heath and Shortleaf-Pine Oak Forests, the greater abundance of early and open S-classes on other lands decreases their departure. High Elevation Red Oak Forests display a different trend. This ecosystem has large amounts of late-successional and old-growth forest in its LANFIRE BpS reference model, and National Forest lands have a much greater proportion of late-successional and old-growth s-classes in every ecosystem than do other lands.

Discussion

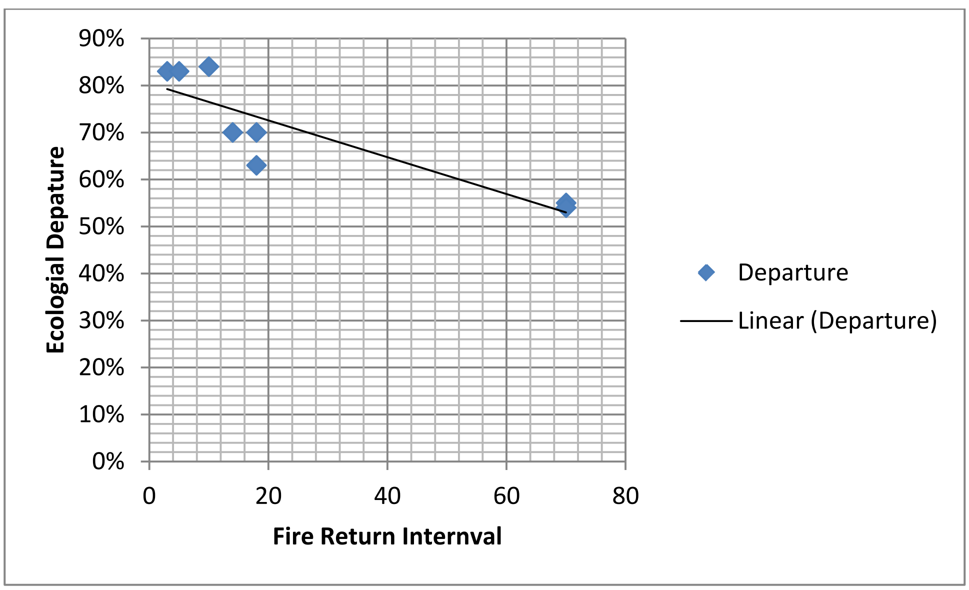
Caution is advised when evaluating the results of this study. There are several potential sources of error, the least of which are errors in LiDAR measurements. Ecological zone mapping is evaluated as no more than 80% accurate in most ecosystems, so mapping errors of ecosystem boundaries have surely occurred. National land cover data is produced at 30 meter pixel size, by far the coarsest pixel size used in this study, so it is likely that misclassification has occurred within pixels defined as forest in this study. Finally, LANDFIRE Biophysical Settings models are works-in-progress and should not be taken as absolute truth. Only the models for Southern Blue Ridge Cove Forest and Southern Appalachian Montane Pine-Forest and Woodland have had sufficient research into their ecology and historical disturbance patterns to not require further studies bolstering them. Even with the comparatively detailed knowledge of those two ecosystems, revisions could certainly be made to all models that would improve their utility and accuracy as reference conditions.

So, rather than focusing on the precision of the results of this study, it is recommended that both LANDFIRE BpS models and the results presented here be evaluated generally. For example, some readers will likely disagree that over 50% of the Mesic-Oak Hickory Forests would have been open-canopied woodlands in their Natural Range of Variation. However, most experts would agree that the 5% of open canopy present in this system on Nantahala-Pisgah National Forest is below an objective

Natural Range of Variation and that efforts should be made to increase woodlands in this ecosystem. Likewise, it is doubtful that there is consensus that 59% of the canopy space of Mesic Oak-Hickory ecosystem would be older than 130 years in age under a natural range of variation, yet it would seem that consensus among experts would be that the 9% of old-growth in this system on National Forests is far below a pre-European Settlement levels.

Identifying the overabundant/under-represented s-classes in each ecosystem is fairly straightforward; simply comparing the current condition to the reference accomplishes that. Less clear are the processes -some of them historical and some of them ongoing - that lead to ecological departure. An ecologist examining Table 3 would note that there seems to be a moisture gradient associated with the ecological departure scores, where drier ecosystems tend to be more departed than wetter ecosystems. An obvious hypothesis is that the departure of many ecological systems is due to a fire regime that is out of line with the reference. Since there is abundant evidence that fire suppression has altered ecosystems across North America, a logical hypothesis is that a lack of fire is leading to the lack of early and open S-classes in dry forests.

Figure 3: Historical fire return interval plotted vs. ecosystem departure from reference conditions for the eight most departed ecosystems on Nantahala-Pisgah National Forest.



A scatter plot of the mean fire return interval used in reference models vs. ecological departure can be used to test the hypothesis that fire return interval is associated with high ecological departure. Ecosystems with the most frequent fire return intervals are the most departed from reference condition. Fitting a line to the scatter plot, with fire return interval on the x-axis and % departure on the y-axis reveals a negative slope with increasing fire return interval. This pattern is present when plotting the eight most departed ecosystems on Forest Service land and the slope of the line only increases when all ecosystems are considered. This lends credence to the hypothesis that the high departure of the most fire dependent ecosystems on Nantahala-Pisgah National Forest is tied to a lack of fire in previous decades.

When looking at ecosystem departure on “All Lands”, National Forest land and other lands have a complementary role. The increased disturbance present on other lands from human activities adds a significant component of early and open S-classes to ecosystems in which they are lacking. The markedly older demographics of ecosystems on National Forest land provide the majority of the rare and under-represented old-growth S-classes on the landscape. From this analysis, an “All Lands” approach emphasizes the importance of National Forests in providing old-growth forest structure, while other lands provide the majority of early and open structure, which unfortunately is not allocated proportional to ecosystem needs.

Table 4: Comparison of the percentage of closed-canopy forest across ecosystems vs. reference models indicates that some ecosystems, like Cove Forests are too disturbed, while several others lack disturbance

Ecosystem	National Forest Land	Other Lands	All Lands	Reference Model
Shortleaf Pine-Oak	85%	65%	74%	3%
Pine-Oak/Heath	92%	82%	87%	8%
Dry Oak Forest	88%	84%	86%	10%
Dry-Mesic Oak-Hickory	88%	78%	82%	22%
Mesic Oak-Hickory	88%	75%	86%	42%
High Elevation Red Oak	91%	84%	89%	42%
Spruce-Fir Forest	73%	73%	73%	72%
Northern Hardwoods	89%	77%	84%	89%
Rich Cove Forest*	84%	68%	75%	96%
Acidic Cove Forest*	94%	88%	91%	96%

* Mid-open S-class not modeled in this ecosystem but analyzed with LiDAR

If the percentages of early and open S-classes are compared across ecosystems, a striking pattern is recognizable (see Appendix A). Some ecosystems in which the reference models predict the least disturbance are the most disturbed ecosystems, regardless of ownership, though this pattern in especially strong outside of Forest Service ownership on “other lands”. It is important to note that early and open S-classes require disturbance for their creation and maintenance, so they can be used as proxy to evaluate disturbance processes. The ecosystems predicted by Landfire BpS models to have the highest percentages of early and open S-classes are those in which fire was historically most frequent. The ecosystems predicted to have the least early and open S-classes are those that receive the least frequent fires and occupy the landforms most protected from weather events, namely Cove Forests. High elevation forests, like Northern Hardwoods Forest and Spruce-Fir Forest that experience very infrequent fire but frequent severe storm events are intermediate in the amounts of early and open S-classes predicted by reference models. In the context of Cove Forests being among the most disturbed ecosystems when looking at “All Lands”, the value of the older, less disturbed Cove Forests on National Forest lands is magnified. With so little of ecosystems such as Rich Cove Forest, Acidic Cove Forest, Mesic-Oak Hickory Forest, Dry-Mesic Oak-Hickory Forest, and Northern Hardwoods Cove Forest reaching old-growth or even late-successional stage on other lands, the need to increase the amount of old-growth in those ecosystems on National Forest lands is enhanced.

When looking at xeric forests with lower economic value, a different trend emerges. Those forests are more disturbed on other lands than on National Forest Lands, likely with some benefits to those ecosystems. However, the disturbances occurring on other lands are still not sufficient to bring those ecosystems into good ecological condition compared to reference models. It is indicative of the economic incentives involved in land management that Rich Cove Forest, predicted to be the least disturbed ecosystem in reference models, is among the top three disturbed ecosystems among all ownerships, while Pine-Oak/Heath Forest with its lack of economic value is among least disturbed of all ecosystems across ownerships, despite having one of the highest rates of historical disturbance.

The lack of management occurring in systems like Pine-Oak/Heath as of 2005 is indicative of a need for change in the management of Nanthala-Pisgah National Forest. Most vegetation management under the 1994 Revised Land and Resource Management Plan focused on creating disturbance and early successional habitat through timber management. Because some of the ecosystems that require the most disturbance in the form of fire, like Dry Oak Forest and Pine-Oak/Heath Forest, have little economic incentive for timber management, they have been neglected under the priorities of the last management plan. Even ecosystems that do have economic incentives for vegetation management – like Dry-Mesic Oak-Hickory Forest, Mesic Oak-Hickory Forest, High Elevation Red Oak Forest, and Shortleaf Pine-Oak Forest – are lacking the important process of fire that influences physical structure and species composition.

Management Implications

The evaluation of the ecological departure of ecosystems in Nanthala-Pisgah National Forest has the potential to clarify the priorities of vegetation management of the forest. In the 1987 Plan, most rationales for vegetation management revolved around the creation of early successional habitat (ESH) in a system in which logging was generally the only acknowledged source of ESH. As the Forest Service has evolved over the years, there has been more openness to considering ESH created from natural disturbances but no practical way until the advent of LiDAR to measure it. The results of this study indicate that, from a vegetation dynamics point of view, most ecosystems currently have enough early development, though not necessarily sufficient levels of early successional habitat for disturbance dependent wildlife species (Litvaitis 2001). There is also concern for species composition issues due to the interruption of the process of fire in the early development that does occur in the analysis area.

This is one of the first studies that attempts to answer the questions of how much early development is currently present and what is the proper proportion of various structural and successional conditions of the ecosystems in the Southern Blue Ridge. The results of this study indicate that cove forests and economically valuable oak-hickory forests actually have more ESH than their reference models, especially when all lands are considered. As previously noted, yellow pine oriented systems do seem to lack early development and fire seems to be lacking from at least six ecosystems. The greatest lack of disturbance associated s-classes in the six most ecologically departed ecosystems is a lack of open habitat – forest structure with between 40% and 60% canopy cover.

While the exact percentage of open-habitats in oak and pine forests is far from settled, the reference models in this study indicate a minimum of 40% open habitat (High Elevation Red Oak) and up to 97% open habitat in yellow pine forests (see Appendix A). The large differences between reference and current conditions indicate that current conditions in these ecosystems are far too closed and that opening the canopy of oak and pine ecosystems by 10% through fire and mechanical means would still fall into the range of conservative managementFor the Dry Oak, Pine-Oak/Heath, and Shortleaf Pine-Oak ecosystems a conservative approach could easily be to open up 20% of the ecosystem.

Table 4: Acreage of the six ecosystems lacking open canopy structure on the Nantahala-Pisgah National Forest portion of the study area

Ecosystem	Total Acres	10% of Acres
Dry Oak Forest	~32,000	3,200
Pine-Oak/Heath	~55,400	5,540
Shortleaf Pine-Oak*	~28,700	2,870
Dry-Mesic Oak-Hickory*	~80,500	8,050
Mesic Oak-Hickory*	~146,000	14,600
High Elevation Red Oak*	~36,000	3,600

*Ecosystems with positive revenue potential

In total, 37,860 acres of National Forest within the study area could be converted to an open canopied structural condition over the next planning period under through prescribed fire, wildfire, and mechanical means. Of those acres, there are approximately 29,000 acres of potential mechanical work that could be revenue positive and help fund other programs on the forest. So, under a conservative, ecological restoration management approach, the next Nantahala-Pisgah Forest Plan could prioritize between 1,400 and 2,900 acres of commercial thinning, annually, in the ecosystems listed above in conjunction with a prescribed fire program to influence the species composition and maintain the open structure created. While this would represent an increase in the amount of logging occurring on the Nantahala-Pisgah relative to contemporary levels, there is evidence to support this activity being ecologically beneficial. The prioritization of activity by ecosystem and s-class would likewise tend to assuage groups and individuals with environmental concerns about logging on public land. The timber harvest and prescribed fire activities in these ecosystems would also likely benefit declining disturbance dependent species (Hunter et al. 2001).

It is important to emphasize that continued restoration of old-growth forests is supported by this study to an equal degree as the need for more open canopied forest. Because most ecosystems are so far below their natural range of variation for old-growth, it is recommended that all old-growth and forests nearing old-growth status, forests over 120 years of age being a possible threshold, be protected and restored on National Forest Land. Because old-growth takes so long to develop, it is important that National Forest managers be strategic when creating disturbances so that old-growth structure is not negatively impacted by management decisions.

By prioritizing vegetation management based on the needs of each ecosystem and focusing on management of ecosystems with the greatest ecological need, Nantahala-Pisgah National Forest has the opportunity to usher in an era of near consensus regarding silviculture, ecological restoration, and vegetation management of the forest. The benefits in terms of wildlife, local economic activity, maintaining traditions of woodcraft, the ecosystem services provided by the forest, and increasing the resilience of ecosystems to coming challenges would be measurable and significant.

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Appendix A: S-Class Distributions in the Ecosystems of Nantahala Pisgah National Forest

S-Class Distribution of Dry Oak Forest Compared to the Natural Range of Variation of Allegheny-Cumberland Dry Oak Pine Forest and Woodland BpS (5713170), revised 11-2012.

S-Class	National Forest	Other Lands	All Lands	Natural Range of Variation
Early (0-19)	5%	9%	7%	6%
Mid-Open (20-69)	1%	2%	1%	13%
Mid-Closed (20-69)	17%	13%	15%	4%
Late-Open (70-129)	2%	6%	4%	18%
Late-Closed (70-129)	66%	71%	69%	3%
Old-Growth Open (130+)	0.2%		0.1%	57%
Old-Growth Closed (130+)	8%		4%	1%

S-Class Distribution of Pine-Oak/Heath Forest Compared to the Natural Range of Variation of Southern Appalachian Montane Pine Forest and Woodland BpS (5713520)

S-Class	National Forest	Other Lands	All Lands	Natural Range of Variation
Early (0-15)	5%	9%	7%	12%
Mid-Open (16-70)	1%	2%	1%	25%
Mid-Closed (16-70)	15%	11%	13%	3%
Late-Open (71+)	3%	8%	6%	55%
Late-Closed (71+)	77%	70%	74%	5%

S-Class Distribution of Shortleaf-Oak Forest Compared to the Natural Range of Variation of Southern Appalachian Low Elevation Pine Forest BpS (5713530)

S-Class	National Forest	Other Lands	All Lands	Natural Range of Variation
Early (0-10)	10%	24%	18%	32%
Mid-Open (11-30)	2%	6%	4%	32%
Mid-Closed (11-30)	28%	27%	27%	2%
Late-Open (30+)	2%	5%	4%	33%
Late-Closed (30+)	58%	39%	47%	1%

S-Class Distribution of Dry-Mesic Oak-Hickory Forest Compared to the Natural Range of Variation of Southern Appalachian Oak Forest BpS (5713150)

S-Class	National Forest	Other Lands	All Lands	Natural Range of Variation
Early (0-19)	8%	14%	12%	6%
Mid Open (20-70)	1%	2%	2%	10%
Mid Closed (20-70)	17%	16%	16%	10%
Late Open (71-129)	3%	5%	5%	14%
Late Closed (71-129)	67%	62%	64%	5%
Old-Growth Open (130+)	0.2%		0.1%	49%
Old-Growth Closed (130+)	4%		2%	6%

S-Class Distribution of Mesic Oak-Hickory Forest Compared to the Natural Range of Variation of Mesic Appalachian Oak Forest BpS, created 11-2012.

S-Class	National Forest	Other Lands	All Lands	Natural Range of Variation
Early (0-19)	7%	14%	11%	5%
Mid-Open (20-70)	1%	4%	3%	7%
Mid-Closed (20-70)	22%	20%	21%	6%
Late-Open (71-129)	4%	8%	6%	6%
Late-Closed (71-129)	56%	55%	55%	5%
Old-Growth Open (130+)	0.5%		0.2%	39%
Old-Growth Closed (130+)	9%		4%	31%

S-Class Distribution of High Elevation Red Oak Forest Compared to the Natural Range of Variation of Mesic Appalachian Oak Forest BpS; created 11-2012.

S-Class	National Forest	Other Lands	All Lands	Natural Range of Variation
Early (0-19)	4%	6%	4%	5%
Mid-Open (20-70)	2%	3%	2%	7%
Mid-Closed (20-70)	17%	18%	17%	6%
Late-Open (71-129)	3%	7%	4%	6%
Late-Closed (71-129)	56%	66%	59%	5%
Old-Growth Open (130+)	1%		0.6%	39%
Old-Growth Closed (130+)	17%		13%	31%

S-Class Distribution of Acidic Cove Forest Compared to the Natural Range of Variation of Southern and Central Appalachian Cove Forest BpS (5713180); revised 11-2012

S-Class	National Forest	Other Lands	All Lands	Natural Range of Variation
Early (0-9)	5%	13%	9%	4%
Mid (10-99)	83%	77%	80%	29%
Late Open (100-139)	1%	1%	1%	1%
Late Closed (100-139)	10%	9%	10%	10%
Old-Growth (140+)	1%		0.6%	56%

S-Class Distribution of Rich Cove Forest Compared to the Natural Range of Variation of Southern and Central Appalachian Cove Forest BpS (5713180); revised 11-2012.

S-Class	National Forest	Other Lands	All Lands	Natural Range of Variation
Early (0-9)	7%	15%	12%	4%
Mid (10-99)	67%	69%	68%	29%
Late Open (100-139)	2%	2%	2%	1%
Late Closed (100-139)	21%	13%	17%	10%
Old-Growth (140+)	3%		1%	56%

S-Class Distribution of Spruce-Fir Forest Compared to the Natural Range of Variation. Central and Southern Appalachian Spruce-Fir Forest BpS (5713500)

S-Class	National Forest	Other Lands	All Lands	Natural Range of Variation
Early (0-35)	18%	18%	18%	18%
Mid-Open (36-65)	6%	8%	6%	11%
Mid-Closed (26-65)	36%	56%	41%	13%
Late-Open (66 +)	5%	1%	4%	0%
Late-Closed (66 +)	37%	17%	31%	58%

S-Class Distribution of Northern Hardwood Cove Forest Compared to the Natural Range of Variation of Southern Appalachian Northern Hardwood Forest BpS (5713090)

S-Class	National Forest	Other Lands	All Lands	Natural Range of Variation
Early (0-24)	5%	9%	7%	9%
Mid Closed (25-75)	24%	27%	26%	18%
Late Open (76+)	3%	9%	6%	4%
Late Closed (76+)	67%	55%	61%	69%

S-Class Distribution of Northern Hardwood Slope Forest Compared to the Natural Range of Variation Southern Appalachian Northern Hardwood Forest BpS (5713090)

S-Class	National Forest	Other Lands	All Lands	Natural Range of Variation
Early (0-24)	12%	9%	11%	9%
Mid-Open (25-75)	3%	4%	3%	0%
Mid-Closed (25-75)	15%	11%	14%	18%
Late-Open (76+)	3%	11%	5%	4%
Late-Closed (76+)	68%	65%	66%	69%

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