Using LiDAR to Analyze Vegetation Structure and Ecological Depature in the Upper Warwoman Watershed, Georgia

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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 sources, where available, for measuring vegetation structure. The current condition of the upper Warwoman Watershed in Rabun County, Georgia was analyzed with the use of ecological zone maps, LANDFIRE Biophysical Settings, and LiDAR vegetation models. In total, 4,900 hectares of Chatahoochee National 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 seven forest ecosystems evaluated, five were found to be highly departed from reference conditions. Age and canopy closure were compared with NRV conditions predicted by the biophysical settings model to determine the level of departure with each ecozone. In general, ecosystems with a more frequent historical fire return interval were more departed from reference conditions than mesic ecosystems. All ecosystems had less young forest than predicted by Biophysical Setting models, demonstrating a very low rate of disturbance. All oak and pine ecosystems had canopies that were much more closed than the reference models,with canopy openings and young forest concentrated in prescribed fire areas. This study indicates that continued fire management and other techniques that create and maintain early-seral and open-canopy forest along with the continued restoration of old-growth conditions on public land in the Warwoman Watershed would be ecologically beneficial.

Introduction

Ecological restoration is a scientific discipline that offers strategies for land management that can improve the health, productivity, and resilience of ecosystems. One difficulty in ecological restoration can be identifying 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 ecosystem processes 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 ST-Sim 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 today. This becomes the reference, or natural range of variation, for each ecosystem (Landfire 2013). Stakeholders for the Warwoman Watershed met in January 2014 to review, revise, and localize the applicable biophysical settings for north Georgia, using models created for western North Carolina in November 2012 as a starting point.

Compared to previous models, the most significant changes were made to the Low Elevation Pine BpS. The Low Elevation Pine Model had not been evaluated or peer reviewed since its original drafting, and new dendrochronological evidence (LaForest 2012) indicates uneven age structure and lower incidence of stand replacement fire than was incorporated in the original model. In other systems, results were quite similar to previous modeling despite that addition of landslide events as a disturbance in cove forests. For all models, fire regimes prior to fire suppression were used, with frequencies of surface fire, mixed-severity fire, and high-severity fire conservatively estimated. surface fire and mixed severity fire were much more common than stand replacement fire in all models.

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). For northeast Georgia, LiDAR data were collected in March and April of 2010.

Analyzing the physical structure of ecosystems requires a reliable map of where ecosystems occur. Fortunately, the Southern Blue Ridge Fire Learning Network has invested substantial resources into mapping the ecological zones of the study area (Simon et al. 2007; Simon 2011). Ecological zones are analogous to the concept of ecological systems and represent potential vegetation rather than existing vegetation. 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, tree height, and natural disturbance.

The eCAP methodology developed by The Nature Conservancy uses Biophysical Settings, ecosystem maps (in this case, ecozone mapping), an assessment of current ecosystem conditions, and scenario forecasting to guide land management. This study measures the ecological departure for the ecosystems in question (Low et al. 2010), however it excludes the scenario forecasting. Ecological departure is calculated by comparing the current percentage of s-classes to the reference condition as determined by the biophysical settings models 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.

Methodology

LiDAR Processing

Raw LiDAR data for the Warwoman Watershed were acquired from Earth Explorer (http://earthexplorer.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 developed by the University of Washington and the USFS Northwest Research Station. The LiDAR data from the USGS are in UTM projection, so all LiDAR models are in units of meters. Canopy height models were produced at 6m pixel size with values <0m and >60m (192') 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 15m pixel size. Percent Canopy cover was determined based on the number of first returns occurring above 1m in height and percent shrub density was calculated from the number of total returns between 1 and 5 m above the ground. The three LiDAR vegetation models (canopy height, canopy cover and shrub density) created in Fusion© were imported into ArcMap as ASCII files and converted to raster format.

GIS Analysis

Ecozones were first lumped into broader types that could be cross-walked to Biophysical Settings (see Table 1). A total of 7 ecosystems were then evaluated separately.

In two cases LiDAR data were used to refine Ecozone mapping of ecosystem boundaries. In the local stakeholder meeting, several participants commented that the Dry-Mesic Oak Hickory ecosystem appeared to be over-mapped. When analyzed with LiDAR it was evident that a significant portion of the Dry Mesic OakHickory Ecozone had a canopy height above 30 meters. While 30m is not uncharacteristic for maximum height in Dry-Mesic Oak-Hickory, large areas of canopy >30 meters tended to occur on concave and north facing slopes. In the opinion of local experts, this section of Dry Mesic Oak-Hickory was improperly mapped. The high-canopy portion of the Dry-Mesic Oak Hickory Ecozone was often adjacent to the Cove Forest Ecozone. The decision was made to intersect the Dry-Mesic Oak Hickory Ecozone with areas of tree height greater than 30 meters. Five majority filter operations were performed on pixels in that zone of overlap to eliminate patches of small pixels, which were then left within the Dry Mesic Oak-Hickory Ecosystem. The results were then erased from the Dry-Mesic Oak Hickory Ecozone and added to the Mesic Oak Hickory Ecozone. The total area refined was 1439 acres (582 hectares), about 16% of the original area of the Dry-Mesic Oak Hickory Ecozone, and within the 80% accuracy threshold sought by the author of the ecozone maps.

In the case of Cove Forest, all of the Cove Forest associated gridcodes (4, 5, 6 & 29) were lumped into a single class and then separated into Rich Cove Forest and Acidic Cove Forest ecosystems based on shrub density. Cove Forest in which shrub density was classified as "high" (>50%) were placed in Acidic Cove Forest while Cove Forest with “low” shrub density was placed in Rich Cove Forest.

Next, the LiDAR vegetation models were reclassified into broad categories and then converted to polygons. Shrub density below 50% was classified as low and the remainder was classified as high shrub density. Canopy cover was reclassified into open or closed canopy depending on whether pixels were below or above 60% canopy cover respectively. Additionaly, canopy height wassplit into two groups, greater than and less than 5m, with forest < 5 m used to denote the Early S-Class.

Taking inspiration from previous studies, Canopy height models served as a surrogate for age) in order to identify the Early S-class,which overlaps but is not necessarily synonymous with concepts of early successional habitat (Weber & Boss 2009. LiDAR height data alone was used becausethere has been no commercial logging in the Forest Service portion of the watershed for 20 years and the FS Veg database does not track young forest created by prescribed fire. Additionally, 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.

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.

The remaining forests were reclassified into Mid, Late and Old-growth age classes based on stand age data extracted from the Forest Service's FSVeg database, which tracks conditions of stands throughout Forest Service ownership (see Table 2). These ages are consistent with and informed by the "Guidance for Conserving and Restoring Old-Growth Forest Communities in the Southern Region" (USDA Forest Service 1998). Old-growth forest was analyzed in systems in which LANDFIRE BpS models have been revised during the Cherokee National Forest Landscape Restoration Initiative and at local workshops in Asheville, NC and Clayton, GA to include old-growth S-classes.

Once the LiDAR vegetation models were reclassified into broad categories, canopy cover, shrub density, age data, and ecozone data were intersected to create a single polygon layer. This was then clipped to a layer of Forest Service ownership. Condition and S-class was determined for each polygon based on its combination of age, canopy cover and shrub density (see Table 3). 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* and *Kalmia*. 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.

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

Ecozone/Ecosystem	Max Early-Seral Height	Mid-Seral Age	Old-Growth Age	Canopy Cover Classes	Shrub Density Classes
Acidic Cove*	5 m (16.4')	< 100 years	≥ 140 years	<60% = Open	>50% = Acidic Cove
Rich Cove*	5 m (16.4')	< 100 years	≥ 140 years	<60% = Open	<50%= Rich Cove
Mesic Oak	5 m (16.4')	< 70 years	≥ 130 years	<60% = Open	>50% = High Shrub Cover
Dry Mesic Oak	5 m (16.4')	< 70 years	≥ 130 years	<60% = Open	>50% = High Shrub Cover
Dry Oak	5 m (16.4')	< 70 years	≥ 130 years	<60% = Open	>50% = High Shrub Cover
Shortleaf Pine	5 m (16.4')	< 70 years	≥ 130 years	<60% = Open	>50% = High Shrub Cover
Pine-Oak Heath	5 m (16.4')	< 70 years	No BpS Model	<60% = Open	>50% = High Shrub Cover

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

Finally, the total area of each S-class and each condition class was used to determine the percentage of each within each ecosystem. 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% are considered to be consistent with reference conditions, those with scores 33% ≥ and ≤ 66% are considered to be moderately departed from reference condition, and scores > 66% reflect high departure from reference conditions.

Results

Five ecosystems evaluated in the upper Warwoman Watershed were highly departed from reference conditions – all of the pine and oak dominated ecosystems – while both Rich Cove and Acidic Cove Forest were moderately departed from reference conditions (see Table 3). The main sources of departure in oak and pine ecosystems were a deficit of old-growth forest, a much greater proportion of closed canopy than is present in the reference models, and a general shortage of the early S-Class, even in the form of small tree fall gaps. Sources of departure in Acidic and Rich Cove Forest systems were similar, except that those are closed canopy systems and do not require more open canopy conditions.

Table 3: Ecological Departure of Ecosystems in the upper Warwoman Watershed

Ecosystem	Departure	Drivers of Departure
Shortleaf-Oak Forest	83%	Too much closed canopy, lacks old-growth, lacks early-seral
Dry Oak Forest	79%	Too much closed canopy, lacks old-growth, lacks early-seral
Pine-Oak/Heath*	83%	Too much closed canopy, lacks early-seral
Mesic Oak Forest	70%	Too much closed canopy, lacks old-growth, lacks early-seral

Dry-Mesic Oak Hickory Forest	68%	Too much closed canopy, lacks old-growth, lacks early-seral
Acidic Cove Forest	55%	Lacks old-growth, lacks early seral
Rich Cove Forest	53%	Lacks old-growth, lacks early seral

* Old-Growth S-classes not included in the Pine/Oak Heath model

The Early S-Class, or areas of forest canopy < 5m tall (16.4'), made up 1.3% of the analysis area as of 2010 for a total of 172 acres (69.6 ha). This figure is inclusive of maintained wildlife fields and canopy gaps as small as 36 square meters (387 square feet). Open canopy forest was likewise a small percentage of the analysis area with 1,072 acres (434 ha) making up 7.9% of Forest Service ownership in the analysis area. The small percentage of young forest and open-canopied forest is indicative of a very low level of disturbance in the upper Warwoman Watershed since the early 1990's.

Shrub density, or the proportion of LiDAR returns that encountered an object between zero and five meters, is a measure that is not accounted for in Landfire Biophysical Setting models. However, it is widely observed that shrub density is high in many parts of the Southern Blue Ridge and there is evidence that shrub density has increased concurrent with the era of fire suppression (Pinchot and Ashe 1898; Frost 2000). Somewhat alarmingly, 71% of the upper Warwoman Watershed had high shrub density (>50% shrub cover) as of April 2010.

While low proportions of young forest and open-canopied forest and a high shrub density characterize the current condition of the upper Warwoman Watershed, significant differences were observed between areas inside and outside prescribed fire units. The Early S-Class was observed to be 12 times more abundant inside prescribed fire units than outside. Open S-Classes were six times more abundant, the condition of high shrub density was 16% less abundant, and median shrub density was 10% lower inside prescribed fire units than outside (See Table 4).

Table 4: Acreages and Relative Percentages of Forest Conditions in the upper Warwoman Watershed

	Rx Fire Units	Non-Fire Units	Upper Warwoman
Early S-Class Acres	132.9	39.3	172.2
% Early S-Class	4.8%	0.4%	1.3%
Open Canopy Acres	665.3	406.8	1,072.1
% Open Canopy	24%	3.9%	8.1%

High Shrub Acres	1,657.2	8020	9,677
% High Shrub Density	59.8%	76%	71%
Median Shrub Density	57%	67%	65%
Total Acreage	2,772	10,538	13,310*

*Combining the first two columns yields 13,389 acres, a small discrepancy caused by "slivers" in the GIS analysis

Discussion

Caution is advised by the author when using LANDFIRE Biophysical Settings as reference conditions. The numerical outputs of 1000 year model runs provide discrete numbers, when a range of values for each S-Class produce the variation in the "Natural Range of Variation". Given the uncertainties with simulating the variation inherent in ecosystems, differences between the current condition and the reference condition should be large to warrant intervention by land managers. Additionally, LANDFIRE BpS models are probably best used to inform the direction of management, rather than an endpoint. Further caution is warranted in the case of the Warwoman Watershed due to the small area covered compared to similar analyses elsewhere in the Southern Blue Ridge (Low 2011; Kelly 2013). It is possible, though unlikely, that very different trends in ecosystem structure occur elsewhere in Chattahoochee National Forest.

This departure analysis of the Warwoman Watershed is at a different scale than similar analyses performed for the North Zone of Cherokee National Forest and the Nantahala-Pisgah National. Both of those analyses were at the sub-regional, landscape level, while this analysis focusses on a single watershed. Because of the smaller scale of the Warwoman analysis, there is a greater possibility that trends in this watershed do not reflect trends elsewhere in the Southern Blue Ridge. However, it is notable that the hierarchy of departed ecosystems for Warwoman is very similar to those if the aforementioned analyses, which should add confidence to the results and affirm that, once again, fire suppression has been a leading cause of ecological departure across the Southern Blue Ridge Ecoregion.

For all ecosystems analyzed, where an old-growth age class was modeled in the Biophysical Setting, a lack of the old-growth age class is a large component of ecological departure. The upper Warwoman Watershed actually harbors more of the old-growth age class, defined as forests over 130 years of age in oak and pine systems and over 140 years in the cove forest systems, than areas analyzed in Cherokee, Nantahala, and Pisgah National Forests. Approximately 14% of the upper Warwoman Watershed qualifies as old-growth under the Region 8 Guidance for Conserving and Restoring Old-Growth Forest. While it is likely that 130 years of age is too young to attain all old-growth characteristics, this age is consistent with the age threshold for many hardwood types in the Region 8 Guidance and there is evidence that by

160 years, some secondary hardwood forests have characteristics of old-growth (USDA 1998; Scheff 2012). From the standpoint of the eCAP methodology, there is clear justification for increasing the oldest age classes in all ecosystems at upper Warwoman.

The rate of disturbance is the past several decades has been remarkably low. Even with an inclusive definition of young forest in which all areas in which the forest canopy is less than five meters tall were counted, only 1.3% of Forest Service Land in the analysis area is in the Early S-Class, and most of that occurs in prescribed fire areas. This seems noteworthy, especially given that the areas as small as 36 m^2 (387 ft^2) were analyzed with LiDAR. Studies on reference sites in mesic hardwood forests support a constant rate of tree fall disturbance on the order of 2-4% per decade (Lorimer, Runkle). Given that most of the Southern Blue Ridge was logged in a short time frame within four decades either side of the turn of the 20th century, it may be that most of the forest in the upper Warwoman Watershed has not reached an age class in which canopy trees are falling as frequently as at the study sites. It is also worth noting that only ¼ of the upper Warwoman Ecosystems fall into the either Mesic Oak-Hickory (1697 acres), Acidic Cove Forest (1,310 acres), or Rich Cove Forest (198 acres). Very few, if any, studies have examined the rate of gap formation in submesic to xeric forests in the Southern Appalachians, and it may be that disturbance in such forests in the absence of fire actually occurs at a lower rate than in mesic forests. This is a topic worthy of investigation. In any case, there is a striking shortage of young forest in the upper Warwoman Watershed relative to reference models.

Open S-Classes, or forests with less than 60% canopy closure, are an abundant structural condition in all of the Biophysical Setting models except for cove forests. According to LiDAR analysis, 8% of the Forest Service ownership at upper Warwoman qualified as open canopy as of 2010. Values for the total proportion of open-canopy predicted by LANDFIRE BpS models ranged from 51% open-canopy S-Classes for Mesic Oak Hickory to 92% open-canopy S-Classes for Shortleaf-Oak. LANDFIRE BpS models predict that 63% of Forest Service ownership in the upper Warwoman Watershed based on 1000 year model runs. Like, young forest, open-canopy forest is dependent on disturbance and edaphic factors like thin soil and rock. The lack of open canopy relative to LANDFIRE BpS models reflects that the rate of disturbance for the past several decades has been lower than the probabilities of disturbance used in the models. A reduction in the frequency and extent of fire since the time of Federal ownership in the early 20th century one factor that has allowed forest canopies to close, and an absence of fire and other disturbance has kept canopies closed.

In addition to historical accounts and modeling efforts, evidence can be found that fire can play a large role in influencing the structure of Southern Blue Ridge forests in comparing areas that have experienced fire to those that have not. In the upper Warwoman Watershed, it is clear that prescribed fire has influenced forest structure, mostly by increasing light penetration, decreasing shrub cover, and increasing the proportion of regenerating forest (see Table 4). Prescribed fire has clearly been the most impactful vegetation management activity at upper Warwoman in recent times and this should be welcome news to fire ecologists and

Chattahoochee, though it may cause worries among those that are skeptical of the role of fire in eastern ecosystems (Matlack 2013). The fact that prescribed fire is having an effect on vegetation structure is indicative of the fact that prescribed fire has been successful in diversifying structural conditions where it has been applied. As an added benefit, reduction of shrub cover would likely mean a decrease in fuel loading and severe fire behavior if continued over the long-term.

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