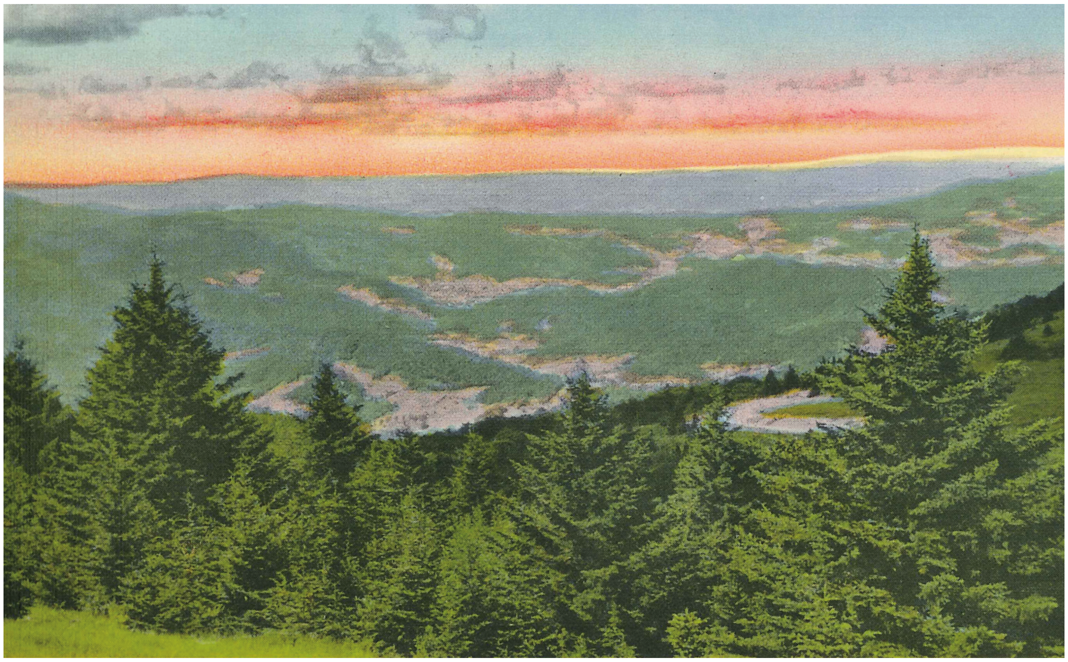
INSTITUTE FOR THE ENVIRONMENT

HIGHLANDS FIELD SITE

2013 INTERNSHIP RESEARCH REPORTS



HIGHLANDS BIOLOGICAL STATION

HIGHLANDS, NORTH CAROLINA

INTRODUCTION

Over the course of their semester at the UNC-IE Highlands Field Site our students have spent untold hours in the field — from coves to ridgetops, outcrops to spruce-fir forest, upon balds and barrens, and in rivers and up creeks (sometimes in more ways than one). They studied on the trail and in the classroom. Indeed, our philosophy is that the trail *becomes* a classroom, and the fabulous natural environment that is the southern Appalachian Mountains became an extension of the Coker Laboratory. Our students are part explorer, part academic, and they lived something of an Indiana Jones model of education (minus the firearms and locals trying to do you in).

We walked in the footsteps of real-life naturalist-explorers, like William Bartram and Asa Gray. This recalls to mind another explorer, one who never visited the southern Appalachians but who would have reveled in its landscape: the legendary 19th century naturalist Alfred Russel Wallace. Wallace was a tropical explorer, co-discoverer with Darwin of the principle of natural selection, and founder of the field of evolutionary biogeography. In the spirit of Wallace and his epic 1869 travelogue *The Malay Archipelago*, we might think of our students as having explored the "Highlands Archipelago." The archipelago analogy is most appropriate, and our students experienced first-hand that this landscape is a mosaic of island-like communities and habitats, its diversity shaped profoundly by underlying geology, topography, age, and degree of connectivity to other such "habitat islands."

With Jim's recent publication of an annotated edition of Wallace's "Species Notebook" in mind — the most important of Wallace's field notebooks kept between 1855 and 1860 during his southeast Asian explorations — we imagine how some of our students' Wallace-style "Highlands Archipelago" notebook entries might read:

— Rhododendron hells well-named

— Mountain streams very cold in October.

— Jim + Karen not kidding about locking Valentine doors (bears love hummus!!!)

— Seine nets impossible to hold after heavy rains

— National Parks + Forests not exempt from Gov.'t shutdowns

— Roach-like stoneflies — single most common insect in mountain streams?

More seriously, IE Highlands Field Site mission would have deeply resonated with Wallace, who far ahead of his time held a holistic "ecological" vision of interconnectedness of nature, and whose eloquent voice for the importance of field study and conservation resonates today. Consider Wallace's conservation ethic expressed in an 1863 address to the Royal Geographical Society: "The naturalist," he wrote, "looks upon every species of animal and plant now living as the individual letters which go to make up one of the volumes of our earth's history; and, as a few lost letters may make a sentence unintelligible, so the extinction of the numerous forms of life which the progress of cultivation invariably entails will necessarily obscure this invaluable record...." We have a responsibility to study and preserve the natural world, he urged, declaring that:

> "If this is not done, future ages will certainly look back upon us as a people so immersed in the pursuit of wealth as to be blind to higher considerations. They will charge us with having culpably allowed the destruction of some of those records of Creation which we had it in our power to preserve; and while professing to regard every living thing as the direct handiwork and best evidence of a Creator, yet, with a strange inconsistency, seeing many of them perish irrecoverably from the face of the earth, uncared for and unknown."

We suspect that Wallace would have enjoyed accompanying our students in their many field explorations as well as their intellectual explorations this semester, and perusing the internship research reports presented here. These fruits of their semester-long labors have taught our students much, and contribute to our understanding and appreciation of the natural world that Wallace loved so well.

~ Jim Costa and Karen Kandl

Highlands Field Site Directors

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Jim Costa and Karen Kandl
IE-Highlands Field Site Directors
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THE EFFECTS OF A POWER LINE RIGHT-OF-WAY ON HABITAT AND MICROCLIMATE IN A SOUTHERN APPALACHIAN FOREST AND THE IMPLICATIONS FOR SALAMANDERS

EMILY C. ALLAN

Abstract. Power line right-of-ways (ROWs) result in forest fragmentation, which may decrease habitat availability and create barriers to movement for terrestrial salamanders due to edge effect. I measured microclimatic and habitat variables such as light intensity, temperature, leaf litter depth and moisture, course woody debris volume and decay class, and soil moisture in a ROW and along four transects in an adjacent forest. Of these, only leaf litter depth varied within the forest, and no variables showed an edge effect due to the ROW. The only variables that varied between the ROW and forest were light intensity and leaf litter depth. Retention of soil moisture and large amounts of coarse woody debris may mitigate microclimatic conditions for salamanders in narrow canopy gaps such as ROWs.

Key Words: Coarse woody debris; decay class; edge effects; forest fragmentation; habitat variables; leaf litter depth; leaf litter moisture; light intensity; power line right-of-way (ROW); salamanders; soil moisture; southern Appalachians; temperature.

INTRODUCTION

The forests of the southern Appalachians are increasingly being disturbed by forest fragmentation (Wear 2002) and many species depend on the forest to provide suitable microclimatic conditions, including terrestrial salamanders (Welsh and Droege 2001). Forest fragmentation occurs as vegetation is removed for roads, logging, agricultural, and urban areas and results in edges, which are transition zones between two adjacent ecosystems or vegetative communities (Murcia 1995) and these edges exhibit higher air and soil temperatures (Williams-Linera 1990, Chen et al. 1993, Gehlhausen et al. 2000, Brooks and Kyker-Snowman 2007) higher light penetration (Greenberg 2001), lower soil moisture (Brothers and Spingarn 1992, Matlack 1993, Marchand and Houle 2006), lower leaf litter mass, depth, and moisture (Ash 1995) and lower humidity (Chen et al. 1993, Gehlhausen et al. 2000) relative to the interior forest areas.

Many species are affected by the removal of vegetation in forests, especially plethodontid salamanders, which require a deep layer of moist leaf litter for dermal respiration, foraging, and burrowing (Feder 1983, Ash 1995, Welsh and Droege 2001). Salamander abundances may be reduced because microclimatic conditions are often negatively affected by forest fragmentation, and the magnitude of the effects is related to the size of the forest clearing. For example, large clear cuts greater than 0.4 ha in size can result in leaf litter depth reductions of 14-29% compared to the adjacent forest (Buckner and Shure 1985), while clear cuts 10 ha in size have shown a 70% reduction in leaf litter depth, 18% reduction in litter moisture, and 13% reduction in litter dry mass (Ash 1995). This suggests that large scale cuts would have greater effects on salamanders, which have been found to avoid clear cuts and clear cut edges (Demaynadier 1998). However, smaller harvest gaps provide similar habitat to natural gaps (Strojny and Hunter 2010), where salamanders usually remain abundant (Greenberg 2001).

Roads are a common form of forest fragmentation and have been shown to significantly reduce the depth of the leaf-litter layer up to 100 m into the forest. Wider roads tend to produce steeper declines in leaf-litter depth and canopy cover (Haskell 2000). Leaf litter depth and moisture have been found to be higher and soil density lower in the adjacent forest compared to on logging roads (Semlitsch et al. 2007). Consequently, plethodontid salamanders are often significantly less abundant in edges near roads (DeMaynadier 2000, Marsh and Beckman 2004, Marsh 2007, Semlitsch et al. 2007).

Power line right-of-ways (ROWs) are another cause of forest fragmentation in the Appalachians. Like roads, they are linear features cleared of vegetation that extend for long distances. However, ROWs have been relatively understudied in terms of their effects on salamander microclimate and habitat (Yahner et al. 2003). In this study, I measured habitat variables along a ROW to examine potential edge effects and the resulting implications for salamanders.

MATERIALS AND METHODS

My study site (35.08645N, 83.2618W) was located along a 16-m wide power line right-of-way (ROW) in Nantahala National Forest along the Ranger Falls Trail in the vicinity of Highlands, Macon County, North Carolina. The site was on a slight slope with a westerly orientation at an altitude of 3877 ft. The ROW was last cut in 2006 and sprayed with herbicide in 2012 (USDA Forest Service, pers. comm.). The adjacent 101 year-old forest consisted primarily of red maple (*Acer rubrum*), chestnut oak (*Quercus prinus*), red oak (*Q. rubra*), and Fraser magnolia (*Magnolia fraseri*) with some understory of rhododendron (*Rhododendron maximum*) and a dense ground cover of huckleberry (*Gaylussacia baccata*) (USDA Forest Service, pers. comm.). In August 2013 I established one transect within the ROW and four parallel transects in the forest at 5, 20, 35, and 50 meters from the forest edge. Each transect was 50 meters long and was marked every 10 meters (Fig. 1). Within 2 m of each transect, I obtained the volume of any coarse woody debris (CWD) > 10 cm in diameter and of decay classes 3, 4, and 5, which are cover objects frequently occupied by salamanders (Petranka et al. 1994, Brannon and Rogers 2005).

Nine surveys of other habitat variables were conducted between August and October 2013. During each survey, I collected 250 cm^2 samples of leaf litter from two randomly selected points along each transect. Samples were transferred to a paper bag and weighed to obtain wet mass, dried at ~65°C for at least 24 hours, and then re-weighed to obtain dry mass (Ash 1995). Litter moisture content was calculated as wet mass minus dry mass and expressed as a percentage of wet mass (Brannon and Rogers 2005).

I also took six measurements of leaf litter depth at 10 m intervals along each transect by pressing a metric ruler through the litter to the point of resistance of the soil (Brannon and Rogers 2005). I measured light intensity (lumen/m^2) and temperature (°C) at ground level 3 times per transect, at 0, 25 and 50 meters, using an Apogee basic quantum meter and a digital thermometer. On the last day of my study, I also decided to measure soil moisture at 10 meter intervals along each transect using a Kelway Soil Tester, due to frequent observations of salamanders in holes within the ROW (unpublished data).

I examined potential edge effects due to the ROW using one-way Analysis of Variance (ANOVA) on the four forest transects for each habitat variable (Zar 1999). Differences between the ROW and the forest were analyzed using Planned Contrast ANOVAs.

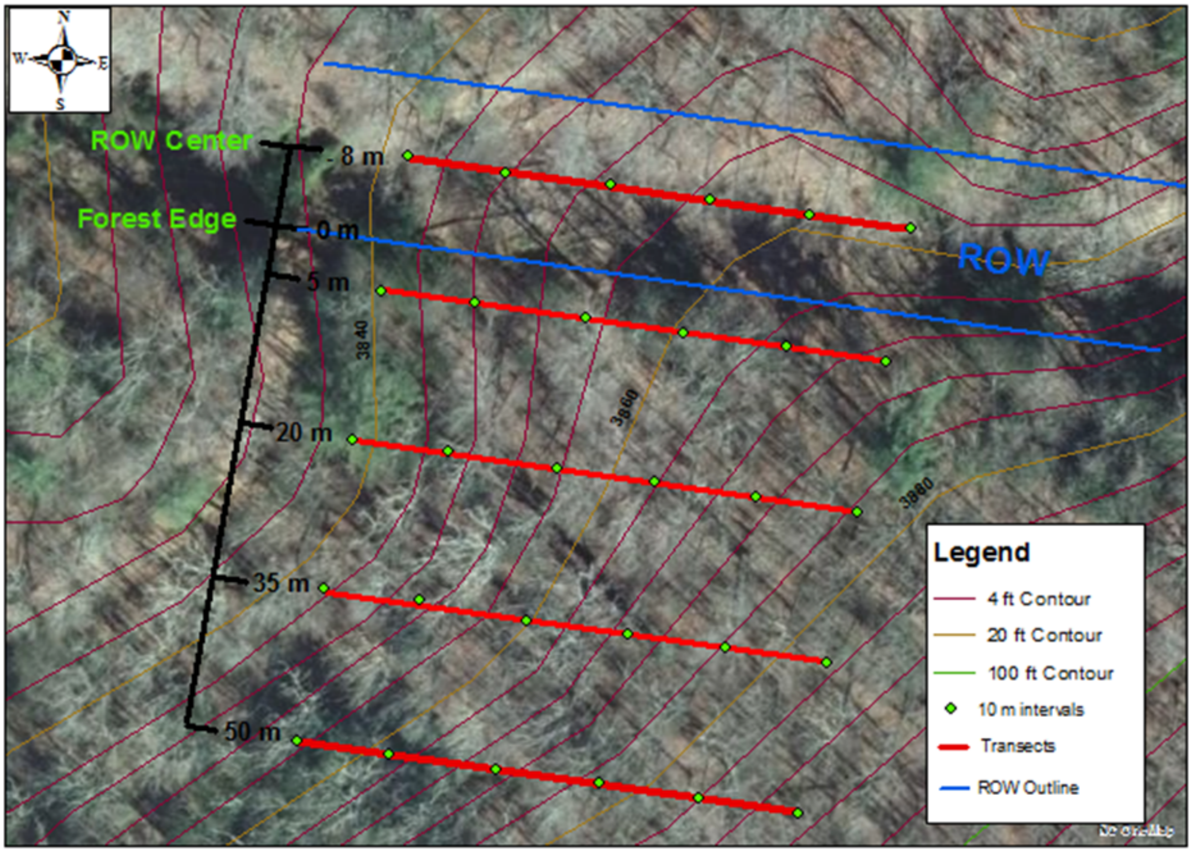

FIG. 1. Study site aerial map with transect setup and topography.

RESULTS

Average leaf litter depth within the forest varied significantly (F=6.53; df=3, 212; p<0.01) but did not show a relationship with distance from the forest edge (Table 1). No other habitat variable differed among the forest transects (Table 1).

Leaf litter depth varied significantly between the ROW and the forest (F=7.19; df=1, 265; p<0.01) with an average depth of 70.41 mm and 116.43 mm, respectively (Table 1). Light intensity was significantly higher in the ROW compared to the forest (F=106.43; df=1, 130; p<0.01; Table 1). No other habitat variables were significantly different, although average leaf litter moisture and CWD decay class were slightly lower, and temperature was slightly higher, in the ROW (Table 1).

TABLE 1. Means for each measured habitat variable and statistical results of one-way ANOVAs analyzing edge effect within the forest, and planned contrast ANOVAs analyzing differences between the forest and the ROW.

One-Way ANOVA						Planned Contrast ANOVA		
Variable	5m	20m	35m	50m	F	Forest	ROW (-8m)	F
Leaf litter depth (mm)	131.44	117.94	105.91	110.44	6.53*	111.43	70.41	7.19*
Leaf litter moisture (%)	53.96	53.63	52.79	51.48	0.09	52.63	42.06	0.51
Light Intensity (lumen/m²)	6.07	9.19	8.52	8.19	0.58	8.63	83.00	106.43*
Temperature (°C)	16.51	16.68	16.60	16.79	0.04	16.69	17.82	0.10
CWD Decay Class	4.23	4.23	4.21	4.17	0.04	4.20	3.57	0.25
CWD Volume (cm³)	147185	141478	45439	153730	1.04	121958	173087	0.57
Soil Moisture (%)	15.00	10.00	14.67	11.50	1.15	12.06	10.00	0.18

Note: * $P < .01$.

DISCUSSION

Salamanders are particularly sensitive to transitions in microclimate and microhabitat that usually accompany forest edges (DeMaynadier and Hunter 1998). Studies have shown that forest fragmentation, such as large clear cuts, can result in increased temperatures (Rothermel and Luhring 2005), decreased leaf litter dry mass, moisture, depth (Ash 1995), and decreased soil moisture (Chen et al. 1993) both in the opening and along the forest edge. However, large amounts of heavily decomposed CWD such as that in the ROW can mitigate unfavorable microclimatic conditions where leaf litter has been reduced (Strojny and Hunter 2010). Effects on microclimate are often minimal in smaller forest clearings or when a partial canopy remains (Greenberg 2001).

Microclimate conditions have also been shown to exhibit the greatest differences between canopy gaps and the forest during the summer (Brooks and Kyker-Snowman 2008) and be more xeric along edges with a more southerly aspect, which may have a more pronounced effect on salamander abundance (Moseley 2009). Because my study was conducted in the fall, and on a northwest-facing slope, it is likely that any microclimatic differences between the ROW and the forest were minimized.

Greater sunlight exposure and a thinner leaf litter layer at my study site are likely a result of the lack of canopy within the ROW. But unlike many studies, this lack of vegetation had little effect on other microclimatic and habitat variables, and resulted in no edge effect in the adjacent forest. The narrowness of the ROW may have mitigated differences in moisture at my study site. For example, Heithecker and Haplern (2006) found that adequate levels of soil moisture may persist in harvested areas, and Redding et al. (2003) found that soil moisture and temperature may be comparable to the forest as far as 7-15 m into a clearing. Similarly, road width has also been found to predict the magnitude of edge effects on salamanders (Marsh 2007).

Some studies have found that small, lightly used roads have little edge effects, and small gaps in the forest canopy have little to no effect on the microclimate and habitat variables (Marsh 2007, Messere and Ducey 1998). Because the microclimatic conditions and habitat variables in the ROW and in the forest edge were not greatly different from those in the forest, it is likely that salamander movement and abundance would be minimally affected. For example, one study found that there were no significant differences in salamander abundances between small canopy gaps, their edges, and the forest (Messere and Ducey 1998). Because the ROW I studied resembled a small canopy gap in width, I would expect to find salamanders in the ROW. Indeed, one study found that although salamanders prefer the forest, they can still be found in ROWs (Yahner et al. 2003).

However, when leaf litter is absent or minimal as in this study, salamanders must retreat into subterranean burrows, and can only do so when the soil is moist and not compacted (Rothermel and Luhring 2005). Consequently, salamanders occupying these spaces are more restricted in their mobility, and probably emerge from their burrows and forage only at night when it is more humid to prevent desiccation (Jaeger 1980). The use of herbicides in ROWs may also limit salamander movements by reducing vegetation for use as protective cover (Roberts and Liebgold 2008) and as foraging spaces (Jaeger 1978), or may have direct effects on mortality (Relyea 2005). Nevertheless, my findings suggest that microclimatic conditions in power line right-of-ways are sufficient to maintain populations of salamanders. They also provide important insight into the effect of human made and maintained vegetationless corridors on microhabitat and salamander abundance. So long as ROWs are made to be a minimal width and are not oriented north to south, they may not affect salamander habitat and populations.

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CREATING A GEOGRAPHIC INFORMATION SYSTEMS MODEL TO MAP POTENTIAL HABITAT SITES FOR *GLYPTEMYS MUHLENBERGII* BOG TURTLE IN MACON AND JACKSON COUNTIES.

ANNA DIMARTINO

Abstract. This project develops a GIS model to predict *Glyptemys muhlenbergii* Bog turtle habitat sites within two western North Carolina Counties, Macon and Jackson. Focusing on conservation of this rare species, the GIS model examines six ecological and geographical features of the landscape in an attempt to determine environmental preferences of the bog turtle. Areas containing selected habitat features were identified and given scores in ArcGIS and ranked by amount of overlap between desirable features, using an additive model and combination procedure. This model could be utilized by conservation groups or herpetological researchers to aid in their attempts at preservation of this precious yet critically endangered turtle species.

Key words: Bog turtle; critically endangered; GIS; Glyptemys muhlenbergii*; habitat model; Jackson County; Macon county; preservation.*

INTRODUCTION

Western North Carolina, and especially the Highlands Plateau, has a steadily and rapidly increasing population due to its natural beauty, which draws people from nearby large cities such as Asheville, Atlanta, and Charlotte. In the thirty years between 1976 and 2006, development in the western part of the state increased 570% (Vogler et al. 2010). This development, in turn, has affected the habitats of many creatures that live in the southern Appalachians, such as the native bog turtle (*Glyptemys muhlenbergii).* In North Carolina, almost 90 species of plants and animals that are considered rare, threatened, or endangered live in nonalluvial mountain wetlands (Murdock 1994). Over half of the wetlands originally present in the contiguous United States have been destroyed in only two centuries (Dahl 1990) and half of a million acres of wetland habitat continue to be destroyed each year (Dahl and Johnson 1991). Wetland and bog habitat must be protected to ensure the continued survival of the bog turtle in the Southern Appalachian Mountains.

Glyptemys muhlenbergii (previously *Clemmys muhlenbergii*), commonly known as the bog turtle, is listed as threatened in North Carolina (Wilson 2013) and has protection under the Endangered Species Act of the United States since 1997. Two disjunct populations exist within the United States. The northern population is found between New York/Massachusetts south to Maryland and the southern population ranges from southern Virginia to northern Georgia. The southern population is the one of interest to this project and is listed at "threatened due to similarity of appearance" to the northern group (USFWS 1997). The bog turtle is the second-smallest turtle species in the world and the smallest in the United States, with the carapace of adults measuring 3-4 inches (7.5-10 cm). They have dark-brown or black shells with a distinctive orange patch on either side of the head. The turtles are omnivorous and spend much of their time hidden either under mud or in nearby grasses or vegetation clumps. Spring seepages are prime habitat for the bog turtle.

This model has been created as a conservation tool for *Glyptemys muhlenbergii* to assess available potential habitat sites for the bog turtle within Macon and Jackson Counties of western North Carolina. The model uses Geographic Information Systems (GIS) and known *Glyptemys muhlenbergii* sites from NC Natural Heritage Program (NC NHP) Data to assign quantitative values to six habitat features and combine these values to represent the amount of overlap between them, indicating levels of potential habitat presence. The habitat at each bog turtle site within Macon, Jackson, Henderson, and Transylvania Counties was analyzed for the additive model. The features utilized were: soils, hydric soils, elevation, slope, wetlands, and spectral signature from ETM+ satellite data. The ultimate product of this project is a map presentation of Macon and Jackson Counties showing levels of overlap of these habitat features to predict habitat that would be suitable for the protection of *Glyptemys muhlenbergii.* This method may be applicable for other locations within the bog turtle's range.

MATERIALS AND METHODS

Focus Areas

Macon and Jackson Counties

Macon and Jackson Counties are located in southwestern North Carolina in the southern Appalachian Mountains. The Cowee Mountains run along the border of these two counties and separate the Tuckasegee River System in Jackson County from the Little Tennessee System in Macon County. The main areas of bog turtle occurrence within the Tennessee basin are in the Little Tennessee and Nantahala River Systems and six sites have been recorded in Macon County (Fig. 1). There are no recorded *G. muhlenbergii* sites in Jackson County based on North Carolina Natural Heritage Program (NC NHP) GIS data (Fig. 2). Species distribution in these two counties is expected to be patchy due to extreme elevation variance found in the southern Appalachian Mountains (Lee 2000).

Transylvania and Henderson Counties

Located just to the east of Jackson County, Transylvania and Henderson Counties comprise part of the lower French Broad River System where *Glyptemys muhlenbergii* is known to inhabit (Lee 2000). These two counties were included in the model as a way to provide additional data on what types of habitats bog turtles prefer. By including them, the range of available habitat was broadened, especially since no points were found in Jackson County.

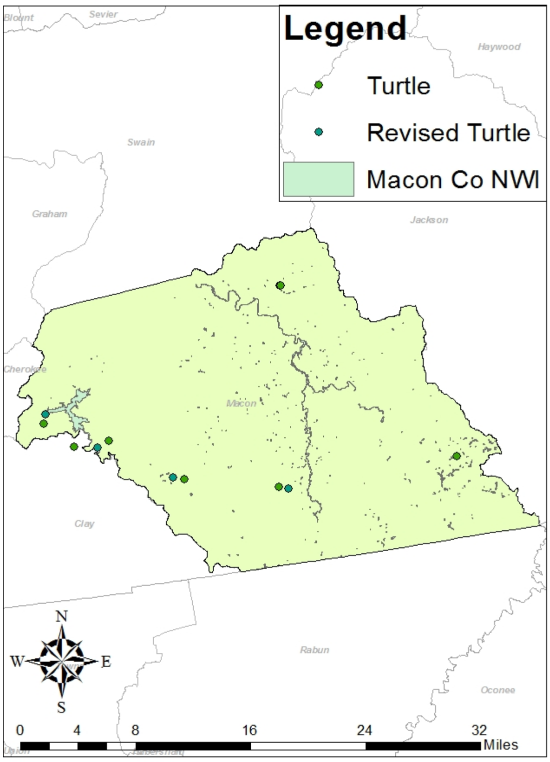

FIG. 1. Macon County, displaying wetlands, Natural Heritage data turtle sites, and modified turtle sites. Created in ArcGIS.

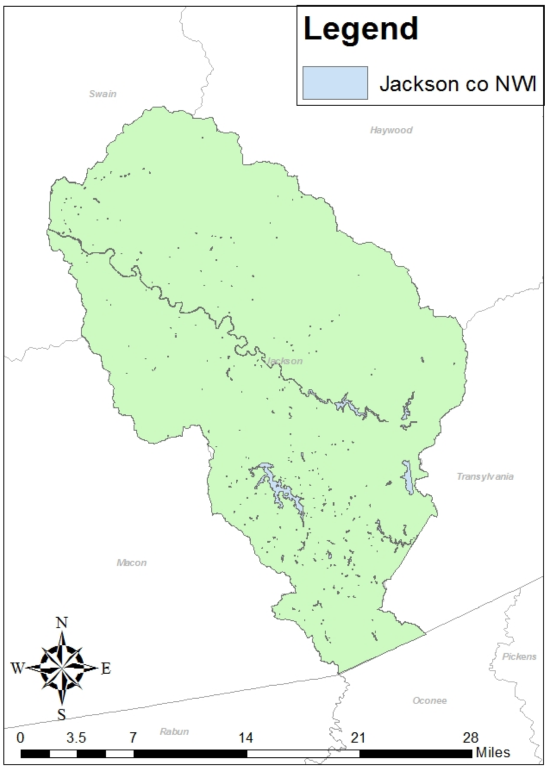

FIG. 2. Jackson County, displaying wetlands. Created in ArcGIS.

TABLE 1. Turtle points and habitat feature data with sources and years for GIS data used. (NHEO= Natural Heritage Element Occurrences; NC DENR=North Carolina Department of Environment and Natural Resources; NWI= National Wetlands Inventory). These features were analyzed using ArcGIS 10.1® (ESRI 2012) and Feature Analyst© extension (ESRI 2011).

Feature	Data Source	Year
Turtle Sites	NHEO through NC DENR	2013
Soils	USDA Soil Surveys of: Macon, Jackson, Henderson, and Transylvania Counties	Various
Hydric Soils	Derived from County Soils data	Various
Elevation	NC Floodplain Mapping Program, 2007	2007
Slope	Derived from Elevation data	2007
Wetlands	NWI Data	2013
Spectral Signature	Landsat 7, ETM+	2013

GIS Data Layers Used to Determine Potential Habitat Sites

Four data layers were used to evaluate potential habitat sites based on preferred features from previously found bog turtle sites (Fig. 3 and Fig. 4). Slope data were generated from the elevation layer and hydric soils data were pulled from general soils data. The six features generated from the four layers were: soils, hydric soils, elevation, slope, wetlands, and spectral signature (Table 1). For each, all the characteristics from the previously found turtle sites were compiled to show all areas in which bog turtles might be found.

Soils

A multitude of soil types exist within Macon and Jackson Counties. The National Cooperative Soil Survey system of classification has 6 categories: order, suborder, great group, subgroup, family, and series. The classification of series is according to the soil horizon, with all soils in a series having similar horizons based on color, texture, structure, reaction, consistence, mineral and chemical composition, and arrangement in the profile. Soils types within series provide more information such as percent slope and probability of flooding (NRCS 1996). The model included all soils upon which bog turtle sites were found in all four counties (Table 3).

Hydric Soils

A hydric soil is defined as "a soil that formed under conditions of saturation, flooding or ponding long enough during the growing season to develop anaerobic conditions in the upper part (NRCS 1996)." Due to the moist nature of these soils and the association of *G. muhlenbergii* to wetland habitat, they were included as a special category in this model. The data for this variable were extracted from each of the counties' soil data.

Elevation

The bog turtle is generally found at elevations greater than 2460 feet and this parameter was therefore included in the habitat model (Ernst 1994).

Slope

Slope can be a valuable variable in determining locations of bog turtle territory because it affects soil type and drainage potential, further identifying habitat possibilities. Generally, wetlands are not found at areas with high slopes because water is not able to collect. Slope data were derived from elevation data, using the Spatial Analyst tool "slope" within ArcGIS 10.1$^{®}$ (ESRI 2012) and were analyzed in percentage, not degree measurements.

Wetlands

Presence or absence of wetlands, and type of wetland (freshwater forested/shrub, lake, freshwater emergent, freshwater pond) were important variables in the determination of likely habitats for this model. Wetland data were also important for movement of the known turtle sites to wetlands, where they are known to live. It was assumed for the model that points not on a wetland were turtles that had strayed from their home and the points were moved to a wetland in order to obtain more accurate data for the model (FWS 2013).

Spectral Signature

A spectral signature is the pattern of electromagnetic radiation that identifies a chemical or compound. Materials can be distinguished from one another by examining which portions of the spectrum they reflect and absorb (*GIS Dictionary* 2013). The spectral signature information was obtained from Enhanced Thermatic Mapper (ETM+) data (NASA) and was analyzed using Feature Analyst in ArcGIS 10.1® (ESRI 2012). For each bog turtle point, the spectral signature was determined and combined and all locations within Macon and Jackson Counties in which these signatures were found were identified and put into map format.

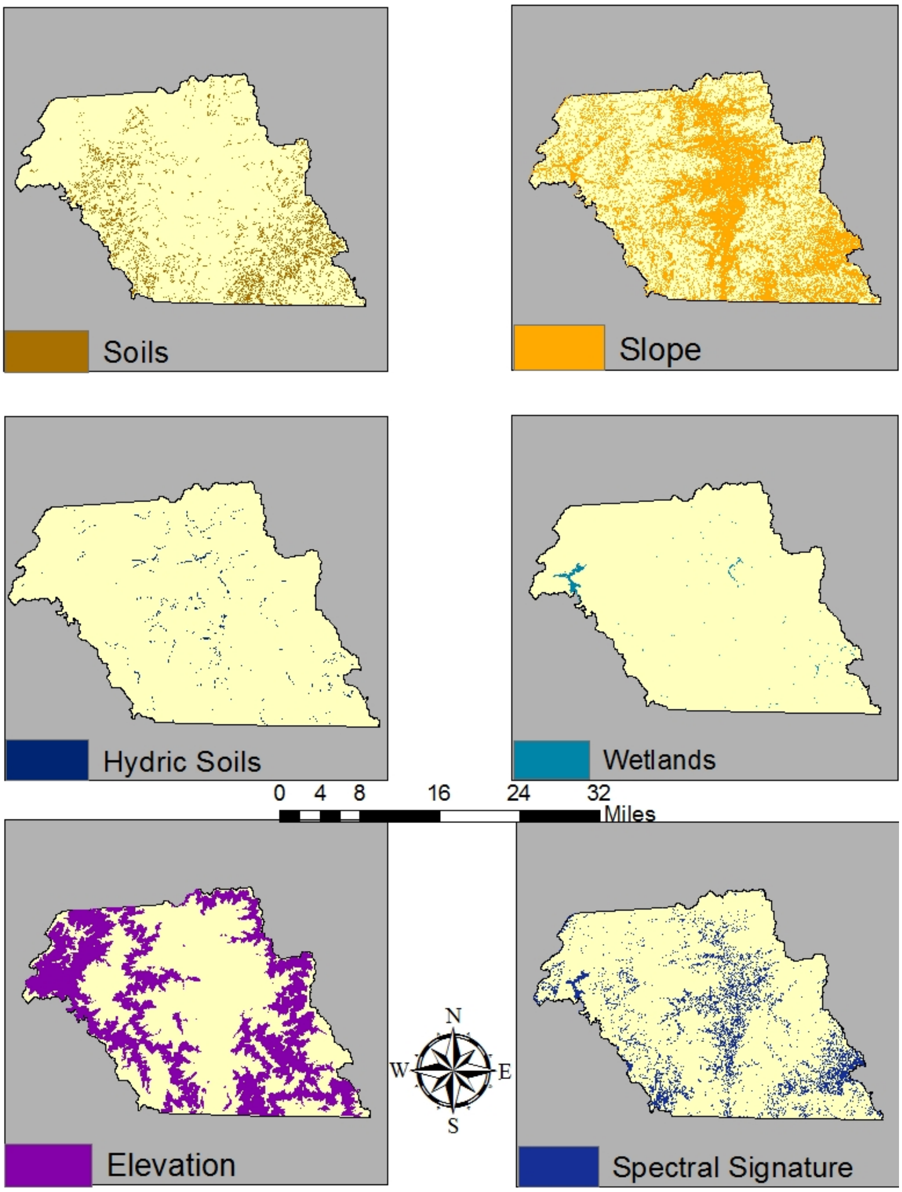

FIG. 3. A map presentation of selected habitat features in Macon County that were prioritized in the model. Created in ArcGIS 10.1® (ESRI 2012).

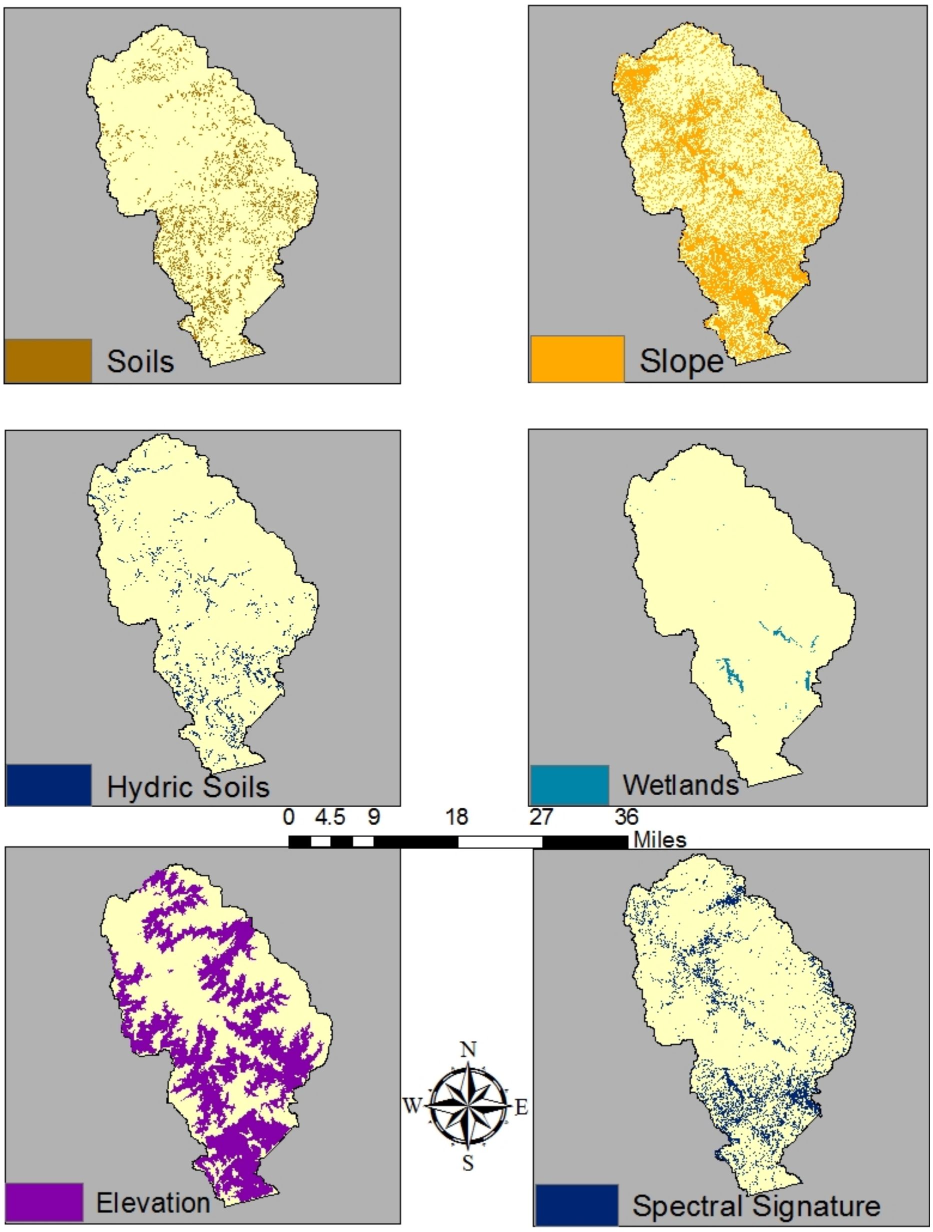

FIG. 4. A map presentation of selected habitat features in Macon County that were prioritized in the model. Created in ArcGIS 10.1® (ESRI 2012).

Assigning Values and the Additive Model

Differing arbitrary values were assigned to each of the six layers of desirable habitat features in ArcGIS 10.1® (ESRI 2012) as a way to show amount of overlap between layers in the final model (Table 2, Fig. 5 , and Fig. 6). The values were assigned by converting the selected areas of desirable habitat to a raster dataset and reclassifying them with unique values. An output raster was created using Spatial Analyst and the Raster Calculator tool by adding the values of the six previously created raster datasets. The output raster reclassified areas of interest with the sum of their unique values and each assigned a different color, located in the legend of the final maps. Areas with the highest values represent the most overlap of desirable features and are therefore places containing the best habitat for *Glyptemys muhlenbergii.*

TABLE 2. Habitat features and assigned values.

Habitat Feature	Assigned Value
Soils	1
Elevation	10
Wetlands	50
Slope	100
Hydric Soils	200
Spectral Signature	1,000

RESULTS

Several potential *Glyptemys muhlenbergii* habitat sites for each county were identified from the model (Fig. 5 and Fig. 6) based on selected features (Table 3).

TABLE 3. Selected attributes used in the model for each habitat feature. Data sources listed in Table 1.

Habitat Feature	Selected Attributes
Soils	Reddies fine sandy loam, 0-3% slopes, frequently flooded (ReA), Cullasaja-Tuckasegee complex, 15-30% slopes, stony (CuD), Dillard loam, 1-5% slopes, rarely flooded (DrB) (Hydric B), Edneyville-Chestnut complex, 15-30% slopes, stony (EdD), Tate fine sandy loam, 8-15% slopes(TeD), Hayesville clay loam, 15-30% slopes, moderately eroded (HcE3), Unaka-Rock outcrop complex, 50-95 % slopes, very stony, Dellwood-Reddies complex, 0-3% slopes, occasionally flooded, Tusquitee stony loam, 15-25% slopes (TuE), Codorus loam, 0-2% slopes (Co), Rosman loam, 0-3% slopes (Ro), Tate fine sandy loam, 7-15% slopes (TeC), Toxaway silt loam, 0-2% slopes (To)
Elevation (ft)	2054-3890
Wetlands	Freshwater Emergent Wetland , Freshwater Forested/Shrub Wetland, Freshwater Pond, Lake
Slope (%)	0-34.68
Hydric Soils	Hydric B

Macon County

There are 2,343.8 acres of suitable bog turtle habitat in Macon County, which is 0.71% of the total land area of the county (USCB 2013). There is a large parcel of desirable habitat (overlap of elevation, wetlands, slope, and spectral signature) in the western portion of Macon County, which is the Nantahala Lake. Lake Emory in the middle of the county also appears to be desirable habitat for the bog turtle, with a few different values. The zoomed-in portion of the map included in Fig. 5 has much desirable habitat, with portions holding the high value of 1,360, signifying prime habitat where elevation, wetlands, slope, hydric soils, and spectral signature overlap. This area is of special interest to this project because it is located near the town of Highlands.

Jackson County

There are 3,083.3 acres of desirable bog turtle habitat in Jackson County, which represents 0.98% of the total area of the county (USCB 2013). This is including the parcel created by error. In the southwestern part of Jackson County, Lake Glenville is shown to have potential as *Glyptemys muhlenbergii* habitat (value: 1,160). Bear Creek Lake, located near the center of the county also has potential although the values there are lower (260 and 350). A value of 260 represents overlap of hydric soils, wetlands, and elevation. A value of 350 indicates choice hydric soils, slope, and wetlands. There is a large portion in Figure 6 that represents error with GIS. The output of the model suggests there is a large waterbody at this location but in reality there is not one there. The presence of a straight line along the eastern boundary also suggests a data anomaly. The error appears to originate with the National Wetlands Inventory (NWI) data layer.

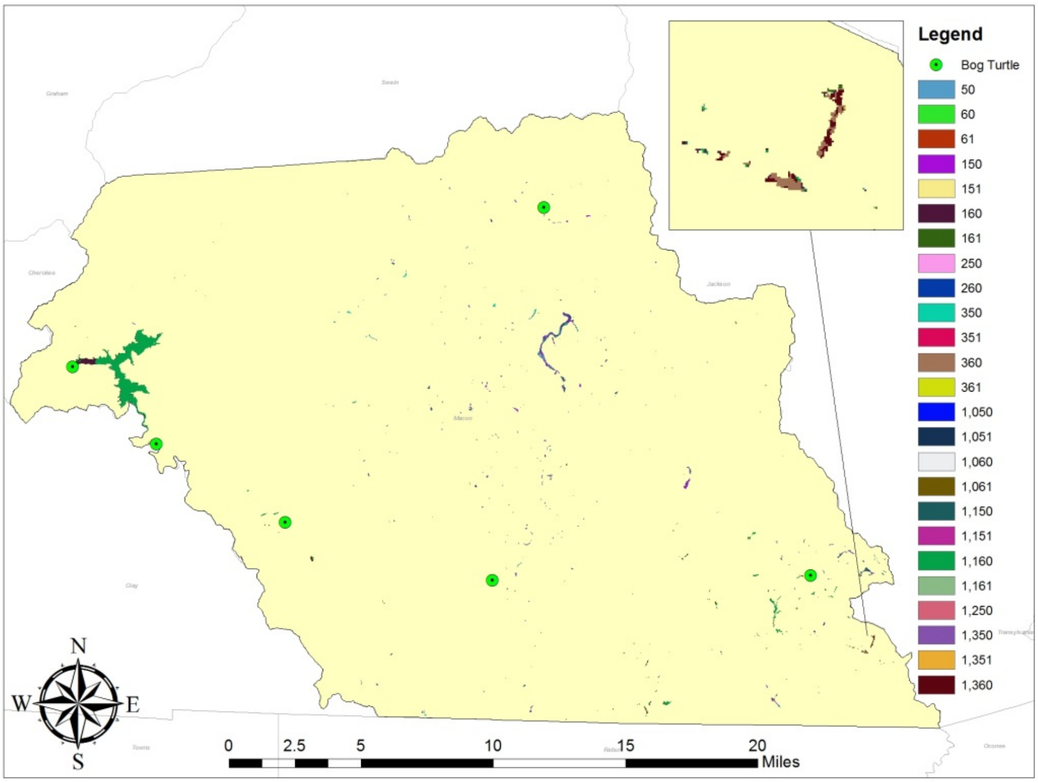

FIG. 5. Likely *Glyptemys muhlenbergii* habitat sites in Macon County, ranked according to similarity with previously found turtle sites, and including a close-up of the Southeastern corner of the county where prime habitat is found (score: 1,360). Altered *G. muhlenbergii* sites are also shown. Created in ArcGIS 10.1® (ESRI 2012).

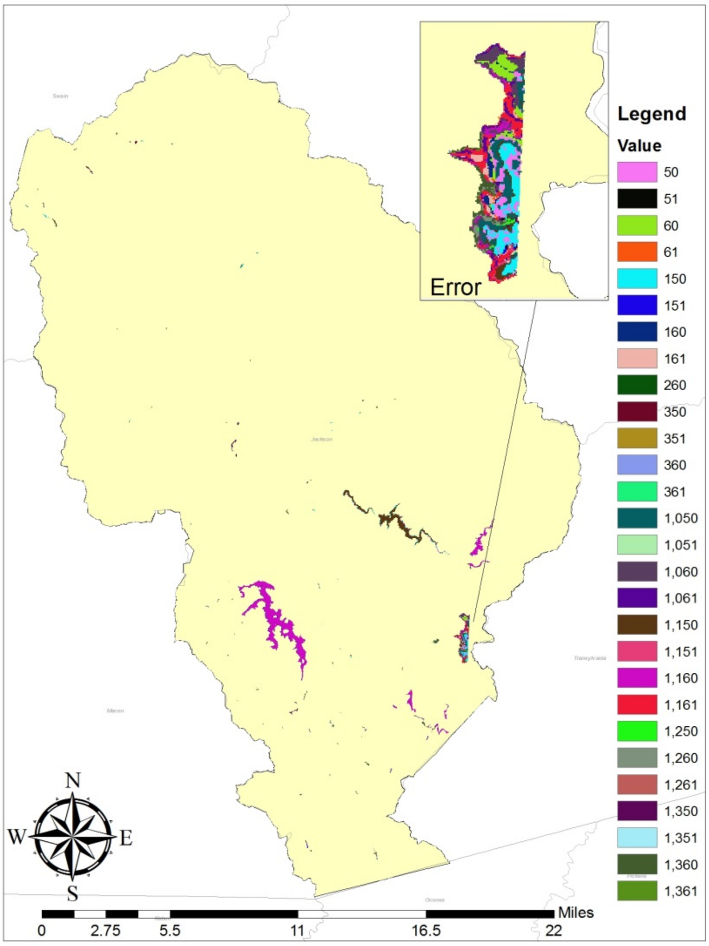

FIG. 6. Likely *Glyptemys muhlenbergii* habitat sites in Jackson County, ranked according to similarity with previously found turtle sites, and site of GIS error. No turtle sites have been recorded in Jackson County. Created in ArcGIS 10.1® (ESRI 2012).

DISCUSSION

There are 5,427.3 acres of desirable habitat for *Glyptemys muhlenbergii* within Macon and Jackson counties, including the error parcel. This is 0.84% of the total acreage for both counties (USCB 2013). The largest parcels of prime habitat are located around bodies of water, which seems accurate due to the need for wetlands for this turtle. This finding is interesting because it may indicate not only suitable habitat but also relict populations where the turtles once were, prior to the creation of these bodies of water, many of which are manmade. There is more desirable habitat for the bog turtle in Macon County according to the final maps when the error is excluded. This agrees with the fact that no turtle sites had previously been found in Jackson County.

The outcome may have been different if the analysis had been run using the actual turtle sites from the Natural Heritage Element Occurrences (NHEO) data, but to improve accuracy with habitat preferences, these points were moved to the nearest wetland. When analysis using the original sites was performed, nearly all of the high elevation portions of Macon County were selected as potential habitat sites and this analysis, therefore, was abandoned for lack of valuable data. GIS data points for threatened species are also sometimes moved in an attempt to preserve the species (G. Wein, personal communication, September, 2013). Aspect and curvature were two other features initially analyzed for the model but they did not provide suitable data because there was no pattern in these features for *Glyptemys muhlenbergii.* The error in the final model of Jackson County is due to NWI data but it was determined the error should remain in order to maintain data in the rest of the map.

The next step for this project would be to send experienced people into the field where there is desirable bog turtle habitat (determined from this model) to look for turtles. The data from these field surveys could be included in the model to show where individuals survive. Field surveys were performed one day during the creation of this model, in various wetlands near Highlands, but none were found, likely because it was October during which time bog turtles are beginning to bury into the mud for winter.

Data from field surveys and the models created from that data could be utilized for protection of the species by distribution to individuals and organizations that work to protect such species, such as the International Union for the Conservation of Nature (IUCN), the NC Herpetological Society, and the United States Fish and Wildlife Service. Informing the public about these data could also change public attitudes to help prevent the drainage of wetlands. The state of the species and the issues it faces could be used more generally to instill a sense of environmental stewardship and responsibility on the general public as well as providing valuable data for the land trust community to aid in identifying conservation target properties.

Conclusions

This habitat model was successful in determining areas within Macon and Jackson Counties in which there exists likely bog turtle habitat. This model cannot fully encompass all of the potential habitat sites for *Glyptemys muhlenbergii* since computerized models have limitations. Expert knowledge as well as logical reasoning should be utilized when examining potential habitat sites. Ground-truthing would be a necessary next step to further improve this model. Land owners of potential bog turtle sites should be contacted to inform them of the importance of their land as a wetland habitat.

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SOIL EFFLUX IN A SOUTHERN APPALACHIAN HARDWOOD FOREST

ISABEL R. HILLMAN

Abstract. Soil efflux is a major component of the global carbon cycle. I studied efflux in a southern Appalachian hardwood stand to determine factors influencing efflux rates. Both portable and automated systems were used to measure efflux, and the impact of temperature, DOY, soil moisture, elevation, and vegetation was determined. Temperature was found to have the greatest influence on soil efflux, accounting for 89% of the total variability efflux, although efflux also declined linearly with DOY during the fall months. Soil moisture was also found to have additional affects, reducing efflux under dry conditions. Vegetation and elevation had little influence, although elevation was weakly correlated with efflux. In scaling to the stand level, an annual total of 1082.10 grams of Carbon per square meter was found.

Key words: Efflux, global carbon cycle, soil moisture.

INTRODUCTION

Soil efflux, the movement of CO_2 from soil into the atmosphere, is a key factor in the global carbon cycle as the second largest terrestrial carbon flux (Bond-Lamberty and Thomson 2010). There is an estimated two to three times more carbon in the global soil pool than in the atmosphere (Zhang et al. 2013). In certain hardwood forests, soil efflux comprises approximately 60-80% of the entire ecosystem's respiration (Davidson et al. 1998). Total soil respiration is the sum of autotrophic respiration and heterotrophic respiration (Zhang et al. 2013). CO_2 is produced belowground by roots, organisms in the soil, and mycorrhizae. At the surface, belowground respiration is combined with surface litter respiration to deliver total respiration (Raich and Schlesinger 1992).

There is interest in studying variation in efflux due to the changing global climate, and how changes in efflux rates will affect environments (Davidson et al. 1998). Respiration rates vary temporally on hourly, diurnal, and seasonal scales, over the age of an ecosystem; and spatially from meters to ecoregions, causing significant regional differences (Vose and Bolstad 2007). Efflux is influenced by interplaying environmental factors such as temperature, soil moisture and vegetation composition (Davidson et al. 1998, Vose and Bolstad 2007, Lamberty and Thomson 2010). Respiration is positively correlated with temperature and can be limited by soil moisture content (Raich and Schlesinger 1992). Since efflux is a combination of heterotrophic respiration from decomposing organic matter and autotrophic respiration from root metabolism, higher respiration rates are expected in areas of high root biomass. Global trends can be explained by these factors; high efflux occurs in regions of high temperature and high moisture such as the tropics, and low efflux is found in cold or dry regions, such as deserts and tundra. Generally, lower latitudes experience greater rates of efflux than higher latitudes (Raich and Schlesinger 1992).

Past studies have shown that the complex relationship between soil respiration and temperature has a diel hysteresis (Phillips et al. 2010, Barron-Gafford et al. 2011, Savage et al. 2012). Diel patters show a lag between time of peak soil temperature and peak soil respiration (Phillips et al. 2010). The lag may be caused by the time it takes for CO_2 produced in soil to diffuse to the soil surface (Phillips et al. 2010, Savage et al. 2012). Diel patterns are known to fluctuate with season, and with the presence of absence of canopy cover (Savage et al. 2012).

CO_2 efflux in some regions has been studied extensively, but there are many gaps in research where further study is needed (Raich and Schlesinger 1992). The southern Appalachian Mountains afford a unique environment to study soil respiration. In this region, wide variation in ecosystems is found, and can provide insight to factors affecting soil respiration between ecosystems over a relatively small distance (Wang et al. 2012). Within southern Appalachian forests there are many different ages of forests due to past logging activity. There is variation in forest type based on elevation, slope, and soil composition. In addition, seasonal variation offers opportunity to observe various temperatures and effects of vegetation as deciduous flora defoliates in fall and refoliates in spring (Vose and Bolstad 2007).

Utilizing a region with varied ecosystems provides insight into differences in soil flux in areas with different amounts of disturbance (Vose and Bolstad 2007). Forest disturbance can result in a lack of soil fertility, negatively affecting vegetation (Butnor et al. 2003). Disturbance can also reduce primary productivity, and alter carbon inputs from detritus, which also modifies efflux (Nuckolls et al. 2009).

In this paper, we will analyze the relationship between CO_2 efflux with soil temperature and moisture in a mature, southern Appalachian broadleaf forest, and compare our results with work done by Vose and Bolstad (2007). We will expand on the previous study by increasing the spatial range of measurements and increasing the frequency of measurements from bi-monthly to weekly. We hypothesize that higher frequency sampling will show a similar temperature-response function, but unlike the previous study, we will observe soil moisture limitations on efflux. We will also determine if biophysical factors, such as vegetation and topography, near sampling locations can explain variability in efflux. We hypothesize that we will measure higher efflux rates in plots with greater basal area due to an increased contribution from root respiration. We do not expect to see major changes resulting from elevation differences because the elevation changes in our study area are relatively small. However, elevation may influence soil moisture, and we expect to see differences in soil moisture from wetter low elevation points to dryer upslope areas. In addition, we will quantify lags between peak soil temperature and peak efflux, and examine these for temporal trends. We anticipate seeing peak efflux lag behind soil temperature, and lag times to decrease when soil moisture is low, due to faster diffusion through the soil. From the data collected, we will be able to estimate annual soil CO_2 efflux from the stand.

METHODS

Measurements were taken at Coweeta Hydrologic Laboratory in Macon County, North Carolina during the summer and fall of 2013. The southern Appalachian hardwood forest was approximately 75 years of age, and consisted of vegetation typical of the region. In most of the study site, Rhododendron was the predominate vegetation form, indicating an acid cove forest (Schafale 2012). Elevation ranged from 702 m above sea level to 754 m above sea level, with an average of 718 m. Average annual precipitation in the area is 179.54 cm, and average annual temperatures range from 3.57- 21.88°C (Coweeta Hydrologic Lab 1934-2007).

Half of the measurements were taken weekly using the Li-6400 portable photosynthesis system (LI-COR, Lincoln, NE, USA) along two transects. Transect A consisted of 14 plots spaced approximately 25 m apart, Transect B contained 13 plots spaced in the same manner. No measurements were taken at Plot 1 of both transects, as they were located at a data collection tower. A piece of PVC pipe 10 cm in diameter and 5 cm in height was located at the center of each plot. The PVC collar was inserted 4 cm into the ground to stabilize the Li-Cor system while measurements were being taken. Li-Cor measurements were taken by placing the extension on top of the PVC pipe and temperature probe 10 cm into the soil at each plot. For each measurement, three replicate cycles were taken and target CO_2 was set to the ambient atmospheric level. During each of the three rotations, CO_2 was cycled out of the chamber and through desiccant and CO_2 scrubber compartments. Each cycle provided a temperature and efflux measurement, giving three data points for each plot in total. Three soil moisture measurements were taken around the PVC collar simultaneously with temperature and efflux using a Time Domain Reflectomotry (TDR) device (Hydrosense, Campbell Scientific, Australia). The TDR uses an electric signal passed along two probes of 20 cm in length, the time it takes for the signal to move along the probe provides the soil moisture measurement.

The remaining measurements utilized two Automated Carbon Efflux System (ACES, USDA Forest Service, US Patent 6692970), which provide data for soil temperature and efflux. Each system was connected to one control chamber and 15 active chambers, which were moved between two locations twice a week. The ACES system took continuous measurements on a 160 minute cycle, moving between each plot on a 10 minute interval and providing one efflux and temperature value per measurement. Chambers were 25 cm in diameter, with a small hole in the top allowing for pressure to equilibrate within the chamber. Each chamber was covered with a piece of reflective solar radiation shield to minimize sunlight within the chamber. Located inside each chamber was a temperature probe, inserted 5 cm into the soil. An exhaust pump was used to circulate air to chambers between measurements to prevent CO_2 accumulation within the chamber (Butnor et al. 2005).

To provide additional information about the environment surrounding each plot on Transects A and B, vegetation recordings were taken. All vegetation was documented by species and diameter at breast height in a one-meter radius around the center of each plot. The same measurements were taken in a three meter radius from the center of each plot, but excluded any vegetation smaller than 2cm in diameter. Vegetation surrounding each plot of the ACES system was classified as open or within a rhododendron thicket.

Temperature measurements from certain plots for two distinct weeks were missing because the Li-Cor temperature probe broke. To find substitute values for these times, gap-filling methods were utilized. To gap-fill, the plots with missing data were compared to plots containing all data points. A linear regression was run between the two and the pair with the r^2 value closest to 1 was chosen. The regression equation was used to provide a temperature value for the missing measurements.

To test the response of efflux to soil temperature and moisture, we used an approach similar to Oishi et al. (2013) where efflux increased exponentially with temperature and was also affected by a function of soil moisture:

$$\text{Efflux} = a * \exp^{(b*\text{Tsoil})} * F_{\text{sm}}$$

where a and b are fitted parameters, Tsoil is soil temperature at 10 cm, and F_{sm} is a second-order polynomial function of soil moisture. For each transect location, a and b parameters were first estimated, then the soil moisture function was fit using residual values (measured efflux divided by efflux estimated from the temperature-response function). When residual values were equal to one it indicated that measured value and estimated value are the same. When residual values are greater than one, the measured value was higher than the estimated value. If the residual value is less than one then some factor besides temperature is acting on efflux and keeping the value lower than expected (Oishi et al. 2013).

RESULTS

Total measurements taken exceeded 400 on the Li-Cor system. Twenty-seven measurements were taken along both transects each week from mid July to early November 2013, DOY 204-319. Spatial variation accounted for differences in vegetation, slope, and soil composition leading to efflux variations within a single day's measurements. Efflux measurements generally did not vary more than 2 μmol on the same day for all plots. Temporal changes from the summer to winter seasons drive changes in respiration outputs in vegetation (Uvarov et al. 2006). Efflux declines as day of year increased and temperature decreased (Fig. 1). The lowest soil temperatures were found on DOY 298, producing an average efflux of 1.65 μmol for that day. Warmest soil temperatures on transect A were found on DOY 224, with an average efflux of 6.53 μmol, and on DOY 205 for transect B with average efflux of 6.78 μmol. Measurements taken here followed similar trends to the data taken by the ACES system. Spatial variation was relatively low compared to temporal variation.

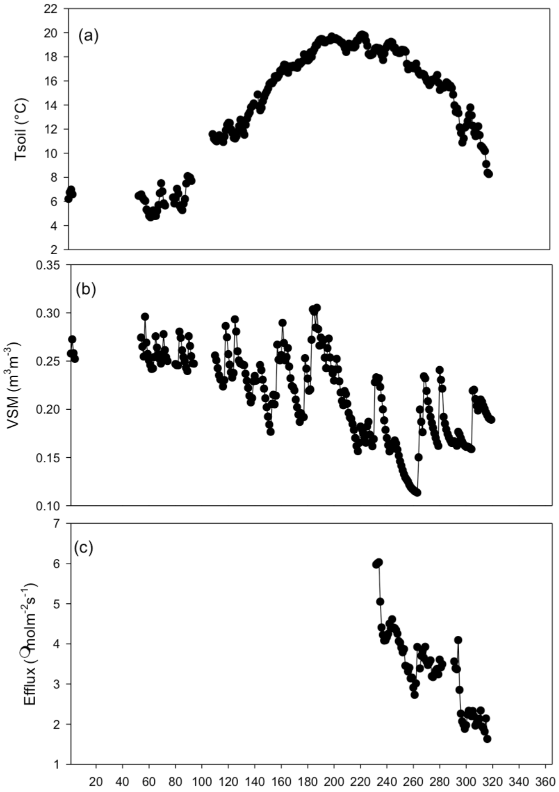

FIG. 1. Annual (a) soil temperature, (b) soil moisture content, and (c) efflux values taken from the ACES system. Shows temporal variation and correlation between soil temperature and efflux.

Soil temperature was compared to efflux using an exponential function (Fig. 3). All relationships had high r^2 values, with the lowest being 0.69 at plot B14, and the highest being 0.96 at plot B6. The average r^2 value for all plots was 0.89, indicating a strong relationship between soil temperature and efflux at all sites. From these measurements, temperature accounts for approximately 89% of efflux across all plots. We also observed a linear decline in efflux over the study period at several plots, so we tested whether a linear regression with DOY produced a better relationship with efflux than the exponential temperature function. The lowest r^2 value was found at B14 again, at 0.57, and the highest was found at B9 with a value of 0.95. The average r^2 value for all plots was 0.84. This value shows a strong relationship between DOY and efflux but is slightly weaker than the relationship between soil temperature and efflux. DOY r^2 values were higher than temperature to efflux value at only five plots. Having higher temperature r^2 values at 22 plots provides evidence that temperature plays a greater role than a constant, linear decline during the fall. Soil moisture was also found to influence efflux. Using an estimated efflux based on soil temperature, I estimated a residual value by dividing measured efflux by estimated efflux based on the temperature-response function (Fig. 2). Residual values represented variability not explained by the regression between soil temperature and efflux (Fig. 4). When soil moisture was compared to residual values, it accounted for some of the variability not explained by soil temperature, although very little (Table 1). A linear relationship between the two produced an r^2 value of 0.07. This suggests that soil moisture can limit efflux, and lower efflux values are expected when soil moisture is lower at the same temperature.

TABLE 1. Exponential function parameters, r^2 values, and estimates of efflux at 18°C using parameters for all plots using Efflux = a*exp(b*Temperature).

Plot	A value	B Value	R2	18 degree efflux
A2	0.4502	0.1353	0.93321	5.141457757
A3	0.4820	0.1159	0.81798	3.882148879
A4	0.4651	0.1275	0.84989	4.615855189
A5	0.3950	0.1465	0.90165	5.518634662
A6	0.1531	0.1948	0.81196	5.102527594
A7	0.1823	0.1834	0.88347	4.948568796
A8	0.3107	0.1488	0.95667	4.524343743
A9	0.2459	0.1537	0.8453	3.910908384
A10	0.3155	0.1586	0.85951	5.480538722
A11	0.2353	0.1723	0.94316	5.230495507
A12	0.2014	0.1840	0.91916	5.526406037
A13	0.0718	0.2377	0.86871	5.179607064
A14	0.1824	0.1791	0.89002	4.582509614
A15	0.7151	0.1284	0.92509	7.212871325
B2	0.4567	0.1423	0.86891	5.916064463
B3	0.2423	0.1493	0.89343	3.560216469
B4	0.2377	0.1504	0.89913	3.562469896
B5	0.1952	0.1691	0.83084	4.096239653
B6	0.4805	0.1318	0.96228	5.152448041
B7	0.3871	0.1460	0.95521	5.35980599
B8	0.8064	0.1272	0.95314	7.959965123
B9	0.5156	0.1229	0.93925	4.710414894
B10	0.5989	0.1456	0.93793	8.232908548
B11	0.4531	0.1275	0.89379	4.496761957
B12	0.3822	0.1627	0.91174	7.147686607
B13	0.4085	0.1603	0.94566	7.316533391
B14	0.3829	0.1261	0.69343	3.705501397

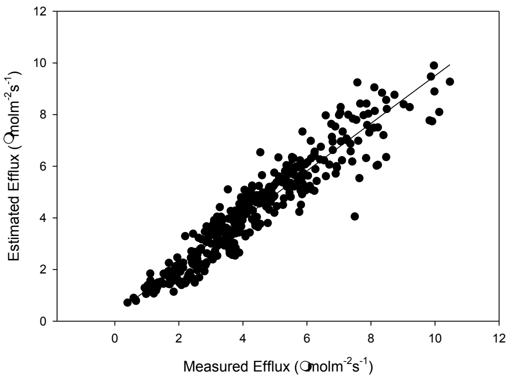

FIG. 2. Measured efflux values from all transects vs. estimated efflux values when temperature is 18°C based off exponential function. Trend line is linear relationship between measured and estimated efflux values.

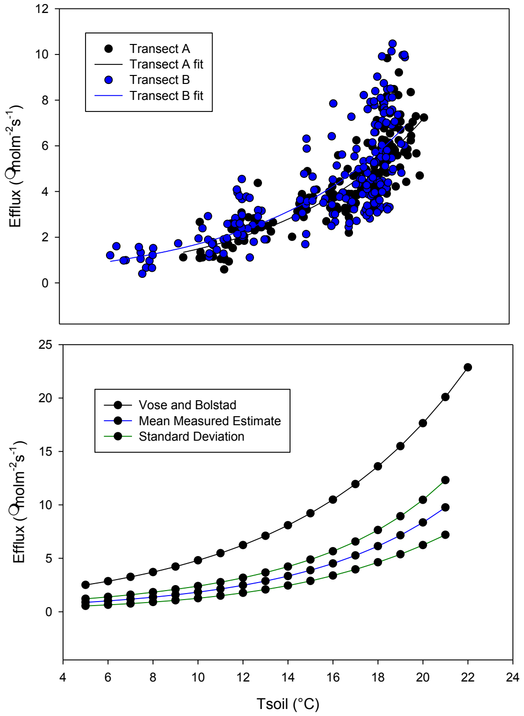

FIG. 3. (a) Soil temperature vs. efflux values for transects A and B. Exponential trend lines for both transects. (b) Soil temperature vs. efflux using mean estimated efflux values from our study, and the same parameters from the Vose and Bolstad study (2007). Black lines indicate standard deviations from Vose and Bolstad measurements.

Spatial variability in efflux was partially explained by biophysical factors. Vegetation composition varied at each plot; some plots were within rhododendron thickets, some were not. In order to compare efflux among plots over the entire study period, I standardized this value by using the exponential functions to estimate efflux at 18°C (mean soil temperature for the early phase of the study). Linear regressions between a reference efflux at 18°C and all vegetation characteristics were insignificant, with $P>0.3$ at all plots. Elevation between plots varied from 702-754 meters above sea level. Efflux at 18°C and elevation showed a weak linear trend, with

P=0.067. No trend was found between soil temperature and elevation, but soil moisture decreased as elevation increased, with *P*=0.027 (Fig. 4). This range in elevation represents topographic variability, but does not represent large-scale changes in elevation seen over the entire region, or in larger mountain ranges.

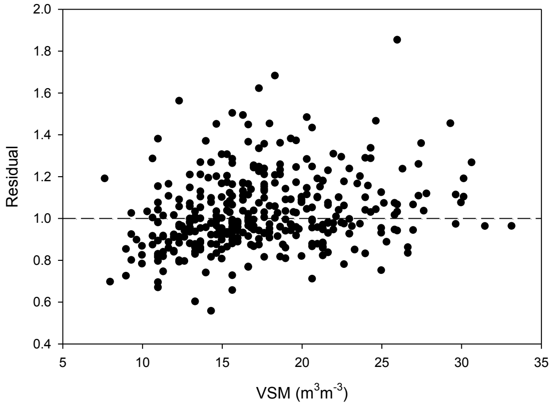

FIG. 4. Soil moisture vs. residual values for both transect's measurements. Dotted line at Y value of 1 to provide reference for values above and below 1.

ACES and transect measurements provided very similar values for soil temperature. When temperature measurements from ACES were compared to transect A measurements, the linear regression produced an r^2 value of 0.98, and for transect B produced an r^2 value of 0.99. This indicates that soil temperature is very similar along both transects or that the measurement systems from both machines are comparable. Efflux measurements from the ACES and transects also produced high r^2 values, but slightly lower than those for soil temperature. ACES compared to transect A gave an r^2 value of 0.81, and compared to transect B gave an r^2 value of 0.83. This shows slightly more variability in efflux measurements between systems, or between plots. Soil moisture showed the most variability between ACES and transect measurements. ACES compared to transect A resulted in an r^2 value of 0.70, and when compared to transect B resulted in an r^2 value of 0.63. This means there is more soil moisture variability between sites, or the two systems read soil moisture differently.

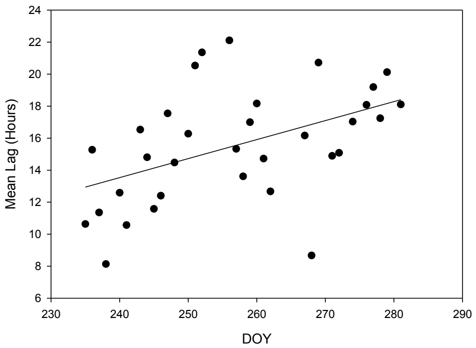

FIG. 5. DOY vs. mean lag time. Shows a slight increase in lag time as DOY increases.

Lag times were analyzed from the ACES data from DOY 235-282. Lags between peak soil temperature and peak efflux varied greatly (Fig. 5). The shortest lags were approximately 8 hours on DOY 238 and 268, and the longest lag was about 22 hours on DOY 256. There was a slight increase in average lag as DOY increased. The average time of maximum soil temperature was 17.8 (5:00 pm), and the average time of peak efflux was 12.8 (12:00 noon). The lag time for the averages is approximately 17 hours. Lags showed a slight decrease as soil moisture increased, but the trend was very weak.

Using the exponential temperature-response functions to estimate daily efflux totals under non-limiting soil moisture conditions for all transect points, estimated annual efflux was 1082 grams of carbon per square meter, with standard deviation of 279 grams of carbon per square meter.

DISCUSSION

Our measurements, when compared to results from Vose and Bolstad (2006), showed substantial differences in expected efflux based off of equation parameters. All expected efflux values based off their parameters were higher than ours, and did not fall within the range of standard deviation of our measurements (Fig. 3). Comparing Q10 values, our average value across all plots was higher (4.79) than Vose and Bolstad's (3.56). However, both study's parameters led to increases in efflux as temperature increased over a range of 5°C to 22°C. Vose and Bolstad did not find limitations on efflux from soil moisture, although they did note that variability of soil moisture could account for some variability in efflux between plots. Our data began to indicate that soil moisture could limit efflux, but further study is necessary to find a definitive relationship. Recent studies have shown that soil moisture can explain some efflux not explained by temperature (Uvarov et al. 2006) including in temperate forests of similar age and species composition (Oishi et al. 2013).

The DOY-efflux relationship showed that from late summer through the fall, efflux declines at nearly a constant daily rate. In other words, phenological cycles in this forest system may determine the temporal variability in efflux for the period including the end of the growing season and leaf senescence. The temperature-efflux relationship suggests that efflux is a function of temperature, and that temperature variation can explain most variation seen in efflux rates. Data taken in our study supports both the DOY-efflux relationship and the temperature-efflux relationship. Similar to past studies, we found higher efflux rates in August than in November (Davidson et al. 1998, Coleman et al. 2002, Garten and Hanson 2006). Over this time period, temperature also decreased. We found that efflux decreased as temperature decreased and DOY increased, supporting both relationships. Future studies that expand upon this research should incorporate springtime and early growing season data.

Other published data has had similar results as our study concerning vegetation and elevation (Garten et al. 1999, Garten and Hanson 2006, Barron-Gafford et al. 2011, Ngao et al. 2012). Variation in vegetation composition should account for some variation in efflux due to differing respiration rates and differences in root biomass between species. Elevation changes can account for differences in soil temperature, soil moisture, and species composition. However, our data did not show a significant relationship between vegetation and efflux. The relationship found between elevation and efflux (P=0.067) was outside the standard rate of significance (P=0.05), but since our study was relatively limited we will still classify it as weakly significant. In regions of greater elevation change, we expect to see greater differences in efflux. Had we conducted our study to include sample points from a stand with similar species near the top of the basin, we may have seen a more significant influence from an elevation gradient.

Since our results did not identify simple biophysical factors that explained spatial variability in efflux, future studies could take into account several additional factors' influence on efflux. Other studies have interpreted the effect of soil nitrogen content, soil porosity, and pH on efflux (Garten et al. 1999, Ngao et al. 2012). Future work could be expanded to account for some of these additional factors, and possibly the addition of considering the slope of each plot's location. Slope could affect the movement of water through and over soil, and impact soil moisture.

Lag times between maximum soil temperature and mean peak efflux were highly variable, but showed a weak trend over time. Other studies have been able to quantify lag times (Phillips et al. 2010). Greater inspection of our data, soil moisture influence, and additional data from a greater time period could provide an estimate of lag time as it varies during the year.

Our stand estimate of 1082.10 grams of carbon per square meter was considerably lower than the estimates made by Vose and Bolstad (2006). Their annual estimate was 1623 grams of carbon per square meter. Vose and Bolstad's (2006) parameters led to higher efflux values than ours at the same temperature, so it was expected for their annual estimate to be higher as well.

CONCLUSION

Study of this particular hardwood forest has led to the conclusion that temperature plays the largest role in influencing soil efflux, accounting for about 89% of efflux. DOY can also contribute, but was found to be slightly less well correlated than temperature. Soil moisture explained some of the variation in efflux not explained by temperature. Elevation and vegetation composition of each plot played little role in determining efflux rates. The estimated annual total efflux for the stand was 1082 grams of Carbon per square meter.

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NICHE DIFFERENTIATION BETWEEN *MAGNOLIA ACUMINATA*, *MAGNOLIA FRASERI*, AND *MAGNOLIA TRIPETALA*

NGUYEN HUYNH AN MARKUS LE

Abstract. Three species of magnolia coexist in western North Carolina: *Magnolia acuminata*, *Magnolia fraseri*, and *Magnolia tripetala*. While these plants are not considered rare, they are relatively uncommon in their range, and seem to prefer specific types of environments to grow in. In this study, the locations of these three species were mapped within Graham, Swain, and Macon Counties, and analyzed using GIS tools in order to determine how the habitats these species prefer differ, if at all. In doing so, it was found that each magnolia species occupies a distinct niche in the environment. *Magnolia acuminata* grew at a relatively wide range of elevations and proximity to water, and preferred flatter, north-facing slopes. *Magnolia fraseri* generally grew at lower elevations, on steeper slopes, and most plants grew close to water. *M. fraseri* also seemed to preferred north-facing slopes. *Magnolia tripetala* had the most narrow habitat preference. It grew exclusively near water, mostly on flat land, within a narrow elevation range. However, unlike the other two species, *M. tripetala* did not seem to have a strong preference for north-facing slopes. These niche differences between the three magnolia species help explain the coexistence of close relatives in the region.

Key words: Magnolia*; nice differentiation; plant ecology; southern Appalachians; western North Carolina.*

INTRODUCTION

Magnolia species can be found all over the world. The genus is most highly concentrated in eastern Asia and North America, with some species scattered throughout Central and South America (Sarker and Maruyama 2002). This disjunct distribution of the genus has been explained through genetic studies and biogeography. Evidence suggests that at one time magnolias had a continuous range, and that they diverged and separated when barriers appeared within their range, probably due to the break-up of supercontinents of the past (Azuma et al. 2001). Despite the magnolias' continued evolution since then, many still consider magnolias examples of primitive angiosperms. The genus was most likely one of the earliest to produce flowers, as their blooms are specialized to be mostly pollinated by beetles, suggesting the flowers evolved before bees (Thien 1974).

Magnolias are important plants to both commerce and science. Commercially, the wood of some species, like *Magnolia acuminata*, have served as lumber, often sold as poplar wood. Due to their large, showy blooms, magnolias have also been grown ornamentally, as part of residential landscaping. Compounds extracted from the plants have proven to be valuable in medicine, and have been used in Asia to treat a variety of ailments, from curing simple headaches to treating cancers (Lee et al. 2011). In eastern North America, magnolias have also been historically used for medicinal purposes by the Native Americans, correlating closely to the use of bioactive compounds from the plants in modern medicine (Shuhly et al. 2001).

Examples of magnolia species present in eastern North America include the cucumber magnolia (*Magnolia acuminata*), southern magnolia (*M. grandiflora*), sweet-bay (*M. virginiana*), umbrella magnolia (*M. tripetala*), big-leaf magnolia (*M. macrophylla*), Ashe magnolia (*M. ashei*), Fraser magnolia (*M. fraseri*), and pyramid magnolia (*M. pyramidata*) (Freedman 2004). Of those species, the cucumber magnolia, Fraser magnolia, and umbrella magnolia are present in western North Carolina (Harvill 1964). The presence of three closely related species within an area suggests niche differentiation between the three species, as niche differentiation has been shown to be a crucial mechanic in allowing plant species coexistence (Silvertown 2004). This study aims to examine and quantify the niche differences between the three magnolias present in western North Carolina: *M. acuminata*, *M. fraseri*, and *M. tripetala*.

METHODS

We identified different wooded study sites in Graham, Swain and Macon Counties in North Carolina each field day during the study. Most of the sites were around Lake Fontana, located on the border of Graham and Swain Counties, and we travelled them on foot. We visually identified specimens of *Magnolia acuminata*, *Magnolia fraseri*, and *Magnolia tripetala* while travelling through the woods, and used a handheld Garmin® GPSmap 60CSx GPS unit to record the locations of large trees (at least 8-10 inches in diameter). If magnolia trees were observed on the sides of roads while travelling by car, the location of those trees was recorded as well. On days when we found no large magnolia trees in an area, we also recorded the locations

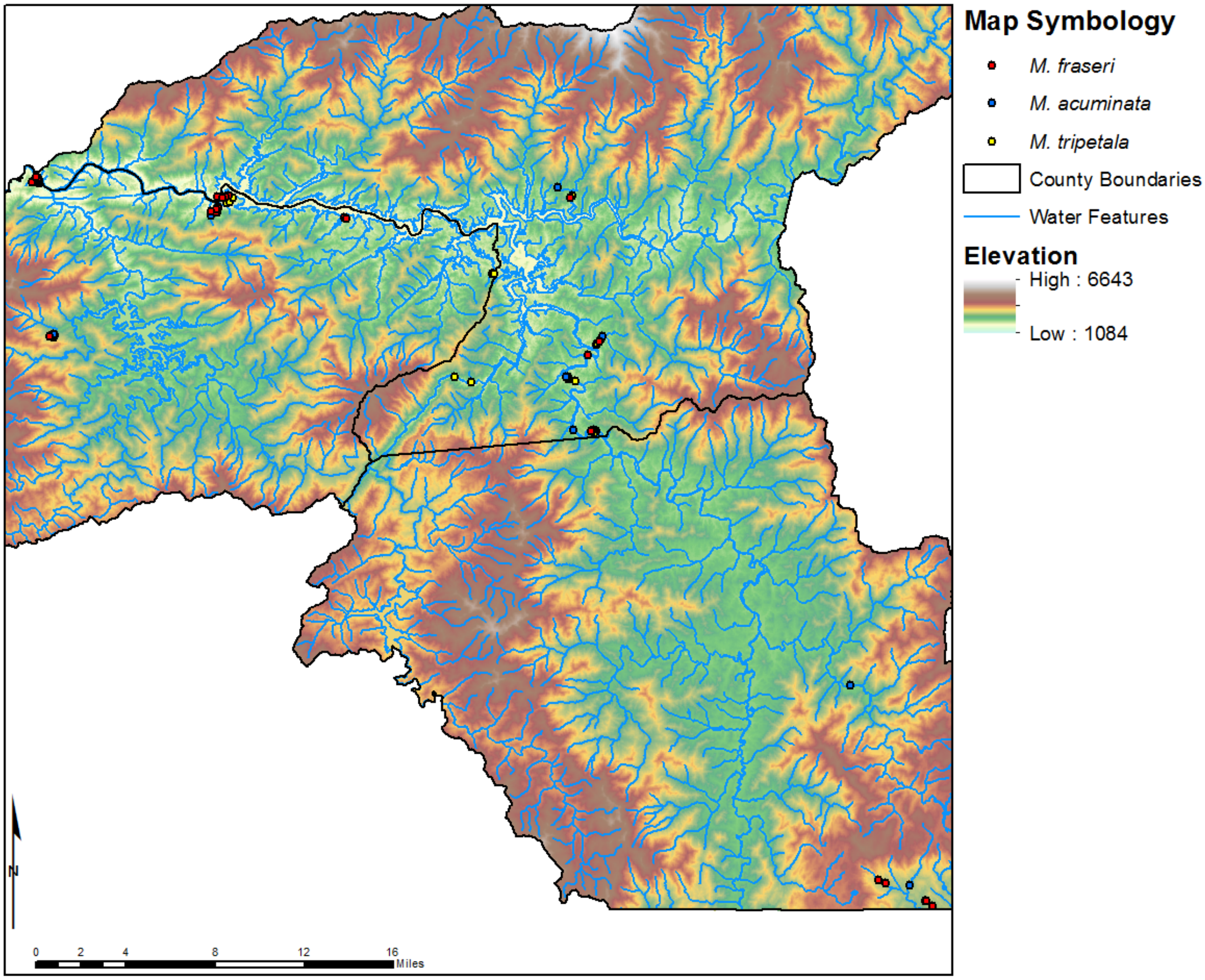


FIG. 1. Map of recorded *Magnolia acuminata*, *Magnolia fraseri*, and *Magnolia tripetala* locations in Graham, Swain, and Macon Counties.

of some smaller magnolia trees to indicate the presence of the trees in an area. In addition to the location of the trees, we used a diameter tape to record the diameter at breast height (DBH) of all the trees whose locations were recorded. The location, DBH, and species of each tree were recorded in a field notebook. These points were then entered into a Microsoft Excel, and imported into ArcGIS 10.1® (ESRI 2012). In order to analyze the data, preexisting aerial imagery and geographic data on elevation and hydrography were downloaded from the North Carolina Department of Transportation and NC OneMap to calculate slope, aspect, and proximity data (NCDENR:DWQ 2012, NC Floodplain Mapping Program 2012, North Carolina Geodetic Survey 2013). This information was used in ANOVAs to determine if there were any significant differences in environmental preference between the three magnolia species.

RESULTS

During the study we found 40 stems of *Magnolia acuminata* in 31 locations, 61 stems of *Magnolia fraseri* in 41 locations, and 49 stems of *Magnolia tripetala* in 31 locations (Fig. 1).

M. fraseri tended to prefer lower elevations than the other two magnolia species, being found mostly between 1000 and 1800 feet above sea level. *M. acuminata* and *M. tripetala* were more common between 1400 and 2200 feet above sea level, but *M. acuminata* was also found at higher elevations than either of the other two species, between elevations 2200 and 2600 feet (Fig. 2). An ANOVA demonstrates that these differences are statistically significant ($p<0.05$) (Table 1).

TABLE 1. A summary of statistics on magnolia elevation.

A) Summary

Groups	Average (feet)	Std. Dev
M. acuminata	2112.087634	393.7425035
M. fraseri	1638.728376	469.8408867
M. tripetala	1781.861278	126.538725

B) ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5052179	2	2526089	18.74795	6.03E-08	3.060292
Within Groups	18998266	141	134739.5			
Total	24050444	143				

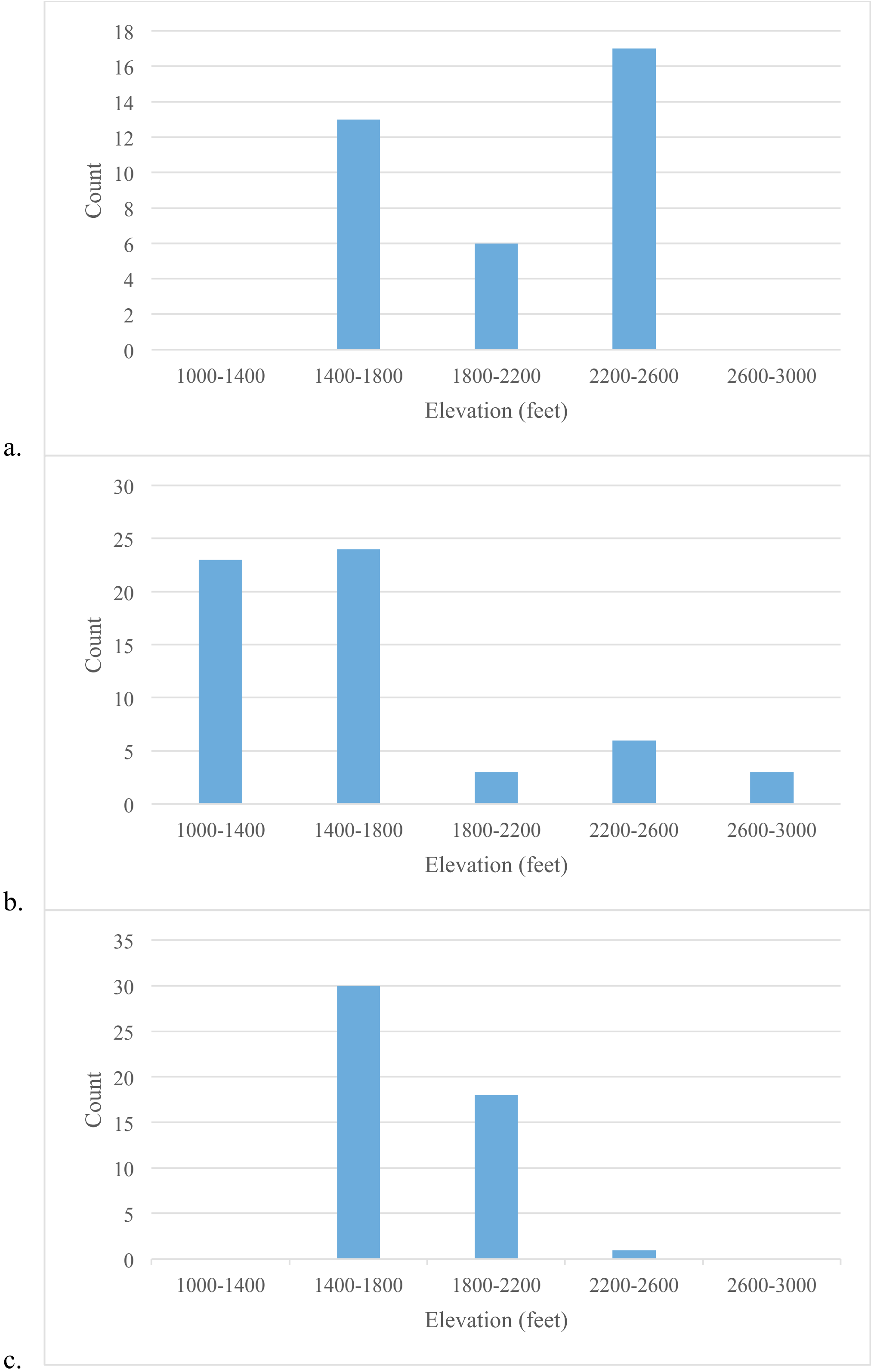


FIG. 2. Histograms showing the elevation distribution of a. *Magnolia acuminata*, b. *Magnolia fraseri*, and c. *Magnolia tripetala*.

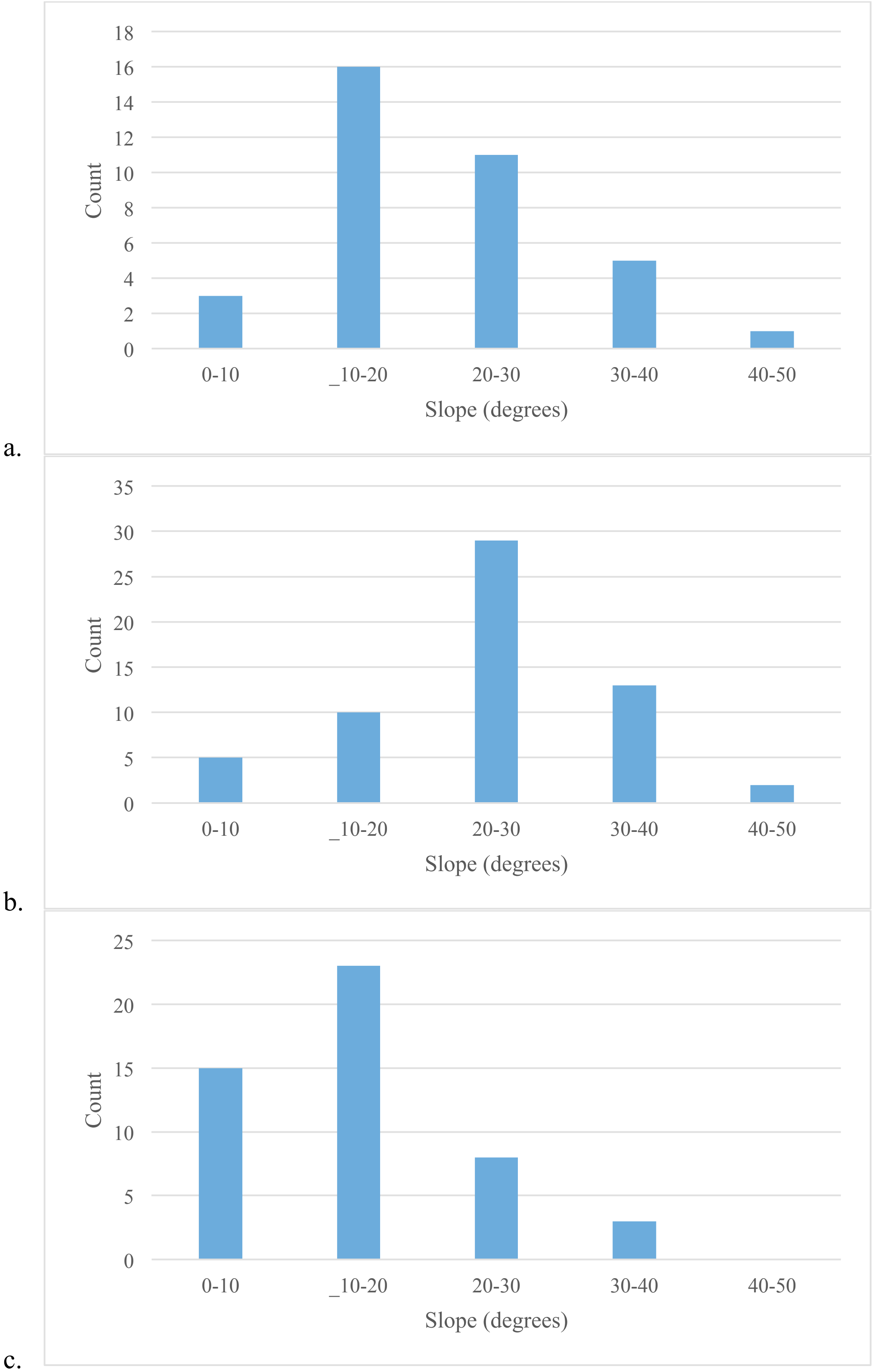


FIG. 3. Histograms showing the slope distribution of a. *Magnolia acuminata*, b. *Magnolia fraseri*, and c. *Magnolia tripetala.*

Generally, all three species of magnolia grew mostly on slopes at or below 30°. However, each species preferred a certain range, with *M. fraseri* growing on the steepest slopes, *M. tripetala* on the most gradual slopes, and *M. acuminata* on intermediate slopes (Fig. 3). Again, an ANOVA demonstrates the statistical significance of the observed differences ($p<0.05$) (Table 2).

TABLE 2. A summary of statistics on magnolia slope.

A) Summary

Groups	Average (degrees)	Std. Dev
M. acuminata	19.43285046	10.16334332
M. fraseri	24.48791194	9.215194646
M. tripetala	13.09146065	8.63687519

B) ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3477.032	2	1738.516	20.22328	1.9E-08	3.060292
Within Groups	12121.21	141	85.96605			
Total	15598.24	143				

All three magnolia species grew most commonly within 500 feet of the nearest body of water. However, as with elevation and slope, there were differences between the three species. *M. tripetala* was found only within 1500 feet of water, while *M. fraseri*, which grows mostly at similar distances to water, was also found in small quantities at higher distances greater than 2000 feet. *M. acuminata*, unlike the other two species, could be found in relatively high quantities at larger distances, more than 1500 feet from water (Fig. 4). Once again, an ANOVA demonstrated the differences between the three species to be statistically significant ($p<0.05$) (Table 3).

TABLE 3. A summary of statistics on magnolia distance from water.

A) Summary

Groups	Average (feet)	Std. Dev
M. acuminata	932.1093363	760.6857533
M. fraseri	505.7813921	655.8280562
M. tripetala	305.2666089	452.0381075

B) ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	8889703	2	4444851	11.23684	2.89E-05	3.05805
Within Groups	57751831	146	395560.5			
Total	66641534	148				

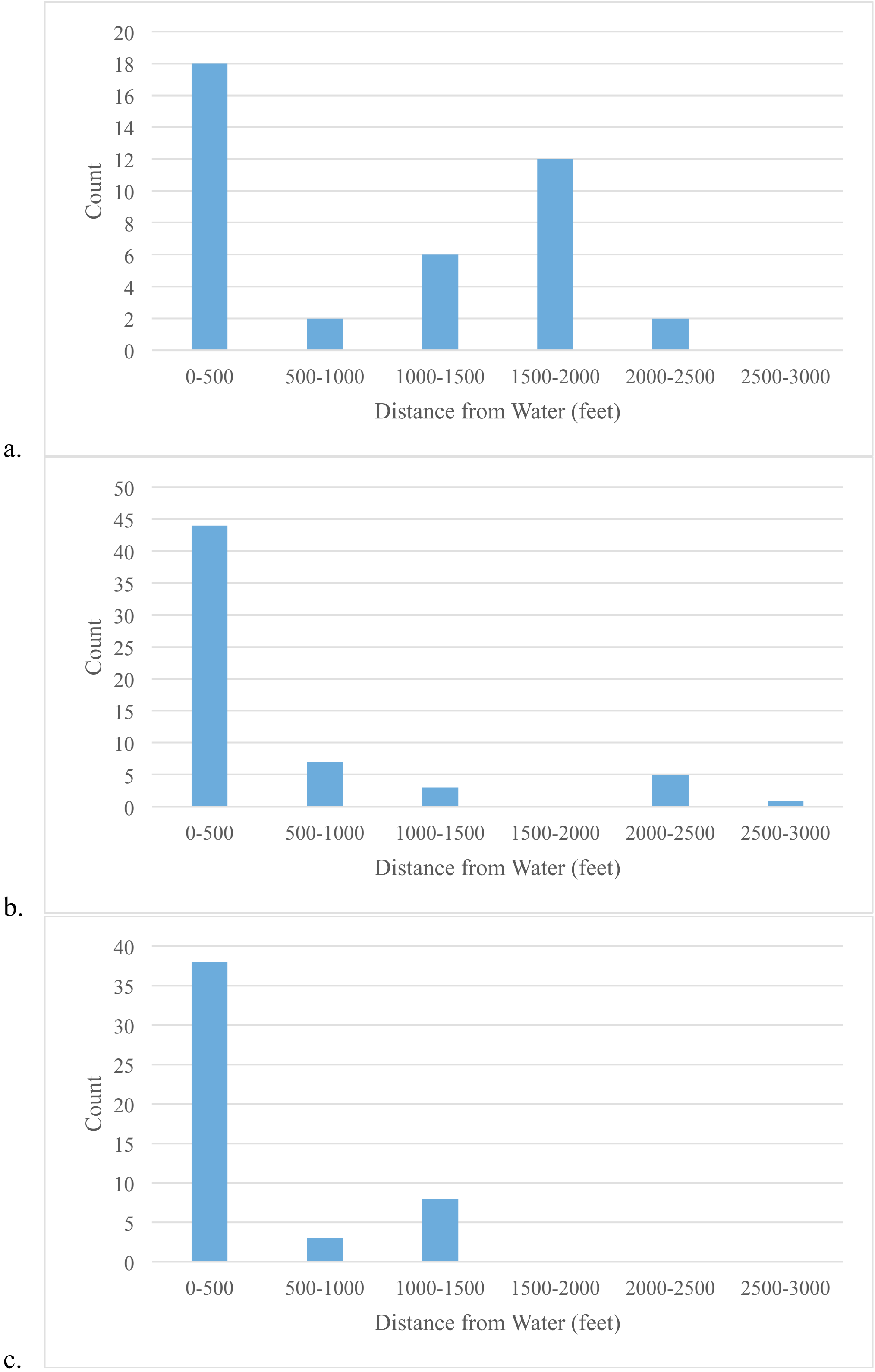
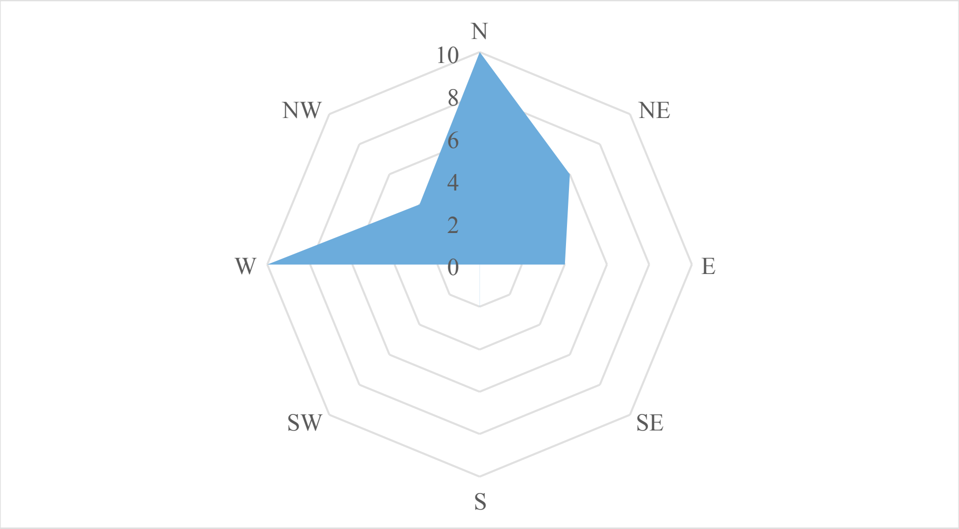


FIG. 4. Histograms showing the distance from water distribution of a. *Magnolia acuminata*, b. *Magnolia fraseri*, and c. *Magnolia tripetala*.

a.



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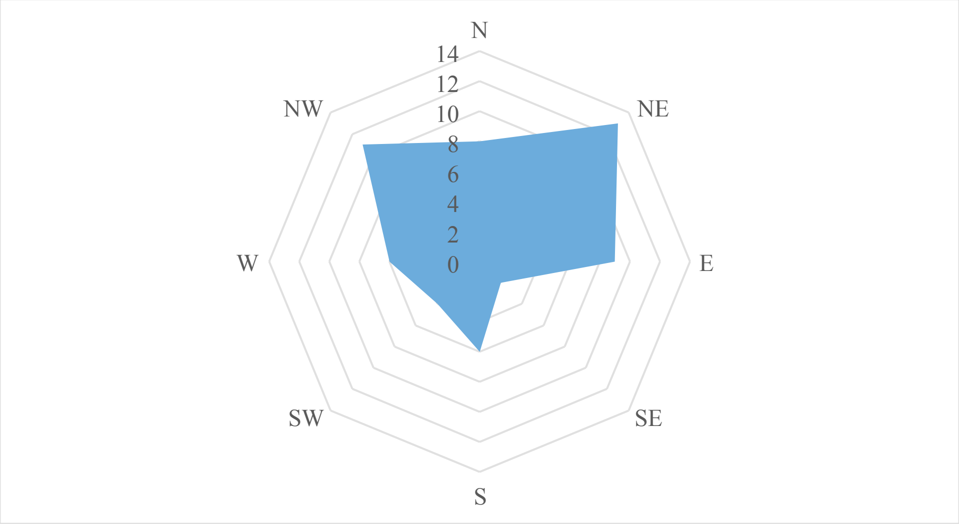

c.

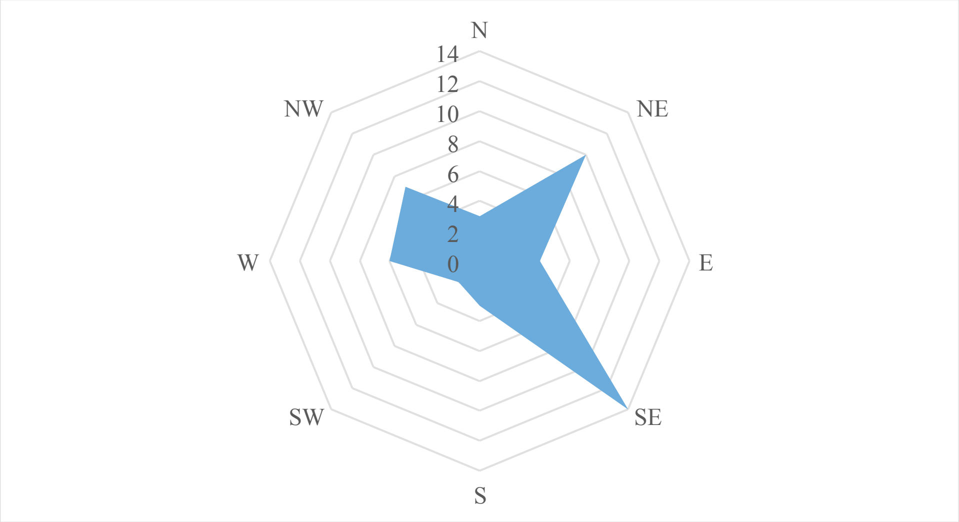

FIG. 5. Radar graphs showing the aspect distribution of a. *Magnolia acuminata*, b. *Magnolia fraseri*, and c. *Magnolia tripetala*. N is between 337.5° and 22.5°, NE is between 22.5° and 67.5°, E is between 67.5° and 112.5°, SE is between 112.5° and 157.5°, S is between 157.5° and 202.5°, SW is between 202.5° and 247.5°, W is between 247.5° and 292.5°, and NW is between 292.5° and 337.5°.

Patterns are also present with regard to slope aspect of observed magnolia habitat. *M. acuminata* and *M. fraseri* were found mostly on slopes facing north. No *M. acuminata* plants were found that grew on south-facing slopes (SE, S, SW), while only a few *M. fraseri* were found in those locations. *M. tripetala*, on the other hand, seemed to have no clear preference for slope aspect (Fig. 5). An ANOVA was not performed for aspect data, as it was uninformative with the non-linear degree scale used.

DISCUSSION

Upon cursory inspection of the magnolia point location map, it seems that the three magnolia species in western North Carolina, *Magnolia acuminata*, *Magnolia fraseri*, and *Magnolia tripetala*, grow in very similar habitat. Some of the statistics show this to be true. For example, all three species tend to grow very near to water, and there is habitat overlap when looking at slope, elevation, and aspect. However, deeper inspection shows that despite the overlap there are important differences. All four of the habitat characteristics examined in the study showed statistically significant dissimilarities between the three magnolia species. *Magnolia acuminata* tended to grow at a wider range of elevation and proximity to water than the other two species, and preferred flatter, north-facing slopes. *Magnolia fraseri* generally grows at lower elevations than the other two species, and on steeper slopes. Like the other two magnolia species, it prefers to grow close to water. However, *M. fraseri* was also found in low amounts growing further away from water. Like *M. acuminata*, *M. fraseri* also seemed to prefer north-facing slopes. *Magnolia tripetala* seems to have the most specific habitat preference. All *M. tripetala* plants recorded grew exclusively near water, mostly on flat land, within a narrow elevation range, with the vast majority of plants recorded growing within an 800 foot range (between 1400 feet and 2200 feet). However, unlike the other two species, *M. tripetula* did not seem to have a strong preference for north-facing slopes.

The specificity of the niche for each species also corresponds to the extent of their geographic distribution. *M. acuminata*, which had a wider niche than the other two species, also has the largest geographic range, and can be found all along eastern North America. On the other hand, *M. tripetala*, which had the narrowest niche, has only a small geographic range in the southern Appalachians. The three magnolia species are essentially filling three distinct roles, *M. acuminata* being a generalist, *M. tripetala* being a specialist, and *M. fraseri* being an intermediate. This niche differentiation likely allows the coexistence of such closely related species in a relatively small geographic area. Whether the actual presence and distribution of the three species came about from divergent evolution, or because they may be relicts of larger ancestral populations is not clear from this study, and is a topic that could be explored in the future through genetic analysis of the magnolias.

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HEALTH ASSESSMENT AND FORMULATION OF MANAGEMENT STRATEGY FOR *JUNIPERUS COMMUNIS* VAR. *DEPRESSA* ON SATULAH MOUNTAIN

SAM LEEPER

Abstract. Satulah Mountain in Highlands, North Carolina is home to many rare species including the dwarf juniper, *Juniperus communis* var. *depressa*. The Satulah population of this species has tremendous ecological and educational importance, but is being threatened by encroachment of ericaceous shrubs and other successional species that overshadow the *J. communis* var. *depressa* specimens and alter the warm and dry soils that they prefer. I surveyed the population and created an arithmetical metric to assess the threat to each specimen and to begin exploring management options for the population.

Key words: Habitat management; Juniperus communis *var*. depressa*; sunlight availability.*

INTRODUCTION

The summit of Satulah Mountain in Highlands, North Carolina, a granite dome pluton, houses a mosaic of heath bald and rock outcrop plant communities characterized by old growth *Quercus prinus, Castanea pumila, Solidago simulans, Diervilla sessifolia, Kalmia buxifolia*, and *Juniperus communis* var. *depressa*. The summit of Satulah holds a thin layer of acidic soil with little moisture, creating conditions suitable for the unique heath bald plant community. This community has been maintained by fire and other disturbance regimes throughout its history (HCLT 2009).

The dwarf juniper *J. communis* var. *depressa* is a relic population that migrated south along the Appalachian chain during the Wisconsonian glaciation. The Satulah population is one of several disjunct populations remaining in the Southern Appalachians, and is the second southernmost documented population of this variety of *J. communis* (Gadd and Finnegan 2012). Two others populations have been documented in the Carolinas; at Crowder's Mountain in Gaston County, NC (Gadd and Finnegan 2012) and at Hitchcock Woods in Aiken, SC (Boni 1998). The variety *J. communis* var. *depressa* is distributed throughout much of the northeastern United States and eastern Canada. It can be found on granitic outcrops, sand terraces, and stabilized dunes near lakes and in other open environments (Marion and Houle 1996). During the most recent ice age, the roughly north-south orientation of the Appalachians allowed for *J. communis* var. *depressa* and many other plant species to migrate south to escape the encroaching glacier without extending themselves into unfavorable climate. According to North Carolina Natural Heritage Program, *depressa* is considered an S1 threatened species in the state (Gadd and Finnegan 2012). It is not federally recognized as threatened because it is much more abundant in northeastern states.

Previous research on this variety of *J. communis* has included how the seed distribution affects the spatial pattern of a population in Quebec, Canada (Marion and Houle 1996), and the interaction of growth and climate factors at several sites including Satulah (Riddle 2011). Neither of these sources mentions *J. communis* var. *depressa* populations that are actively managed for conservation.

Satulah Mountain is managed by the Highlands-Cashiers Land Trust as its flagship property, and one of its most visited. Species such as *J. communis* var. *depressa* make Satulah an important tool for education regarding plant biogeography and ecology, and the views and accessibility of Satulah make it an important tourist attraction for Macon County. The preserved summit of Satulah stands in stark contrast to the vacation homes that populate many of the peaks and ridges in the area.

The population of *J. communis* var. *depressa* is currently threatened by encroachment of woody vegetation on the summit. Many areas that were once bare rock have been colonized by sand myrtle (*K. buxifolia*) and dwarf juniper, but some of these areas have since progressively given way to blueberry bushes, mountain laurel and rhododendron. Other members of the population are near forest edge habitat and are threatened by white pine and hardwood species in some locations. Based on my observations, progressive soil accumulation is leading to the successional pattern I've described here. *J. communis* var. *depressa* is intolerant of shade and found in open environments; colonizing plants reach maximum abundance on harsh, stressed environments in which competition is lacking. It grows on nutrient poor soils, tolerates full sun and wind and is pH adaptable (Radford et al.). My project was to survey the population and then develop a management strategy for the *J. communis* var. *depressa* population.

METHODS

I sought to document every individual or clump of individuals of dwarf juniper on Satulah Mountain. For the purpose of my study I defined a clump as any number of individual plants growing in close proximity and thus creating a continuous crown of vegetation. In many cases, I was unable to discern whether I was observing an individual or a clump. In this paper, I use "specimen" to refer to either an individual or a clump.

My surveying methods require a Garmin® 60CSx model GPS unit, a field tape measure, a meter stick and survey tape. For each *J. communis* var. *depressa* I marked a GPS point, measured the longest crown dimension and the perpendicular dimension with a tape measure, recorded three random soil depth measurements underneath the crown, recorded whether the specimen was producing cones, estimated the percentage the specimen was shaded and the percentage of vegetation on the specimen that was dead or dying. I chose not to use a densiometer to estimate shading because the plants and most of the overlying vegetation are too near to the ground to be captured by normal densiometer technique, and obtaining a densiometer reading from the center of the shrub would certainly damage some of the branches.

The data I compiled consisted of measurements for each specimen in five categories: soil depth, shade, dead vegetation, cone production and crown dimensions. For the purposes of my research, I defined dead vegetation as any desiccated stems or branches that held only brown needles or no needles at all. To create a numerical Total Risk Metric, I first divided the major crown dimension by 100 for all specimens. I ranked the soil depth, shade and dead vegetation data, split it into four equal categories and assigned all soil depth values within the first quartile one point, within the second quartile; two points, and so on. Shade and dead vegetation were in percent format, so I assigned all values less than or equal to 25% one point, between 25% and 50%; two points, and so on. Finally, I added a single point to specimens on which I observed cones.

The sum of these values comprised a metric to quantify the health of individual specimens. Higher values correspond to higher levels of threat due to encroachment of woody vegetation. I came up with this analysis on my own and it is not based on a precedent in any study of a population. This procedure was far from exact and was supplemented with qualitative observations in the field to identify at-risk specimens. The map I produced from these data helped visualize where the most threatened specimens were located.

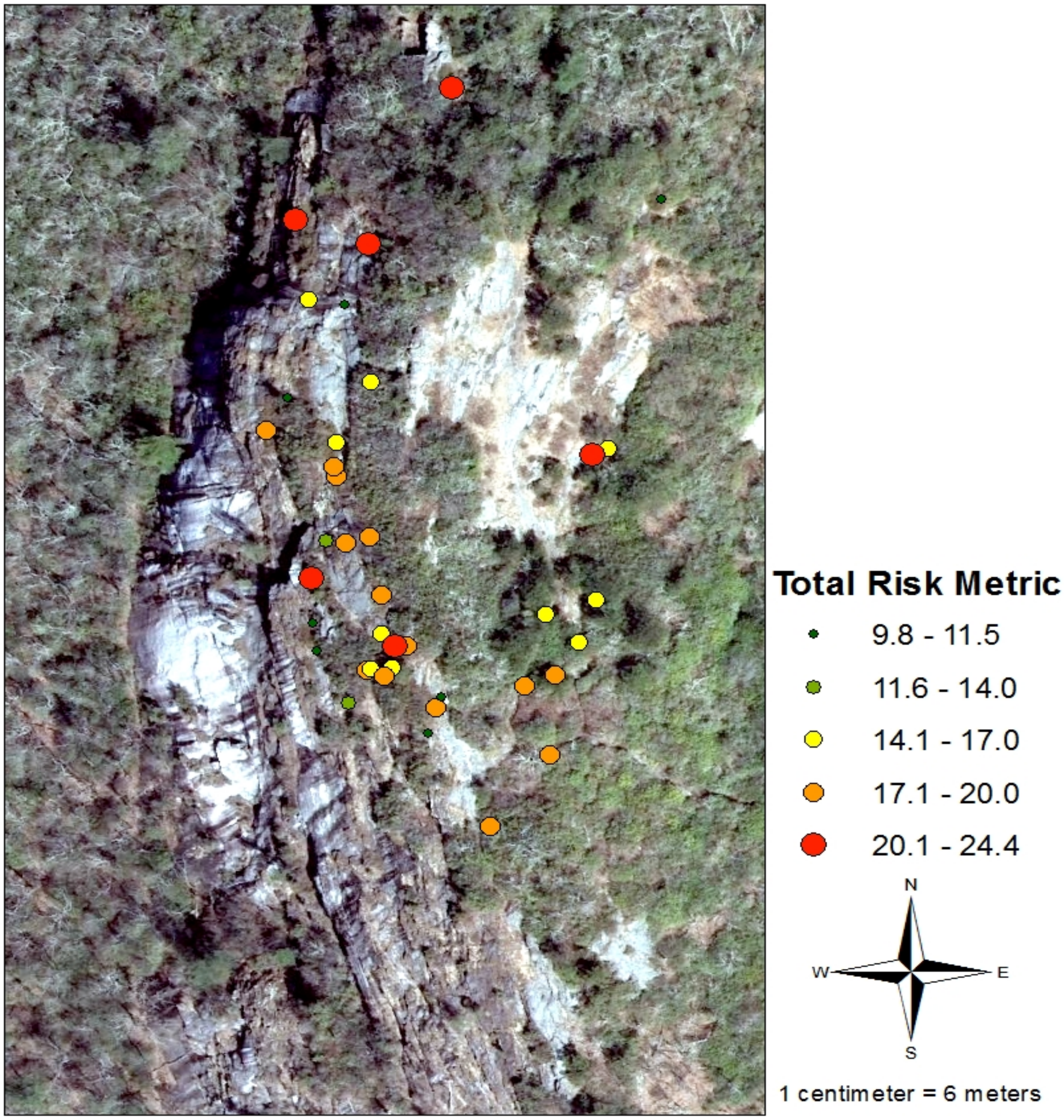
RESULTS

I recorded 39 *J. communis* var. *depressa* individuals on Satulah, ranging between 1361.47 to 1391.94 meters in elevation, with a mean elevation of 1376.29 meters. The majority, 25 specimens, grew in open areas on the west facing cliffs of the mountain, with some scattered through a mountain laurel (*Kalmia latifolia*) thicket on the south end of the summit as well as in cliffside areas with more substantial soil mats. The average percent shade cover for all specimens on Satulah was 54% (Table 1). This distribution was highly variable however, with a standard deviation of over 31%, and specimens at both ends of the spectrum. The mean percentage of dead vegetation for all specimens was 28%, with specimens ranging from zero percent to 95%. The major crown dimension of the specimens averaged over 3 meters, and ranged from less than 1 meter to nearly ten meters across (Table 1).

TABLE 1. Summary statistics for the Total Risk Metric and the four categories that comprise it. (N=39).

Category	Mean	Standard Deviation	Maximum Value	Minimum Value	Range
Shade (%)	54	31.47	100	0	100
Dead Vegetation (%)	28	24.19	95	0	95
Soil Depth (cm)	9.4	3.39	17.6	3.1	15
Major Crown Dimension (cm)	335.55	211.92	981	69	912
Total Risk Metric	16.71	3.92	24.4	9.8	14.6

My risk metric produced values between 9.8 and 24.4 based on the four major metrics that I analyzed, soil depth, dead vegetation, cone production and crown dimension (Fig. 1). Higher values correspond to greater risk, with values above 20 considered to be of highest conservation priority.



By Sam Leeper, Highlands-Cashiers Land Trust

Fig. 1. Map of *J. communis* var. *depressa* specimens and their risk metric on Satulah Mountain. Created in ArcMap v. 10.1.

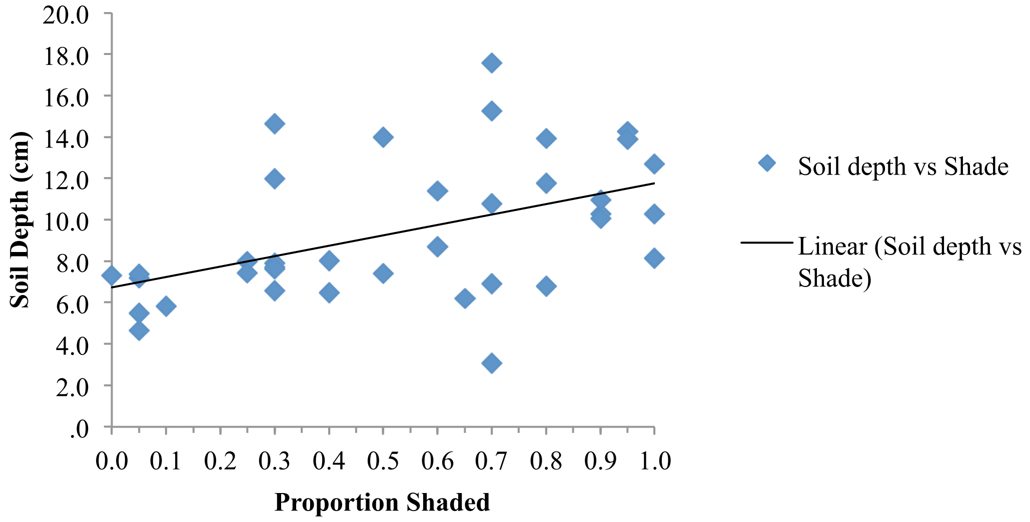


FIG. 2. Percent shade versus soil depth for each *J. communis* var. *depressa* specimen. R^2=0.2275.

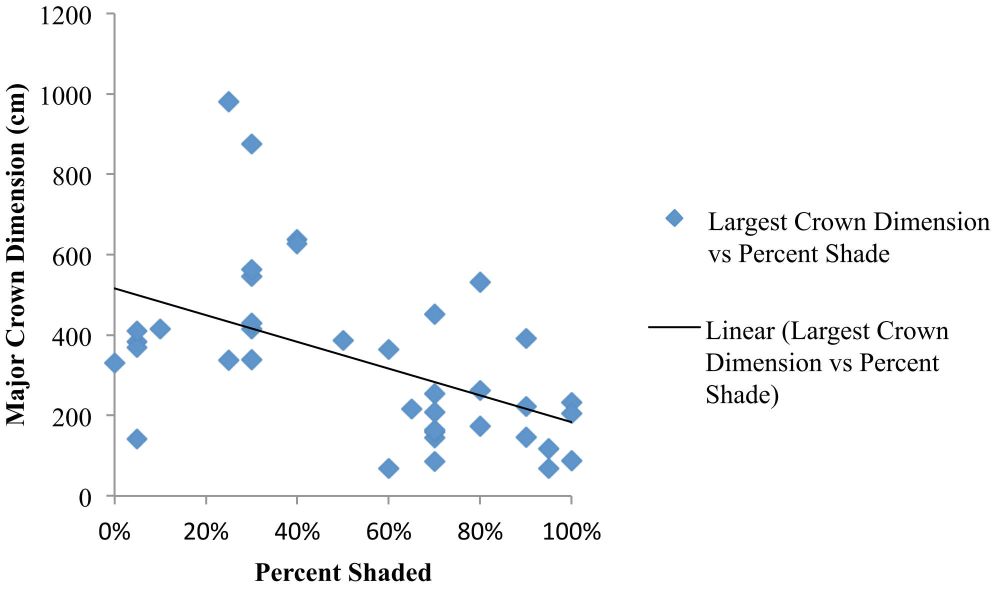


FIG. 3. Largest crown dimension of each *J. communis* var. *depressa* specimen versus percent shaded. R^2=0.2507.

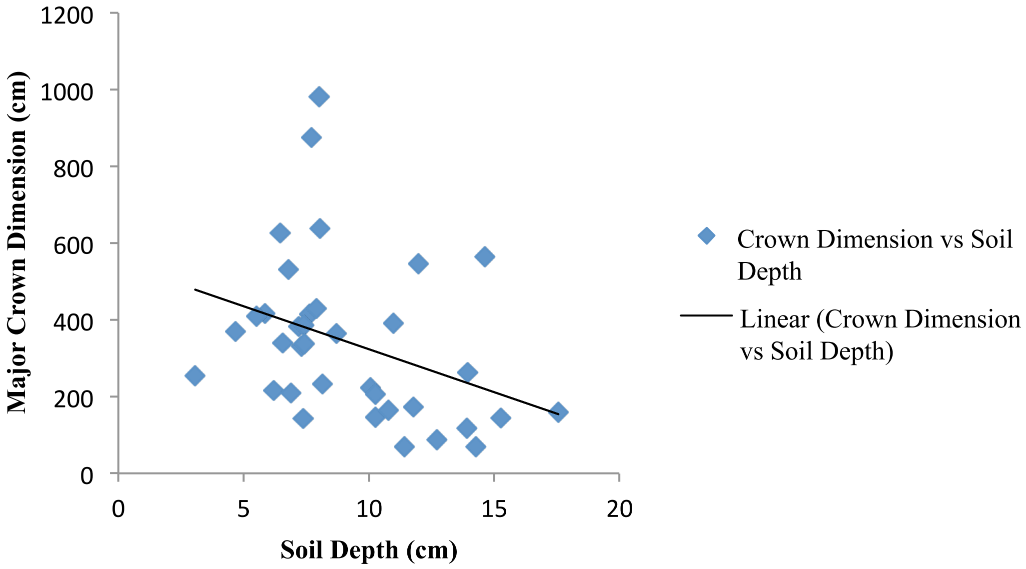


FIG. 4. Major crown dimension plotted against soil depth. R^2=0.1239.

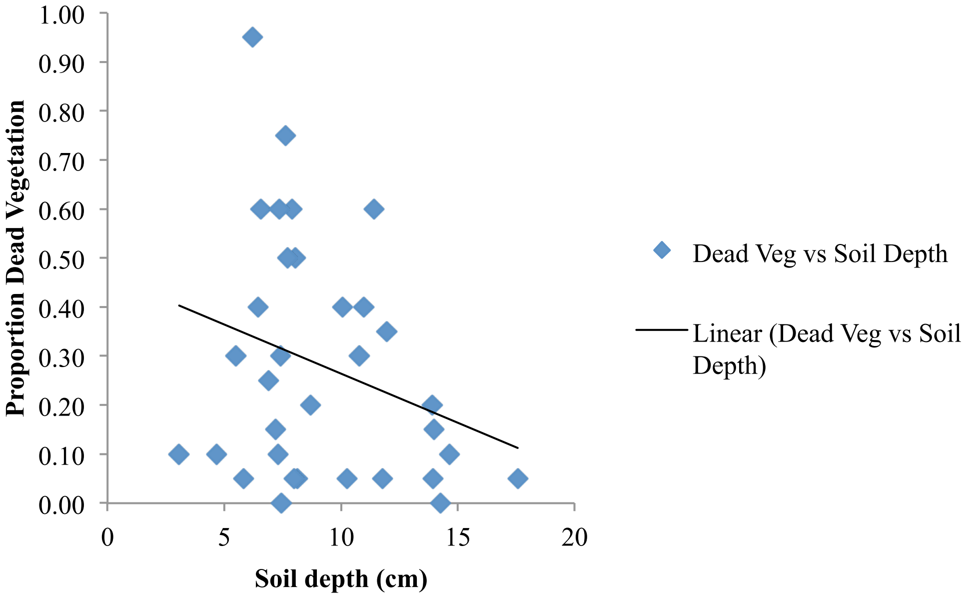


FIG. 5. Percent dead vegetation plotted as a function of soil depth. R^2=0.0747.

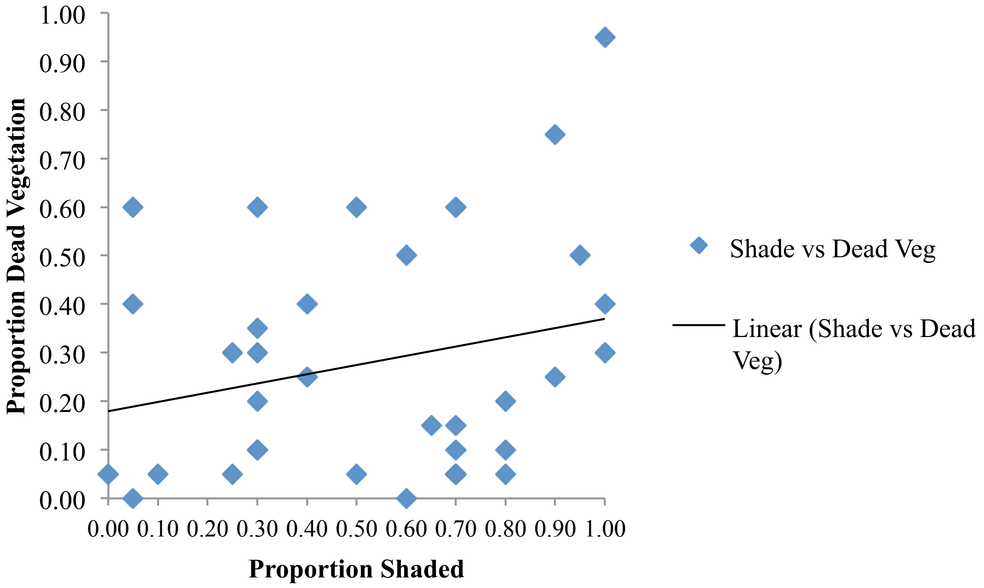


FIG. 6. Proportion dead vegetation plotted as a function of proportion shade. R^2= 0.0594.

DISCUSSION

My results indicate that about one third of the *J. communis* var. *depressa* population is at risk due to encroachment and shading, including 8 specimens on which 50% or more of their vegetation is dead or dying. I observed modest inverse correlations between greater soil depth and major crown dimension, with an R^2 value of 0.1239 (Fig. 4), percent shade cover and major crown dimension (R^2=0.2507; Fig. 3), and greater soil depth and greater shade cover (R^2=0.2275; Fig. 2). Furthermore, shade cover and soil depth explained some of the variation in percentage of dead vegetation in this population (Figs. 5 and 6).

J*uniperus. communis* var. *depressa* is commonly found in poor soil such as sand dune environments at higher latitudes, because it requires well drained soil. My data suggest that some specimens on Satulah are struggling in soils that are hold moisture and receive minimal direct sunlight. Junipers growing in shade develop thin, open vegetation and are more susceptible to disease and insects (Westerfield 2012). My study found a modest inverse correlation between soil depth and dead vegetation (R^2=0.0747; Fig. 5) but a direct correlation between shade cover and dead vegetation (R^2=0.0594; Fig. 5). The lack of strong trends suggests that soil depth and shade cover are imperfect proxies for soil moisture content and drainage. Therefore I would recommend incorporating a measure of soil moisture into future research.

Juniperus communis var. *depressa* are shade intolerant nonetheless. Due to their low height, the specimens on Satulah are at risk of being encroached upon by opportunistic species that capitalize on the soil mats they accumulate around their bases. Common culprits on Satulah are *Rhododendron minus*, *Kalmia latifolia, Rubus sp.* and *Vaccinium sp.* I observed these species growing in close associations with *J. communis* var. *depressa* and in many cases growing over top of them, limiting the availability of sunlight. A particularly telling specimen was growing among a thicket of *Vaccinium sp.* in a spot where the edge of its crown coincided with a sharp transition to *Kalmia latifolia* heath. Both individuals growing in the *Kalmia latifolia* thicket were small and had noticeably thin vegetation. Compared to the grove of *Vaccinium sp.*, the thick vegetation of *Kalmia latifolia* allowed much less sunlight to penetrate to the level of the *J. communis* var. *depressa*.

Research has indicated that *J. communis* var. *depressa* is particularly inefficient at seed dispersal (Marion and Houle 1996). One scientist has remarked that, for this variety, "we have never observed any damage from herbivores on *J. communis* vegetative structures" and, "the majority of the mature cones fall on the ground directly under the plant crown" (Marion and Houle 1996). The apparent unpopularity of *depressa* cones among birds and other foragers, and the small population size on Satulah raise serious questions about the population's reproductive capability. In such a small population, each and every specimen holds important genetic diversity. Dispersal by herbivores is the only viable means of seed dispersal for *J. communis* var. *depressa*; female cones that fall beneath the shrub are smothered by the dense vegetation and are unlikely to be pollinated.

Succession occurring near the summit of Satulah is creating soil and leaf litter accumulation that threatens the survival of many specimens of *J. communis* var. *depressa*. The risk assessment metric revealed no obvious spatial pattern to the distribution of at risk specimens. The highest values were distributed throughout the habitat range on the summit. As a result, the map I produced is most useful as a tool to act upon rather than an analytical one. For Satulah, I strongly recommend that vegetation be cut back in selective spots to allow more sunlight to reach the specimens. Specific locations that are high priorities include the heath bald communities between the summit and Mushroom Rock, and the southwest portion of the main cliff face. Ideally, clearing areas of heath would generate more favorable soil characteristics for *J. communis* var. *depressa* and help return the summit of Satulah to a more open state.

ACKNOWLEDGEMENTS

I would be remiss to finish this paper without acknowledging the individuals who made it possible for me to complete this project. This list includes Kyle Pursel and Dr. Gary Wein of the Highlands-Cashiers Land Trust, whose expertise in conservation I continuously relied upon; Ana DiMartino, who graciously offered up her time and energy to assist with my data collection; Dr. Jim Costa and Michelle Ruigrok for their patience in reviewing drafts of this paper; and Dr. Karen Kandl, who spent countless hours organizing the field site program, including my internship opportunity and so many other experiences this semester that would not be possible without her.

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THE EVENTS LEADING TO THE ACTIONS PRIOR TO THE REMOVAL ACT OF 1830 WITHIN COWEE, NC: PRELIMINARY RESEARCH

STEPHEN ODOM

Abstract. I provide a preliminary background on the history of Cowee before the Removal Act of 1830 using historical documents. In 1775 William Bartram traveled to what is today Cowee; the following year Captain William Moore provides another account of the region. Following these events, Rutherford's expedition (1776) left the region in turmoil and disarray only to be followed by more war on a different front. The United States did not hold up their end of the bargain in the Treaties of 1817 and 1819. These were the events and actions by the settlers that lead to the ultimate removal of the Cherokee citizens to what is today the Eastern Band of the Cherokee Nation.

Key words: Cherokee Indians; Cowee; cultural history; Griffith Rutherford; parcels; Removal Act of 1830; tracts; Treaty of 1817; Treaty of 1819; United States Forest Service; William Bartram.

INTRODUCTION

Conservation involves preserving both our natural resources and our cultural history. At one point in time the Cherokee Nation occupied 640,000 acres of land in what is now Alabama, Georgia, North Carolina, and Tennessee (Jurgelski 2004). From the late 1700s to the mid 1800s, the United States ravaged Cherokee property by burning buildings, crops, and laying waste to the middle towns (Moore 2009, Walbert 2009). William Moore also noted the scalping of prisoners (Moore 2009). These were indeed horrifying events that took place at the time. The purpose of this paper is to describe a picture of Cowee in the mid-1700s leading up to the events that lead to its disappearance. This preliminary research will lay down the framework for further research on property ownership and land use following the Removal Act of 1830.

My area of focus is the Cowee Mountain Range, whose ridge straddles the Jackson, Swain, and Macon County boundaries of western North Carolina (NC; Fig. 1). The entire range consists of around 253 square miles, which is an extremely rough estimate. Surrounding the range are three major river systems: the Cullasaja River, the Little Tennessee River, and the Tuckasegee River. To the north, the Alarka Mountains jut out from the range near its peak, which is at an elevation of 4,944 feet. Down in the valley, southwest of the peak, sits the town of Cowee, NC. Recently purchased by the Cherokee Nation, the Cowee Mound stands in isolation on the other side of the Little Tennessee River from the town (Fig. 1).

The Cowee-West Mill's Historic District occupies an area of 369 acres, which crosses NC 28. Among the properties included on the premises are housing, a school, church, cemetery, and post office each with historical significance (Ervin and Martin 2000). Cowee Mound can be seen from the base having a formation evidently constructed by human hands. This is true for most of the Cherokee town sites. From this vantage point the Cowee Mountain Range can nearly be seen in its entirety. This was originally the location of the town of "Cowe" in which William Bartram ventured (Bartram 1791) and the army of Captain William Moore burned to the ground (Moore 2009). Along with these events, the existence of the Native American village and the nation

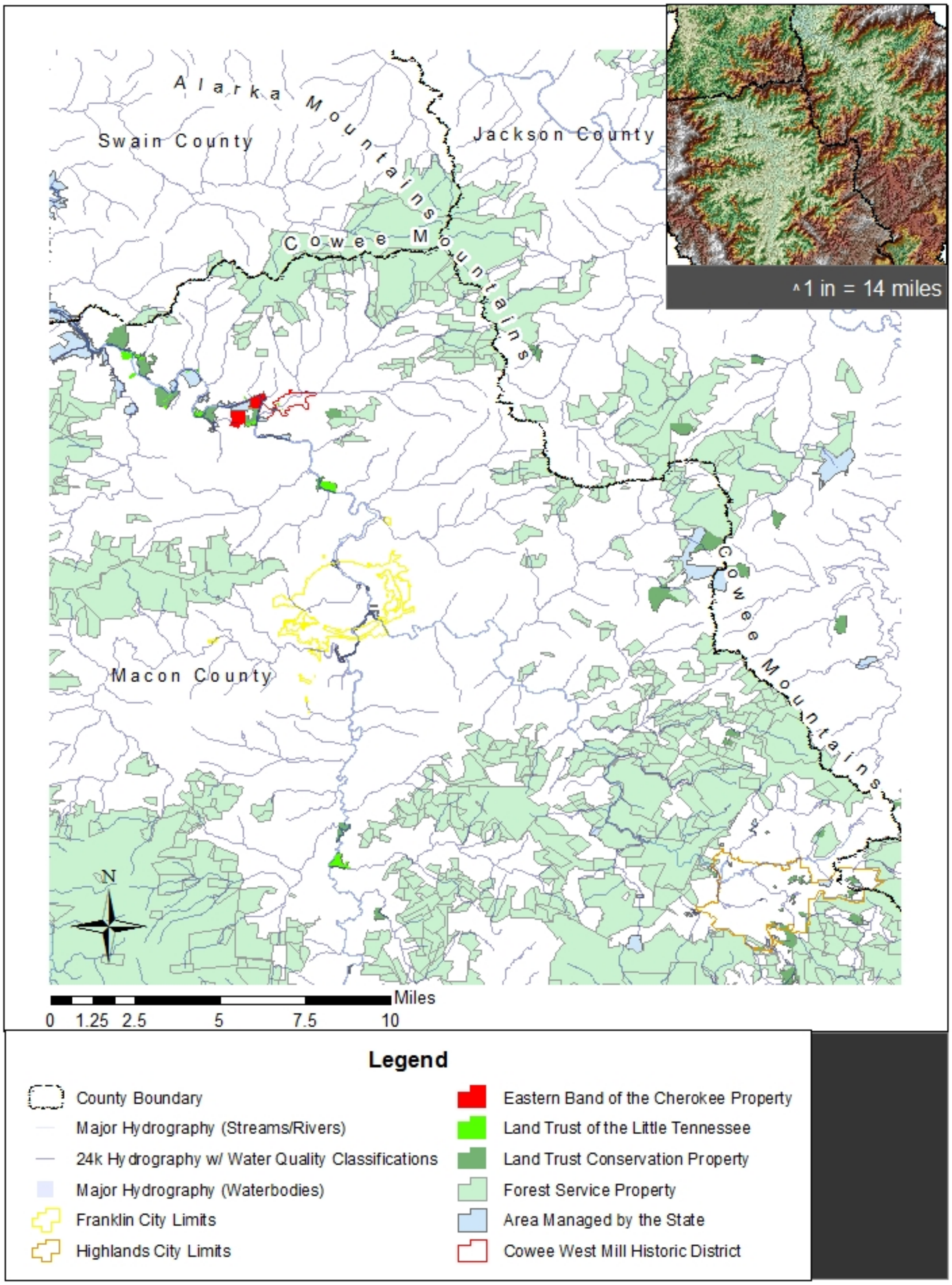

FIG. 1. Full extent of present day public lands of the Cowee Mountains including Cherokee property. The data frame in the upper right corner of the map is a visual aid for identifying the ridges and mountain formations using hill shade and elevation data. Refer to Table 1 for source information (ArcGIS 10.1®(ESRI 2012)).

would then be whittled down by the Treaties of 1817 and 1819 and finally the Removal Act of 1830.

METHODS

This research on the historical use of the Cowee Mountains by native Cherokee took place from early September to late November 2013. I began by looking at documents in the Nantahala Ranger District Office located in Franklin, NC. I located the owners of some United States Forest Service (USFS) land along the mountain range and their deed information by analyzing Geographic Information System (GIS) data from the USFS database. This was done by joining a tract ownership shapefile with the tract ID shapefile in ArcGIS. I then joined the new shapefile geographically with the tax parcel information derived from the Macon County GIS and Mapping office.

Once the deed book and page number had been combined with the tract and ownership information, I visited the Macon County Register of Deeds office to find property transactions. Any particular owner may own multiple properties, and this is especially true of the earliest records. Property locations are based on descriptions of the surveyor's notes. Older documents often provide a description of the property but lack a map. Landscape details change over time, especially over centuries; therefore, it is extremely difficult to pinpoint a detail that no longer exists. Eventually I compared hundreds of properties owned by the same person and their descriptions just to find one parcel of land. This was ineffective, so I changed tactics.

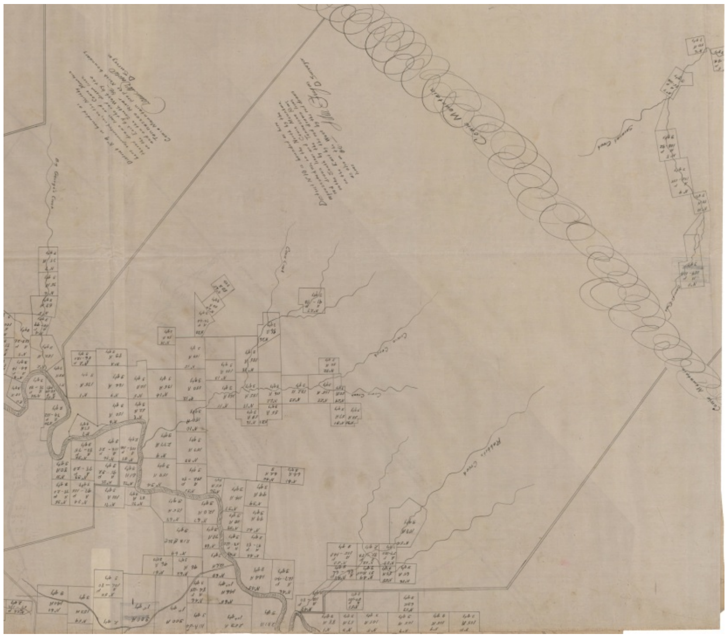

FIG. 2. A cropped section of the southwest portion of the Robert Love Survey. The original map is 12.4 x 11.5 feet. This is the correct orientation of the map from south to north on the paper; however, the map was written on from north to south, upside-down (Love 1911).

The Robert Love Survey created after the Treaty of 1819 is a conglomeration of several district maps written by different surveyors. District 10, cataloged by Adam Fryus, is the section that details the location of the current Cowee-West Mill Historic District (Fig. 2). I sought to geo-register particular points on the survey (using heads-up-digitizing), but needed a map image to do so. Unfortunately the map was too large for any scanner available on-site. Two other sources were provided for digitized files of the map: Lamar Marshall and North Carolina Maps, a constituent of the University of North Carolina in Chapel Hill. Marshall has photographic pictures of each district on the survey; however, due to morphology and magnitude of the database, I could not accurately geo-register the raster image with the time allotted. The North Carolina Maps database was much more helpful since their images cover several districts at once. Still, due to the limited scope of this project, I could not geo-register and compare the survey to the Cherokee citizen map.

I eventually compared historical documents derived from the Library of Congress, the North Carolina Archives, the National Archives, and David Rumsey's map database. Thousands of images and text were sifted through related to the area of western North Carolina. In addition, Barbara Duncan, Education Director at the Museum of the Cherokee in Cherokee, NC, provided an initial description of the Cherokee citizen reservations in Cowee, NC.

GIS Data

Many publicly available sources of historical information were used to do this project (Table 1). There was some discrepancy between Macon County parcels and USFS tracts possibly due to the different styles of format, projection, and equipment used to establish the shapefiles. When viewing any of the maps displayed within this document, please take into consideration the variety of shapefiles and their sources.

Macon County Register of Deeds

There are two systems for identifying the correct deed or set of deeds. In order to locate the specific land acquisitioned by the USFS, the grantee is listed as the United States of America. Between 1928 and present day, there are 16 sets of alphabetically organized deed books (A-1, A-2, A-3…B-1, B-2, B-3…). Letters later in the alphabet correspond to more recent documents. The grantor can also be found listed next to the grantee under the grantee index booklets. Once the grantor has been identified, the deed book and deed number can be searched by hand. Deeds listed before 1928 are organized solely based on the alphabet (A, B, C… AA, BB, CC…), the earliest of which is 1828. This is a year before the first Macon County boundaries were established. The Macon County Register of Deeds office also houses the land grants within the county; however, since the county boundary has changed many times (Long 2012; Fig. 4), some of those land grants may be recorded in other deeds' offices in the state. For years prior to 1928, descriptions of the property may be replaced with maps. Unfortunately, some of these maps have been lost over the years. At this point it is nearly impossible to identify some deeds with current parcels without a description or a surveyor map.

TABLE 1. Geographic Information Systems Data used in Fig. 1. Some of this data was sent via email and do not have a website destination.

Source	Data	Website
Atlas of Historic County Boundaries Project	NC_Historical_Boundaries.shp	http://publications.newberry.org/ahcbp/pages/North_Carolina.html
ESRI Database	World_Topo_maps	http://www.arcgis.com/home/item.html?id=30e5fe3149c34df1ba922e6f5bbf808f
United States Forest Service	FS_AQ_OnFile.shp, FS_CE_MC.shp, S_USA_SurfaceOwnership.shp, Ownership&FS_Tracts.shp, Tracts_w_Nantahala_R_District.shp	http://svinetfc4.fs.fed.us/vector/index.php
Jackson County	Elevation	http://maps.jacksonnc.org/gomapsags/
Macon County	Par_View.shp, Parcels.shp, HCLM.shp, FCLM.shp, Elevation	http://gis2.maconnc.org/www2/gis/
Swain County	Elevation	http://maps2.roktech.net/Swain/#
NC One Map	ltcp.shp, NC1Map_Hydrography	http://data.nconemap.com/geoportal/catalog/main/home.page
Land Trust for the Little Tennessee	Cowee West Mills Historic Distric.shp, ltlt.shp	N/A
North Carolina Division of Transportation Connect	CountyBoudaries.shp	https://connect.ncdot.gov/resources/gis/Pages/GIS-Data-Layers.aspx

Nantahala Ranger District Office

The United States Forest Service is organized into districts. Originally there were two districts for the Southern Appalachians. The Highlands and Nantahala districts divided Cowee; however, these have been combined into what is now the Nantahala Ranger District. Nantahala tract documents are divided into maps and acquisition paperwork. In this arrangement, tract location is based on the standard United States Geological Survey 7.5 minute scale quad maps.

The district office also contains more files on the land description similar to that found within a deed, letters of engagement, written during the time of acquisition, and archeological reports. The filing system organizes the reports and acquisitions based on the name of the individual whose property is being condemned along with the Tract ID. Tract IDs are given a letter, depending on the location, and a number corresponding to how recent that tract was acquired (the higher the number, the more recent the acquisition). Some documents are missing.

RESULTS AND DISCUSSION

Historical Descriptions of Cowee

Two main accounts of Cowee during the year 1775 and 1776 exist: one of William Bartram and one of Captain William Moore. At the beginning of Bartram's book, *The Travels of William Bartram* (1791), he embarks on a great adventure from Charleston, South Carolina to what is the region of Cowee (referred to as "Cowe"). The descriptions throughout his book provide vivid detail of the flora and fauna of his travels including the natural landscape, referring to an "extensive and fruitful vale of Cowe." At the time, he describes Cowee as being the center of the Cherokee Nation. Consisting of about "one hundred dwellings," the town surrounds the base of the mound on both sides of the "Tanase," which is present day Little Tennessee River (Bartram 1791). It is unknown who initially "built" the mound on which the council-house sits. According to Bartram's description, the origin of its creation has been lost due to tribal takeover (Bartram 1791).

A year later Captain William Moore wrote a description of Cowee to his superior, Brigadier General Griffith Rutherford. As of 1775 William Bartram had already traveled through the area. On September 1 of 1776, following the Declaration of Independence that year, General Rutherford's corps laid waste to most of the middle towns of the Cherokee nation (Walbert 2009). In his report to Rutherford, Moore leads a scouting party of 97 men to the town of Cowee. To their surprise the town was completely deserted save two Indians who were chased across the river, shot and scalped (Moore 2009). This just shows how horrific these soldiers were to the Native Americans during this time period. Moore only refers to 25 buildings of new construction and the council-house having no coverings, as if recently erected (Moore 2009). This is very peculiar considering William Bartram describes the town having only one year ago comprised of "one hundred buildings" and a finished council-house (Bartram 1791). It is unclear whether William Bartram's account was an exaggeration. The existence of Rutherford's corps in Cowee is further supported by an article written in 1867 (Rockwell 1867, Swain 1867).

Treaty of 1817 and Treaty of 1819

Following the events of the Rutherford's Expedition, the Cherokee Nation had little room to breathe. The Treaty of 1817 was the first cession allowing the heads of households to claim 640 acres of land around their estates on the stipulation that they become United States citizens (Jackson 1817; Fig. 3). The precedent for creating the second treaty, the Treaty of 1819, came from two main issues: settler occupation and extension of property claims (Fig. 3). Settlers were beginning to occupy land already owned by Cherokee citizens, therefore the government issued that these alien occupiers be removed from the property. In addition to removing these settlers, the United States government revised the original decision to provide reservation lots for heads of households. The Treaty of 1819 now permitted any Cherokee member to claim land in the event that it was being used for industrial and productive purposes. The second treaty also gave provisions for the president to appoint commissioners to oversee the boundaries for each state affected by the treaty (Calhoun 1819).

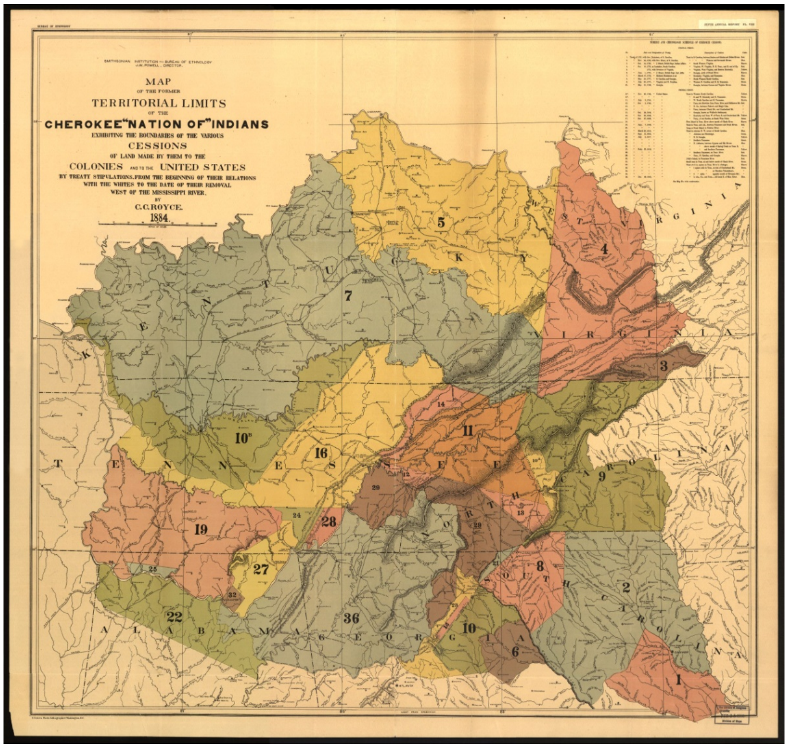

FIG. 3. Map of all Cherokee Nation Cessions. The two treaties of interest here are 29 (Treaty of 1817, Mauve) and 36 (Treaty of 1819, Blue) (Royce 1884).

It is currently unknown the extent to which the president-appointed commissioners disregarded the claims by the Cherokee citizens living within the southern Appalachians. Having spent some time at the Macon County Register of Deeds office, I could not find a record of any Cherokee names within the land grant booklet. I can only speculate that another county office has these files, the Cherokee claims were never recorded, or a white man used his name to represent several Cherokee citizens at once.

FUTURE RESEARCH

Land Use Timeline in Cowee

Over the next few years, I hope to develop a timescale of the various land ownerships within the region. There is an extremely extensive parcel database for present day ownership. Each parcel has date information that can be viewed over time. ArcGIS 10.1® (ESRI 2012) contains a timescale application that allows the user to produce a video of layers given a time stamp or date. The Atlas of Historical County Boundaries Project best represents this idea. They have created an entire database of all the historical counties and their creation in the United States resulting in a video of county changes (Long 2012; Fig. 4). The same can be applied to land ownership in Macon County from 1828 to present day.

I will also create a model of the land coverage of the Cowee area after Cherokee removal to present day by determining the percentage of tree cover within the tract of interest. The same type of information was recorded in the Census of 1860 for the Cherokee Nation and is available for present day lands in the USFS database.

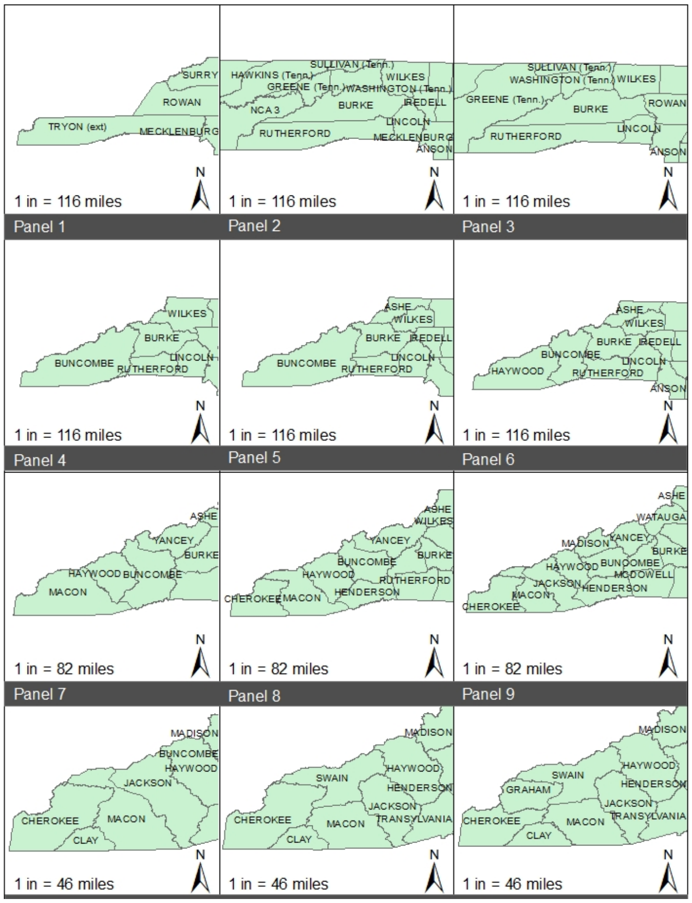

FIG. 4. Map of Panels displaying the NC County Boundary change for the area of and surrounding Macon County. Panel 1 covers 4/10/1769 to 2/11/1779. Panel 2 covers 2/12/1779 to 1/5/1787. Panel 3 covers 1/6/1787 to 1/18/1792. Panel 4 covers 1/19/1792 to 12/29/1794. Panel 5 covers 12/30/1794 to 12/14/1808. Panel 6 covers 12/15/1808 to 1/9/1829. Panel 7 covers 1/10/1829 to 1/3/1839. Panel 8 covers 1/4/1839 to 1/28/1851. Panel 9 covers 1/29/1851 to 9/20/1861. Panel 10 covers 9/21/1861 to 2/23/1871. Panel 11 covers 2/24/1871 to 2/1/1872. Panel 12 covers 2/2/1872 to 12/31/2000 (Long 2012, ArcGIS 10.1®(ESRI 2012)).

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I would like to take some time to thank the many constituents in association with this preliminary research. This project was inspired by Brent Martin, Director of the Southeastern Chapter of the Wilderness Society. This project would not have been possible without his guidance. He and his wife are not only mentors, but also friends, and have shared their life experiences and knowledge with me. Lamar Marshall was instrumental in providing an extensive database on Robert Love's Survey along with documents associated with the controversy of Love's commission. A conference by the William Bartram Society, in conjunction with Lamar Marshall, provided commentary on Bartram's travels. Through these interactions I gained a better understanding of the legacy that Bartram left on the world. I would not have had the opportunity to attend this event without the timely donation of R.B. Haynes. Dr. Jim Costa, the Executive Director of the Highlands Biological Station, has also been instrumental in my understanding of William Bartram. Cherokee history is extremely extensive and vast; I am grateful to Dr. Barbara Duncan for her help in procuring documents on the census data and reservations of the early Cherokee nation. I would like to thank the staff of The Macon County Register of Deeds office, Macon County Historical Society, and the Nantahala Ranger District office for their guidance. The Land Trust for the Little Tennessee and Dr.

Gary Wein, Executive Director of the Highlands-Cashiers Land Trust, provided data and expertise on GIS. I would especially like to thank Gary Wein for increasing my understanding of how to take advantage of the tools within ArcGIS. Dr. Karen Kandl is an extraordinary woman. How she learns to balance working with students and taking care of children is beyond me, but she does it and she does it well. Her advice has been extremely crucial to the creation of this paper and the research involved in its study. Last, but not least, I would like to thank Michelle Ruigrok for her dedication in supporting the students and being the connection between students and professors. She was instrumental in editing this paper. It is these individuals and organizations that I hold in such high esteem, and I hope that as I continue on this project, they are just as instrumental in its progress as in its creation.

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CONTRIBUTION OF MID-CANOPY TREES AND SHRUBS TO FOREST BIOMASS, LEAF AREA, AND SURFACE AREA IN THE SOUTHERN APPALACHIAN MOUNTAINS

ELLEN J. QUINLAN

Abstract. Allometric equations were developed for seven mid-canopy tree and shrub species *(Acer rubrum* L.*, Betula lenta* L.*, Carya* spp.*, Kalmia latifolia* L.*, Liriodendron tulipifera* L., *Quercus alba* L.*,* and *Quercus rubra* L.*)* at the Coweeta Hydrologic Laboratory in Macon County, North Carolina, U.S.A. These equations related overbark DBH to three dependent variables: above ground biomass (AGBM), leaf area index (LAI), and surface area index (SAI). Coefficients of determination (R^2) ranged from 0.92-0.99 for AGBM, 0.34-0.97 for LAI, and 0.84-0.99 for SAI. These equations were then used to estimate the understory component of three forest stands including a 30-year old clear cut, an 80-year old stand, and an old growth stand over 200 years in age. The 80-year old plot exhibited the highest understory AGBM, LAI, and SAI, while the old growth stand had the lowest AGBM and SAI.

Key words: Allometric equations; biomass; leaf area index; leaf mass; mid-canopy; southern Appalachian Mountains; surface area; surface area index; understory.

INTRODUCTION

Biomass, leaf mass, and surface area are all important variables for understanding forest ecosystem processes and function. Carbon flux modeling in forest ecosystems, for example, require accurate estimations of stem surface area (Clark and Schroeder 1986). However, the collection of these data is often time consuming and requires destructive sampling. Instead, allometric equations are commonly used to predict various tree attributes by relating them to overbark DBH (diameter at breast height) or height. Many such regression equations already exist for modeling large trees (Martin 1998) and seedlings (Elliot and Clinton 1993) in the southern Appalachians, however, a considerable gap exists for trees in the understory and mid-canopy (1.0 to 8.0 cm DBH).

The mid-canopy layer is a significant contributor to the forest system, as it acts as a facilitator for the growth of shade-tolerant species in the understory. It also drives changes in forest dynamics as it matures to replace the overstory (Donato et al. 2011). Less is known about how much mid-canopy trees contribute to fluxes such as evapotranspiration, photosynthesis, and respiration. In order to predict future community structure in forested systems and quantify understory and mid-canopy fluxes of water and carbon, the mid-canopy structural characteristics must be accurately predicted.

The purpose of this study was twofold: (i) to generate allometric equations for predicting biomass, leaf mass, and surface area from overbark DBH for seven mid-canopy deciduous tree and shrub species at the Coweeta Hydrologic Laboratory/Long Term Ecological Research site including the species *Acer rubrum* L.*, Betula lenta* L.*, Carya spp.* Nutt.*, Kalmia latifolia, Liriodendron tulipifera* L.*, Quercus alba* L.*, Quercus rubra* L., and (ii) analyze the changing above ground biomass (AGBM), leaf area index (LAI), and surface area index (SAI) in the understory and mid-canopy across aging forest stands.

METHODS

Study site

The study was conducted at the Coweeta Hydrologic Laboratory of the United States Department of Agriculture, Forest Service. The 2185-ha laboratory is located in the Nantahala Mountains of western North Carolina, USA (35° 03' N Lat., 83° 25' W Lon.). Elevation ranges from 685 m to 1592 m. Climate is classified as marine, humid temperate (Swift et al. 1988). Mean annual temperature ranges from 12.8 °C at the valley floor (685 m elevation) to 9.8 °C at higher elevations (1398 m) (Laseter et al. 2012). Mean annual precipitation ranges from 1795 mm yr^{-1} at the valley floor to 2359 mm yr^{-1} at higher elevations and averages >100 mm during all months (Laseter et al. 2012). Soils in the basin are generally very deep (solum layer >1 m) and well drained (Thomas 1996). The laboratory is ~96% forested with a mix of cove hardwood, northern hardwood, oak and oak-pine communities (Day et al. 1988). The current study was conducted in several sites representing mature aging forest stands of cove hardwood communities.

Harvesting

Trees of each species were selected in order to represent a range in overbark DBH between approximately 1.0 cm and 8.0 cm at a variety of sites within the study area. Once a specimen of appropriate size was chosen, the DBH was recorded to the nearest 0.1 cm, and then cut at the base using a hand-saw. After cutting, height was measured with a transect tape to the nearest 0.1 m. Leaves and wood were separated and placed in paper bags for drying. Leaves and stems of each tree were placed in a drying oven at 15.6 °C for seven days or until the sample reached a constant mass.

Analysis

Leaf mass was determined by weighing the leaves in their respective bags, discarding the leaves, re-weighing the bags, and then recording the difference. Large logs (>4 cm diameter) were cut into smaller segments for measurement. Mass of the large wood from each tree was taken by weighing each log to the nearest 0.01 g and then summing the pieces. To calculate surface area of large wood (>3.0 cm diameter) for each tree, the diameter and length of each log was recorded and summed. To calculate surface area of small wood for each tree, the mass and surface area of the smaller wood was taken by sorting the pieces of each tree into size classes based on diameter of the piece. The size classes were 0-0.5 mm, 0.5-1.0 mm, 1.0-2.0 mm, and >2.0 mm. Once sorted, each size class was weighed and then five representative pieces of each size class for each species were set aside. The width, length, and mass of each of these representative pieces was then recorded and used to calculate a species-specific ratio of surface area to mass for stems in that class.

Simple linear regressions were then computed relating DBH to total biomass, leaf mass, and stem surface area using log-transformed data for each of the variables with the equation:

$$[1] \log_{10} Y = a \log_{10} X + b$$

in which X is the overbark DBH (cm), Y is the dependent variable (biomass, leaf mass, or surface area), a is the slope, and b is the intercept.

The computed species-specific regressions were then applied to previously collected community data for three forest stands: a 30-year-old stand, 80-year-old stand, and an old-growth stand with many trees >200 years old. In each site, ten plots, each 5 x 5 m, were established and all trees >1.0 and <10 cm DBH were identified to species; DBH was measured to the nearest 0.1 cm.

RESULTS

Regressions between overbark DBH and biomass had high coefficients of determination with the R^2 value for all trees at 0.94 and R^2 values for individual species all falling above 0.90 (Table 2). The R^2 values for the leaf mass allometric equations varied among species from 0.34 to 0.97, resulting in a value for all trees of 0.64 (Table 2). *K. latifolia* L. had the lowest R^2 at 0.34. The surface area equations were more similar to those for biomass, with all species except *Q. alba* L. with an R^2 above 0.90, whose value was only slightly below at 0.84 (Table 2). The surface area R^2 value for all trees was 0.92 (Table 2).

The equations found by Martin et al. (1998) for large trees at the same site were plotted with the equations found in this study (Fig. 1). The equations for large trees exhibited a similar slope, although that of biomass and leaf mass was slightly greater for large trees and the y-intercept was always below that given for trees in the mid-canopy for biomass, leaf mass, and surface area.

TABLE 1. Species, sample size and DBH (diameter at 1.37 m) range of trees and shrubs used to develop allometric equations.

Species	Family	Code	*n*	DBH (cm)		Height (m)	
				Minimum	Maximum	Minimum	Maximum
Acer rubrum L.	Aceraceae	ACRU	7	1.10	7.70	2.45	11.80
Betula lenta L.	Betulaceae	BELE	7	1.01	7.40	2.40	13.25
Carya spp. Nutt.	Juglandaceae	CASP	7	1.15	5.92	3.05	8.21
Kalmia latifolia L.	Ericaceae	KALA	6	1.20	4.50	2.08	6.16
Liriodendron tulipifera L.	Magnoliaceae	LITU	7	1.25	7.40	2.20	13.10
Quercus alba L.	Fagaceae	QUAL	5	1.16	4.91	2.60	8.60
Quercus rubra L.	Fagaceae	QURU	6	1.19	7.28	2.90	9.80

(USDA, Natural Resources Conservation Service Plant Database)

In the forest plots sampled, the above ground biomass (AGBM) and surface area index (SAI) of the sub-canopy was highest in the 80-year-old plot and lowest in the 200-year-old plot (Fig. 2). The leaf area index (LAI) was the highest in the 80-year-old plot and lowest in the 30 (Fig. 2).

TABLE 2. Allometric regression equations for biomass, leaf mass, and surface area (for tree species abbreviation key see Table 1).

Species code	*a* (SE)	*b* (SE)	R^2
Biomass			
ACRU	2.19 (0.20)	-0.88 (0.11)	0.96
BELE	2.35 (0.24)	-0.85 (0.13)	0.95
CASP	2.43 (0.16)	-0.83 (0.08)	0.98
KALA	1.71 (0.23)	-0.56 (0.10)	0.93
LITU	2.30 (0.07)	-0.99 (0.04)	0.996
QUAL	2.17 (0.37)	-0.75 (0.17)	0.92
QURU	2.42 (0.08)	-0.76 (0.04)	0.996
All trees	2.22 (0.09)	-0.80 (0.05)	0.94
Leaf Mass			
ACRU	1.82 (0.35)	1.10 (0.19)	0.84
BELE	2.14 (0.44)	1.00 (0.25)	0.82
CASP	2.08 (0.30)	1.23 (0.14)	0.90
KALA	0.66 (0.46)	1.85 (0.21)	0.34
LITU	1.01 (0.25)	1.51 (0.14)	0.77
QUAL	1.10 (0.66)	1.39 (0.30)	0.48
QURU	1.99 (0.22)	1.38 (0.12)	0.97
All trees	1.62 (0.16)	1.32 (0.08)	0.69
Surface area			
ACRU	1.67 (0.15)	-1.00 (0.08)	0.96
BELE	1.75 (0.25)	-0.98 (0.14)	0.91
CASP	1.70 (0.11)	-1.05 (0.06)	0.98
KALA	1.29 (0.20)	-0.76 (0.09)	0.91
LITU	1.84 (0.09)	-1.05 (0.05)	0.99
QUAL	1.48 (0.37)	-1.02 (0.17)	0.84
QURU	1.87 (0.12)	-0.95 (0.06)	0.98
All trees	1.71 (0.08)	-0.99 (0.04)	0.92

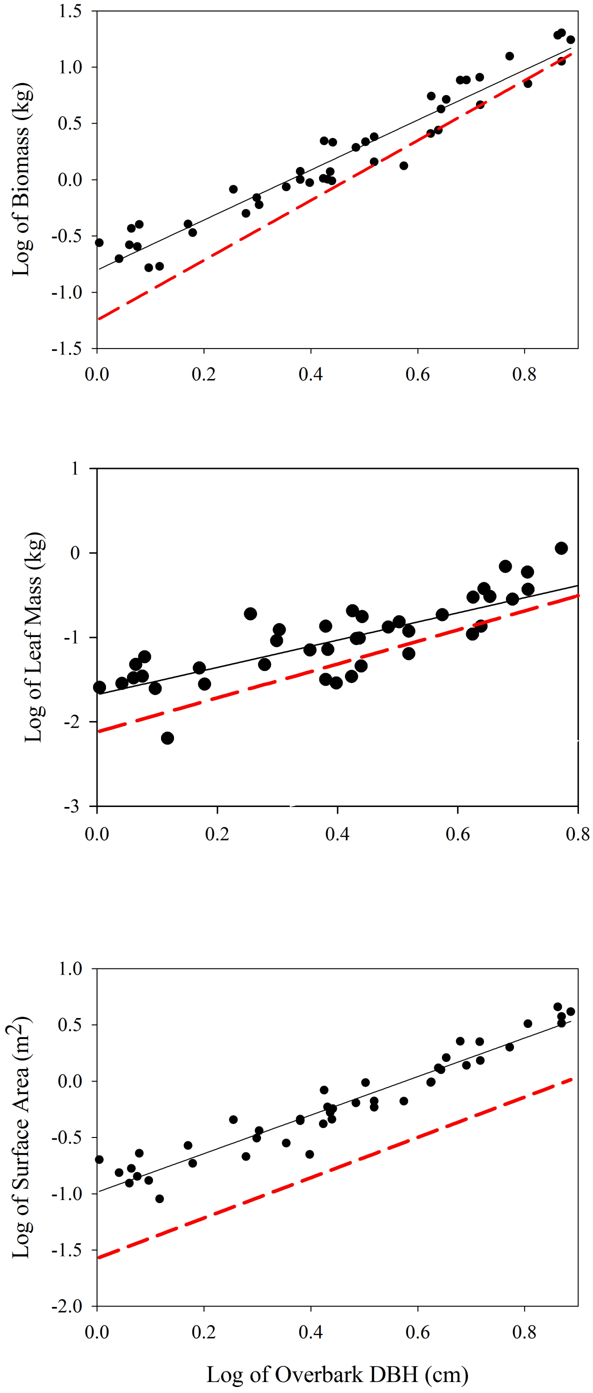

FIG 1. Biomass, leaf mass, and surface area as a function of overbark DBH (log-log plot) for seven different tree and shrub species in the Coweeta Basin, plotted against equations previously determined by Martin et al. (1998) for large trees of the same species.

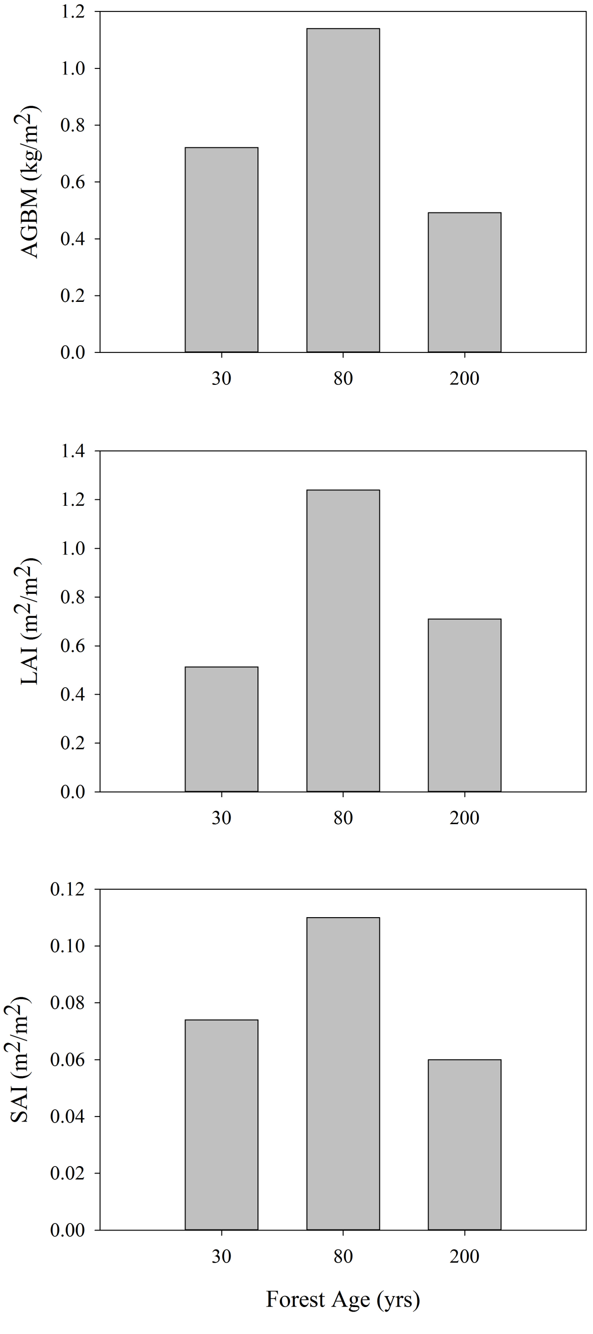

FIG 2. Above ground biomass (AGBM), leaf area index (LAI), and surface area index (SAI) for all the tree and shrub species present in each of the 30, 80, and 200 year old plots.

DISCUSSION

The mid-canopy is a significant contributor to the structural complexity of the forest and thus it is important to be able to accurately measure the biomass, leaf mass, and surface area. Depending on density and species composition, the mid-canopy may contribute considerably to ecosystem fluxes such as photosynthesis, respiration and evapotranspiration. It also functions as a facilitator to the growth of the understory, while also emerging to replace the dying overstory. As the layer matures, the implications for the ecosystem function and impact on the forest process increase (Donato et al. 2011).

Equations for large trees (e.g. from Martin et al. 1998) should not be applied to those of the same species in the mid-canopy. All three variables showed a higher y-intercept for mid-canopy trees, and slopes were different for biomass and leaf mass in comparison to large trees. Thus, applying the regression equations for large trees to mid-canopy trees might result in a substantial underestimate of the biomass, leaf mass, or surface area of the understory depending on forest age and structure. The allometric equations determined by Boring and Swank (1986) for leaf, branch, and bole biomass could not be compared to our equations because the DBH was measured at the base of the tree instead of at breast-height.

DBH was used in this study rather than height to relate these tree attributes because measuring DBH in study plots is generally the fastest and most efficient way to survey a large area. Biomass and surface area showed such strong relationships to DBH that incorporating height into the allometric equations would be unnecessary. Equation 1 did not apply well to *K. latifolia* L. or *Q. alba* L., however, as their allometric regressions received the lowest R^2 values in every category (Table 1). The worst correlation for these species was with the leaf mass regression, in which the R^2 values were 0.34 and 0.48 respectively (Table 1). Possible corrections for this could include using height and diameter to relate biomass, leaf mass, and surface area in the allometric equations in replacement of DBH. The diameter of *K. latifolia* L. could also be measured from the base, as in the Boring and Swank (1986) study instead of breast height.

Applying these equations to the study plots showed that the 80-year-old plot had the highest AGBM, LAI, and SAI. However further investigation determined that the sub-canopy of this stand was populated heavily with *R. maximum.* This is a common occurrence in heavily disturbed sites across the southern Appalachians like this one, which was previously logged. The understory of the 30-year-old stand and the 200-year-old stand were very similar, which attributed to the low values for SAI, LAI, and AGBM. In the 30-year-old stand, almost all of the trees had just recently grown up above 10 cm, eliminating the understory. The 200-year-old plot was largely undisturbed so a large population of *R. maximum* was never able to develop and thus it lacked this heavy biomass contributor.

Estimating forest characteristics such as biomass, leaf mass, and surface area are often time consuming and expensive. Individual characteristics across forest layers must be considered, and therefore a single predictive model cannot be applied to the entire system. We suggest three separate sets of equations for each stand: one for large trees (>10 cm DBH), one for the sub-canopy/mid-canopy trees (as reported here) and one for herbaceous vegetation and seedlings. Additionally, while it would be ideal to use site-specific equations, this is not usually practical and the allometric equations presented in this paper should be useful for plants of the same species within the same size range, and under comparable conditions, across the southern Appalachians.

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THE PRESENCE OF THOUSAND CANKERS DISEASE IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK

JENNIFER G. RICHTER

Abstract. A survey of health was conducted in black walnut (*Juglans nigra*) communities within the Great Smoky Mountain National Park. With the threat of fungal disease decimating another major tree species in the forest, the purpose of our investigation was to assess the extent of the damage in the park and its potential to spread. Using Schomaker's crown ratings, crown condition of black walnuts within the park were analyzed and results were mapped by the park service to set the groundwork for future understanding of the canker.

Key words: Black walnut, dieback, Juglans nigra, *live crown ratio, thousand cankers disease, vigor, walnut twig beetle.*

INTRODUCTION

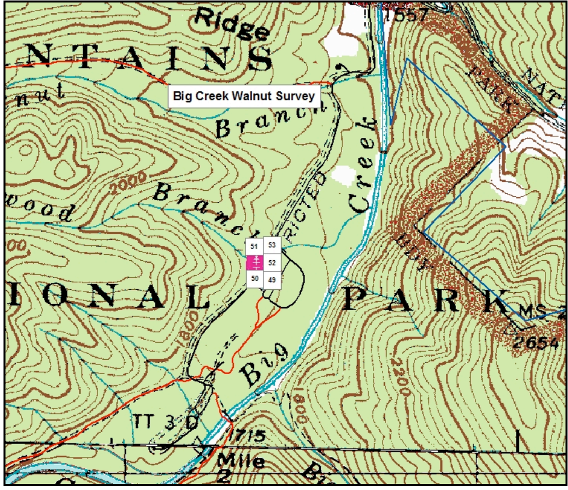
The Smoky Mountains are no longer home to the old growth forests that once covered the land. The effects of lumbering, invasive species, and introduced disease have threatened the health of many tree species in the area (Yarnell 1998). The great American chestnut (*Castanea dentata*) has been decimated, the eastern hemlock (*Tsuga canadensis*) is disappearing, and now the black walnut (*Juglans nigra*) may be in peril. A fungal disease that has previously only existed in the west has recently infected black walnut trees in the eastern United States. The fungus, *Geosmithia morbida*, is spread from population to population by the walnut twig beetle (*Pityophthorus juglandis*; Curculionidae: Scolytinae). Native to the United States, Thousand Cankers Disease (TCD) was affecting black walnut trees in Colorado as early as 2003 (Grant 2011). Unfamiliarity with the disease and inability to contain the fungus led to spreading throughout many western states, including Oregon, Washington, Utah, Idaho, Arizona, Utah, New Mexico, Nevada, and California (Grant 2011). The first reports in the east came out of Knoxville, Tennessee in 2010 and during the following summer of 2011 TCD was apparent in certain walnut tree populations in Virginia and Pennsylvania as well (Randolph 2013). In 2012 the first reports of the diseased trees were identified at two locations on the eastern side of the Great Smoky Mountains National Park (Grant 2011).

The fungus is not easily detected in the early stages of infection because TCD creates cankers under the bark of the limbs. The cankers occur in very shallow places along the outside of the tree and lead to destruction of the phloem (Tisserat 2011). However, an infected tree may show signs of unseasonal, premature yellowing in the foliage, dwarfing of the leaves, and thinning of the upper crown (Tisserat 2011). As the ailment progresses, the tree will experience branch dieback in the canopy, and eventually the fungus moves to the trunk further cankering the tree, coalesce, and kill the tree (Randolph 2013). In addition, repeated beetle feeding carrying spores of the fungus cause multiple cankers on a tree, eventually make the tree succumb to the multiple infections. This process may take several years for the tree to die depending upon the insect population levels (Randolph 2013). However, during the earlier stages of TCD infection, tree symptoms may be minimal so that observers cannot readily assess individuals visually and miss infected trees during surveys. Because the disease continues to encroach in the area, and two locations within the GSMNP have been confirmed, this study will be used to determine the extent of the infection within the park.

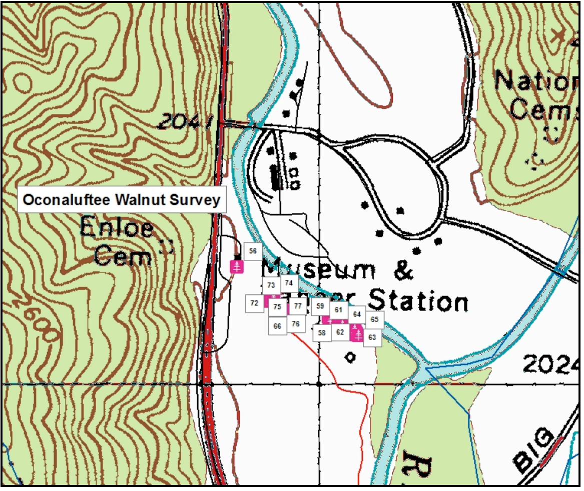
Site Descriptions

The survey on black walnuts in the Great Smoky Mountains National Park began in the late summer of 2013 under the leadership of Dr. Richard Baird. I continued the work throughout the fall. Dr. Baird visited the areas around Cataloochee Fields and Big Creek, where the canker was suspected, and later confirmed, to be the initial outbreak sites in the eastern United States. I visited six sites on the North Carolina side of the park (Fig. 1): Big Creek and Cataloochee, both confirmed sites, as well as Oconaluftee Fields, Deep Creek, Hazel Creek, and Chambers Creek, although Chambers Creek had no black walnut trees and so was dropped from the study.

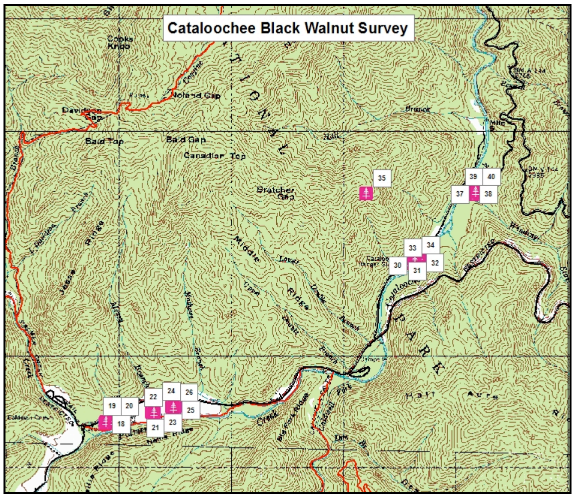
(a) Big Creek



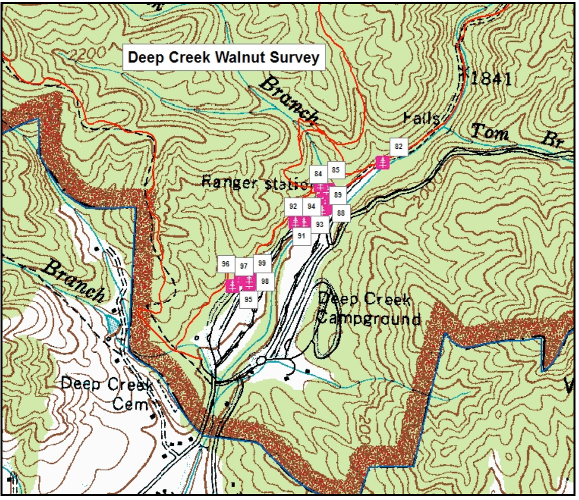
(c) Oconaluftee Fields



(b) Cataloochee



(d) Deep Creek



(e) Hazel Creek

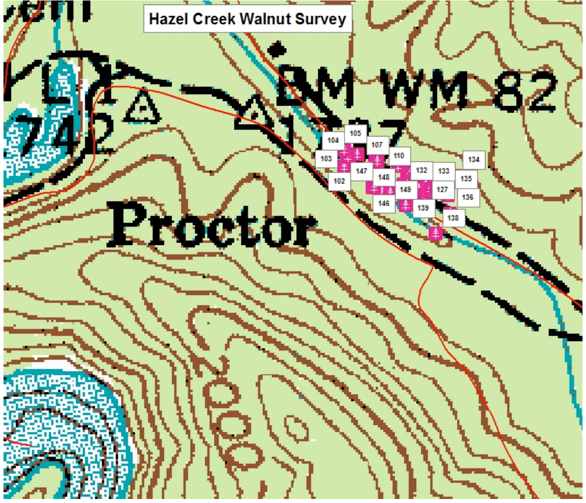


FIG 1. The five locations of surveyed black walnuts in Great Smoky Mountains National Park (GSMNP).

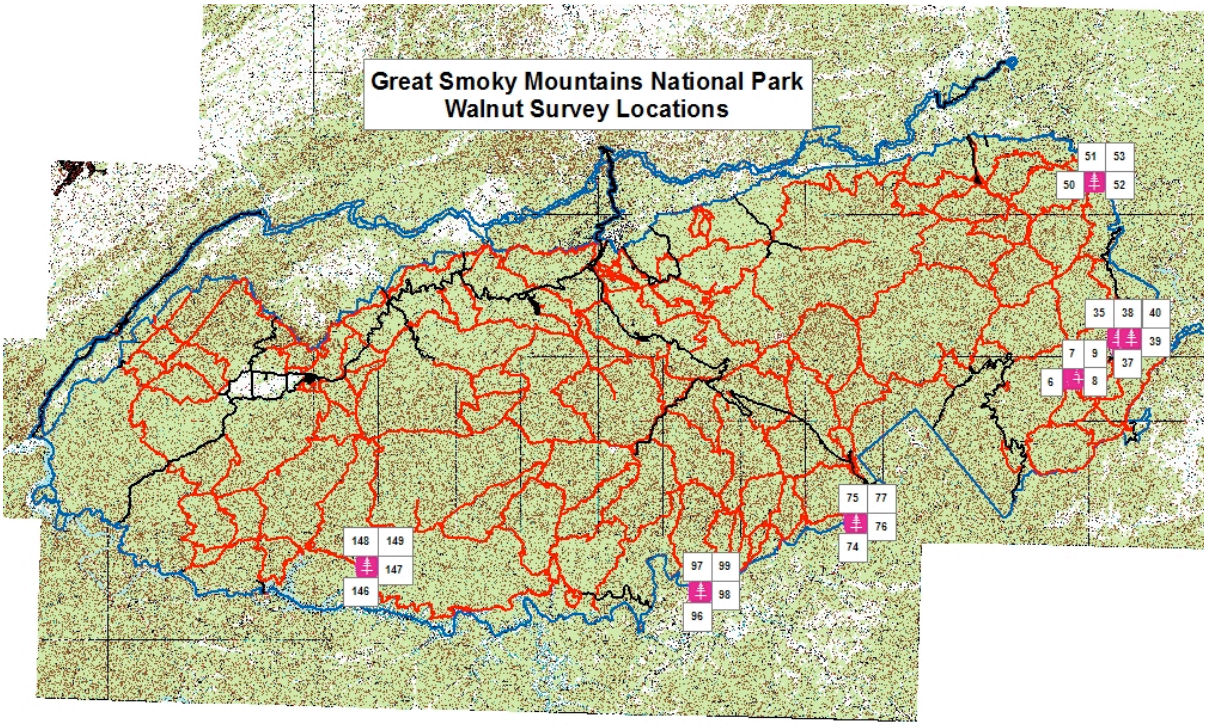


FIG 2. The location of each study site within the GSMNP.

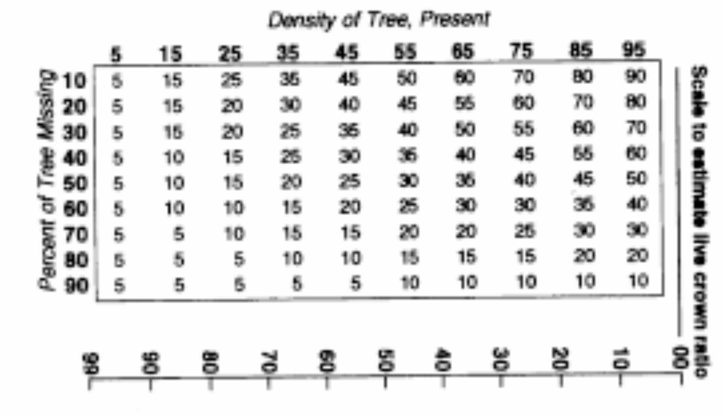
Every study site is along a river or stream and associated with a historic home site (Fig 2). The location of each site could have something to do with walnut seed dispersal by waterway, or because populations were encouraged by communities because of their practical value as a food source. Big Creek is a largely wooded area that runs along a river (Fig. 1a). The trees sampled here were along a gravel roadway that led from a forest station into the park. Big Creek was the original site surveyed and it has been confirmed that several walnuts in that area have TCD. The walnuts surveyed at Cataloochee bordered a field and an old homestead that were at the mouth of several trailheads (Fig. 1b). Cataloochee is a site where the presence of TCD has been confirmed. Oconaluftee Fields and Cherokee village was once a homestead in the Smoky Mountains. Now it exists as a historic site and visitor center, but the landscape remains largely the same. Running along the Oconaluftee River, a riparian zone of large hardwoods separates the water and the open fields in where the settlement, surrounded by black walnuts, remains (Fig. 1c). Deep Creek is a recreational area in the park. Running through the area is a stream, hiking trails, and several campgrounds (Fig. 1d). The trees lined mainly the parking lots and roadways. Hazel Creek is a small waterway that flows into Fontana Lake. The land and historical community of Proctor which surround Hazel Creek are only accessible by boat (Fig. 1e). Proctor was once a lumbering town and many of the structures from that era remain standing.

MATERIALS AND METHODS

To assess the effects of TCD in the GSMNP and test our hypothesis, select black walnut tree health conditions were rated based on scales by Schomaker (2007) at five locations within the park. Initially, practice ratings were done to ensure uniformity and precision for the field study verified by Dr. Richard Baird, Plant Pathologist/Mycologist at Mississippi State University.

The survey of black walnuts in the Great Smoky Mountains National Park began in the late summer of 2013. To develop baseline information data to compare to other locations, trees at the two known infection sites in the GSMNP were evaluated, including Cataloochee Fields and Big Creek. Additional locations on the North Carolina side of the park were used for comparison including Oconaluftee Fields, Deep Creek, Hazel Creek, and Chambers Creek, although Chambers Creek had no black walnut trees. Based on the Schomaker (2007) rating scales, tree crown health was assessed using the following data per tree: Live Crown Ratio (Fig. 3), Crown Density (Fig. 4), Crown Transparency (Fig. 4), Crown Branch Dieback (Fig. 5), and Crown Vigor.

The live crown ratio is measured by considering the trunk of a tree, base to the top, and determining approximately where the foliage begins (Fig. 3). The ratio is the percentage of tree height that supports live crown. To determine the crown density, the tree was considered a mosaic of light blocking branches, fruit, and foliage (Fig. 4). I compared the open portions of the crown against the areas occupied by foliage, and gave a percentage that reflected that ratio. To assign a transparency percentage, I assessed the crown from multiple viewpoints beneath the tree. The transparency value of the canopy increased as the amount of light penetrating the canopy increased (Fig. 4). Branch dieback was a value that was difficult to assign. Black walnuts require large amounts of sunlight and naturally shed their lowest branches if they no longer have the resources available to live and contribute to the health of the tree (Grant 2011). I considered this when the branch dieback was assigned, and focused on dead branches that were higher in the crown and theoretically should have been in good health (Fig. 5). The vigor class takes the previous measurements into account to gauge the overall status of an individual tree. The vigor classes ranged from one to six. Class 1 represents a healthy tree, class 2 signals light decline, class 3 is moderate decline, class 4 is severe decline, while 5 and 6 are assigned to dead trees (Schomaker 2007). At each stage of decline, the foliage continues to yellow and dwarf, crown braches die, and the tree produces less fruit (Randolph 2013). After assessment, I measured the diameter at breast height (DBH) of each tree, tagged each trunk, and if any of the foliage could be reached, I collected a tissue sample and froze it for future use in genetic assessment. Using Garmin® Map60 handheld GPS unit, I marked the coordinates of each tree, and these points were later used by the United States Department of Agriculture's United States Forest Service (USFS) to create maps of the tree communities.



Density of Tree, Present

Percent of Tree Missing	5	15	25	35	45	55	65	75	85	95
10	5	15	25	35	45	50	60	70	80	90
20	5	15	20	30	40	45	55	60	70	80
30	5	15	20	25	35	40	50	55	60	70
40	5	10	15	25	30	35	40	45	55	60
50	5	10	15	20	25	30	35	40	45	50
60	5	10	10	15	20	25	30	30	35	40
70	5	5	10	15	15	20	20	25	30	30
80	5	5	5	10	10	15	15	15	20	20
90	5	5	5	5	5	10	10	10	10	10

FIG. 3. Schomaker's guide to estimating live crown ratio.

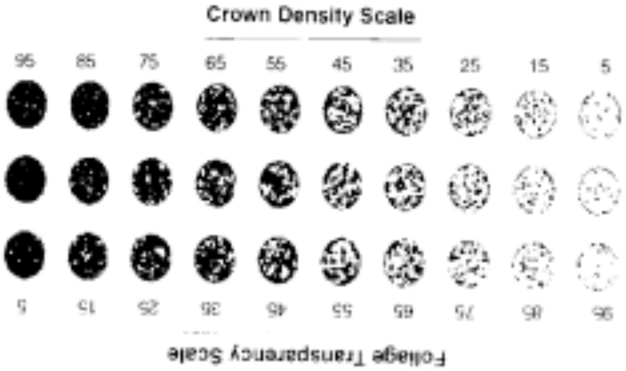


FIG. 4. Schomaker's crown density and foliage transparency scales.

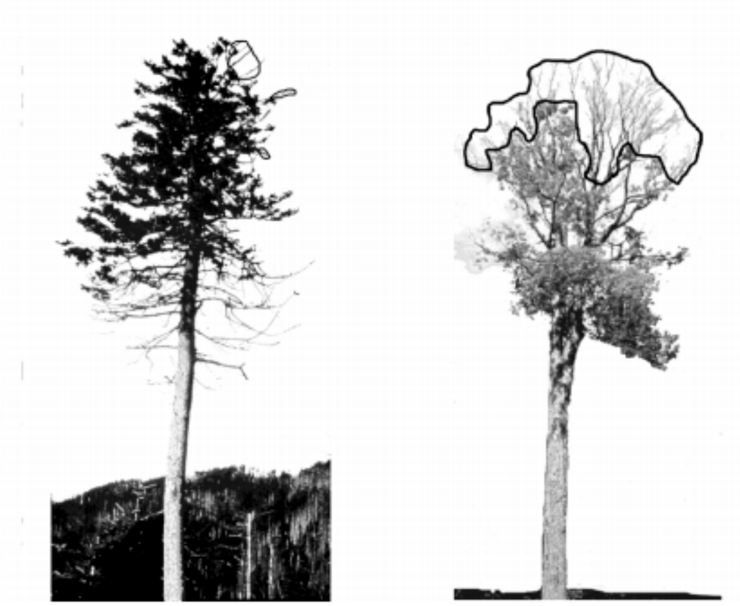


FIG. 5. Two examples of branch dieback in the upper canopy where crown is expected to be most dense in a healthy tree.

RESULTS

I collected data from 149 black walnut trees. I then conducted an analysis of variance (ANOVA) for each category of crown condition between the different locations. Using the least significance difference (LSD) test, a comparison technique for ANOVA results, the means of each crown health criteria were compared in order to find significant differences between populations (Table 1). The changes in each crown health category prove to be significant except for that of vigor class (Table 1). Big Creek, the initial site, had the lowest mean value in each category and the lowest DBH, while Cataloochee and Hazel Creek presented less severe results, but not optimal crown health (Table 1).

TABLE 1. Crown health data rating of five locations in GSMNP 2013. Data were collected using the Schomaker (2007) crown condition classification.

	Tree Crown Health Data					
Locations and Sample Size Per Site	Crown (%)	Density (%)	Transparency (%)	Dieback (%)	Vigor (scale)	Tree Diameter (DBH)
Oconaluftee (21)	62.5	58.0	45.0	16.1	2.0	12.5
Cataloochee (40)	56.1	47.5	56.0	31.6	1.9	24.7
Deep Creek (22)	48.9	56.5	36.1	17.8	1.5	12.4
Hazel Creek (49)	41.6	44.2	48.9	15.9	1.8	10.6
Big Creek (15)	39.7	34.3	73.7	52.7	2.3	9.5
LSD	10.9	11.4	11.5	10.7	NS	5.1

The analysis reveals significant among-population differences for each variable individually, but when compared on a relative scale of range from infection site, there was no significant difference among sites (Table 2). However, there was a numerical trend to the data.

This trend shows that black walnut trees that are confirmed as infected have a smaller live crown ratio, a lower density, a larger percentage of transparency, greater branch dieback, a higher vigor class, and a smaller tree diameter, and as the trees move farther from the site of an outbreak, these values improve (Tables 2 and 3).

TABLE 2. Comparison of black walnut crown tree health parameters between confirmed trees at Big Creek and Cataloochee, GSMNP, to trees adjacent and distant. Least Significant Difference (LSD) analysis shows that while there are numerical differences and trends present, these are statistically non-significant.

	Crown Health Parameters					
Tree Status	Crown (%)	Density (%)	Transparency (%)	Dieback (%)	Vigor (scale)	Tree Diameter (DBH)
Positive	42.5	39.0	65.0	41.0	2.4	42.5
Adjacent	51.9	42.6	62.1	38.8	2.2	51.9
Negative	55.2	46.5	57.9	34.5	1.7	55.2
LSD	NS	NS	NS	NS	NS	NS

TABLE 3. Comparison of tree crown data between the positive trees from 2012 and health data of adjacent trees. Data statistically non-significant but suggest numerical trends of greater crown loss at locations with confirmed TCD and a better crown health as distance from confirmed sites increased.

	Crown (%)	Density (%)	Transparency (%)	Dieback (%)	Vigor (scale))	DBH
a) Big Creek						
Positive Trees	27.0	22.0	80.0	57.0	2.6	7.4
Adjacent Trees	46.0	40.5	70.5	50.5	2.2	10.6
LSD	NS	NS	NS	NS	NS	NS
b) Cataloochee						
Positive Trees	58.0	56.0	50.0	25.0	2.2	29.5
Adjacent Trees	57.3	44.6	54.6	28.2	2.1	26.1
Others	55.2	46.5	57.9	34.5	1.7	23.1
LSD	NS	NS	NS	NS	NS	NS

The confirmed locations of Big Creek and Cataloochee served as controls in the experiment. As the only two sites of infection, they set the baseline crown data to which the other walnut populations were compared. Big Creek is the first known site of infection in the study and the crown health values were more severe at that site than those assessed at Cataloochee (Table 4). The difference in crown health between the two confirmed locations show the potential effects of TCD over time.

TABLE 4. Comparison of tree crown health between positive (control) black walnut diseased locations in GSMNP. Using the LSD as a comparison tool, live crown ratio, transparency, branch dieback, and tree diameter among locations differ significantly.

	Crown Health Parameters					
Positive Locations	Live Crown Ratio (%)	Density (%)	Transparency (%)	Dieback (%)	Vigor (stage)	Tree Diameter (DBH)
Cataloochee	56.1	47.1	56.0	31.6	1.9	24.7
Big Creek	39.7	34.3	73.6	52.7	2.3	9.5
LSD	15.3	13.4	13.3	16.7	0.5	7.9

Although the vigor did not differ significantly when measured between sites (Table 1), there was a correlation between vigor and live crown ratio, density, transparency, and dieback (Table 5). There are correlations between all crown health categories, except for DBH (Table 5). The diameter of the tree only influenced live crown ratio and density, but had no relationship to vigor class, dieback, or transparency (Table 5).

TABLE 5. Correlations between measured criteria at all locations. Shows the interaction between control tree and adjacent tree data.

	Tree Crown Health					
	Crown	Density	Transparency	Dieback	Vigor	DBH
Crown	-----	0.71	-0.49	-0.43	-0.61	0.36
Density	0.71	-----	-0.67	-0.56	-0.70	0.22
Transparency	0.49	0.67	-----	0.7	0.71	NS
Dieback	-0.43	-0.57	0.71	-----	0.64	NS
Vigor	-0.61	0.70	0.71		-----	NS
DBH	0.36	0.22	NS	NS	NS	-----

DISCUSSION

The five locations that produced the bulk of my data have very different histories; their historical land use ranges from the abandoned lumbering yards surrounding Hazel Creek to the recreational area of Deep Creek. The five populations are not only geographically unique, but may have been genetically unique as well. Although without genetic testing this can not be confirmed, and instead you must consider the environmental differences from site to site. For example, soil characteristeric, pests, disease, and weather exposure at each location could also account for morphological differences. The black walnut trees from Hazel Creek were tall and straight, with very little branching, indicated by the relatively low crown ratio. The ancestors of this population were not planted to support a lush, fruit-bearing crown, but to become timber for the Ritter Lumber Company, which clear-cut the land decades ago (Johnson 2013). Because of their genetic disposition, the average live crown ratio of the Hazel Creek walnuts is similar to that of the trees at Big Creek, a confirmed site for TCD infection. Considering that Hazel Creek has never been confirmed to have TCD, isolating only one crown condition does not accurately portray the health of any community.

The Oconaluftee Fields site had the highest live crown ratio. This area was once an old home site, supporting a small Cherokee community (Ballas 1960). The trees at this site were likely used for fruit and shade, neither of which mattered at the lumbering site of Hazel Creek. The large canopies and full crowns produced the most dense foliage and fruit. These trees were planted as a food source rather than as a timber to be milled. Many stood alone, uncrowded, and under these conditions, the lack of competition for resources allowed the black walnut trees to grow outward as well as upward. The lumber yard trees all stood together in a field. Growing side by side forced these trees to grow upward as quickly as possible. If resources were used to grow lush and full, only a small portion of the trees would have successfully grown in the same amount of space. When considering these growing conditions, it becomes much more difficult to use live crown ratio, or even the density and transparency of the crown, as the sole indicator of tree infection by TCD. There are different baselines for each population based on the unique environment conditions of each.

Although vigor values did not differ significantly in the overall study, Deep Creek had the best mean vigor values (Table 1), which does reflect the health of that individual population. When looking at the crown categories, Deep Creek typically reflects a healthy population. The low transparency and branch dieback are evidence of this; however, with a live crown ratio lower than Cataloochee, a confirmed infected site, land use, again, became a major consideration in the discussion of this population's health (Table 1). Deep Creek was the homestead of several families prior to the establishment of the park (Wuerthner 2003). The black walnut trees at this site were most likely communal trees that mixed in with the other hardwoods around the creek, and grew depending on the availability of forest resources that they shared. Deep Creek is not a heavily visited site within the park, although it is a destination that sees steady visitation. It does not have the same access and attention that many other locations do, which makes this black walnut population a little more isolated and unique. Of all the sites, I believe that Deep Creek has felt far less of an anthropogenic impact than any other community.

Perhaps the most useful analysis in this study was the comparison of crown health in the context of spatial scale. The results for the majority of the criteria, such as density and branch dieback, were expected. Crown health was poorest near the area where TCD is confirmed. Density will increase with distance from diseased populations and branch dieback will decrease. A trend that I did not expect was that tree diameter increased as distance from confirmed disease sites increased (Table 2). Thousand Cankers Disease could not reduce the diameter of a tree. This could suggest that smaller trees, or younger populations, are more sensitive to the beetle or that the larger trees, by definition are survivors. These trees have withstood many threats throughout their lifetime and may have a higher natural resistance to disease and pathogens. However, when DBH was compared to the crown criteria of the entire data set, there was no significant correlation between DBH and tree crown health (Table 5). The correlations between DBH, live crown ratio, and density only show that the larger the trunk of a tree, the fuller the crown.

Thousand Cankers Disease is relatively new to the park, and the data in this study is insufficient to show that this trend is statistically significant. Perhaps as further populations are surveyed, and the canker has persisted in the park for a longer period of time, an evident trajectory will appear. For the time being, there is only the suggestion of a trend. The pathways by which the fungus has spread is uncertain and the understanding of population susceptibility to the canker is limited. This analysis was successful in establishing a status model for black walnut trees in Great Smoky Mountains National Park; however, the potential impact of TCD is unclear.

Another giant in the eastern forest is threatened, but the slow moving nature of the canker makes it difficult to detect infection early and its future trajectory hard to predict.

ACKNOWLEDGEMENTS

I thank Dr. Richard Baird, for his support during this research. Clarence E. Watson Jr. provided support for the statistical analysis of the data, and Glenn Taylor helped to make the maps of study site locations. I also thank Jim Richter, who provided transportation to locations with limited access, and Dr. Karen Kandl, Dr. Jim Costa, and Michelle Ruigrok who provided support throughout the duration of my research.

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EFFECTIVENESS OF STREAM VISUAL ASSESSMENT PROTOCOL AS A BIOLOGICAL INTEGRITY PROXY

WILL RUDISILL

Abstract. Eight wadeable stream reaches within the Little Tennessee watershed were sampled using the Stream Visual Assessment Protocol (SVAP). SVAP data were statistically compared with biological integrity data collected in 2013 by the Land Trust for the Little Tennessee. A correlation coefficient of 0.4949 and an R^2 value of 0.245 were found, indicating a weak correlation between the Index of Biotic Integrity (IBI) and SVAP for these stream reaches. This result suggests that SVAP is a poor proxy for IBI assessment for streams in this watershed.

Keywords: Habitat Assessment; IBI; Little Tennessee River; southern Appalachians; stream health; stream visual assessment protocol; SVAP; western North Carolina.

INTRODUCTION

Waterways are vital elements of the landscape, serving as corridors, habitats, nutrient transports, recreational outlets, water sources and scenic areas. They are the arterial networks that keep earth alive. A degraded physical stream habitat is a major stressor to aquatic systems (Barbour et al. 1999). Stream and river health impacts all organisms within its reach. A systematic understanding of physical structure is consequently crucial to any biological assessment of a stream. Chemical and biological assessments, while effective, are costly and require equipment and expertise to use. The Index of Biological Integrity (IBI) is a health classification system suitable for wadeable streams based on fish or benthic macro invertebrate species diversity and trophic structure (Overton 2006). Collection is costly and time intensive, generally requiring specialized netting and shocking equipment. Physical assessments, in contrast, are easier to make and require little to no training or equipment. The Stream Visual Assessment Protocol (SVAP) is designed for riparian landowners and serves as a quick, user-friendly physical classification system for wadeable Appalachian streams and riparian areas (Bjorkland et al. 2001). Stream features exist in a delicate balance; stream power, sediment load, and channel roughness can result in stream widening or down wasting. Riparian vegetation provides shade, habitat, and buffers to erosion and runoff. Changes in these and other factors may create or destroy fish and macroinvertebrate habitat (USDA 1998).

The purpose of this study was to examine the correlation between physical stream and riparian characteristics (SVAP) and biological integrity data (IBI) for eight low order stream reaches within the Little Tennessee River in Rabun County, Georgia and adjacent Jackson County, North Carolina. IBI scores have been shown to correlate well with residential land use practices on the watershed scale in low order West Virginia, Rhode Island, and Wisconsin streams (Wang et al. 1997, Snyder et al. 2003, Lussier et al. 2008), but there are fewer studies of solely in-stream metrics and riparian buffer effect on IBI (Teels et al. 2006). One northern Virginia study implemented riparian buffer improvements on a number of low order streams and found that SVAP had a greater correlation with baseline IBI than watershed land use (Teels et al. 2006).

Developing a physical stream classification system that correlates strongly with biological indices like IBI would allow for more comprehensive and cost effective stream assessments across larger scales; SVAP is less time and money intensive, and can be done by untrained riparian land owners. A broader understanding of stream health and the effects of riparian buffers throughout the nation and globe is an essential first step in crafting better watershed management policies and protecting dwindling aquatic biodiversity.

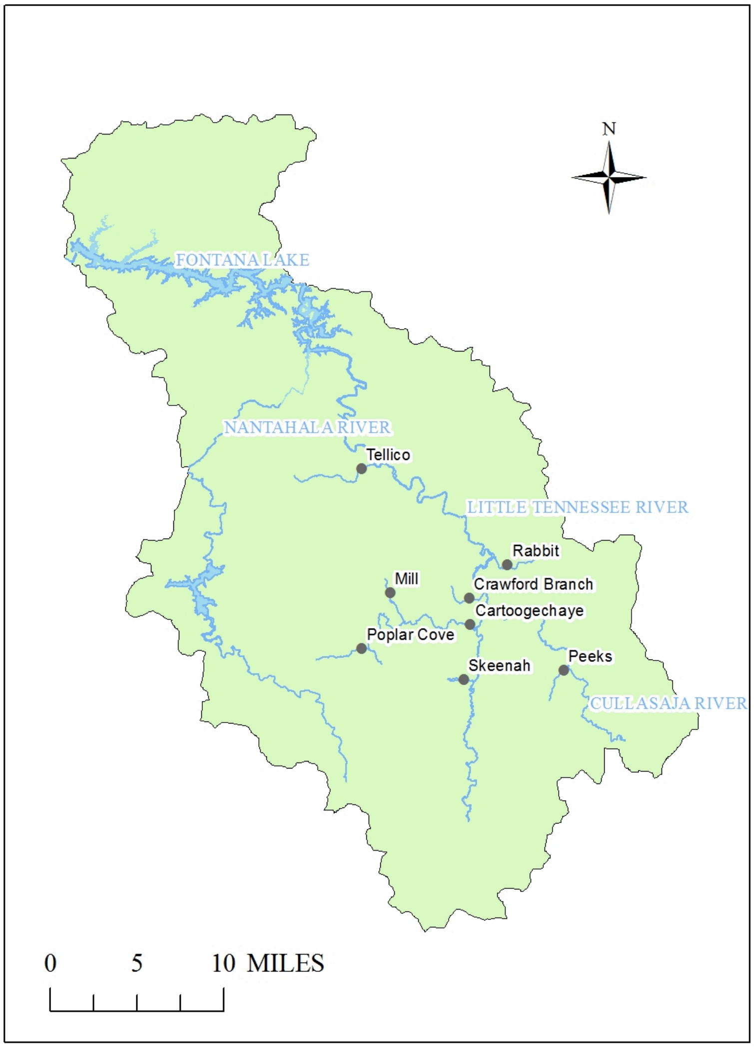

FIG. 1. Little Tennessee River watershed map showing sampling locations (ArcMap10.1™ ESRI 2012).

METHODS

I visited thirteen streams in the Little Tennessee River watershed, but only eight of these sites had recent IBI data collected (Fig 1). One site per stream was sampled. Sample sites were based on ease of access; often times simply the first pull-off with a clear view of the creek. The length of each reach examined was fifteen times larger than the average stream reach width (Bjorkland et al. 2001). Channel widths varied between five and eight meters. Criteria bearing on stream health assessed included channel condition, bank condition, riparian quantity and quality, canopy cover, external nutrient sources, pools, barriers to fish movement, available habitat, embeddedness, and trash. Each category was assigned a score of 1 through 5 following the protocol of Bjorkland et al. (2001), where 1 represents ideal conditions and 5 represents altered or unhealthy conditions. SVAP data were collected between September and October 2013. Meaningful SVAP data were not collected after those dates because of change in leaf density, affecting canopy cover scores. The North Carolina version of the Index of Biotic Integrity (NCIBI) data used for comparison with SVAP data were collected by the Land Trust for the Little Tennessee throughout 2013. NCIBI is suitable for wadeable streams of North Carolina, and each physiographic region has different criteria. The Little Tennessee watershed is in the mountain physiographic region. Its 12 measurement criteria include total fish, species diversity, trophic diversity, and presence of tolerant species with possible scores from 1 to 5 (Overton 2006). IBI and SVAP data were compared using a linear regression. ArcGIS 10.1 was used to create a map of sampling locations. Excel 2010 was used for data management, statistics, and graphing.

Results

SVAP and IBI scores showed a weak but statistically significant correlation (R= 0.494981, R^2 = 0.24501). SVAP scores ranged from fair to excellent (Bjorkland et al. 2001). IBI scores also range from poor to excellent (see criteria in Overton 2006).

TABLE 1. SVAP and IBI data for eight streams in the Litte Tennessee River Watershed. Measurement criteria include: channel condition (Ch Co), bank condition (Bnk Co), riparian quantity (Rip Qt), riparian quality (Rip Ql), canopy cover (Can Cov), nutrients (Nut), livestock (Lvk), pools (Pls), barriers to fish movement (BFM), available habitat (Hab), embeddedness (Emb), and trash scores (TR) respectively. IBI scores were based on data collected in 2013 based on a single assessment per site.

Stream	Ch. Co	Bnk Co	Rip Qt	Rip Ql	Can Cov	Nut	Lvk	Pls	BFM	Hab	Emb	TR	Total SVAP	IBI
Skeenah	1.5	1.5	1.5	1.5	4	4	4	3	4	2	3.5	3	33.5	33
Cartoogechaye	2.5	2.5	2.5	2.5	3.5	2	4	4	3.5	3	3	3	36	41
Mill	3.5	3.5	3.5	3.5	1	2	4	3	2	2.5	3.5	3	35	30
Poplar Cove	1.5	1.5	1.5	1.5	3.5	2	3	2	4	2	2.5	3	28	42
Tellico	4	4	4	4	2.5	4	4	3	2.5	2.5	3	4	41.5	44
Peeks	2.5	2.5	2.5	2.5	2.5	4	4	4	4	3	3	4	38.5	51
Crawford Branch	2	2	2	2	1	2	4	3	2	2	3	4	29	28
Rabbit	2.5	2.5	2.5	2.5	3	3	4	3.5	4	2.5	3	4	37	36

Discussion

The correlation coefficient, R, seen in Fig. 2 is greater than 0 indicating a positive trend. However it is not very close to 1, indicating a weak correlation between SVAP and IBI scores. The R^2 value of 0.24501 is interpreted to mean that only 24% of the variability of the IBI data can be related to changes in SVAP. This degree of correlation is too weak to warrant use of SVAP as a proxy for measurement of IBI.

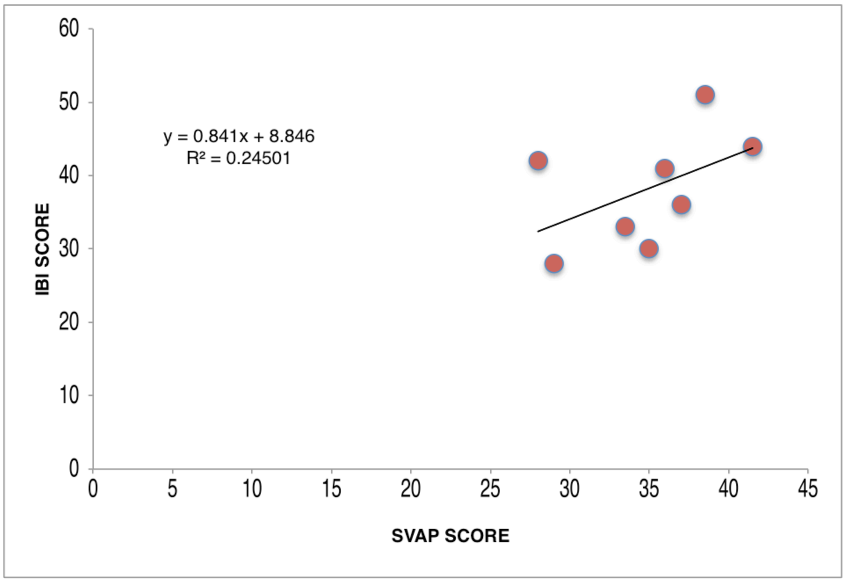

FIG. 2. SVAP data compared to IBI for eight streams in the Little Tennessee River watershed. There is a weak but statistically significant correlation between the two assessment indices. The correlation coefficient (R) = .494981, R^2 = .24501

There are multiple reasons to explain the lack of correlation. First and foremost, SVAP is a purely visual assessment and is subject to imperfections of observation. This study is also limited by its scope. Multiple SVAP measurements taken along the reach and averaged would make a better means of comparison to IBI as opposed to one sample site per reach; fish are mobile and a single IBI measurement represents a larger range than one SVAP analysis. Furthermore, another large source of error is the small sample size. A more statistically significant study would have more than 8 points of data for the linear regression. It is important to bear in mind that SVAP is also a tool solely for physical habitat assessment; chemical effects may have a more direct correlation with IBI in the Little Tennessee watershed. Other possible effects explaining the difference in IBI and SVAP are timescale; fish populations may not immediately respond to changes in landscape; sediment may flush out and woody debris may accumulate creating excellent habitat, but there is a time lag before fish repopulate. The study of SVAP and IBI in Virginia reported R=0.70 for a linear regression, and noted that the effects were greater for lower order streams (Teels et al. 2006). Yet other studies report that watershed area land use, specifically residential land use, is a primary control of IBI. Residential land correlates positively with greater runoff and higher levels of dissolved inorganic nitrogen, an environmental toxin (Lussier et al. 2008). Wang et al. (1997) report a threshold value of 20-30% urbanization of a watershed before fish IBI scores drop precipitously in Wisconsin streams. A similar West Virginia study noted a threshold value of 7% urban land use (Snyder et al. 2003).). It is difficult to discern an explanation of the discrepancy between this study and that of Teels et al. (2006). A possible reason is that their study looked at the effects of re-establishing riparian buffers along streams, which correlate with improved fish IBI, yet the baseline IBI is likely more of a function of watershed land use as the Wang, Snyder and Lussier studies indicate (Wang et al. 1997, Snyder et al. 2006, Lussier et al. 2008).

Consequently, based on the present study and others, future physical IBI proxy models should incorporate an in-stream and riparian vegetation metric as well as total watershed land use data. The Stream Visual Assessment Protocol ultimately is a useful metric for assessing in stream and riparian buffer health but cannot alone serve as a proxy for the North Carolina Fish Index of Biological Integrity.

ACKNOWLEDGEMENTS

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SALAMANDER ABUNDANCES IN POWER-LINE RIGHT-OF-WAYS

MATTHEW C. SILINSKI

Abstract. Plethodontid salamander abundances can be reduced by edge effects in forest ecosystems. However, it is unclear as to what affect power-line right-of-ways (ROWs) have on salamander abundances. I performed both daytime area-constrained searches of cover objects and nighttime visual assessments on one ROW transect and four forested transects. No significant difference in salamander abundance existed between the ROW and adjacent forest. However, salamanders were only observed in the ROW at night. Our results suggest that narrow power-line right-of-ways provide suitable but restrictive habitat for salamanders.

Key words: Abundance; Plethodontid; *power-line right-of-way*; s*alamanders; southern Appalachia; western North Carolina.*

INTRODUCTION

Plethodontid salamanders, the largest of ten salamander families, are a terrestrial group of salamanders that are good indicators of forest ecosystem health due to their abundance in many forest ecosystems throughout the Southeastern United States and their sensitivity to disturbance (Welsh and Droege 2001). Salamanders require moist skin to respire (Feder 1981, Welsh and Droege 2001), therefore they primarily inhabit forested woodlands with moist soil and a deep litter layer (Degraaf and Yamasaki 2002, Monteith and Paton 2006). Fragmentation, caused by disturbances, creates edges within the forest, which may decrease salamander habitat quality due to increased edge effects and their associated environmental changes. (Demaynadier 1998).

Clear-cutting results in the change of air temperatures, soil temperatures, and other environmental factors, known as edge effects, in the disturbed habitat (Chen et al. 1993). These edge effects decrease the abundances of salamander populations significantly at the site of disturbance and can even affect salamander abundances within the forests near these patches (DeGraaf and Yamasaki 2002). Roads and paths that cut through the forest also have potential edge effects on the microclimatic conditions of the forests that surround them (Marsh and Beckman 2004); however, the degree to which roads and paths affect the microclimatic conditions of forests varies depending on the width of those paths (Marsh 2007). Roads decrease the abundance of salamanders near the edges of forests (Gibbs 1998, Demaynadier 2000), and can act as barriers to mobility and foraging (Haskell 2000, Marsh et al. 2005).

Narrow power-line right-of-ways (ROWs) may produce similar effects to that of roads, however few studies that investigate these effects have been conducted. In a study performed in Pennsylvania, Yahner et al. (2001a, 2001b) determined that salamanders could inhabit ROWs, but were less abundant than in the adjacent forest. The purpose of my study was to examine how salamander abundances might be affected along a ROW in the southern Appalachians of western North Carolina.

METHODS

Study Location

My study site was located within the Nantahala National Forest, off of Flat Mountain Road in Highlands, North Carolina, on the Ranger Falls trail (N 35.08645 W 083.22589). This site consisted of a 101 year old section of hardwood forest bisected by a 16m wide ROW. The site was on a hillside facing due west, with an altitude of 1181.7 m. Primary vegetation consisted of mainly rosebay rhododendron (*Rhododendron maximum*), red maple *(Acer rubrum*)*,* chestnut oak (*Quercus prinus*), red oak (*Quercus rubra*), and Fraser magnolia (*Magnolia fraseri*), with a dense ground cover of huckleberry (*Gaylussacia brachycera)*.

The ROW was created in 1949 and has been maintained since. It was last cut in 2006 and sprayed with herbicidal treatment in 2012, which has kept the ROW relatively bare of vegetation (USFS, pers. comm.). The volume of logs on the ground floor of the ROW was comparable to that of the ground floor of the adjacent forest, but there was significantly less leaf litter in the ROW, except for moss/lichen that grows on the ground floor and makes it spongy (unpublished data).

Transects

I set up five parallel 50 m transects within our plot in order to compare salamander abundance in the power-line right-of-way with abundances in the surrounding forest. The first transect was established in the center of the ROW. The four forest transects were spaced at 15 m intervals at 5 m, 20 m, 35 m, and 50 m from the forest edge.

I performed eight day and eight night visual assessments, which consisted of counting and identifying the species of each salamander I saw, from August to October 2013 in order to examine salamander abundances along each transect. All daytime visual assessments were conducted by searching under logs of >10 cm diameter for salamanders within 2.5 m of each transect (Crawford and Semlitsch 2007), as logs are suitable habitats in which salamanders could reside (Smith and Petranka 2000). Nighttime visual assessments were performed approximately thirty minutes after sunset. I searched both the leaf litter and the ground floor vegetation within 2.5 m of each transect (Crawford and Smilitsch 2007), because studies suggest salamanders climb small plants to seek protection from predators and to forage for insects. (Jaeger 1978, Roberts and Liebgold 2008).

Statistical Tests

To test for edge effects, I compared overall salamander abundances between each of the forest transects, using a One Way Analysis of Variance (ANOVA; Zar 1999). I repeated this for daytime search data and nighttime search data. I also performed a Planned Contrasts ANOVAs on all of the transects to compare the abundance of salamanders on the ROW to the abundance of salamanders within the forest transects as a whole (Zar 1999).

RESULTS

I found a total of 239 salamanders of five different species in the sixteen visual assessments I performed (Table 1). The most abundant species in both the ROW and forested transects was the Southern gray-cheeked salamander (*Plethodon metcalfi)*, which accounted for 89.5% of all observations, 61.9% of all day observations and 92.2% of all night observations. A greater abundance of salamanders was observed during nighttime searches than daytime searches. No salamanders were found within the ROW during any day visual assessments and all salamanders observed in the ROW during night searches were large adults.

No significance difference existed in the overall abundance of salamanders within the forested transects overall ($F = 0.0349$; df = 3, 60; $p = 0.9912$), during daytime ($F = 0.5478$; df = 3, 28; $p = 0.6537$) or during nighttime ($F = 0.1407$; df = 3, 28; $p = 0.9348$). Overall abundance of salamanders did not differ significantly between the ROW and the forest overall ($F = 0.1633$; df = 1,75; $p > .05$), during the day ($F = 1.266$; df = 1, 35; $p > .05$) or during the night ($F = 0.2840$; df = 1, 35; $p >.05$).

TABLE 1. Summary of salamander observations obtained from visual searches.

Species Name	Common Name	ROW		Forest		
		Day	Night	Day	Night	Total
Eurycea wilderae	Two-lined salamander	0	3	2	5	10
Notophthalmus viridescens	Eastern newt	0	0	5	2	7
Plethodon metcalfi	Southern gray-cheeked salamander	0	56	13	145	214
Plethodon serratus	Southern red-backed salamander	0	0	0	1	1
Plethodon teyahalee	Southern Appalachian salamander	0	2	1	4	7
	Total	0	61	21	157	239

DISCUSSION

Changes in microclimatic conditions in large forest clearings can decrease the abundance of salamanders (Demaynadier 1998, Marsh and Beckman 2004). Narrow power-line right-of-ways can reduce salamander abundance as well (Yahner et al. 2001a, 2001b) by decreasing the return rate of foraging salamanders (Marsh et al. 2005) and decreasing the amount of available insect prey (Haskell 2000). Also, herbicides used within ROWs can directly harm salamanders, as it can be lethal, (Relyea 2005) and can reduce the amount of vegetative cover (Roberts and Liebgold 2008). However, unlike previous studies (Yahner et al. 2001A, 2001b), in this study we found no differences in salamander abundances between the forested and ROW transects.

The sizes of gaps within the forest determine the severity of the edge effects on the forest (Marsh 2007). For example, Marsh (2007) found that wide, heavily used roads showed a decrease in salamander abundance, while relatively undisturbed habitats, such as narrow, abandoned logging roads, did not. Small-scale gaps contain conditions similar to that of the forested environment. For example, Redding et al. (2003) found that soil temperature and moisture remained comparable to that of the forest as far as 18m into the clearing. As our ROW was 16 m wide, moisture levels could have been adequate to support salamander populations, despite a thin leaf litter layer (unpublished data).

Plethodontid salamanders depend on moist environments such as a deep leaf litter layer or heavily rotten logs to prevent desiccation while surface active (Jaeger 1980, Welsh and Droege 2001). However, in less optimal habitats salamanders often burrow underground (Rothermel and Luhring 2005), where they are more restricted in their mobility, but can forage at night when the air humidity is higher. This probably explains why only adults were found in the ROW as they have stronger burrowing capabilities than juvenile salamanders and are more resistant to desiccation (Ash 1997, Rothermel and Luhring 2005).

The results of this study suggest that environmental conditions found in power line right-of-ways are adequate to support populations of Plethodontid salamanders at levels comparable to that of the surrounding forest. However, as only adults could persist in the ROW, the gap may act as a barrier for dispersal for juveniles, which could affect salamander population sizes. The scope of this study was limited. My sampling was restricted to the fall and only one aspect, due west, was sampled. Further studies should take into account seasonal variation and multiple sample sites with varying conditions, such as habitat type, slope, aspect, and elevation, to gain a better understanding of how salamander abundances are affected by ROWs.

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GPS MAPPING AND HABITAT ANALYSIS OF *STEWARTIA OVATA* IN WESTERN NORTH CAROLINA

ELIZABETH A. THURMAN-IRONS

Abstract. The rare tree species, *Stewartia ovata*, is found in the southern Appalachians, requires specific conditions to grow and is very sensitive to disturbances. The objective of my study was to discover new populations of *S. ovata*, and to use their locations to learn more about the plant. I found 77 populations of *S. ovata* in western North Carolina. I measured each plant with DBH tape and mapped it using Garmin® GPSmap 60CSx. Using ArcMap10.1™ I was able to locate the populations and use existing maps to determine aspects of their habitat. I found that the elevation range for these populations in western NC was 1125 ft – 2587 ft, the slope ranged from 0-40.9 degrees, and the aspect covered a range of directions, with peak frequency on northwest-facing slopes. I determined through qualitative observations that power lines play a significant role in creating habitat for *S. ovata*. My study supports and adds to the existing knowledge of *S. ovata* habitat.

Key words: *GPS; habitat analysis; Lake Fontana; Little Tennessee River; southern Appalachians;* Stewartia ovate*; western North Carolina.*

INTRODUCTION

Stewartia ovata, commonly known as mountain camellia, is an elusive tree species found primarily in the mountains of the southern Appalachians. It is a small tree with hairless, gray twigs, and bright green ovate, pubescent leaves, which have a finely saw-toothed edge. In the spring it produces large, white flowers with five rounded, waxy petals (Little 1980). The plants have a single floral bract on each flower. The flowers are roughly 2.5 in diameter (among the largest of the *Stewartia* genus), with yellow or purple stamen filaments (Spongberg 1975). The flowers bloom in July, and have a short blooming period of only two weeks (Martin 2011).

S. ovata is found in acid cove forests with moist, well-draining soil. It often grows on slopes, particularly where a steep slope meets a flatter slope, although it can also be found on rounded tops of knolls (Johnston pers. comm.). In this sense, slope and aspect seem to be crucial to the growth of the tree (Martin 2011). It is a canopy gap species, so it needs sunlight from gaps in the canopy, often created by streams, rocky areas, or old roads. In addition, old trees that die and fall often create a canopy gap, making an ideal habitat for *S. ovata*. A common type of canopy gap is created by dead, fallen eastern hemlocks (Johnston, pers. comm.). *S.* grows best where there is little human disturbance. It is fire intolerant due to its thin bark. In certain cases a burning will encourage growth, but the seedlings are inevitably killed in subsequent fires (Johnston pers. comm.).

The objective of my study was to discover new *Stewartia ovata* populations in Swain, Graham, and Macon County of Western North Carolina, particularly around Lake Fontana and the Little Tennessee River, and to use that information to further understanding of *Stewartia ovata* habitat in this region.

MATERIALS AND METHODS

Data

The area surveyed included multiple sites, all in western North Carolina, in Graham, Swain, and Macon Counties. Many sites were around Lake Fontana or the Little Tennessee River. Data were collected from late August through November of 2013.

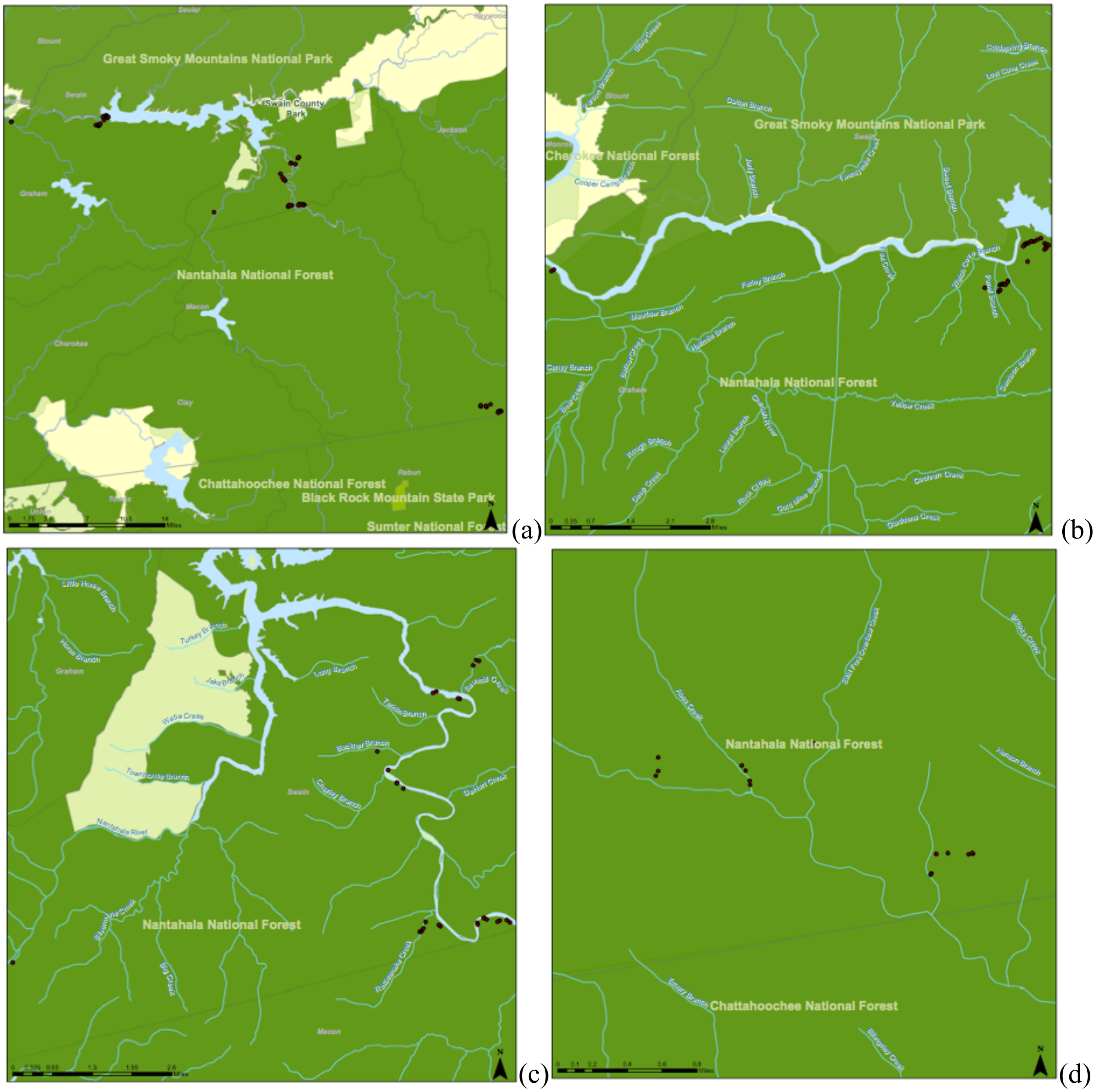


FIG. 1. Locations of *S. ovata* populations in this study: All populations (a), Graham County (b), Swain County (c), and Macon County (d). Black points represent *S. ovata* populations.

Using previously acquired knowledge of *S. ovata* habitat, I sought places that would create an ideal habitat for the tree species; that is, in acid cove forests, low on slopes, and near streams. Upon finding a population, I recorded the location of the trees using a Garmin® GPSmap 60CSx. I counted the trees of measurable size (greater than 0.1 in diameter) within the population, measured the diameter of the trunks using a DBH tape, and took any noteworthy qualitative observations of the area.

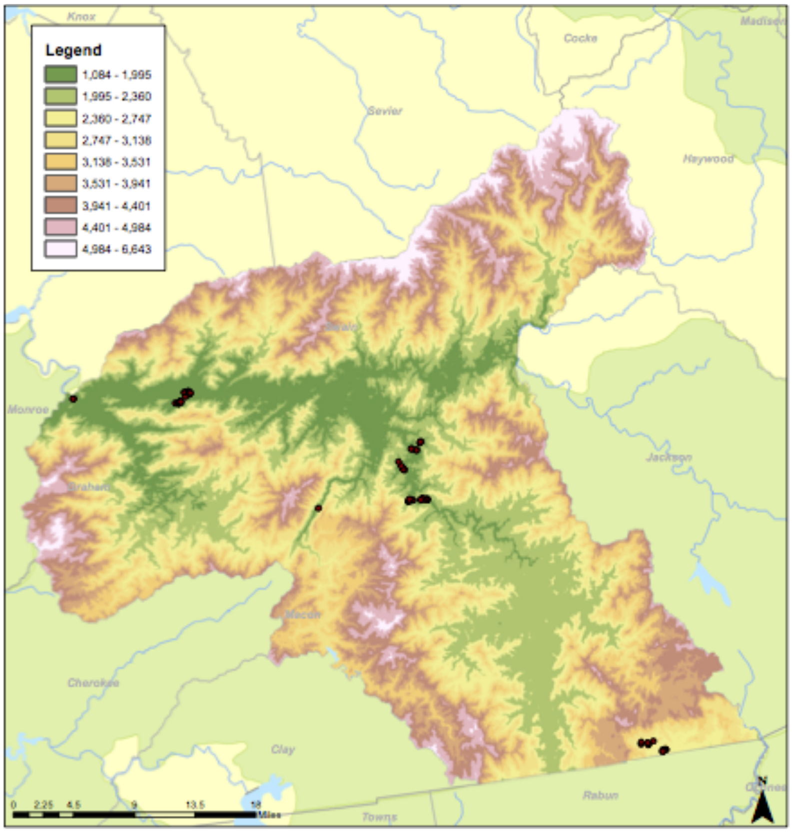
Analysis

I used ArcMap10.1™ (ESRI 2012) to plot the locations of *S. ovata* populations. Using GIS data from the North Carolina Department of Transportation (NCDOT), I determined the elevation, slope, and aspect of the individual locations and noted ranges and trends in the habitat. In addition, I looked for trends in size class of *S. ovata*, and compared the environmental factors to the size class. Finally, I used the qualitative observations to draw any further conclusions about the habitat of the species.

RESULTS

I found a total of 77 populations (P1-P77), and 227 total plants of *S. ovata* in Macon, Swain, and Graham counties, in western North Carolina (Fig. 1).

Using the elevation data from the NCDOT, I was able to plot the populations to determine the elevation, slope, and aspect (Fig. 2).



(a)

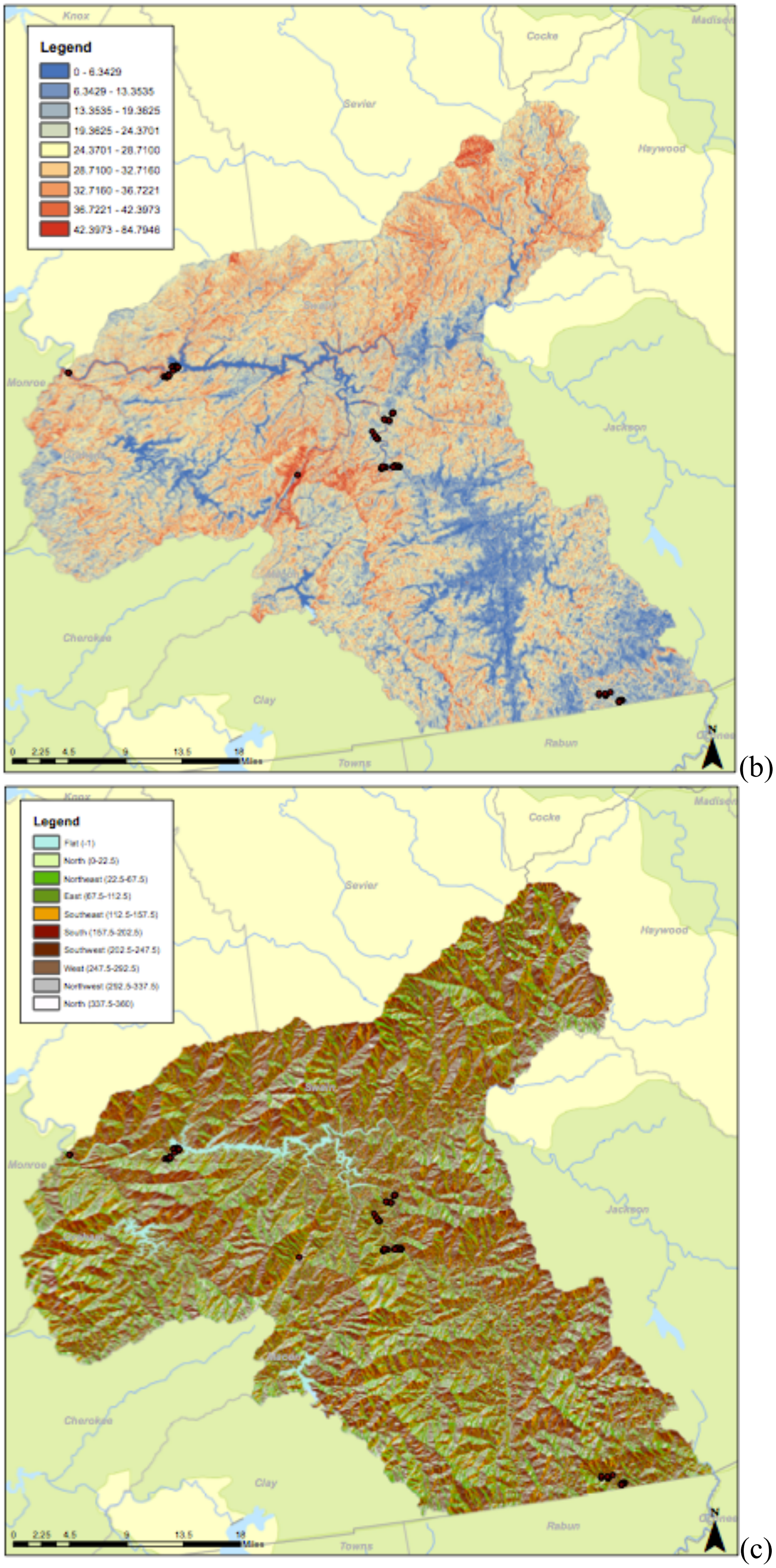


FIG. 2. *S. ovata* habitat: elevation (a), slope (b), aspect (c). Black points represent *S. ovata* populations.

I used the map to extrapolate ranges of acceptable habitat conditions in this region. The range of elevation was found to be fairly low, from 1125 ft – 2587 ft (Table 1). The range of slope was found to be 0 – 40 degrees (Table 1). The range of aspect covered essentially every direction, with peak frequency of aspect occurring at Northwest-facing slopes, and the fewest number of individuals growing on southeast slopes (Fig. 3).

TABLE 1. Ranges of *S. ovata* habitat in western North Carolina.

Habitat	Range	Mean
Elevation (ft)	1125 – 2587	1880.96
Slope (degrees)	0 – 40.9	20.5
Aspect (degrees from North)	-1 – 356.18	197.63

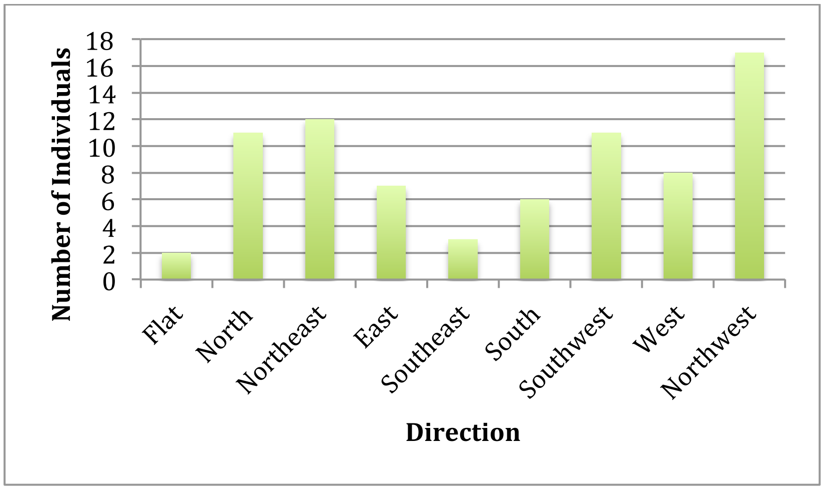


FIG. 3. Frequency of aspect of *S. ovata.*

I determined the size class of every individual, and sorted the plants accordingly. The analysis of size class showed a distribution between 0-3.5 in. diameter, with a peak abundance of plants between 0.5 and 1.0 in., and the abundance declining steadily at larger sizes (Fig. 3).

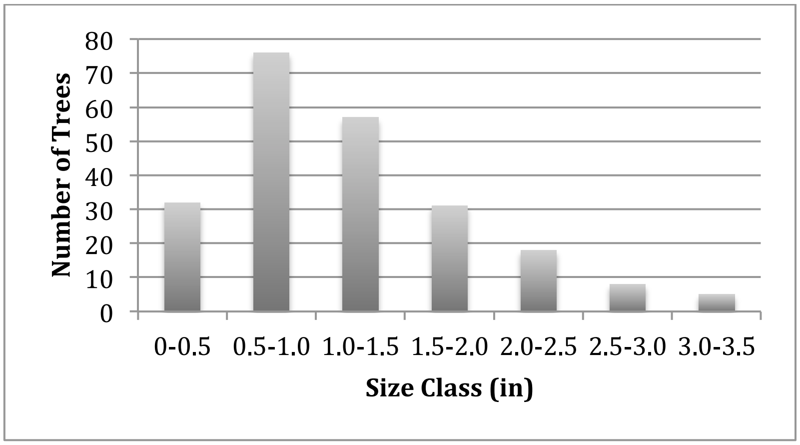


FIG. 4. Frequency of size classes in *S. ovata.*

DISCUSSION

The habitat conditions that I found for *S. ovata* show several trends, including low elevation, moderate slope, and a range of aspect with a preference for northwest facing slopes. In general, the larger size classes of plants correlated with the most abundantly found habitat conditions, though this was not always the case. In addition, I found evidence that although the species has high sensitivity to disturbance, certain disturbance events that create ideal habitat may have a positive effect on the growth of the species, though more evidence is needed.

Considering the elevation range in the region as a whole, the plants I found were at fairly low elevation (1125 ft – 2587 ft), although this is a larger range than what has previously been observed by Hobson and Houser (2010) which was only 1500 – 2000 ft. The mean elevation that I found (1880.96 ft) is also in the upper part of the previously found range, supporting a higher elevation habitat than previously found, though still low in the region as a whole. *S. ovata* seems to thrive at low elevation conditions, perhaps because of warmer climatic conditions.

Since *S. ovata* is often found where a steep slope meets a flatter slope it makes sense that the slope would range from essentially flat (0 degrees) up to a 40.9 – degree angle. This is a lower slope range than I would have predicted based on the habitat of the plants; however, many of the trees that I surveyed were on the tops of knolls, or at areas where a steeper slope met a flatter slope. Previous research has found that these trees may thrive on slopes below 25 degrees because they are not as susceptible to erosion (Purvis 2012).

The peak abundance of plants on northwest slopes is important to the habitat preferences of this tree. West-facing slopes are generally warmer because the sun is in the west when it is warmest during the afternoon. Similarly, the northern facing slopes are often moister due to the lower amount of direct sunlight and wind; therefore, this aspect analysis supports that the preferred habitat of *S. ovata* is warm but moist.

Bearing in mind the range of sizes that I found in *S. ovata* plants, it is evident that the trees do not often grow larger than 3.5 in. in diameter in this region. The largest size class (3.0-3.5 in) contained only five individuals in four populations (P9, P28, P35, P59). P35 is also an unusually large population, containing 16 individuals, two in the largest size class. Interestingly, all the populations of the largest size class are east-facing slopes (P35 NE, P9 SE, P28 E, P59 E), even though the majority of trees grow on west-facing slopes. However, more samples should be measured to determine if a pattern exists.

It is possible that *S. ovata* is able to grow larger when it has a larger area of suitable habitat in which to grow. This would indicate that the ideal habitat conditions, particularly canopy gaps, rarely exist for an extensive area, but when they do, both individual trees, as well as the populations, are large. This was the case for P35, which had a large population of 16 individuals, as well as containing two plants in the largest size class.

Since the trees are so susceptible to disturbance, they may have the potential to reach a larger size if they are in habitats with no disturbance such as those with no nearby development, no fires, etc., although this was not directly observed.

I observed a number of patterns qualitatively that have led me to believe that power-lines can play a key role in creating the ideal habitat, canopy gaps, for *S. ovata* in this region. For example, I found a large new population (P35) directly beneath a power line running across the Little Tennessee River (N 35°20.230, W 083°31.707). This was one of the largest populations with 16 individuals. P71 (2 individuals) was also found underneath a power line (N 35°26.326, W 083°48.665), as were many populations in the Fontana Dam region (P37 – P55).

Stewartia ovata is sensitive to human disturbance yet it thrives in some types of disturbance. Disturbance that creates canopy gaps can have a beneficial effect on the growth. Deans (2012) surveyed 75 *S. ovata* sites in Rabun County, GA and found that 74 of the 75 populations existed in canopy gaps, so it is clear that this is an important habitat feature. Often power-lines are maintained by cutting, grazing, burning or the application of herbicide. Different formulations of herbicide can have various effects on different tree species (Luken et. al. 1994). However, we do not know exactly how these power-lines are maintained or what is the formulation of herbicide, if any, so it is difficult to make conclusions about the resilience of the plant.

My data support and add to the previous knowledge of the habitat of *Stewartia ovata*. Its ideal growing conditions are low elevation, acidic cove forests. It often grows on moderately sloped inclines, and prefers northwest-facing hills. Additional factors that may assist in growth include the presence of power lines.

ACKNOWLEDGEMENTS

I'd like to thank my mentor Jack Johnston for all of his work and dedication to the project, as well as Gary Wein of the Highlands-Cashiers Land Trust for his help in constructing the GIS analysis. I'd also really like to thank Michelle Ruigrok for all her guidance and edits, as well as Dr. Karen Kandl and Dr. Jim Costa for their support. Special thanks also goes to Markus Le for assisting me in my data collection.

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LACK OF SUNLIGHT AVAILABILITY INHIBITS CARNIVORY IN *SARRACENIA PURPUREA* VAR. *MONTANA*

JORDAN M. TONY

Abstract. Woody vegetation encroachment and habitat loss threaten the persistence of the Southern Appalachian endemic, *Sarracenia purpurea* var. *montana*. Observational and manipulative studies show correlations between pitcher plant morphology and prey capture ability. Further studies describe the deleterious effects that a reduction in prey capture has on the plant's fitness. I examined the effect of sunlight availability on plant morphology in order to determine the consequence of woody encroachment. Woody vegetation reduces available sunlight for low-lying plants like the purple pitcher plant, and this reduction is correlated with an altered plant morphology that diminishes the plant's ability to capture prey. I concluded that plants in full or half full sunlight are more likely to express a morphology that is conducive to prey capture.

Key words: Conservation management; pigmentation; plant morphology; prey capture; Sarracenia purpurea *var.* montana*; sunlight availability; woody plant encroachment.*

INTRODUCTION

Sarracenia purpurea var. *montana* (Fig. 1) is a variety of the purple pitcher plant found in high elevation bogs and fens (Schnell and Castanea 1997). These wetland ecosystems are characterized by open canopy, high moisture content and limited nutrient availability (Pittillo 1994). The variety *montana* occurs sparsely throughout southwestern North Carolina, northern Georgia, and northwestern South Carolina (Schnell and Castanea 1997).

Unfortunately, many of the remaining bogs and fens in which it occurs are under encroachment by woody vegetation, and the vitality and number of plants is dwindling (Ne'eman and Ellison 2006). In addition to these stressors, the plant, which is valued by gardeners, is heavily poached for sale at markets (Folkekts 1999).

Pitcher plants are able to survive in the nutrient poor bogs and fens due to morphological adaptations that allow them to form carnivorous "pitchers" through adiaxal folding of leaf parts (Ellison and Gotelli 2002). In healthy plants, these pitchers have purple or red veins throughout their hood, which are responsible for attracting prey, but this can vary with changing environmental conditions (Ellison and Gotelli 2002).

The size and shape of pitcher plants has been shown to be heavily plastic (Ellison and Gotelli 2002). When nitrogen levels are high, the plant focuses less on prey capture and more on photosynthesis, resulting in small mouths and relatively large photosynthetic keels or leaf-like structures (Ellsion and Gotelli 2002; Fig. 2).

This study examines the habitat conditions of *S. purpurea* var. *montana* and how they relate to its morphology and coloration. I will describe conditions found *in situ* that quantify sunlight restriction as well as the morphology and coloration of *S. purpurea*. The environmental conditions described throughout this paper should draw awareness to the ever-increasing need for conservation action to be taken for this plant.

FIG 1. Photo taken by author.

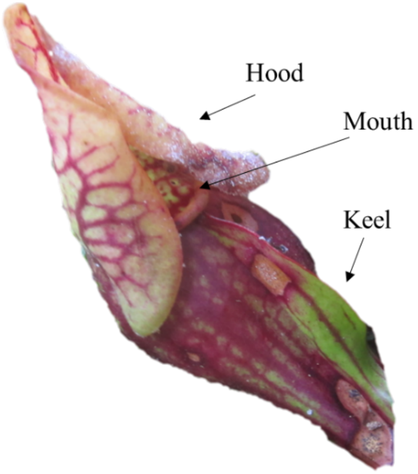

FIG 2. Single pitcher (labeled). Photo taken by author.

MATERIALS AND METHODS

My study took place from early September to early November 2013. At each site where I located plants, I took a GPS measurement to determine the elevation and latitude-longitude coordinates. All 10 sites are in southwestern North Carolina. The first of seven measurements was a determination of sunlight availability. If more than half of the area above the plant was covered by woody vegetation, I considered the plant to be in "full shade", if half of the area was covered, it was in "half shade", if less than half of the area was covered, it was designated "partial shade" and finally, if none of the area above the plant was covered, it was designated "no shade."

Next, I measured the size of the plant in centimeters using a yardstick. I measured plant width, which I determined to be the longest straight line connecting two pitcher mouths. This number provided a radius that we used to find the average rosette size, which I later used to estimate percent cover. I then placed the yardstick facing up in the center of the rosette and the tallest point on the plant marked the plant height.

After determining the dimensions of the plant, I counted the modified leaves that made up the rosette to get a more accurate representation of the size of the plant. I then photographed many of the rosettes and gave them a designation describing their color and the presence or lack of venation.

The final measurement provided a ratio of keel width to mouth width (Fig. 2). I chose one modified leaf from each of the rosettes that were measured. Leaves were randomly selected using a compass and two coins. I flipped both coins and their orientation coincided with a cardinal direction. If both were tails the corresponding direction was north, if one was tails and one was heads the corresponding direction was east and so on. After the direction was assigned, I placed the compass at the center of the rosette, and selected the leaf that the direction pointed to be measured. I then used a 16 cm ruler to measure the largest portion of the keel and the widest extent of the mouth.

Once I recorded the measurements for the respective bog or fen, I conducted a threat assessment and recorded the prevalent plant species present. This information allows for a more accurate picture of the overall health of the bog.

RESULTS

Keel:Mouth Ratio Alteration

I found the keel to mouth ratio to be exponentially related to the amount of shade covering the rossette (y=0.4658e^0.4509x, R^2 = 0.4438; Fig. 3). Pitchers growing in open areas with little to no shade were found to have a much lower keel to mouth ratio. The keel on these pitchers was often little more than a small ridge, marking the line on which the adiaxial folding became fused. On pitchers in partial or half shade the ratio was often 1:1. Full shade pitchers showed the greatest morphological variation. Some keels were measured at 12 times wider than the mouth and others were completely lacking a mouth; the exponential relationship explains this phenomenon. The average full shade pitcher had a keel width 3.25 times wider than the mouth.

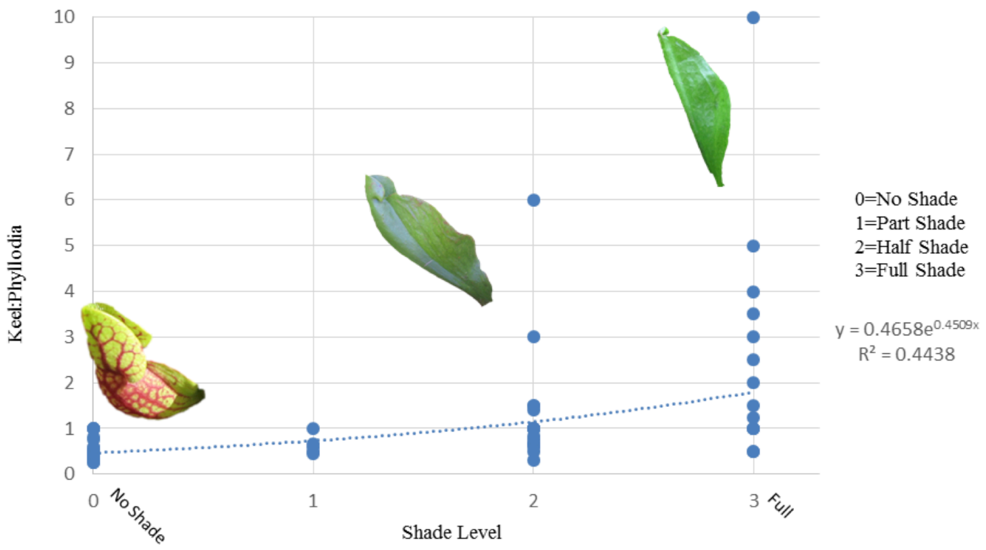

FIG. 3. Morphological response of *S. purpurea* var. *montana* to sunlight availability. Keel to mouth ratio is keel width/mouth width. Shade level: no shade (0), partial shade (1), half shade (2) and full shade (3). Plants in no shade had small photosynthetic keels and relatively larger mouths. Plants in full shade had larger photosynthetic keels and very small mouths. All photographs were taken by the author.

Color of Rossette Dulled by Shade

Individual pitchers are often lined beneath their hood and throughout their body with intricate red and purple veins. Based on these characteristics I assigned them into one of three categories: purple-green with veins (1), green with some veins (2), and green-yellow (no veins) (3). As I will discuss later, these groups are correlated with the plants ability to capture prey. A one-way ANOVA test showed significant differences between treatment groups (P-value < 0.001, Table 1). The groups also showed a positive correlation when plotted against shade level, that is; the more heavily shaded the plant, the less red coloration (y = 0.517x + 1.1769, R^2 = 0.5294; Fig. 4).

The range in coloration was so drastic that the untrained eye would undoubtedly split them into at least three or four species. Pitchers found in full sun expressed brilliant purple and red veins that sometimes spread so far as to cover the majority of the plant. Plants in partial or half shade presented some veins, but on average the pigmentation covered less than a quarter of the plant. When plants were completely shaded by woody vegetation, they expressed little to no purple coloration and they were often a solid dark green color.

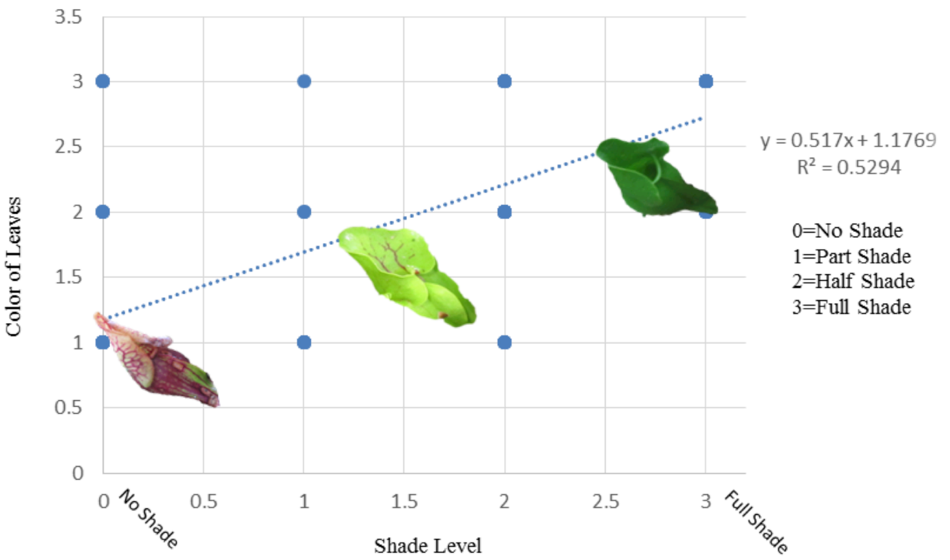

FIG. 4: Pigmentation response of *S. purpurea* var. *montana* to sunlight availability. Color of leaves: purple-green with veins (1), green with some veins (2), green-yellow (3). Plants in full sun often displayed more red coloration than plants in in full shade. All photographs were taken by the author.

TABLE 1. ANOVA: Single Factor (shade level and pitcher color).

a) Summary						
Groups	Count	Sum	Average	Variance		
0	38	50	1.315789	0.438122		
1	12	16	1.333333	0.424242		
2	54	112	2.074074	0.371768		
3	64	180	2.8125	0.154762		
b) ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	62.78815	3	20.92938	68.19705	1.11E-28	3.903275
Within Groups	50.3309	164	0.306896			
Total	113.119	167				

Number of Leaves Reduced by Shade

The number of leaves showed a negative correlation when plotted against shade levels (y=-5.8595x + 29.881, R^2 = 0.2325; Fig. 5). Plants in full sun could have upwards of 70 modified leaves packed into a symetrical rossette. In full shade, the plants often had fewer than 30 leaves and many of them were designated as “scrawny” in the field notes. Full shade plants with less than 10 small gangly leaves were not uncommon.

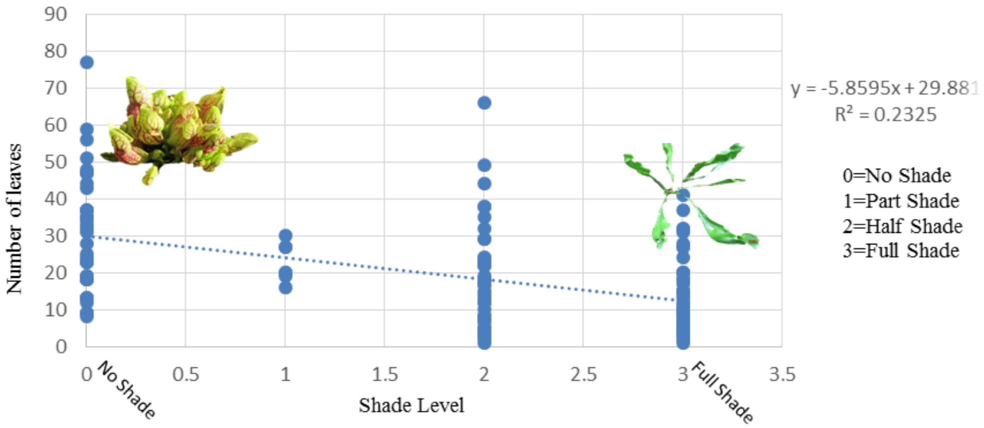

FIG. 5: Leaf number response of *S. purpurea* var. *montana* to sunlight availability. Plants found in areas with less sunlight often had fewer leaves than their full sun counterparts. All photographs were taken by the author.

Total Abundance by Site

Due to the threat of poaching, I chose not to release GPS data or the names of my study sites. Some bogs were considered to be very healthy, as far as numbers go, with populations nearing 300 plants (Table. 2). Others had as few as 5 to 7 plants, many of which were very small and crowded by grasses and woody vegetation. The highest estimated percent cover was around 8 percent and the lowest was less than a 100th of a percent.

TABLE 2. Number of plants and estimated percent cover (EPC) at each site.

Site	Total Plants	EPC
1	176	2.1
2	63	2.2
3	297	8.0
4	7	<0.01
5	61	1.0
6	33	0.6
7	5	<0.01

DISCUSSION

The data collected during this experiment have numerous applications in conservation ecology, plant physiology and environmental management. The more this plant is understood, the better we will be able to manage its habitat and protect it from extinction. When combined with data from previous studies, these findings can explain the mechanism by which woody encroachment extirpates *Sarracenia*, and contribute information to the decision making process for the most effective management techniques.

Reason for Morphological Variation

Although pitcher plants absorb nutrients in a rather unique fashion, they photosynthesize by the traditional mechanism (Wakefield et al. 2005). Anthocyanins, pigments that do not contribute to photosynthesis, are what give the plants their red and purple coloration (Sheridan and Mills 1998). In an open canopy environment, they are able to capture the necessary amount of sunlight with fewer chloroplasts. This allows them to have a small photosynthetic keel and a small green to red pigment ratio. The abundant sunlight provides them the flexibility to allocate more leaf space to anthocyanin.

In a shaded environment, the plants are forced to capitalize on every ray of light that comes through the canopy, so they need to have as much chlorophyll as possible in each of their leaves. This causes many shaded plants to express a solid green color with almost no red venation.

How Prey Capture and Nutrient Uptake Relate to Shade Levels

The mechanism by which many subspecies of *Sarracenia purpurea* capture prey is a combination of plant morphology and pitcher color (Sheridan and Mills 1998). The purple veins found in healthy pitchers are attractive to ants, flies, grasshoppers, bees, wasps, spiders, moths, beetles, and leafhoppers (Ne'eman et al. 2006). These insects often climb into the pitchers to investigate the color, which is reminiscent of carrion, and some are trapped by the water. They are then broken down by a variety of bacteria, aquatic mites and insect larvae (Bradshaw and Creelman 1984).

In 1998, Sandra J. Newell and Anthony J. Nastase used video cameras to monitor *S. purpurea* prey capture in the New Jersey Pine Barrens. They noted that significantly more potential prey visited pitchers with a greater amount of red venation. Another study by H. Martin Schaefer and Graeme D. Ruxto isolated the factor of color by painting some pitchers red and others green (2008). Their results supported the findings of Newell and Nastase (1998), in that they found an overall higher number of insects in the artificially red colored pitchers. Because shade is correlated with green pigment plants, we can extrapolate from these experiments that shaded plants would be visited by fewer potential prey insects than their red and purple counterparts in full sun.

Furthermore, the aerobic detritivores in pitchers can create an anoxic environment by decomposing an overabundance of prey (Bradshaw and Creelman 1984). When this happens, the plant begins to use photosynthetic bacteria to capitalize on the available carbon dioxide and break down the remaining prey (Bradshaw and Creelman 1984). Bradshaw and Creelman measured the nitrogen uptake of purple pitcher plants with varied light availability and found that nitrogen uptake was significantly higher in the more well-lit plants, presumably because they had more productive photosynthetic bacteria (1984).

In addition to the fact that pitchers in full sun are more attractive to prey because they are better able to focus on red veins, they also have a larger number of pitchers and more available light for anaerobic bacteria. This combined with the smaller keel to mouth ratio puts them at an extreme advantage when it comes to prey capture and overall consumption capacity.

Prey Capture and Fitness

A 2006 study at Tom Swamp in the Harvard Forest suggested that covering the mouths of pitcher plants greatly reduced their ability to set seeds (Ne'eman et al. 2006). In order to determine the importance of carnivory to nutrient uptake, the researchers broke the plants up into three treatment groups: Pitchers Open (PO, control), Pitchers Mostly Covered (PMC), and Pitchers Totally Covered (PTC). The control plants (PO) were left untouched and allowed to catch prey, the PMO plants were covered with netting to prevent prey capture and the PTC plants were completely obscured from sunlight and prey capture by sphagnum moss.

By the end of the growing season, when the plants had come to fruition, the researchers collected the ovules from each of the study plants and counted the number of seeds in each. They found that control plants produced 14 percent more seeds than PMO plants and 37 percent more seeds than PTC (Ne'eman et. al. 2006). Many of the full shade plants in my study were obscured by dense woody overgrowth and grass.

As I previously mentioned, they also expressed a morphology that exaggerated the keel width and minimized the mouth size. Combined, these conditions prevent sunlight from reaching the plant and reduce prey capture, the very thing that the PTC treatment was meant to simulate. Although we did not count seeds from the plants in our study, inference tells us that they were similarly affected.

Using Pitcher Plants as a Biological Indicator

Atmospheric NOx deposition and nitrogen runoff from agricultural land threaten habitats for nutrient-poor adapted species, which has created a demand for equipment that can be used to monitor nitrogen levels in the field (Ellison and Gotelli 2002). The previously mentioned study by Ellison and Gotelli (2002) proposed that since *S. purpurea* responds morphologically to nitrogen it could be used as a cheap biological indicator for N-deposition, as the conventional test equipment is expensive and inaccessible. While this is partially true, it is not without flaw considering the other inputs that can alter the plant's morphology. A later study, that Ellison and Gotelli were both involved in, found that pitcher morphology did not differ significantly across different control groups when they varied only nutrient inputs (Wakefield et al. 2005).

The findings in this study highlight just one of the potentially many factors to control if using this method to measure nitrogen levels. If disregarded, variable sunlight levels would skew results obtained using *S. purpurea* as a biological indicator for N-deposition. Variable nitrogen levels at our sites could also account for some of the variation that we found and explain the relatively low R-squared values in our analysis.

Conclusion

In order for a population to thrive, pitcher plants rely heavily on prey capture and light availability (Ne'eman et. al. 2006). Morphological characteristics influence the amount of prey that any individual plant is able to capture, and these morphological characteristics are governed by sunlight levels. Many of the sites visited during this study were greatly encroached upon by woody vegetation and in others, the pitcher plants were obscured by grasses and shrubbery. It is important to note that while I sampled almost every site where *S. purpurea* var. *montana* occurs naturally, I only sampled seven sites in total. Some of which contained fewer than 10 plants and in others, the plants were no longer present. This species is limited to quickly receding habitat and if proper conservation action is not taken, we will continue to see it disappear.

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I thank my mentor, Mara Alexander, from the Fish and Wildlife Service for taking time to escort me to many of the remote sites that I visited for this study, and also helping to funnel my thoughts and data into a cohesive paper. I thank Dr. Karen Kandl and Michelle Ruigrok for their advice and edits. If it weren't for the staff of the Highlands Biological Station allowing me to borrow their equipment, I might still be covered in mud and lost in the woods. Finally, none of this would have been possible if not for the many generous landowners that allowed me on their property in the name of ecological conservation.

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AN ASSESSMENT OF THE ECOLOGY AND STREAM HEALTH OF CANEY FORK, A TRIBUTARY TO THE TUCKASEGEE RIVER

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Abstract. Increased human development has led to the impairment of many southern Appalachian streams. Caney Fork stream in Cullowhee, NC has experienced increased development in its watershed. In order to determine if this development has affected the stream, we conducted a habitat analysis, BEHI assessment, pebble count, chemical analysis, NCBI assessment and FIBI assessment. We found that the habitat assessment value decreases and BEHI increases downstream, likely due to development. Pebble size decreases downstream resembling an expected distribution. NCBI and FIBI suggest that the stream is fairly healthy. Accumulation of all assessments allows us to conclude that Caney Fork is currently healthy but threatened by encroaching development.

Key Words: Appalachian streams; BEHI; Caney Fork; chemical analysis; FIBI; fish; macroinvertebrates; NCBI; pebble count; stream health; watershed; western North Carolina..

INTRODUCTION

Appalachian headwater streams are increasingly at risk of impairment from development, agriculture, and other human activities (Pond 2012). Erosion and pollution affect the structure of the stream, as well as resident organisms (Vannote 1980, Castro and Reckendorf 1995). As non-forested land cover increases along streams, so do substrate embeddedness and streambed instability (Sutherland et al. 2002). Macroinvertebrate species richness tends to be lower in disturbed stream sites (Pond 2012) and relative abundance of fish that spawn in benthic crevices declines as the proportion of non-forested land cover increases (Sutherland et al. 2002).

TABLE 1. Percentages of Land Cover in the Caney Fork Watershed.

	Percent
A) Comparison of Forest and Non-Forest	
Forested Land	94.7
Non-Forest Land	5.3
B) Forest Land Only	
Deciduous Forest	96.8
Evergreen Forest	2.2
Mixed Forest	2.0
Percent Non-Forested Land	5.3
C) Non-Forested Land Only	
Open Space	40.5
Low Density	0.9
Medium Density	0.1
Barren Land	0.2
Shrub	9.8
Grassland	4.8
Pasture	43.3
Woody Wetlands	0.4

As humans increasingly modify land around streams, it has become more important to assess anthropogenic effects on streams and their inhabitants. Human populations around the Caney Fork of the Tuckasegee River in Cullowhee have been steadily increasing since the 1960s (US Census Bureau), coinciding with development along the stream. Caney Fork drains from the Blue Ridge Parkway in eastern Jackson County, NC and its watershed covers 51.33 square miles (Fig. 1). The riparian landcover includes deciduous forest, developed spaces, pasture, grassland, and woody wetlands (USGS

Land Cover Data). Non-forested land comprises 5.3 percent of the total watershed, and much of this land borders the stream, 40.5 percent of the 5.3 percent is open space and 43.3 percent is pasture (Table 1).

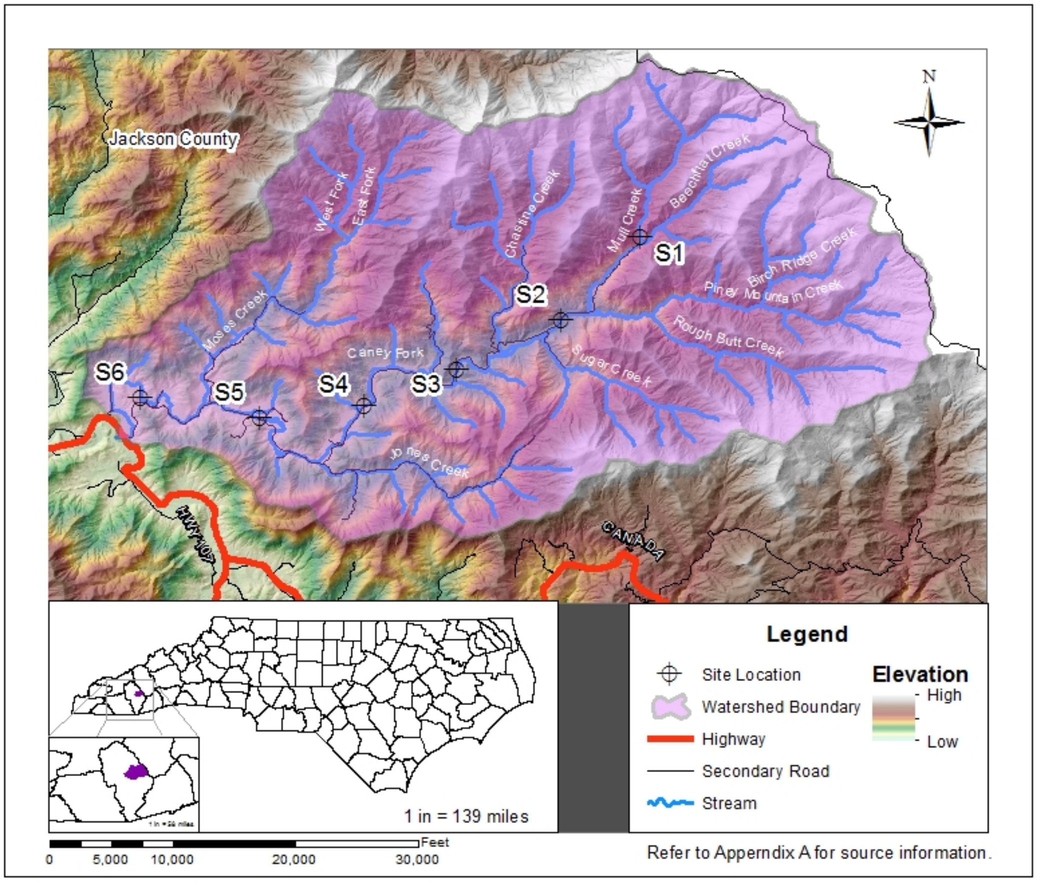

FIG. 1. A map of the Caney Fork Watershed, site location, stream, and elevations. In the left corner is a map of the location of the watershed in North Carolina along with a map of the location of the watershed in Jackson County (ESRI 2012).

We implemented a series of qualitative and quantitative tests along Caney Fork: Bank Erosion Hazard Index (BEHI) assessment, pebble count, chemical analysis, North Carolina Biotic Index (NCBI) assessment and Fish Index of Biotic Integrity (FIBI) assessment. Mountain streams normally decrease in competency, the maximum particle size a stream can transport, from the headwaters to the mouth (Foster 2013) and so we expect to find that the size of bed sediments decreases downstream. The top section of the stream is in a forest while the lower sections are surrounded by extensive development and anthropogenic landscape alteration so we expect to find that the BEHI and embeddedness of bed sediments increase downstream. The headwaters of mountain streams tend to have more bedrock and large boulders, which buffer the effects of bank erosive processes (Foster 2013). Similarly, since human development increases downstream, we expect to find that riparian zones decrease in width and chemical pollutants from runoff increase in concentration downstream. Since embeddedness, channelization, and chemical pollutants are expected to rise in occurrence downstream, we also expect to find higher NCBI at upstream sites compared to downstream sites. If NCBI values and habitat assessment scores are lower downstream, we also expect lower FIBI values at downstream sites compared to upstream sites because there will be less habitat and food for fish.

METHODS

Site Locations

Six sites (designated S1 –S6) were established for analysis along Caney Fork from areas easily accessible by land. A stream is accessible when land between the road and stream bank can be easily traversed. Bridges and grassy stream banks are the most easily accessed on Caney Fork. S1 resides within United States Forest Service Land, chosen for its location on Mulls Creek, a headwater stream of Caney Fork. S1 is 9,849 feet from S2. S2 is 10,191 feet from S3. S3 is 11,146 feet along Caney Fork from S4. S4 is 13,904 feet along Caney Fork from S5. S5 is 11,951 feet along Caney Fork from S6. The total length from S1 to the outflow of the stream into the Tuckasegee River is approximately 10.8 stream miles (Fig. 2).

FIG. 2. Aerial photograph of S1 (top left), S2 (top center), and S3 (top right), S4 (bottom left), S5 (bottom center), and S6 (bottom right). Black lines represent Caney Fork Road. The blue line in S1 is Mull Creek and the blue line for the rest of the sites is Caney Fork. Gray lines represent minor roads and driveways (ESRI 2012).

As part of the assessment of the health of Caney Fork and its watershed, we used Habitat Assessment Field Data Sheets, developed by the state of North Carolina, for evaluation of habitat at each site (NCDENR:DWQ 2012). These data sheets outline a visual assessment of stream habitat quality in a reach. The assessment gives a basic description of the physical characteristics of the stream and its surroundings, such as bank angle, bank height, stream width and depth, modifications, man-made structures, turbidity, flow conditions, weather conditions, and land usage. It includes eight different scored sections qualifying the habitat of the stream, which are summed for an overall habitat quality score for the reach. The highest possible score is 100. The eight sections included in the assessment are Channel Modification, Instream Habitat, Bottom Substrate, Pool Variety, Riffle Habitat, Light Penetration, Bank Stability and Vegetation, and Riparian Vegetative Zone Width. Each section included space for qualitative notes or statements not described by the numerical scores alone. Finally, we drew a plan view sketch of each reach at every site, to use as a reference (Fig. 3).

FIG 3. Habitat Assessment Plan View of S6 (ESRI 2012).

BEHI

In order to determine the Bank Erosion Hazard Index, BEHI, we observed a cross section of the stream reach at each site and measured 5 stream bank aspects in that cross section: bank height ratio (ft/ft), root depth ratio percentage, root density percentage, bank angle (degrees), and surface protection percentage. We determined bank height ratio by taking the ratio of bank height to bankfull height, the point at which the flow just begins to enter the active floodplain (Leopold 1994). “Common bank-full indicators in streams include top of bank, top of point bars, and other changes in channel slope” (Rathbun 2008). The bank height is the height from the deepest part of the riffle to the top of the bank where the ground begins to level off. We determined the root depth ratio by taking the ratio of the root depth to bank height. We determined the root depth by visibly locating the point on the bank where the average depth of plant roots reaches. Root density, expressed as a percent, was determined by measuring the proportion of the stream bank surface covered, and therefore protected, by plant roots (Rathbun 2008). Bank angle is determined by visually estimating the angle of the bank from the water surface to top of the bank. Since the bank angle categories on our worksheet were very broad, visual estimates are generally sufficient to measure bank angle (Rathbun 2008). We determined surface protection, as a percentage, by visually estimating the percent of the bank that was covered by plant roots, downed logs and branches, and large rocks.

We converted each bank aspect value to an index value, ranging from 1 to 10, using the BEHI conversion worksheet and then summed each index to get a total field index (TFI), which could range from 5-50. We made numerical adjustments to the TFI using the BEHI worksheet based on the bank composition. If a stream bank was composed of bedrock or boulders, we lowered the BEHI value and if they were composed of sand we increased the BEHI value. If the bank sediments were stratified the index was adjusted up. A total index score less than 10 means the erosion hazard is very low, an index of 10-20 is a low erosion hazard, an index of 20-30 is a moderate erosion hazard, an index of 30-40 is a high erosion hazard, an index of 40-45 is a very high erosion hazard, and an index greater than 45 is an extreme erosion hazard.

Chemical Analysis

We used Hach® test kits for chemical analysis of water at each of the sites, following instructions included in each kit (Hach Company, Loveland, CO). Analysis was done in the field at each stream site. Chloride (mg/L) was analyzed with model CD-51, free and total chlorine (mg/L) with model CN-80, nitrates (mg/L) with NI-11, orthophosphates (mg/L) with PO-19A, and sulfates (mg/L) with SF1.

Pebble Count

At each site, we surveyed substrate material sizes using the Wolman pebble count procedure in 10 transects chosen to accurately represent the pools and riffles of the stream reach (Wolman 1954). Each transect consisted of 10 randomized samples from the substrate. We measured the samples onsite along their intermediate axis, in millimeters using a ruler, and these measurements were recorded and categorized by size class (i.e. sand, gravel, cobble, boulder, or bedrock) in a data table (Internal Technical Guide for Stream Work in North Carolina). The data were then used to create graphs of cumulative size class distributions for each test site, using a Microsoft Excel template (Pebble Count Analyzer).

Macroinvertebrates

We also examined benthic macroinvertebrates at the six sites along the Caney Fork stream, using four collection methods at each site (Barbour 1999). Utilizing four 1-minute kick net samples, four 1-minute sweep net samples, four leaf pack samples, and eight 5-minute visual examinations, we collected any visible macroinvertebrates. We excluded those organisms that were small enough to be difficult to catch with forceps. Collected organisms were placed in jars filled with an ethanol and water mixture of approximately 75% ethanol labeled with the site name. We examined macroinvertebrates in the lab under a dissecting microscope and identified them to family to determine a NCBI for each site, which is a valuable tool in evaluating water quality (Hilsenhoff 1982).

Fish

A backpack electro-fisher model HT-2000 (Halltech Research, Guelph, Ontario) method was employed to collect samples of fish at two sites, S3 and S6, on Caney Fork. Current strength was adjusted according to environmental conditions and the size of fish we aimed to stun. Fish were collected in buckets for identification and observation. Once we covered the entire reach of the stream with the backpack shocker, we removed the catch-net out of the water and brought to the stream bank for examination.

We repeated this process a number of times at both sites and kept a record of fish species and abundances and to determine a FIBI for each site. We also noted whether or not a fish appeared to be diseased or deformed. After our survey was complete, we returned the fish to the stream.

RESULTS

Habitat Assessment

The overall total score for each section of the assessment at each site was condensed into a single number (Table 2). The ideal or maximum value possible was also included in order to provide a basis for the scale in which each section was calculated. Riffle habitats were lower downstream when compared to upstream sites (Table 2). Riparian vegetative zone width, when different, was wider on the left bank of the stream (Table 3). In general, the overall total score declined downstream (Fig. 4, Fig. 5).

TABLE 2. Habitat assessment scores.

	Assessment Site						
	S1	S2	S3	S4	S5	S6	Ideal
Channel Modification	5	2	4	3	4	3	5
Instream Habitat	16	15	20	20	19	16	20
Bottom Substrate	15	15	14	13	15	6	15
Pool Variety	6	10	5	6	10	0	10
Riffle Habitat	16	16	16	16	3	7	16
Bank Stability and Vegetation	14	12	13	6	14	13	14
Light Penetration	10	7	2	2	7	7	10
Riparian Vegetative Zone Width	10	5	8	6	4	8	10
Total	92	82	82	72	76	60	100

Note: Scores for left and right bank were interpreted from sheets and modified from recorded values due to data collection error.

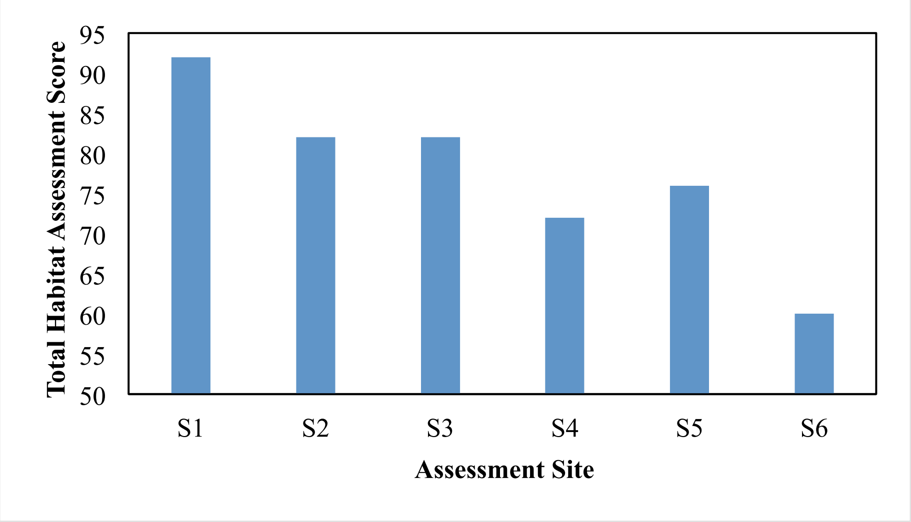

FIG 4. Habitat assessment total score variation across sampled sites.

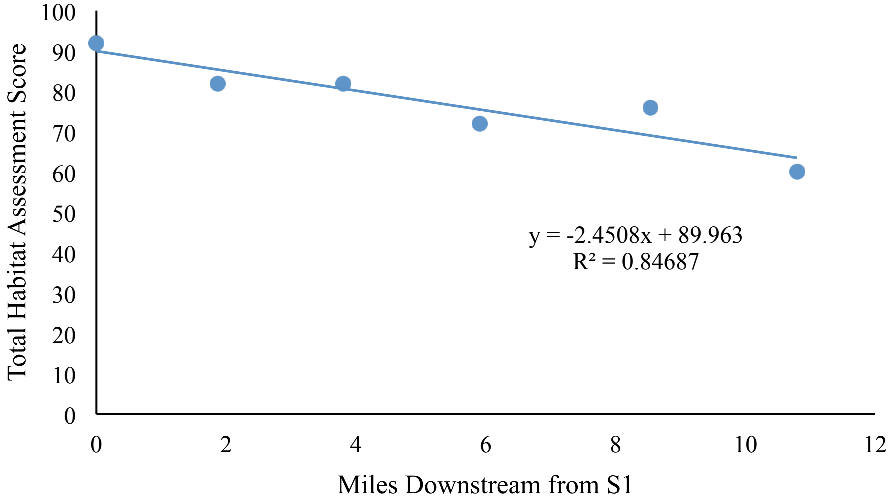

FIG 5. Total Habitat Assessment score over river mile distances.

BEHI Assessment

At S1 the adjusted BEHI Index was 6, meaning that the erosion hazard at this site was low. At S2 the adjusted BEHI Index was 13.5, or moderate erosion hazard. At S3 the adjusted BEHI was 9, or low erosion hazard. S4 had a BEHI index of 12.5, or moderate erosion hazard. S5 had a BEHI of 18.5, or moderate erosion hazard, and S6 had a BEHI index of 15, or moderate erosion hazard (Fig. 7).

TABLE 3. Comparison of left bank and right bank assessments across sampled sites.

	Assessment Site					
	S1	S2	S3	S4	S5	S6
A) Bank Stability and Vegetation						
Left bank	7	6	7	2	7	6
Right Bank	7	6	6	4	7	7
B) Riparian Vegetative Zone Width						
Left Bank	5	3	5	4	3	4
Right Bank	5	2	3	2	1	4
C) Total Bank Specific Score						
Left Bank	12	9	12	6	10	10
Right Bank	12	8	9	6	8	11

Both the TFI and Adjusted BEHI scores show a general trend of increasing as we moved downstream (Fig. 6). However, no specific measurement, such as bank height angle or root density, showed a spatial trend (Table 4, Fig. 8).

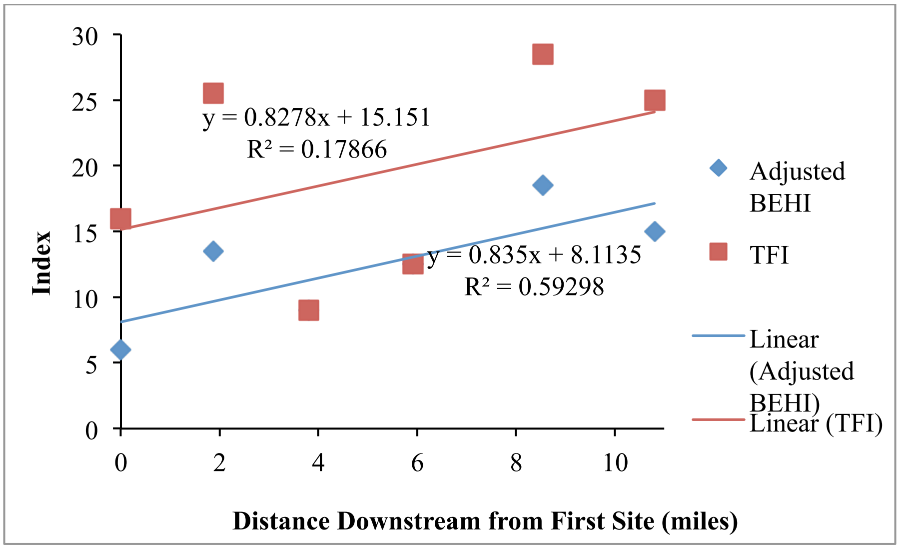

FIG 6. Adjusted BEHI and original TFI change with increasing distance downstream in Caney Fork.

TABLE 4. Distance of each site from the first headwater site, the bank height ratio, root depth ratio, root density percent, bank angle, surface protection percent, the Total Field Index (TFI), and the Adjusted BEHI at each site.

Site	Bank Height Ratio (ft/ft)	Root Depth Ratio (%)	Root Density (%)	Bank Angle (degrees)	Surface Protection (%)	Total Field Index (TFI)	Adjusted BEHI	Erosion Potential
S1	1	100	45	90	100	16	6	Low
S2	3	100	30	55	40	25.5	13.5	Moderate
S3	1	100	70	35	99	9	9	Low
S4	1	30	90	30	95	12.5	12.5	Moderate
S5	1.75	50	50	80	20	28.5	18.5	Moderate
S6	2	100	70	85	30	25	15	Moderate

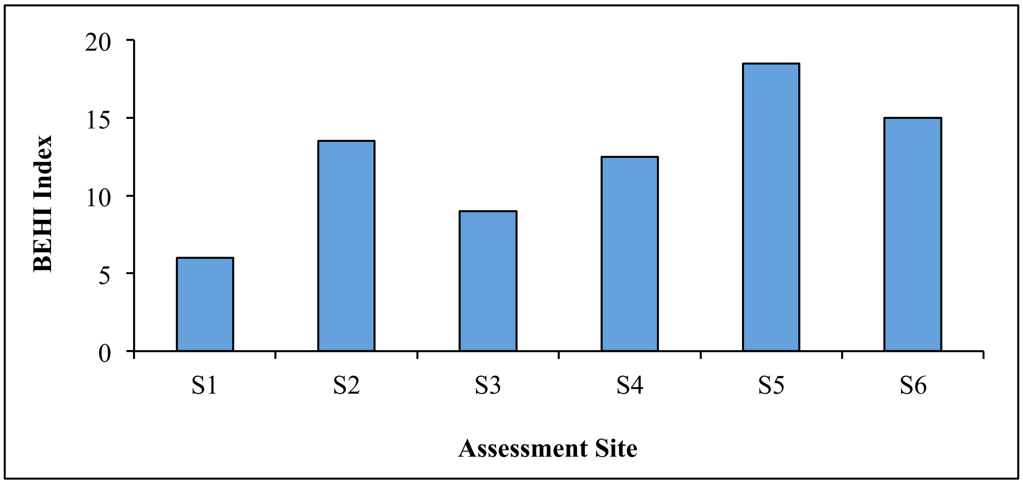

FIG 7. BEHI of each site after numerical adjustments were made. The first site has the lowest Adjusted BEHI and the fifth site has the highest Adjusted BEHI.

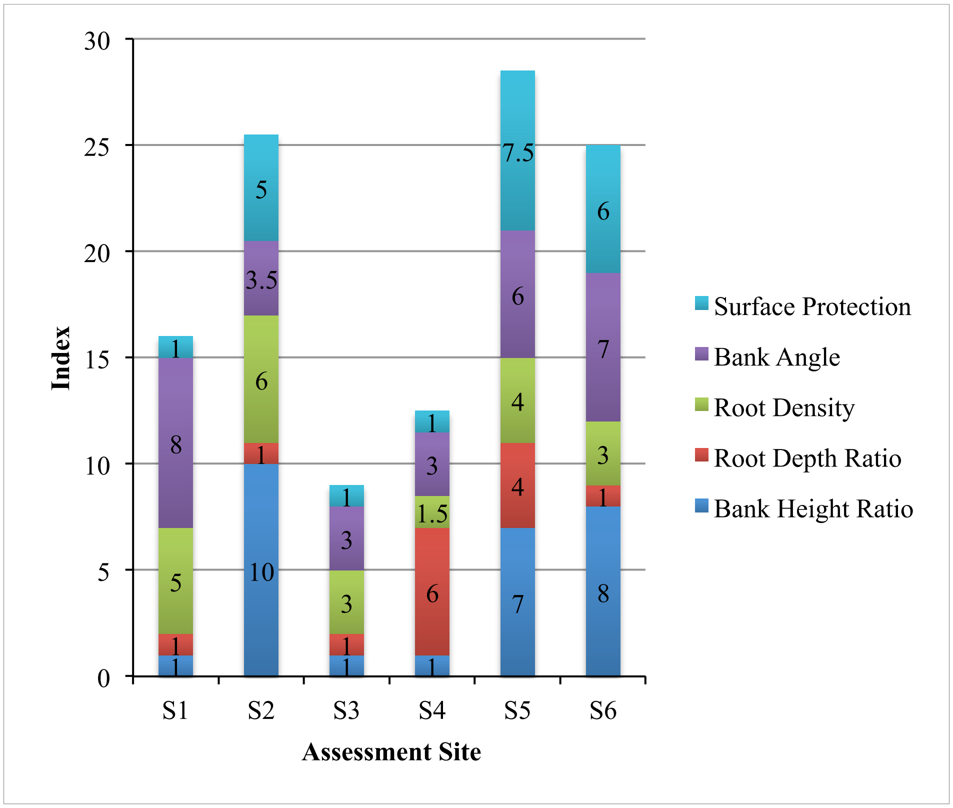

FIG 8. TFI of each site and includes each bank aspect measurement index.

Chemical Analysis

The test kits detected small concentrations of chlorine and phosphate at sites S1, S2, S3 and S6, and S2 and S3, respectively. All other chemicals tested for were not detected by our sampling (Table 5).

TABLE 5. This table shows the chemical levels at all six sites.

Site	Free Chlorine (mg/L)	Total Chlorine (mg/L)	Orthophosphates (mg/L)	Nitrates (mg/L)	Sulfates (mg/L)	Chloride (mg/L)
S1	0.04	0.04	0	0	<50	<500
S2	0.04	0.04	0.04	0	<50	<500
S3	0.04	0.04	0.04	0	<50	<500
S4	0	0	0	0	<50	<500
S5	0	0	0	0	<50	<500
S6	0.04	0	0	0	<50	<500

Pebble Count

The most common size classification of substrate was small cobble (64-90mm), with medium cobble (90-128mm) being second-most common (Fig. 9). The predominant substrate at S5 was bedrock and this site was also the only one where sand comprised >5% of the sample (Fig. 9). All of the substrate at S6 was between 22.6 and 256 mm in size (coarse gravel-very large cobble), forming a narrower range than at any of the other sites (Fig. 9). S4, S5, S1, and S2 were the only sites were bedrock was recorded. Sizes were classified and median particle size was recorded.

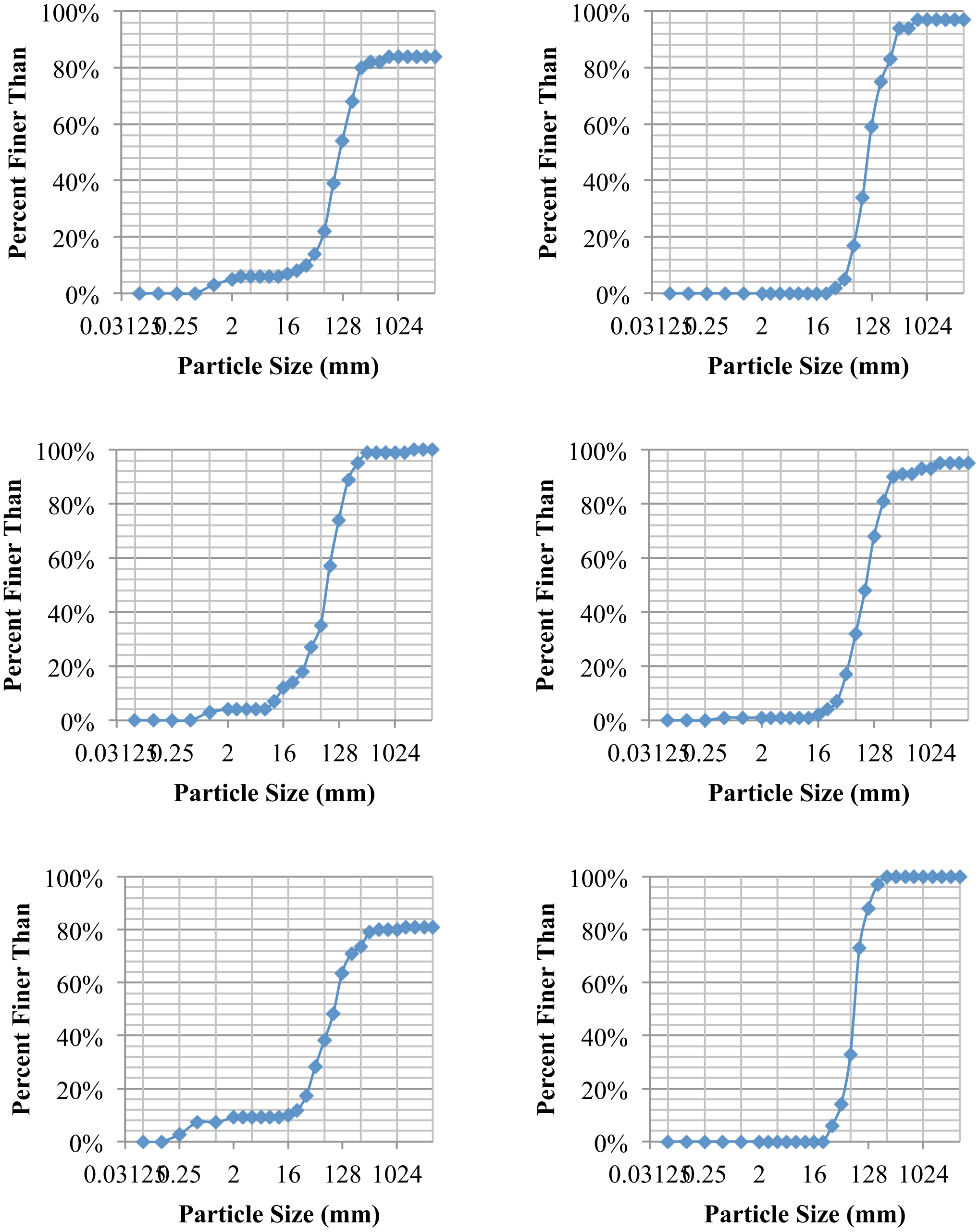

FIG.9. Graph of cumulative size class distribution of substrate material at S1(top left), S2 (top right), S3 (middle left), S4 (middle right), S5 (bottom left), S6 (bottom right) using the Wolman Pebble Count Procedure (Wolman 1954).

Macroinvertabrates

TABLE 6. Median particle size of stream substrate in sites S1 through S6.

Site	D_{50} Particle Size (mm)
S1	116.4
S2	113.04
S3	81.73
S4	93.6
S5	94.24
S6	75.05

All seven orders of macroinvertebrates were found at each location. The most abundant order sampled was Plecoptera at all sites except S1. At S3, S4, and S5 Plecoptera had double or greater abundance of any other order. There also were more macroinvertebrates in general at S3, S4, and S5 (Fig. 10).

Macroinvertebrates of nine feeding groups were sampled. At S1, filterers were the most abundant, making up 52% of our sample. Shredders were the most abundant at S2, S3, S4, and S5 with 34%, 69%, 44%, and 45% of the population respectively. At S6, predators made up the majority of the sample with 40%. Collectors, gatherers, predators/collectors, shredders/scrapers, and shredder/collectors made up small percentages of the sample. Of these five feeding groups, the most abundant were gatherers and shredder/scrapers with 4.76%, both at S6 (Fig. 11).

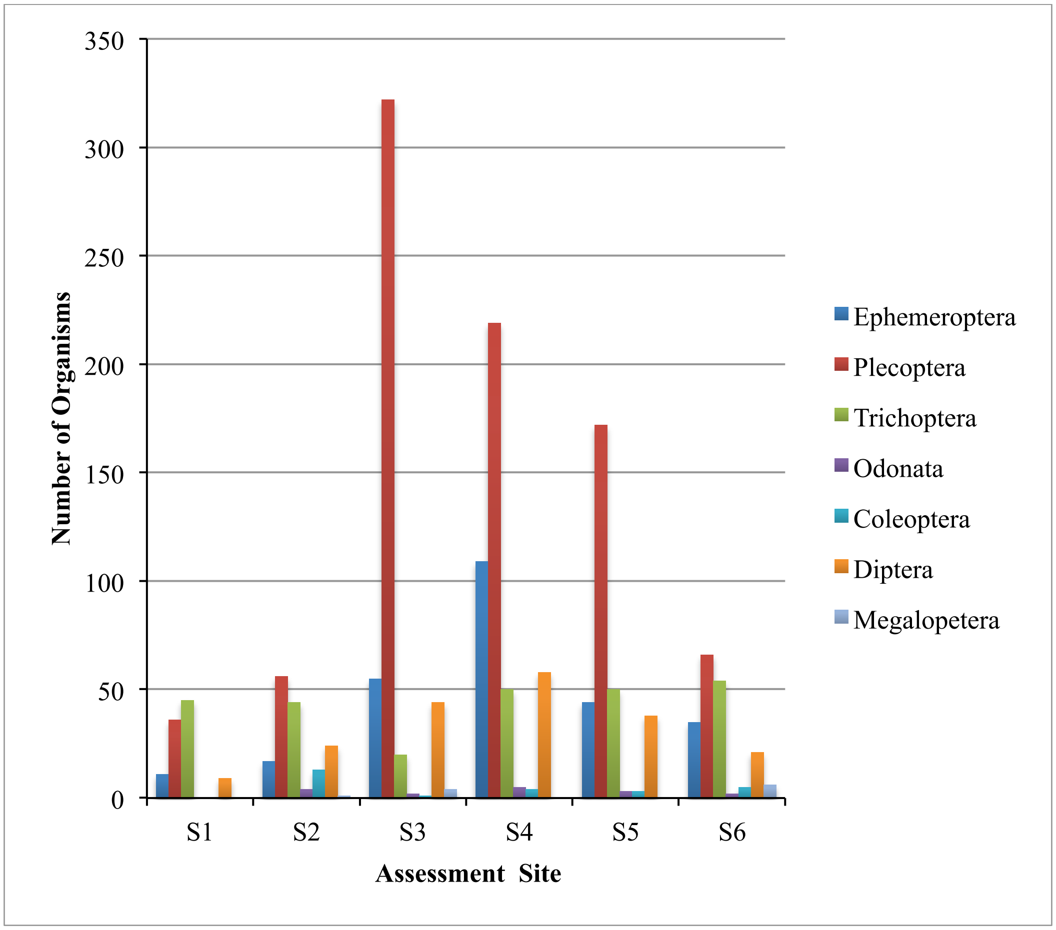

FIG 10. Number of individuals by order from each site

Biotic indexes of macroinvertebrates ranged from 0 to 8 at Sites 2, 3, and 8. At Sites 1, 4, and 5 the biotic index ranged from 0 to 6. The overall biotic index for Caney Fork is 2.568, indicating that the stream is healthy based on the number of intolerant organisms found. The lowest biotic index, 2.252, was found at S3, and the highest biotic index, 2.937, was found at S6 (Fig. 12).

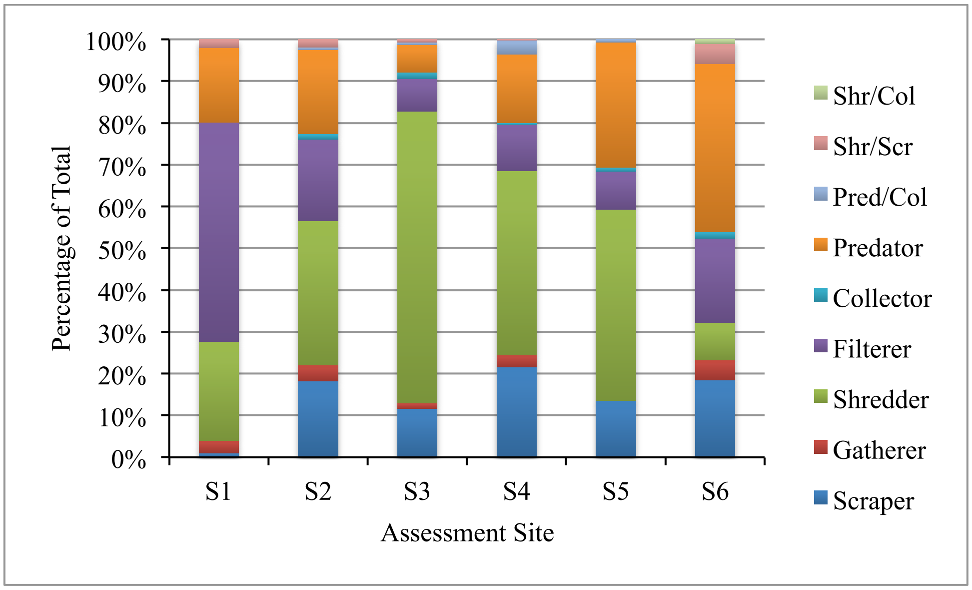

FIG 11. Percentage of Feeding Groups from each site

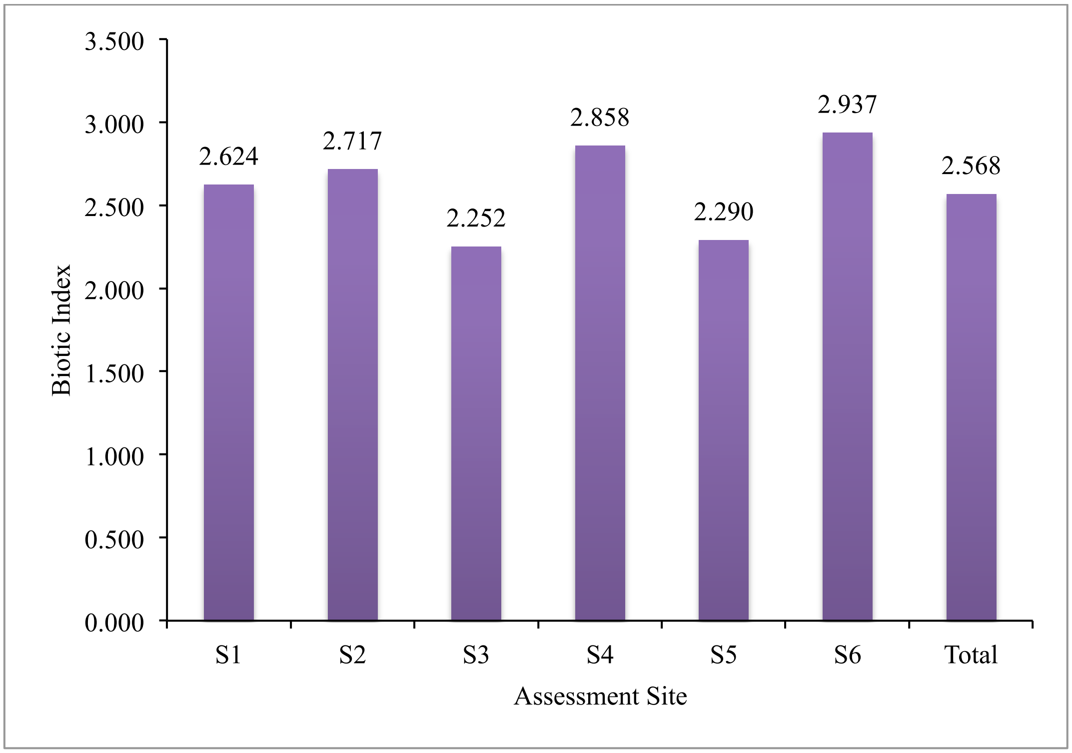

FIG 12. Calculated BI of each site

In general, sites that had higher habitat analysis scores had lower BEHI scores; thus there is an inverse relationship between habitat analysis score and BEHI score (Table 7).

TABLE 7. Comparison of scores from Biotic Indices (BI), Habitat Analysis, and BEHI.

	Assessment Site					
	S1	S2	S3	S4	S5	S6
BI	2.624	2.717	2.252	2.858	2.290	2.937
Habitat Analysis	92	82	82	72	76	60
BEHI	6	13.5	9	12.5	18.5	15

Fish

Fifteen species of fish were found at the upstream site (S3) and 14 were found at the downstream site (S6). A number of intolerant species, such as the rock bass (*Ambloplites rupestris),* smoky dace (*Clinostomus sp Smoky Dace*) and gilt darter (*Percina evides*) were found at the two sites, but the majority of fish were mottled sculpin (*Cottus bairdii*) at both sites (Table 8). Only two exotic species, both introduced trout (*Salmo trutta, Oncorhynchus mykiss*), were found at the two sites. Information about each species we found, such as feeding habits, origin, and tolerance levels are displayed in Table 8.

These characteristics and classifications correspond to a score on the Fish Index of Biotic Integrity (IBI). The upper site scored 45.1 out of 60.5, which classifies the steam as “very good.” This site scored fairly well in every category, but did poorly in the presence of insectivores, which indicate a healthy insect population (Table 9). The lower site scored slightly less with 40.7 out of 60.5. This score places the lower portion of the river in the “good” range. The lower stream scored better in the number of insectivores, but did poorly in its proportion of omnivores and herbivores, as well as its percentage of sculpins and darters (Table 10). Only three fish appeared to have fin damage or disease and they were all found at the lower site (Table 10).

DISCUSSION

Habitat Analysis

We observed two strong trends in the Habitat Assessment. First, the overall habitat score decreases from the first (upstream) to the last (downstream) site, indicating that more upstream portions of the stream are generally of higher habitat quality than downstream locations. A linear regression, shows that the total habitat assessment score declines at an average of about 2.45 points per river mile (Fig. 5). This decline in stream quality downstream is likely due to land usage and construction surrounding the stream. Moving downstream we also observed visually that the amount of farmland and residential areas increases, encroaching on the riparian zone, and decreasing the overall stream habitat quality. Also, moving downstream, the slope gradient of the streams usually naturally decreases, negatively impacting habitat variety and the amount of riffle habitat, a trend which we observed in Caney Fork as well.

TABLE 8. Fish species in the Caney Fork river basin

Species	Caney Fork – Upper	Caney Fork – Lower	Origin	Feeding Habits	Tolerance Level
Rainbow trout	19	0	Exotic	Invertivore	
Mottled sculpin	45	30	Native	Invertivore	
Brown trout	3	1	Exotic	Piscivore	
Creek chub	6	9	Native	Omnivore	Tolerant
Central stoneroller	3	1	Native	Herbivore	
Blacknose dace	1	0	Native	Generalist Feeder	
Longnose dace	8	3	Native	Specialized Insectivore	
Mountain brook lamprey	2	1	Native	Herbivore	
Rock bass	1	2	Native	Piscivore	Intolerant
Smoky dace	10	0	Native	Specialized Insectivore	Intolerant
Northern hogsucker	4	4	Native	Invertivore	
River chub	7	21***	Native	Omnivore	
Black redhorse	1	0	Native	Invertivore	
Tuckasegee darter	1	0	Native	Specialized Insectivore	
Tennessee shiner	1	13	Native	Specialized Insectivore	
Warpaint shiner	0	8	Native	Specialized Insectivore	
Gilt darter	0	2	Native	Specialized Insectivore	Intolerant
Fatlips minnow	0	1	Native	Specialized Insectivore	
Greenfin darter	0	1	Native	Specialized Insectivore	
TOTAL	112	97			

Notes: ***= 3 fish with blackspot.

The second clear trend that can be seen in the data is that the riparian vegetative zone width on the right bank of the river, if different from the left, is always smaller than the vegetation zone on the left bank of the river. This trend is caused mostly by man-made structures. Houses and pasture land tended to be on the right side of the stream, generally leading to higher amounts of disturbance on that side, even if the road was on the left side of the stream, and thus a decrease in the riparian zone width.

With the other scores however, no clear trends exist. The scores for the other categories fluctuate from site to site without any defined patterns. However, as we can see from the trend in the overall habitat assessment score, these scores add up to create a declining trend, showing that many different factors contribute to the habitat quality of a stream.

TABLE 9. IBI metric scoring for the upstream site.

Fish IBI (Upper Site)		Score
Total Number of Native Species	13.00	5.5
Number of Darter Species	1.00	3.3
Number of Sucker Species	1.00	3.3
Number of Intolerant Species	2.00	3.3
Proportion of Individuals as Tolerant Species	5.36	5.5
Proportion of Individuals as Omnivores, Generalists or Herbivores	16.96	3.3
Proportion of Individuals as Specialized Insectivores	17.86	1.1
Proportion of Individuals as Piscivores	3.57	5.5
Catch Rate Per Unit Effort	22.40	3.3
Percentage of Individuals as Darters or Sculpins	41.07	5.5
Percentage of Individuals with disease, tumors or fin damage	0.00	5.5
	Score	45.1

TABLE 10. IBI metric scoring for the downstream site.

Fish IBI (Lower Site)		Score
Total Number of Native Species	13.00	5.5
Number of Darter Species	2.00	3.3
Number of Sucker Species	1.00	3.3
Number of Intolerant Species	2.00	3.3
Proportion of Individuals as Tolerant Species	9.28	5.5
Proportion of Individuals as Omnivores, Generalists or Herbivores	32.99	1.1
Proportion of Individuals as Specialized Insectivores	28.87	3.3
Proportion of Individuals as Piscivores	3.09	5.5
Catch Rate Per Unit Effort	19.40	5.5
Percentage of Individuals as Darters or Sculpins	34.02	1.1
Percentage of Individuals with disease, tumors or fin damage	3.09	3.3
	Score	40.7

BEHI

In general, TFI and Adjusted BEHI correlate positively with distance from the headwater sections (Fig. 6). While headwater sites are characterized by steeper gradients with seemingly more erosive potential, the banks are buffered by large boulders and bedrock lining the streambed. Downstream sites have less bedrock and fewer boulders and consequently the bank sediments are more likely to erode. This is supported by our data which shows that the surface protection percentage was lowest, and the surface protection index was highest, at the last two downstream sites (Fig. 8). Furthermore, upstream sites have received less development and human intervention in the form of channelization, development, and removal of riparian vegetation than the downstream sites.

Vegetation plays a significant role in stream bank stabilization (Wynn et al. 2004) and consequently measurements of root depth ratio and root density correlate strongly with erosion potential and stability of the stream bank. Root density is highest at the first two sites, but ultimately there is no spatial trend. Forested vegetation provides better protection against stream bank erosion by providing greater fine root density (Wynn et al. 2004) and so we expect forested sites to have a higher root density and a lower BEHI. S1 had a large, forested riparian zone and high root density, as expected. However, S2 had a small riparian zone but the highest root density, suggesting that root density and forested riparian zone size are not always correlated. The riparian zone of S4 was composed primarily of grasses with short, weak roots and had the lowest root depth ratio. Weak, short roots do a poor job of holding soil in place and thus increase bank erosion potential. Studies have found that erosion is higher in streams flanked by pasture land than in forest streams (Laubel et al. 1999). The only site that had cattle grazing next to the stream, S5, had the highest BEHI out of all the sites. Furthermore, S1 was in a heavily forested area with a dense riparian zone and had the lowest BEHI score.

Chemical Analysis

Levels of all chemicals tested were either undetected or at the lowest threshold of the test units' sensitivity. The Caney Fork watershed is about 96% forested with small plots of farmland. There are no industrial point sources of pollutants upstream of any sites to our knowledge and we believe runoff of agricultural wastes, specifically manure, are likely the source of orthophosphates found at S1 and S2 (Wood et al. 1996). The testing methods were carried out by different individuals at each site, possibly introducing some variability in the results. Additionally, the tests were only carried out once and at roughly the same time of day for all sites, creating very little sampling variation.

Pebble Count

Pebble count can be used to measure the competency of a stream (Komar and Carling 1991). As we moved down the stream, median substrate particle size tended to decrease (116.4 mm at S1 to 75.05 mm at S6) (Table 5). The likely cause of this trend is a decrease in stream competency, affected by anthropogenic channelization and a decreasing elevational gradient. Exposed bedrock made up much of the substrate at both S1 (16%) and S5 (19%). Large particle sizes at S1 were likely due to high competency at this undeveloped and steep stretch of stream high up in the watershed. At S5, the median particle size was higher due to the presence of bedrock, but was balanced out by the high amount of particles classified as sand. In contrast to S1 and S5, S2, S3, S4, and S6 all had very uniform substrate particle size distributions. The reaches of stream sampled at S3, S4, and S6 were relatively straight and had fewer boulders and riffles than the other sites.

Fish and invertebrate distributions at both the macro- and micro- scale are substantially affected by stream substrate (Vannote et al. 1980). Benthic macroinvertebrates characteristic of erosional stream environments are adapted to large substrate particle sizes and therefore built for clinging, attaching, and avoiding the current. Similarly, macroinvertebrates that prefer depositional habitats are also adapted to their environs and these adaptations help determine at which sites certain macroinvertebrates will be found (Cummins and Lauff 1969).

Macroinvertebrates

The high number of Plecoptera in the various sites can be attributed mostly to the number of Peltoperlidae in the streams, especially at S3. These organisms have a tolerance value of 2, which indicates a fairly healthy stream.

The most upstream site contains mainly filterers, and the most downstream site contains mainly predators, while the middle sites exhibit mostly shredders. The habitat and prey present are expected to change while moving downstream because of a gradient in physical conditions (Brown 2007; Vannote et. al 1980).

There is no pattern in the macroinvertebrate biotic index. This may indicate that individual sites have elements affecting the health of the stream, but the elements are not continuous along the length of the stream. However there seems to be a correlation between the habitat analysis scores, the BEHI scores and the macroinvertebrate biotic indices. In general, the areas that had a combination of lower habitat scores, less favorable habitat, and higher BEHI scores, more erosion potential, had higher biotic indices, meaning they contained organisms more tolerant of disturbance.

The highest BI, 2.937, was found at S6. This site was a residential area, so there may be anthropogenic disturbance contributing to the elevated BI at this region (Death and Winterbourn 1995). This site also had a fairly high BEHI value of 15, and the lowest habitat assessment of 60, indicating that high erosion and habitat disturbance is correlated with the high BI. Conversely, the lowest BI value of 2.252 is at S3. This site has a relatively high habitat analysis value of 82 and relatively low BEHI value of 9 further supporting the correlation between the three.

The overall BI of 2.568 indicates the stream as a whole is fairly healthy. This means that the organisms that are present in the stream are fairly intolerant of polluted waters, and therefore can only exist in measurable abundance if the stream is moderately clean.

Fish

The fish at both sites were diverse and abundant. Every trial with the backpack shocker resulted in the capture of numerous fish. Our evaluation of the Caney Fork River Basin suggests that the upstream reaches are more favorable than downstream reaches for supporting fish populations, although both are considered good.

Intolerant species are sensitive to environmental alteration and are easily extirpated from waterways. Each has its own condition or set of conditions that it cannot tolerate, so a range of species present can indicate the condition(s) of the stream. The gilt darter, for instance, is intolerant to sedimentation and hydrologic alteration (Miltner et al. 2004.) Since they were present in our stream, we can determine, without using sophisticated technology that the stream is not experiencing over-sedimentation and the hydrology has not been recently altered.

The IBI score for the lower end of the stream, S6, was 40.7 (S6), which is a “good” designation. The upstream site, S3, scored slightly higher, with 45.1 which gave it a “very good” designation. This variation suggests that the water upstream is somewhat more productive. A number of environmental conditions found to be different at the two sites explain the variation.

The lower site was located on private property and ran along tended yards with very little riparian zone. The stream width at this site was substantially larger than the upper site, resulting in higher sunlight levels and shallower water. Much of the lower site was a run with few large rocks or snags, meaning there was very little favorable fish habitat. Many of the fish that contributed to the "good" IBI score were caught in a pool at the end of the reach.

The upper site was characterized by its proximity to the road. The right bank had a very slim riparian zone, while river left, going downstream, supported a substantial forest. The stream width here was narrower than the lower zone, and the water was faster moving. Much of this reach was a riffle, and there were a number of large boulders and fallen trees in the water. The canopy cover was slightly higher than the lower site, which could contribute to restricted primary production.

The sites between S3 and S6, were both classified by high BEHI scores, with high potential for erosion. S5 was influenced by proximity of pastureland to the stream, which could also explain the difference of IBI between sites (Duncan 2011). Our small sample size provides an opportunity for further research in this area.

One possible source of error is that each stream health assessment was conducted by a different group of people. While each group was instructed in collecting and recording data, there are undoubtedly small imperfections in the subjective aspects of data collection. Furthermore, there is a bias resulting because sites were selected based on proximity to the road and ease of access.

Overall, the data suggest that Caney Fork is representative of an average mountain stream. It appears to be a fairly healthy stream that supports viable communities of fish and macroinvertebrates, but human development at the downstream portion is negatively affecting the habitat quality and is experiencing increased erosion potential. Resident organisms may be similarly affected by development on a longer time scale but the effects have yet to be seen.

ACKNOWLEDGEMENTS

We would like to thank Steve Foster for teaching us how to measure the health of a stream. We would also like to thank Karen Kandl and Michelle Ruigrok for assisting us in our measurements and data collection. We would also like to acknowledge the assistance of Dave Penrose, Jason Meador, and Tom Martin in the macroinvertebrate and fish sampling efforts, respectively.

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Appendix A

GIS and Landscape Analysis Procedure Log

Goals:
- Land Cover Percentage Analysis
- Distances between Site Locations

Watershed Data Frame

Data Frame Projection: GCS_WGS_1984

Sources and Corresponding Initial Data:

Geo Community (http://data.geocomm.com/catalog/US/61083/2039/group1-3.html)
Digital Raster Graphics – USGS Topographic Maps Georeferenced
- o35082b8.tif – Lake Toxaway, NC
- o35082c8.tif – Sam Knob, NC
- o35082b1.tif – Big Ridge, NC
- o35083b2.tif – Glenville, NC
- o35083c1.tif – Tuckasegee, NC
- o35083c2.tif – Sylva South, NC
- o35083d1.tif – Hazelwood, NC
- o35083d2.tif – Sylva North, NC

Jackson County (http://www.mrlc.gov/nlcd06_data.php)
- Jackson.sid
- Major_Roads.shp

National Land Cover Database (http://www.mrlc.gov/nlcd06_data.php)
- nlcd2006_landcover_4-20-11_se5.img

NCDOT (https://connect.ncdot.gov/resources/gis/pages/gis-data-layers.aspx)
- LRS_ROUTE.shp
- County_Boundary.shp
  - Elevation

Procedure:

Catalog: New > Shapefile > Output: CF_WS.shp
Dialog: Use the topographic maps and their contour lines to define the polygon for the Caney Fork Watershed. This is done by editing CF_WS and drawing the line feature to represent the watershed.

Catalog: New > Shapefile > Output: CF_HW.shp
Dialog: Use the topographic maps and their stream lines to define the points for the stream intersections and headwater beginnings. This is done by editing CF_HW and drawing points.

Catalog: New > Shapefile > Output: CF_SS.shp

Dialog: Use the topographic maps and their stream lines to define the major stream systems within the Caney Fork Watershed excluding the Moses Creek Watershed. This is done by editing CF_SS and drawing the line feature to represent the streams.

Error: Please make a note that when compared to the aerial photograph Jackson.sid CF_SS and LRS_ROUTE do not match the location on the aerial photograph. This could be due to separate projections as well as the consideration that the aerial photograph may have been taken at an angle. Not to mention that systems used to capture that data may have been calibrated differently

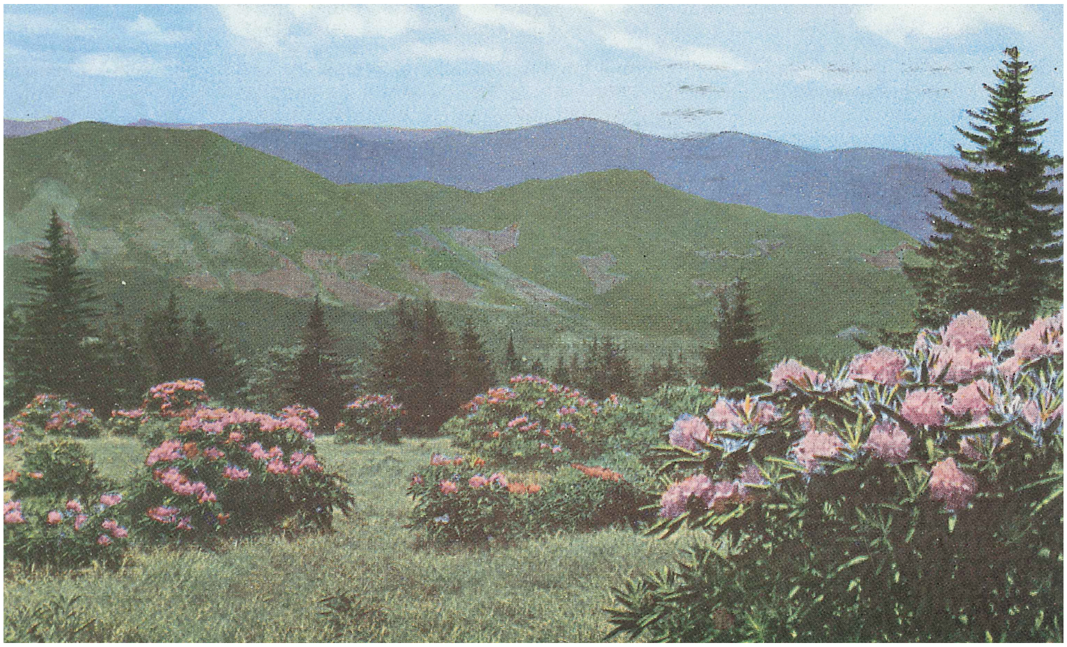
Catalog: New > Shapefile > Output: MC_SS.shp
Dialog: Use the topographic maps and their stream lines to define the stream for the Caney Fork Watershed. This is done by editing MC_SS and drawing the line feature to represent the stream.
Further Dialog: MC_SS is being used for another project and there is no need to repeat what already has been done.

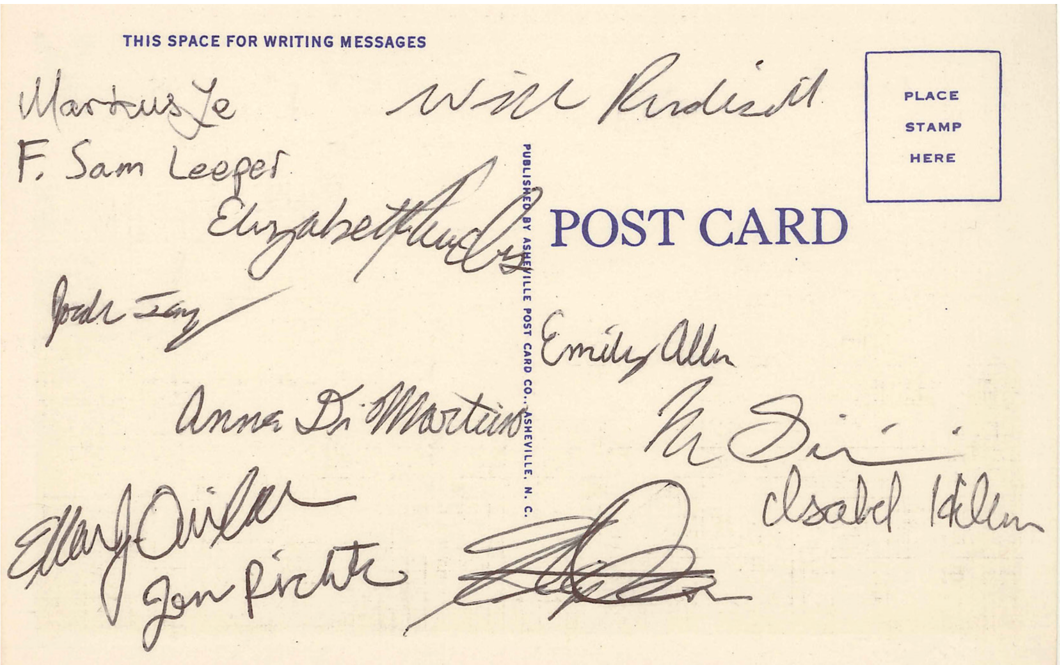
Function: Extract by Mask
Input: Elevation
Mask: CF_WS.shp
Output: CF_Elev.shp
Transparency: 60 percent

Function: Hillshade
Input: CF_Elev
Output: CF_HSHA

Non-Analytical Data:
- LRS_ROUTE.shp
- Caney Fork.shp
  - [This data was acquired using a GeoTrimble device in addition to ArcPAD, the devices software. Standard operating projection was used.]

Land Cover Analysis:
In order to determine the percentages of land cover in the Caney Fork Watershed, data was taken from the National Land Cover Database. The area was then recorded for each land cover within the Caney Fork Watershed.





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