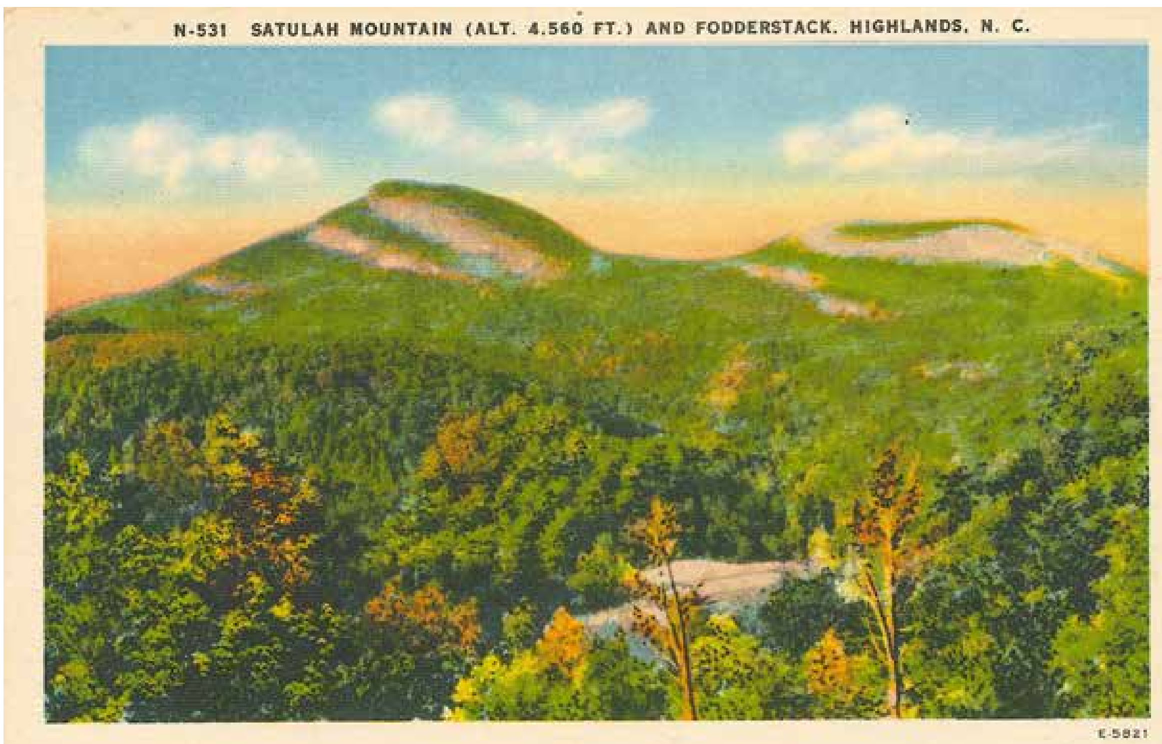
Institute for the Environment
Highlands Field Site
2012 Internship Research Reports



Highlands Biological Station
Highlands, North Carolina

INTRODUCTION

> *What we don't know about the natural world far exceeds what we know. Whether in pursuit of camellia habitats or other mysteries of nature, the limitless horizons of discovery infinitely intrigue and invite.*
>
> Brent Martin in *Searching for Camellias*

This semester we let the mountain landscape of the Highlands Plateau inspire us and enrich our lives. We learned about the magnificent mountainous world around us in our explorations and our research, which is one of the main focuses of the IE semester at the Highlands Field Site. Each year we compile that research in a volume to share with the public. You are holding the compilation of research conducted by our IE students during the 2012 Fall Semester.

Why spend so much time and effort on undergraduate research in environmental science? The answers to this question are varied and far-reaching: Research engages our intellectual inquisitiveness. Students are able to ask questions and spend quiet time discovering an answer. Immense learning occurs when undergraduate students do research. This learning is often more intense, more in-depth, and more personal than traditional forms of coursework learning. Through research, students gain insight into their environment and their own identities as they push the limits of their knowledge. Research gives us a sense of accomplishment when we complete a project, and it opens up new doors as we realize that one question leads to dozens of others. Research also gives us a basis to form personal relationships with those who mentor us. Students benefit from the wisdom, knowledge, and experience of a mentor, but the relationship is reciprocal, as mentors share in the students' discoveries and the energy a student brings to the project.

We embarked upon our learning and research this semester with enthusiasm, following in the footsteps of many that have come before us. Ralph M. Sargent, a founder of the Highlands botanical garden, wrote in the prelude to his book *Biology in the Blue Ridge,*

> *With its natural wealth of vegetation and animal life the Highlands region will support indefinitely a varied program of research….*

And later in his book, he writes,

> *Dr. Deacon then offered a powerful and moving account of the vast potentiality for the biological research in the Highlands area. He surveyed the entire animal and vegetable kingdoms so richly alive in the southern mountains….*

This semester we have, with the support of many others, given these IE students an opportunity to explore the richly diverse Highlands area through research. We hope that the IE students learned from these beautiful mountains, and that they will forever carry their knowledge from their Highlands semester with them, and share that knowledge with those that they meet. Finally we hope that they will use this knowledge to help protect these mountains and their abundant diversity.

Tom Martin, Interim Director, HBS
Karen Kandl, Associate Director, HBS
Michelle Ruigrok, Program Assistant, HBS

Acknowledgements

On behalf of the IE-HFS class of 2012, we would like to thank the many individuals who took time from their busy lives to help teach the IE courses, and to support and mentor the student research. We thank the internship mentors Patrick Brannon (Nature Center of Highlands Biological Station), Steven Brantley (Coweeta Hydrologic Laboratory), Jack Johnston (Clayton, GA), Tom Martin (Western Carolina University), Ed Pivorun (Clemson University), Kim Novick (Coweeta Hydrologic Laboratory), and Gary Wein (Highlands-Cashiers Land Trust) whose knowledge and guidance made these research experiences possible.

We thank Steve Foster (Watershed Science, Inc.) without whom we could not have done our Capstone Project. His knowledge, expertise, and deep love for the rivers of western North Carolina guided us in the field and in the writing of our the Capstone Project. Dave Penrose (Watershed Science Inc.), and Jason Meador (Little Tennessee Land Trust) also contributed their expertise of macroinvertebrates and fish, respectively, to our Capstone Project.

We are grateful to Gary Wein of the Highlands-Cashiers Land Trust for once again teaching the Landscape Analysis course and helping with the GIS components of this year's internships. We appreciate, too, the many guest instructors that contributed to this year's program, including Brent Martin (The Wilderness Society), Rich Baird (Mississippi State University), James Reynolds (Brevard College), Sonya Carpenter (Highlands Biological Foundation), Patrick Brannon (Highlands Biological Station Nature Center), and Russ Regnery (Highlands Plateau Audubon Society), by providing their individual expertise for the modular course.

We thank the HBS staff — Michelle Ruigrok, Guy Cook, Patrick Brannon, Erika Selman, Cynthia Soderstrom and Sonya Carpenter — for making the working and living experience of the students at HBS very positive. We would like to give Michelle Ruigrok special thanks for her help in mentoring the IE students on a daily basis, for participating in all of our activities, and for driving the van countless miles on all of our field trips. We thank Amelia Kiechle of the IE program in Chapel Hill for her assistance in recruiting students to the program and in organizing the internships, and the IE and Study Abroad staff at Chapel Hill for their support. Thanks to Jessica Webb at *The Highlander* newspaper for sharing with the Highlands community our many activities and excursions from classroom and lab to river and trail. We are grateful, finally, for the hospitality shown by residents of the town of Highlands who continue to welcome our students into the community each semester.

Tom Martin and Karen Kandl
IE-Highlands Field Site Directors
December 2012

TABLE OF CONTENTS

THE MORTALITY RISK OF DISCARDED ROADSIDE BOTTLES ON SOUTHERN APPALACHIAN SHREWS

LINDSEY BARGELT

Abstract. We inspected discarded roadside bottles for small mammal skeletal remains at 46 sites in the Highlands Plateau region to examine potential conservation implications. Small mammal remains were found in approximately 4.5% of the open bottles and at 54% of the sites. A total of 114 small mammals were collected, representing four species of shrews and two species of rodents. We calculated overall small mammal capture rates in bottles to be 10.2% across all sites, with an annual mortality rate of 29.16. Annual accumulation of open bottles was calculated to be 1.53 (0.7 traps) per site. Discarded bottles along roadways in the Highlands Plateau region should be regarded as a considerable mortality risk to shrews.

Key words: Blarina, *conservation*, *discarded bottles, Highlands Plateau, shrews, small mammals,* Sorex

INTRODUCTION

The phenomenon of small mammals, particularly shrews, becoming entrapped in discarded bottles along roadsides has been reported in several studies in North America (Pagels and French 1987, Gerard and Feldhamer 1990, Benedict and Billeter 2004). Shrews enter bottles while exploring and may be attracted to moisture or smells (Morris and Harper 1965). Bottles landing in an inclined position allow small mammals to enter but not escape (Gerard and Feldhamer 1990), and may drown animals if they contain rainwater (Clegg 1966).

Small mammal data collected from bottles have been used to analyze species geographic distributions (Pagels and French 1987, Brannon et al. 2010) and to compare trap effectiveness to other methods (Gerard and Feldhamer 1990, Taulman et al. 1992). Large numbers of bottles on roadways may be a potential conservation threat to shrews, especially to those that are rare or are state listed as of special concern. Pagels and French (1987) estimated mortality as high as 71 small animals per km at sites across Virginia, and Benedict and Billeter (2004) found that it exceeded 183 animals per km in areas with larger accumulations of bottles.

Gerard and Feldhamer (1990) suggested that bottles must be in place for a prolonged period before they become effective traps. Because the length of time bottles had been in place was unknown, previous studies (Pagels and French 1987, Benedict and Billeter 2004, Brannon et al. 2010) capture rates were based solely on the proportion of bottles containing animal remains. From September 2007 to November 2009, Brannon et al. (2010) examined 10,461 bottles at 220 sites along the southern Blue Ridge escarpment. During the study, bottles were emptied and left in place at each site. The objective of this study was to revisit many of these sites, where the number of days since the previous search is known, in order to determine the capture rate of small mammals over time and the accumulation rate of new bottles.

METHODS

From August 2012 to November 2012, we counted and examined bottles for small mammal skeletal remains at 46 of the 220 sites of Brannon et al. (2010). These sites were located in the Highlands Plateau region of Macon and Jackson Counties, North Carolina, and Rabun County, Georgia, at an elevational range of 448 to 1188 m. We chose these sites to revisit based on accessibility and because at higher elevations there is a greater diversity of shrew species (Ford et al. 2006). We matched the locations of study sites with Brannon et al. (2010) sites by comparing latitude, longitude, and elevation data. We selected vehicle pull offs as sites because these areas are often used as illegal dumping sites and tend to accumulate large numbers of bottles (Brannon et al. 2010). Typically, the sites had steep embankments and were approximately 100 m in length and of varying distances into the surrounding area. Vegetation and habitat varied among sites, but were comprised primarily of northern hardwood, cove hardwood and montane streamside communities (Brannon et al. 2010).

"Bottles" were defined as any plastic or glass container of any size, including jars, milk jugs and other similar items of trash (Brannon et al. 2010). Like Brannon et al. (2010), aluminum cans were excluded because no vertebrate remains were found in them. We searched for bottles visually by walking through the site and shuffling our feet to expose those buried in leaf litter (Brannon et al. 2010).

We counted the number of open bottles (i.e., potential traps), the number of closed bottles, and collected the ones that appeared to contain animal remains. These were often indicated by evidence of dried fur, foul odors, murky water and dead invertebrates. Contents were poured out and then picked through with tools to find any bones. Skulls, mandibles, and other bones were placed in labeled plastic bags and deposited at the Highlands Biological Station (Brannon et al. 2010). We identified species by tooth arrangements and comparisons with reference skulls.

Individual species capture rates were determined as total number of captures divided by total number of open bottle traps. We calculated time intervals for each site and accumulations of bottles using data from Brannon et al. (2010). We were unable to determine precisely when new bottles were added since the previous search; therefore we used the minimum number of trap nights (TN) as determined by the number of bottles present (n=973) in the previous study. We calculated annual small mammal capture rates as the number of captures divided by the average annual minimum number of trap nights. Annual small mammal mortality rates were calculated as the annual capture rates multiplied by the total number of open bottle traps. We calculated bottle accumulation rates as the number of new bottles divided by the number of days passed since the last search at each site (Brannon et al. 2010).

RESULTS

We collected specimens at 27 sites (54%) with an average of 2.52 animals per site. Of the 2,306 bottles we examined, 1,118 (48.5%) were open and served as potential traps, with an average of 23.9 traps per site. Of these, 51 (4.56%) were actual traps with specimens found inside. Bottles frequently trapped more than one animal. On average we found 2.24 animals per bottle, with the most being 19 in one bottle representing two species. Consequently, the overall small mammal capture rate was 10.2%.

We collected a total of 114 small mammals, including four species of shrews and two species of rodents (Table 1). The Northern Short-tailed Shrew (*Blarina brevicauda*) was the most common species found (*n*= 76; 66.7% of captures; site occurrence = 21), followed by the Smoky Shrew (*Sorex fumeus;* n=24; 21.05% of captures; site occurrence=13). We also captured three Masked Shrews (*S. cinereus*), one Pygmy Shrew (*S. hoyi*), nine Deer Mice (*Peromyscus* *maniculatus),* and one Southern Red-backed Vole (*Myodes gapperi*) (Table 1). One bottle also collected a Blue Ridge Two-lined Salamander (*Eurycea wilderae*).

TABLE 1. Summary of small mammal captures at 46 sites.

Family and Species	Common name	*n*	% Captures	Capture Rate	# Sites
Soricidae:					
Blarina brevicauda (Say)	Northern Short-tailed Shrew	76	66.7	6.798	21
Sorex fumeus (Miller)	Smoky Shrew	24	21.05	2.147	13
S. cinereus Kerr	Masked Shrew	3	2.63	0.268	3
S. hoyi (Baird)	Pygmy Shrew	1	0.88	0.089	1
Muridae:					
Peromyscus maniculatus Wagner	Deer mouse	9	7.98	0.805	3
Myodes gapperi (Vigors)	Southern Red-backed Vole	1	0.88	0.089	1
Totals		114		10.196	

An average of 1,643 days per site had passed since the last search (Brannon et al. 2010), with a minimum of 1,595,269 trap nights. Since the previous study (Brannon et al. 2010), 316 new bottles (145 new traps) were found. Annual accumulation of bottles was 1.53 (0.7 traps) per site, or 255.5 TN.

Annual small mammal capture rates were 2.61% across all sites and 0.06% per site. Annual mortality rate was 29.16 small mammals across all sites and 0.64 per site. An average of 243.04 traps and 24.78 mammals per km was found for the 4.6 km of roadsides searched.

DISCUSSION

Capture rates in our study are consistent with the findings of Brannon et al. (2010) and Benedict and Billeter (2004). As with previous studies, the Northern Short-tailed Shrew was the most abundant and widespread species collected (Pagels and French 1987, Benedict and Billeter 2004, Brannon et al. 2010). It may be more frequently captured because of its semi-fossorial lifestyle and use of echolocation, which may result in the shrew interpreting the mouth of the bottle as a tunnel entrance (Gould et al. 1964). Smaller mammals may be less likely to be captured because they can more easily escape (Gerard and Feldhamer 1990). Our calculations of capture rates may be an underestimate because the tiny bones of smaller shrews are more quickly scavenged by carrion beetles (Benedict and Billeter 2004), and because we had to use the minimum number of trap nights, as based on numbers of open bottles from the previous study. Furthermore, we may have missed several bottles during our searches because of the difficulty in finding them in deep leaves during the fall. Capture rates may also reflect relative local abundances of individual species (Ford et al 1997, Laerm et al. 1999).

We found the concentration of bottles per km to be comparable to previous studies for rural areas (Pagels and French 1987) but lower than others conducted in urban areas with higher levels of traffic (Benedict and Billeter 2004). Although our searches were limited to pull off sites, such areas contain greater concentrations of bottles than along roadsides because many serve as illegal garbage dumps which may reduce the local abundance of individual shrew species (Courtney and Fenton 1976). In steep mountainous terrain, bottles may be a greater mortality risk to shrews because they roll far down slopes into thick vegetation, and are more likely to land in a “kill position” (Benedict and Billeter 2004). Bottles far off the shoulder of the road are seldom picked up by cleanup crews. This was verified by finding decades old bottles based on labels and bottle design (Brannon et al. 2010).

Diversity of North American Soricidae is greatest in the Southern Appalachians due to high precipitation and a variety of forested habitats which result, in part, from steep altitudinal gradients (Ford et al. 2006, Berman et al. 2007). Large numbers of bottles in high elevation and mesic habitats where shrew diversity is higher may pose a conservation threat, especially to rare species of shrews (Laerm et al. 1999, Brannon et al. 2010). The Pygmy Shrew, Rock Shrew (*S. dispar*) and Water Shrew (*S. palustris*) are uncommon or listed as a North Carolina "species of special concern" (Laerm et al. 2000). We collected one Pygmy Shrew in a bottle during our limited study. However, this capture emphasizes the potential mortality risk of discarded bottles on rare species.

We found the accumulation rate of new open bottle traps to be relatively low in this study. Despite this, significant concentrations of bottles currently exist at pull off sites. Once bottles are in place they may remain and function continuously as traps unless they are removed, broken, or the entrance is buried via erosion. In addition, traps accumulated since the last search augment the already ever-growing number of trap nights. These bottles will account for an additional 52,925 TN per year, for a total of 1,808,100 TN minimum per year. Moreover, additional discarded bottles will continue to accumulate on an annual basis and further increase the number of trap nights. Therefore, accumulations of open bottles along roadways in the Highlands Plateau region should be regarded as a considerable mortality risk to shrews.

Acknowledgements

I would like to thank my mentor Patrick Brannon, Director of the Highlands Nature Center, for his help with this study and paper. I would also like to thank Karen Kandl, Associate Director of Highlands Biological Station, for editing this paper and her support of the project.

Literature Cited

Benedict, R. A., and M. C. Billeter. 2004. Discarded bottles as a cause of mortality in small vertebrates. Southeastern Naturalist **3**:371-377.

Berman, J., T. S. McCay, and P. Scull. 2007. Spatial analysis of species richness of shrews (Soricomorpha: Scoricidae) in North America north of Mexico. Acta Theriologica **52**:151-158.

Brannon, M. P., M. A. Burt, D. M. Bost, and M. C. Caswell. 2010. Discarded bottles as a source of shrew species distributional data along an elevational gradient in the southern Appalachians. Southeastern Naturalist **9**:781-794.

Clegg, T. M. 1966. The abundance of shrews, as indicated by trapping and remains in discarded bottles. Naturalist (Hull) **899**:122.

Courtney, P. A., and M. B. Fenton. 1976. The effects of a small rural garbage dump on populations of *Peromyscus leucopus* Rafinesque and other small mammals. Journal of Applied Ecology **13**:413-422.

Ford, W. M., J. Laerm, and K. Barker. 1997. Soricid response to forest stand age in southern Appalachian cove hardwood communities. Forest Ecology and Management **91**:175-181.

Ford, W. M., T. S. McCay, M. A. Menzel, W. D. Webster, C. H. Greenberg, J. F. Pagels, and J. F. Merritt. 2006. Influence of elevation and forest type on community assemblage and species distribution of shrews in the central and southern Appalachian Mountains. Pages 303-315 *in* J.F. Merritt and S. Churchfield, editors. Advances in the Biology of Shrews II. Special Publication of the International Society of Shrew Biologists No. 1, Powdermill Biological Station of the Carnegie Museum of Natural History, Pittsburgh, Pennsylvania.

Gerard, A. S., and G. A. Feldhamer. 1990. A comparison of two survey methods for shrews: pitfalls and discarded bottles. American Midland Naturalist **124**:191-194.

Gould, E., N. Negus, and A. Novick. 1964. Evidence for echolocation in shrews. Journal of Experimental Zoology **156**:19-38.

Laerm, J., W. M. Ford, T. S. McCay, M. A. Menzel, L. T. Lepardo, and J. L. Boone. 1999. Soricid communities in the southern Appalachians. Pages 177-193 *in* R.P Eckerlin, editor. Proceedings of the Appalachian Biogeography Symposium. Virginia Museum of Natural History Special Publication No. 7, Martinsville, Virginia.

Laerm, J., W. M. Ford, and B. R. Chapman. 2000. Conservation status of terrestrial mammals of the southeastern United States. Occasional Papers of the North Carolina Museum of Natural Sciences and the North Carolina Biological Survey **12**:4-16.

Morris, P. A., and J. F. Harper. 1965. The occurrence of small mammals in discarded bottles. Proceedings of the Zoological Society of London **145**:148-153.

Pagels, J. F., and T. W. French. 1987. Discarded bottles as a source of small-mammal distributional data. American Midland Naturalist **118**:217-219.

Taulman, J. F., R. E. Thill, T. B. Wigley, and M. A. Melchiors. 1992. A comparison of bottles and snap traps for short-term small mammal sampling. American Midland Naturalist **127**:208-210.

A STUDY OF SOIL MOISTURE CONTENT AT WHICH PINE TREES EXPERIENCE STRESS

KIRSTAN BLENDER

Abstract. Pine trees are among the most abundant trees in Southeastern United States forests. Pine plantations are widely used to supply softwood timber used for a variety of products. Currently, land managers do not have a model designed specifically for them in order to know when their trees are under stress. This project will determine conductance and transpiration rate, and identify the critical soil moisture level at which stomatal conductance becomes limited in pine trees. Data was analyzed using a Jarvis type model in MatLAB®. The study found that the optimal soil moisture level for southern pine trees was between 0.03 and 0.3 depending on location.

Keywords: Conductance; transpiration; pine trees; sap flux; vapor pressure deficit; relative humidity; soil moisture.

INTRODUCTION

Pine trees provide the United States economy with a plethora of goods, as well as jobs for cultivating, managing, harvesting, and processing timber into goods. The southeastern region of the United States has the largest total forestland and timberland as compared to the other regions of the United States, or to any other country since 1986 (Wear and Greiss 2011). Forestland was defined as "land at least 10 percent stocked by forest trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated" (U.S. Census Bureau 2011). Timberland was defined as "forest land that is producing or is capable of producing crops of industrial wood and that is not withdrawn from timber utilization by statute or administrative regulation" (U.S. Census Bureau 2011). By having the largest amount of forested and timbered land, the southern U.S. is the largest producer of sawtimber, as measured by board feet, timber growth, and timber removals. Most trees that are harvested have a diameter of at least five inches and are taller than four and a half feet (U.S. Census Bureau 2011). As of 2009, the timber industry provided more than one million jobs, and the government provided aid to help forest owners, which included fire protection (Wear and Greiss 2011).

In 1985, southern pine trees accounted for 37 percent of the country's soft wood timber, and as of the 1990's, planted pines consist of 19 percent of forest (USDA 1985, Wear and Geiss 2011). Southern pine species include longleaf pine (*Pinus palustris*), loblolly pine (*Pinus taeda*), slash pine (*Pinus elliottii*), and shortleaf pine (*Pinus echinata*). Products that result from southern pines include pulpwood for the paper industry; poles used for telephone lines and power lines, as well as construction; plywood; and railway ties (USDA 1985). Loblolly pine (*P. taeda)* is the most abundant species and is the focus of this study. *P. taeda* has the widest range of any southern pine species, from Texas to Virginia, and grows best in sandy soils, which are dominant in the southeast. The majority of the timber used for paper in the United States is *P. taeda* because more than half of the paper industry's resources come from the southeast where it is the most abundant species (Doran et al. 2009). Pine trees are also important because they sequester a large amount of carbon, release large amounts of oxygen back into the atmosphere, and could be used as a bioenergy source (Stoy et al. 2008, Wear and Greiss 2011).

Stomatal conductance simultaneously controls the amount of CO_2 that a plant can absorb from the atmosphere, as well as plant transpiration (Phillips et al. 2002). Since stomata are regulated in order to control the amount of gas exchange, conductance is controlled. Conductance (G_c) is the rate at which transpiration occurs. Transpiration (T) is the loss of water through the stomata. When there are drought conditions, carbon assimilation will be lower due to lower stomatal conductance because there is less available water for transpiration.

This study is part of the United States Department of Agriculture (USDA) Forest Service's Remote Assessment of Forest Ecosystem Stress (RAFES) project (Novick et al. 2011). The project aims to develop procedures to "permit automated quality control and analysis of sap flux data," and to use process-based models to "identify periods of tree moisture stress" (Novick et al. 2011). Sap flux is related to the water use of a tree. The RAFES project will provide land managers with real time meteorological and edaphic conditions, and a model of how trees responded to similar conditions in the past.

The goals of this project are to (1) perform quality control on meteorological data, (2) determine conductance and transpiration rate, and (3) identify the critical soil moisture level at which stomatal conductance becomes limited in pine trees. Hourly meteorological and sap flux data from five sites for nearly the past three years will be quality controlled and analyzed. Data will then be compared to models in order to identify the critical soil moisture threshold.

METHODS

Data were collected via satellite-connected probes from June 2010 until August 2012 with the exact begin and end date varying between the five study sites, and was placed on a continuous time stamp from January 1, 2010 to December 31, 2012. Data collected included year, day of year, hour, minute, battery voltage, air temperature, relative humidity, fuel moisture, fuel temperature, soil moisture, soil temperature, soil matric potential, photosynthetically active radiation, precipitation, and sap flux. Data were processed using Matlab® (Mathworks, Natick, Massachusetts).

Study locations

Meterological and sap flux data were collected in six sites in the Southeastern United States: two sites in the Duke Forest (Blackwoods Upper and Lower), one site in Southern Arkansas (Crossett), one site in Southwestern Georgia (Jones Center), and one site in Eastern North Carolina (Parker). The Blackwoods Upper and Lower sites are located in the Blackwoods Division of Duke Forest near Chapel Hill, North Carolina. The land was once over farmed and has depleted soils and nutrition (Duke forest at Duke University n.d.). The tree species studied at the Blackwoods Upper site consist of red maple (*Acer rubrum*), loblolly pine (*Pinus taeda*), and white oak (*Quercus alba*) (Novick et al. 2011). The tree species studied at the Blackwoods Lower site consist of red maple (*Acer rubrum*), loblolly pine (*Pinus taeda*), and tulip poplar (*Liriodendron tulipifera*) (Novick et al. 2011).

The Crossett site is located in Crossett, Arkansas. The area was used by the lumber industry prior to becoming a research station for the United States Department of Agriculture (USDA) in 1934 (Adams et al. 2004). The studied tree species is loblolly pine (*Pinus taeda*) (Novick et al. 2011).

The Jones Center site is located in the Joseph W. Jones Ecological Research Center at Ichauway in Newton, Georgia. Prior to being a research center, the Joseph W. Jones Ecological Research Center was a hunting reserve for quail (Jones Center n.d.). The studied tree species at this site is longleaf pine (*Pinus palustris*) (Novick et al. 2011).

The Parker site is located in Roper, North Carolina. The site has a long record of being part of a pine plantation (Ameriflux n.d.). The studied tree species at this site is loblolly pine (*Pinus taeda*) (Novick et al. 2011).

Meterological and Edaphic Data

Meteorological and soil data at each site were measured at a climate station located in a clearing near the study sites. Six trees were monitored at each site. Fuel temperature and moisture of the fuel were measured from probes inserted into each tree. Soil moisture and temperature were recorded from probes that were inserted into the ground adjacent to the base of the tree. PAR, Photosynthetically Active Radiation, was measured with a Li-190 Quantum Sensor (Li-Cor Biogeosciences, Lincoln, NE, USA). Precipitation was measured with a tipping bucket. Relative humidity and air temperature were measured with a HMP-45C TA/RH probe (Vaisala, Vantaa, Finland). Soil moisture content in the top 30 cm of the soil was monitored at three locations in each site using a CS616 water content reflectometer (Campbell Scientific, Logan, UT, USA). Sap flux was measured using Granier-type sap flux probes using the same procedures as Ford et al. (2004). A set of brass tubing was inserted 1.3 m above the ground into vertically separated pre-drilled holes that were 5 cm apart and attached to a data logger. The lower probe was heated while the upper probe was not.

Vapor pressure deficit (D) was calculated from air temperature and relative humidity according to Campbell's equations (1977). I used Campbell and Norman's (1998) equation to calculate saturation vapor pressure from temperature:

$$e_s(T_C)=0.611\exp\left(\frac{17.502\times T_C}{T_C+240.97}\right),$$

where e_s is saturated vapor pressure and T_C is temperature in Celsius (Baldocchi 2012). Relative humidity is found by:

$$h_r=\frac{e_a}{e_s(T)},$$

where h_r is relative humidity, e_a is actual vapor pressure, and T is temperature (Baldocchi 2012).

Thresholds were placed on meteorological data in order to exclude data from malfunctioning probes, whether it was too high or too low. Any data that were recognized as bad were changed to -9999 in order to minimally affect equations. Precipitation data that were greater than 50 mm an hour were replaced. Air temperatures that were less than -10 °C, greater than 50°C or equal to zero were replaced. Relative humidity that was less than or equal to zero or greater than 110% was removed. Radiation (PAR) data that was less than -30 umol/m2/s or greater than 1,200 was replaced. Soil temperatures that were less than -2°C, greater than 60°C, or equal to zero were replaced. Fuel temperatures that were less than -20°C, greater than 60°C, or equal to zero were replaced. Matric potential data that was less than -2°C, greater than 20°C, or equal to zero was replaced. Sap flux data that was less than one or greater than 50 was replaced. Data were recorded and stored at hourly intervals.

Sap Flux Data

Raw temperature data from the sap flux probes that were less than one or greater than 50 were replaced with -9999 in order to remove spurious data. Data were averaged over the 12 probes in order to normalize the data. I used Clearwater's equations (2004) to calculate sap velocity and the rate of sap flow from the raw temperature data. Clearwater's equation 1 for sap velocity is: $v = 0.119k^{1.231}$, where v is sap velocity, and k is related to the temperature difference between the two probes. The parameter k is determined as $(\Delta T_m - \Delta T)/\ \Delta T$, where ΔT_m is the maximum temperature difference between the probes observed each night when sap velocity is zero. The rate of sap flow through the sapwood, or transpiration (T), is then determined as T = vA, where A is the cross-sectional area of the sapwood.

Sap flux probes were determined to be malfunctioning by comparing data from one probe against other probes for the same tree. In this example, probes one and two are positively related (Fig. 1a). Probes two and three (Fig. 1b), as well as probes three and four (Fig. 1c), do not express the same relationship. Since probes one and four are positively related (Fig. 1d), then four must be positively related to probe two, and thus, probe three must be malfunctioning.

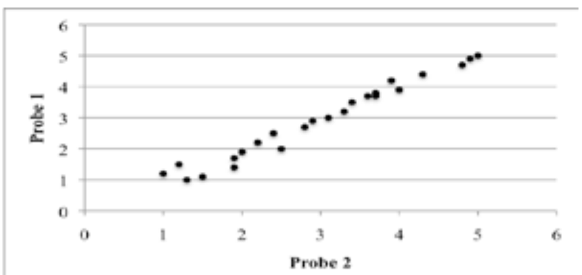


FIG. 1A. Probe 2 vs. Probe 1.

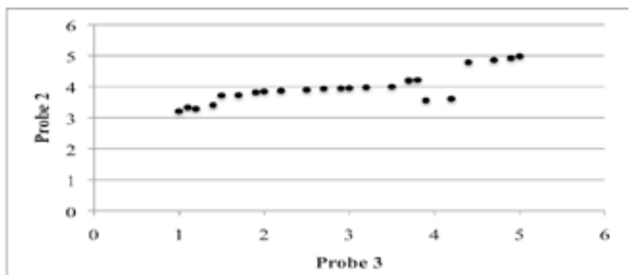


FIG. 1B. Probe 3 vs. Probe 2.

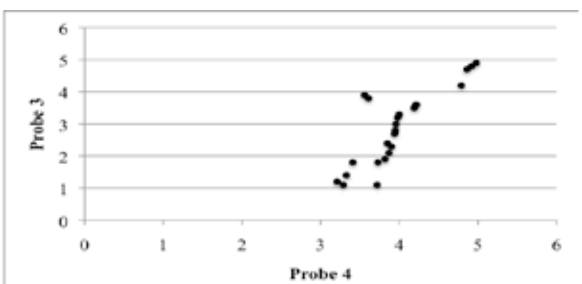


FIG. 1C. Probe 4 vs. Probe 3.

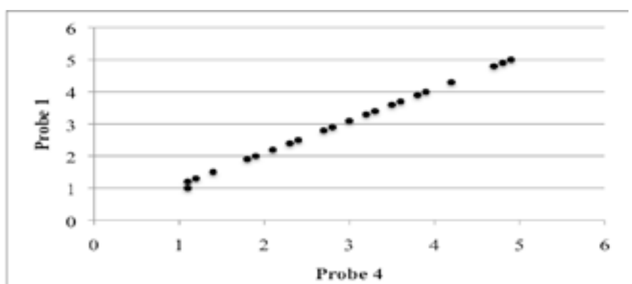


FIG. 1D. Probe 4 vs. Probe 1.

Derivation of conductance from sap flux and its relationship to meteorological data

Canopy stomatal conductance (G_c) was determined from the transpiration data and vapor pressure deficit data as:

$$G_c = T/D$$

Canopy stomatal conductance is related to meteorological variables like PAR, D, and soil moisture content (θ) according to:

$$g_c = g_{cref} * f(PAR) * f(D) * f(\theta),$$

where g_{cref} is the reference conductance for high PAR, high soil moisture content and vapor pressure deficit is 1 kPa.

RESULTS

Soil moisture content at each study site varied through the study period (Fig. 2a-2e). Soil moisture content is generally highest in the spring of 2011 (01Jan11 – 30Jun11), and lowest at the end of summer and fall of 2011 (30Jun11 – 01Jan12). For sites Blackwoods Upper, Blackwoods Lower, and Crossett, soil moisture content is consistent from year to year. Jones Center soil moisture content varies greatly from year to year. The Parker site results show a possible predictable trend pattern from year to year, but due to a large amount of missing data in 2012, the pattern is not as defined as at other sites. Drought seasons were during the end of the summer and the beginning of fall for all sites except for Jones Center.

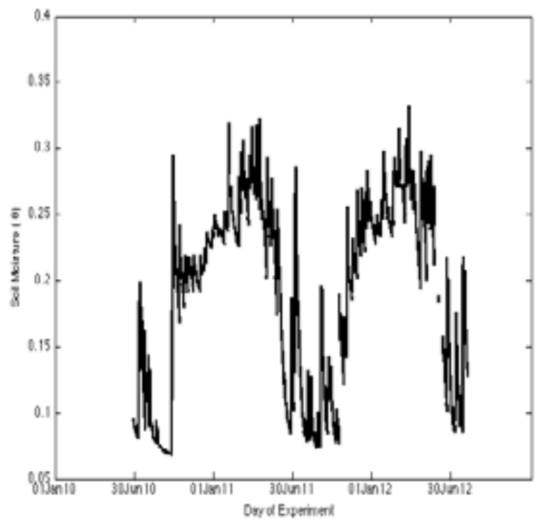


FIG. 2A. Blackwoods Upper soil moisture content.

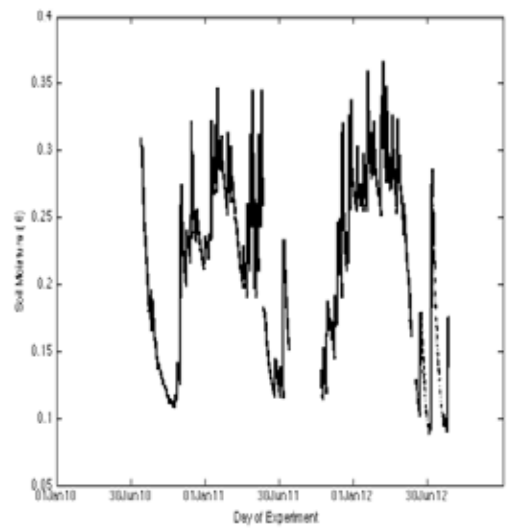


FIG. 2B. Blackwoods lower soil moisture content.

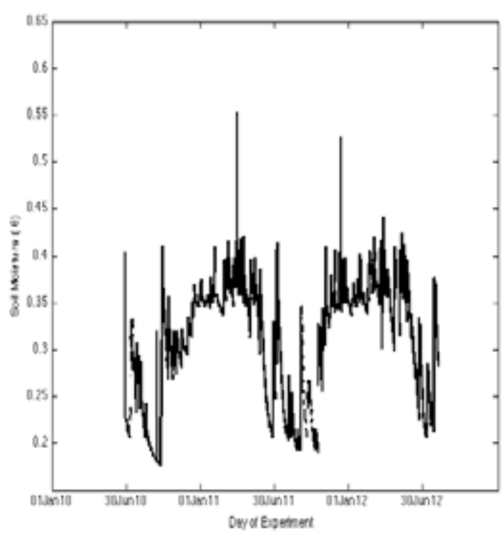


FIG. 2C. Crossett soil moisture content.

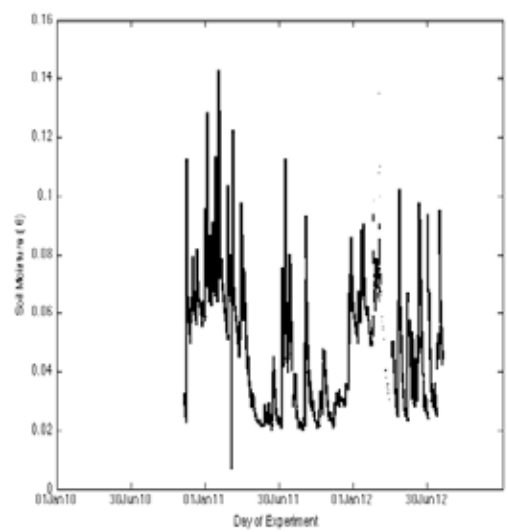


FIG. 2D. Jones Center soil moisture content.

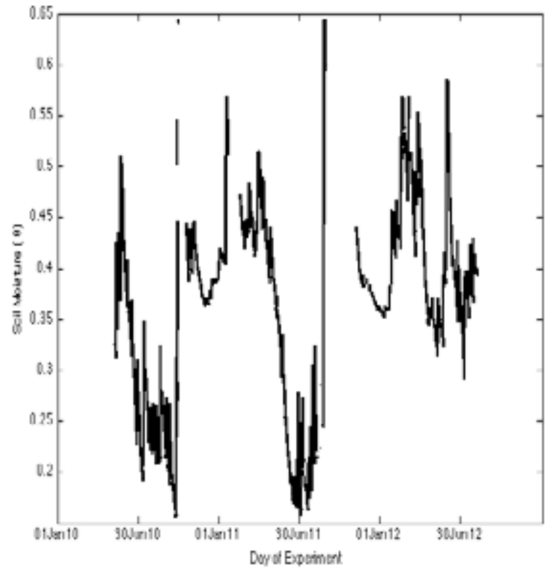


FIG. 2E. Parker soil moisture content.

Transpiration and conductance varied over time at each site (Fig. 3a – 3e). Gaps in data are present either because the probes went offline or the data were changed to -9999 for quality control. Transpiration is positively related to soil moisture. Transpiration patterns generally remain in a similar pattern from year to year with varying high points. Spikes in conductance data are caused when vapor pressure deficit (D) is low.

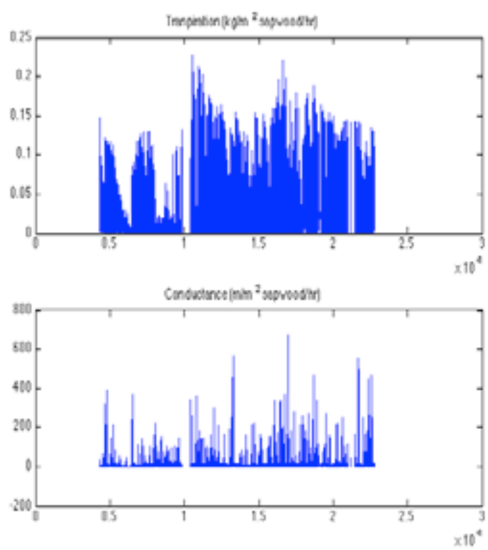


FIG. 3A. Blackwoods upper transpiration and conductance trends.

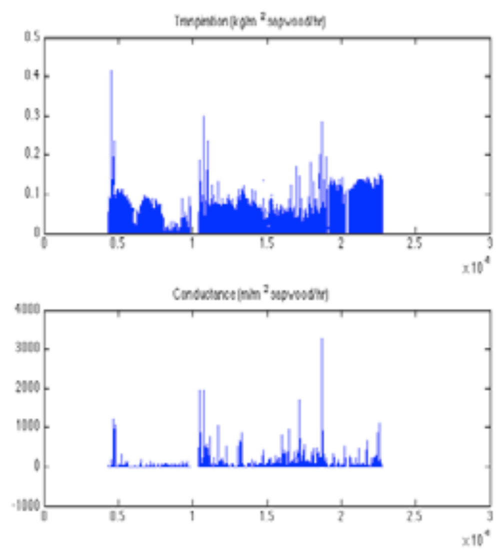


FIG. 3B. Blackwoods lower transpiration and conductance trends.

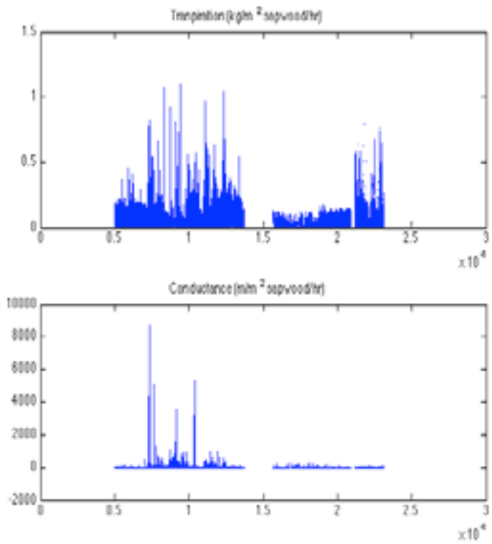


FIG. 3C. Crossett transpiration and conductance trends.

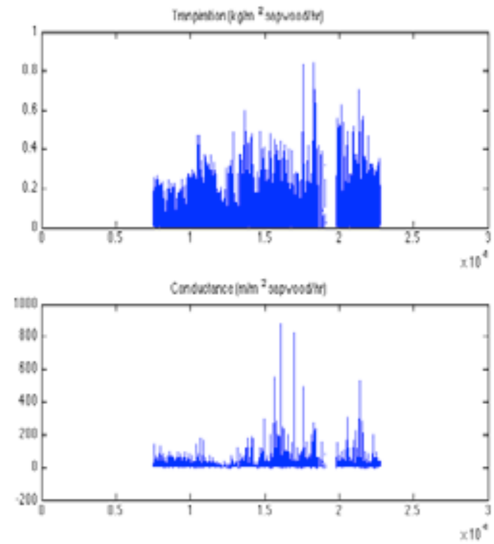


FIG. 3D. Jones Center transpiration and conductance trends.

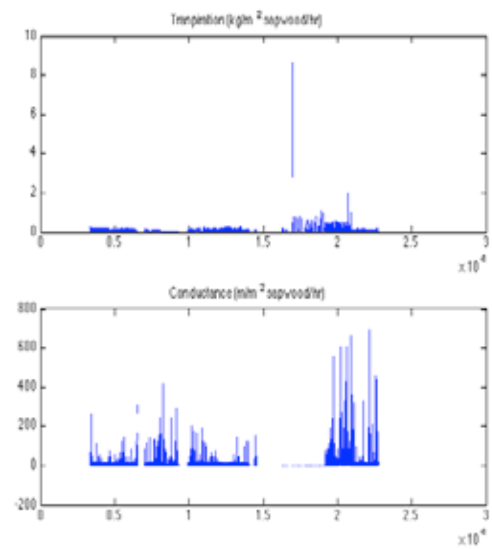


FIG. 3E. Parker transpiration and conductance trends.

Stomatal simulation varied with light when data were selected for high light and high soil moisture content, and vapor pressure deficit was set to one (Fig. 4a-3). If data followed multiple best-fit lines, then it was divided in order to show each best-fit line. G_{cref} is G_c when D is 1. At each site, G_c decreases as vapor pressure deficit (VPD = D) increases.

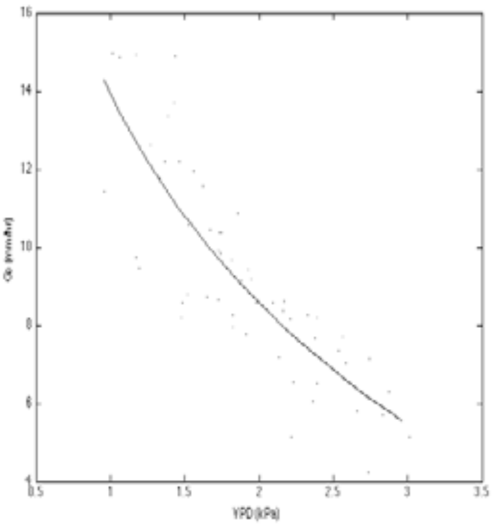


FIG. 4A. Blackwoods Upper VPD and conductance.

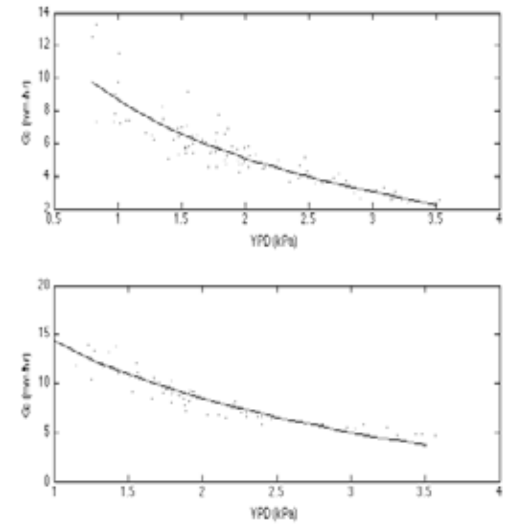


FIG. 4B. Blackwoods Lower VPD and conductance.

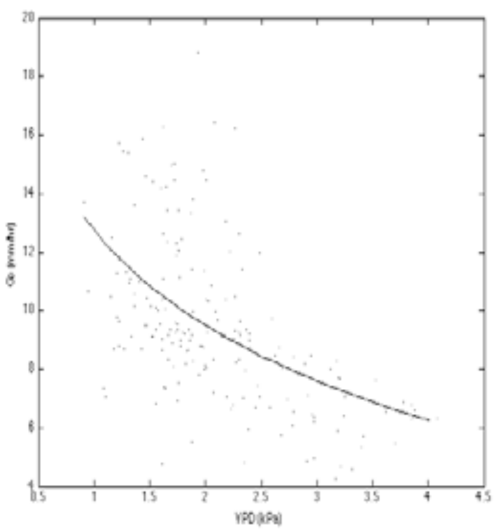


FIG. 4C. Crossett VPD and conductance.

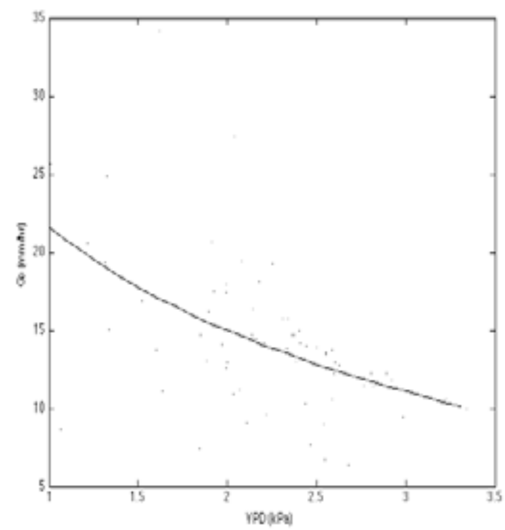


FIG. 4D. Jones Center VPD and conductance.

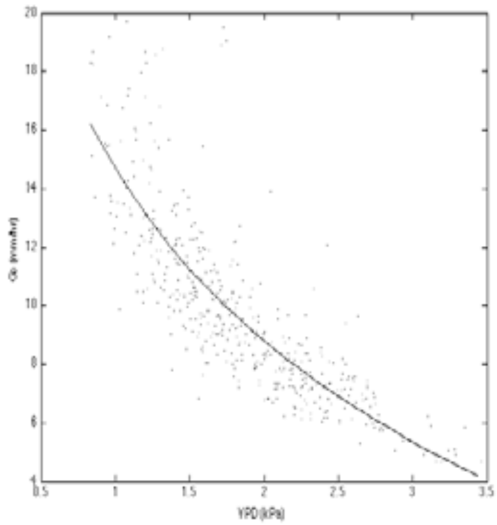


FIG. 4E. Parker VPD and conductance.

Conductance (G_{ref}) generally increases with soil moisture content for each site when data were grouped according to range of soil moisture content based on high light (Fig. 5a-e). G_{ref} increases with soil moisture content until reaching the threshold at which conductance no longer increases with soil moisture content but rather decreases as soil moisture increases. The Crossett site had a relatively high threshold, but conductance over the threshold rapidly decreased. Jones Center had a comparatively high threshold. Blackwoods Upper's critical soil moisture content was 0.14. Blackwoods Lower's critical soil moisture content was 0.3. Crossett's critical soil moisture content was 0.16. Jones Center's critical soil moisture content was 0.036. Parker's critical soil moisture content was 0.45.

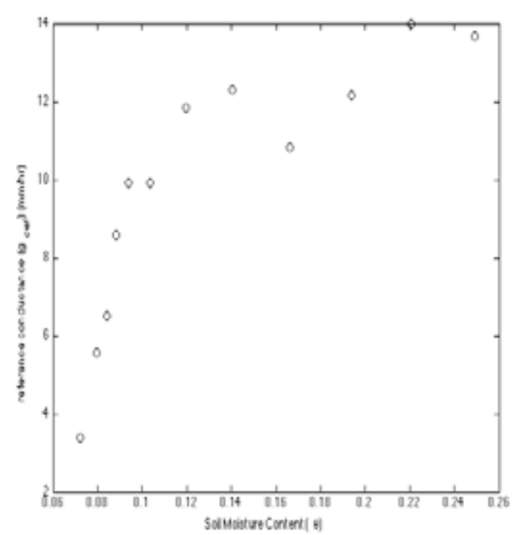


FIG. 5A. Blackwoods Upper conductance and soil moisture.

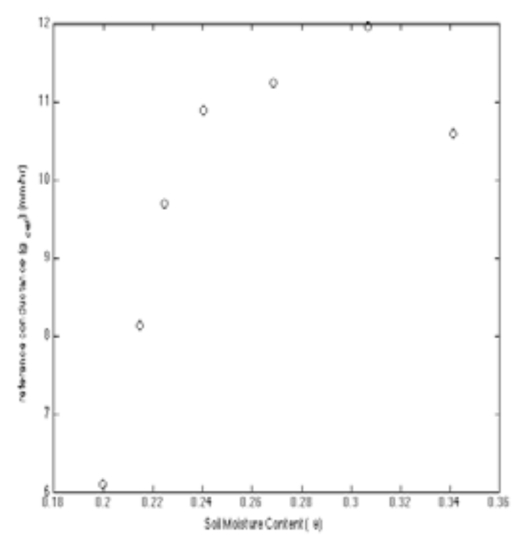


FIG. 5B. Blackwoods Lower conductance and soil moisture content.

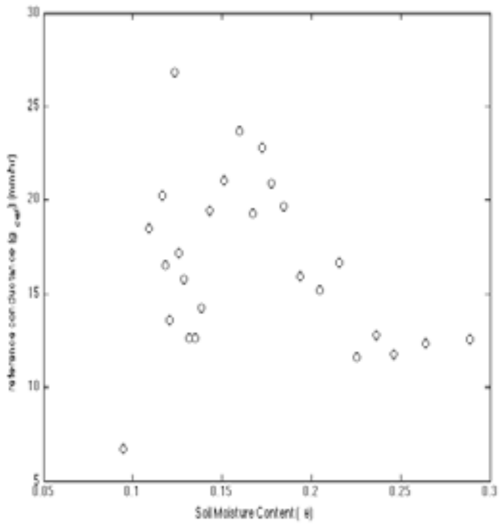


FIG. 5C. Crossett conductance and soil moisture content.

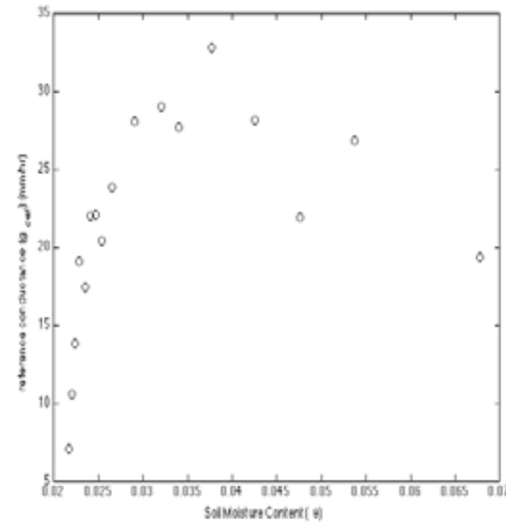


FIG. 5D. Jones Center conductance and soil moisture.

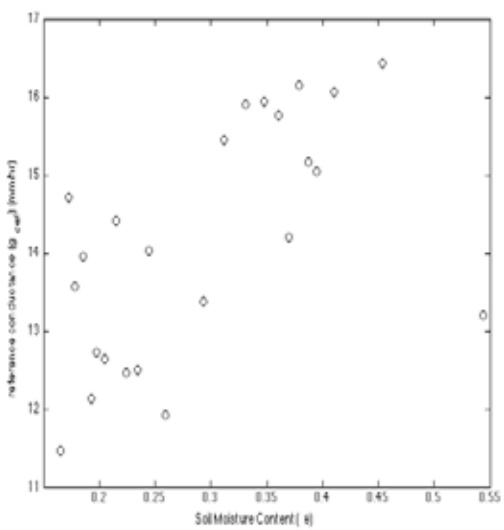


FIG. 5E. Parker conductance and soil moisture content.

DISCUSSION

Pine trees are an important timber resource and their management is of utmost importance. The southeastern United States has the largest percent of forested land, which provides most of the sawtimber for the nation (U.S. Census Bureau 2011). Land managers do not have a model designed specifically for them that provides information of when trees become stressed, primarily by water, on a local scale.

Southern pine trees require soil moisture levels that vary depending on site (Fig. 5a- 5e). Critical soil moisture contents varied from a low of 0.036 at the Jones Center to a high of 0.45 at the Parker site.

Limited soil moisture has the potential to reduce growth of southern pine trees. Water limitation causes reduction in stomatal conductance because leaves will close stomata in order to prevent or reduce water loss or damage (Oren et al. 1999). Stomatal conductance causes decreased carbon assimilation because plants are not taking in CO_2 to use for photosynthesis (Oren and Pataki 2001). The more carbon available, the more cells a plant creates, and the quicker it will grow. Land managers are interested in carbon assimilation because it is directly related to the size and quality of their timber.

The use of radial profiles contributed to error in the use of sap flux probes because of the difference in sap flux around the trunks of trees (Ewers et al. 2000). Also, sap flux changes over time (Ford et al. 2004). The coefficients in Clearwater's equations are not universal due to differences in active sapwood between species (Bush et al. 2010). Since data were taken as averages within species and species distribution data were not available, data is not scaled to canopy as many equations and methods used in this study are, and turbulence varies within the canopy, both vertically and horizontally, which affects vapor pressure deficit and transpiration (Ewers et al. 2000). The magnitude of conductance and transpiration is suspicious because of assumptions made of conductance data due to probe placement (Ewers et al. 2000). Soil moisture data are not precisely accurate because soil moisture sensor custom calibration was not performed for site-specific critical soil moisture meters. Even though the magnitude of transpiration conductance and soil moisture is uncertain, the trends in each over time should not be affected by errors in magnitude. Future studies will be needed in order to correct for errors and continuing the study by determining irrigation need.

ACKNOWLEDGEMENTS

I would like to thank those at Coweeta Hydrologic Lab, including Dr. Chelcy Ford and Chris Sobek for helping throughout the project. I would like to thank John Chamblee for providing me with MatLAB®. Thank you to Dr. Kim Novick for mentoring me through the entire process. Thank you to those at Highlands Biological Station, Tom Martin, Karen Kandl and Michelle Ruigrok, for providing guidance during the fall semester and providing so many opportunities.

LITERATURE CITED

Adams, M. B., L. Loughry, and L. Plaugher. 2004. Experimental forests and ranges of the USDA Forest Service. Gen. Tech. Rep. NE-321. Newtown Square, Pennsylvania, USA. Department of Agriculture, Forest Service, Northeastern Research Station.

Ameriflux is sponsored by Oak Ridge National Laboratory and describes the Parker site (http://ameriflux.ornl.gov/fullsiteinfo.php?sid=71).

Baldocchi, D. 2012. Lecture 14, water, humidity, pressure and trace gases, part 1 [lecture notes]. Retrieved December, 4, 2012, from http://nature.berkeley.edu/biometlab/.

Bush, S. E., K. R. Hultine, J. S. Sperry, J. R. Ehleringer. 2010. Calibration of thermal dissipation sap flow probes for ring- and diffuse-porous trees. Tree Physiology **30**:1545–1554.

Campbell, G. S., and J. M. Norman. 1998. An Introduction to Environmental Biophysics. Springer Verlag, New York.

Clearwater, M. J. 1999. Potential errors in measurement of nonuniform sap flow using heat dissipation probes. Tree Physiology **19**:681-687.

S. Decagon Devices' website describes the soil moisture sensor custom calibration (http://www.decagon.com/services/soil-moisture-sensor-custom-calibration/).

Doran, F. S., C. W. Dangerfield, F. D. Cubbage, J. E. Johnson, J. W. Pease, L. A. Johnson, and G. M. Hopper. 2009. Tree crops for marginal farmland: loblolly pine. Virginia Cooperative Extension. Retrieved November, 14, 2012, from http://pubs.ext.vt.edu/446/446-604/446-604.html.

Duke forest at Duke University describes the Duke forest and Blackwoods sites (http://www.dukeforest.duke.edu/forest/index.html).

Ewers, B. E., and R. Oren. 2000. Analyses of assumptions and errors in the calculation of stomatal conductance from sap flux measurements. Tree Physiology **20**:579–589.

Ford, C. R., M. A. McGuire, R. J. Mitchell, and R. O. Teskey. 2004. Assessing variation in the radial profile of sap flux density in Pinus species and its effect on daily water use. Tree Physiology **24**:241–249.

Joseph W. Jones Ecological Research Center at Ichauway's website describes the foundation (http://www.jonesctr.org/index.html).

Novick, K. A., B. D. Clinton, and J. M. Vose. 2011. Identifying signals of tree water stress with data from a new stress monitoring network (poster). AGU Fall Meeting, Dec 5 – 9, San Francisco, California.

Oren, R., and D. E. Pataki. 2001. Transpiration in response to variation in microclimate and soil moisture in southeastern deciduous forests. Oecologia **127**:549 – 559.

Oren, R., J. S. Sperry, G. G. Katul, D. E. Pataki, B. E. Ewers, N. Phillips, and K. V. R. Schäfer. 1999. Survey and synthesis of intra- and interspecific ariation in stomatal sensitivity to vapour pressure deficit. Plant, cell and environment **22**:1515 – 1526.

Phillips, N., B. J. Bond, M. G. McDowell, and M. G. Ryan. 2002. Canopy and hydraulic conductance in young, mature and old Douglas-fir trees. Tree physiology **22**:205 – 211.

Stoy, P. C., G. G. Katul, M. B. S. Siquerira, J. Y. Juang, K. A. Novick, H. R. McCarthy, A. C. Oishi, and R. Oren. 2008. Role of vegetation in determining carbon sequestration along ecological succession in the southeastern United States. Global Change Biology **14**:1409–1427.

United States Census Bureau. 2011. Statistical abstract of the United States: 2011. Retrieved November, 14, 2012, from http://www.census.gov/prod/2011pubs/11statab/natresor.pdf.

United States Department of Agriculture. 1985. Retrieved November, 14, 2012, from http://www.fpl.fs.fed.us/documnts/usda/amwood/256spine.pdf.

EXPLORING THE DISTRIBUTION AND ECOLOGY OF *STEWARTIA OVATA* ALONG THE CHATTOOGA RIVER AND ITS DRAINAGES

SUSAN DEANS

Abstract. Stewartia ovata, or mountain camellia, is a rare shrub endemic to the southern Appalachian region. Due to its small and somewhat scattered distribution, not much is known about the ecology of this species. We located and collected data on the habitat and associated species of 75 sites with *S. ovata* present in the Chattooga River watershed in federally owned lands in Georgia and South Carolina. Our findings indicate that ideal habitat conditions for the success of *S. ovata* include moist, low-elevation acidic cove forests in riparian zones with abundant light. Seeds are not often successful at germinating, but this process may be aided by the death of large hemlocks. Conservation efforts should focus on preserving sites where *S. ovata* currently occurs and on cultivation of this attractive native shrub.

Key Words: Stewartia ovata*; mountain camellia; Chattooga River; phylogeography; acidic cove forest; habitat; canopy gap; hemlock.*

INTRODUCTION

Stewartia ovata, the only representative of the Theaceae family found in the southern Appalachians, is a rare endemic shrub with showy white flowers (Swanson 1984). Commonly referred to as mountain camellia, it is found in six states in the Southeast, but is not common in any portion of its range (www.natureserve.org/explorer/). There is only one other native *Stewartia* found in the Southeast: *Stewartia malocodendron* or silky camellia, another rare shrub similar to mountain camellia but found in an entirely different habitat (Prince 2009). *Stewartia malocodendron* is found only at lower elevations, usually around coastal plain swamps, while *S. ovata* is more commonly found in acidic montane coves and mesic forests (Weakley 2011). Mountain camellia has an S-2 or "imperiled" ranking in North Carolina, South Carolina, Virginia, and Alabama, an S-1 or "critically imperiled" ranking in Mississippi, and an S-3 or "vulnerable" ranking in Georgia and Kentucky. Due to its sensitivity to human disturbance and habitat fragmentation, and its slow growing habit, it is not an abundant plant despite its relatively broad range (www.natureserve.org/explorer/).

Not only is *S. ovata* unusually rare, its phylogeography remains mysterious. The genus *Stewartia* exhibits a distribution pattern that about 60 other woody plant genera share—the southeastern United States and eastern Asia disjunction (Xiang et al. 2004). This pattern was formed largely by climatic changes (Little 1983). Fossil records suggest that many woody plant species were widely spread across the temperate northern hemisphere in what is known as the Arcto-Tertiary Flora. When the last glaciations occurred, eastern North America and eastern Asia were two of the only places that served as refugia for these woody species (Little 1983). Despite surviving in both regions, most of these genera have far more species in eastern Asia. *Stewartia* is no exception with around 18 representatives in Asia and only two in North America. Higher rates of net speciation and molecular evolution occur in eastern Asia when comparing different members of the same woody plant genera, potentially causing this diversity (Xiang et al. 2004). Possible explanations include greater topographic and climatic diversity in eastern Asia creating more ecological niches, physical barriers, and low dispersal, leading to sexual isolation (Xiang et al. 2004). This may have led to the generation of many more species of *Stewartia* in eastern Asia than in the southeastern U.S. It is worth noting that *Stewartia* is the only genus in the Theaceae to exhibit this disjunct distribution—the other genera exist within only one geographic region (Prince 2009).

The phylogenetic relationships between the North American and Asian *Stewartia* species remain unclear. Two (possibly distinct) genera, *Hartia* and *Stewartia* make up the monophyletic tribe Stewartieae in the family Theaceae (Prince 2002). These genera differ in that *Hartia* species are evergreen and have winged petioles, whereas all *Stewartia* species (both new and old world) are deciduous and lack a winged petiole. Pollen studies also demonstrate numerous differences between *Hartia* and *Stewartia* species (Heo et al. 2011). However, other evidence suggests the two groups may belong in a single genus, *Stewartia.* Data from nuclear and chloroplast DNA from *Stewartia* and *Hartia* reveal that the two species of *Stewartia* found in the eastern U.S. likely form a clade with the evergreen *Hartia* species of eastern Asia, and that the rest of the deciduous *Stewartia* in eastern Asia form a clade of their own (Prince 2002). The pollen of new world *Stewartia* show mixed characteristics, sharing features with both *Hartia* and old world *Stewartia* (Heo et al. 2011). Essentially, there is no consensus on whether *S. ovata* is more closely related to the evergreen *Hartia* or the old world *Stewartia.*

There has been little research on the ecology of mountain camellia, perhaps due in part to its elusiveness. It often grows in dense thickets of rhododendron, which are difficult to navigate. It is an inconspicuous shrub with broadly elliptic, slightly pubescent leaves and tan, furrowed bark (Radford 1968). It is notoriously difficult to cultivate, due to its slow growth and the difficulty of getting seeds to germinate and survive the winter. Any conservation efforts would require more information about the distribution of mountain camellia within its range. There is currently very sparse information available of this kind.

The goal of this research project was to explore a portion of the range of *Stewartia ovata* in order to better understand the ecological conditions that support this shrub and its pattern of distribution in the southern Appalachians. We visited known populations in drainages of the Chattooga River, and explored potential habitat in search of new populations. We compiled a database of habitat characteristics of known *Stewartia* populations, including associated plants and environmental conditions. We also recorded the exact location of every population we found in order to improve our understanding of the specific range and biogeography of this rare species.

MATERIALS AND METHODS

Study Area

The Chattooga River forms the northwestern border between Georgia and South Carolina. It is the only river in the southeastern U.S. with the Wild and Scenic designation. This mandates a protective corridor around the river from its headwaters below Whiteside Mountain in North Carolina to the Tugalo Dam in South Carolina, 58 miles downstream (www.rivers.gov). The study area consisted of areas within Chattahoochee National Forest in Georgia, Sumter National Forest in South Carolina, and Ellicott Rock Wilderness Area in South Carolina. These areas are in Rabun County, Georgia and Ocoee County, South Carolina. We focused our search for *S. ovata* in riparian acid cove forests, ranging in elevation from 1,000 to 2,500 feet. We surveyed the riparian zone of sections of the Chattooga River within the protective corridor, as well as riparian zones of several tributaries of the Chattooga River. Surveys for *S. ovata* took place during September, October, and November of 2012.

Methodology

Stewartia ovata prefers well-drained, acidic soil in or near the floodplain, and relatively sterile, often Ericaceae-dominated understory (J. Johnston, pers. comm.). We used several characters to identify individual plants, including alternate leaf arrangement, intersecting ridges on the bark, broadly ovate leaves with cilia along the margins and veins, and a rounded crown (Radford 1968).

For each positively identified *S. ovata* site, we recorded the latitude and longitude and number of plants present. Because *Stewartia* often has many shoots coming from one root stock, we counted individuals rather than stems. We did not include seedlings or plants shorter than ~1m as separate plants, but noted their presence and approximate abundance for each site. We recorded the associated plant species for each site, including the most abundant overstory trees, dominant shrubs, and any abundant herbaceous plants or vines. Other aspects of the habitat were also noted, including the presence of significant canopy gaps, proximity to water (whether the site was within 50 meters of a creek or river), and any evidence of recent disturbance or interference with natural growing conditions such as fire, cutting, or herbicide application.

Collection

I collected nine specimens of *S. ovata* and pressed them using a plant press. These specimens were taken from plants at nine different sites, most of which were undiscovered prior to this project. I selected a portion with leaves that were relatively intact, with color and arrangement that seemed representative of the site from healthy looking plants. These specimens and associated data will be archived in the herbarium at the University of North Carolina at Chapel Hill. There are limited herbarium specimens of this species currently available because of its small range, so these specimens will be helpful in future research about the morphology and distribution of *S. ovata*.

RESULTS

Locations

We located 75 separate sites with *Stewartia ovata* present, totaling 550 individual plants. Most of these sites had fewer than 10 individuals, though 16 had more than 10, including one site with 70 individuals (FIG. 1). Even though some of these less populated sites were in close proximity, they were recorded as two sites because they were not within visual distance of one another.

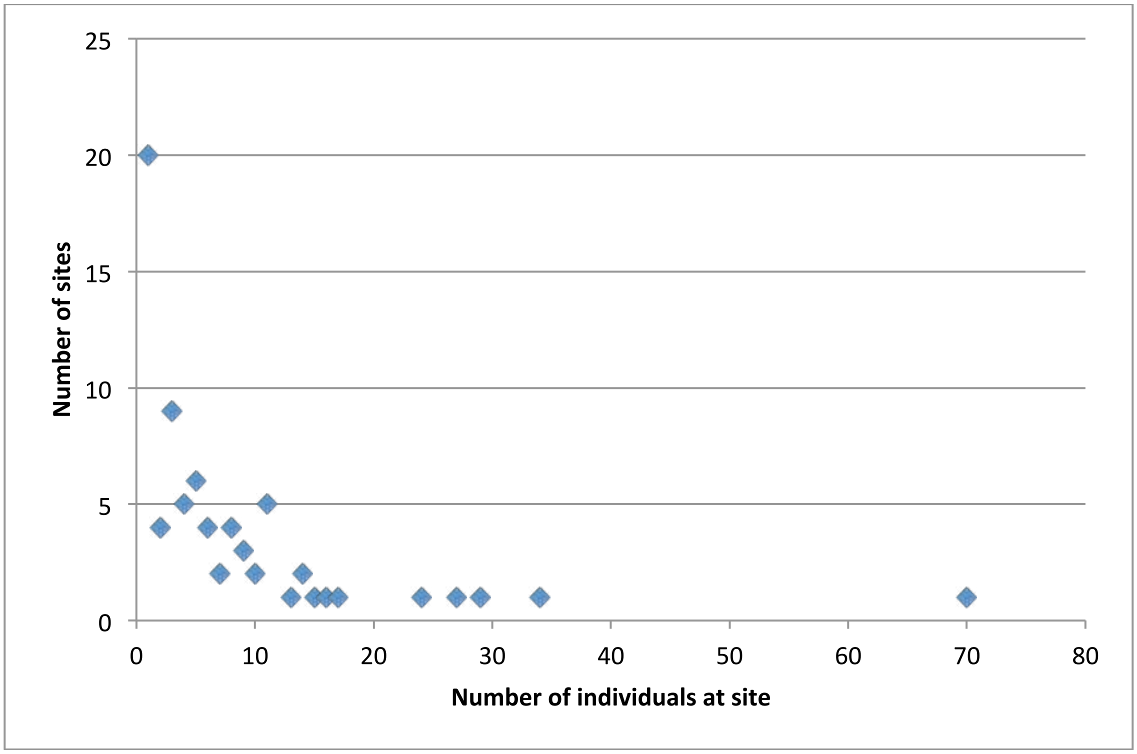


FIG. 1: Number of sites by number of individuals.

There were four separate areas that had large numbers of sites with *S. ovata* present. Warwoman Creek and its tributaries (including Sarah's Creek, Walnut Fork, and Tuckaluge Creek) in the Chattahoochee National Forest in Georgia had 34 sites (FIG. 2). The southern portion of the Chattooga River in the Chattahoochee National Forest in Georgia and the Sumter National Forest in South Carolina had 17 sites (FIG. 3). The area around Holcomb Creek, Big Creek, and Long Branch in the Chattahoochee National Forest had 13 sites (FIG. 4). The northern portion of the Chattooga River in the Ellicott Rock Wilderness Area of Georgia and South Carolina had 11 sites (FIG. 5).

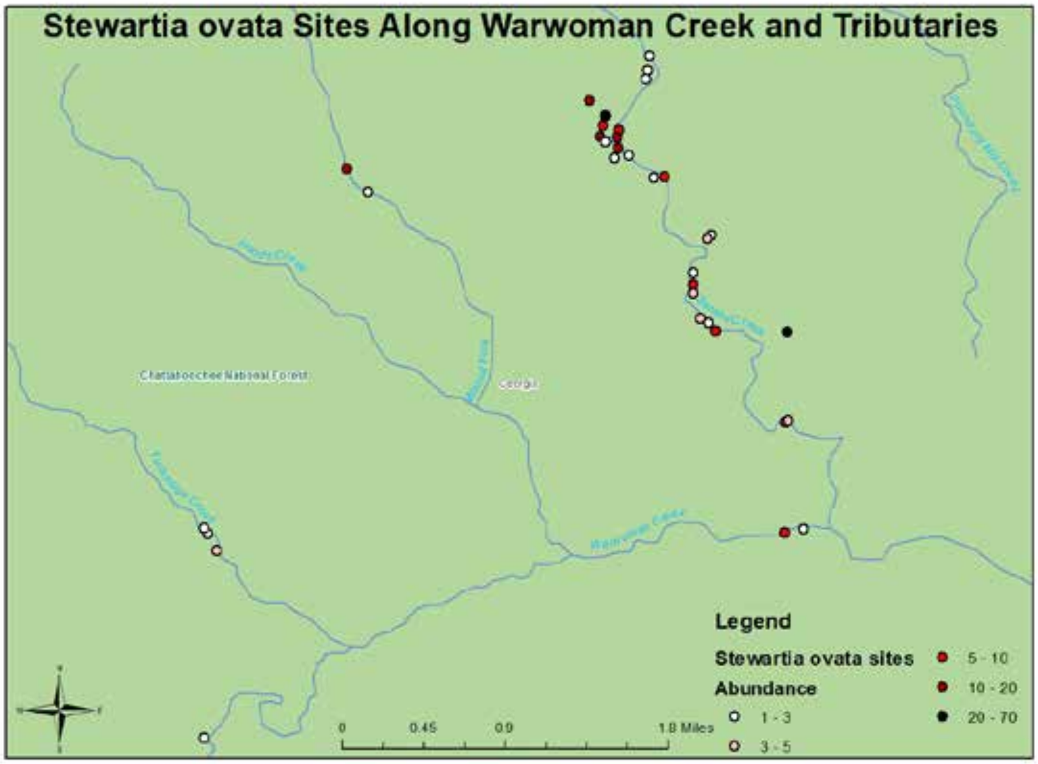


FIG. 2: Site localities on Warwoman Creek and tributaries.

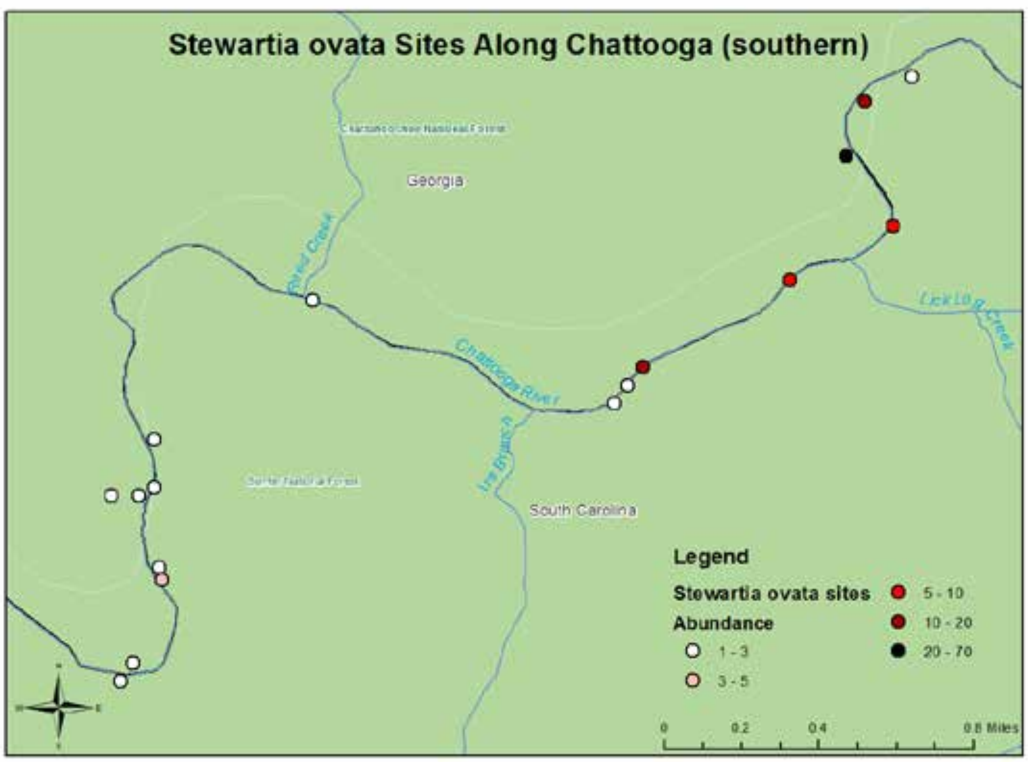


FIG. 3: Site localities on Southern portion of Chattooga River.

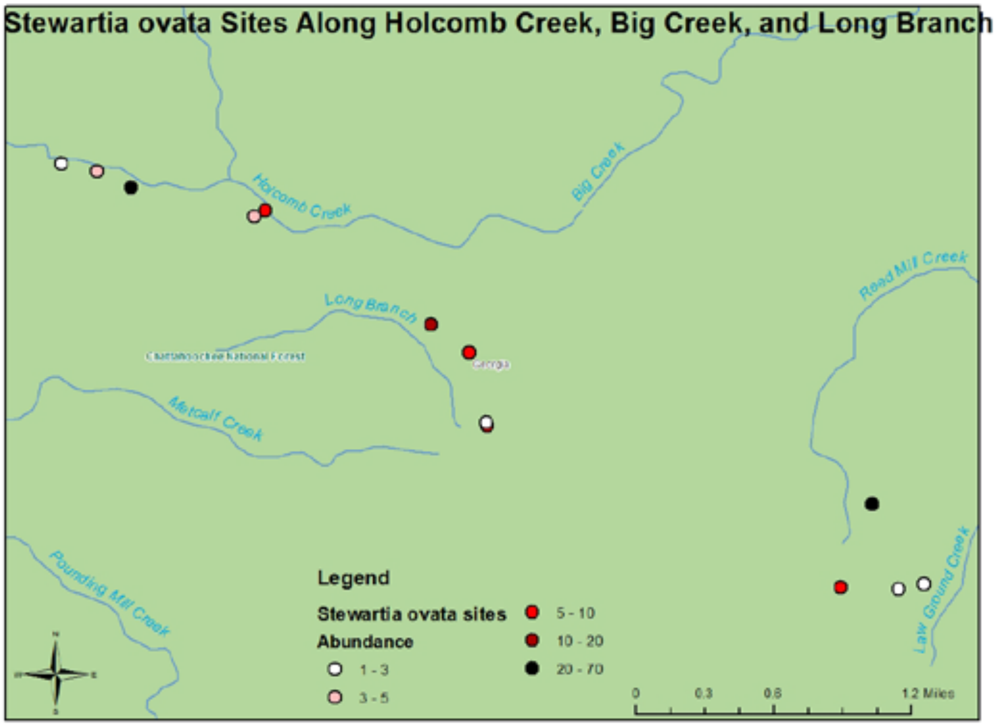


FIG. 4: Site localities in Holcomb Creek area.

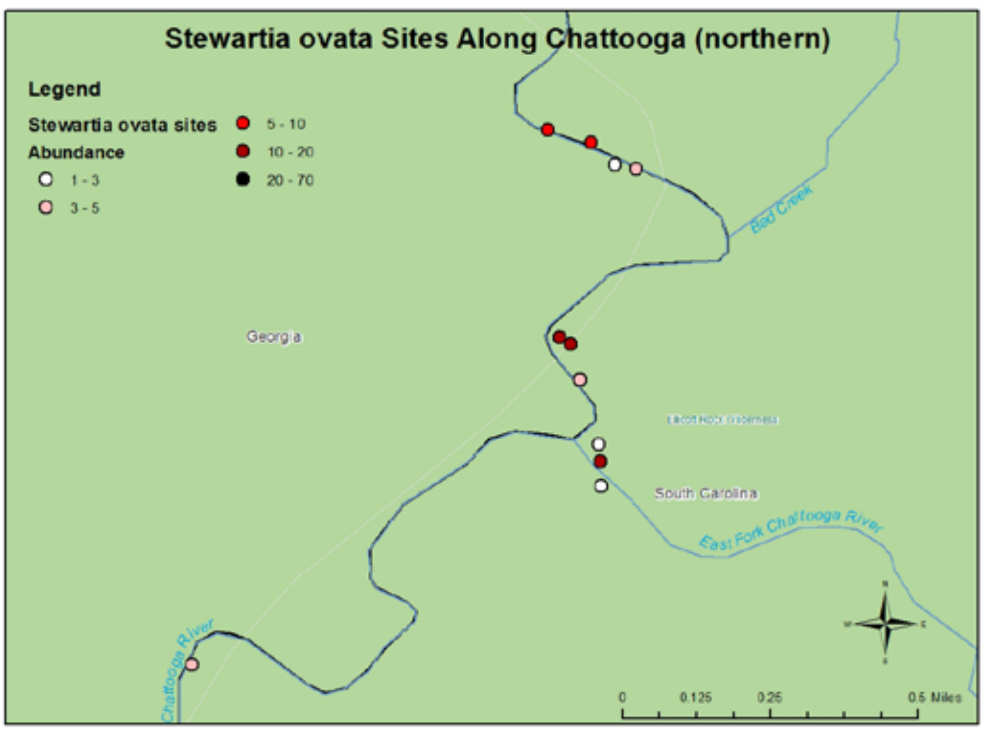


FIG. 5: Site localities on Northern portion of Chattooga River.

Habitat

Ninety-three percent (70 total) of these sites occurred within 50 meters of flowing water, either by the Chattooga or one of its smaller tributaries. Only five sites were not close to water, but most of these were in depressions and well-drained soil, or near springs.

Seventy-four of the 75 sites existed beneath a canopy gap. The causes of these gaps varied. Natural gaps next to the river or stream provided suitable habitat for *S. ovata*. There were also many sites alongside forest service roads or trails, where the cleared vegetation provided additional light. Still other sites occurred around the edges of camping areas. A few sites had canopy gaps caused by the recent death of large plants that had previously shaded the area, primarily hemlocks killed by the woolly adelgid. The sites with canopy gaps that had been created recently (usually from hemlock deaths) also had seedlings. This is significant, as seedlings were only observed at 22% of the sites. Of these, 100% were beneath a canopy gap and about a third had canopy gaps that appeared to be recently created.

Aside from recent canopy gaps, there were several other observable recent disturbances at many sites. Most of the sites near camping areas had individuals that were damaged in some way, usually from being cut back or destroyed. Two sites experienced a fire that killed the main stems of some individuals, causing them to die and new sprouts to grow from the root stock. One site had several plants that had been destroyed by beavers. Another site was adjacent to an area that had been sprayed with herbicide intended to kill kudzu. The plants at this site were damaged, some by kudzu overgrowth and others by herbicide overspray. The majority of damaged plants were near campsites.

The most typical environment that these sites existed in was an acidic cove plant community. This is a fairly common community type at lower elevations in moist areas like the Chattooga River drainage. It is characterized by a relatively sterile and open understory dominated by *Rhododendron maximum* (rosebay rhododendron) and/or *Leucothoe fontanesiana (*dog hobble) (Schafale 2012). The main trees in this community are *Liriodendron tulipifera* (tulip poplar)*, Betula lenta* (sweet birch)*, Tsuga canadensis* (Canadian hemlock)*,* and *Acer rubrum* (red maple) (Schafale 2012) (Table 1).

TABLE 1. Most common associates at all 75 sites.

Type	Species Name	Sites (out of 75) Containing Species
Tree	*Acer rubrum*	79%
	Tsuga canadensis	65%
	Pinus Strobus	61%
	Oxydedrum arboreum	52%
Shrub	*Kalmia latifolia*	64%
	Rhododendron maximum	61%
	Leucothoe fontanesiana	31%
	Ilex opaca	39%
Herb	*Polystichum achrostichoides*	45%
	Hexastylis sp.	32%
	Mitchella repens	29%
	Thelypteris novaboracensis	29%

Because 44 of the 75 sites had only five or fewer individuals of *S. ovata*, observations of the growing conditions of the most successful sites may be more indicative of the ideal habitat preferred by *S. ovata.* Sixteen of the 75 sites had more than 10 individuals, representing about 21% of the overall sites. Of these 16 sites, all of them were in a canopy gap and 14 were within 50 meters of flowing water. The most common associated species for these higher abundance sites are slightly different than those of the all the sites together (Table 2).

TABLE 2. Most common associates at the 16 sites with more than 10 *Stewartia ovata*

Type	Species Name	Sites (out of 16) Containing Species
Tree	*Acer rubrum*	81%
	Oxydendrum arboreum	75%
	Liriodendron tulipifera	63%
	Tsuga canadensis	56%
Shrub	*Gaylussacia ursina*	38%
	Kalmia latifolia	38%
	Ilex opaca	31%
	Hamamelis virginiana	25%
	Rhododendron maximum	25%
	Leucothoe fontanesiana	25%
	Halesia caroliniana	25%
Herb	*Polystichum achrositchoides*	50%

The main difference in the associates at the sites with higher abundance of *S. ovata* was the increase in frequency of *Oxydendrum arboreum* (sourwood) and *L. tulipifera* (tulip poplar) in the canopy. The frequency of the most common shrubs was also different—there was a higher occurrence of shrubs that were not present at as many of the overall sites. Shrubs like *Halesia caroliniana* (Carolina silverbells), *Hamamelis virginiana* (witch hazel), and *Gaylussacia ursina* (bear huckleberry) were all more frequent at the sites that had more than 10 individuals of *S. ovata* than they were at all of the sites combined. It is noteworthy that for this subsection of sites, there was only one herbaceous species that occurred in more than two of the sites, *Polystichum acrostichoides* (Christmas fern), which occurred at about the same frequency as it did in the overall comparison. Most of these sites had a very sparse herbaceous layer, and 25% had no herbaceous associates at all.

DISCUSSION

The vast majority of the sites in this study exist beneath a canopy gap, indicating the importance of abundant light for the success of *S. ovata*. In addition, most *S. ovata* were within 50 meters of flowing water, and were often situated at the bottom of a slope. They also were often associated with dense evergreen shrubs, such as *K. latifolia, L. fontanisana,* and *R. maximum.* These factors suggest that moist environments with well-drained, acidic soils are ideal for *S. ovata.* In addition, *S. ovata* may occur commonly with *R. maximum* not only because it is a common acidic cove species, but also because they share a mycorrhizal relationship (J. Johnston, pers. comm.).

Most of our study sites had very low numbers of individuals. The cause of this is uncertain. One explanation is that seedlings are rarely found near their parent plants in normal growing conditions (J. Johnston, pers. comm.).

Most of our sites did not have seedlings present. However, when there is a disturbance that creates additional light for a site, seedlings are more likely to exist. This was observed repeatedly, as *Tsuga canadensis* was one of the more common associated species. When a large, recently dead *T. canadensis* was present, creating an influx of light, it was common to find seedlings at the site. Within the study area, there are no old-growth hemlocks remaining (J. Johnston, pers. comm.).

The range of *S. ovata* is limited to the southern Appalachians (Kartesz 2011). The acidic coves in which it occurs in northwestern Georgia and northeastern South Carolina likely served as habitat refuges for this species during the last glacial periods. The current distribution likely represents the remnants of what was once a more broadly distributed plant, though this is uncertain. It appears that hotter or colder climates are unfavorable to this species, as individuals in Alabama (hotter) and the Cumberland mountains of Kentucky (colder) tend to be much smaller and less successful (J. Johnston, pers. comm.). This suggests that changing climactic conditions could further restrict the range of *S. ovata.*

Stewartia ovata seeds take two to five years to germinate. Once they do germinate, the plants grow very slowly, and a single stem can persist for up to 80 years if undisturbed. The roots can then support the growth of subsequent stems after the main stem dies, but eventually stop growing altogether, killing the plant (Johnston, pers. comm.). This could be one the main causes of its rarity. Because it grows so slowly, and its seeds take so long to germinate, usually requiring dispersal away from the parent, it may simply not have had enough time to spread to other suitable habitats since glaciation.

Additionally, human disturbance of the forests that it inhabits has increased drastically in recent years. Activities such as agriculture, clearing of roads, camping, and introduction of alien invasive species like kudzu all threaten *S. ovata.* The protective corridor along the Chattooga River due to its Wild and Scenic designation has sheltered many of the *S. ovata* sites from some of these threats, but still we observed damaged plants from campers and herbicides. In order to conserve *S. ovata* as a species, it is imperative that its habitat is protected. Additionally, cultivating *S. ovata* more broadly could allow it to persist more robustly. Because of its charismatic large flowers and rarity, mountain camellia has the potential to be horticulturally valuable.

Acknowledgements

I would like to thank Jack Johnston for the invaluable knowledge he shared about the distribution and cultivation of mountain camellia, and for the many hours that he spent in the woods with us searching for this plant. I am also grateful for the support and revisions provided by Karen Kandl and Michelle Ruigrok while writing this paper.

Literature Cited

Heo, Kyeong-in, S. L., C. Lee, and S. Kim. 2011. Generic delimitation and infrageneric classification of *Stewartia* and *Hartia* (Theaceae; Stewartiaea): insight from pollen morphology. Plant Systematics and Evolution **297:**33-50.

Johnston, J. Personal communication. Interview and email. December 2012.

Kartesz, J. T. 2011. The Biota of North America Program (BONAP). *North American Plant Atlas.* Retrieved November 10, 2012 from http://www.bonap.org/BONAPmaps2010/Stewartia.html.

Little, E. L. 1983. North American trees with relationships in Eastern Asia. Annals Missouri Botanical Garden **70:**600-615.

Prince, L. M. 2002. Circumscription and biogeographic patterns in the Eastern North American-East Asia genus *Stewartia* (Theaceae:Stewartieae): Insight from chloroplast and nuclear DNA sequence data. Castanea **67**(3):290-301.

Prince, L. 2009. Theaceae. Pages 322-323 *in* Flora of North America Editorial Committee, editors. Flora of North America North of Mexico. Flora of North America Association, New York, New York, USA.

Radford, A. E., H. E. Ahles, C. R. Bell. 1968. *Stewartia ovata*. Pages 707-708 *in* Manual of the vascular flora of the Carolinas. The University of North Carolina Press, Chapel Hill, North Carolina, USA.

Schafale, M. P. 2012. Classification of the natural communities of North Carolina: Fourth approximation. North Carolina Natural Heritage Program, Raleigh, North Carolina.

Swanson, R. E. 1994. A field guide to the trees and shrubs of the southern Appalachians. JHU Press, Boston, Maryland, United States.

Weakley, A. S. 2012. A flora of the Southeastern and Mid-Atlantic states. UNC Herbarium, UNC-Chapel Hill. <http://herbarium.unc.edu/flora.htm>.

USDA Plants Database. 2012. *Stewartia ovata* species page. United States Dept of Agriculture. Natural Resources Conservation Service. Retrieved October 29, 2012 from <http://plants.usda.gov>.

Xiang, Q., W. H. Zhang, R. E. Ricklefs, H. Qian, Z. D. Chen, J. Wen, and J.H. Li. 2004. Regional differences in rates of plant speciation and molecular evolution: A comparison between Eastern Asia and Eastern North America. Evolution **58**(10):2175-2184.

MAPPING THE DISTRIBUTION OF INVASIVE SPECIES *CORBICULA FLUMINEA* IN WESTERN NORTH CAROLINA

EJ DWIGANS

Abstract. Rivers in three major watersheds were surveyed to determine the distribution of *Corbicula fluminea* in Western North Carolina. *Corbicula* were observed to be present in the Little Tennessee River, the Tuckasegee River, and the Pigeon River. Based on our observations, dams serving as barriers to dispersal may limit upstream ranges, and cooler water temperatures may limit dispersal into tributaries and headwaters.

Key words: Asian clam; Corbicula fluminea*; Little Tennessee River; Pigeon River; Tuckasegee River.*

INTRODUCTION

Corbicula fluminea are small, lightly colored, filter-feeding bivalves whose native range lies within Southern Asia, the Eastern Mediterranean, Africa, and Southeast Asia (Morton 1986). Although they are considered an important fishery resource in Japan they are considered an invasive species in the United States (Kasai and Nakata 2005). Since they were first discovered in the Columbia River in Washington in 1938, they have spread rapidly across the U.S. (Counts 1986). Established populations of *Corbicula* were discovered in North Carolina near Charlotte by 1970 (Counts 1986). By 1986, *Corbicula* had established populations in several North Carolina rivers. They are now found in the majority of watersheds in the state (USGS 2004), though there are no records in the USGS Nonindigenous Aquatic Species database for the upper Tennessee River drainages in western North Carolina. The purpose of this study was to determine the distribution of *Corbicula* within several rivers in western North Carolina.

Due to their tolerance for warmer water temperatures and their ability to reproduce rapidly, *Corbicula* are well known as a bio-fouler of electrical and nuclear power plants that draw water for cooling purposes. Warm water effluent from these power plants provides ideal environments for maintaining established populations of *Corbicula*. *Corbicula* are introduced into water bodies by accidental bait bucket introductions, accidental introductions, and intentional introductions by people who buy them as a food source (Devick 1991). Accidental introductions occur when people unknowingly carry *Corbicula* larvae on their boats or by other means as they move between water bodies. Birds and fish are not thought to be important vectors of distribution (Counts 1986, Isom 1986), but Voelz et al. (1998) concluded that fish were at least partially responsible for upstream movements in a blackwater stream within the restricted access Savannah River Site.

The introduction of *Corbicula* has had major environmental, economic, and ecological impacts. Because *Corbicula* are a prominent bio-fouler they result in an estimated one billion dollars worth of removal costs each year. *Corbicula* have also been known to weaken concrete made with sand and gravel derived from *Corbicula* habitat because they can burrow to the surface as the cement sets (Sinclair and Isom 1961). The effects of *Corbicula* introduction on river ecosystem food webs are not completely understood but some studies indicate that fish may alter their diets to feed on *Corbicula* (Garcia 2005). There is conflicting evidence about whether or not *Corbicula* have an impact on the distribution of the already imperiled native mussel populations.

MATERIALS AND METHODS

Study Reaches

The Little Tennessee River is part of the Little Tennessee river basin and flows north and northwest from headwaters in northern Georgia through western North Carolina into Tennessee where it joins the Tennessee River. The river is impounded in the town of Franklin, NC by the Lake Emory Dam. Before reaching Lake Emory the river flows through a wide, flat valley. Below Lake Emory the river becomes swifter and more constricted before flowing into the Fontana Lake. Seven sites were sampled on the Little Tennessee River with the lower sampling site of the study being North of Franklin, NC off of Needmore Road and the upper sampling site of the study being South of Franklin, NC off of Riverside Road. Two tributaries were sampled including the Cullasaja River and Cartoogechaye Creek with one sample site on each.

The Tuckasegee River flows northwest beginning at the confluence of Panthertown Valley and Greenland Creek in Jackson County, NC and joins the Little Tennessee River within the reservoir created by Fontana Dam. There are several hydroelectric dams on the Tuckasegee and its tributaries, however Cullowhee Dam on the Tuckasegee River, and the Ela Dam on the Oconaluftee were the only dams within the study area. The lower sampling site of the study was in Bryson City, NC and the upper reach of the study was in Cullowhee, NC. The Oconaluftee River, Scotts Creek and Cullowhee Creek were also surveyed.

The Pigeon River begins near the Blue Ridge Parkway in southern Haywood County, NC and flows north into Tennessee where it joins with the French Broad River. It is impounded by Walter's Dam just before entering Tennessee as well as by a low-head dam on the property of a paper mill in Canton, NC. There is also a dam on Richland Creek, a major tributary to the Pigeon and another on the West Fork of the Pigeon upstream of Canton. The lower sampling site on the Pigeon was at Ferguson Bridge and the upper sampling site on the Pigeon was near the USGS gauging station upstream of Canton.

Survey Protocol

Sample sites were chosen based on accessibility. Bridges, public access points, and areas that provided easy access to the river from the road were preferred. At each site, we visually searched for any evidence of the presence of *Corbicula* such as living mussels, empty shells, or shell fragments for 30 minutes. If we found evidence of their presence, we collected 20 quantitative samples from suitable microhabitats across the river. Live *Corbicula* were collected by using a stovepipe sampler (0.324 m^2). To obtain a sample, the stovepipe sampler was placed on the river bottom in habitat likely to contain *Corbicula* across the breadth of the river. The stovepipe was placed firmly into the substrate and then we excavated about 8 cm of substrate from inside the stovepipe sampler. The contents of the sample were then examined for presence of *Corbicula* and the number of individuals present was recorded. Because our samples were taken from microhabitats with sand or gravel rather than random locations, our estimates represent maximum densities rather than mean densities. We continued to choose additional survey sites upstream until we were unable to find evidence of *Corbicula* presence during the 30-minute visual inspection at two consecutive sites.

RESULTS

Corbicula were found to be present in the Little Tennessee River, the Tuckasegee River, and the Pigeon River (Fig. 1). In the Little Tennessee River *Corbicula* were present between Fontana Lake and the Lake Emory Dam in Franklin, NC but were not found at survey sites upstream of Lake Emory. *Corbicula* were found to be present on the Tuckasegee between Fontana Lake and the NC 107 bridge at Love Field near Sylva, NC, but were not found in the three tributaries to the Tuckasegee that were surveyed. *Corbicula* were present on the Pigeon River at all survey sites downstream of the dam in Canton. They were also present at the survey site downstream of the Lake Junaluska Dam on Richland Creek. *Corbicula* were not found upstream of the reservoir in Canton, nor upstream of Lake Junaluska on Richland Creek.

Details of the analysis of density data are presented in a companion report (Elyse Will, this publication). Densities tended to be greater at the Little Tennessee River and Pigeon River sample sites.

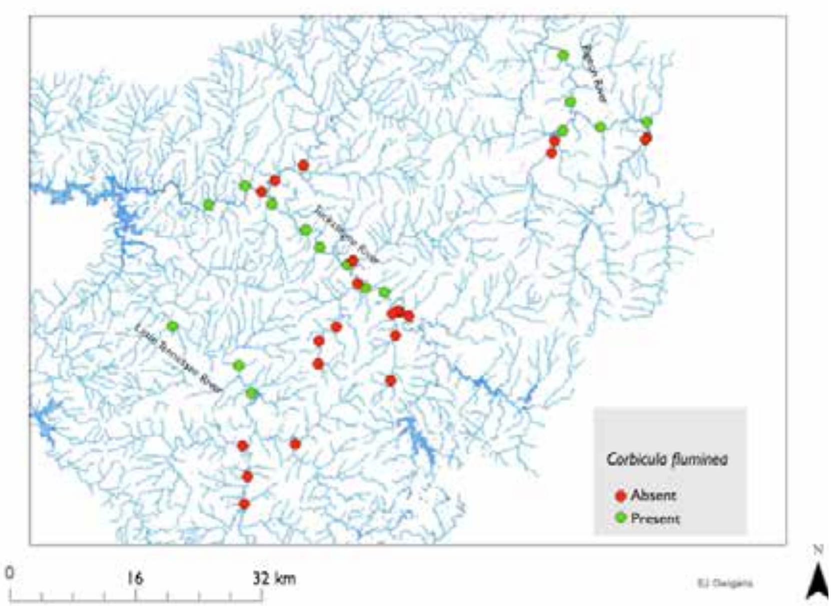


FIG. 1. A map of the survey sites on the Pigeon River, Tuckasegee River, and Pigeon River indicating where *Corbicula* were found.

DISCUSSION

Corbicula fluminea were present in the downstream reaches of almost all rivers surveyed. Upstream ranges were limited on the Little Tennessee River by the Lake Emory Dam and on the Pigeon River by the reservoir in Canton. Dams may serve as barriers to dispersal since fish are at least partially responsible for *Corbicula* dispersal (Voelz 1998). Dams may also limit raccoons, birds, and other creatures from transporting *Corbicula* upstream and prevent unaided upstream movement of *Corbicula* themselves (Voelz 1998). One possibility is that there are no real barriers to the dispersal of *Corbicula* and that the sampled populations below these reservoirs merely indicate that this is the front of the *Corbicula* invasion. In some cases water temperature may be the limiting factor for *Corbicula* dispersal. For example, *Corbicula* were found in the Tuckasegee River but not in the Oconaluftee tributary possibly because the water in the Oconaluftee was noticeably cooler than the Tuckasegee. More work is needed to understand exactly how *Corbicula* are dispersing throughout North American watersheds. Now that established populations of *Corbicula fluminea* have been officially sampled and recorded in Western North Carolina, future studies can begin to examine their effects on the ecology of rivers in Western North Carolina.

LITERATURE CITED

Counts, C. L., III. 1986. The zoogeography and history of the invasion of the United States by *Corbicula fluminea* (Bivalvia: Corbiculidae). American Malacological Bulletin, Special Edition No. **2**:7-39.

Devick, W. S. 1991. Patterns of introductions of aquatic organisms to Hawaiian freshwater habitats. Pages 189-213 *in* W. S. Devick, editor. New Directions in Research, Management and Conservation of Hawaiian Freshwater Stream Ecosystem. Proceedings Freshwater Stream Biology and Fisheries Management Symposium. Department of Land and Natural Resources, Division of Aquatic Resources, Honolulu, Hawaii.

Garcia, M. L., and L. C. Protogino. 2005. Invasive freshwater mollusks are consumed by native fishes in South America. Journal of Applied Ichthyology **21**: 34-38.

Isom, B. G. 1986. Historical review of Asiatic clam (*Corbicula*) invasion and biofouling of waters and industries in the Americas. American Malacological Bulletin, Special Edition No. **2**:1-5.

Kasai, A. K., and A. K. Nakata. 2005. Utilization of terrestrial organic matter by the bivalve *Corbicula japonica* estimated from stable isotope analysis. Fisheries Science **71**(1):151-158.

Morton, B. 1986. *Corbicula* in Asia - an updated synthesis. American Malacological Bulletin, Special Edition No. **2**:113-124.

Sinclair, R. M., and B. G. Isom. 1961. A preliminary report on the introduced Asiatic clam *Corbicula* in Tennessee. Tennessee Stream Pollution Control Board, Tennessee Department of Public Health.

U.S. Geological Survey. 2004. Nonindigenous Aquatic Species Database, Gainesville, Florida. Retrieved December 17, 2012, from http://nas.er.usgs.gov, queried 17.

Voelz, N. J., J. V. McArthur, and R. B. Rader. 1998. Upstream mobility of the Asiatic clam *Corbicula fluminea*: Identifying potential dispersal agents. Journal of Freshwater Ecology, **12**(1):39-45.

A STUDY OF LEAF LITTER INTERCEPTION ACROSS VARYING AGED HARDWOOD FORESTS

AMANDA FREEMAN

Abstract. Interception refers to the process whereby gross rainfall is caught by the tree canopy and then redistributed as throughfall, stemflow, and evaporation from the standing vegetation. Interception is a key part of the total hydrologic budget and it is the focus of this research project. I quantified the amount of precipitation intercepted by leaf litter. I collected data on leaf litter mass and tree species in forest stands of different ages. Stands are 12, 35 and 85 years of age and are located in the Nantahala Mountain Range of western North Carolina. To quantify potential interception by the litter layer for each age class I analyzed throughfall, stemflow, and litter interception loss equations previously established at Coweeta Hydrologic Laboratory. I found that percent interception is inversely proportional to annual precipitation.

Keywords: Annual precipitation; climate change; hydrologic budget; litter interception; southern Appalachian Mountains.

INTRODUCTION

Interception refers to the process whereby gross rainfall is caught by the tree canopy and then redistributed as stemflow or evaporates from the standing vegetation. A portion of precipitation, known as throughfall, penetrates the canopy through natural gaps. A portion of throughfall is caught on the litter layer of the forest and evaporated without adding to moisture in the mineral soil (Helvey and Patric 1965), thus preventing the moisture from reaching the soil where it can be absorbed by plants and used for transpiration or contribute to groundwater recharge. This portion of rainfall is known as litter interception.

The primary focus of this project was to quantify the effects of forest age and structure on the hydrologic budget by measuring variations in hydrologic components across an early succession to old-growth forest chronosequence in the southern Appalachian Mountains. Alterations of the hydrologic budget are caused by changes in forest structure during succession. In younger forests *Liriodendron tulipifera* (tulip poplar) dominates, whereas more mature forests are dominated by a mix of *Acer rubrum* (red maples) and *Quercus* sp. (oak), species that vary in water use and structure thus affecting the hydrologic balance (Ford et al. 2011). Forest water balance affects multiple ecosystem services in the southern Appalachians, including water supply, forest productivity and forest and stream biodiversity (Ford et al. 2011). This study will help improve the ability to project future water supplies as forests age.

There are three reasons why the effects of interception are imperative to understand. First, population growth in Appalachian-fed watersheds has been among the highest in the nation over the past two decades (Ford et al. 2011). This is straining water supplies and storage capacity designed for smaller populations (Ford et al. 2011). Second, future land use, driven by demographic shifts and alternative energy sources will likely lead to substantially different regional forest structures which will affect water supply. Third, the hydrologic budget of future forests may be altered by climate change. The climate of the southeastern U.S. during the 21st century is predicted to include novel climates – combinations of seasonal temperature and precipitation that have no historical or modern counterpart (Ford et al. 2011). In this study we focus on three questions: 1) How much precipitation is intercepted by hardwood forests leaf litter and does litter interception vary with forest age? 2) How does total annual litter interception vary with annual rainfall? 3) How does the percentage of total annual rainfall vary with annual rainfall?

Materials and Methods

We collected field data in forest stands of different ages. Stands were 12, 35 and 85 years of age and are located in the Nantahala Mountain Range of western North Carolina. Sites have similar terrain, elevation, soils, and species composition (Table 1). In one hectare of forest at each study site we placed two sample plots, 20x40 m in area. The plots were arranged so that they did not overlap and within each plot we identified vegetation species. We identified all canopy trees that were >10 cm dbh (diameter breast height) in each plot to species. We measured dbh to the nearest 0.01 m. We also established five randomly placed 5x5 m subplots within each plot and identified all woody plants 1-10 cm dbh.

We collected leaf litter from each site in early to mid-September, typically the lowest litter mass of the year. In each subplot, we cut O horizon samples with a knife using a 0.09 m^2 template. The determination of the O and A horizon boundary was based on visual assessment of organic content and color differences between the organic layer and mineral soil. Fresh O_i horizon litter was separated from fragmented litter plus humus (Oet & Oa horizons), then dried at 60° C to a constant mass and pooled by plot. Samples were then ashed to correct for mineral soil in the samples, using a 2 mm sieve.

To quantify potential interception by the litter layer for each age class we used an excel spreadsheet and equations previously used by Coweeta hydrologic lab, for the water years 1999-2010. The variables we used in the spreadsheet are: 1) mass of litter on the forest floor, 2) the rate at which litter moisture content increased during rainfall, and 3) the rate litter dried after rainfall stopped to estimate the amount of rainfall evaporated from the litter layer (Helvey 1962). Throughfall (T) was calculated using the equation $T= 0.901P – 0.031$, where P is the gross rainfall in millimeters (Helvey and Patric 1965). Litter Interception Loss was calculated using $L = (T+S) – R$, where R is the net Rainfall and S is stemflow. This is rainfall retained in the litter layer and evaporated without adding to moisture in the underlying soil.

We estimated litter mass (Mg ha^{-1}) for each month in each year on the low point data (lowest leaf litter mass) collected in September similar to methods used by Helvey and Partric (1965). Total daily precipitation data was collected by an 8 in. standard rain gauge (NWS). Rainfall volume and intensity were recorded by a Recording Rain Gage (Belfort Universal Recording Rain Gage, Belfort Instrument Co) (Laseter et al. 2012). Throughfall was calculated using the equation $T= 0.901P – 0.031$, where P is the gross rainfall in millimeters (Helvey and Patric 1965).

Results

As annual rainfall increased, the interception of rain increased slightly (Fig. 1). One exception to this occurred during water year 1999-2000 when interception was quite high but rainfall was relatively low. Three to 13% of rainfall is intercepted by leaf litter depending on the amount of rain in a given year (Fig. 2). The percent of rain intercepted is inversely proportional to the amount of rainfall.

TABLE 1. Location, slope aspect, dominant species, basal area, leaf area index (LAI) and standing litter of 12-, 35-, and 85-year old stands.

Stand Age	Location	Slope	Aspect	Dominant Species	Basal Area (cm^2/m^2)	LAI (m^2/m^2)	Standing Litter (max, min)
12	Shingle Tree (NNF)	30.3%	South-facing	*L. tulipifera, Q. alba*	15.73	2.42	9.47, 8.07
35	WS7 (Coweeta)	32.6%	South-facing	*L. tulipifera, Q. velutina*	32.55	4.83	9.13, 6.49
85	Tower Site (Coweeta)	35.7%	Northeast-facing	*L. tulipifera, Q. alba*	29.51	4.51	9.66, 7.09

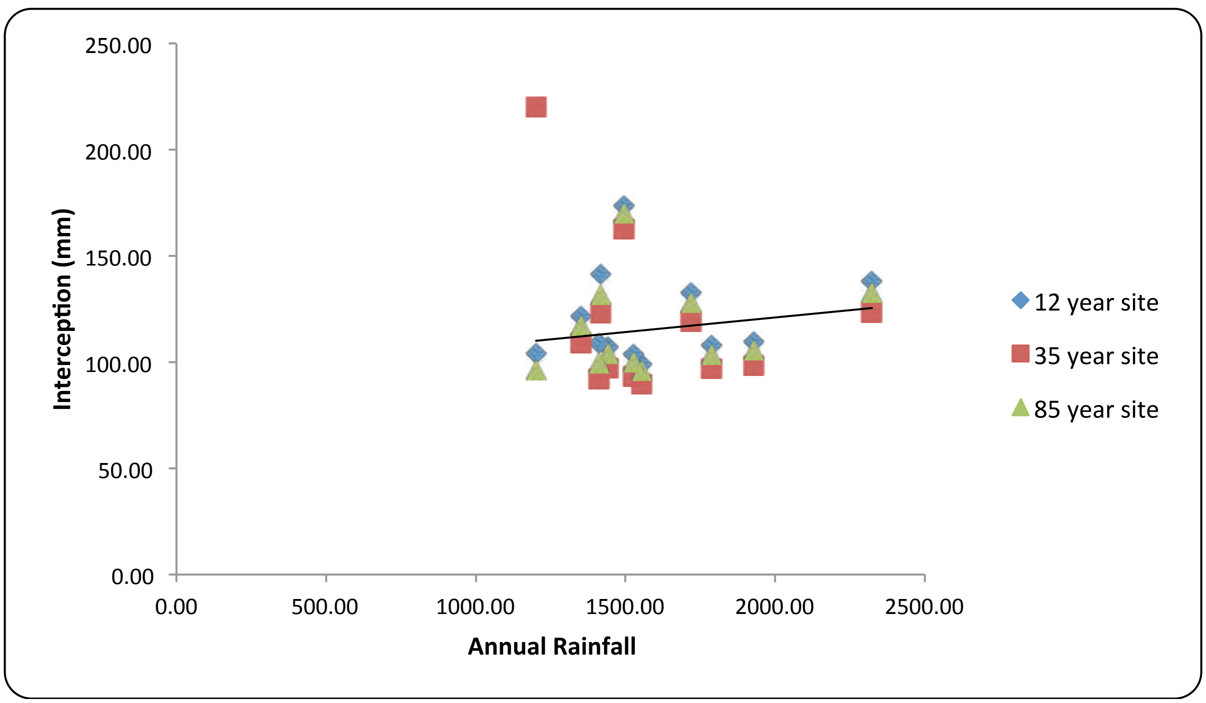


FIG 1. Interception vs. annual rainfall from 1999 to 2011.

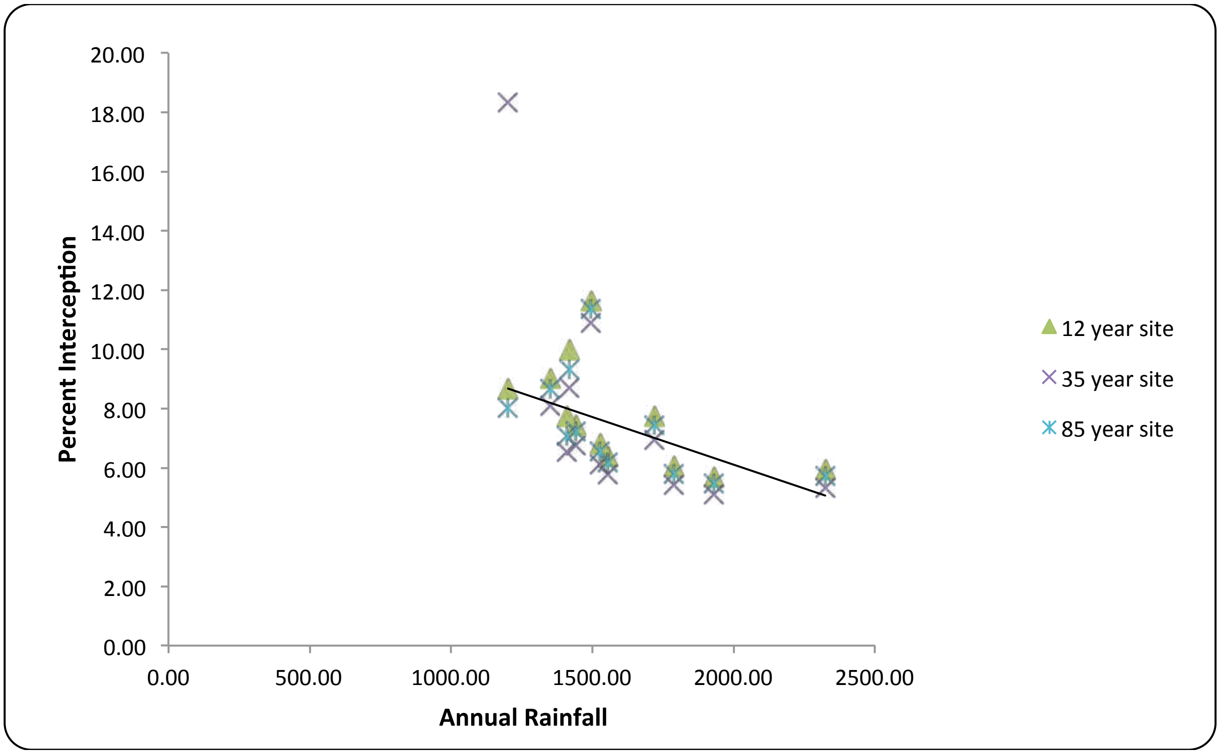


FIG. 2. Interception as a percent of annual rainfall from 1999-2011.

The main variable that affects litter interception across all sites is litter mass. Mass did not vary by age class. Overall a small, but important, percentage of rainfall is intercepted by litter at all sites. Interception (mm) is proportional to increase in annual rainfall while percent interception decreases as precipitation increases.

DISCUSSION

Litter mass did not vary by age class. This may be indicative of differences in litter decomposition (slower in the youngest site) but has important implications for variations in interception across age classes. The 35 yr site intercepts the most during large rain events while the 12 and 85 year old sites tend to reach a peak saturation point at which interception ceases to increase. This is logical since a forest at 35 years of age, mid-succession, will have peak diversity and therefore the most demanding and complex water balance.

The rainfall data in Fig. 1 show a small positive trend in the total amount of rainfall per year. Interception does not follow the same positive trend. The outliers in Figs. 1 and 2 are speculated to be caused by large infrequent storm events causing interception to reach its maximum potential while precipitation persists.

When comparing figures 1 and 2, the amount of rainfall that interception represents to the percent interception per water year similar trends in the data emerge. The percent of interception does not increase proportional to the amount of precipitation; rather, interception actually decreases as precipitation increases. This is because potential interception is subject to the amount of moisture already in the leaf litter. This means that the percentage of rainfall intercepted by litter is inversely proportional to rainfall. This is important because many process-based models treat litter interception as a static variable—i.e it does not change from year-to-year. When annual interception is entered into a model as a percent it does not account for potential changes year to year precipitation. Future research should consider an alteration to the way interception data is entered into such models.

These results may also be important in future studies on the effects climate change will have on hydrologic budgets. While it is difficult to predict changes in total precipitation, studies have already shown changes in rainfall distribution patterns (Laseter et al. 2012). There is a trend towards smaller, more frequent and larger, less frequent storm events. This trend is supported by a 70th and 10th percent quantile regression analysis of annual precipitation data from 1940 to 2010 at Coweeta (Laseter et al. 2012). The change in storm event patterns is also supported by a quantile regression of each July and September of those years (Laseter et al. 2012). The data show that summer months of drought are becoming drier while the fall months are becoming wetter due to heavy precipitation events. Interception is shown to be the greatest during drier years when the leaf litter is at its maximum water holding capacity and large infrequent storm events during these years may allow for the highest annual interception. Future studies of leaf litter interception could utilize a simulation based model to support novel research on how climate change affects hydrologic partitioning and these data provide a good starting point for those studies.

ACKNOWLEDGEMENTS

I would like to thank Dr. Chelcy Ford for the opportunity to work at the Coweeta Hydrologic Laboratory. I would like to thank Dr. Steven Brantley for all of his help and guidance throughout this project, without him I would have never made it this far. I would like to thank those at Coweeta Hydrologic Lab including Bob McCollum, Chris Sobek, Neil Muldoon, Patsy Clinton and Stephanie Laseter for all of their technical support and for always making me feel like a welcome part of the team. I would also like to thank Karen Kandl and Tom Martin for all of their support throughout the semester. A special thanks to Michelle Ruigrok for making this project possible from the very beginning.

LITERATURE CITED

Laseter, S. H., C. R. Ford, J. M. Vose, and L. W. Swift Jr. 2012. Long-term temperature and precipitation trends at the Coweeta Hydrologic Laboratory, Otto, North Carolina, USA. *Hydrology Research* **43.6**(2012): 890-901.

Ford, C. R., J. M. Vose, P. V. Bolstad, K. A. Novick, and S. T. Brantley. 2011. Consequences of stand age and structure on forest water yield. *AFRI Project Proposal.* 16 pages.

Helvey, J. D. 1962. Rainfall interception by hardwood forest litter in the southern Appalachians. **1962**:1-10.

Helvey, J. D., and J. H. Patric. 1965. Canopy and litter interception of rainfall by hardwoods of Eastern United States. *Water Resources Research, Second Quarter* **1.2**(1965): 193-20.

HABITAT PREFERENCE OF SMALL MAMMALS IN PANTHERTOWN VALLEY

BRANDON HAYS

Abstract. Small mammals play an important role in the ecology of southern Appalachian forests yet are relatively understudied. I sampled small mammal populations in two forests types, *Rhododendron* and rich cove, within Panthertown Valley in the Nantahala National Forest in Jackson County, North Carolina. Sherman live capture traps and pitfall traps were used from September to December for a total of 2,157 trapping nights. Significantly more small mammals were found in the *Rhododendron* forests than the rich cove forests, indicating a distinct habitat preference. This finding may result from a number of variables not measured in this study, including food availability as well as predators' habitat preferences and population dynamics.

Key words: Rhododendron; *rich cove forest; small mammals; southern Appalachians.*

INTRODUCTION

Comparatively little research has been done on small mammals in the southeastern United States relative to the rest of the country. Studies of small mammals are complicated by a number of factors: most small mammals are nocturnal and difficult to observe interacting with their environment, many areas in southern Appalachian forests are difficult to access, and trapping success is often very low and consequently it may take a long time to accumulate sufficient data. Small mammals are an integral part of the ecosystems which they inhabit and the food chains in which they participate in. They have a significant impact on plant and fungus species composition and distribution throughout an ecosystem. They gather and cache seeds of various plants and eat hypogeous fungi spores, aiding in distribution and propagation of various plant and fungus species. Small mammals also serve as an essential link between primary producers and secondary and tertiary consumers in the transfer of energy up the trophic chain. They assimilate much of the primary production into energy accessible to secondary consumers and make up a large portion of many predators' diets, including coyotes, owls, hawks, weasels, and others. (Carey and Johnson 1995). They also serve as controls on insect populations and in some cases even stimulate primary production via grazing (Sieg 1987). Additional studies of small mammals are essential to understanding the ecology and dynamics of southern Appalachian forests.

Two of the most common types of forest ecosystems in the southern Appalachians are *Rhododendron* dominated acid cove forests and rich cove forests. *Rhododendron maximum* is a woody evergreen shrub which grows up to forty feet tall. After forest disturbances they are quick to replace surrounding trees and often form thick impenetrable forests in which the *Rhododendron* accounts for up to 80% of the forest cover (Anderson 2008). The thick carpet of waxy leaves they drop prevents other trees from successfully dispersing and germinating seeds which results in gradual reduction of tree recruitment (Dighton 1992). Likewise, the limited light penetration due to the dense canopy created by *Rhododendrons* makes it more difficult for shade intolerant species to survive within the growing *Rhododendron* forest. The net result is a reduction in plant diversity within an extremely thick and shaded forest of mostly

Rhododendron shrubs. The 'rhodo-hells' grow best in acidic soils in xeric areas such as mountain coves and valleys. Many botanists and the US Forest Service see the profusion of the plant as undesirable because of the *Rhododendron*'s propensity for lowering the plant diversity in its surrounds, and call it a 'serious woody weed' (Anderson 2008).

Conversely, rich cove forests are seen as a highly desirable forest type because of the high plant diversity associated with them. These forests consist of a stable but unevenly aged plant community with a mix of early and late successional trees creating a dense tree canopy. They have relatively open mid-stories and dense herbaceous layers. They are characterized by tulip poplar (*Liriodendron tulipifera)*, sugar maple (*Acer saccharum)*, basswood (*Tilia americana),* black cherry (*Prunus serotina)*, white ash (*Fraxinus americana)*, and Fraser magnolia (*Magnolia fraserii*) (Schafale 2012). They also serve as habitat for larger mammals, such as deer and bears, and support numerous species of salamanders and birds which contribute to the regions high biodiversity (NC WRC 2011).

Although these rich cove forests may engender high plant diversity, they may also have relatively low small mammal diversity and abundance (Ed Pivorun personal communication). The objective of this study was to examine diversity and abundance of small mammals in *Rhododendron* and rich cove forests and to document potential habitat preferences of small mammals between the two highly different habitats. I hypothesized that greater abundance and diversity will be observed in the *Rhododendron* forests. This study provides basic natural history of small mammals in common southern Appalachian forest types and augments knowledge of small mammal ecology in the region.

MATERIALS AND METHODS

The study was conducted in Panthertown Valley within the Nantahala National Forest in Jackson County, NC between September and December of 2012. Panthertown Valley is a 2,550 ha backcountry area at elevations ranging from 900 m in the valley to nearly 1,500 m at the highest ridge. Logged in the 1920's and then sold to a private developer before Duke Power purchased the area to construct a power line, Panthertown has suffered significant human impacts. Since the NC Nature Conservancy purchased the area in 1989 it has been preserved as a recreation area within the Nantahala National Forest. The forests have been left to regrow since logging and today pine stands, rich and acid cove forests, heath balds, and even a bog can be found in the valley (www.panthertown.org).

The sampling sites were determined based upon accessibility and suitability to trapping. Proximity to water was also a deciding factor as small mammals are more likely to be found near sources of water (Ed Pivorun personal communication). I identified *Rhododendron* thickets by lack of light penetration, a less abundant herbaceous layer, and lower diversity of tree species (near entirely *Rhododendron*) (Anderson 2008). Rich cove forests were determined by an abundant herbaceous layer, a relatively diverse mix of trees, and high light penetration (NC WRC 2011).

I used Sherman live-capture metal traps (16.5x5.5x6.5 cm) and pitfall traps (150 cm deep, 30 cm wide) to capture small mammals. Sherman traps were baited with peanut butter to attract rodents and pitfall traps were stocked with wet cat food to keep captured shrews alive. Trapping was performed according to two separate methods over the course of the study. Initially, I established transects over the length of Little Green and Big Green Mountains. Traps were laid approximately every 10 meters up and down Little Green Mountain and approximately every 30 meters up and down Big Green Mountain until 45 traps had been laid on each transect. After the third week of trapping the transects were abandoned in favor of plots roughly 20 meters by 50 meters. I laid traps in a grid pattern with approximately 5 meter lateral intervals and approximately 10 meter longitudinal intervals. In both cases, traps were placed in locations most likely to be traveled by small mammals. These were located next to downed logs, rocks, or other objects which would provide cover to moving animals or might be sources of insects or fungi. Pitfall traps were dug into the ground immediately next to large logs which would serve as barriers to smaller shrews and which would force them to move along the log until they fell into the pitfall. Traps were set out for three nights at a time to sample as much of the resident population as practical. I laid 90 traps each week over ten weeks for a total of 2157 trapping nights, 1275 in rich cove forest and 882 in *Rhododendron* forest. The animals were weighed and sexed, their body length and foot length were measured, and they were released next to the trap in which they were captured.

FIG 1. Sampling sites within Panthertown Valley.

The data for all sampling sites were compiled according to habitat type. Trap nights were used as replicates, with a successful trap night represented by a 1 and an unsuccessful night a 0. I performed a Wilcoxon rank sum test due to the non-normal nature of the data using R statistical package (R Development Core Team 2012). The alternative hypothesis was that abundance was greater in *Rhododendron* versus rich cove forests.

RESULTS

Significantly more animals were captured in the *Rhododendron* forests than the rich cove forests (Wilcoxon rank sum test, $p<0.005$) (Table 1). Assuming that trapping rates are indicative of abundance and that trapping rates are not dependent upon forest type or sampling location, these results indicate that there is a significant difference in the numbers of small mammals in the two forest types. At none of the sampling sights did the rich cove yield a higher catch/effort than the *Rhododendron* forests. Since trapping on Little and Big Green Mountains was carried out prior to a shift in study goals, three quarters of the area sampled was rich cove forest.

TABLE 1. Animals captured according to habitat type and sampling location.

Sampling Location	Habitat Type	Trap Nights	Number of Species Present	Number of Animals Trapped
Little Green Mountain	Rich Cove Forest	405	2	7
Big Green Mountain	*Rhododendron* Forest	207	1	4
	Rich Cove Forest	198	2	2
Panthertown Valley Trail	*Rhododendron* Forest	135	1	1
	Rich Cove Forest	135	0	0
Mac's Gap Trail	*Rhododendron* Forest	135	0	0
	Rich Cove Forest	135	0	0
Wilderness Falls Trail	*Rhododendron* Forest	405	2	15
	Rich Cove Forest	402	1	1

Four species of rodents were captured: deer mice, golden mice, smoky shrews, and a southern flying squirrel (Table 2). The unknown refers to an incident in which an animal entered a trap and escaped such that the animal was not identified. This was most likely a shrew based on the size of the hole and the scat left behind.

TABLE 2. Species captured and percent of total catch.

Species	Percentage
Peromyscus maniculatus	70
Ochrotomys nuttalli	17
Sorex cinereus	7
Glaucomys volans	3
Unknown	3

DISCUSSION

Significantly more small mammals were found in *Rhododendron* forests than in rich cove forests, indicating a habitat preference for *Rhododendron* forests. There are several possible explanations for this finding.

Rhododendron forests have thicker canopies and are more densely populated with woody vegetation, often to the point of being impenetrable by humans. In addition the floor of a *Rhododendron* forest is thickly carpeted with leaves throughout the year. The presence of such dense vegetation and leaf litter likely offers greater protection from predators, especially avian predators or large predators such as coyotes. Increased predator pressure in recent years from growing fox and coyote populations may contribute to lower populations in the more open rich cove forests (Myers 2012).

There may be a greater abundance or diversity of food sources within *Rhododendron* forests which might account for the greater number of small mammals present. While rich cove forests have an abundance of seeds due to their diverse herbaceous layers, these seeds are not available in the winter. Subterranean fungi associated with *Rhododendron* may attract mycophagous small mammals in fall and winter, when seed abundance is diminished and insects are less abundant. *Rhododendron* is able to associate with a wide range of mycorrhizae, which may account for its ability to thrive in nutrient poor soils (Dighton and Coleman 1992). However it has also been found that mycorrhizal colonization of other tree species is inhibited in *Rhododendron* thickets (Walker et al. 1999). To my knowledge no one has studied the abundance of fungi within *Rhododendron* forests or the relationships between the mycorrhizae of *Rhododendrons* and small mammals. These are important topics which would benefit from further research. Small mammals serve as the primary dispersal vector for the spores of hypogeous fungi (Maser et al. 1978). Since many such fungi are obligate mutualists with tree species which rely upon them for fixation of nitrogen and other nutrients, small mammals can play an essential role in maintaining the health of their forests (Maser et al. 1978). It could be that small mammals play an important role in the proliferation of *Rhododendron* in the area.

Insufficient data and changes in methodology limit the interpretable results of the study. The switch in sampling methodology after the first three weeks was due to a reevaluation of the study goals and the efficacy of sampling in long transects. Out of a total of ten weeks of sampling, I caught almost no animals during two weeks at two separate sampling sites. In one case this was due to the interference of raccoons that mangled the traps and rendered the sampling site untenable. The second was perhaps due to a full moon reducing rodents' willingness to venture out when there would be potentially greater predator pressure (Ed Pivorun personal communication). Additionally, the trapping methodology did not sample the entire community of small mammals equally. Sherman traps baited with peanut butter are not likely to attract insectivorous mammals such as shrews, and significantly more trapping effort was invested in Sherman traps versus pitfalls (90 vs. 6 per trapping session). The narrow temporal scale of the study did not allow for the sampling of species which undergo seasonal or yearly population shifts, such as red-backed voles which experience population cycles over 5-10 year intervals (Pivorun and Bunch, 2005). Finally, it has been observed that small mammal populations in the surrounding area were notably depressed last summer, potentially due to an unusually mild winter and increased predator pressure (Ed Pivorun, personal communication). In general the study would have greatly benefited from a longer study time scale, longer trapping periods, and more samplings sites to provide more robust results.

This study should be considered a preliminary investigation of a broader subject and the results obtained in one area should not be extrapolated to the entire Southern Appalachian Mountains without extensive further study. The study was performed on a narrow geographic scale and did not take into account landscape patterns of small mammal populations. Large temporal or spatial scale movements of animals were not accounted for by the experimental design. It is possible that populations of certain species may shift from habitat to habitat as seasons change or over many years. Future studies should focus on causes of the observed habitat preference. The limitations imposed by time and lack of equipment prevented any in-depth analysis of causative variables in this study, however examination of such factors as water availability; food availability in the form of fungus, seed banks, and insect populations;

and predators' habitat preference and population dynamics could elucidate the cause for the *Rhododendron* forest preference.

It is hoped that this study will serve as a basis and impetus for future research of small mammal communities in southern Appalachian forests.

ACKNOWLEDGEMENTS

I would like to acknowledge Ed Pivorun for mentoring me through this project and introducing me to the study of small mammals. I would also like to express my gratitude towards Tom Martin and Karen Kandl for their advice and assistance in designing this study and writing this paper. Finally I would like to thank Michelle Ruigrok for her advice and encouragement, and for making this project possible from the beginning.

LITERATURE CITED

Anderson, M. 2008. *Rhododendron maximum*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado, USA.

Carey, A., and M. Johnson. 1995. Small mammals in managed, naturally young and old-growth forests. Ecological Applications. **5**: 336-253.

Dighton, J., and D. Coleman. 1992. Phosphorous relations of roots and mycorrhizas of *Rhododendron maximum* L. in the southern Appalachians, North Carolina. Mycorrizha. **1**:175-184.

Maser, C., J. Trappe, and R. Nussbaum. 1978. Fungal-small mammal interrelationships with emphasis on Oregon coniferous forests. Ecology. **59**:799-809.

Myers, G. 2012. Fox and coyote populations study, final report. North Carolina Wildlife Resources Commission. Raleigh, NC, USA.

NC WRC. 2011. Cove Forests, Southern Blue Ridge Mountains , NC Wildlife Resources Commission. Raleigh, NC, USA

Pivorun, E., M. Bunch. 2005. Carolina red-backed vole. SC Department of Natural Resources. South Carolina, USA.

R Development Core Team. 2012. R: A language and environment for statistical computing. Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Schafale, M. 2012. Guide to the natural communities of North Carolina, fourth approximation. North Carolina Department of Environment and Natural Resources, NC, USA.

Sieg, C. 1987. Small mammals: Pests or vital components of the ecosystem. *Great Plains Wildlife Damage Control Workshop Proceedings*. Rocky Mountain Forest and Range Experiment Station, Rapid City, South Dakota, USA.

Walker, J., O. Miller, T. Lei., S. Semones., E. Nilsen., and B. D. Clinton. 1999. Suppression of ecotomycorrhizae on canopy tree seedlings in Rhododendron maximum L. (Ericaceae) thickets in the southern Appalachians. Mycorrhiza. **9**(1): 49-56.

PREDICTIVE MODELING OF *STEWARTIA OVATA* POPULATIONS IN RABUN COUNTY, GEORGIA

LINDSEY PURVIS

Abstract. *Stewartia ovata* is a rare native tree species of the mid-elevations of the southeastern United States most notable for its spectacular blooms. Natural history and habitat of this plant are relatively unknown. We identified and mapped populations of *S. ovata* in the Chattooga watershed, specifically in the northeastern portion of Rabun County, Georgia. We analyzed elevation, slope, aspect, soil type, spectral signature, land cover, and stream data to categorize the strongest factors influencing *S. ovata* survival and reproduction. We used these data to create a predictive GIS model of ideal *S. ovata* habitat within Rabun County. We found several sites of promising habitat that will need to be verified for *Stewartia ovata* plants.

Key words: Stewartia ovata*, rare species, Rabun county, southern Appalachia conservation, GIS, predictive modeling.*

INTRODUCTION

Stewartia ovata (also spelled *Stuartia*) is a small, rare, deciduous flowering tree indigenous to the mountains and piedmont area forests of the southeastern United States. There are populations in Kentucky, Tennessee, North and South Carolina, Georgia, and Alabama (Spongberg 1974). There is also a single population of *S. ovata* comprised of 32 plants in the Chesapeake Bay National Estuarine Research Reserve in Virginia (Reay and Moore 2009). On a global scale, tribe *Stewartieae* (of family Theaceae) consists of 26 species divided into three groups: Old World evergreen *Hartia* and deciduous Old World and New World *Stewartia*. The two New World species are noteworthy because they show mixed pollen characteristics between Old World *Stewartia* and *Hartia* species, but they are genetically more similar to the evergreen *Hartia* species than to the Old World deciduous species (Prince 2002, Heo et al. 2011).

Typically, well-established plants have several limbs protruding from the base of the plant, each with tight, grayish-brown bark in a pattern of close, shallow fissures. Ovate leaves with small tooth serrations and finely pubescent undersides turn various shades of yellow and/or dark purple before dropping in autumn (Spongberg 1974). Besides Magnolia, *Stewartia* has the largest flower of any group of woody plants in the U.S. with filament color ranging from blue, reddish, purple, or clear and often changing annually (J. Johnston, pers. Comm.). Other common names for this tree include mountain camellia and summer dogwood, so named for the silky white, five-petal, 6-8 cm diameter blossoms which bloom in the early summer (Curtis et al. 1996).

The seed capsules are reddish-brown, finely-pubescent with five compartments and contain ripe seeds from mid-September until October. Seeds take between 2-5 years to germinate. Canopy gaps, which arise from disturbances like storms or flooding, help seeds to germinate. *Stewartia* can also reproduce vegetatively. New stems may grow off of shallow roots exposed by erosion or mechanical disturbance or sprout off of an old stump as the dominant stem begins to lean or age. Tightly bound growth rings on old stems 5-6 meters in height indicate that stems may live for as long as 80 years (Johnston 2012). However, one stem is capable of producing a root system hundreds of years old. When the original root system is unable to sustain new sprouts, the plant will die.

The growth of *S. ovata* is slow. Many factors may inhibit the growth of *S. ovata* including interspecific competition for sunlight and resources (J. Johnston, pers. comm.). Plant species found growing around *S. ovata* are often relatively common plants and trees such as red maple (*Acer rubrum*), white oak (*Quercus alba*), rosebay rhododendron (*Rhododendron maximum*) Canadian hemlock (*Tsuga canadensis*), mountain laurel (*Kalmia latifolia*), and Christmas fern (*Polystichum acrostichoides*), and it is likely that *S. ovata* competes with these species for resources. The slow seed germination time and growth of *S. ovata* likely contribute to the rarity of *S. ovata* in a common forest landscape.

The goal of this study was to create a useful predictive habitat model based on information gathered from *S. ovata* populations in the Chattooga River (South Carolina and Georgia) watershed. This model should prove useful for the discovery of new populations and the conservation of this rare and beautiful tree species.

Materials and Methods

Study Areas

Our study focused on the Chattooga watershed area in Rabun County, Georgia in the northeast corner of Georgia. We located populations on foot or by car using old forest service trails within or near the riparian zone of the Chattooga River, including the Burrell's Ford Bridge, Sandy Ford Road, Tuckaluge Creek, Walnut Creek, Sarah's Creek, Warwoman Road, Nicholson Ford Road, Lick Log Creek, and Earl's Ford Road areas. For this study we collected data on eight days between September 5, 2012 and November 10, 2012).

Data Collection

Once an *S. ovata* stem was identified, we recorded geographic coordinates with a hand-held Garmin GPSMAP® 60CSx global positioning system receiver at a distance within five meters of the largest plant. We recorded the number of established *S. ovata* stems and seedlings composing the population, the relative distance of the population to a water source (greater or less than 50 meters), presence or absence of canopy gaps to determine sunlight availability, and associated species surrounding *S. ovata*. We recorded seedlings as separate from established stems because seedlings cannot reproduce and experience higher mortality from disturbances and interspecific competition than do established stems.

We performed a qualitative rather than quantitative inspection around *S. ovata* stems and seedlings to determine the most common species sharing the habitat of *Stewartia ovata*. Dense understory vegetation such as *Rhododendron maximum, Smilax,* and *Leucothoe fontanesiana* combined with steep slopes made a quantitative assesement of habitat associates impossible.

Data Analysis

I converted GPS coordinates of each *S. ovata* population site into decimal degrees. I recorded date of collection, nearest road for a location identifier, number of stems, number of seedlings, location in riparian zone (yes/no), and presence of canopy gaps (yes/no). These data were added into ArcMap™ 10 (ESRI 2011) as XY data and converted into a map layer of points which was displayed using proportional symbols based on number of stems at each site.

I used maps of landcover types for southern Appalachia from the Coweeta Long Term Ecological Research website (http://coweeta.uga.edu/gisdata/) and of soil types for Rabun County, GA from USDA Soil Data Mart (http://soildatamart.nrcs.usda.gov/). I ran all subsequent analyses in ArcMap™ 10 (ESRI 2011). I identified soil types present at *S. ovata* locations, and in ArcMap created a layer of *S. ovata* favorable soils. I converted this layer to a raster using Feature to Raster tool, then reclassified values of favorable soils as 1 and other soils as 0 so soil type could be used in the predictive raster model.

From ArcGIS™ 9 Data & Maps 9.3.1 (ESRI 2009), I uploaded map layers of named streams and rivers, county outlines, and topographic quads in the continental United States. I created a new polygon shapefile by tracing the outline of Rabun County in the county outlines layer, then clipped the named streams and rivers layer to Rabun county to limit data volume to the area of study. I used the Buffer tool to create a 50 meter buffer around streams and rivers within Rabun County. Next I recorded the names of the fourteen topographic quads overlapping Rabun County and downloaded a digital elevation model (DEM) for each quad from the Georgia GIS Clearinghouse (https://data.georgiaspatial.org/index.asp). Then I stitched these together using the Mosaic to New Raster tool to create continuous elevation coverage for Rabun County.

I calculated a layer of slope and of aspect (both in degrees) from elevation coverage. I confined data coverages to Rabun County. Next I used the Extract Values to Points tool in order to determine elevation values at each of the 75 *S. ovata* population points, repeating this analysis for the slope and aspect layers to determine these values at each of the 75 population sites. These data ranges gave me favorable elevation, slope, and aspect ranges to use for my predictive model. I reclassified these three data layers into ideal range (between observed values for slope and elevation at *S. ovata* sites, and between 210-280 degrees for aspect), then lower and higher values than this range. This compressed the data into three categories for each layer. I used the Reclassify tool to display ideal range with a value of 1 and numbers below or above the ideal range with a value of 0, compressing data into two categories for each layer.

I identified the spectral signature below the coordinates of the observed *S. ovata* population points using Enhanced Thematic Mapper (ETM) data. I reclassified this layer of spectral signatures into areas with (given a value of 1) and without (given a value of 0) the spectral signatures present at *S. ovata* sites.

By adding all reclassified layers (elevation, slope, aspect, soils, and spectral signature) in Raster Calculator, I then created a preliminary predictive model based on these five categories. To incorporate the stream buffer into the model, I converted our five-category predictive raster model into a polygon map layer, made a selection of sites that satisfied requirements for four or five of the desirable categories, created a new layer from this selection, and then clipped this new map layer to the layer of stream buffers. In the landcover layer, I removed all land cover types that were not mixed, deciduous, or evergreen forest from the display. By overlaying this landcover with the preliminary predictive model clipped to a stream buffer, I was able to complete my final predictive model.

RESULTS

We found 506 *S. ovata* trees (Fig. 1). Each population averaged 7 ± 8 plants with a minimum of one plant, maximum of 55 plants (Fig. 2). We also observed 190 seedlings with a minimum of 0, a maximum of 67, and mean of 3 ± 11 for each site (Fig. 3). Most observed populations had no seedlings, although many established plants had multiple shoots off of the same root system present which were counted as one plant.

Stewartia ovata populations were found only within the riparian zone extending roughly 50 meters from the river body with the exception of three sites. Populations occurred between 483-699 ft in elevation with an average elevation of 582 ± 69 ft (Fig. 4). The elevation range for Rabun County is 203-4338 feet. The range for slope was 0 – 33 degrees with average 10 ± 8 ft (Fig. 5). Aspect ranged from -1 to 357 degrees and averaged 192 ± 88 degrees (Fig. 6).

Stewartia was found growing primarily in two soil types: fine sandy loam and loam. Loam is considered ideal for gardening and agriculture because of its nutrient retention and ability to hold onto water while allowing the excess to drain away (Lerner 2000). All observed populations were located within evergreen, deciduous, or mixed forest landcover types. When the preliminary predictive model was created and clipped to the 50-meter stream buffer layer, all predicted sites of *S. ovata* were above these three land cover types so further clipping of the model to these land cover types was unnecessary.

The final predictive model covers a total area of 7,963,431 square meters, which need to be verified for *S. ovata* (Fig. 8). These sites are located primarily in the southwestern portion of Rabun County near areas of open water.

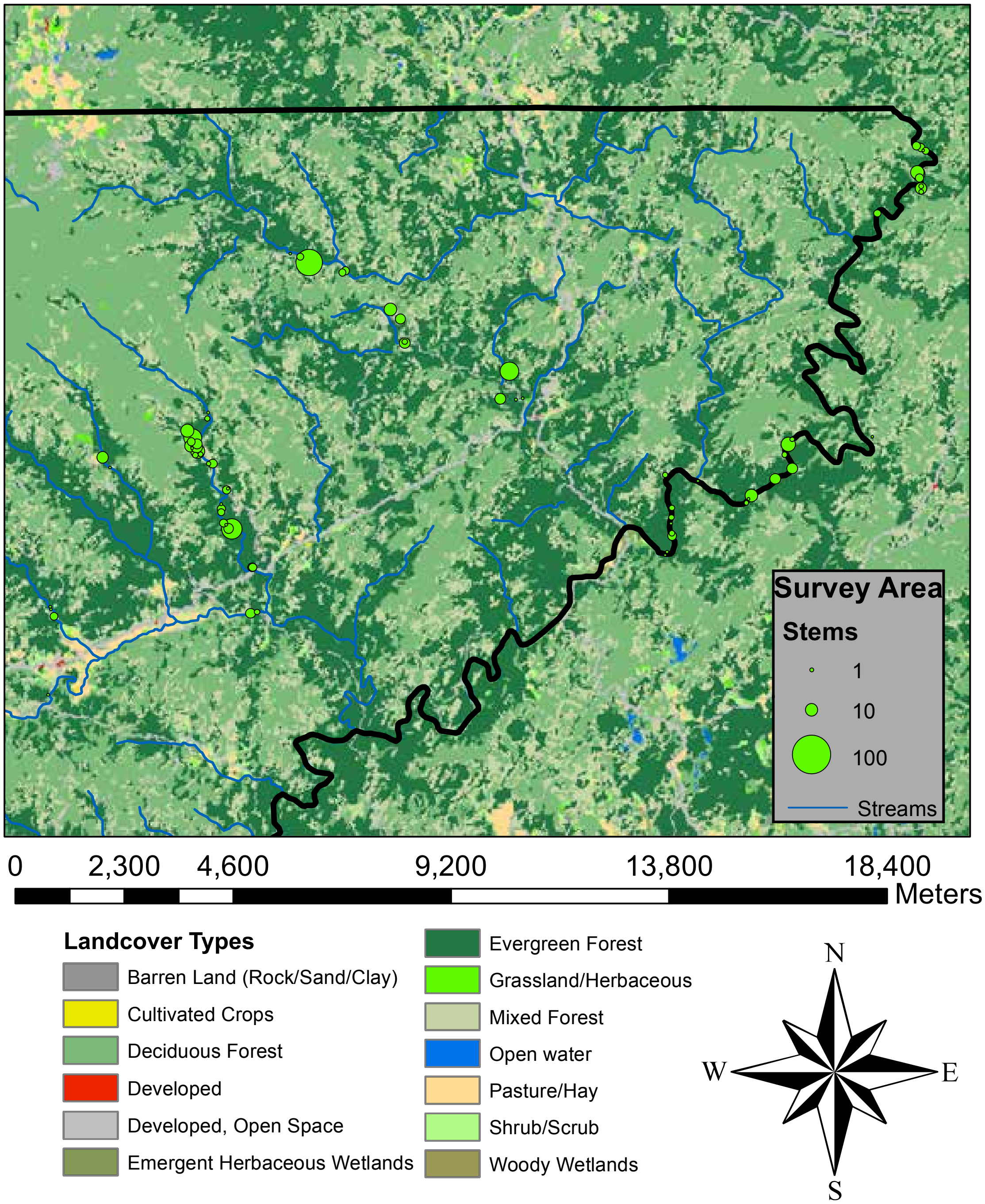


FIG. 1. Map of surveyed *S. ovata* populations. Proportional symbols show the relative size of each population based on the number of established plants.

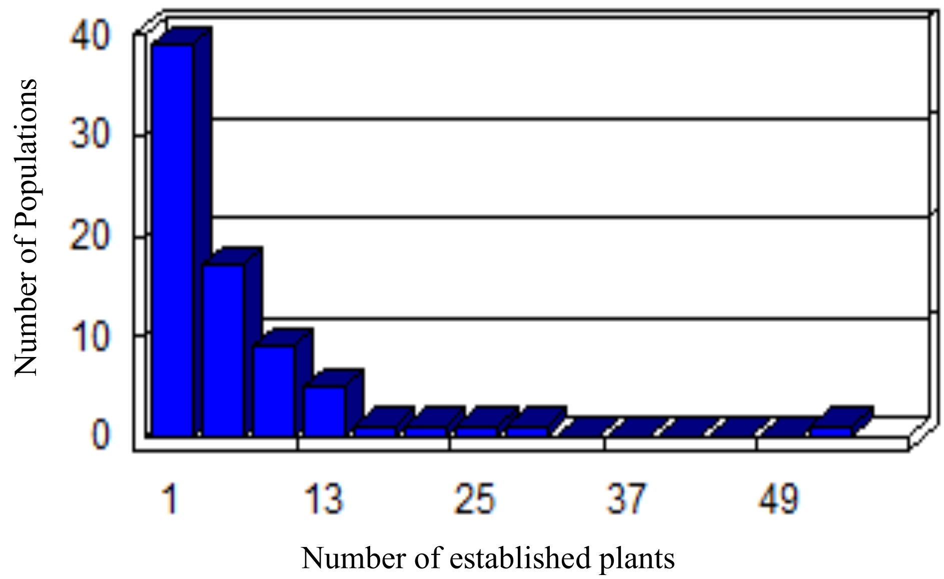


FIG. 2. Distribution of established plants in *S. ovata* observed populations.

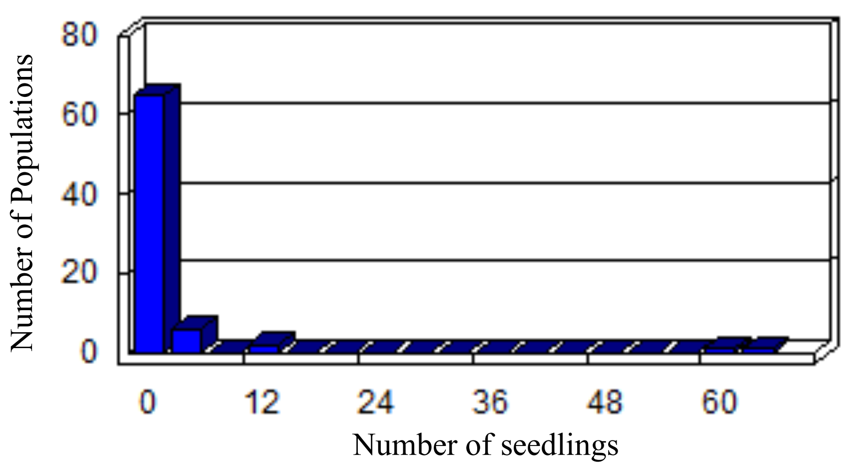


FIG. 3. Distribution of seedlings in *S. ovata* observed populations.

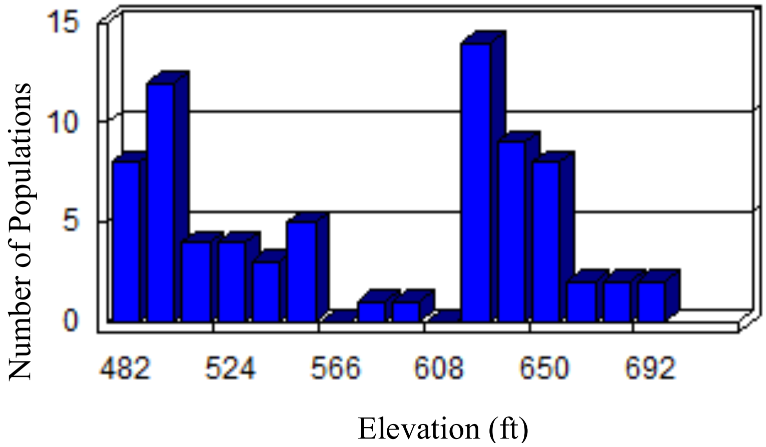


FIG. 4. Elevation values at observed *S. ovata* sites.

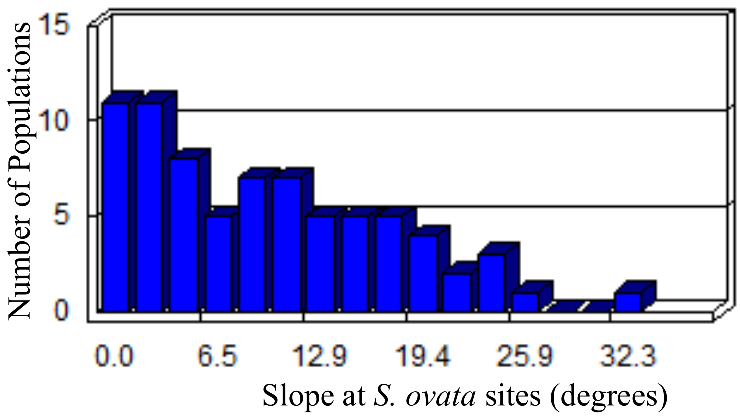


FIG. 5. Slope values at observed *S. ovata* sites. The observed range of 0 – 33 degrees was used as the ideal slope parameter in the predictive model.

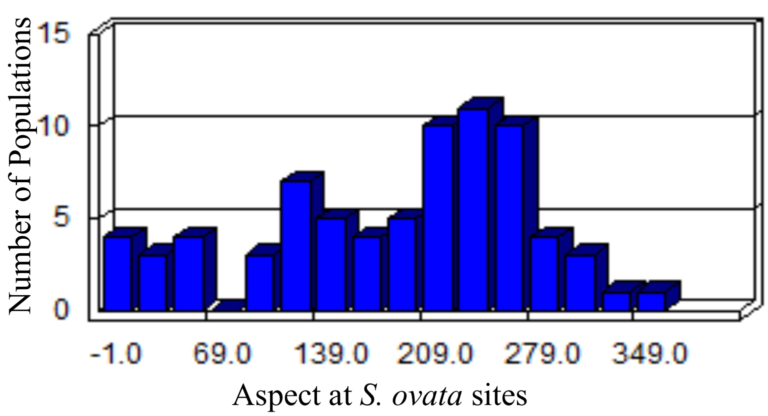


FIG. 6. Aspect values observed at *S. ovata* sites. Because values range all along the compass, aspect may not be a significant factor in predicting *S. ovata* locations. However, the predictive model used aspect values between 210-280 as the ideal range because these values are clustered.

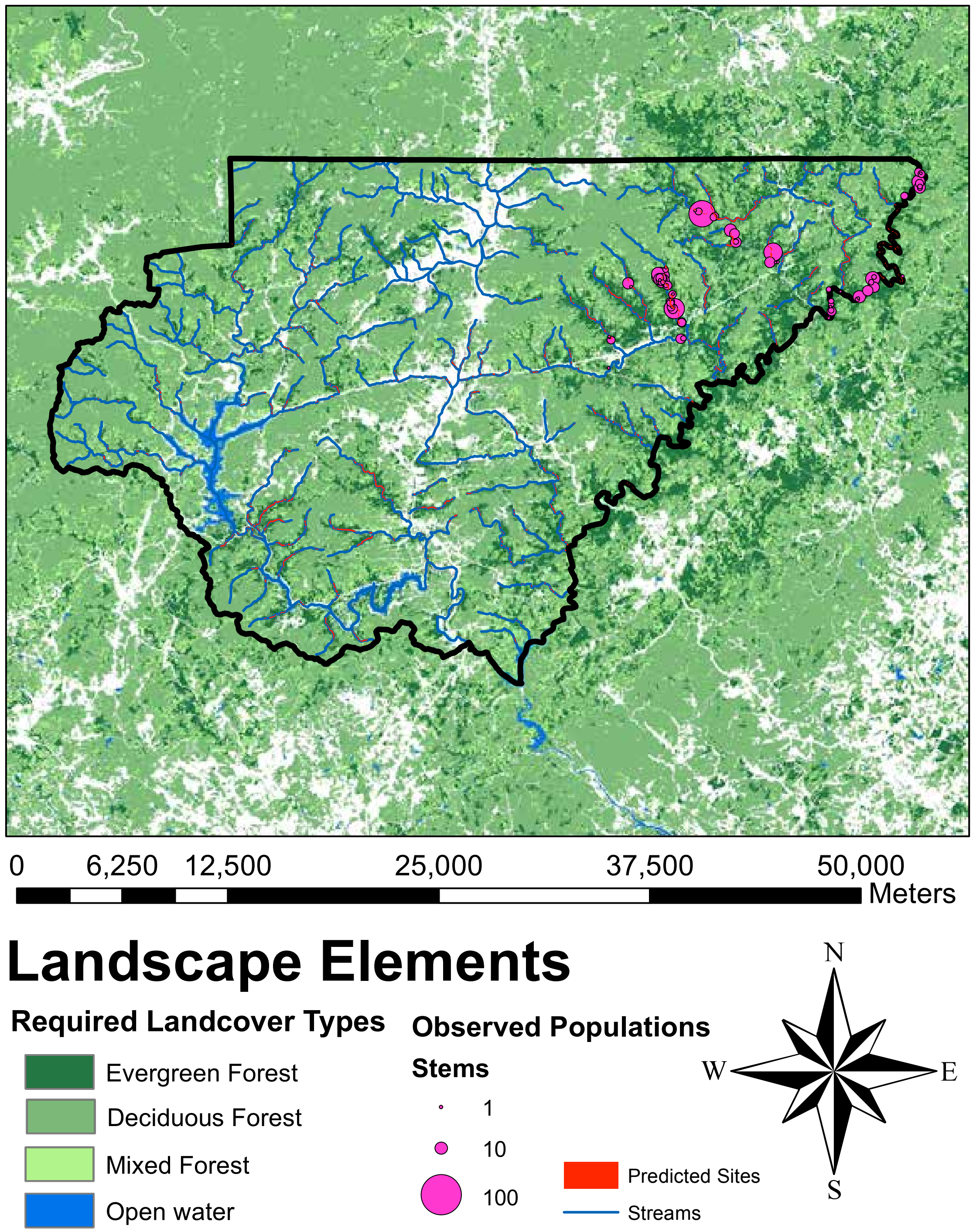


FIG. 7. Final predictive model showing predicted *S. ovata* habitat primarily in the southeastern portion of Rabun County.

DISCUSSION

Stewartia ovata requires abundant sunlight for optimum growth and fruit bearing so, not surprisingly, all populations were found along trails, roadsides, and other areas with large gaps for sunlight to reach the forest floor.

We found that *S. ovata* is associated with particular plant communities. *Acer rubrum* and *Rhododendron maximum* are the two most common tree species in *S. ovata* habitat (Fig. 8). These are notorious for growing over and shading *S. ovata*, a slower-growing understory species. Their presence in *S. ovata* habitat decreases the reproduction and survival of *S. ovata*, perhaps contributing to its rarity in the wild. Mycorrhizae associated with *R. maximum* are found on *S. ovata* roots, indicating that it has long been a common associate species despite its competitive edge (J. Johnston, pers. comm.). Old growth hemlocks were once a part of this plant community as well, however the destruction of this species from the hemlock wooly adelgid in recent years has created canopy gaps which have increased favorable *S. ovata* habitat as now only the young hemlocks remain.

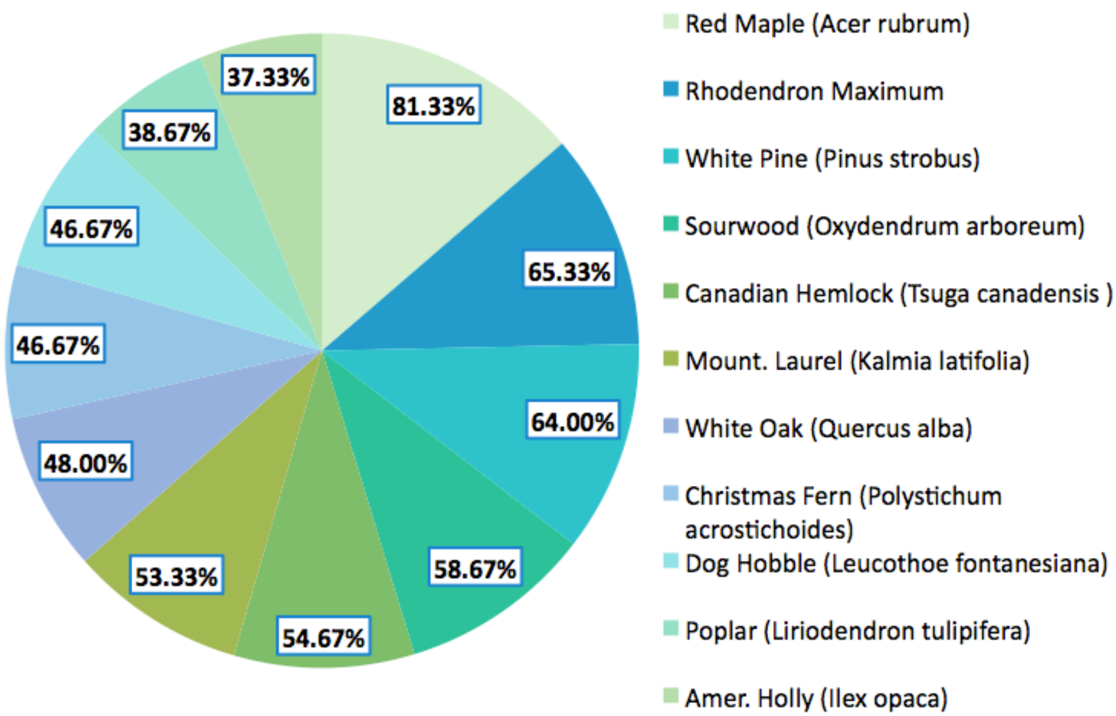


FIG. 8. Associate species present at 35% or more of the observed *S. ovata* population sites.

Stewartia ovata occurs at elevations of 1,500 – 2,000 ft in western North Carolina (Hobson and Houser 2010). Our model predicts that *S. ovata* will occur only at elevations between 482-692 feet. This is a consequence of our data collection. We only surveyed the northeastern portion of Rabun County which is relatively low in elevation, so these are the only elevations that appear to support *S. ovata* growth. *S. ovata* is not confined to these particular elevations when other factors are favorable (Hobson and Houser 2010).

Stewartia *ovata* can exist at steeper slope gradients, but it may have a higher success rate growing on less steep slopes below 25 degrees (Fig. 5). Growth on a steeper slope subjects *S. ovata* to a higher risk of habitat destruction from soil erosion and mortality from tree fall (J. Johnston, pers. comm.). The wide distribution of aspect values indicates that *S. ovata* does not have a strong preference for aspect. This finding is corroborated by another study of *Stewartia ovata* habitat in western North Carolina, which used Rayleigh's Test for circular uniformity to determine that no preference for aspect existed in observed *S. ovata* populations (Hobson and Houser 2010). In our final predictive model, we used aspect values between 210-280 as our parameter for favorable habitat because we observed a slight clustering of values in this range. This may have made the model more restrictive than necessary if *S. ovata* has little to no preference for aspect.

S. ovata prefers well-drained soils such as loam. The map layer of Rabun County soils was divided into 31 soil classifications. We recognized only a few of these as loam, and these were the ones that we used in our predictive model. It is possible that more of these soil classifications were loam type soils, but we did not recognize them as such. This may have further narrowed the predictive model sites for *S. ovata* below what would be observed in nature. Increasing the number of soil classifications used in the predictive model would have increased areas of possible *S. ovata* habitat.

In the preliminary predictive model, the map layers of slope, aspect, elevation, soil, and spectral signature were added together using the same weight for each layer despite the unknown significance of each factor in determining *S. ovata* habitat. Increasing the number of observed *S. ovata* populations may have helped to better determine the significance level of these factors for a predictive model, particularly for aspect since the slight clustering of values could have been due to random chance.

Land cover type seems to be a significant factor of predicting *S. ovata* habitat since the 75 populations were only observed in three land cover types (evergreen, deciduous, and mixed). The most recent landcover data available was from 2006, so it is possible that some predicted areas of the final model have been developed in the last six years and will not contain *S. ovata* when examined.

Despite what we know about *S. ovata* habitat preferences, we observed several outliers while surveying established populations. *S. ovata* does not normally tolerate fire disturbance. However, at a site in Sarah's Creek where an established stem was killed by fire, we discovered 67 seedlings in the nearby area. There were also three observed *S. ovata* sites further than 50 meters from a stream or river. These may have been next to a spring or other underground water source instead, a factor which was not taken into account by the predictive model but which may expand the areas where we could find wild *S. ovata*. At another site in Sarah's Creek, we observed an established *S. ovata* stem growing out of a quartzite rock, suggesting that *S. ovata* can thrive in a very thin (~1 cm) layer of soil if other conditions are favorable. This site was adjacent to an old forest service road with plentiful sunlight, which may indicate that sunlight availability is among the most important factors determining *Stewartia ovata* habitat and deserves additional weight in a predictive model. It is unfortunate that canopy gaps could not be included in our predictive model for lack of data. Conservationists who use this model to look for new population sites should note that areas with canopy gaps, such as those along roads or trails, are favorable to *S. ovata* growth.

The influence of past natural and anthropogenic disturbances play a role in determining *S. ovata* habitat. This is another factor that was not addressed in our model. Vast sections of the southern Appalachians were clear cut or logged selectively in the early to mid 20^{th} century. This may have decimated *S. ovata* completely in some areas. For example, a site along Warwoman Road contained *S. ovata* stems that had been smashed by a falling log. Selective logging, however, will create new canopy gaps that may allow *S. ovata* to thrive. Introduced pathogens and pests like the chestnut blight and hemlock wooly adelgid could also have killed *S. ovata* stems as dying trees toppled over, or benefited *S. ovata* by opening canopy gaps. Anthropogenic disturbance besides land development has also diminished possible *S. ovata* habitat. At a site at Tuckaluge Creek campers had been cutting *S. ovata* trees for firewood. Another observed source of mortality for *S. ovata* plants comes from beavers which chew down established *S. ovata* trees (observed at a site on Earl's Ford Rd) and create ponds that can destroy *S. ovata* habitat.

Hard-to-predict, small-scale disturbance factors, including extreme weather events, will decrease our ability to use this predictive model to find *S. ovata*. Conversely, our predictive model may be too restrictive to predict all possible *S. ovata* habitat in Rabun County. We found several populations that were not predicted by the model. Additional groundtruthing is necessary to verify the presence of viable *S. ovata* populations. It is our hope that this model will lead to the discovery of new *S. ovata* populations in Rabun County or to the creation of predictive models for other areas of the southern Appalachians where *S. ovata* is known to occur, such as the Cumberland Plateau of Tennessee and Kentucky (Tackett 2012). Ideally scientists can use models such as this to develop a better understanding of the ecological conditions required for *S. ovata* to grow, and from these, make land use recommendations to potential loggers and developers to preserve this rare native species.

ACKNOWLEDGEMENTS

We would like to thank our tireless mentor Jack Johnston for all of his time in the field, background knowledge of southern Appalachian flora, and devotion to *Stewartia* conservation. Special thanks to Gary Wein of the Highlands-Cashiers Land Trust for several hours of GIS consultation and help with analyses, as well as GIS Librarian of UNC-Chapel Hill Amanda Henley for her help locating GIS data sources. This paper would also not have been possible without Karen Kandl and Michelle Ruigrok for their support, comments, and editing during the writing process. Additional thanks to the Georgia GIS Clearinghouse, USDA Soil Data Mart, Coweeta LTER and USGS Earth Resources Observation & Science Center for providing free GIS data online.

LITERATURE CITED

Curtis, D. L., T. G. Ranney, F. A. Blazich, and E. P. Whitman II. 1996. Rooting and subsequent overwinter survival of stem cuttings of *Stewartia ovata*. Journal of Environmental Horticulture, **14**(3):163-166.

Environmental Systems Research Institute (ESRI) 2009. ArcGIS Desktop: Release 9.3.1. Redlands, California, USA.

Environmental Systems Research Institute (ESRI) 2011. ArcGIS Desktop: Release 10. Redlands, California, USA.

Heo, Kyeong-in, S. L., C. Lee, and S. Kim. 2011. Generic delimitation and infrageneric classification of *Stewartia* and *Hartia* (Theaceae; Stewartiaea): insight from pollen morphology. Plant Systematics and Evolution **297:**33-50.

Hobson, G. P., and M. T. Houser. 2010. Physical descriptions and associated ecological analyses of western North Carolina *Stewartia ovata* populations. Institute for the Environment Highlands Field Site Internship Reports. 37-50.

Lerner, B. R. 2000. What is loam? Purdue University Consumer Horticulture.

Prince, L. M. 2002. Circumscription and biogeographic patterns in the eastern North American-east Asian genus *Stewartia* (Theaceae: Stewartieae): Insight from chloroplast and nuclear DNA sequence data. Southern Appalachian Botanical Society, **67**(3): 290-301.

Reay, W. G., and K. A. Moore. 2009. Introduction to the Chesapeake Bay National Estuarine Reserve in Virginia. Journal of Coastal Research **57**: 1-9.

Spongberg, S. A. 1974. A review of deciduous leaved species of *Stewartia* (Theaceae). Journal of the Arnold Arboretum **55**:182-214.

Tackett, K. L. 2012. Forest dynamics of two multi-aged hemlock-mixed mesophytic forests in the northern Cumberland Plateau, Kentucky. Online Theses and Dissertations*,* Paper *56.*

CREATING A PARCEL-BASED CONSERVATION VISION MODEL FOR TWO BLUE RIDGE FOREVER FOCUS AREAS IN THE SOUTHERN BLUE RIDGE MOUNTAINS.

JULIE TIERNEY

Abstract. This project develops a parcel-based conservation vision model for two watershed-based Blue Ridge Forever focus areas in the quickly developing and ecologically rich Southern Blue Ridge Mountains. Emphasizing the preservation of natural heritage and ecological processes, this GIS model focuses on eight features representing five conservation values reflecting the missions of Blue Ridge Forever and Highlands-Cashiers Land Trust. Parcels containing the targeted conservation features were identified and scored in ArcGIS, and a simple additive model and combination procedure was used to classify parcels as low, medium, or high priority for conservation. This prioritization model will inform a land acquisition strategy for Highlands-Cashiers Land Trust for the conservation of the most ecologically rich private land in the region.

Key words: *Conservation model; GIS; land trusts; southern Blue Ridge Mountains; natural heritage.*

INTRODUCTION

With the rapid development of western North Carolina, pursuing long-term protection of land is necessary to preserve the many ecological and cultural resources of this region. Development has increased in this region 570% from 1976 to 2006 (Vogler et al. 2010). The Highlands-Cashiers region, a popular vacation area, is especially susceptible to development because of its proximity to urban centers such as Atlanta, Asheville, and Charlotte. In order to protect the rich natural heritage of this region, a conservation strategy is needed.

Land trusts or conservancies, which are private, non-profit organizations, work to preserve land through land donations, purchases, or voluntary conservation agreements with landowners. These agreements, known as conservation easements, are legal agreements between a landowner and a land trust in which the landowner agrees to preserve the natural condition of the land without excessive disturbance and the land trust has the right to monitor the property and enforce the terms of the conservation easement (CTNC 2010). Landowners who donate conservation easements are, in turn, eligible for federal, state and local tax incentives. Land trusts have become the major conduit for transfer of important conservation lands to the U.S. Forest Service or state agencies. Land Trusts often receive funding to purchase land from grants through the Land and Water Conservation Fund, NC Natural Heritage Trust Fund Program, and NC Clean Water Management Trust Fund. According to the Conservation Trust for North Carolina (CTNC), land trusts in North Carolina have conserved over 350,000 acres of land in 2,000 locations across the state (2012).

Blue Ridge Forever (BRF), a collective of 10 land conservation organizations including Highlands-Cashiers Land Trust, has drafted a Conservation Vision – an initiative to connect protected lands on a landscape scale, prioritizing areas that contain: 1) nationally or state significant ecological values, 2) important wildlife habitat, 3) high water quality, 4) cultural and economic significance and scenic value, and 5) working farms and forest lands (BRF 2012). As a part of this conservation vision, BRF has identified 28 focus areas in the Southern Blue Ridge Mountains that meet these five conservation criteria for a joint conservation effort. The objective of this project was to create a parcel-based conservation vision model for two watershed-based BRF focus areas within the Highlands-Cashiers Land Trust (HCLT) service area in southern Jackson and Macon Counties – Chattooga Headwaters and Whiteside Mountain, and the Upper Tuckasegee Gorge – to inform future conservation efforts for HCLT. This model uses Geographic Information Systems (GIS) data to assign priority to land parcels based on the conservation priorities outlined by both BRF and HCLT. We used land parcels as the basic unit for analysis because the transactions involved in land conservation occur at the property owner-level. The ultimate product of this project is a map presentation that quantitatively describes the conservation priority value of land parcels in these two focus areas that best adhere to the goals set by BRF and HCLT. This model can then be applied to other focus areas identified in the BRF Conservation Vision.

METHODS

Focus Areas

Chattooga Headwaters and Whiteside Mountain

Located on the southern Macon-Jackson County line, the headwaters area of the Chattooga Watershed contains numerous scenic granite cliff-faces, which are home to rare species such as Peregrine falcons, ravens, and wintering golden eagles (BRF 2012) (Fig. 1). The Chattooga River is one of the few free-flowing rivers in the Southeast, and holds status as a National Wild and Scenic River. This area also contains Whiteside Mountain and part of the Nantahala National Forest. Although much of the southern portion of this focus area is managed by the USDA Forest Service, the majority of this area is unprotected and faces a significant risk of development.

Upper Tuckasegee Gorge

The Tuckasegee River was once the site of several major Cherokee settlements, and is considered sacred by the Cherokee people. Located in Jackson County, this watershed is surrounded by Nantahala National Forest and contains Panthertown Valley, a popular recreation area managed by the U.S. Forest Service and known as the “Yosemite of the East.” This Focus Area contains over 150 occurrences of threatened and sensitive species as well as many rare and significant habitats such as trout streams and southern Appalachian bogs (BRF 2012). Much of this area is at risk for development; very little land is under protection east of Panthertown Valley (Fig. 2).

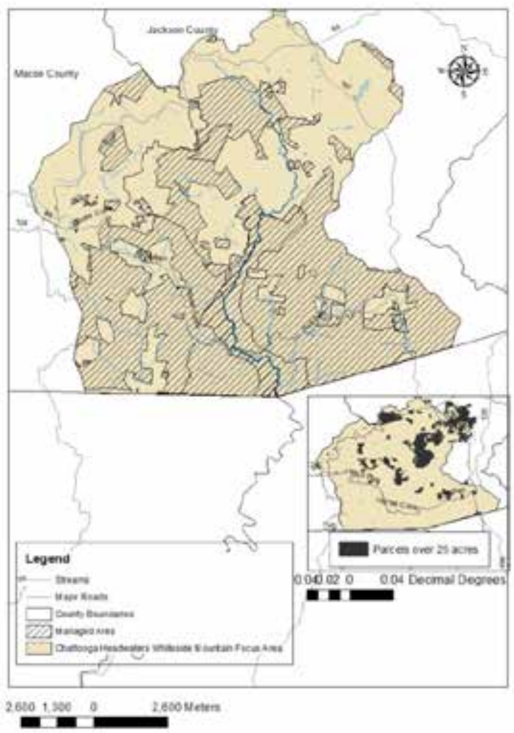


FIG. 1. A map of Chattooga Headwaters and Whiteside Mountain BRF Focus area, displaying stream coverage, major roads, county boundaries, already managed areas, and privately-owned land parcels exceeding 25 acres in area. Created in ArcGIS.

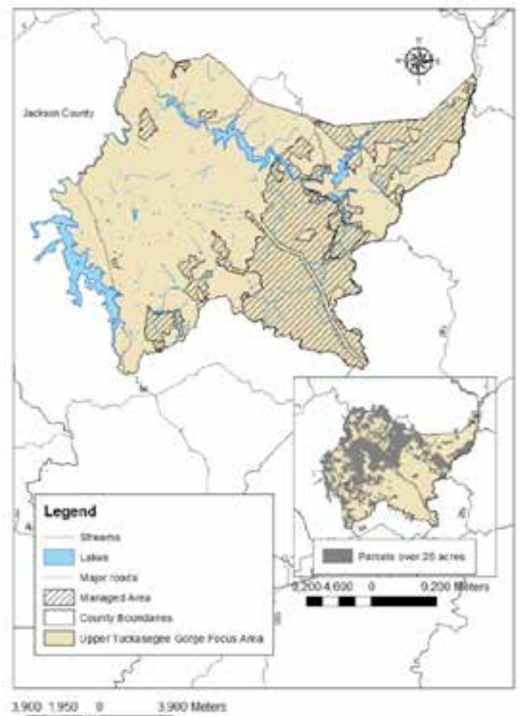


FIG. 2. A map of Upper Tuckasegee Gorge BRF Focus area, displaying stream coverage, lakes, major roads, county boundaries, already managed areas, and privately-owned land parcels exceeding 25 acres in area. Created in ArcGIS.

GIS data layers and conservation values used for prioritizing parcels

For the conservation assessment of the two BRF focus areas, only parcels with an area greater than or equal to 25 acres were analyzed in accordance with the guidelines set by the North Carolina Wildlife Resource Commission for the size and contiguity of property eligible for tax credits (2008). Currently managed conservation land was not included in the analysis. Land parcel data was obtained from Jackson County Land Records and Macon County GID Departments. Eight conservation features representing five conservation values in accordance with the conservation goals of BRF and HCLT were evaluated for all parcels (Table 1).

The specific conservation goals of HCLT are:

- to acquire and manage natural areas;
- to protect native species of plants and animals;
- to preserve the area’s rural and cultural heritage;
- to sustain air and water quality and biological diversity;
- to provide opportunities for outdoor education and recreation; and
- to enhance buffer communities.

TABLE 1. Five conservation values, their respective conservation features, and the sources and years of the GIS data used. (NC DENR = North Carolina Department of Environment and Natural Resources; NC DOT = North Carolina Department of Transportation; US SSURGO = United States Soil Survey Geographic; USGS NHD = United States Geological Survey National Hydrography Dataset).

Conservation Value	Conservation Feature	Data Source	Year
Important ecological features	Natural Heritage Element Occurrences	NC DENR	2012
	Significant Natural Heritage Areas	NC DENR	2012
	Cliff faces	NC DOT LiDAR data	2007
	Wetland habitat	US SSURGO	1996-97
Water resources	Riparian buffer zones	USGS NHD	2007
Habitat connectivity	Buffering managed lands		
Prime agricultural lands	Prime agricultural soils	US SSURGO	1996-97
View shed	View shed	NC DOT LiDAR data	2007
		USGS 7.5 minute Topographic Maps	Most current available

These features were analyzed using ArcGIS 10© and Spatial Analyst© extension (ESRI 2011).

Important Ecological Features

The Southern Blue Ridge Mountains region is a known biodiversity hotspot, and is home to many rare and endemic species as well as sensitive and unique ecosystem types. Protecting these natural heritage elements is essential to effective biological conservation. Because of its significance, important ecological features were identified from two GIS datasets: Natural Heritage Element Occurrences, Significant Natural Heritage Areas and two topographic features: cliff-faces, and hydric soils as a surrogate for wetland habitats. The Natural Heritage Program, which is a division of the North Carolina Department of Environmental and Natural Resources (NC DENR), has compiled geo-referenced data of rare and endangered species as well as habitats and ecosystems of special significance. This data is available online at NC OneMap (http://data.nconemap.com/geoportal). Two already-existing databases were used to select parcels containing important ecological features. The Natural Heritage Element Occurrences data identify locations of rare and endangered species populations as well as occurrences of unique ecosystems (NC DENR 2012 [1]), and the Significant Natural Heritage Areas data defines areas containing ecologically significant natural communities or rare species (NC DENR 2012 [2]).

In addition to the NC DENR data sets, areas with cliff-faces were identified as indicators of rare plant communities. The extreme environments of cliff-faces are associated with rocky outcrop communities, which harbor many rare, endemic, and disjunct plant species (Wiser et al. 1996). These cliff-faces are also potential sites for the cedar cliff community type, a diverse and rare community type (Small and Wentworth 1998). Because cedar cliffs are an unlisted community type in North Carolina (Shafale and Weakley 1990), this analysis could identify significant natural heritage features potentially disregarded by the NC DENR data. Cliff-faces in the two focus areas were identified in ArcGIS© using NC DOT LiDAR elevation data for Macon County and Jackson County (NC DOT 2007). Slopes greater than or equal to 45°, the slope value defined by the Mountain Ridge and Steep Slope Committee to identify slopes targeted for protection (2008), were identified using Spatial Analyst ©, and parcels containing these slopes were selected.

We also assessed wetland habitat as an important ecological feature. Mountain wetlands are one of the most important habitats for rare species in the Southeast, and are of critical importance in conservation (Murdock 1994). Wetlands can be identified by the presence of hydric soils. Parcels containing wetland habitats in the two focus areas were determined by selecting for hydric soils in the USGS SSURGO Soil Datasets for Jackson and Macon Counties (http://soils.usda.gov/survey/geography/ssurgo/) (NRCS 1996, 1997).

Water Resources

These two focus areas are delineated by watershed boundaries, which are basic and ecologically important landscape units of the Appalachian region. A watershed is an area of land in which all surface and ground water drain into a common river system. Riparian areas, the interfaces between aquatic and terrestrial ecosystems, have great biological significance. Preserving the health of riparian areas of this region is essential to protecting the incredibly diverse salamander populations of this region as well as maintaining nutrient cycling processes in riparian ecosystems (Petranka and Smith 2005, Knoepp and Clinton 2009).

Riparian boundaries are dependent on several factors, and can be delineated by changes in soil conditions, vegetation, and other factors that influence the interactions between aquatic and terrestrial ecosystems (Knoepp and Clinton 2009). Defining riparian boundaries and buffer zones is essential to protect stream water quality from disturbance. Proposed riparian buffer corridor widths have varied widely, but research has indicated corridors as narrow as 10-30 m are sufficient for protecting these areas (Karr 1978). Riparian corridors of these widths have also been applied in regional studies (Knoepp and Clinton 2009).

In order to prioritize parcels for riparian zone protection, we created a layer file identifying parcels within a 100 ft (30.48 m) buffer zone of the USGS NHD stream coverage (2007) in ArcGIS. HCLT land protection staff indicated that 100 ft buffers are usually sufficient to protect water quality in the mountains of WNC.

Habitat Connectivity

With rapid human development encroaching on the ecosystems of this region, maintaining high quality, connected habitat for wildlife is a conservation priority. Habitat fragmentation due to development reduces the amount of forest habitat, and causes patch isolation and edge effect. Habitat fragmentation has also been identified as one of the main factors contributing to the extinction of species (Wilcox and Murphy 1985). In order to maintain the gamma diversity of a region, Noss (1983) recommended interconnecting habitat patches.

In order to manage habitat fragmentation and conserve land that could provide potential wildlife corridors, parcels within 100 m of already-managed conservation lands (*i.e.* National Forest land) were selected and incorporated into a GIS layer. A buffer distance of 100 m was used to account for any error in the overlap between the GIS layer for managed area and the parcel map.

Prime Agricultural Lands

In addition to conserving land for its ecological significance, protecting working agricultural lands is a component of BRF's conservation vision. Selecting for working agricultural lands in the two focus areas was accomplished by creating a layer file in ArcGIS that identified parcels containing prime agricultural soils as identified by the NRCS in the Soil Surveys of Macon and Jackson Counties (1996-97).

View Shed

BRF aims to protect land with scenic value. View shed analyses from popular scenic overlooks in the two focus areas were performed using Spatial Analyst in ArcGIS using NC DOT LiDAR elevation data (2007). In the Chattooga Headwaters and Whiteside Mountain focus area, a point shapefile was made in ArcGIS at three observer points: Chimney Top Mountain, Whiteside Mountain, and downtown Cashiers. These points were used as representative view points for the view shed analysis. All parcels in the focus area visible from these points were selected. In the Tuckasegee Gorge focus area, a view shed was constructed using the Blue Ridge Parkway adjacent to the focus area as a "viewpoint".

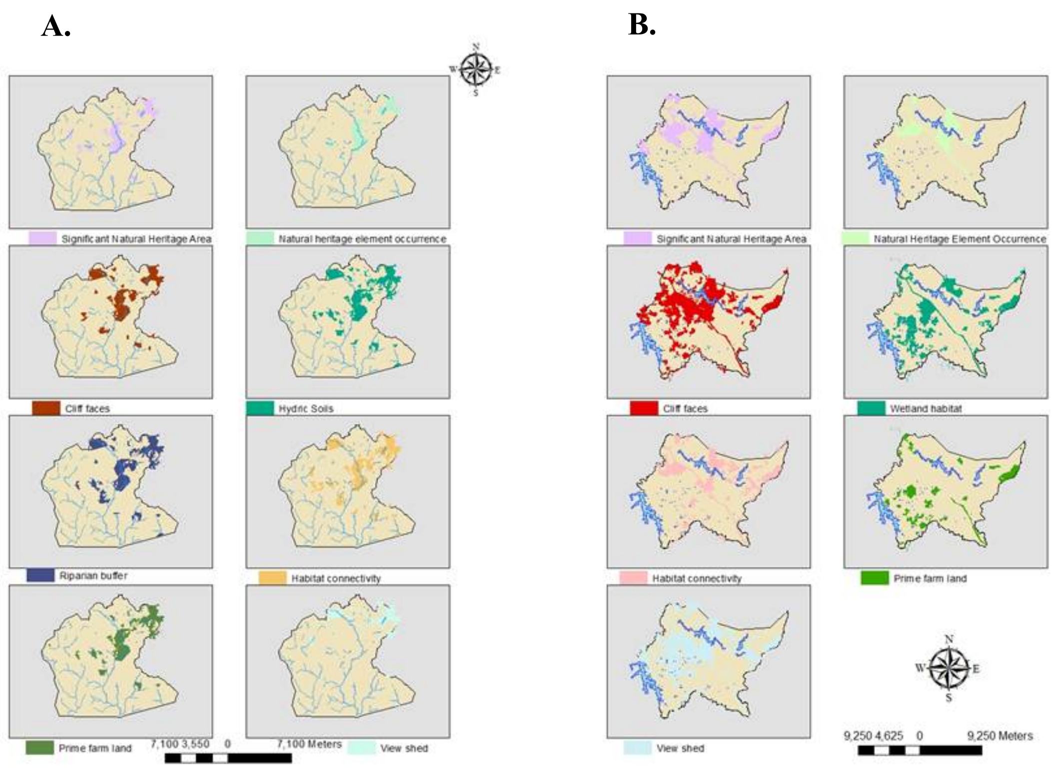


FIG. 3. A map presentation of parcels in the (A.) Chattooga Headwaters and Whiteside Mountain and (B.) Upper Tuckasegee Gorge Focus Areas that contain the conservation features prioritized in the model. Created in ArcGIS.

A linear shapefile of this section of the Blue Ridge Parkway was delineated from a topographic map. The layer files created representing parcels that contain each of the eight conservation features for the Chattooga Headwaters and Whiteside Mountain and Upper Tuckasegee Gorge focus areas are displayed in Figures 3 and 4, respectively. Parcels containing riparian buffer zones in the Tuckasegee Gorge focus area were not prioritized because all parcels in this focus area contained a riparian buffer zone.

Maps depicting GIS layers of parcels selected for each conservation feature in both focus areas are displayed in Figure 3. The Upper Tuckasegee Gorge Focus Area has only seven conservation feature parcel selection maps because all parcels contained a riparian buffer zone.

Ranking system and Combination Procedure

We used a simple additive model to identify the highest priority parcels in the two focus areas. Each layer file representing the parcels selected for the eight conservation features was converted to a raster dataset and reclassified with arbitrary unique values. The values of these raster datasets were added using the Raster Calculator tool in Spatial Analyst, resulting in an output raster that reclassified parcels with the sum of their combined unique values.

Analysis

The output of parcel scores was analyzed for three levels of priority: low, medium, and high priority. Four of the eight conservation features (Significant Natural Heritage Area, Natural Heritage Element Occurrences, riparian buffer zone, and habitat connectivity) were identified as highest-priority features and were given more weight in the analysis. Parcels that intersected four or more of the eight conservation features were identified as low priority. Parcels that intersected four or more of the features, three of which were highest-priority features, were scored as medium priority. High priority parcels intersected seven or eight of the conservation features.

RESULTS

The final conservation vision models for the two BRF focus areas identifying parcels of three levels of conservation priority are represented in figures 5 and 6.

Chattooga Headwaters and Whiteside Mountain Focus Area

Of the 2,049 parcels within this Focus Area, 23 were identified as high conservation priority, 79 were medium priority, and 151 were low priority. All parcels identified for conservation are within Jackson County (Fig. 4).

Upper Tuckasegee Gorge Focus Area

Of the 360 parcels analyzed in this focus area, 10 were given a high conservation priority, nine were medium priority, and 100 were low priority. One of the parcels designated as high priority is the Duke Energy transmission line, which diagonally bisects the watershed and runs through Panthertown Valley (Fig. 5).

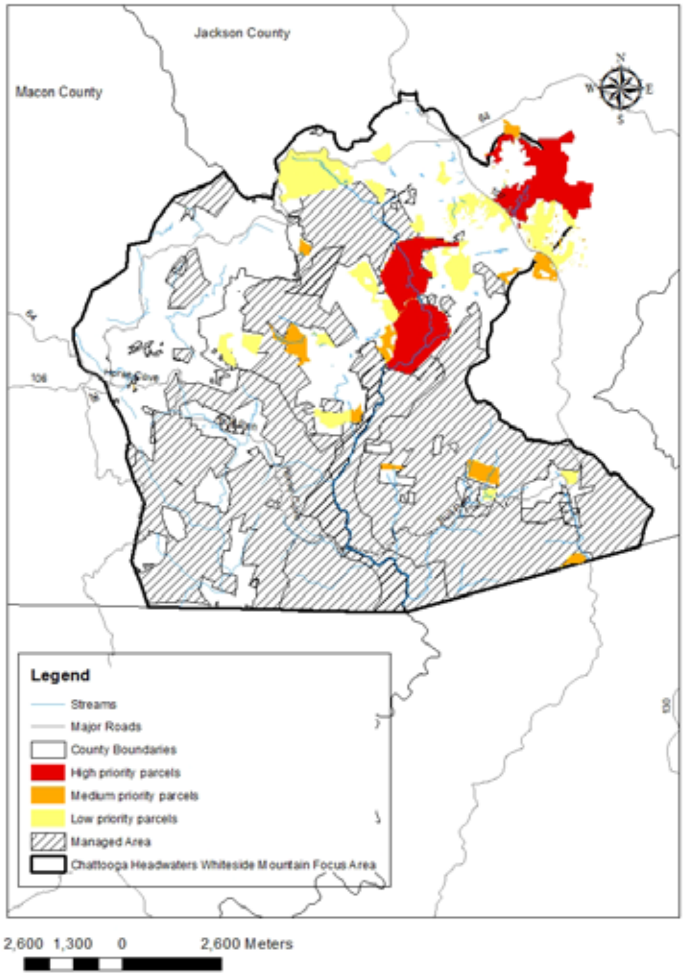


FIG. 4. Target high, medium, and low priority parcels and already-conserved lands in the Chattooga Headwaters and Whiteside Mountain Focus Area. Created in ArcGIS.

DISCUSSION

All of the parcels targeted for conservation efforts in this focus area are located in Jackson County. Generally, parcels in Jackson County are larger than those in Macon County. Comparatively few Macon County parcels were included in the analysis; only 33 parcels of the 2,049 parcels in the focus area over 25 acres were located in Macon County (Fig. 1). It can be assumed that the private land in Macon County is already highly developed and fragmented. Furthermore, there is a significant amount of Macon County land within the focus area that is already under protection (Fig. 5). Conservation efforts for this focus area should be concentrated in Jackson County.

In both focus areas, larger parcels are generally ranked with a higher priority. This pattern most likely occurs because parcels that cover a larger area have a greater probability of encompassing more conservation features. The largest parcels are valuable to these conservation efforts because they would provide the most diverse, continuous and unfragmented habitat. One of the parcels identified as high priority in the Upper Tuckasegee Gorge Focus Area is owned by

Duke Energy and is currently the site of a transmission line. This parcel diagonally bisects nearly the entire focus area, thus covering a wide diversity of habitats and other conservation features. However, the land covered by the Duke Energy transmissions lines realistically has very low conservation value because field observation has confirmed heavy use of herbicides in this area. The exclusive use of a computerized model to make conservation decisions has limitations; therefore reasoned judgment should be used in conjunction with computer analysis in the final selection of the highest priority parcels for this conservation vision model.

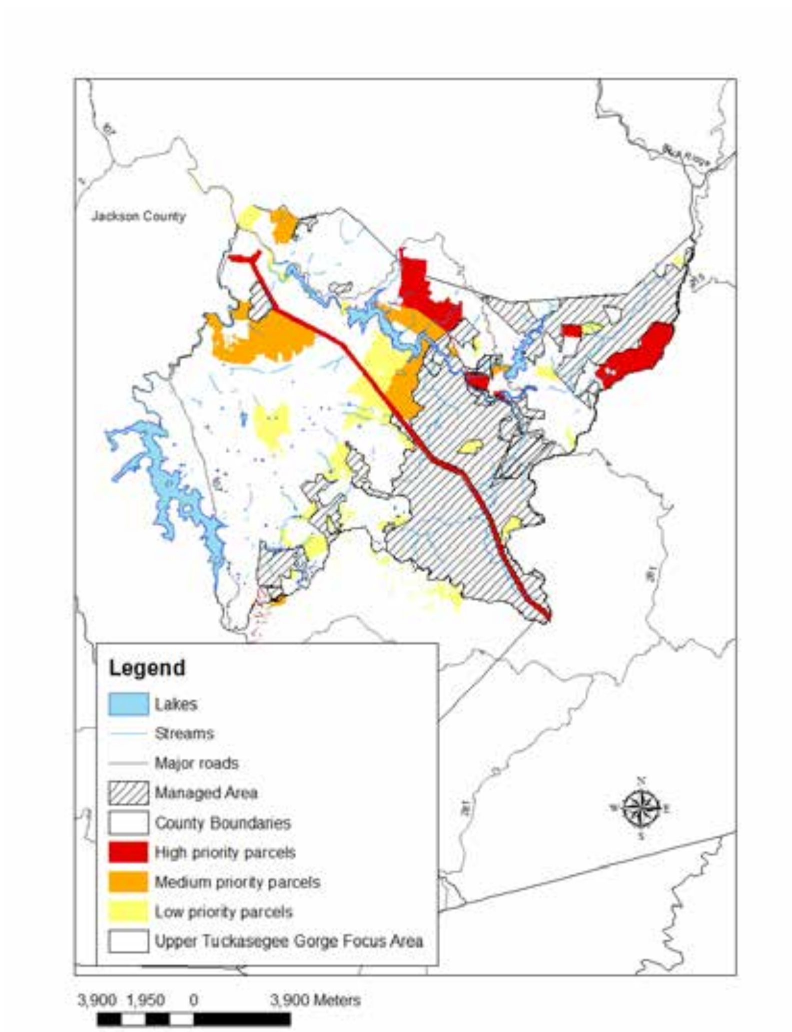


FIG. 5. Target high, medium, and low priority parcels and already-conserved lands in the Upper Tuckasegee Gorce Focus Area. Created in ArcGIS.

The next step for this project is to incorporate expert knowledge into this conservation vision model in order to further strategize which parcels to protect. This involves identifying the landowners of these parcels using the land parcel data from Jackson County Land Records and Macon County GID Departments. A communication campaign should be initiated by HCLT to contact the landowners about opportunities for conservation easements, purchases, and donations. Land surveys and ground-truthing are also essential for verifying the level of conservation priority of these parcels.

This model can be applied to other focus areas in the BRF Conservation Vision depending on the availability of data in their respective counties. Most of the data used is available through state or federal agencies and is available for all counties. The land parcel data, however, is only available at the county level. Some counties do not have the resources to incorporate tax parcel information into GIS data, so creating a parcel-based conservation vision model would not be possible in these counties. In counties without tax parcel data, a similar feature-based conservation vision model could be used that would identify areas of land containing valuable conservation features. Potential conservation properties could then be identified by physically locating these areas and identifying property owners.

Conclusions

This conservation vision model was successful in targeting parcels for potential protection by HCLT, and can be implemented in other BRF focus areas in western North Carolina. However, this model would not be appropriate for use elsewhere because conservation values should be determined regionally. Furthermore, the limitations of a computer-generated conservation model need to be recognized. Although this model is effective in determining potential conservation targets, we must also incorporate local and expert knowledge, reasoned judgment, and ground-truthing for this model to be effective. Although GIS is an extremely helpful tool for land trusts, no computerized model can include all facets of conservation values. Land trusts must also be opportunistic in land acquisition, so priorities must also consider variables such as the immediate threat of development, changes in land prices, and the availability of land. For successful implementation of this model, the owners of the identified parcels should be contacted and invited to participate in the conservation of the rich natural heritage of this region through partnership with land trusts.

ACKNOWLEDGEMENTS

I would like to thank my mentor Dr. Gary Wein of the Highlands-Cashiers Land trust for his immense help and guidance with this project. I would also like to thank Hanni Muerdter of the Southern Appalachian Highlands Conservancy for her extremely helpful advice. My gratitude also goes out to Dr. Karen Kandl of Highlands Biological Station for her guidance and reviewing.

LITERATURE CITED

Blue Ridge Forever. 2012. Conservation Vision. Retrieved November 15, 2012, from http://www.blueridgeforever.info/conservation-vision.

Conservation Trust for North Carolina. 2010. Voluntary Conservation Agreements: An Introduction for North Carolina Land Owners.

Conservation Trust for North Carolina. 2012. “About CTNC.” Retrieved November 15, 2012, from http://www.ctnc.org/about/.

Environmental Systems Research Institute (ESRI). 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Karr, J. R., and Schlosser, I. J. 1978. Water resources and the land water interface. Science **201**:229-34.

Knoepp, J. D., and B. D. Clinton. 2009. Riparian zones in southern Appalachian catchments: Carbon and nitrogen responses in forest cutting. Forest Ecology and Management. **258**(10): 2282-2293

Mountain Ridge and Steep Slope Advisory Committee. 2008. Mountain Ridge and Steep Slope Protection Strategies. Land of Sky. Retrieved November 16, 2012, from http://www.climatechange.nc.gov/PDFs/LandofSky-MRSSPS-report%205-28-08.pdf.

Murdock, N. A. 1994. Rare and endangered plants and animals of Southern Appalachian wetlands. Water, Air and Soil Pollution **77**:385-405.

Natural Resources Conservation Service. 1996. Soil Survey of Macon County, North Carolina. United States Department of Agriculture.

Natural Resources Conservation Service. 1997. Soil Survey of Jackson County, North Carolina. United States Department of Agriculture.

The North Carolina Department of Environmental and Natural Resources, Division of Parks and Recreation. 2012. Natural Heritage Element Occurrences. Retrieved November 15, 2012, from http://data.nconemap.com/geoportal/catalog/search/resource/details.page?uuid={80E6FD27-9F46-4AA5-A796-1EB6B1036AC0}.

The North Carolina Department of Environmental and Natural Resources, Division of Parks and Recreaton. 2012. Significant Natural Heritage Areas. Retrieved November 15, 2012 from http://data.nconemap.com/geoportal/catalog/search/resource/details.page?uuid={3994E180-3854-45F3-95CF-757C874D1B45}.

North Carolina Wildlife Resource Commission. 2008. Guidelines for review of applications for conservation tax credits.

Noss, R. F. 1983. A regional landscape approach to maintain diversity. Bioscience **33**:700-706.

Petranka, J. W., and C. K. Smith. 2005. A functional analysis of streamside habitat use by southern Appalachian salamanders: Implications for riparian forest management. Forest Ecology and Management **2010**(1-3): 443-454.

Schafale, M. P., and A. S. Weakley. 1990. Classification of the natural communities of North Carolina: third approximation. North Carolina Natural Heritage Program, North Carolina Department of the Environment, Health and Natural Resources.

Small, C. J., and T. R. Wentworth. 1998. Characterization of montane cedar-hardwood woodlands in the Piedmont and Blue Ridge provinces of North Carolina. Castanea **63**:241-261.

Vogler, J. B., D. A. Shoemaker, M. Dorning, and R. K. Montemeeyer. 2010. Mapping historical development patterns and forecasting urban growth in western North Carolina. The Center for Applied GIScience at UNC-Charlotte. UNC-Charlotte.

Wilcox, B. A., and D. D. Murphy. 1985. Conservation Strategy: the effects of fragmentation on extinction. American Naturalist. **125**(6): 879-887.

Wiser, S. K., R. K. Peet, and P. S. White. 1996. High-elevation rock outcrop vegetation of the southern Appalachian Mountains. Journal of Vegetation Science **7:**703-722.

Appendix A

Maps of Chattooga Headwaters and Whiteside Mountain and Upper Tuckasegee Gorge Focus Areas (digital archive on attached CD).

Appendix B

Map presentations of parcels within the Chattooga Headwaters and Whiteside Mountain and Upper Tuckasegee Gorge Focus Areas selected for conservation features (digital archive on attached CD).

Appendix C

Maps of Chattooga Headwaters and Whiteside Mountain and Upper Tuckasegee Gorge Focus Area displaying high- , medium-, and low-priority parcels (digital archive on attached CD).

THE DENSITY OF *CORBICULA FLUMINEA* IN WESTERN NORTH CAROLINA WATERSHEDS

ELYSE WILL

Abstract. The invasive freshwater mussel species *Corbicula fluminea* has invaded nearly every major river system in the country, including the Little Tennessee Watershed, the Tuckasegee Watershed, and the Pigeon River watershed in western North Carolina. The presence of *Corbicula* in regional watersheds may negatively affect native biodiversity, aquatic ecosystem functioning, and the economy. The goal of this project is to determine how far upstream *Corbicula* have travelled in western North Carolina watersheds and to determine population densities. By examining four rivers in western North Carolina—the Little Tennessee, the Tuckasegee, the Oconaluftee, and the Pigeon—we attempted to better understand the *Corbicula* invasion in the region. We found *Corbicula* populations in all of the rivers we visited with the exception of the Oconaluftee River. Furthermore, the results of this study indicate that the highest *Corbicula* density occurred in the Pigeon River, which is the most disturbed river in the region, and the lowest *Corbicula* densities occurred in the upstream reaches of all rivers and the downstream reaches of the Tuckasegee and Oconaluftee Rivers, which is likely due to cooler water temperatures. Overall, *Corbicula* populations appear to be currently limited to the downstream reaches of the watersheds sampled, with their upstream range bounded by dams and/or cooler water.

Key words: Asian clam; Corbicula fluminea*, population density, western North Carolina, Little Tennessee River, Tuckasegee River, Oconaluftee River, Pigeon River.*

INTRODUCTION

The freshwater mussel *Corbicula fluminea*—also known as the Asian clam—is an invasive species from Southeast Asia that was first found in the United States in 1938 along the banks of the Columbia River in Washington and has since spread to 38 states and the District of Columbia (Counts 1986, USGS 2012). The species was purposely introduced to the west coast of North America and it is believed to have entered the states as a food item via Chinese immigrants (Vaughn and Spooner 2006). Currently, *Corbicula* have invaded nearly every major river system in the country and studies have shown that humans are the principal agent of dispersal (Counts 1986, Strayer 1999).

Corbicula possess several key life history traits that have enabled their rapid colonization in the United States. For example, characteristics such as early sexual maturity, short life span, high fecundity, and rapid growth allow *Corbicula* populations to expand rapidly in new environments (Cooper 2007, Sousa et al. 2008). *Corbicula* may have separate sexes or be hermaphroditic and are capable of self-fertilization (Sousa et al. 2008). Additionally, they have an extended breeding season and may reproduce multiple times within a season, though usually only twice (Sousa et al. 2008). The species has a short life span ranging up to 7 years (usually 2-4) and the annual fecundity rate can be as high as 68,000 juveniles per individual (McMahon 2002, Sousa et al.

2008). In addition to filter feeding, *Corbicula* may also pedal-feed, enabling them to feed from sediments (Hakenkamp et al. 2001).

The presence of *Corbicula* in watersheds may negatively affect native biodiversity, aquatic ecosystem functioning, and the economy. Studies have shown that *Corbicula* abundance is negatively correlated with native mussel abundance at small spatial scales (Vaughn and Spooner 2006). For example, *Corbicula* can live in a broader range of microhabitats than native mussels, are more tolerant of highly degraded environments, and tend to outcompete native mussels for limited resources (Vaughn and Spooner 2006, USGS 2012). However, native freshwater mussels play major roles in the aquatic ecosystem through filtering algae, excreting and biodepositing nutrients, oxygenating habitats, and providing habitat for other organisms (Vaughn et al. 2004). Furthermore, invasive mussel species such as *Corbicula* can fundamentally alter habitat structure and material cycling by increasing stocks of spent shells (Strayer and Malcom 2007). Therefore, the decline in native freshwater mussel biomass can alter the functioning of river ecosystems (Biggins and Butler 2000). Additionally, biofouling is a major economic problem associated with *Corbicula* and the species has caused millions of dollars worth of damage by clogging pipes in power plants, water systems, and irrigation canals (USGS 2012).

Due to the potential ecological influence of this exotic species, which first invaded the Little Tennessee River drainage system in the early 1990s, it is important to determine the distribution and density of *Corbicula* (Steve Fraley, NC Wildlife Resources Commission, personal communication). The goal of this project is to determine how far upstream Corbicula have travelled in western North Carolina watersheds and to determine population densities. By examining four rivers in western North Carolina—the Little Tennessee, the Tuckasegee, the Oconaluftee, and the Pigeon—we can better understand the scale of the *Corbicula* invasion.

METHODS

We sampled for *Corbicula* within three major watersheds in western North Carolina—the Little Tennessee watershed upstream of Fontana Reservoir, the Tuckasegee watershed, including the Oconaluftee River, and the Pigeon River watershed upstream of Waterville Reservoir, including Richland Creek. Within each watershed, sample sites were chosen where there was convenient access from the road.

Beginning downstream on each river, we conducted 30-minute visual searches at each sample site for evidence, either shells or living organisms, of *Corbicula*. If we did not find any evidence of *Corbicula* during this 30-minute interval, we did not sample for density. If, however, we found evidence during the 30-minute period, we conducted a quantitative survey for density and continued this process at sites along each stream until we found two consecutive sites that did not contain any evidence of *Corbicula*.

Density samples were obtained using a sampler constructed from an 8-in stovepipe ($0.0324\ m^2$) (Turner and Trexler 1997). During the sampling process, we placed the stovepipe on sand or gravel substrate and dug approximately 8 cm into the substrate and collected the material in the netting attached to the stovepipe. We collected 20 samples across the width of the stream, focusing on sand and gravel substrate, which is the preferred habitat of *Corbicula* (Strayer 1999). Sample locations and the microhabitats sampled were not random – we specifically sampled substrate where we believed *Corbicula* were likely to be. Therefore, our density estimates are biased and should not be viewed as average density, but as an average maximum density.

Location data was collected using a handheld Garmin GPS 60C Sx unit (Garmin, 1200E. 151st Street Olathe, KS 66062-3246). Maps were then generated to illustrate the distribution and density of *Corbicula* along these four rivers using ArcMap 10 (Esri, 380 New York Street, Redlands, CA 92373).

We used all samples from within reaches containing evidence of *Corbicula* colonization to test for differences in density among streams. We rank-transformed the data to fit the assumptions of ANOVA, then used Tukey a posteriori comparisons to test for differences between pairs of streams. All statistical analyses were computed using R version 2.15.2 (R Core Team 2012).

RESULTS

Corbicula were found at several sample sites on the Little Tennessee River, the Tuckasegee River, the Pigeon River, and Richland Creek (Table 1, Fig. 2). Densities were greatest in the Pigeon River and lowest in the Tuckasegee River (Fig.1).

TABLE 1. Average density of Corbicula in the Little Tennessee River, the Tuckasegee River, the Oconaluftee River, the Pigeon River, and Richland Creek.

Site	Location	Average Density (*Corbicula*/m^2)	Site	Location	Average Density (*Corbicula*/m^2)
LT1	N 35°17.302' W 83°29.452'	66	O2	N 35°27.527' W 83°21.454'	0
LT2	N 35°14.860' W 83°23.785'	176	O3	N 35°26.756' W 83°22.525'	0
LT3	N 35°12.996' W 83°22.660'	1398	P1	N 35°36.854' W 82°57.979'	238
T1	N 35°25.658' W 83°26.886'	37	P2	N 35°33.690' W 82°57.234'	819
T2	N 35°27.079' W 83°23.943'	60	P3	N 35°32.094' W 82°54.617'	221
T3	N 35°20.237' W 83°12.007'	85	P4	N 35°32.502' W 82°50.803'	642
O1	N 35°28.636' W 83°19.174'	0	RC1	N 35°31.704' W 82°57.791'	90

Among sample sites along the Little Tennessee River, the highest densities were observed immediately downstream of the Lake Emory Dam in Franklin, NC at site number 3 (LT3) and no evidence of *Corbicula* was found upstream of the reservoir. Overall, the Tuckasegee River contained the lowest average density of *Corbicula,* which could be caused by colder water temperatures and the disturbance in the natural flow regime resulting from hydroelectric dams along the stream. No evidence of *Corbicula* was found at the three sample sites in the Oconaluftee River. While sampling along the Oconaluftee River, we noticed that the water was colder than many of the other sampling sites, which could indicate that the water temperature of this river is outside of the tolerance range for *Corbicula. Corbicula* density was consistently highest in the Pigeon River and is likely influenced by the large amount of human disturbance along the river (e.g. The Canton Paper Mill, wastewater treatment plants).

TABLE 2: Summary of ANOVA using rank-transformed counts of *Corbicula* per sample.

	SS	df	MS	F	P
River	238196	3	79398.7	26.8	<0.0001
Residuals	640762	216	2966.5		
Total	878958	219	4013.5		

TABLE 3: Summary of Tukey pair-wise comparisons of rank-transformed *Corbicula* counts.

Comparison	Difference In Mean Rank	SE	t	P
Tuckasegee – Little Tennessee	-58	9.9	-5.837	< 0.001
Richland – Little Tennessee	-48	14.1	-3.408	0.004
Pigeon – Little Tennessee	19	9.3	2.043	0.170
Richland – Tuckasegee	10	14.1	0.719	0.886
Pigeon – Tuckasegee	77	9.3	8.283	< 0.001
Pigeon – Richland	67	13.6	4.915	< 0.001

Since the p-value is less than 0.0001, our results are significant (Table 2). There is no relationship between the Pigeon River and the Little Tennessee River or Richland Creek and the Tuckasegee River, as evidenced by the high p-values for these two comparisons (Table 3).

DISCUSSION

The goal of this project was to document the *Corbicula* invasion into watersheds in western North Carolina. We found *Corbicula* populations in all of the rivers we visited with the exception of the Oconaluftee River. The populations appear to be currently limited to the downstream reaches of the watersheds sampled, with their upstream range bounded by dams and/or cooler water. *Corbicula* have a low tolerance to cold temperatures and no growth has been reported in water temperatures less than 10 °C (Strayer 1999, Cooper 2007, USGS 2012). While sampling upstream of Lake Emory, Canton, and Lake Junaluska, we noted cooler water temperatures, which may explain the low density of *Corbicula* in these reaches.

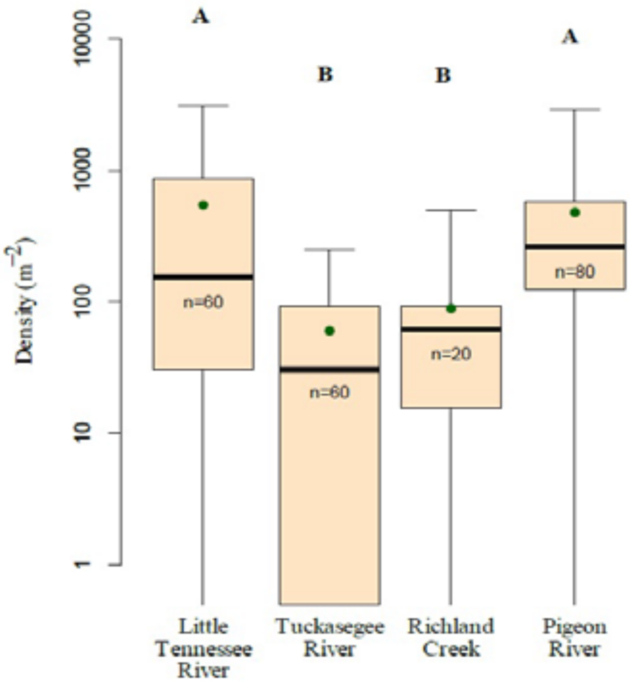


FIG. 1. Boxplot of *Corbicula* densities within the colonized zones of each river. The closed circles represent mean densities; *n* refers to the number of samples for each river. The densities differed significantly among rivers and the bold letters above the plots summarize the results of pair-wise comparisons of rank-transformed data; means that share a letter do not differ significantly.

Corbicula tend to replace native mussels by preferentially invading sites where native communities are already in decline due to negative anthropogenic activities (Vaughn and Spooner 2006). North American native mussel populations are declining, which may provide opportunities for exotic mussel species such as *Corbicula* to invade (USGS 2012). Over the last several years the Appalachian Elktoe (*Alasmidonta raveneliana*) population in the Little Tennessee River has declined while the population in the Tuckasegee appears to be expanding (J. Fridell, USFW, personal communication). Furthermore, all molluscs were apparently extirpated from the Pigeon River downstream from the paper mill at Canton, NC during the many years that untreated or inadequately treated effluent was discharged into the river. Water quality in the Pigeon River has greatly improved in the last two decades, but native mussels have not recolonized. These declines in native mussels or the disturbances that induced them may explain why the Pigeon River and Little Tennessee River had significantly higher densities of *Corbicula* than did the Tuckasegee and Oconaluftee Rivers in this study.

Cooper (2007) examined the correlation between *Corbicula* abundance and different habitat variables influenced by disturbances on the Roanoke River in North Carolina. The Roanoke River, like the Pigeon River, receives discharge from a paper mill and a wastewater treatment plant – effluent that is typically warmer than the river water and tends to raise the temperature of the stream (Poff et al. 1997). Cooper found high mean *Corbicula* densities downstream of paper mill discharge and suggested that the effluent may have had a beneficial effect on *Corbicula* because it is warmer and contains suspended organic matter during winter when food sources are scarcer.

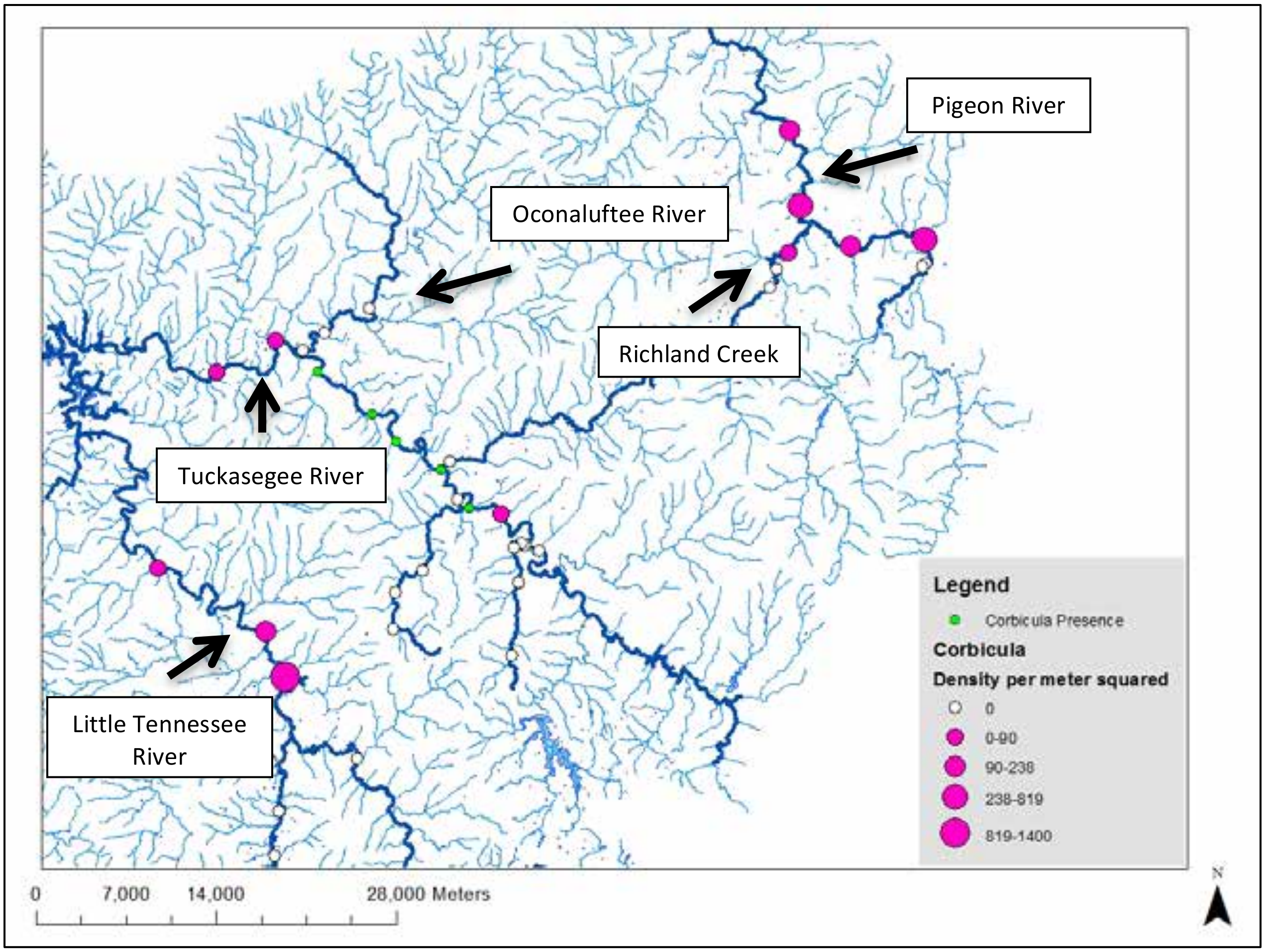


FIG. 2. Density distribution of *Corbicula* in three major western North Carolina watersheds.

We found the highest densities of *Corbicula* downstream of the paper mill located in Canton, NC. But, similarly to what Cooper (2007) found, the sites closest to the outfall had lower densities than did samples from farther downstream. Cooper's study also found lower densities downstream of a wastewater treatment plant, which he attributed to low dissolved oxygen content and the toxicity of the effluent (Matthews and McMahon 1999, Cooper 2007). So, while *Corbicula* are more tolerant to warmer water temperatures than native mussels, other water quality parameters such as dissolved oxygen content and nutrient content impact *Corbicula* density.

The Tuckasegee River, which supported the lowest *Corbicula* density, contains several hydroelectric dams, which alter the natural flow regime of the river (Poff et al. 1997). Extreme events such as high flows and low flows can disrupt the ecological community and influence the relative success of different species (Poff et al. 2009). *Corbicula* are known to undergo rapid die-offs during times of low river flow, which may be a result of pulse batch releases from the hydroelectric dams (Ilarri and Antunes 2011). The hydroelectric dams on the Tuckasegee River employ hypolimnetic withdrawals resulting in significantly cooler water being released than would be expected in their absence, particularly during summer months (Duke Energy 2004). The combination of altered flow regime and cooler water may help explain the lower densities of *Corbicula* found in the Tuckasegee.

Overall, the results of this study indicate that the highest *Corbicula* density occurred in the Pigeon River, which is the most disturbed river in the region, and the lowest *Corbicula* densities occurred in the upstream reaches of all rivers, and the downstream reaches of the Tuckasegee and Oconaluftee Rivers, which is likely due to cooler water temperatures.

ACKNOWLEDGEMENTS

I would like to thank Dr. Tom Martin for being an excellent mentor and advisor, Dr. Karen Kandl for her support and advice, E.J. Dwigans for his assistance in the field, and the Highlands Biological Station for providing the platform to conduct this research. Thank you!

LITERATURE CITED

Biggins, R. G., and R. S. Butler. 2000. Bringing mussels back in the southeast. Endangered Species Technical Bulletin **25**:24-27.

Cooper, J. E. 2007. *Corbicula fluminea* (Asian clam) in the Roanoke River, North Carolina: a stressed population. Southeastern Naturalist **6**:413-434.

Counts, C. L. 1986. The zoogeography and history of the invasion of the United States by *Corbicula fluminea* (Bivalvia: Corbiculidae). American Malacological Bulletin-Special Edition **2**:7-39.

Duke Energy Corporation. 2004. Final report: temperature and dissolved oxygen, Tuckasegee River, West Fork, East Fork, and Dillsboro Projects. FERC relicensing applications for Nantahala region. Retrieved December 5, 2012, from http://www.duke-energy.com/pdfs/WQ1_TuckasegeedraftTLT.pdf.

Hakenkamp, C. C., S. G. Ribblett, M. A. Palmer, C. M. Swan, J. W. Reid, and M. R. Goodison. 2001. The impact of an introduced bivalve (*Corbicula fluminea*) on the benthos of a sandy stream. Freshwater Biology **46**:491-501.

Ilarri, M. I., and C. Antunes. 2011. Massive mortality of the Asian clam *Corbicula fluminea* in a highly invaded area. Biological Invasions **13**:277-280.

Matthews, M. A., and R. F. McMahon. 1999. Effects of temperature and temperature acclimation on survival of zebra mussels (*Dreissena polymorpha)* and Asian clams (*Corbicula fluminea*) under extreme hypoxia. Journal of Molluscan Studies **65**:317-325.

McMahon, R. F. 2002. Evolutionary and physiological adaptations of aquatic invasive animals: R selection versus resistance. Canadian Journal of Fisheries and Aquatic Sciences **59**:1235-1244.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime. Bioscience **47**:769-784.

Poff, N. L., and J. K. H. Zimmerman. 2010. Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. Freshwater Biology **55**:194-205.

R Core Team. 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Sousa, R., C. Antunes, and L. Guilhermino. 2008. Ecology of the invasive Asian clam *Corbicula fluminea* in aquatic ecosystems: an overview. Annales de Limnologie **44**:85-94.

Strayer, D. L. 1999. Effects of alien species on freshwater mollusks in North America. Journal of the North American Benthological Society **18**:74-98.

Strayer, D. L., and H. M. Malcom. 2007. Shell decay rates of native and alien freshwater bivalves and implications for habitat engineering. Freshwater Biology **52**:1611-1617.

Turner, A. M., and J. C. Trexler. 1997. Sampling aquatic invertebrates from marshes: evaluating the options. Journal of the North American Benthological Society **16**:694-709.

U.S. Geological Survey. 2012. Nonindigenous Aquatic Species Database. Gainesville, Florida.

Vaughn, C. C., and D. E. Spooner. 2006. Scale-dependent associations between native freshwater mussels and invasive *Corbicula*. Hydrobiologia **568**:331-339.

Vaughn, C. C., K. B. Gido, and D. E. Spooner. 2004. Ecosystem processes performed by unionid mussels in stream mesocosms: species roles and effects of abundance. Hydrobiologia **527**:35-47.

BIOLOGICAL AND PHYSICAL DIFFERENCES OF TWO APPALACHIAN STREAMS WITHIN THE TUCKASEGEE WATERSHED: A QUANTITATIVE COMPARISON OF AN IMPAIRED AND A HEALTHY STREAM

LINDSEY BARGELT, KIRSTAN BLENDER, SUSAN DEANS, EDWARD J. DWIGANS III, AMANDA FREEMAN, BRANDON HAYS, LINDSEY PURVIS, JULIE TIERNEY, ELYSE WILL, STEVE FOSTER, KAREN KANDL, TOM MARTIN, MICHELLE RUIGROK

Abstract. We examined the ecological health of two streams in the Tuckasegee River watershed: Savannah Creek, a waterbody classified as impaired by the state of North Carolina due to fecal coliform, and Cullowhee Creek, an unimpaired stream. Metrics of analysis included fish and macroinvertebrate diversity, potential for bank erosion, habitat quality, bed sediment particle size distribution, land use patterns, and chemical water quality. Selected sites on Savannah creek were tested for fecal coliform content. The streams had many similarities based on the metrics used, but were significantly different in macroinvertebrate composition. Additionally, further testing for fecal coliform is recommended.

Key words: Appalachian stream, BEHI, Cullowhee Creek, macroinvertebrates, pebble count, Savannah Creek, Tuckasegee River, water quality, watershed, western North Carolina.

INTRODUCTION

The streams and rivers of the southern Appalachians reflect the remarkable species diversity of this region and serve as an indicator of the health of the surrounding environment. Savannah and Cullowhee Creeks, two streams in the southern Blue Ridge region of North Carolina, feed into the Tuckasegee River in the upper Tennessee River drainage. Savannah Creek is a 21.6 km tributary to the Tuckasegee River in Jackson County, NC. Similarly, Cullowhee Creek is a 14 km tributary to the Tuckasegee. The mouth of Cullowhee Creek is approximately 39 km upstream from that of Savannah Creek. Both streams flow along busy roads, near commercial buildings, and through residential areas.

In 2008, Savannah Creek was listed as an impaired waterbody due to fecal coliform (NCDENR-DWQ 2012a). While fecal contamination may not have a significant impact on the ecological health of the stream, it does raise concern for recreational users due to the risk of contact with pathogens. In 2008 the Watershed Association of the Tuckasegee River determined that the source of the fecal coliform was untreated domestic sewage (a "straight-pipe") from a single residence (Williams 2010). After working with the homeowners and the Jackson County Health Department, the problem was resolved and fecal coliform levels in 2010 were found to be below the recreational use limit (Williams 2010). However, until a total maximum daily load (TMDL) is applied to this waterbody, it cannot be removed from the 303(d) list (http://water.epa.gov/lawsregs/).

Both Cullowhee Creek and Savannah Creek have been structurally modified to accommodate development and infrastructure, including the use of culverts and bank stabilization near roads. For example, Cullowhee Creek underwent a major restoration project on the campus of Western Carolina University in 2005 and 2006. This project altered the channel of the stream in an attempt to improve habitat heterogeneity that had been lost due to previous channelization (unpublished data).

Cullowhee Creek and Savannah Creek are geographically similar, yet Savannah Creek continues to be classified as impaired while Cullowhee creek continues to receive a healthy status. Our objective was to examine the biological and physical aspects of both streams to determine what differences may exist.

MATERIALS AND METHODS

Study Locations

We collected data from Cullowhee and Savannah Creeks between September and November of 2012. We selected four sites in each stream to sample based on ease of access and how representative each site appeared to be of that stream. For each stream we sampled an uppermost site, two intermediate sites, and a site close to the mouth. At each stream sampling site we recorded latitude and longitude (Table 1, Fig. 1).

TABLE 1. Sampling sites located in Cullowhee Creek and Savannah Creek, latitudes and longitudes, and site codes.

Creek	Latitude	Longitude	Code
Cullowhee	N 35° 14.299'	W 83° 11.142'	C1
Cullowhee	N 35° 17.362'	W 83° 10.927'	C2
Cullowhee	N 35° 18.845'	W 83° 11.266'	C3
Cullowhee	N 35° 19.012'	W 83° 10.818'	C4
Savannah	N 35° 15.196'	W 83° 17.228'	S1
Savannah	N 35° 16.769'	W 83° 17.238'	S2
Savannah	N 35° 17.737'	W 83° 15.890'	S3
Savannah	N 35° 20.828'	W 83° 14.239'	S4

The uppermost site on Cullowhee Creek (C1) was located near the confluence of Cullowhee Creek and Wolf Creek near a little-used unimproved road (Fig. 1). This reach was delimited by a small waterfall at the upper end of the sample area and a bridge with a 6 foot corrugated culvert at the lower end. The second site heading downstream on Cullowhee Creek (C2) was on Cullowhee Mountain Road where it intersects Parker Farm Rd at the Jackson County Recreation complex in Cullowhee, NC. This C2 reach was delimited by a bridge at the upper edge of the sample area. The stream has roads on both sides that allowed access to development (i.e. a recreation park and abandoned gas station). The third location on Cullowhee Creek (C3) flowed through a recreational area on Western Carolina University’s campus between the softball field and the track. This reach was previously part of a restoration project where cross vanes, grade control and bank erosion prevention measures have been implemented. The downstream-most site (C4) was located just upstream of the confluence of Cullowhee Creek and the Tuckasegee River at Monteith Gap Road in Cullowhee, NC, and downstream of Western Carolina University’s main campus. Both banks of the reach consisted of residential property boundaries.

The uppermost site on Savannah Creek (S1) was located on State Road 1302 off of Pumpkintown Road in Sylva, NC. The upper most region of the sample site was constrained by a waterfall and the lower by a bridge. The right bank was intersected by a power line gap and the left was private property with evidence of construction and home auto repair. The second site on

Savannah Creek (S2) was located immediately upstream of High Country Tire and Service Station on US 441 in Sylva, NC. Within this reach, the stream parallels US Highway 441. The right bank had been altered for stability and the left bank riparian zone was constrained by a power line right-of-way approximately 18 meters from the stream. The third site on Savannah Creek (S3) was adjacent to Ralph Tatham Road near the Savannah Fire Department. Ralph Tatham Road passes over Savannah Creek via bridge with a four-box concrete culvert; two of the boxes were constricted by sediment and vegetation. The top of the right bank was delimited by the Fire Station and parking lot. The left bank bounded a small basketball court and a mix of residential and agricultural land. The downstream-most site on Savannah Creek was near the confluence with the Tuckasegee River (S4) near Rock Quarry Road in Dillsboro, NC. The sample area right bank was bordered by homes and the left bank was bordered by a road with residential property beyond. The left bank was also modified for stability by the use of large boulders.

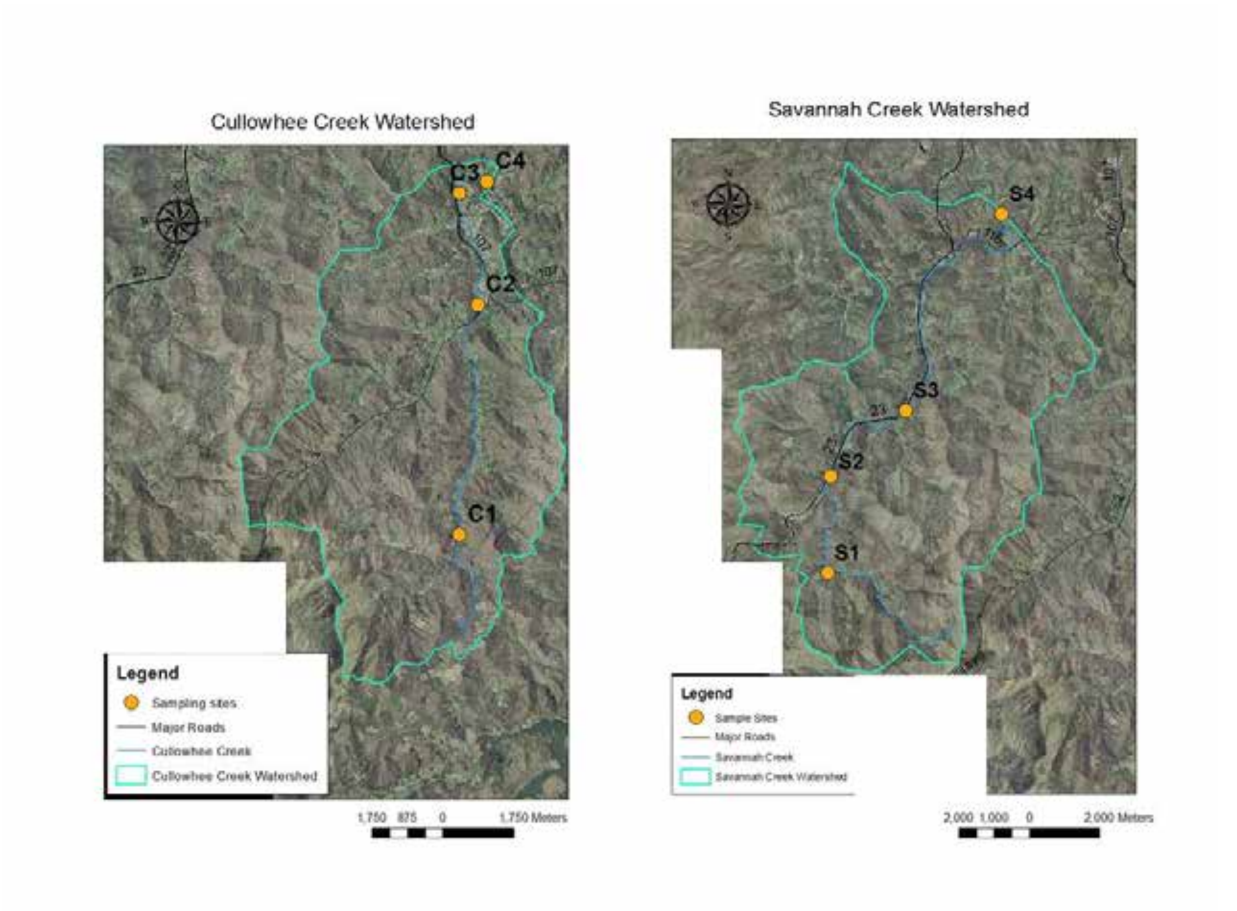


FIG. 1. Cullowhee Creek and Savannah Creek watershed boundaries and sample locations. Aerial photography sourced from Jackson County GIS Department.

GIS

Location data was collected in the field using a Garmin 60CSx (Garmin International Inc., Olathe, KS). We used this vector data in addition to using USGS 7.5 minute topographic maps and the USGS NHD stream coverage data (2007) to create two maps displaying the delineated watersheds of Cullowhee Creek and Savannah Creek in ArcGIS© (ESRI, Redlands, CA). The Southern Appalachia NCLD data was used to display the distribution of landcover classes in these two watersheds, and the land coverage was classified based on 2006 data developed by Coweeta LTER personnel (Hepinstall-Cymerman 2011). Percentages of total landcover classes were calculated from the total cell count of each landcover class in the raster dataset.

Chemical Analysis

At each site, we measured temperature, pH, conductivity, and turbidity (Oakton, Acorn series 5, serial number 209330 for pH; the Oakton, Acorn series, con15, 170958 for conductivity; and the Oakton, Acorn series, T-100, 222954 for turbidity (Oakton Instruments, Vernon Hills, IL). Fecal coliform grab samples were analyzed by a commercial laboratory (Environmental, Inc., Sylva, NC) from three sites along Savannah Creek (S1, S2, S4).

Habitat Analysis

We assessed the habitat of each sample location using a modified version of the North Carolina Department of Environment and Natural Resources' Standard Operating Procedures for Collection and Analysis of Benthic Macroinvertebrates (2011). The survey parameters included physical characterization (visible land use of the immediate area that you can see from sampling location), width, bank height, bank angle, flow conditions, turbidity, channel flow status, weather conditions, visible channel modifications, in stream habitat, bottom substrate, pool variety and presence. Other parameters were riffle habitats, bank stability and vegetation, light penetration and riparian vegetative zone width. In order to increase consistency in estimates, the same people conducted the habitat analysis at each sample site. Accuracy and precision are difficult to achieve when conducting habitat analyses except through repeated observation and comparison of observations by the same individual or team.

Pebble Count

We examined substrate particle size at all eight sampling sites using the Wolman Pebble count procedure (Wolman 1954). We restricted the procedure by collecting pebbles in only riffle zones due to impracticalities of sampling in pools. We measured the intermediate axis of the particle with a ruler, in millimeters, and classified the particle by size class (i.e. sand, gravel, cobble or boulder). This allowed us to describe particle size distribution using cumulative percent composition and median particle size (D50).

Bank Erosion Hazard Index

The Bank Erosion Hazard Index (BEHI) is used to estimate the erosion potential of a stream and takes into account bank height ratio, root depth ratio, root density, bank angle, and surface protection (Rosgen 2001). Bank height ratio is the ratio of bank height to bankfull height. Root depth ratio is the ratio of the average plant root depth to the bank height. Root density is the proportion of the stream bank area covered by plant roots. Bank angle is the angle of the bank from the waterline to the first bank or "lower bank". Surface protection is the percentage of stream bank with some type of cover, e.g. rocks, vegetation, and logs. We evaluated the left and right bank of each sample location for each of these parameters. To reduce variability in estimates, the same two people conducted the BEHI assessment at each sample site. Accuracy and precision are difficult to achieve when conducting BEHI except through repeated observation and comparison of observations by the same individual or team. We used these data to generate the total field index or score of the stream, or Bank Erosion Hazard Index. A higher index indicates a higher probability of erosion. Total index values were adjusted as necessary based on stratification, presence of sand, bank stability, root depth, and surface protection.

Benthic Macroinvertebrates

Macroinvertebrate data was collected using the kick-net and visual survey methods described in the North Carolina Department of Environment and Natural Resources' Standard Operating Procedures for Collection and Analysis of Benthic Macroinvertebrates (2011). EPT organisms (i.e. Ephemeroptera, Plecoptera, and Trichoptera) were the primary focus of this examination due to their sensitivity to water quality. We sampled Cullowhee and Savannah Creeks for macroinvertebrates at the upstream (C1 and S1) and downstream (C4 and S4) sites on each creek. We performed three kicks at each site sampled; each kick was thirty seconds in duration in an area of one square meter. We identified macroinvertebrates to family and recorded their abundance at each site. From these data, we calculated the biotic index for each site (NCDNR 2011). Chi-square tests of homogeneity were used to test for differences in the distribution of counts among all sites sampled; between the two creeks; between downstream sites of the two creeks; and between upstream sites.

Fish

We collected data on fish diversity and abundance at the two downstream sites (C4 and S4) using a backpack electro-fisher model HT-2000 (Halltech Research, Guelph, Ontario). Fish sampling followed a modification of the approach taken by the Land Trust for the Little Tennessee. We identified each specimen collected to species and calculated the biotic index for each site (Saylor and Ahlstedt 1990).

RESULTS

Observations of the land use patterns in the immediate vicinity of the sampling sites reveal similar conditions among all sites (Table 2). The headwaters drained mostly forested catchments, and residential and commercial land-use become more prevalent downstream along both streams. Only the downstream site (C4) of Cullowhee Creek had any active cropland in its vicinity.

The landcover maps created in ArcGIS reveal similar land use throughout both watersheds (Fig. 2). Deciduous forest was the dominant cover type in the headwaters region of both watersheds, and developed and agricultural land was more common in the downstream areas. But there was more medium-intensity development in the downstream reaches of Cullowhee Creek, due to the campus of Western Carolina University. The top five most common land cover classes for both watersheds were the same, with deciduous forest cover dominating both watersheds (76% in Cullowhee, 73% in Savannah) (Table 3).

TABLE 2. Immediately visible land use among sampling sites, observed November 2012.

	Percent Land Use			
Site	Forest	Residential	Commercial	Active crop
C1	70	30	0	0
C2	50	30	20	0
C3	20	20	60	0
C4	30	40	20	10
S1	70	25	5	0
S2	30	30	40	0
S3	30	20	50	0
S4	60	40	0	0

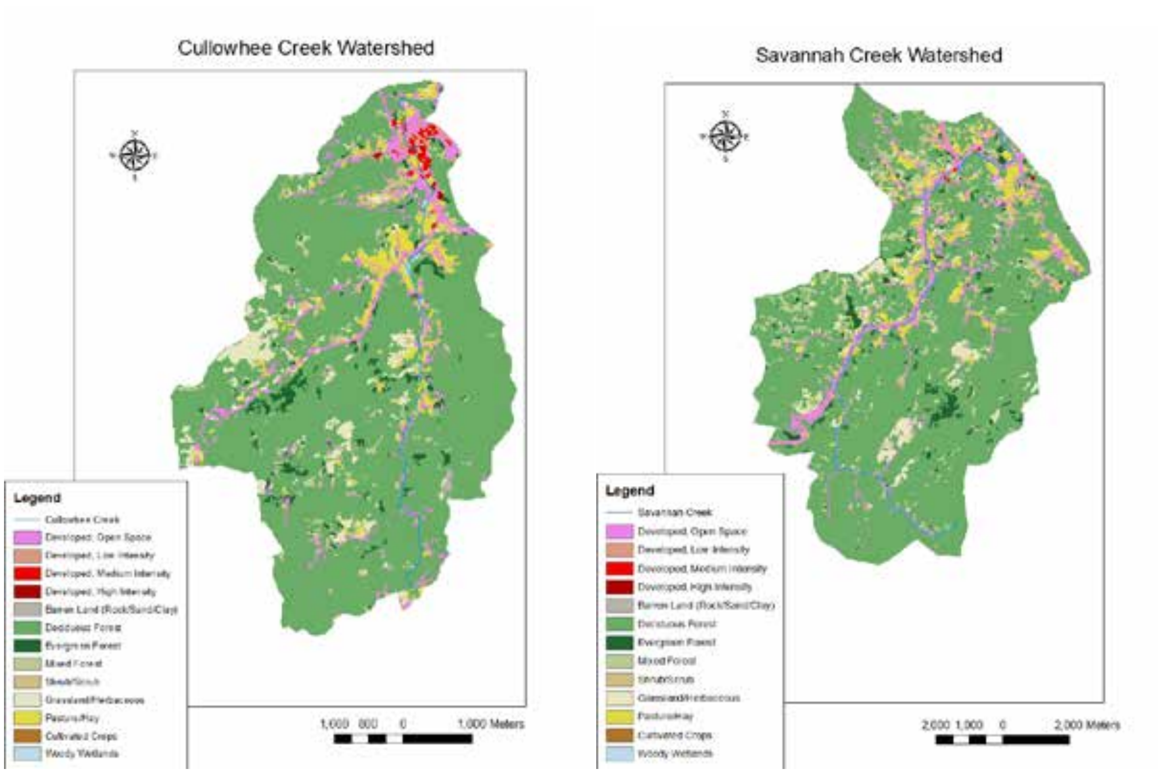


FIG. 2. Distribution of landcover classes as of 2006 in Cullowhee Creek and Savannah Creek watersheds.

TABLE 3. Percent coverage of the top five landcover classes in Savannah Creek and Cullowhee Creek watersheds

Cullowhee Creek Watershed		Savannah Creek Watershed	
Landcover Class	%	Landcover Class	%
Deciduous Forest	76	Deciduous Forest	73
Developed, Open Space	5	Mixed Forest	6
Pasture/Hay	4	Developed, Open Space	6
Grassland/Herbaceous	4	Pasture/Hay	5
Mixed Forest	3	Grassland/Herbaceous	4

Water quality variables were similar at all sites between streams (Table 4). Conductivity ranged from 16.4 µS/cm (C1) to 35.4 µS/cm (C3) in Cullowhee Creek and from 19.9 µS/cm (S1) to 31.2 µS/cm (S2) in Savannah Creek (Table 4). Conductivity was lowest at the headwater sites of both streams and was around 30 µS/cm at the downstream sites. The pH for all sites was similarly homogeneous. The majority of the sites were within a slightly acidic range of 6.3 (S3) to 6.8 (C3), but site S4 was slightly alkaline with a pH of 7.5. The turbidity of all sites was generally low, ranging from 0.94 NTU (C3) to 2.4 NTU (S2). Water temperature ranged between 10°C (C2) and 13°C (S4). Sites C1 and C2 were not sampled for water temperature. The water quality results were generally homogenous and contained few observable trends between metrics.

TABLE 4. Physical and chemical water characteristics among samplings sites, observed November 2012.

Site	Conductivity (µS/cm)	pH	Turbidity	Temperature (°C)
C1	16.4	6.58	1	N/A
C2	29.7	6.7	1.07	10
C3	35.4	6.8	0.94	10.1
C4	32.2	6.78	1.74	N/A
S1	19.9	6.5	1.7	9.7
S2	31.2	6.5	2.4	11
S3	29.7	6.3	1.35	11
S4	26	7.5	1.13	13

Fecal coliform exceeded 1260 colony forming units (CFU)/100 mL at the headwaters of Savannah Creek, which is far above the acceptable geometric mean standard set by the NC Division of Water Quality (2007). The fecal coliform content remained high at the next site downstream (980 CFU/100 mL), but was considerably lower at the mouth (30 CFU/100 mL).

Habitat scores ranged from 44 (C2) to 91 (C1) (Fig. 3). All stream sites had similar instream habitat and bottom substrate, and channel modification was relatively low for all sites. Site C2 differed notably from C1 because it lacked a riparian vegetation zone and pool variety. The distribution of pebble sizes did not differ significantly between sites on the two streams ($P>0.05$, Kolmogorov-Smirnov test) (Figs. 4 and 5). In a cumulative distribution of pebble sizes, the 50th percentile (D50) for all sample sites except two was very coarse gravel. The D50s for C2 and C3 were coarse gravel and small cobble, respectively.

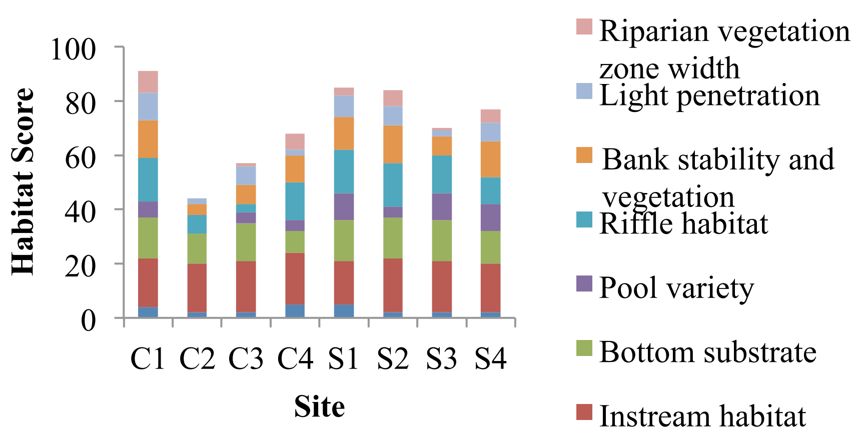


FIG. 3. Habitat scores and sub-scores for all sites along Savannah and Cullowhee Creeks in accordance with the DWQ Habitat Assessment, observed November 2012.

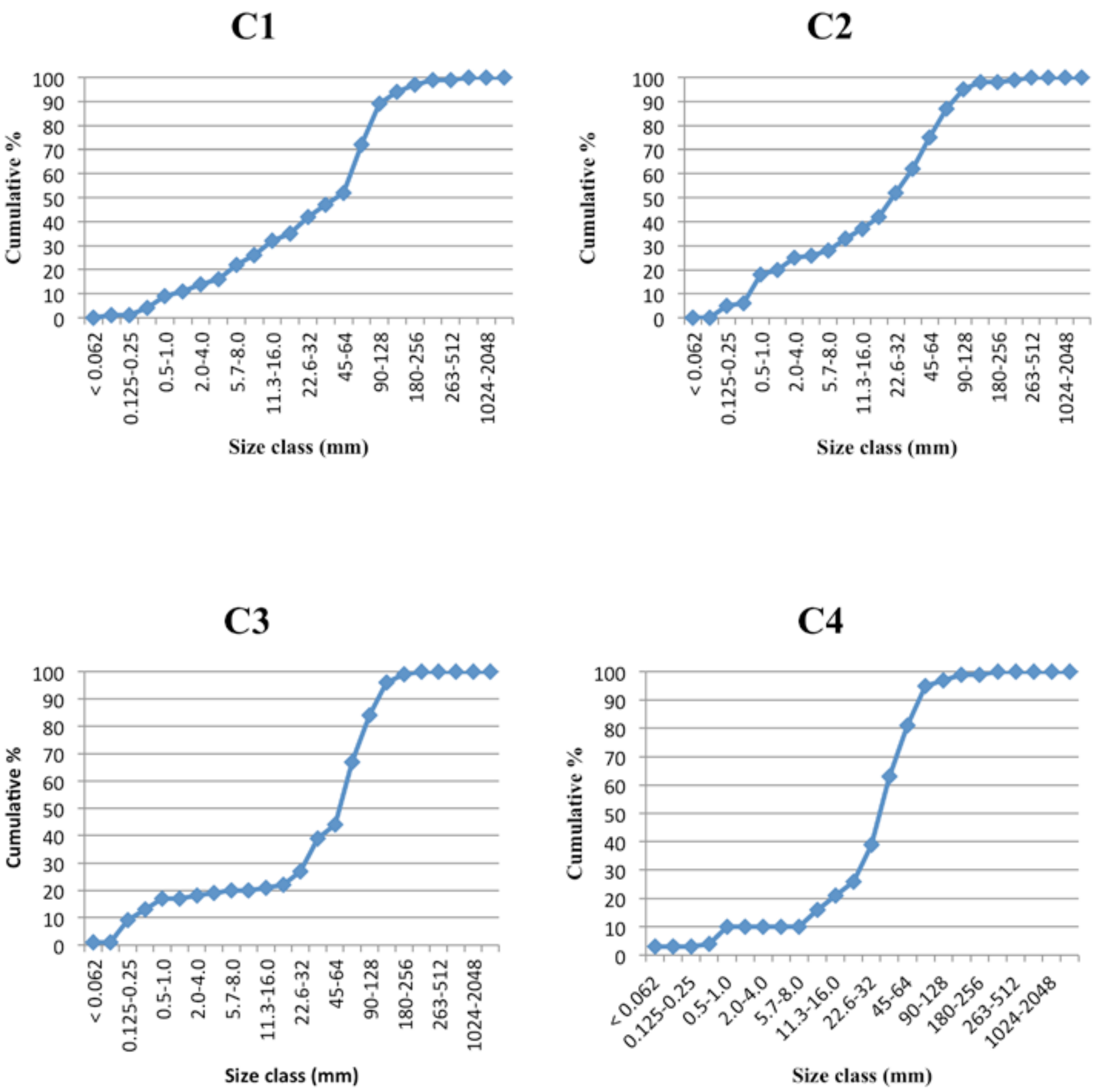


FIG. 4. Pebble count particle size distributions for sampling sites along Cullowhee Creek, observed November 2012. D50 for C1=45-64, C2=45-64, C3=32-45, C4=23-32.

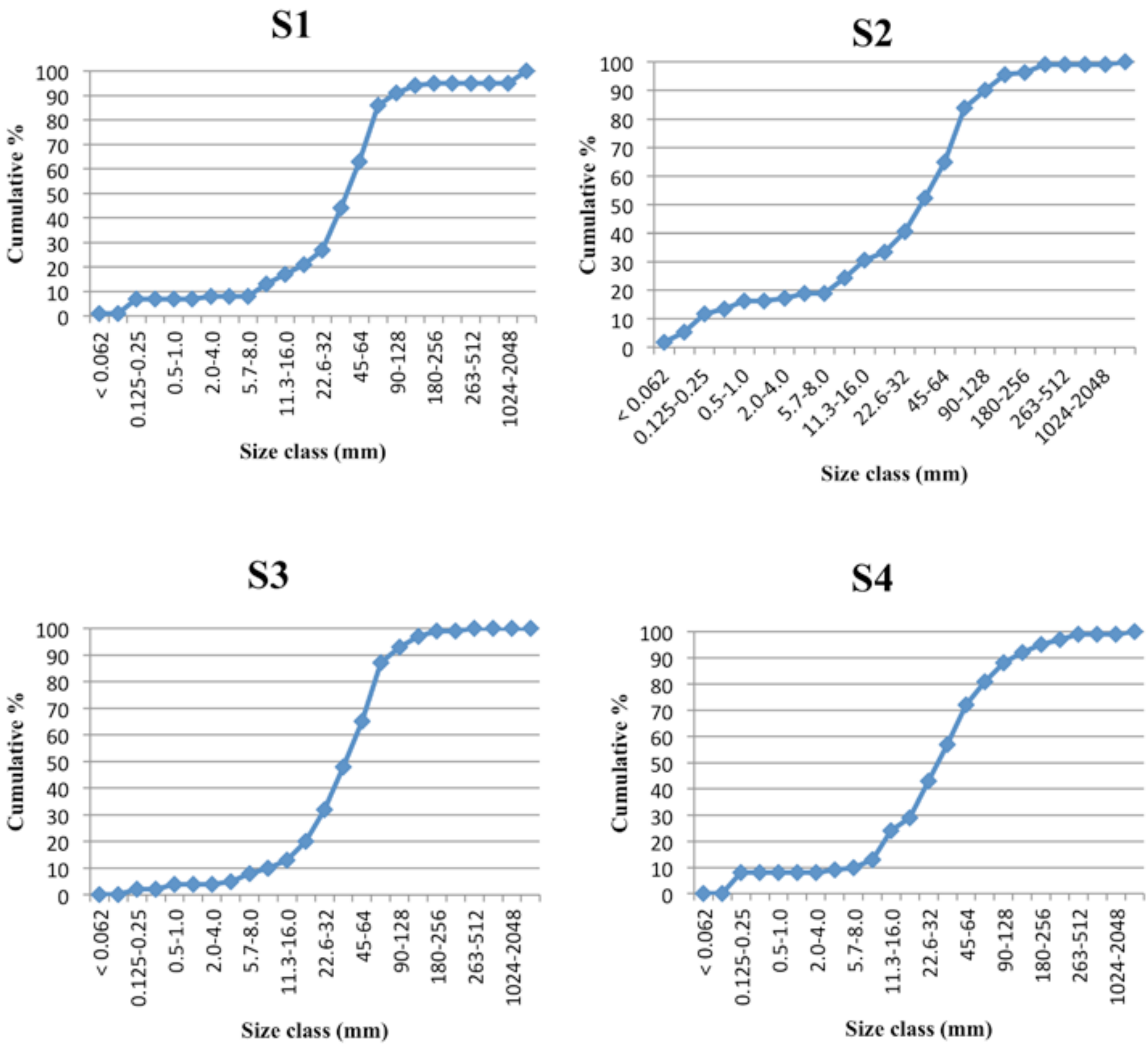


FIG. 5. Pebble count particle size distributions for sampling sites along Savannah Creek, observed November 2012. D50 for S1=45-64, S2=32-45, S3=45-64, S4=32-45

There was little evidence of a trend of Bank Erosion Hazard Indices within the streams and the scores were generally comparable between the streams (Fig. 6). Neither the adjusted score nor the individual metrics were significantly different between streams when a t-test was applied (P>0.05). The sole exception was bank height ratio, which was significantly greater along Savannah Creek (t-test, p=0.046). The greatest differences between streams were due to adjustments made because of the abundance of sand at sites S3 and S4, as well as the stratification of soils at site C2.

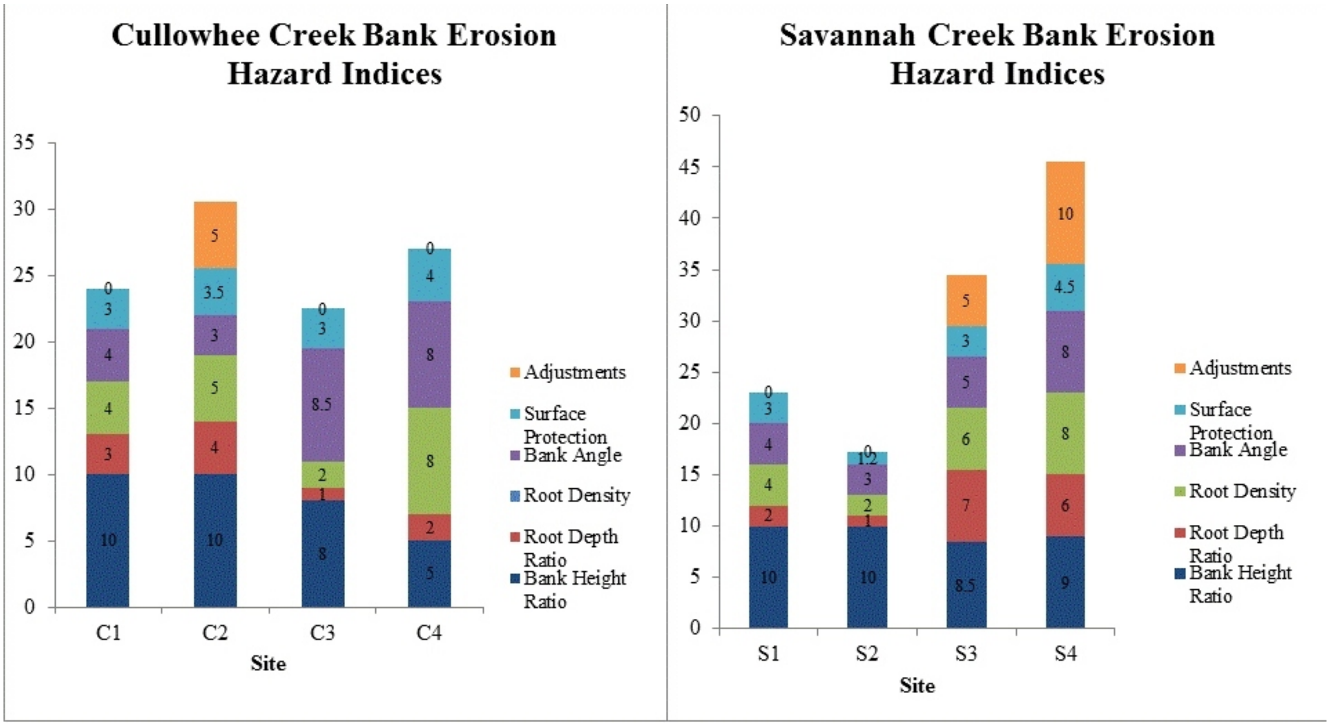


FIG. 6. Bank Erosion Hazard Index values for recorded for sampling sites at Cullowhee and Savannah Creeks in November 2012.

For benthic macroinvertebrates, the upstream sites of Cullowhee and Savannah Creeks had identical biotic indexes of 3.4 (Table 5). There was a greater difference in the EPT scores between the upstream and downstream sites of Cullowhee Creek (3.4 and 2.4, respectively) than between those of Savannah Creek (3.4 and 3.0, respectively). The differences in EPT Biotic Indices between the four sites are generally unremarkable. The water quality at all four sites was classified as “excellent” based on the NC DWQ Standard Operating Procedures for Benthic Macroinvertebrates (NCDENR-DWQ 2012b).

TABLE 5. The EPT Biotic Index and water quality classification for Savannah and Cullowhee Creeks upstream and downstream sites. Sampled in October 2012.

Site	EPT Biotic Index	Water quality classification
C1	2.4	Excellent
C4	3.4	Excellent
S1	3.0	Excellent
S4	3.4	Excellent

Tolerance scores for all EPT taxa collected at each site ranged from 0-4. The top four EPT taxa collected at each upstream and downstream site are compiled in Table 6 along with the tolerance values and percentage of individuals collected in each taxon. The most common taxon at each site was Baetidae, a relatively tolerant family of order Ephemeroptera. Pteronarcyidae, a very intolerant family of order Plectoptera, was in the top four EPT taxa at both upstream sites, but was more common at C1. The absence of this intolerant family in the top four EPT taxa both downstream sites suggests an increase in tolerant species at downstream sites.

TABLE 6. Percentage of each top four EPT taxa collected at upstream and downstream sites for Savannah and Cullowhee Creeks, sampled in October 2012.

Site C1			Site C4		
EPT Family	Tolerance	%	EPT Family	Tolerance	%
Baetidae	4	22	Baetidae	4	38
Pteronarcyidae	0	20	Philopotamidae	3	21
Hydropsychidae	4	13	Heptageniidae	4	15
Heptageniidae	4	13	Hydropsychidae	4	9
Site S1			Site S4		
EPT Family	Tolerance	%	EPT Family	Tolerance	%
Baetidae	4	38	Baetidae	4	39
Perlidae	2	25	Hydropsychidae	4	21
Heptageniidae	4	14	Perlidae	2	14
Pteronarcyidae	0	6	Heptageniidae	4	12

All of the chi-square tests, except the one between downstream sites, were significant ($P<0.0001$, Table 7.). There were almost four times as many shredders at C1 than there were at S1 while the number of scrapers at C1 was approximately 60% of that at S1 (Table 8).

TABLE 7. Chi-square tests of homogeneity of the distribution of functional feeding groups at four stream sites.

Comparison	χ^2	df	P
Overall comparison	137.96	12	<0.0001
Cullowhee Creek versus Savannah Creek	28.51	4	<0.0001
(within upstream samples)	27.97	3	<0.0001
(within downstream samples)	8.11	4	0.0878

TABLE 8. Distribution of feeding classes among sampling sites used for chi-square test of homogeneity.

Site	Filterers	Gatherers	Scrapers	Shredders	Predators
C1	15	0	41	37	20
C4	40	2	65	0	10
S1	13	0	71	10	38
S4	34	7	73	2	21

The downstream sites of Cullowhee and Savannah Creeks scored within the “good” IBI Bioclassification for fish (C1=49.5; S4=52.2) (Table 9). Although most IBI sub-scores for both sites were identical, there were two pollution intolerant species sampled at S4 and no pollution intolerant species at C4 (Table 9). However, 3.6% of individuals at site C4 were diseased, while there were no diseased fish sampled at S4.

DISCUSSION

Water Quality

Temperatures for sampled sites were well below the maximum temperature for mountain waters. Turbidity values were much lower than the maximum 10 NTU (Nephelometric Turbidity Units) for streams designated as trout waters, possibly due to a lack of rain and low stream discharge during the sampling period. An increase of precipitation would increase runoff and lead to higher turbidity values. Conductivity values ranging from 16.4 to 35.4 µS/cm were also much lower than the recommended levels of 150-500 µS/cm for a freshwater stream. Conductivity outside of this range could indicate that the water is not suitable for certain species of fish or macroinvertebrates (NC Water Quality Standards), however our data indicate a plentiful population of both fish and macroinvertebrates. Based on conductivity results for six sites in the Upper Cullasaja watershed in 2011 (between 30 and 70 µS/cm) this conductivity range could be routinely observed during base flow conditions in southern Appalachian mountain streams.

TABLE 9**.** Index of Biological Integrity (IBI) scores for fish sampled at the downstream sites of (a.) Cullowhee Creek and (b.) Savannah Creek in October 2012.

a. Site C4

Metric	Results	IBI Score
Total No. native species	14	6.7
Total No. darter species	2	4.0
Total No. intolerant species	3	6.7
Proportion of individuals as tolerant species	0	6.7
Proportion of individuals as omnivores/herbivores/generalists	16%	6.7
Proportion insectivores	54.5%	6.7
Catch rate	15.7	6.7
% darters and sculpins	16%	1.3
% disease	3.6%	4.0
	Total Score:	**49.5**
	IBI Bioclass:	**GOOD**

b. Site S4

Metric	Results	IBI Score
Total No. native species	13	6.7
Total No. darter species	3	6.7
Total No. intolerant species	2	4.0
Proportion of individuals as tolerant species	3	6.7
Proportion of individuals as omnivores/herbivores/generalists	15%	6.7
Proportion insectivores	74.5%	6.7
Catch rate	13.6	6.7
% darters and sculpins	12.6%	1.3
% disease	0%	6.7
	Total Score:	**52.2**
	IBI Bioclass:	**GOOD**

Fecal coliform samples showed abnormally high (CFU) levels for sites S1 and S2 (>1260 CFU/100mL for S1 and 980 CFU/100mL for S2). According to North Carolina water quality standards, fecal coliform units "should not exceed a geometric mean of 200 CFU/100mL (Membrane Filter count method) based upon at least five consecutive samples examined during any 30 day period". Violations of the fecal coliform standard are expected during rainfall events and, in some cases, this violation is expected to be caused by uncontrollable nonpoint source pollution" (15A NCAC 2B. 0211(3)(e)). Due to limited data, we could not determine a violation in water quality standards for Savannah Creek.

BEHI and Habitat

To reduce variability in estimates, the same two people conducted the BEHI assessment at each sample site. Accuracy and precision are difficult to achieve when conducting BEHI except through repeated observation and comparison of observations by the same individual or team.

Bank height ratio was the only BEHI metric to exhibit significant differences between Savannah Creek and Cullowhee Creek. Savannah Creek had a significantly higher bank height ratio than Cullowhee Creek, potentially due to the decreased stream width and sinuosity from the construction of Highway 441. The stream was wedged between the road structure and a steep mountainside, effectively decreasing the width of the stream and increasing the velocity of the stream, leading to greater erosion potential of the stream bed.

A higher habitat score, on a scale from 0-100, suggests a better physical habitat. The greatest difference observed among sites was between sites C1 and C2 due to a significant decrease in scores for riparian vegetation zone and pool variety. The low scores for C2 are reflective of the encroachment of houses and urban infrastructure on both sides of the stream.

Substrate

Fine sediment deposition is a major pollutant that affects water quality in U.S. streams (Cover et al. 2008). When fine sediment is deposited, it fills interstitial pore spaces in the streambed, which in turn, can alter the abundance and composition of benthic macroinvertebrate and fish assemblages (Cover et al. 2008, Angradi 1999). Furthermore, fine sediments less than 2 mm (i.e. sand, silt, and clay) increase turbidity, limit light penetration, and potentially reduce primary productivity (Woods and Armitage 1997). Factors such as land use, soil type, and ground and vegetation cover control the process of sedimentation (Woods and Armitage 1997).

In order to determine the size and distribution of sediments in Cullowhee and Savannah Creeks, we conducted a Wolman Pebble Count at each site. From our pebble count results, we discovered that the most common D50--the particle size that 50% of the samples are equal to or smaller than--for our sample sites was "very coarse gravel" falling between 32 and 64 mm. Although fine sediments were recorded in the pebble count, the majority of sediments were coarser, which could indicate either biased sampling or healthier streams.

Benthic Macroinvertebrates

Benthic macroinvertebrates are highly suitable indicators of water quality because they are ubiquitous, sensitive to a variety of disturbances, and show responses over a short timeframe (Hauer and Resh 1996; Wang and Pan 2011). High benthic macroinvertebrate taxa richness and a large proportion of EPT organisms relative to the total benthic macroinvertebrate community indicate a healthy stream ecosystem (Courtemanch 1996). Chemical and physical methods can also be used to monitor water quality, but these methods merely provide a snapshot of existing conditions in the stream environment (Resh et al. 1996). In contrast, benthic macroinvertebrates provide a "moving picture" of the health of the aquatic ecosystem, reflecting both past and current conditions of the stream (Resh et al. 1996).

Certain EPT organisms, however, are less tolerant of pollution, as indicated by a lower score on the EPT Biotic Index (BI). For example Pteronarcyidae, a family of the order Plecoptera, has a BI value of 0, indicating that it has a low tolerance to pollution. While Pteronarcyidae occur in the top 4 ranking at both upstream sites, the downstream sites do not contain this family in the top 4 rankings. This could indicate higher pollution levels downstream (Table 6). Furthermore, the family Glossosomatidae of the order Trichoptera has a BI of 0, indicative of its pollution intolerance, and is only found at the upstream sites. Rhyacophilidae, a family of the order Trichoptera, has a BI of 0 and was found upstream in both creeks and downstream in Savannah Creek. However, it is likely that the Rhyacophilidae recorded at the downstream site on Savannah Creek was the species *Rhyacophila fuscula*, a relatively tolerant species (Dave Penrose, personal communication). Baetidae was the most common family found at all sites which is likely due to its high tolerance to pollution (BI=4). Overall, there are lower BI values upstream, which could indicate better water quality in the upstream regions of Cullowhee and Savannah Creeks.

The distribution of feeding groups changed from upstream to downstream, which would be expected based on the River Continuum Concept (Vannote et al. 1980). For example, collectors were much more abundant downstream because there is less detritus and collecting is a more effective feeding strategy (Vannote et al. 1980). Shredders were four times more abundant at the headwaters of Cullowhee Creek than at the headwaters of Savannah Creek, while Cullowhee Creek had only 60% of the scrapers found at the headwaters of Savannah Creek. These results may suggest differences in the headwater habitat of the two streams not observed in the habitat assessment. For example, the forested riparian zone surrounding Savannah Creek could allow for more sunlight but less allochthonous detritus, an important food source for benthic communities, to enter the stream (Minshall 1966). Additionally, the higher numbers of scrapers in Savannah Creek could be attributed to raw sewage effluent, which would increase nutrient content and create a greater potential for in-stream production and growth of periphyton—a food source for scrapers (Tom Martin, personal communication). Although predators were more common at the upstream sites, most of the predators we found belong to the order Plecoptera, which are generally more tolerant to pollution (Dave Penrose, personal communication).

Fish

Based upon the IBI scores for fish classified both streams were classified as "Good." This classification indicates that species richness is below expectation, particularly due to loss of intolerant species. Some species may show less than optimal abundance or size distribution and trophic structure showed signs of stress (Little Tennessee Watershed Association 2011). Both creeks had a low percentage of sculpin and darters, which are generally intolerant of pollution and sometimes sedimentation (NCSU Water Quality Group 2003). This may be explained based on the temporal scale of the study. Our sites were sampled from September to November when the migration of river species into tributaries, such as the whitetail and mirror shiner, could have displaced other species. The presence of some non-migratory species of fish, such as the fatlips minnow and wounded darter, in both creeks is an indication of viable fish populations. We found twelve fatlips minnows and one wounded darter in Savannah Creek during sampling, while we observed only three fatlips minnows in Cullowhee Creek during sampling. Cullowhee Creek also had a small percentage of diseased fish, which could indicate slightly higher pollution levels than Savannah Creek. This may be due to nonpoint pollution sources carried by runoff, as there is less forested area around Cullowhee Creek than Savannah Creek, particularly at downstream sites.

By conducting physical, chemical, and biological assessments of Cullowhee and Savannah Creeks, we have gained a better understanding of the ecological health of two tributaries to the Tuckasegee River in western North Carolina. High fecal coliform counts at sites S1 and S2 warrant additional testing to assuage significant concern over possible failing septic systems, straight pipes, or animal waste runoff in these areas. It is our hope that this study will provide background and illumination for future research on the health of the Tuckasegee watershed.

ACKNOWLEDGEMENTS

We acknowledge High Country Tire and Service Station, the Savannah Fire Department in Sylva, and Mr. Blankenship for allowing us the use of their property. We would also like to acknowledge the advice and assistance of Jason Meador and Dave Penrose in the fish and macroinvertebrate sampling efforts, respectively. Without their oversight we would not have been able to carry out these analyses.

LITERATURE CITED

Angradi, T. R. 1999. Fine sediment and macroinvertebrate assemblages in Appalachian streams: a field experiment with biomonitoring applications. Journal of the North American Benthological Society **18**:49-66.

Courtemanch, D.L. 1996. Commentary on the subsampling procedures used for rapid bioassessment. Journal of the North American Benthological Society **15:**381-385.

Cover, M. R., May, C. L., Dietrich, W. E., and Resh, V. H. 2008. Quantitative linkages among sediment supply, streambed fine sediment, and benthic macroinvertebrates in northern California streams. Journal of the North American Benthological Society **27:**135-149.

Environmental Protection Agency (EPA). 2012a. 4.1 Stream Habitat Walk. Water: Monitoring And Assessment. 4 Dec. 2012. http://water.epa.gov/type/rsl/monitoring/vms41.cfm.

Environmental Protection Agency (EPA). 2012b. Water Monitoring & Assessment: Conductivity. http://water.epa.gov/type/rsl/monitoring/vms59.cfm.

Environmental Protection Agency (EPA). 2012c. Water Total Maximum Daily Loads (303d). http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/overview.cfm.

ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Halltech aquatic research. 2009. HT-2000 Battery Backpack Electro-fisher Manual. http://www.halltechaquatic.com/pdfs/HT2000manual.pdf. Ontario, Canada.

Hauer, F. R., and Resh, V. H. 1996. Benthic macroinvertebrates. Methods in Stream Ecology. Academic Press. San Diego, CA.

Little Tennessee Watershed Association (LTWA). 2011. The State of the Streams in the Upper Little Tennessee Watershed: A Report Summarizing 21 Years of Water Quality and Habitat Trends.

Minshall, W. G. 1966. Role of allochthonis detritis in the trophic structure of a woodland springbrook community. Ecology, **48**:139-149.

North Carolina Department of Environment & Natural Resources: Division of Water Quality (DWQ). 2007. Classifications and Water Quality Standards Applicable to Surface Waters and Wetlands of N.C. Raleigh: Environmental Management Commission.

NC Division of Water Quality. 2010. Project Plan to address fecal coliform contamination in Scotts and Savannah Creek and the Tuckasegee River in Jackson and Swain County, NC.

North Carolina Department of Environment & Natural Resources: Division of Water Quality (DWQ). 2012a. North Carolina 303(d) List Category 5. Approved by EPA on August 10, 2012.

North Carolina Department of Environment & Natural Resources: Division of Water Quality (DWQ). 2012b. Standard Operating Procedures for Benthic Macroinvertebrates. NC Department of Environment and Natural Resources. Environmental Sciences Section, Biological Assessment Unit. Raleigh, NC.

Oakton. 1998. pH 5 and pH 6 acorn series meters. 4 dec 2012. http://www.4oakton.com/Manuals/pHORPIon/Arocn%20pH%205_6%20meter%20mnl.pdf

Oakton. 2002 .Instruction manual Con 6/TDS 6. Web. 4 Dec 2012. http://www.4oakton.com/Manuals/ConductivityTDS/35606-10-15.pdf.

Oakton. 2003. Instruction manual TN-100/T-100. 4 Dec 2012. http://www.4oakton.com/manuals/Turbidity/35635-00.pdf.

Resh, V. H., Myers, M. J., and Hannaford, M. J. 1996. Macroinvertebrates as Biotic Indicators of Environmental Quality. Methods in Stream Ecology. Academic Press. San Diego, CA. 647-667.

Rosgen, D. 2001. A practical method of computing stream bank erosion rate. Proceedings of the Seventh Federal Interagency Sedimentation Conference. Vol. 2, pp. II - 9-15, March 25-29, 2001, Reno, NV.

Saylor, C.S. and S.A. Ahlstedt. 1990. Little Tennessee River Biomonitoring Baseline Data and IBI Scoring Criteria. 1989. Tennessee valley Authority, Water Resources, Biology Department. Norris, Tennessee.

Taylor, R. N., and Love, M., 2003. Part IX Fish Passage Evaluation at Stream Crossings. California Department of Fish and Game.

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R., and Cushing, C. E. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences. **37:**130-136.

Wang, Z., and Pan, B. 2011. River Ecology and Stream Restoration. River Ecosystems Dynamics, Management and Conservation. Nova Science Publishers. New York, NY. 1-107.

Wolman, G. 1954. A method of sampling coarse river-bed material. Transactions, American Geophysical Union **35:**951-946

Wood, P. J. and Armitage, P. D. 1997. Biological effects of fine sediment in the lotic environment. Environmental Management. **21:**203-217.