# INSTITUTE FOR THE ENVIRONMENT HIGHLANDS FIELD SITE 2007 INTERNSHIP RESEARCH REPORTS



# HIGHLANDS BIOLOGICAL STATION HIGHLANDS, NORTH CAROLINA

#### INTRODUCTION

This volume represents the culmination of the semester-long internship research component of the Institute for the Environment at Highlands Field Site during fall 2007. The Institute for the Environment (IE) sponsors off-campus programs for students of the University of North Carolina, Chapel Hill, and the Highlands Biological Station has served as one of its Field Sites since 2001. Located on the Blue Ridge Escarpment of the southern Appalachian Mountains, the Highlands Biological Station affords IE students abundant opportunities to study aspects of the ecology and evolution of the region's rich biota, its complex history of land use, and increasing threats to southern Appalachian natural systems. Aside from the coursework that students complete, a central component of the IE program at the Highlands Field Site is an internship experience in which students identify areas of personal interest and are paired with mentors in matching fields. This year's mentors come from research institutions, government agencies, non-profit organizations, and innovative "green" business groups. Mentors from each organization work directly with each student to design and help them to implement hands-on projects in such diverse areas as ecology, conservation, land use planning, and policy. The students spend two days per week on their projects collecting and analyzing data, ultimately presenting their results in scientific paper format.

This year's projects not only highlight the environmental problems facing the Highlands Plateau and environs; they also reflect innovative solutions to pressing conservation concerns. Some students explored unique and threatened plant and animal communities, while others contributed directly to private and public efforts to conserve them. The fruits of their labors – from maps and data tables to policy recommendations and interpretive material – are presented here as contributions toward an improved understanding of the complex nature of natural biological systems and the ways in which humans impact them.



#### ACKNOWLEDGEMENTS

On behalf of the IE-HFS class of 2007, we would like to thank the mentors who took the time out of their already busy professional lives to help develop and guide these projects: Richard Betz, Carrie Blaskowski, Patrick Brannon, Paul Carlson, Barry Clinton, Tom Goforth, Tom Hatley, Brian Kloeppel, Brent Martin, Timm Muth, Kate Parkerson, Hillrie Quin, Periann Russell, Matt Shuler, Michael Skinner, Jesse Tilghman, and Gary Wein. We also thank Brennan Bouma of the IE for his assistance organizing and overseeing the internships and Gary Wein for generously assisting with the GIS component of several projects in addition to the one he mentored. The warm hospitality of Joe and Fran Gatins, long-time friends of the Program, was much appreciated. Thanks also to Coweeta Hydrologic Laboratory, Land Trust of the Little Tennessee, Highlands-Cashiers Land Trust, Jackson County Green Energy Park, Crow Dog Native Ferns Nursery, North Carolina Division of Water Quality, Balsam Mountain Preserve and Trust, The Wilderness Society, and the Town of Highlands for facilitating and encouraging the participation of their employees as mentors in the IE. Finally, we also thank Katie Brugger for their journalistic work on the students' projects.



Jim Costa, Site Director Anya Hinkle, Associate Site Director

# TABLE OF CONTENTS

Introduction	i
Acknowledgements	ii
Table of Contents	iii
2007 Mentors	iv
Research Papers	
BAKER, JASON: Response and restoration following a dam breach event	1

BETZ, KATHERINE: Cherol	kee settlement and histori	ical activity in the Y	ellow Creek va	lley of the
Little Tennessee R	iver basin, Graham Coun	ty, North Carolina		10

- VANDENBERG, ANNA: Anaerobic digestion of municipal solid waste as a supplemental biogas source for the Jackson County Green Energy Park......112

WHISLER, SALLY: Hybridization in the fern genus Dryopteris......120

# 2007 IE-HFS INTERNSHIP MENTORS

Jason Baker worked with Michael Skinner of the Balsam Mountin Trust and Jesse Tilghman of the Balsam Mountain Preserve

Katherine Betz worked with Paul Carlson and Kate Parkerson of the Land Trust for the Little Tennessee

Melissa Burt worked with Patrick Brannon of the Highlands Biological Station

Brian Houseman worked with Gary Wein of the Highlands-Cashiers Land Trust

Brian Levo worked with Hillrie Quin of the Highlands Greenway Committee and Richard Betz and Matt Shuler of the Town of Highlands

Andrea Martin and Sandy Skolochenko worked with Brian Kloeppel and Barry Clinton of the Coweeta Hydrologic Laboratory

Katie Supler worked with Brent Martin of The Wilderness Society

Anna Vandenbergh worked with Timm Muth and Carrie Blaskowski of the Jackson County Green Energy Park

Sally Whisler worked with Tom Goforth of Crow Dog Native Ferns Nursery

Matt Whitehead worked with Richard Betz and Matt Shuler of the Town of Highlands

### RESPONSE AND RESTORATION FOLLOWING A DAM BREACH EVENT

#### JASON E. H. BAKER

*Abstract.* On June 7, 2007, a dam holding back a small irrigation pond within a large development project in Jackson County, North Carolina failed, sending rushing water and sediment deposits approximately eight miles downstream to the Tuckasegee River. This paper documents and evaluates the success of the cleanup process, both physically and procedurally, and attempts to analyze protocols which may aid in response to future water quality issues. Balsam Mountain Preserve, the project's developer, was largely successful in mitigating the effects of the dam break, as evaluated by sediment recovery, but turbidity levels in affected waterways are still slow to recover.

Key words: dam break; response protocols; sediment deposition; stream restoration; turbidity; water quality

#### INTRODUCTION

The Balsam Mountain Preserve (BMP) is a private development project located in Jackson County, North Carolina between the towns of Waynesville and Sylva. Designed to encompass 354 home sites, a golf course, and other amenities for residents, a portion of the site amounting to over 3,000 acres will be placed in a conservation easement with the North American Land Trust. The Balsam Mountain Trust (BMT) is a registered 501(c)(3) non-profit organization set up both to manage the area within the conservation easement, and to provide educational programs and guidance both for residents and the surrounding community.

On June 7, 2007 at approximately 8:45 AM, a dam holding back an irrigation pond within the site failed. Sugarloaf Creek, also known as Cripple Creek along lower sections, received the bulk of the material flow and damage from the breach. Additionally, initial water flow and sediment deposition occurred downstream as Sugarloaf Creek reached its confluence with Scotts Creek just off of the BMP property, and sediment deposition continued to be found downstream as far as the Tuckasegee River, which Scotts Creek enters within the Dillsboro, NC town limits.

The dam's failure was ultimately ascribed to its construction with an incorrect soil type which had not been adequately compacted during assembly. Erosion around an outbound pipe eventually led to the occurrence of a massive breach. Though better protocols for the construction and inspection of this dam possibly could have prevented the massive breaching, discussion of the engineering aspects of this project are beyond the scope of this paper.

While fortunately the dam breach resulted in no injuries or loss of life, the environmental impacts of the breach were substantial. The initial break caused a great deal of scouring on much of the upper sections of the creek, while a great deal of sedimentation occurred downstream as both materials from the dam itself as well as scoured material were redeposited both in and around the stream channel.

This paper seeks to evaluate the efficiency of both the initial response as well as long term efforts to restore the downstream waterways and surrounding properties, as well as to make recommendations to assist in the efficient response to similar events in the future. While the dam break at BMP probably could have been avoided, sediment deposition events in the future will likely continue to contribute to negative water quality in the region. Developing better protocols for rapid response to water quality issues will help to mitigate their impact on our natural environment.



FIG. 1. Sugarloaf Creek and surrounding area. The brownish-orange area of disturbance in this aerial photograph is now a part of the recently completed golf course.

# METHODS

Three times per day, turbidity levels at six locations downstream from the dam breach site were collected. Turbidity is a measure of particulate matter dissolved in a body of water and is useful for estimating the ecological health of a stream, as many aquatic species are highly sensitive to the effects of turbid water (Karr and Dudley 1981). The six locations for the sample were determined under consultation with the NC Department of Natural Resources Division of Water Quality (DWQ), the NC Wildlife Resources Commission (WRC), and the US Army Corps of Engineers (USACE). These locations included Sugarloaf Creek adjacent to the BMP development office (Site 1), Sugarloaf Creek at the confluence with Scotts Creek (Site 2), Scotts Creek just above the confluence with Sugarloaf Creek (Site 3), Scotts Creek near the Jackson Paper Mill (Site 4), Scotts Creek at the confluence with the Tuckasegee River (Site 5), and the Tuckasegee River close to its confluence with Scotts Creek (Site 6). A simplified graphic of the sampling locations is presented as Fig. 2. Jesse Tilghman of BMP also took turbidity readings included in this study, as the readings were required for regulatory compliance.



FIG 2: Turbidity sampling locations.

Turbidity samples were measured using an EPA certified LaMotte<sup>®</sup> 2020e field turbidity meter. This meter was calibrated as needed against solutions of a known nephelometric turbidity unit (NTU) value. Additionally, one set of samples per day from locations two, four, and five were saved for analysis by PACE Analytics Laboratory in Asheville, NC to verify against the numbers sampled in the field.

While taking turbidity samples, sediment check dams, which had been put in place to catch sediment for later removal, were inspected to ensure that they were operational. Any debris present or damage to the check dam was recorded so that the dam could be repaired by work crews. An estimate of the average depth of silt caught at each check dam was determined with a simple measuring stick, in order to assess the dam's effectiveness and determine when manual removal of the buildup was necessary.

Sediment deposition occurring along the banks of Sugarloaf Creek was quantified and mapped in an attempt to estimate the total amount of silt and debris which had been stabilized. Any sites in need of manual stabilization through rechanneling, hydroseeding, or other techniques were identified at this time. In order to estimate the total volume of the sediment deposits, I approximated of the length, width, and depth of each deposit area. Deposition was measured using a counter-style measuring wheel and/or an open reel surveyor's tape depending on terrain. While not all areas of sediment deposition mapped clearly to a regular polygon, attempts were made to estimate a rectangular approximation. When this technique seemed to greatly distort the total area observed, multiple smaller rectangles were used in conjunction. Depth was measured using a variety of metal stakes as probes, and each area of deposition was sampled multiple times depending on its area to attain an average depth of sediment. These two figures were then multiplied to provide an estimated cubic yardage of sediment present at each location mapped. On some portions of the creek, I worked with Anna Salzberg of ClearWater Environmental Consultants to perform the measurements. In addition to physical sampling techniques, interviews and informal conversations were held with staff of the BMP, BMT, consulting organizations, applicable state agencies, and affected property owners to evaluate the efficiency of the process as a whole and help to determine ways in which the restoration efforts could be improved.



FIG 3: The author analyzing turbidity levels along Sugarloaf Creek.

# RESULTS

Turbidity sampling showed that, for the most part, the affected waterways are recovering, both naturally and through sediment removal efforts. During the time in which I sampled turbidity, September and October 2007, 93% of readings were within compliance with regulations, which stipulate a maximum permitted level of 50 NTU. This is not significantly different from samples collected in prior months, with June, July, and August of 2007 all exhibiting 90% or more of samples under 50 NTU. All of the days during this study in which samples were found not to be in compliance were during significant rain events or direct disturbance from stream restoration efforts.



FIG 4: Changes in turbidity levels at six sampling locations monitored across eight weeks. Samples taken during days with .5 in or greater of rainfall were not considered as they produced samples which were outside of the turbidity meter's designed range of operation. These readings did not significantly affect relative levels of turbidity.

On average, the lowest levels of turbidity were observed at Site 1, which is closest to the dam break location. Sampling indicated no significant difference between turbidity levels in the affected portions of Scotts Creek (Site 2) and levels just upstream from its confluence with Sugarloaf Creek (Site 3). In fact, a majority of samples showed a higher level of turbidity upstream from the confluence. Scotts Creek became significantly more turbid after passing through the towns of Sylva and Dillsboro, as indicated by levels recorded at Site 5, and undoubtedly the Tuckasegee River was much more turbid than any of its upstream tributaries affected by the dam break.



FIG 5: Average turbidity level at the six sample points. While standard deviation is relatively high, this is likely due to inconsistent calibrations of the turbidity meter rather than high variance in actual turbidity.

Overall, turbidity samples proved highly variable, ranging from 0.78 NTUs to 20.2 NTUs on days in which rain events or stream rechanneling work did not skew results. High turbidity levels measured during rainfall events and other periods of disturbance were highly erratic and showed little if any pattern, indicating that the meter was probably not effective in determining the actual turbidity level for such high levels. Most days showed an NTU of 10 or below for all locations.

Sediments caught within silt mats and check dams were removed regularly by work crews, and added to the totals collected from the use of sand wand, manual removal with shovels, and other techniques used by staff in order to ensure compliance with DWQ mandates. However removal was limited by availability of staff and ordered by priority, rather than being done on a regular daily or weekly basis. Additionally, sediment buildup was affected by rainfall and other natural variables, such that in-stream sediment deposit totals were not useful for quantifying the rate of sediment disappearance from the waterway.

Mapping of sediment deposition areas yielded approximately 263 cubic yards of sediment along the upper portions of Sugarloaf Creek and another 737 cubic yards along the lower portions. This total of 1000 cubic yards almost exactly matches the estimated volume of material lost from the dam itself. Much of this area had been marked for hydroseeding at the time of measurement, and thus can assume to be stabilized at least semi-permanently. Maps of the sediment deposition sites were hand drawn and included as part of the compliance report compiled by ClearWater Environmental Consultants on behalf of BMP. These can be seen in Figs. 6 and 7.



FIG 6: Sediment deposition locations along the upper portion of Sugarloaf Creek, Jackson County, NC along the BMP property. The largest concentrations of deposits were located in areas of the creek with relatively little elevation change.



FIG 7: Sediment deposition locations along the lower portion of Sugarloaf Creek, Jackson County, NC outside of the BMP property. As the lower portion of the creek contained far less elevation change, deposits here were generally larger in both area and depth.

#### DISCUSSION

The efforts of BMP to clean up affected portions of Sugarloaf and Scotts Creeks and the Tuckasegee River have been closely watched and often scrutinized (Johnson 2007). However, overall it appears that BMP is successfully recovering from the water quality issues resulting from their dam break in June 2007. Water quality levels as measured by turbidity are, on average, lower in the creeks most directly affected by the dam break than those into which the affected creeks flow.

However, the success of BMP's cleanup effort is largely based on the conditions set out by the DWQ, USACE, and WRC that BMP recover or account for all material lost or scoured in the dam break, and that they restore the turbidity of affected creeks to compliant levels. These measures are certainly helpful in restoring aquatic ecosystems to the area, but do not measure the true health of the stream, only the living conditions present.

Prior to the purchase of the property by Chaffin/Light Associates for the construction of the BMP development, the site had been for several decades under the ownership and management of Champion Paper Company (Canton, NC). Because of extensive logging, a higher than natural amount of sediment was already likely entering waterways before construction of the BMP development project began. Logging has been shown to have a detrimental effect on water quality for years after operations cease as the forest continues to heal (Bolstad and Swank 1997).

Additionally, logging of the tract produced a great number of roads which had a preexisting negative effect on water quality. While the roads may have actually aided in increasing water quality in recent years as construction has been able to reuse them rather than creating a new road network, roads generally have a negative effect on water quality and therefore upon aquatic ecosystems (Trombulak and Frissell 2000).

There are a number of areas in which regulatory and communication improvements could be made. One flaw in the data collection process requested by state agencies seems to be an overwhelming focus on information pertinent only to levels of sediment recovery. Alternatively, it would be more useful for the remediation process to include a requirement that the organization in violation both report on measures relevant to coming into compliance with cited statutes as well as reporting on factors directly relevant to overall stream health, including biological sampling.

For example, while at BMP, I spent time in search of aquatic insects to gauge the stream's suitability for the restocking of fish. BMP is also in the process of planning and constructing an insect emergence house to serve as a permanent observatory for aquatic invertebrates. But both of these initiatives stemmed from an interest by the organization prior to their receipt of a notice of violation in monitoring and improving stream quality. Consideration of biological indicators by relevant agencies would serve as a helpful additional indicator of stream health.

Of the state agencies involved in evaluating compliance of the cleanup efforts, the Division of Land Quality provided the most straightforward response to the initial dam break. Because of the agency's focus on human safety, the availability of a flowchart of required actions and list of emergency contacts made response to this area of the dam breach much faster. A similar flowchart of required actions and contact list could be constructed by the DWQ, USACE, and WRC to aid in faster response to relevant regulations during the critical period immediately following a disaster.

There seemed to be significant overlap in the processes conducted by the various agencies involved in the process. For example, the process for determining responsibility for cleanup was not coordinated between divisions within the Department of Environment and Natural Resources. Efforts to reduce this overlap would have perhaps improved response times.

Another useful tool which could be coordinated between the various agencies involved would be an approved vendor list for local resellers of equipment and other supplies necessary for the cleanup effort. For example, though the DWQ recommended the installation of Floc/Pam Logs in Scotts Creek to catch sediment, BMP was unable to acquire these items because the retailer required prior written permission from WRC in order to use them in a trout stream. Better coordination between agencies and retailers of tools and materials necessary for remediation would help prevent such tie-ups. Additionally, coordination with retailers would allow agencies to help organizations more immediately acquire the items necessary for a more rapid response to water quality issues.

The culmination of these and other suggestions to respond faster to a water quality violation may help reduce total response time and therefore reduce the total amount of sediment or other pollutants released into a waterway initially, speed the recovery from said release, or both. In order to effectively determine the best way to improve response to point-source water quality issues, an interagency study of existing protocols and methods for improvements should be conducted, and the results implemented in such a way as to allow organizations found to be in

violation of water quality standards to quickly and easily determine the steps required to mediate harm done.

#### **ACKNOWLEDGEMENTS**

I would like to thank Michael Skinner of the Balsam Mountain Trust for his help in conceptualizing and guiding this project. I would also like to thank Jesse Tilghman of the Balsam Mountain Preserve for sharing with me his in-depth knowledge of the site itself, restoration procedures, and monitoring techniques. Jim Costa and Anya Hinkle of the Highlands Biological Station were instrumental in the editing and composition of the final draft of this paper.

#### LITERATURE CITED

- Bolstad, P. V. and W. T. Swank. 1997. Cumulative impacts of landuse on water quality in a southern Appalachian watershed. Journal of the American Water Resources Association **33**:519-534.
- Johnson, B. 2007. In the wake of a washout. Smoky Mountain News 9:10-13.
- Karr, J. R. and D. R. Dudley. 1981. Ecological perspective on water quality goals. Environmental Management 5:55-68.
- Trombulak, S. C. and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18-30.

# CHEROKEE SETTLEMENT AND HISTORICAL ACTIVITY IN THE YELLOW CREEK VALLEY OF THE LITTLE TENNESSEE RIVER BASIN, GRAHAM COUNTY, NORTH CAROLINA

#### KATHERINE A. BETZ

*Abstract.* Yellow Creek Valley lies in Graham County, North Carolina. This valley was well-suited for settlement by the native people of the area because of the directional orientation of nearby mountain gaps. The orientation of the mountains creates a natural pathway exists that would have likely funneled people through this valley along trading routes. Both direct and indirect evidence indicate that the Cherokee formerly occupied this site. By researching and interviewing long term valley residents and local historians, I have compiled known information to aid the Land Trust for the Little Tennessee in their efforts to conserve this area. I have also documented a putative trail which was likely used by the Cherokee and/or the British as a trading route, and marked areas where the trail needs maintenance. This trail could likely become an informational center-point for visitors to the valley.

Key words: Cherokee Indians; cultural landscape; Graham County, North Carolina; interpretive signage; Junaluska; Land Trust for the Little Tennessee; Little Tennessee River, North Carolina; Thomas, William Holland; Welch, John; Wacheaucha; Yellow Creek Valley, North Carolina.

#### INTRODUCTION

After the removal of the majority of the Cherokee Indians from the Southern Appalachians, there was a period of some neglect of Cherokee cultural heritage (T.J. Holland pers. comm.). Recently however, there has been a growing interest in preserving and celebrating Cherokee culture. One important way in which to achieve this is through the documentation of sites which have cultural significance including former settlements of the Cherokee, locations of which may no longer be known. Much of the land which was so fit for the Cherokee is also very well suited for modern farming, so many of the greatest Cherokee sites discovered so far have already been destroyed by the plows of 19<sup>th</sup> and 20<sup>th</sup> century farmers. Because of this, it is very rare to find a relatively pristine historic Cherokee settlement. Within the center of the ancient Cherokee heartland, however, such a settlement location very likely exists. My project involves documentation groundwork for this site, Yellow Creek Valley of the Little Tennessee River basin.

Within the heartland of the Cherokee nation lived a group who called themselves "Yun-Wiya," or the "real people" (Middleton 1999). This group was possibly the preeminent faction of Cherokee. Within their historic range lie two earthen mounds, the Cowee and the Nikwassee. These mounds were considered extremely significant to the ceremonies of the Cherokee (Middleton 1999). This historic tribe was most likely not only ceremonially significant, but also culturally significant due to extensive trading through the region.

The Appalachian Mountains cut through North America in a north-south orientation, acting as a barrier to the movement of organisms, including humans. There is a gap in these mountains, however, that runs east-to-west, thus creating a natural passage, a perfect setting for a

trading center for the Cherokee (T. Hatley pers. comm.) (Fig. 1). Yellow Creek Valley has been in the possession of ALCOA, the Aluminum Company of America, for many years. It was originally acquired during World War II for use as a possible reservoir to produce electricity to power aluminum factories in western North Carolina and eastern Tennessee. Soon after the acquisition, however, the war ended and the reservoir was no longer needed. It has remained in ALCOA's possession since, but they have recently decided to sell the property. The Land Trust for the Little Tennessee (LTLT) succeeded in securing an option to purchase some 910 acres at the lower end of Yellow Creek Valley. The LTLT is dedicated to conserving the resources and heritage of the Upper Little Tennessee River, the most diverse river in the world, outside of the tropics (P. Carlson, Executive Director, LTLT, pers. comm.). It is their hope to continue that conservation into the rich historical landscape of Yellow Creek Valley.

In this paper, I will make a case for the existence of a Cherokee town-site in Yellow Creek Valley, as well as present evidence that I have gathered in favor of the idea. I will give anecdotal evidence from interviews with scientists, historians, and families from neighboring property who have lived in the area for generations. I will also use photographic evidence of river-side bottomland, mountain gaps, and river cane stands to show the suitability of the area for Native American movement and settlement.

Additionally, I have studied a trail within the valley that was once likely used by the Cherokee, and later the British. I have begun an examination of this trail for evidence that it is a remnant of an old passageway through the mountains. I have also documented the condition of the trail and taken photographs of the locations which need maintenance. I have secured documents to aid the LTLT in preserving this trail in the future. This trail is an embodiment of the LTLT's overall goal for this valley: to document, preserve, and learn from this cultural landscape.

### MATERIALS AND METHODS

To gather data on Yellow Creek Valley, I researched literature on the area, including general Cherokee history. I utilized the library and rare books and maps collection at the University of North Carolina at Chapel Hill for most of this research. Additionally, I interviewed neighbors of the Yellow Creek Valley property for insight from locals' perspectives. I also interviewed Dr. Tom Hatley, a Western Carolina University professor who specializes in Cherokee history, Mr. T.J. Holland, the manager of the Junaluska Museum in Robbinsville, NC, and Mr. Tom Magnuson, a historic trail researcher.

In addition, I gathered cemetery data from the Graham County survey records and created a table of GPS positional data to aid the LTLT in projecting a map of the cemeteries in Yellow Creek Valley (see Table 1). In the future, this will be useful in finding historic land ownership. I also used aerial photographs and ground-truthing to find the best possible paths to connect certain historical locations within the valley. Maps showing the layout of two candidate trails, a 3-mile loop and a 3-mile out-and-back, were created using ArcGIS (ESRI 2005.). Furthermore, I have created a template of an interpretive sign for the LTLT to use in the future.

A large part of my project required me to photograph Yellow Creek Valley. The LTLT plans to use some of these photographs in publications in the future. Some were also used to illustrate various evidence used in my paper, including a Cherokee fish weir, river bottomland, a river cane stand, mountain gaps, and Yellow Creek Falls Trail. These photographs were taken

and edited using the following equipment: Nikon Coolpix 4200, Nikon FM3A, Nikon F5, Nikon AF Nikkor 28-105 mm / 1:3.5 – 4.5 D Lens, and IBM Thinkpad T42.

#### **RESULTS AND DISCUSSION**

#### Evidence of the Cherokee in the Yellow Creek Valley of the Little Tennessee River basin

The Little Tennessee River basin lies in what was once Cherokee heartland, in the middle of a 40,000 square mile territory (Mooney 1992). In fact, the river contains many old Cherokee fish weirs so sturdy in their construction that they still exist and funnel waters to this day (Fig. 3). It is assumed that the Cherokee Indians inhabited most or all rich bottomland available in this area at the pinnacle of their civilization (Davis 2000). Because Yellow Creek Valley has both fertile farmland and lies along ideal trading routes, evidence strongly confirms that the Cherokee Indians lived in and around the Yellow Creek area at some point. It is difficult to establish the size and significance of the settlement without some doubt though, because historical records of such a settlement are not abundant (T. Hatley pers. comm.; T.J. Holland pers. comm.).

Junaluska, the great Cherokee chief and warrior, was buried just outside of present-day Robbinsville, NC, in the Cheowah settlement near Yellow Creek (Mooney 1992). This is good support for the assumption that Yellow Creek was both the geographical and cultural center of the Cherokee nation. T.J. Holland, manager of the Junaluska Museum, is convinced that the Yellow Creek area was deeply significant to the Cherokee. He maintains that there is a rich oral history of the area passed down by the Cherokee of the Snowbird Mountains, adjacent to Yellow Creek (T.J. Holland pers. comm.).

Neighbors to the Yellow Creek property, such as Jeff and Nancy Hoch, report that by digging around anywhere in the Yellow Creek Valley, one is certain to find Native American artifacts. Jeff and Nancy are advanced amateur archaeologists who have collected artifacts for years and they have virtually no room left in the office of their inn to display all the artifacts they have found, of both Native American and Spanish origin (J. Hoch and N. Hoch pers. comm.). Before the creation of Fontana Lake, it was a regular occurrence to find Native American artifacts from the west in that valley (Middleton 1999).

According to Middleton (1999), the distinct white pottery found here was only made in the Cherokee village of Kohlowee, located at present-day Cullowhee, indicating that there must have been extensive trade into Yellow Creek Valley, consistent with the valley's favorable location with respect to topography and trade routes. If Cherokee from the major trading townships were exchanging with people to the west, such as tribes located along the Mississippi, it is likely that they would have moved through Yellow Creek Valley and over the mountain gap to get there. Mississippian culture probably moved east into the southern Appalachian Mountains around 1,000AD. This would have been the first stage in a trade connection between the pre-Cherokee and the Native Americans of the Tennessee Valley and west (Rozema 1995).

Mooney (1992) reports cairns that were supposedly located somewhere in Yellow Creek, one of which is the grave of a Cherokee killed in an ancient battle, the other a location of laurel bushes which one must gnaw the twigs of when passing to ensure good fortune. Mooney (1992) also describes a Cherokee legend of "Yawa place," on the south side of Yellow Creek, where a mysterious being reportedly haunted a knob. When this personage was detected, distant echoes of gunfire could often be heard.

The best piece of evidence that we have that Yellow Creek was a town site for the Cherokee is a series of old maps. Figs. 4a and 4b distinctly show the fork of the Little Tennessee and Tuckaseegee Rivers and depict a settlement at the fork. When compared to current maps, it appears likely that the location is Yellow Creek. Fig. 4c shows Cherokee settlements from 1721-1730, Fig. 4d shows settlements from 1755-1762, Fig. 4e shows settlements from 1775-1776, Fig. 4f shows the area occupied by the Cherokee Nation from 1819-1838, and Fig. 4g shows the lands of the Eastern Band of Cherokee Indians in 1881. I have marked what is assumed to be Yellow Creek Valley with a circle on all of these maps.

# Typical Settlement Patterns and Pathways

Cherokee settlements generally followed the floodplains in long and narrow configurations. Such bottomland is where the most fertile ground is located (Middleton 1999). Figs. 5a—d illustrate the typical farmland that would have been used by the Cherokee. Fig. 5a shows the valley along which Highway 28 now runs, very near to the Cowee Mound site. Fig. 5b shows the fields directly beside this mound site, a known large settlement of the Cherokee, and possibly the location of their most prominent political city. Figs. 5c and 5d depict the valley alongside the Little Tennessee River much closer to the Yellow Creek area. The river moves much more slowly here, and the patterns of the sediment can be seen under the surface in Fig. 5d. This sediment is what provided the rich soil for farming for the Cherokee, and still provides nourishment for modern crop fields. When the river overflows it deposits the sediment, which contains organic matter from the rich mountain forests farther upstream.

Because the Cherokee came from fertile lands from the north or west, they were accustomed to the fertile farmland of the Mississippi region. Their entire civilizations had been built upon "meander-belt" river bottoms (Davis 2000). Thus, the rich bottomland soil they found along the Little Tennessee River was vital for their crops. Being near the water also had trading advantages, as the Cherokee used canoes extensively. Also, an essential supply of river cane grows along the marshy sides of slow-moving rivers such at the Little Tennessee (Davis 2000).

In the early 19<sup>th</sup> century, William Holland Thomas, who was half Cherokee, was adopted as the son of Chief Drowning Bear. He regularly visited Washington, DC to fight for the Cherokee's right to their land (Finger 1984). He also bought land in Yellow Creek Valley (T.J. Holland pers. comm.) for a mixed-blood man named John Welch, of the Valley River area (Finger 1984). In those times, the Cherokee could not own land, but sometimes white men would buy the land for them (King 1979). Ownership would be recorded in the name of the white man, but would actually be owned by Cherokee (King 1979). Welch generally bought the most significant tribal land, under the direction of Wacheaucha, Chief Junaluska's brother. Thus, if Welch owned land at Yellow Creek, we know that such land must have been important to the Cherokee. One of the reasons that this land is so important is that it is rumored that Junaluska's mother, Nancy Catatahee is buried at Yellow Creek.

Another way in which the Cherokee were able to attain land was through economic programs from wealthy men. The Reverend William C. McCarthy, for example, desired to help the Cherokee economically, so he bought 247 acres of farmland less than a mile from Robbinsville, NC and provided the Cherokee with all that they needed to run it (Finger 1984). It is records such as this that need to be further researched to find connections to the Yellow Creek Property.

It is for that very reason that I researched the locations of all cemeteries in Graham County (Table 1), with special concentration on the cemeteries at Yellow Creek. This information might be useful to researching past land holdings and to find the location of Cherokee graves. For instance, within Yellow Creek is a cemetery located on present-day Caringer Road, behind which is an old Cherokee trail. Following the trace of this, Wacheaucha Trail, from the cemetery along the ridge top leads to Wacheaucha Bald, where there is said to be a rock with Cherokee writing on it. This is the grave of Junaluska's mother (T.J. Holland pers. comm.). More study should be done to determine the exact location of this rock, and if it is similar to Judacullah Rock, which is covered in as-yet-undeciphered marks 7,000 years old (Middleton 1999).

It is possible that this is the trail referred to by the British as "Wakaiecee Trail" which extended up a creek and crossed the Cherokee trade trail, now the Appalachian Trail, in a deep gap called Wakaiecee Pass (Middleton 1999). It is also possible that "Watuga Gap" along the Cosaleechee Trail may be an alternative spelling of the same Cherokee name (Rozema 1995). There was once a Cherokee town named Waseechee, for example, of which there is no record of destruction by the British, an anomaly in that time period (Middleton 1999). Because there was no set language or pronunciation for many of these words, people and place names have changed over the centuries (Middleton 1999).

One of the difficulties in finding information about this time period stems from the scarcity of the historical record. The United States Army was directed to move through all areas and mark how many settlements there were, and how many houses per settlement. However, the Cherokee of the Snowbird Mountains were notoriously fierce and it appears that the Army often did less surveying than they were supposed to. Thus, entire settlements could have escaped the notice of the white men in these rugged mountains (T.J. Holland pers. comm.). For example, there is documentation of a wilderness area about thirteen miles up the Little Tennessee River from Franklin was a wilderness area known to be full of "robbers" (Middleton 1999).

T.J. Holland also spoke of gold in the Yellow Creek area, which could be how the name originated. Middleton describes an "Indian Princess" who was captured by the Spanish and was told to lead them to the source of the Cherokee's wealth of gold. While they were traveling in the direction of Yellow Creek, in an area about 20 miles away from present-day Franklin the princess escaped and the Spanish never found their gold (Middleton 1999). DeSoto's men also sought gold from indigenous populations and would kill those who wouldn't show them the way to (perhaps non-existent) goldmines (Rozema 1995).

In the following subsections I summarize information bearing on resources and topographical features that would make Yellow Creek Valley a desirable settlement area:

# i. River Cane

The presence of a river cane stand at the historic barn site in Yellow Creek Valley would have proven attractive to the Cherokee (Figs. 6a—b). River cane was the most economically important plant to the Cherokee. It is a type of bamboo and grows in tall stalks, making it very easy for the Cherokee to simply tie together in order to create a teepee-shaped shelter; by then taking other stalks and weaving them horizontally in between these vertical shoots, the housing became relatively weather-tight. River cane has an exceptional ability to be twisted and bent to take many forms, and was also ideally suited for basket weaving. The Cherokee basket-weaving

tradition is a long, proud one, and their baskets are known to be watertight. River cane was also used to make blow guns, which were used for hunting small game (Brown 2000).

Though it is a native plant that grows in stands across the southeast, healthy river cane stands have ebbed. When farmsteads became established, the settlers diverted water from marshy areas to flow into their crop fields. This desiccated the soil supporting many stands of river cane that used to be prevalent throughout the southern Appalachians (Brown 2000). Davis states that river cane "flourished in great abundance" at one time, but after World War II, "was only sporadically observed" (Davis 2000). He describes its usefulness, and calls the plant "essential," for it was used for insulation, weather-proofing, and structural integrity in Cherokee homes (Davis 2000).

A possible explanation for the decline of river cane is the lessening of fire regimes to propagate the plant. The Cherokee regularly burned the river cane stands to choke out the competing vegetation. The ashes from the fire also added nutrients to the soil (Davis 2000). After the ingress of the settlers and the extirpation of the Cherokee, controlled burning dwindled. Without this support, the river cane became less prevalent across the landscape. River cane also made a great food source for livestock. At first, livestock have no effect on the cane because of its strong underground root structure, but consistent grazing takes its toll. Cane brakes can all but disappear in five years time due to steady grazing (Davis 2000). What we see today is the result of this progressive loss of river cane habitat.

#### ii. Mountain Gaps

Gaps through the mountains provided the fastest, most efficient path for traders moving between settlements. By examining the topography on elevation maps of the area, routes can be established that are most likely the same ones that the Cherokee would have used. The pathway up through Yellow Creek Valley, for example, can be seen in Fig. 7a. Such pathways can now be studied as a cultural landscape that stretches from Tuskeegee all the way to Ft. Loudon, most certainly crossing through Yellow Creek (Middleton 1999). This was an important and welcome trading center for the Cherokee, and they became middlemen in trade between the Carolinas because of Ft. Loudon (Hatley 1995).

Some examples of mountain gaps as seen from the floor of Yellow Creek Valley can be seen in Figs. 7b—d. These photographs show how the mountains can funnel travelers. People will move through the most efficient and logical path through rough terrain like this. Even many years later, it is easy to project the likeliest path the Cherokee would have taken through this area based on its unchanged topography.

#### Yellow Creek Valley

# i. 18<sup>th</sup> Century

Within Yellow Creek Valley there is a trail that leads up to a waterfall. This trail is currently in use by kayakers, who keep it very well-marked up to the point of the waterfall. However, after the trail reaches the waterfall, it is not maintained and thus becomes increasingly overgrown. When walking this trail, one can easily detect a trace winding around the current path, pre-dating recent use. The LTLT believes that this trace may be an old trading route used by the Cherokee, and then the British. It is wide enough to allow for horses and wagons, and it follows a much lower gradient than the current trail, which is likely the reason for the current trail's different position. There also appear to be remnants of fords along this trail at locations where the trail crosses the creek.

When the Cherokee people originally came to the southern Appalachians, they apparently pushed out the tribe that had lived there before them (Middleton 1999). They would have likely have kept contact with their original homeland, by trading or intermarriage (Middleton 1999). The Cherokee also laid claim to hunting grounds in Kentucky and Tennessee, so perhaps the trail was used for movement between summering and wintering grounds (Mooney 1992). It is also conceivable that the trail connects to the Da'anawa Sa'tsunyi, a "war crossing" ford in Cheowah River 3 miles south of present-day Robbinsville, NC. This ford was known to have been used by northern tribes, perhaps the Shawano or Iroquois (Mooney 1992). The different nations of Native Americans living in eastern North America at that time did not observe static boundaries. There was constant encroachment into other tribes' and peoples' territory and regular skirmishes to control the land (Mooney 1992). Thus, good paths between the east and west would have become very well-established over time and much tread.

It is possible that Yellow Creek Falls Trail was used during the removal of close to 17,000 Cherokee from their native land, 4,000 of whom likely died due to the journey (Mooney 1992). Mooney describes the movement of the Removal parties through the mountains to Tennessee, "it was like the march of an army, regiment after regiment, the wagons in the center, the officers along the line and the horsemen on the flanks and at the rear" (Mooney 1992). It is likely that they would have selected an already-established trail, one capable of handling horses and wagons and groups of one thousand Cherokee at a time (Mooney 1992). Yellow Creek Trail would have been well situated to guide these parties through the mountains.

# ii. 21<sup>st</sup> Century

Yellow Creek Valley in the 21<sup>st</sup> century is an area well-suited for cultural history preservation and education projects. Because the area is now open to conservation from ALCOA for the first time in years, the land remains largely undisturbed. The LTLT plans to maintain it in that state, in conformity with their mission statement. Although it should remain principally undeveloped, the LTLT also believes that there should be opportunities for education to the public about the Cherokee history in the area. Such a hands-on education could prove to be a valuable experience for learning the history of the valley.

One of the best places to study the valley is at the trail to Yellow Creek Falls. For that reason, I have documented areas of the trail that need to be improved and maintained in order to make it easier to navigate. I have also obtained the official Trail Construction and Maintenance Notebook from the USDA Forest Service Technology and Development Program to aid in the future maintenance of this trail to ensure accessibility (USDA 1996). I have documented the areas in need of repairs in Figs. 8a—f.

## Next Steps

Yellow Creek Valley in its current condition is well suited for protection for generations to come. The LTLT is dedicated to further preservation and restoration of the valley through a modern conservation project. Together with the upgrade of the Yellow Creek Falls Trail, this area will become an important locality for exploration of the cultural landscape of the 18<sup>th</sup>

century Cherokee Indians. Further study must be done in this area, especially in the form of archaeological work. Because there has never been any comprehensive exploratory work on the valley, there is no way of knowing the extent of the archaeological finds in the area. It is imperative that the Cherokee Indians be included in this work as much as possible due to the oral histories of the land that they may possess knowledge of.

A more tangible goal is that of the trail itself. It is important to extend this trail past the waterfalls, perhaps even to a road to make a loop trail. It would be very beneficial for it to be clearly established and then maintained, and there should also be an interpretive kiosk informing people of its location, providing a history of the area, and identifying points of interest along the hike. I have provided both a map and a sample template for the interpretive kiosk, Figs. 9a and 9b.

Because of the limited nature and time constraints of this study, many resources could not be fully explored. I have therefore attached a list of contacts (Appendix A) that the LTLT could put to good use as they transition into the restoration part of their conservation plan. It is my hope that through the groundwork of this study, the Land Trust will be able to make some very important finds in the area, and will be able to better educate the public about the people who lived here long ago in this historic area.

#### **ACKNOWLEDGEMENTS**

I acknowledge the editorial assistance of Dr. James Costa, Dr. Anya Hinkle, and Paul Carlson. The idea of cultural pathways through mountain gaps is gratefully attributed to Paul Carlson. I also acknowledge the help of the UNC Rare Books and Maps Collection librarians. This work was conducted while I was an undergraduate student in the Institute for the Environment of the University of North Carolina at Chapel Hill, studying at the Highlands Biological Station in Highlands, North Carolina, under the direction of Dr. James Costa and Dr. Anya Hinkle. My internship with the Land Trust for the Little Tennessee, under the direction of Paul Carlson, Executive Director and Kate Parkerson, Membership & Outreach Coordinator.

#### LITERATURE CITED

- Bancroft, G. 1846. Bancroft's history of the United States. Charles C. Little and James Brown. The University of North Carolina at Chapel Hill rare books and maps collection.
- Brown, M. L. 2000. The wild East: a biography of the Great Smoky Mountains. University Press of Florida, Florida, USA.
- Davis, D. E. 2000. Where there are mountains: an environmental history of the southern Appalachians. The University of Georgia Press, Athens, Georgia, USA.
- ESRI, Inc. 2005. ArcMap 9.1. Redlands, CA.
- Finger, J. R. 1984. The Eastern Band of the Cherokees 1819-1900. The University of Tennessee Press, Knoxville, Tennessee, USA.
- G.G. Smith.
- Hatley, T. 1995. The dividing paths: Cherokees and South Carolinians through the revolutionary era. Oxford University Press, New York, New York, USA.
- Hatley, T. Personal Interview. Cowee Mound site, near Franklin, North Carolina. September. 2007. Summary is in Appendix A.
- Hoch, J and Hoch, N. Personal Interview. September. 2007.
- Holland, T. J. Personal Interview. Junaluska Museum, Robbinsville, NC. September. 2007. Summary is in Appendix A.
- Hunter, George. 1730. Cherokee Nation and traders' path from Charles Town via Congaree. Manuscript map. Hargrett Rare Book and Manuscript Library, University of Georgia, Athens.
- King, D. H. 1979. The Cherokee Indian Nation: a troubled history. The University of Tennessee Press, Knoxville, Tennessee, USA.
- LTLT. 2007. Map of the Yellow Creek Property.

Magnuson, T. Personal Communication. September. 2007. Summary is in Appendix A.

- Middleton, T. W. 1999. Qualla: home of the middle Cherokee settlements. WorldComm, USA.
- Millsaps, B. and W. Millsaps. 1984. USGS Cemetery Study. Accessed at the Graham County Public Library, Robbinsville, North Carolina, USA.
- Mooney, J. 1992. History, myths, and sacred formulas of the Cherokees. Bright Mountain Books, Asheville, North Carolina, USA.
- Rozema, V. 1995. Footsteps of the Cherokees: a guide to the eastern homelands of the Cherokee Nation. John F. Blair, Winston-Salem, North Carolina, USA.
- USDA Forest Service Technology and Development Program. October 1996. Trail Construction and Maintenance Notebook. 4E42A25- Trail Notebook.



FIG. 1. Yellow Creek Valley

 TABLE 1. Cemeteries of great interest in terms of historic Cherokee graves are marked with an asterisk (Millsaps 1984).

		Latitude	Latitude	Latitude	Latitude	Longitude	Longitude	Longitude	Longitude
* #	Site	Degrees	Minutes	Seconds	Decimal	Degrees	Minutes	Seconds	Decimal
1	Cedar Cliff	35	19	11	35.319722	83	53	50	83.897222
2	Carver (Long Hungry)	35	19	43	35.328611	83	52	4	83.867778
3	Hudson	35	25	26	35.423889	83	56	57	83.949167
4	Orr	35	25	21	35.4225	83	56	44	83.945556
5	Farley	35	27	8	35.452222	83	53	22	83.889444
* 6	Gladden	35	25	47	35.429722	83	53	51	83.8975
* 7	Cheesquire	35	21	14	35.353889	83	49	48	83.83
8	Massey	35	19	52	35.331111	83	50	26	83.840556
9	West Buffalo Baptist	35	19	4	35.317778	83	50	23	83.839722
1	0 Lone Oak	35	21	39	35.360833	83	50	41	83.844722
* 1	1 Millsaps	35	21	53	35.364722	83	49	15	83.820833
* 1	2 Upper Yellow Creek	35	24	50	35.413889	83	49	50	83.830556
1	3 Williams	35	24	42	35.411667	83	48	38	83.810556
1	4 Guge	35	25	32	35.425556	83	42	14	83.703889
1	5 Blakenship	35	24	49	35.413611	83	43	22	83.722778
1	6 Delozier	35	23	46	35.396111	83	43	50	83.730556
1	7 Sawyer's Creek	35	24	6	35.401667	83	42	20	83.705556
1	8 Hooper I	35	18	10	35.302778	83	54	20	83.905556
1	9 Hooper II	35	18	0	35.3	83	54	10	83.902778
* 2	0 Wachacha	35	15	20	35.255556	83	53	8	83.885556
2	1 Dry Creek	35	21	15	35.354167	83	41	15	83.6875

		Latitude	Latitude	Latitude	Latitude	Longitude	Longitude	Longitude	Longitude
* ‡	<sup>‡</sup> Site	Degrees	Minutes	Seconds	Decimal	Degrees	Minutes	Seconds	Decimal
4	22 Guy Cable	35	22	16	35.371111	83	40	43	83.678611
4	23 Greene	35	23	42	35.395	83	43	25	83.723611
4	24 Welch Cove	35	25	9	35.419167	83	47	56	83.798889
2	25 Odom	35	22	8	35.368889	83	50	53	83.848056
2	26 Phillips	35	19	4	35.317778	83	47	45	83.795833
2	27 Deyton	35	21	18	35.355	83	50	45	83.845833
* 2	28 Cornsilk	35	18	28	35.307778	83	49	35	83.826389
* 2	29 Rattler	35	17	10	35.286111	83	50	17	83.838056
	80 Peter Brown	35	19	0	35.316667	83	51	35	83.859722
	31 Barker	35	17	34	35.292778	83	49	0	83.816667
	32 Old Mother	35	19	9	35.319167	83	47	53	83.798056
* (	33 Yellow Branch	35	25	56	35.432222	83	42	55	83.715278
	34 Gunter	35	24	26	35.407222	83	44	7	83.735278
	35 Upper Sawyer's Creek	35	23	3	35.384167	83	43	12	83.72
	36 Holloway	35	19	53	35.331389	83	45	34	83.759444
	37 Jones	35	19	43	35.328611	83	31	55	83.531944
	38 Zion Hill	35	17	25	35.290278	83	31	50	83.530556
* (	9 Chickelelee	35	18	41	35.311389	83	51	15	83.854167
2	0 McDonald	35	22	40	35.377778	83	52	50	83.880556
2	1 Odom Chapel	35	23	6	35.385	83	52	40	83.877778
2	2 Wall	35	23	40	35.394444	83	52	40	83.877778
4	3 Metz	35	17	49	35.296944	83	49	44	83.828889
* 2	4 Junaluska	35	19	11	35.319722	83	48	2	83.800556
4	5 Dobson Hill	35	18	50	35.313889	83	51	50	83.863889
4	6 First Baptist Church	35	19	15	35.320833	83	48	25	83.806944
4	7 Methodist Church	35	19	20	35.322222	83	47	40	83.794444
4	9 Bear Creek Church	35	16	22	35.272778	83	43	20	83.722222
4	50 Davis	35	22	35	35.376389	83	52	40	83.877778
4	51 Sellers	35	25	57	35.4325	83	26	24	83.44
4	52 Johnson	35	23	41	35.394722	83	42	59	83.716389
* 4	53 Lower Yellow Creek	35	25	0	35.416667	83	52	30	83.875
* 4	54 Wiggins	35	17	53	35.298056	83	46	39	83.7775
4	55 Grindstaff	35	19	1	35.316944	83	43	15	83.720833
4	56 Rice	35	20	34	35.342778	83	45	15	83.754167
4	57 Clyde Cable	35	22	31	35.375278	83	38	30	83.641667
4	58 Randolph	35	22	23	35.373056	83	41	4	83.684444
4	59 Edwards	35	22	32	35.375556	83	40	53	83.681389
(	50 Adam Cable	35	22	50	35.380556	83	40	50	83.680556
(	51 Holder	35	24	2	35.400556	83	40	30	83.675
* (	52 Panther Creek	35	24	21	35.405833	83	37	30	83.625
(	53 Conseen	35	18	15	35.304167	83	52	22	83.872778
* (	4 Hunting Boy Branch	35	16	39	35.2775	83	52	30	83.875
* (	5 Hickory Tree Gap	35	17	3	35.284167	83	52	2	83.867222
(	66 Ledford	35	16	45	35.279167	83	52	34	83.876111
(	57 Denton	35	15	28	35.257778	83	54	43	83.911944
(	58 Wakefield	35	20	14	35.337222	83	48	42	83.811667
* (	9 Stecoah-Jenkins	35	22	4	35.367778	83	41	9	83.685833
	0 Hazie Brown	35	22	7	35.368611	83	41	48	83.696667

		Latitude	Latitude	Latitude	Latitude	Longitude	Longitude	Longitude	Longitude
* #	Site	Degrees	Minutes	Seconds	Decimal	Degrees	Minutes	Seconds	Decimal
* 71	Mountain Creek	35	21	10	35.352778	83	47	18	83.788333
72	2 West	35	16	37	35.276944	83	43	53	83.731389
73	Campbell-Sherrill	35	15	20	35.255556	83	45	14	83.753889
74	Cable Cove	35	25	47	35.429722	83	45	18	83.755
75	Breedlove	35	24	40	35.411111	83	43	6	83.718333
76	Huckleberry Knob	35	19	10	35.319444	83	59	30	83.991667
77	Hedrick	35	19	32	35.325556	83	54	20	83.905556
78	Esau George and wife	35	21	15	35.354167	83	49	28	83.824444
79	Thomas Carver and wife	35	20	10	35.336111	83	51	47	83.863056
80	) Stratton	35	20	13	35.336944	84	1	53	84.031389
* 81	Kirkland	35	19	33	35.325833	84	1	57	84.0325
82	2 Yearwood	35	31	31	35.525278	83	57	15	83.954167
83	Tom Lawson Carver	35	30	10	35.502778	83	49	44	83.828889
84	Winona Wood	35	18	53	35.314722	83	53	30	83.891667
85	Eller Cove	35	15	42	35.261667	83	51	33	83.859167
86	Beech Creek Cem.	35	19	26	35.323889	83	43	51	83.730833
87	V Nichols Cove	35	26	10	35.436111	83	59	12	83.986667
88	3 Orr Mountains	35	25	7	35.418611	83	57	13	83.953611



FIG. 2. Cherokee fishing weir, Little Tennessee River just north of Franklin, North Carolina.



FIG. 3a. Historic Map I (Hunter 1730).



FIG. 3b. Historic Map II (Bancroft 1846).



FIG. 3c. Cherokee settlements from 1721-1730 (King 1979).



FIG. 3d. Cherokee settlements from 1755-1762 (King 1979).



FIG. 3e. Cherokee settlements from 1775-1776 (King 1979).



FIG. 3f. Area occupied by the Cherokee Nation from 1819-1838 (Finger 1984).



FIG. 3g. The lands of the Eastern Band of Cherokee Indians in 1881 (Finger 1984).



FIG. 4a. Typical Little Tennessee farmland, along Highway 28 North, Macon County, North Carolina.



FIG. 4b. Typical Little Tennessee farmland with livestock, close to Cowee Mound site, Macon County, North Carolina.



FIG. 4c. Little Tennessee floodplain, Graham County, North Carolina.



FIG. 4d. Sand patterns in the calm water of the Little Tennessee, Graham County, North Carolina.



FIG. 5a. River cane stand, Yellow Creek Valley, Graham County, North Carolina.



FIG. 5b. Robust river cane, Yellow Creek Valley, Graham County, North Carolina.



FIG. 6a. Pathway through Yellow Creek Valley (red bounded area), seen as developed land between mountain ranges (LTLT 2007).



FIG. 6b. Mountain gap, facing west in Yellow Creek valley.



FIG. 6c. Mountain gap, facing west in Yellow Creek valley.



FIG. 6d. Mountain gap, facing east in Yellow Creek valley.



FIG. 7a. Logs blocking trail, facing toward falls, Yellow Creek Trail.



FIG. 7b. Steep section of trail with rocks, facing toward falls, Yellow Creek Trail.



FIG. 7c. Logs across trail, facing toward falls, Yellow Creek Trail.



FIG. 7d. Typical shot of trail, facing toward falls, Yellow Creek Trail.


FIG. 7e. Typical shot of trail, facing toward falls, Yellow Creek Trail.



FIG. 7f. Yellow Creek Falls, at end of Yellow Creek Trail.



FIG. 8a. Yellow Creek Falls Interpretive Trails Proposal. Trail marked in blue is 3-mile loop; trail marked in red is 3-mile out-and-back.



FIG. 8b. Example text and layout for interpretive sign.

# **APPENDIX A**

Personal Interview- Hatley, Tom, Sequoya Professor of Cherokee Studies, Western Carolina University

Interviewers: Katy Betz and Kate Parkerson of the Land Trust for the Little Tennessee

Date and time: September 19, 2007

Location: Canoe trip to Cowee Mound, The Little Tennessee River near Franklin, NC

Subject of Interview: Information gathering about Cherokee settlement in Yellow Creek Valley

Summary: Cherokee land use in the southern Appalachian Mountains; the cultural and ecological importance of river corridors; significance of the Cowee Mound and its surrounding regions; the History of the extirpation of the Cherokee from the area; the disagreements about how to interpret the history of the Cherokee in modern times.

Worthy of note:

- There was definitely a Cherokee settlement in Yellow Creek
- The stream ford locations would be very interesting to look into, try contacting Tom Magnuson

Personal Interview – Hoch, Jeff and Nancy, Local residents of Yellow Creek Valley

Interviewers: Katy Betz and Kate Parkerson of the Land Trust for the Little Tennessee

Date and time: September 21, 2007

Location: The Hike Inn, owned by Jeff and Nancy Hoch

Subject of Interview: Information gathering about the Yellow Creek Valley property

Summary: The interview consisted of Kate Parkerson and Katy Betz inquiring about how to proceed in gathering information on the Yellow Creek Property. Jeff and Nancy mostly gave information about who would be the most profitable to talk to. They are also advanced amateur archaeologists and displayed some of their finds from both Florida and the Yellow Creek area. They are convinced that the Spanish and the British both moved through this Cherokee country based on the artifacts they have uncovered in the area.

Worthy of note:

- The US Forest Service has been researching some old trails; contact Harold and Mettie Jenkins for more information, their son Perry is a wealth of knowledge
- DeSoto likely followed the "Yellow Hammer Trail;" several hiking clubs have been researching it. Contact Lenny Bernstein (828-236-0192 or www.carolinamtnclub.com) of the Carolina Mountain Club, T.J. of the Eastern Kodak Club, or the AT Club for more information.
- Gifford and Shelia Beasley live on Hwy 28 through Yellow Creek; are good people to ask for a history of the property.

- Bill and Wilma Millsap live up Cochran's Creek and worked on a book celebrating the 100 year anniversary of Graham County.
- T.J. Holland is a good person to contact (479-4727)

Personal Interview – Holland, T.J., Manager, Junaluska Museum, Robbinsville, North Carolina

Interviewers: Katy Betz and Kate Parkerson of the Land Trust for the Little Tennessee

Date and time: September 21, 2007

Location: The Junaluska Museum, managed by T.J. Holland

Subject of Interview: Information gathering about Cherokee settlement in Yellow Creek Valley.

Summary: The interview consisted mostly of T.J. telling us about land ownership records in western North Carolina and the Cherokee settlements of the Snowbird Mountains.

Worthy of note:

- There is a survey note in the historic John Welch collection of land ownership by William Holland Thomas. Thomas lived on the Valley River and bought land for Wacheaucha before the Cherokee were allowed to own it themselves. Because of this, he generally only bought tribally significant land. Since he owned Yellow Creek at one point, we know it was tribally significant. This information could be found in the Duke Collection- a six box collection of correspondences with William Holland Thomas.
- It is rumored that Junaluska and Wacheaucha's mother, Nancy, was buried in Yellow Creek
- A good person to contact is Brett Riggs, an Archaeologist at UNC-Chapel Hill. He has some old maps at the research labs that might be useful.
- The Gladdens cemetery up Old Field Gap Road was possibly once a village called Cheowah. There remains a scattered cemetery to this day.
- Army surveyors often didn't go deep into the back country to survey all Cherokee town sites like they were required because of the danger. Thus, they may have categorized settlements on Buffalo Creek, Tallulah Creek, or at Cheowah based on pure conjecture.
- The name of Yellow Creek may have been derived from a secret goldmine that supplied wealth to the entire Cherokee nation.
- "No doubt there was a town site."
- Cherokee towns went right along creeks; were long and narrow; were in open, rolling areas that would have been good for agricultural use.
- Wacheaucha Trail runs from the old cemetery on Caringer Road (behind which are scattered Cherokee graves), over a log bridge, up to Wacheaucha Bald where there is a rock with Indian writing on it. This may be the location of Junaluska's mother's grave.

Personal Communication – Magnuson, Tom, historic trail researcher

Interviewers: Katy Betz, through emails

Subject of Interview: Stream ford locations in Yellow Creek

Summary: Email correspondence describing how to find ancient trails and stream fords

Transcript:

In areas of heavy undergrowth, where stream banks are choked, Indians and frontier Europeans generally stayed near ridge crests. In the mountains many (perhaps most) trails stayed near creek banks as the streams were shallow enough to allow the use of the stream as a trail when the banks were impassable. If you are working along Yellow Creek Rd, then you are probably on a wagon road but not necessarily on the Indian footpath or subsequent packhorse trail. That may actually be farther into the floodplain. Even the earliest wagon road may be closer to the creek than is the paved road.

Just south of the town of Yellow Ck, on an ortho can be seen what appears to be an overgrown old "sunken road." If that is in fact what I'm seeing, it was probably part of the unpaved, wagon version of Yellow Ck Rd. In fact, scrolling east and west along Yellow Ck Rd indicates that the old roadbed is between the paved road and the creek.

I will need to play with some old maps to have any idea of the antiquity of the Yellow Ck valley rd. My guess is that it was an important trail for a long time as the valley is pretty much unobstructed; great farm land, and connects important n-s avenues.

On the orthos I'm using it appears that Yellow Crk has fairly deep banks. If the banks are over a couple of feet high, if the shores are not sloped into the creek so that you can walk right in anywhere, then the method for getting into and out of the creek (for fording of men or horses) would have been to enter and exit by feeder creeks. I look for opposing feeder creeks to find a regular fording point. They each throw down gravel and thus make a shallow spot all the way across the stream to be forded. You can frequently find the cut in the feeder creek bank where travelers regularly entered or exited from the ford. It will be as far up the feeder as is needed to comfortably step into the creek. Most people and horses with burdens are uncomfortable taking a step of over two feet into an invisible bottom, so the ideal entry is one where you can 1) see the bottom, and 2) enter on a gentle slope with no step or almost no step at all.

There are frequently regularly used camp sites near the feeder creek entry; if the stream to be forded is in flood, the travelers would wait out the flood at the ford if it wasn't going to take too long.

Each side of most streams had trails that went from ford to ford. That way if one ford was flooded the traveler could move upstream to a shallower more practical ford. When people traveled on foot or horseback there was little cost, if any, in maintaining these parallel trails but wagon roads are expensive to maintain and one result was that the county courts chose which side of a creek would get the road, or the road would meander

back and forth over the stream but you'd sill only have one option where previously you almost always had two options about how to move up or down stream.

I'll look at some old maps.

# DISCARDED BOTTLES AS A SOURCE OF SMALL MAMMAL DISTRIBUTIONAL DATA ALONG THE SOUTHERN BLUE RIDGE ESCARPMENT

# MELISSA A. BURT

*Abstract.* Small mammal remains were collected from discarded bottles at 90 sites along the Blue Ridge Escarpment to examine elevational gradients in the distribution of two species of shrews, the Masked Shrew (*Sorex cinereus*) and the Southeastern Shrew (*S. longirostris*). Although insufficient data were collected to determine distributional overlap in these species, results are consistent with the findings of previous studies suggesting that these species are allopatric in this region. Relatively large numbers of open bottles were found at nearly every site, with greater than 74% of the sites yielding small mammal specimens. Approximately 5.2% of the open discarded bottles on the mortality of small mammals are discussed.

Key words: Blue Ridge escarpment, bottles, mammals, shrews, Sorex cinereus, Sorex longirostris, southern Appalachians

### INTRODUCTION

The phenomenon of small mammals becoming trapped in discarded open bottles was first described in England in the 1960s (Morris and Harper 1965, Clegg 1966). Small mammals often found in discarded bottles include a variety of species of shrews and rodents (Gerard and Feldhamer 1990). In their search for food, water, or shelter these small mammals may enter the bottle and become trapped. They may also be attracted to the scent of the contents of the bottle (Benedict and Billeter 2004). Animals may be unable to escape an open bottle for a variety of reasons. If the bottle is oriented with its opening facing upslope on a steep incline, an animal may have trouble climbing out of the bottle on the slippery plastic or glass surface of the container (Benedict and Billeter 2004). Many bottles may also be partially filled with rainwater, resulting in the trapped animal's death from drowning (Benedict and Billeter 2004).

The remains of small mammals collected from discarded open bottles can be used to examine distributions of individual species. Such data have been used to determine the ranges of Northern Short-tailed Shrew (*Blarina brevicauda*) and the Southern Short-tailed Shrew (*B. carolinensis*) in Virginia (Pagels and French 1987). These species were found to be allopatric throughout most of the state, but several new locations were identified where distributional overlap occurred (Pagels and French 1987). Using that study as a model, our primary objective was to delineate the potential distributional overlap of two largely allopatric species of shrews, the Masked Shrew (*Sorex cinereus*), and the Southeastern Shrew (*S. longirostris*), along an elevational gradient of the Blue Ridge escarpment.

The Blue Ridge escarpment region lies in the mountainous area of western North Carolina, northeastern Georgia, and northwestern South Carolina. It is characterized by a sharp decline in elevation over a relatively short distance from north to south (Ford et al. 2001). Elevational gradients within this geographic range, coupled with a variety in habitat types, result in a large diversity of small mammal species (Johnston 1967). Relictual northern species, which are often habitat specialists, occur at high-elevation boreomontane habitats of North Carolina,

while other species may be found at a wider range of elevations (Laerm et al. 1995, 1999). Much of the mountain habitat in South Carolina and Georgia is characterized by xeric mixed oak and pine communities (Laerm et al. 1995). Shrews such as *B. brevicauda* and *Sorex fumeus* and rodents such as *Peromyscus leucopus* and *P. maniculatus* are widespread in the region, while other species such as *S. cinereus* and *S. longirostris* occur in close geographic proximity but rarely sympatrically (Johnston 1967, Mengak et al. 1987, Laerm et al. 1999, Ford et al. 2001).

In a long term study involving extensive pitfall trapping, Ford et al. (2001) found that Masked Shrews and Southeastern Shrews exhibit contiguous allopatry based on elevation and habitat associations. *Sorex cinereus* was found at elevations above 2018 ft (615 m) almost exclusively in mesic hardwood and montane streamside forests. *Sorex longirostris* was found to occur mostly at elevations below 3028 ft (923 m) in primarily xeric upland hardwood and pine forests (Ford et al. 2001). Similar observations were made in western Virginia by Pagels and Handley (1989).

In addition, this study examines the general impacts of littering on the mortality of small mammals. Large numbers of discarded bottles along roadsides may pose a potentially serious conservation threat (Pagels and French 1987, Benedict and Billeter 2004). Our second objective was therefore to quantify the number of open bottles that serve as potential traps, as well as the number of deaths caused by entrapment in such bottles and the variety of small mammal species that become entrapped.

### METHODS AND MATERIALS

Bottles were collected from sites along roadsides at overlook and pull-off areas near Highlands, North Carolina and the surrounding region in the autumn of 2007. This included sites in Macon, Jackson and Transylvania Counties in NC; Oconee and Pickens Counties in SC; and Rabun County in GA. Most sites were located along primary highways including Hwy 28 S, Hwy 441, Hwy 107, and Hwy 281, although several other secondary roads were also included for supplemental site data including War Woman Rd., Hwy 130 S, Hwy 76E and Hwy 11. Sites were chosen based on their location along the potential range of *S. cinereus* and *S. longirostris*. Many sites were located along the area in which the elevational distributions of *S. cinereus* and *S. longirostris* could potentially overlap (around 2000 ft; Ford et al. 2001). A large study area was used because it covered a greater extent of the range of these two shrew species.

These roads were also selected because they carry a higher volume of traffic which should result in a greater amount of discarded bottles, and overlook and pull-off areas were used as study sites for accessibility reasons and because of the tendency for a greater accumulation of bottles in such places. Latitude, longitude and elevation at each site were obtained and logged with a Garmin eTrex Legend<sup>®</sup> HCx GPS unit and were plotted on a road and county coverage map using ArcGIS (ESRI 2005). A general description of the habitat at each site was also recorded.

Bottles at each site were located visually by walking roadsides and adjacent forested areas. Plot size varied according to site conditions such as slope steepness and thickness of the vegetation. The search area was generally limited to 100 meters long, but bottles were collected as far into the woods from the shoulder of the road as they could be found.

Both the number of open bottles and the number of bottles with caps were counted during the search. Open bottles, which function as potential traps (Clegg 1966), were examined for animal remains. Bottles that appeared to hold vertebrate material usually also contained water,

dirt, and invertebrates such as carrion beetles and had a foul smell. Those bottles were emptied in the field, and any skulls or other bones were extracted and placed in a resealable plastic bag marked with the site number, date, and general locality information (i.e. state, county, road name). The number of bottles containing remains and the number of specimens removed were also recorded.

Skulls were returned to the Highlands Biological Station for examination with the aid of a stereoscope. Small mammal specimens were identified to species by dentition and other distinctive skull characteristics (Caldwell and Bryan 1982, Pivorun et al. 2006). Other animal remains such as those of reptiles and amphibians were identified using various field guides (e.g., Conant and Collins 1998) and comparative anatomy.

# RESULTS

Of the 90 sites examined in this study, 23 sites were located in Macon County, NC; 20 sites were located in Jackson County, NC; six sites were located in Transylvania County, NC; 18 sites were located in Rabun County, GA; 22 sites were located in Oconee County, SC; and one site was located in Pickens County, SC (Fig. 1). The sites used in this study ranged in elevation from 910 to 4257 ft (277 to 1297 m). A total of 4150 bottles were examined, and the majority of these were located far from the shoulder of the road down steep embankments and deep into the woods. Of this total, 2289 bottles (55.2%) were open and served as potential traps with an average of 25.4 open bottles occurring at each study site.

Bottles containing animal remains were found at 67 (74.4%) of the sites (Fig. 1) with a mean of 2.5 specimens per site (range = 0 to 12). Of the 2289 open bottles, 118 (5.2%) contained animal remains. Glass bottles generally lacked caps and collected more animals than plastic bottles. Specimens were collected most often from bottles that were facing upslope and contained water. In addition, multiple specimens (mean = 1.9) were often collected from individual bottles containing remains, especially from large ones such as two-liter soda bottles. For example, the largest number of species was three. Many of the bottles found in this study appeared to have been left undisturbed for a long period of time based upon the design of the bottles and their labels. Glass Clorox<sup>®</sup> bottles, two liter soda bottles with metal caps, and a glass milk bottle were among these older bottles found. Many of the bottles had become buried due to the length of time they had been on the roadside at the study site.



FIG. 1. Map of study site locations. Sites containing bottles with remains are denoted by a black circle. Sites denoted by an open circle with a small dot are those where remains were not found.

In this study a total of 220 mammal specimens were collected, consisting of 4 species of shrews and 4 species of rodents (Table 1). The most prevalent species found was the Northern Short-tailed Shrew, *B. brevicauda* (n=130, or 57.8% of the total captures). In addition to having the highest incidence of capture, *B. brevicauda* also was collected at the greatest number of study sites (n=44 or 48.9%) and was the most widely distributed with an elevational range of 1338 to 4257 feet (408 to 1297 m) (Fig. 2a), consistently collected from mesic hardwood forest habitats.

Other species of shrews found were the Smoky Shrew (Sorex fumeus; n=46), the Masked Shrew (*S. cinereus*; n=11), and the Southeastern Shrew (*S. longirostris*; n=3). Sorex fumeus was collected at 27 (30.0%) of the sites and was also widely distributed (Fig. 2b). These specimens were found at sites ranging in elevation from 1471 to 3788 ft (449 to 1155 m). Sorex cinereus was found at 8 sites ranging in elevation from 2943 to 4257 ft (897 to 1297 m), whereas *S. longirostris* occurred at 3 sites ranging in elevation from 1540 to 2387 ft (469 to 728 m) (Fig. 2d). In addition to being found within mature, moist forest habitats with Smoky Shrews and Masked Shrews, Southeastern Shrews were also found in more xeric, pine-dominated habitats.

Rodents included the White-footed Mouse (*Peromyscus leucopus*; n=18), the Deer Mouse (*P. maniculatus*; n=5), the Eastern Harvest Mouse (*Reithrodontomys humulis*; n=5), and the Woodland Vole (*Microtus pinetorum*, n=2). *Peromyscus leucopus* specimens were collected at 11 (12.2%) of the study sites, which ranged in elevation from 1409 to 3685 ft (429 to 1115 m) (Fig. 2c). *Peromyscus maniculatus* specimens were collected at five (5.6%) of the study sites ranging in elevation from 2216 to 3498 ft (675 to 1066 m) (Fig. 2c). Both *Peromyscus* species were found in a variety of habitat types ranging from mesic hardwood forest to rhododendron

thickets to xeric, mostly pine-dominated stands. *Microtus pinetorum* specimens were collected at only two (2.2%) sites at elevations of 2908 ft (886 m) and 2224 ft (678 m), and *Reithrodontomys humulis* was found at one site in Oconee County, SC at 1676 ft (511 m) in elevation (Fig. 2c).

In addition to small mammal species, two species of salamanders, the Southern Redbacked salamander (*Plethodon serratus*; n=1) and the Southern Gray-Cheeked salamander (*P. metcalfi*; n=3), and one species of snake, the Eastern Wormsnake (*Carphophis amoenus*; n=1) were also collected from bottles (Table 1), although these mostly consisted of skeletal fragments. In addition to the small mammal, amphibian, and reptile species captured in bottles, a variety of invertebrates such as earthworms, snails, beetles, and millipedes were also found in large numbers at each site.

Species Collected Common Name		Common Name	Total Captured	Percent of Total Captures (%)	Number of Site Occurrences	Percent of Total Sites (%)	
Mammalia	1						
Soi	ricidae						
	Blarina brevicauda	Northern Short-tailed Shrew	130	57.8	44	48.9	
	Sorex cinereus	Masked Shrew	11	4.9	8	8.9	
	S. fumeus	Smoky Shrew	46	20.4	27	30.0	
	S. longirostris	Southeastern Shrew	3	1.3	3	3.3	
Mu	ıridae						
	Microtus pinetorum	Woodland Vole	2	0.9	2	2.2	
	Peromyscus leucopus	White-footed Mouse	18	8.0	11	12.2	
	P. maniculatus	Deer Mouse	5	2.2	5	5.7	
	Reithrodontomys humulis	Eastern Harvest Mouse	5	2.2	1	1.1	
Reptilia							
Co	lubridae						
	Carphophis amoenus	Eastern Wormsnake	1	0.4	1	1.1	
Amphibia							
Plethodontidae							
	Plethodon metcalfi	Southern Gray-cheeked Salamander	3	1.3	3	3.3	
	P. serratus	Southern Red- backed Salamander	1	0.4	1	1.1	

TABLE 1. Diversity of small mammal, reptile, and amphibian species found at a total of 90 sites. A total of 225 vertebrate specimens were collected.



FIG. 2. Distribution of small mammals based on specimens collected in bottles: (a) *Blarina brevicauda* (black circle); (b) *Sorex fumeus* (black circle); (c) Rodents: *Peromyscus leucopus* (triangle), *P. maniculatus* (star), *Microtus pinetorum* (circle), and *Reithrodontomys humulis* (square); (d) *Sorex cinereus* (circle) and *S. longirostris* (triangle).

### DISCUSSION

One of the objectives of this study was to examine the distributions of *S. cinereus* and *S. longirostris*. These species have been found to be contiguously allopatric along elevational and habitat gradients (Ford et al. 2001). Although there were insufficient data to delineate range overlap in this study, specimens of these two species were collected at elevations and habitats consistent with Ford et al. (2001). Masked Shrews were found only at elevations above 2943 ft (897 m), while Southeastern Shrews were only found at elevations below 2387 ft (728 m) outside of North Carolina. Moreover, Masked Shrews were collected only from mesic hardwood habitats, while Southeastern Shrews were additionally collected from xeric pine-dominated stands. Further collections of bottles with more specimens of *S. cinereus* and *S. longirostris* could yield more data on the potential distributional overlap zone of these species. As demonstrated in this study, other shrews, such as *B. brevicauda* and *S. fumeus*, are found

throughout the Blue Ridge escarpment. Likewise, most rodents, such as *P. leucopus*, *P. maniculatus*, and *M. pinetorum* are also widespread, while others such as *R. humulis* are restricted to lower elevations (Johnston 1967, Laerm et al. 1999).

Although many species of vertebrates may become trapped in open bottles, larger species of shrews, such as *B. brevicauda* and *S. fumeus*, are more frequently collected than other small smaller species of shrews, amphibians and reptiles (Benedict and Billeter 2004). As observed in previous studies (Pagels and French 1987, Gerard and Feldhamer 1990, Benedict and Billeter 2004), *B. brevicauda* was the most common and widespread small mammal collected, which is likely the result of its abundance in forest-floor leaf litter, poor vision, tunneling behavior, and use of echolocation while foraging (Gould et al. 1964). When viewed with echolocation, the opening of a bottle may resemble a tunnel entrance (Benedict and Billeter 2004). Shrews such as *B. brevicauda* also have high metabolic water turnover rates (Getz 1961), and may enter bottles in search of standing water and perish by drowning (Clegg 1966).

Although small species of *Sorex* may be naturally less abundant in southern Appalachian forests than *B. brevicauda* (Laerm et al. 1999), the lower numbers of specimens collected in bottles likely under-represent actual population sizes (Pagels and French 1987, Gerard and Feldhamer 1990, Benedict and Billeter 2004). Depending on their shape, most bottles when lying horizontally often have their openings too high for small shrews to accidentally enter (Gerard and Feldhamer 1990). Small *Sorex* species also have a better ability to jump (MacLeod and Lethiecq 1963) and escape through the narrow opening of a bottle than the larger *B. brevicauda* and *S. fumeus* (Benedict and Billeter 2004). Additionally, the small bones of *Sorex* species or salamanders may decompose faster, be scavenged, or be more easily overlooked than those of larger shrews and rodents (Benedict and Billeter 2004).

Small mammals are most commonly collected using pitfall traps, snap traps, or Sherman live traps (MacLeod and Lethiecq 1963, Williams and Braun 1983, Laerm et al. 1999, Ford et al. 2001). These are sometimes advantageous in comparison to discarded bottles in that the trapping period is known (Gerard and Feldhamer 1990). However, pitfall traps frequently capture large numbers of nontarget animal species (Gerard and Feldhamer 1990). In addition, these methods require a great deal of time and labor whereas data from bottles, as our study demonstrates, can be obtained in a very short period of time (Pagels and French 1987). The use of discarded bottles as a source of small mammal distributional data can be particularly valuable, especially for *B. brevicauda*, and make return visits to a site unnecessary (Pagels and French 1987, Gerard and Feldhamer 1990). Data from small mammals collected in bottles are limited only by the geographic area sampled and the diversity of species (Pagels and French 1987).

Our results are consistent with those of Benedict and Billeter (2004), who found that glass bottles collected more vertebrate specimens than plastic ones. Whereas caps remained on most plastic bottles, glass bottles were generally open and represented a greater percentage of the potential traps. Glass also provides less traction than plastic, especially when the bottle is oriented facing up a steep slope (Benedict and Billeter 2004). Also, plastic bottles weigh less than glass bottles and are more easily moved or rolled so that the animal can escape (Benedict and Billeter 2004). Unlike glass, plastic is also capable of being chewed through by small mammals.

In the mountainous terrain of the southern Appalachians, discarded bottles frequently end up at the bottom of steep wooded ravines far away from the shoulder of the road. Such bottles are often overlooked or ignored by litter cleanup crews (Benedict and Billeter 2004). As a result, accumulated bottles may function as traps for an extended length of time. Many of our vertebrate specimens were extracted from bottles that were years or even decades old as indicated by the design of the bottle, or clues on its label such as movie-related promotional logos and sell-by dates.

If bottles have been trapping small mammals in an area for a significant period of time, a specimen could serve as an important record of its historical range, and could be used to track any changes in its distributions such as those associated with habitat alteration or competitive exclusion. Unfortunately, there is no way to determine exactly when during that period that the animal was captured (Gerard and Feldhamer 1990), for an old bottle can capture a recent specimen. More important are the conservation implications of discarded bottles that could serve as potential traps for animals almost indefinitely. Relatively large numbers of open bottles were found at nearly every site, and greater than 74% of the sites yielded vertebrate specimens. The capture rate in our study exceeded 5%, which is higher than those of other studies (Pagels and French 1987, Benedict and Billeter 2004).

Our research demonstrates the effectiveness of examining discarded bottles as a source of small mammal data. Although the phenomenon of small mammals being captured in bottles is well known by mammalogists, this study is one of only a few on the subject in North America (Pagels and French 1987, Gerard and Feldhamer 1990, Benedict and Billeter 2004), and only the second to use bottles as a survey technique in an examination of small mammal species distributions (Pagels and French 1987). This study illustrates that litter has impacts beyond aesthetics. As additional discarded bottles continue to accumulate over the years, the numbers of trapnights represented could pose a serious threat to small mammals in the southern Appalachians, especially to species which may be threatened or rare.

### ACKNOWLEDGEMENTS

I would like to thank my mentor Patrick Brannon, Director of the Highlands Nature Center, for his help with this study. Additionally, I would like to thank Gary Wein, Executive Director of the Highlands Cashiers Land Trust for his contribution to the maps in this paper. I would also like to thank Anya Hinkle and Jim Costa for their contributions in the editing of this paper.

#### 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.
- Caldwell, R.S., and H. Bryan. 1982. Notes on distribution and habitats of *Sorex* and *Microsorex* (Insectivora: Soricidae) in Kentucky. Brimleyana **8**:91-100.
- Clegg, T.M. 1966. The abundance of shrews, as indicated by trapping and remains in discarded bottles. Naturalist Hull **899**:122.
- Conant, R. and J.T. Collins. 1998. A Field Guide to Reptiles and Amphibians: Eastern/Central North America. Houghton Mifflin Company, New York, New York, USA.
- ESRI, Inc. 2005. ArcMap 9.1. Redlands, CA.
- Ford, W.M., M.A. Menzel, T.S. McCay, and J. Laerm. 2001. Continuous allopatry of the masked shrew and southeastern shrew in the Southern Appalachians: segregation along an elevational and habitat gradient. The Journal of the Elisha Mitchell Scientific Society 117:20-28.
- 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.
- Getz, L.L. 1961. Factors affecting the local distribution of shrews. American Midland Naturalist 65:67-88.
- Gould, E., N. Negus, and A. Novick. 1964. Evidence for echolocation in shrews. Journal of Experimental Zoology **156**:19-38.

- Laerm. J., E. Brown, M.A. Menzel, A. Wotjalik, W.M. Ford, and M. Strayer. 1995. The masked shrew, Sorex cinereus (Insectivora:Soricidae), and red-backed vole, Clethrionomys gapperi (Rodenta: Muridae), in the Blue Ridge Province of South Carolina. Brimleyana 22:15-21.
- Laerm, J., W.M. Ford, T.S. McCay, M.A. Menzel, L.T. Leopard, and J.L. Boone. 1999. Soricid communities in the Southern Appalachians. Pages 177-193 in R. Eckerlin, editor. Proceedings of the Appalachian Biogeography Symposium. Virginia Museum of Natural History Special Publication Number 7.
- Johnson, D.W. 1967. Ecology and distribution of mammals at Highlands, North Carolina. The Journal of the Mitchell Society 83:88-98.
- MacLeod, C.F., and J.L. Lethiecq. 1963. A comparison of two trapping procedures for *Sorex cinereus*. Journal of Mammalogy 44:277-278.
- Mengak, M.T., D.C. Guynn, J.K. Edwards, D.L. Sanders, and S.M. Miller. 1987. Abundance and distribution of shrews in western South Carolina. Brimleyana 13:63-66.
- 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 distribution data. American Midland Naturalist **118**:217-219.
- Pagels, J.F., and C.O. Handley. 1989. Distribution of the southeastern shrew, Sorex longirostris Bachman, in western Virginia. Brimleyana 15:123-131.
- Pivorun, E., M. Harvey, F. van Manen, M. Pelton, J. Clark, K. Delozier, and B. Stiver. 2006. Interactive CD Guide to the mammals of Great Smoky Mountain National Park: images, skulls, and information (CD-ROM). GSMNP Interactive CD Series, Clemson University Department of Biological Sciences, Clemson SC.
- Williams, D.F. and S.E. Braun. 1983. Comparison of pitfall and conventional traps for sampling small mammal populations. Journal of Wildlife Management **47**:841-845.

# JACKSON COUNTY HILLSIDE DEVELOPMENT ORDINACE AND ITS IMPLICATIONS FOR LAND CONSERVATION

# BRIAN R. HOUSEMAN

Abstract. On August 6th, 2007 the Jackson County Board of Commissioners enacted one of the most stringent steep-slope ordinances of western North Carolina - The Mountain and Hillside Development Ordinance of Jackson County, North Carolina. In the interests of land conservation towards sustainable mountain development, this paper seeks to quantify the amount land in Jackson County that will be affected by this ordinance. An analysis of Macon County slopes was also performed in order to conduct a similar assessment of roughly how much land would be development-restricted if a similar ordinance were adopted in that county. A digital elevation model derived from LIDAR (Light Detection and Ranging) data was reclassified into maps of both slope and aspect. Working with the Highlands-Cashiers Land Trust, I identified larger, privately owned parcels that have not yet been developed. Under the restrictions of this ordinance, the larger undeveloped parcels have the greatest chance of at least partly becoming a conservation easement. This paper assesses the impact that Jackson County's new ordinance will have on the availability of land for development in the future.

Key words: digital elevation model; GIS; Jackson County, NC; land conservation; lot density; mountain and hillside development ordinance; slope analysis.

### INTRODUCTION

The Mountain and Hillside Development Ordinance of Jackson County, North Carolina is one of the most extensive mountain and hillside development ordinances in western North Carolina. Within Jackson County's ordinance, improper development is said to have the potential to: (a) endanger the quality of surface water by increasing erosion, stream sedimentation, and storm water runoff; (b) induce landslides; (c) adversely affect ground water due to the difficulty in providing proper sewage disposal; (d) damage the habitat for some species of wildlife (both plants and animals); and (e) detract from the scenic and natural beauty which is vital to the recreation and tourism industry of Jackson County (JCBC 2007). An interesting part of this ordinance is the lot density limits that restrict the number of lots per acre. The exact limits to lot size for development in accordance with the ordinance have been outlined in Table 1. The slope classes governed by the Jackson County ordinance were chosen because steep hillsides and thin soils are inherently unstable (JCBC 2007). These limits are set forth not only for aesthetic purposes, but also for the protection of public health, safety, welfare, and economic progress of Jackson County (JCBC 2007).

Sustainable development of steep mountain slopes is a legislative issue that must be confronted on the local level. As outlined in the United Nations Agenda 21 (UNDSEA 1992), mountain slopes are susceptible to accelerated soil erosion, landslides and rapid loss of habitat and genetic diversity. Since complete preservation of these slopes is unlikely, a mountain and hillside development ordinance seeks to strike a compromise in the best interests of the general public. Olshansky's (1998) study on the history of hillside ordinances found that 75% of a 190

ordinance sample in the United States emphasized the protection of scenic quality. Furthermore, 71% of hillside development ordinances in the United States recognized the natural phenomena of the land, such as mountain slope and aspect, while 64% promoted public safety as reasons for hillside development regulation (Olshansky 1998). Jackson County's hillside development ordinance identifies with all three of the major objectives typical of similar ordinances in the United States: protection of aesthetic views, protection of unique ecological values, and insurance of public safety. No matter the reasons for adopting such an ordinance, new laws against steep slope development will have a significant impact on conservation and development within Jackson County, NC.

In this paper I will interpret the distribution of slope within Jackson and Macon Counties, and its implications for conservation and sustainable development. I derived the percentages of land within county and individual parcels that are restricted by this ordinance. The distribution of slope within each parcel class was mapped in order to graphically represent the fact that smaller parcels, on average, exhibit shallower slopes than those of larger parcels. The identification of these larger, typically steeper parcels is a springboard for pinpointing possible conservation easements. It is hoped that the method of slope analysis applied within the parameters of this paper will prove to be a useful tool for a similar examination of land conservation.

Slope Class	Average Slope of Lan Subdiv	d to Be Developed or vided	Minimum Lot Size (in	Maximum Density (lots per acre)	
	Degrees	Percent	ucresy		
1	0-16.7°	0-29%	exempt	exempt	
2	16.7 - 19.3°	30-34%	2	0.5	
3	19.3 - 21.8°	35-39%	2.5	0.4	
4	21.8-24.2°	40-44%	5	0.2	
5	$24.2^{\circ}$ or more	45% or more	10	0.1	

TABLE 1. Lot density requirements as defined by the Mountain and Hillside Development Ordinance of Jackson County, NC

### MATERIALS AND METHODS

All maps created in this study were derived using ArcMap<sup>TM</sup> 9.1 (ESRI 2005). Original LIDAR DEM maps were obtained freely from the North Carolina Geologic Survey. Digital elevation models (DEM) for both Jackson and Macon Counties, North Carolina, were converted into maps of slope in degrees, and again in percent. Parcel data for Jackson and Macon County was obtained from Dr. Gary Wein and the Highlands-Cashiers Land Trust, and can be found in the online GIS database for both of those counties.

The slope classes used in this study were the same as outlined in the Jackson County ordinance: 0-29%, 30-34%, 35-39%, 40-44%, and 45% or more. However, slope class 1, 0-29%, is not governed by the restrictions of the ordinance. To determine the percentage of county lands that fall under the restrictions of these slope classes a simple reclassification of the DEM maps for both counties was performed within ArcGIS (ESRI 2005).

In addition, I used county parcel data, which is a map of all property lines in the county, to determine how much of each parcel is in a particular slope class. For example, one can select a single 100 acre parcel and charted how much of the land within its boundary is 0-30% slope,

how much is 30-34% slope, and so on. The degrees slope map was reclassified into 5 degree increments.

The parcel classes from Jackson County's hillside development ordinance (2-2.49, 2.5-4.99, 5-9.99, 10-99.99, and  $\geq$  100 acres) were applied to the slope map. Larger parcels that are currently withheld from development such United States Forest Service (USFS), The Nature Conservancy, State of North Carolina, Land Trust, or similar conservation plots were excluded from this analysis. For the 100 acre or greater parcel sets, a 20-parcel systematic sample was taken for Macon, and again for Jackson. An analysis of slope within each individual parcel was recorded, and then all acreages and percentages within each slope class were averaged. For those parcels less than 100 acres, the average slope distribution within each parcel class was derived using all parcels within their respective classes. For example, the slope distribution of parcels 2 – 2.49 acres in area was averaged using all parcels of this size instead of a systematic random sample. The distribution of slope within each parcel class was mapped (Appendix A) and graphically summarized in Figs. 2 and 3.

### RESULTS

Roughly 68% of Jackson County lands fall under the building restrictions (slope classes 2-5) of that county's new development ordinance (Table 2). On average, 40% of Jackson County parcels over 100 acres are comprised of 45% slope land or more (Fig. 2). 2-2.49 acre parcels are comprised of 10% less of the steepest slope class than 100 acre parcels (Fig. 2). Therefore, there appears to be a positive correlation between parcel size and the average slope of that parcel (see Appendix A for maps). The topography of Macon County, NC represents a trend similar to Jackson County. However, a slightly larger percentage of Macon County is categorized into slope class one. About 64% of the lands in Macon County would be governed by a hillside development ordinance similar to the one already adopted by Jackson County. More specifically, 38% of Macon County slopes would be restricted to just one lot for every 10 acres. Additionally, Fig. 3 shows that roughly 40% of sampled 100 acre parcels lay within slope class 5, which is 20% more than a 2 - 2.49 acre parcel. Similar to Jackson County, larger parcel

Although not represented graphically, smaller parcels in both Jackson and Macon Counties also show a positive correlation with development – the smaller the parcel, the greater chance it will have already been developed. Therefore, the larger, steeper parcels within both Jackson and Macon County are of special importance because they have the lowest likelihood of having been developed - thus greater chances that the land shares similar characteristics with that covered by existing conservation easements in both counties. Of course this correlation could be an artifact, or effect, of large-parcel owners curving off smaller lots for sale – in other words, small lots are often created specifically to be developed.



FIG 1. Slope gradient within the study area, Jackson and Macon Counties, NC

TABLE 2. Proportion of Jackson and Macon County (NC) lands within each slope class. Excludes USFS lands and other private or public owned conservation parcels

Slope Distribution on County Lands						
Slope Class	Slope Class Slope Jackson County Macon County					
1	0-29%	32.24%	35.59%			
2	30-34%	8.53%	8.39%			
3	35-39%	9.00%	8.66%			
4	40-44%	9.15%	8.72%			
5	45% or more	41.09%	38.63%			



FIG 2. Slope distribution relative to parcel acreage. Jackson County, NC



FIG 3. Slope distribution relative to parcel acreage. Macon County, NC

TABLE 3. Example of area calculations regardless of parcel distributions. Jackson County, NC

Percent slope (%)	Raster cells (20x20ft)	Square feet	Area (acres)	Area (hectares)	Percent of Jackson County lands
0 to 29	11117111	4446844400	102085.50	41312.54	32.24%
30 to 34	2940827	1176330800	27004.84	10928.47	8.53%
35 to 39	3103911	1241564400	28502.40	11534.51	9.00%
40 to 44	3154348	1261739200	28965.55	11721.94	9.15%
<u>&gt;</u> 45	14170864	5668345600	130127.31	52660.65	41.09%

TABLE 4. Example of area calculations regardless of parcel distributions. Macon County, NC

Percent slope (%)	Raster cells (20x20ft)	Square feet	Area (acres)	Area (hectares)	Percent of Macon County lands
0 to 29	12888846	5155538400	118354.88	47896.52	35.59%
30 to 34	3038788	1215515200	27904.39	11292.51	8.39%
35 to 39	3137703	1255081200	28812.70	11660.09	8.66%
40 to 44	3158611	1263444400	29004.69	11737.78	8.72%
<u>&gt;</u> 45	13991121	5596448400	128476.78	51992.71	38.63%

TABLE 5. Distribution of slope class within each parcel class. Jackson County, NC

	Parcel Class (acres)					
Slope Class	<u>&gt;</u> 100	10 - 99.99	5 - 9.99	2.5 - 4.99	2 - 2.49	
1	35.66%	42.05%	53.16%	56.07%	57.19%	
2	7.89%	8.96%	9.21%	9.10%	9.21%	
3	8.52%	8.93%	8.39%	8.04%	8.01%	
4	8.99%	8.65%	7.55%	6.93%	6.74%	
5	38.93%	31.41%	21.69%	19.85%	18.85%	

TABLE 6. Distribution of slope class within each parcel class. Macon County, NC

	Parcel Class (acres)					
Slope Class	<u>&gt;</u> 100	10 - 99.99	5 - 9.99	2.5 - 4.99	2 - 2.49	
1	35.66%	42.05%	53.16%	56.07%	57.19%	
2	7.89%	8.96%	9.21%	9.10%	9.21%	
3	8.52%	8.93%	8.39%	8.04%	8.01%	
4	8.99%	8.65%	7.55%	6.93%	6.74%	
5	38.93%	31.41%	21.69%	19.85%	18.85%	

# DISCUSSION

### Conditions of the Ordinance

It is important to note that Jackson County's new ordinance does not exclude land from development; it only serves to guide development through environmentally and sociologically sound principles. The explicit intent of this ordinance is "to encourage a sensitive form of development and to allow for a reasonable use that complements the natural and visual character of the community" (Jackson County Board of Commissioners, 2007). One interesting aspect of the ordinance can be found within section 8 concerning exemptions. The conditions for exemption from the ordinance include: agriculture and forestry, landscape maintenance, additions to single-family residences, existing lots of record, prior development plan approval, and non-regulatory lots. All of these exemptions, of course, have explicit wording that governs exemption claims by land owners/developers. A lot is defined as non-regulatory if it is not within the defined boundaries of the Mountain and Hillside Development District, or if the average slope of the lot is below 30 percent. The Mountain and Hillside Development District is

that portion of the county outside of the jurisdiction of the various municipalities and the Qualla Reservation (JCBC, 2007). Numerous routes of exemption to Jackson County's hillside ordinance are possible. Therefore, the mapping process derived within this study seems to serve the broader purpose of identifying possible conservation parcels on the basis of slope; while subjecting those selected parcels to exemption requirements could help land owners realize the advantageous of a conservation easement.

# **Conservation Easements**

One of the most important questions to address is the likelihood of setting aside large amounts of land for the conservation of ecosystems. The answer may lie in the amount of area that could possibly be consolidated into a conservation easement. Due to the implications of this ordinance on building and grading in an area of steep slopes, it may be more advantageous for the parcel owner to create a conservation easement. Additional complications to subdivision development include the fact that Jackson County's hillside ordinance requires a strictly guided topographic survey, soils report, hydrologic report and plan, and geotechnical analysis and report. Atop the specifications for lot density, Jackson County Subdivision Ordinance adopted August 6, 2007 requires that at least 25% of a subdivision development contain green space (JCBC 2007). Given the number of hurdles and hoops that must be navigated during the development process, less ambitious land owners may be more apt to create a conservation easement as an alternative.

The creation of a conservation easement limits owner usage rights, while simultaneously providing the land owner a tax exemption. For example, one might give up the right to build on his or her land, while also retaining the right to grow crops. If the donation benefits the public by permanently protecting important conservation resources and meets other federal tax code requirements, it can qualify as a tax-deductible charitable donation. The amount of the donation is the difference between the land's value with the easement and its value without the easement.

Although the implications of this new Mountain and Hillside Development Ordinance can seem like a bane to developers, it can be most advantageous for those seeking to protect areas of ecological significance. There is often a debate on whether single large areas should be protected versus several small areas. Deciding on which size reserve can depend on whether you are seeking to maximize species richness or minimizing species extinction (Burkey, T. V., 1989). This study of both Jackson and Macon Counties sheds light on the possibility of protecting those single large parcels, or several smaller parcels that may be more economically beneficial as a conservation easement. Because of the slope restrictions in Jackson County's steep slope ordinance and because of the nature of larger parcels being as of yet undeveloped, conservation efforts by organizations such as the Highlands-Cashiers Land Trust may be better spent in negotiating with large-parcel land owners.

# Development District

The establishment of the Mountain and Hillside Development District in concordance with the Jackson County steep slope ordinance places some parcels outside the bounds of lot density restriction. As defined in Section 6 of the ordinance, the Mountain and Hillside Development District includes lands not within the bounds of USFS property, Qualla Reservation, or municipality lands. Although, this study removed the first two exemptions to the ordinance, the third, municipality lands, was included. However, the acreage within these municipalities does not represent a large portion of the study area. Further analysis of Jackson or Macon County steep slope development is needed to assess the result of excluding municipalities such as Sylva or Franklin, NC from the study area.

Many of the larger parcels located within both Jackson and Macon County are located outside of municipality boundaries. Trends in the data show that as parcel size increases, the average slope of that parcel also increases. Therefore, exclusion of parcels within existing municipalities would reduce the amount of total land within the smaller slope class of 0 - 29%. It stands to reason that of the amount of land that could be subject to the ordinance, a larger portion will likely fall within the steeper of the five slope classes, and thus increase the percentage of county lands subject slope class 4 or 5 restrictions. However, the statistical significance of such a shift can not be substantiated without further analysis of the parcel distribution.

# Conclusion

The Mountain and Hillside Development Ordinance of Jackson County, NC will have a significant impact on land conservation in that county. Adopting a similar ordinance in Macon County, NC would have a similar effect, with slight differences in affected acreage due to the varying sizes of the counties and their respective municipalities. Although outside the bounds of this study, Jackson County's Subdivision Ordinance will likely play a large role in determining the amount of acreage that would experience restricted development rights. Yet it is likely that further research into number of lots per exact acreage of land will yield more conclusive support for the creation of conservation easements on larger parcels.

#### ACKNOWLEDGEMENTS

I thank Dr. Gary Wein for guiding me in the creation of the maps and data for this project. Without Dr. Wein's knowledge of the ArcGIS software, I would not have been able to quantify any of my data. I also thank the North Carolina Geological Survey for providing me with the LIDAR data for Macon County, NC. I acknowledge the editorial assistance of Dr. James Costa and Dr. Anya Hinkle.

#### LITERATURE CITED

- Burkey, T. V. 1989. Extinction in nature reserves: the effect of fragmentation and the importance of migration between reserve fragments. Oikos 55(1):75-81.
- ESRI Inc. (2005) Arc Map 9.1. Redlands, CA.
- Jackson County Board of Commissioners. 2007. Jackson County mountain and hillside development ordinance. http://www.jacksonnc.org
- Jackson County Board of Commissioners. 2007. Jackson County subdivision ordinance. <u>http://www.jacksonnc.org</u> UN Department of Social and Economic Affairs. 1992. Agenda 21.

http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21toc.htm

Olshansky, R. B. 1998. Regulation of hillside development in the United States. Environmental Management 22(3):383-392.

APPENDIX A: Slope class distribution within each ordinance parcel class. Class 1 (0-29%), class 2 (30-34%), class 3 (35-39%), class 4 (40-44%), class 5 (45% or more)



# **APPENDIX B**

Photo Gallery



PICTURE 1: An example of a less than 30% slope



PICTURE 2: An example of a 30 – 34% slope



PICTURE 3: An example of a 35 – 39% slope



PICTURE 4: An example of a 40 – 44% slope



PICTURE 5: An example of a 45% slope or greater.

# DEVELOPING ORDINANCES AND MAPPING THE INAUGURAL SEGMENT OF THE HIGHLANDS GREENWAY SYSTEM

# BRIAN M. LEVO

*Abstract.* At the August 3<sup>rd</sup> Board of Commissioners meeting in 2005, the Town of Highlands Commissioners appointed an ad-hoc Greenways Committee. This committee was charged with the tasks of designing the infrastructure for the town greenway system and developing a comprehensive greenway map. Initial steps to advance the plan involved establishing the spatial layout of the greenway, as well as amending the necessary town codes to ensure the greenway system met legal standards. I assumed the task of developing and proposing these ordinances to the town, relying on town codes from other municipalities as guidelines. I used Geographic Information Systems (GIS) and Global Positioning System (GPS) technologies to map portions of the comprehensive greenway system, digitize future greenway trails, and publicize a Comprehensive Greenway Map for the Town of Highlands. In addition to these maps, this study produced ordinance amendments that have been approved by the Town of Highlands Planning Board, and are pending approval from the Town of Highlands Board of Commissioners.

Key words: GIS; GPS; greenway; mapping; ordinance; Town of Highlands

### INTRODUCTION

Greenway systems are corridors used by a municipality to provide recreation for its citizens while preserving natural areas. Typically greenways serve as connectors of green spaces and public locations, resulting in a scenic, and often time natural, trail network. The greenway trails under development in Highlands, North Carolina, have been designed to both satisfy the public demand for recreation as well as meet the town's objective to conserve the natural landscape.

The original greenway system for the Town of Highlands was outlined in the town's 1989 Land Use Plan as a system that would serve to create trails and connect sites preserved by the Highlands-Cashiers Land Trust (HCLT) (Town of Highlands 1989). By 1995 the greenway system project had unfortunately suffered significant setbacks. As a result the entire project, including the portion of the trail already constructed, was abandoned. The project was not reintroduced again until 2005. At the August 3<sup>rd</sup> Board of Commissioners meeting that year the Town of Highlands commissioners formed an ad-hoc Greenways Committee. The responsibility of the committee was to develop the infrastructure of the new greenways system, and present to the board a comprehensive greenway map. Within the next two years the Greenways Committee had conceptualized the spatial layout of the trails and outlined the political organization necessary to establish the greenway.

Although a comprehensive 'initial loop' of the greenway trail had already been created, there were still two significant portions of the trail located on Big Bear Pen Mountain that required plotting. In this study I used GPS and GIS technologies to plot, digitize, and map the remaining connecting trails. I also researched and developed ordinances necessary to legally establish the greenway's infrastructure. I then presented and received approval of these ordinances from the Town of Highlands Planning Board.

# MATERIALS AND METHODS

The initial loop of the greenway system included the pre-existing greenway trail, established hiking trails, sidewalks, and conceptual trails not yet pioneered or plotted. To complete the conceptualized loop is was necessary to forge new connecting trails on Big Bear Pen Mountain to connect the Kelsey Trail Preserve with Rhododendron Park, and to join Upper Lake Road with the Rhododendron Trail. A Trimble Pathfinder ProXH<sup>™</sup> GPS unit and a range pole were utilized to plot these trails, while flagging was distributed to readily identify the location of the proposed pathways. The primary criterion used to define the pathways was the comparative flow of the trail with the contour of the land. Areas of steep slopes, dense and old growth vegetation, and rock obstructions were avoided. After the GPS data points were collected the trails were digitized using ArcMap 9.1 by ESRI (ESRI Inc. 2005). Maps of the digitized trails were subsequently created in ArcMap. The greenway data layers were then loaded into Manifold System Release 8.0 (Manifold Net Ltd. 2007) GIS software to generate the Town of Highlands Comprehensive Greenway Map, which is available on the town website for citizens to access (http://gis.highlandsnc.org/greenwaymap/default.asp).

The data and structure incorporated into the Greenway Ordinances developed in this project were derived from the adaptation of municipality regulations of various towns across North Carolina. Intensive research, assessment, and ingenuity were required to develop these ordinances, and ensure they were tailored to the interests of both the Town of Highlands and the Greenways Committee. The ordinance regarding Conditional Use Permits was modeled after similar ordinances existing in Cary and Wesley Chapel, North Carolina (Town of Cary 2007, Town of Wesley Chapel 2005). The Minimum Lot Size ordinance is a product of an analogous lot size exemption ordinance currently accessible in the Town of Highlands Land Use Regulations (Town of Highlands 2002). The Setback ordinance was composed at the request of the Town of Highlands Planning Board, and is therefore not modeled after a pre-existing regulation. The Buffer Area ordinance was fashioned from portions of the greenway dimension ordinances from Davidson, NC (Town of Davidson, 2001). The Greenway definition was framed after the Highlands Master Sidewalk Plan in the town ordinances (Town of Highlands 2007). Finally, the specific ordinances outlining approved and prohibited vegetative buffer species were compiled from native vegetation lists provided by commissioner Hank Ross, and the Land Stewards of the Highlands Plateau organization. These lists were also supplemented by native and nonnative vegetation data found in Miller (2003), Nonnative Invasive Plants of Southern Forests: A Field Guide for Identification and Control, and Radford et al. (1968), Manual of the Vascular Flora of the Carolinas. In order to avoid uncertainty, the scientific names of the prohibited species of vegetation, in addition to the common names, were included in the ordinance language. The composition of these ordinances is modeled after a similar native species ordinance in the Highlands Land Use Regulations (Town of Highlands 2007). Upon completion, the ordinances were reviewed by the Town Administrator Richard Betz, the Town Attorney Bill Coward, and the Greenways Committee before their formal proposal. The ordinances were then proposed and approved by the Planning Board on 22 October 2007, and were subsequently presented to the Board of Commissioners on 7 November 2007. The ordinances are currently pending approval, which is anticipated at the meeting on 16 January 2008.

### RESULTS

# Plotted Field Sites and Maps

The preliminary connecting trail that was plotted and digitized links the northern boundary of Rhododendron Park to the eastern boundary of the Kelsey Preserve on Big Bear Pen Mountain (Appendix A). Both the park and the preserve are currently owned by the HCLT, but are scheduled for donation to the Highlands Greenway Committee upon the construction of the initial greenway trail loop. Establishing this connector trail has been vital to the greenway system as it provides a community accessible corridor between the previously founded Kelsey trail and the proposed Rhododendron Trail. Before a connecting path could be plotted, however, an accord had to be reached between the Greenway Committee and one of the town's citizens. The individual agreed to a future donation of a section of property needed for access to the Kelsey Preserve.

The second connecting trail plotted and digitized joins the portion of the greenway designated to Upper Lake Road with the Rhododendron Trail located in Rhododendron Park (Appendix B). This connector, also located on Big Bear Pen Mountain, links the southern portion of Rhododendron Park to the greenway trail passing through the Highlands Biological Station. The trail extends all the way to the HCLT property located at Sunset Rock. By effectively uniting the loop trail, this ensures that the greenway system is not disjointed.

The Town of Highlands Comprehensive Greenway map is comprised of the proposed connecting trails, the existing trail, and the original greenway trail layers provided by the HCLT and the Town of Highlands (Appendix C). The map illustrates the complete greenway loop that the Greenways Committee currently seeks to construct. The trail stretches from the original greenway trail in the west, passes through downtown, and links nearly all of the HCLT properties together in the east side of town. This cartographic data is stored at the Highlands Town Hall, and is posted on the town's website.

# **Developed** Ordinances

The ordinances crafted to acquire political institution of the greenway discuss an assortment of issues (Appendix D). The Conditional Use Zoning ordinance is designed to introduce a technique of land acquisition for the greenway system. In the event a landowner or developer seeks a conditional use permit they will be required to provide an easement should their property coincide with the greenway. The dimensions of this easement, 25-50 feet, are similar to those adopted by several other North Carolina municipalities.

The lot size and setback ordinances (Appendix D) serve to mitigate any penalizing effects of freely dedicating property to the Highlands Greenway. These ordinances modify the current required minimum lot size and the setback regulations to ensure the property owner is in agreement with them post-land dedication. The lot size ordinance reduces the minimum lot size requirements by the amount of the land dedicated, while the setback ordinance eliminates any setback requirements from the dedicated property. Collectively they present further incentive for property-owners to contribute unused or excess land.

A buffer area ordinance (Appendix D) ensures that constructing greenway systems within stream buffers is permissible, providing it does not pose a threat to ecosystem or water quality. The regulation requires a minimum 20-foot native vegetative buffer between the stream and the greenway path. This buffer will protect against harmful runoff, and potential pollution introduced as a result of locating a trail within its proximity. The ordinance also dictates a maximum trail width of 10 feet to discourage excessive impermeable pathways, which could prompt degradation of the ecosystem.

The definition of the Highlands Greenway (Appendix D) serves as a legal identification for the existence of the greenway. Though technically it is not an ordinance, the definition serves an important role by adopting the Town of Highlands Greenway Plan Map as the official record documenting the spatial layout of the greenway.

The regulations governing the species permitted and prohibited in vegetative buffers (Appendix D) ensure that the vegetation employed is entirely native to the Highlands region. These ordinances outline the approved native species in addition to prohibited nonnative and invasive species deemed exceptionally harmful to southern Appalachian landscapes. In effect, these outlines will modernize the existing regulation since the new regulations contain extensive lists of species better suited to the climate of Highlands.

### DISCUSSION

The connecting trails mapped in this report are vital to finalizing the proposal for the preliminary installment of the Highlands Greenway System. After plotting the paths on Big Bear Pen Mountain, it was then possible to complete the Comprehensive Greenway Map for public display on the town website. Additionally, with the connecting trail data the town was able to produce the Town of Highlands Greenway Plan Map. This currently serves as the official greenway map document adopted in the greenway ordinances. However, the ultimate plan that the Greenways Committee envisions for the completed greenway system has not yet been plotted or mapped. It is hoped that with the successful installment of this inaugural portion of the trail, the town Planning Board and Board of Commissioners can be persuaded to consider further expansion of the trail network. It would also be necessary to obtain the required easements from private property owners to support future greenway development. The extension of the greenway system hinges on the ability of the HCLT and the Greenways Committee to acquire such properties exhibiting high connectivity.

The ordinances produced by this study have increased the viability of the Highlands Greenway plan considerably. Their design establishes the political bases needed to progress and eventually expand the greenway project. These ordinances have been tailored to connect and preserve natural areas, provide incentives for property dedication, and with the trails inception, to encourage recreation, all of which exemplify the fundamental goals of the Greenways Committees.

While the ordinances have been significantly enhanced as a result of this effort, their impending approval by the Town of Highlands Board of Commissioners will determine the true success of this report. Required alterations to ordinance structure recommended by the Board of Commissioners must be completed before the Highlands Greenway can begin construction. Future ordinance development may also be required, as greenway network expansion could possibly raise additional political concerns not addressed in these initial regulations.

#### ACKNOWLEDGMENTS

I thank my mentor Hillrie Quin, the chairman of the Greenways Committee, for providing essential documents and field guidance to develop these ordinances and plot the greenway connecting trails. I wish to thank Richard Betz the Town Administrator and Bill Coward the Town Attorney for their assistance in perfecting the ordinance language. I want to thank the Executive Director of the HCLT, Gary Wein, for the tools, knowledge, and supervision necessary to plot and map the greenway trails. Finally, I would like to thank Sam Chambers, an employee of the HCLT for his technical assistance in the field.

#### LITERATURE CITED

ESRI Inc. 2005. ArcMap 9.1. Redlands, California, USA.

Manifold Net Ltd. 2007. Manifold System Release 8.0. Carson City, Nevada, USA.

- Miller, J.H. 2003. Nonnative invasive plants of southern forests: a field guide for identification and control. General Technical Report SRS-62. Asheville, North Carolina, USA. U.S. Department of Agriculture, Forest Service, Southern Research Station. 93p
- Radford, A.E., H.E. Ahles, and C.R. Bell. 1968. Manual of the vascular flora of the Carolinas. The University of North Carolina Press, Chapel Hill, USA.

Town of Cary. 22 March 2007. Dedication of Greenway Land ordinance.

Town of Davidson. 13 February 2001. Greenway Engineering and Design Specifications.

Town of Highlands. 20 September 1989. The Land Use Plan.

Town of Highlands. 22 March 2002. Lot Size Exemption ordinance.

Town of Highlands. 11 July 2007. Zoning Ordinance: Zoning Certificates, Appendix A.

Town of Wesley Chapel. 10 January 2005. Dedication of Land ordinance.

**APPENDIX A. Digitized connector trail map linking the Kelsey Preserve to Rhododendron Park. 16 November 2007.** 





64

**APPENDIX B. Digitized connector trail map linking Upper Lake Rd. to the Rhododendron Trail. 16 November 2007.** 



Connecting Trail from Upper Lake Road to the Rhododendron Trail



APPENDIX C. Town of Highlands Comprehensive Greenway Map. 16 November 2007.

**APPENDIX D. Ordinances developed and proposed to establish the Town of Highlands Greenway System. 29 October 2007.** 

# PROPOSED AMENDMENTS OF ZONING ORDINANCE GREENWAYS

# 1. <u>Conditional Use Zoning</u>.

Add the following to Section 709II, Paragraph (D), [renumber existing paragraph (1)]:

"(2) A petition for reclassification of property to a conditional zoning district pursuant to this section, where such property is located partially or entirely within the Highlands Greenway, as shown the "Town of Highlands Greenway Plan Map," shall not be granted without the dedication to the Town of Highlands of an easement for a strip of property for said Greenway ranging between twenty-five (25) and fifty (50) feet in width, as determined to be necessary, by the Town in its sole discretion, to promote the purposes of the Greenway project. Upon the effective date of a resolution of the Board of Commissioners that such easement is no longer required for the Highlands Greenway, the easement shall terminate and the Town shall, upon request of the owner, and at the owner's expense, file in the Register of Deeds for Macon County an instrument providing for such termination as a matter of public record."

2. Lot Size Exception for Greenways.

Add the following to Sections 201.4, 202.5, 203.5, 204.5, 205.5, 206.5, 207.5, 213.5(C), and 214.5(B):

"\*\* except that when a portion of the property is dedicated to the Highlands Greenway, the minimum lot size may be reduced by the amount of land dedicated."

Add the following to Sections 209.3, 209A.3, 210.3, and 211.3:

"or when a portion of the property is dedicated to the Highlands Greenway."

3. <u>Setback Exception for Greenways.</u>

Add the following paragraph to Sections 201.6, 202.6, 203.6, 205.6, 206.6, 207.6, 208.6, 213.6, 214.6, and 214.6:

"Where property has been dedicated to the Town of Highlands for the purpose of extending the Highlands Greenway, the portion of the lot dedicated as a part of the Greenway shall not be considered for setback purposes, provided however that if the easement is terminated under Section 709II, Paragraph (D)(2), the setback requirements shall again apply except as to improvements completed or substantially completed prior to such termination."

4. <u>Buffer Areas</u>.
Delete paragraph 209.6(B), 209A.6(B), 210.6(B), and 211.6(B), and add the following paragraph (C) to said sections:

"No new development is allowed in the buffer except for water dependent structures, as defined by this Ordinance, and public projects such as road crossings and greenways where no practical alternative exists. These activities should minimize built-upon surface area, direct runoff away from the surface waters and maximize the utilization of stormwater Best Management Practices. Greenways constructed within the Highlands Greenway, as shown on the "Town of Highlands Greenway Plan Map," shall be provided with a minimum twenty (20) foot vegetative buffer between the perennial stream and the nearest edge of the Greenway. Such buffers shall be composed of any of the recommended locally adapted and native species identified in Section 702.2(A)(6) of this Ordinance. Surfaces of Greenways may be a maximum of ten (10) feet in width, and may consist of asphalt or any other impermeable or permeable surfaces. These Greenways must possess a cross slope of two percent (2%) directed away from the perennial waterways to which they are adjacent. In addition, to insure proper stormwater runoff, catch basins with drains and underground culverts may be required."

5. <u>Definition</u>.

Add the following definition to Article 1000:

"<u>Greenway or Highlands Greenway</u>. An area for pedestrian use dedicated to the Town of Highlands, as shown on the "Town of Highlands Greenway Plan Map." Said map is adopted simultaneously herewith, may be amended from time to time in accordance with Section 706 of this Ordinance, and shall be permanently kept on file in the office of the Town Clerk."

# 6. Species Allowed in the Vegetative Buffer.

Amend 702.2 (A)(6), and Appendix D to the following:

"(6) To protect and preserve the natural environment and beauty of the Town of Highlands, any landscaping plan is encouraged to consider the following recommended locally adapted and native species:

(a) Large or medium hardwood canopy trees, including Red Maple, Sugar Maple, Striped Maple, Yellow Birch, Sweet Birch, American Beech, Tulip Poplar, Sourwood, Sassafras, Shingle Oak, Chestnut Oak, Scarlet Oak, Northern Red Oak, White Oak, Black Gum, Black Locust, Black Walnut, Fraser Magnolia, Cucumber Magnolia, White Ash, Black Cherry, American Chestnut, Chinquapin, Pignut Hickory, Mockernut Hickory, Red Hickory, American Basswood, and White Basswood.

(b) Large or medium evergreen canopy trees, including White Pine, Pitch Pine, Table Mountain Pine, Virginia Pine, Fraser Fir, Red Spruce, Eastern Hemlock, and Carolina Hemlock.

(c) Small flowering understory trees, including Downy Serviceberry, American Holly, Mountain Holly, American Hornbeam, Carolina Silverbell, Flowering Dogwood, Alternateleaf Dogwood, Silky Dogwood, Pagoda Dogwood, Fringe-Tree, Yellowleaf Hawthorn, Fanleaf Hawthorn, Dotted Hawthorn, Dwarf Hawthorn, American Mountain Ash, Persimmon, Eastern Red Cedar, Mountain Sweet Pepper Bush, Yellow Buckeye, Southern Crabapple, and Sweet Crabapple. Other fruit trees (apple, peach, pear, etc.) are allowed though they may not be planted along the Town of Highlands Greenway system, as most species are nonnative.

(d) Shrubs, including Bristly Locust, Clammy Locust, Witch-Hazel, Smooth Sumac, Nine bark, Lowbush blueberry, Highbush blueberry, Mountain Myrtle, Bushy St. Johnswort, Shrubby St. Johnswort, Eastern Sweetshrub, Smooth Azalea, Flame Azalea, Pinkshell Azalea, Pinxter Azalea, Catawba Rosebay, Rhododendron (Maximum and Minus), Carolina Laurel, Mountain Laurel, Mapleleaf Viburnum, Southern Arrowwood, Possumhaw, Wild Hydrangea, Oakleaf Hydrangea, and Silverleaf Hydrangea."

## 7. Species Not Permitted in Vegetative Buffer.

Add to 702.2 (A) and Appendix D:

"(7) To protect and preserve the natural environment and beauty of the Town of Highlands, any landscaping plan is encouraged to refrain from the usage of any of the following invasive and nonnative species:

(a) Trees: Tree-of-Heaven (*Ailanthus altissima*), Silk Tree (*Albizia julibrissin*), Princess Tree (*Paulownia tomentosa*), Chinaberry Tree (*Melia azedarach*), Tallow Tree (*Triadica sebifera*), Norway Maple (*Acer platanoides*), Paper Mulberry (*Broussonetia papyrifera*), White Mulberry (*Morus alba*), White Poplar (*Populus alba*), and Russian Olive (*Elaeagnus angustifolia*).

(b) Shrubs: Silverthorn (*Elaeagnus pungens*), Autumn Olive (*Elaeagnus umbellata*), Winged Burning Bush (*Euonymus alatus*), Chinese Privet (*Ligustrum sinense*), Japanese Privet (*Ligustrum japonicum*), Amur honeysuckle (*Lonicera maackii*), Morrow's honeysuckle (*Lonicera morrowii*), Tatarian honeysuckle (*Lonicera tatarica*), Sweet-breath-of-spring (*Lonicera fragrantissima*), Bell's honeysuckle (*Lonicera xbella*), Sacred Bamboo (*Nandina domestica*), Multiflora Rose (*Rosa multiflora*), Macartney Rose (*Rosa bracteata*), Cherokee Rose (*Rosa laevigata*), Japanese Barberry (*Berberis thunbergii*), Japanese Knotweed (*Polygonum cuspidatum*), and Wineberry (*Rubus phoenicolasius*).

(c) Vines: Oriental Bittersweet (*Celastrus orbiculatus*), Climbing Yams (*Dioscorea bulbifera*), Winter Creeper (*Euonymus fortunei*), English Ivy (*Hedera helix*), Japanese Honeysuckle (*Lonicera japonica*), Kudzu (*Pueraria montana*), Common Periwinkle (*Vinca minor*), Bigleaf Periwinkle (*Vinca major*), Chinese Wisteria (*Wisteria sinensis*), Japanese Wisteria (*Wisteria floribunda*), Mile-a-minute (*Polygonum perfoliatum*), and Porcelain Berry (*Amelopsis brevipedunculata*).

(d) Grasses: Giant Reed (*Arundo donax*), Tall Fescue (*Lolium arundinaceum*), Red Fescue (*Festuca rubra*), Cogongrass (*Imperata cylindrica*), Nepalese Browntop (*Microstegium vimineum*), Chinese Silvergrass (*Miscanthus sinensis*), and Golden bamboo (*Phyllostachys aurea*). "

# EFFECTS OF EASTERN HEMLOCK MORTALITY ON FOREST MICROCLIMATE AND SPECIES COMPOSITION

#### ANDREA MARTIN AND SANDY SKOLOCHENKO

Abstract. Extirpation of eastern hemlock (Tsuga canadensis) throughout its natural range is occurring due to attack from the exotic hemlock woolly adelgid (Adelges tsugae Annand). Death of the eastern hemlock, a foundation species, will affect many ecosystem characteristics. Both aboveground and belowground processes will be altered, likely resulting in microclimatic changes in temperature, moisture, and solar radiation. However, the empty niche created by its death will provide opportunities for other species. This study investigates the changes in these microclimatic and species compositional factors due to hemlock mortality in the southern Appalachians through the use of experimental plots that simulate current and future hemlock conditions, from the onset of infestation to complete hemlock absence. We found that light penetration through the canopy increased as hemlock trees died, although there was high interception from the subcanopy evergreen shrub Rhododendron maximum, potentially limiting available resources for new species establishment. Soil moisture increased in hemlock plots, especially in the winter months when hemlock is the only transpiring canopy species. Average soil temperature did not increase over time in experimental hemlock plots, although the temperature was consistently higher in plots without hemlock present. Variation in soil temperature was not affected by hemlock mortality or absence. Hemlock basal area and wood biomass increment decreased due to the adelgid-induced mortality, and Betula lenta and Liriodendron tulipifera growth suggests that these species may take its place, although the long-term changes are unclear. With the loss of the eastern hemlock foundation species, it seems that its accompanying biota and climatic factors will be altered and perhaps lost, replaced by a distinctly different forest type.

Key words: Adelges tsugae; Eastern hemlock; hemlock woolly adelgid; microclimate; riparian zones; Tsuga canadensis

#### INTRODUCTION

Preserving forest diversity is of utmost importance ecologically, economically, and aesthetically. Within a forest there are typically several ecosystems present that are shaped by the geography and microclimate of a particular area. Foundation tree species shape their own ecological communities, controlling the biota present and the functions of that ecosystem (Ellison et al. 2005). The southern Appalachians support a diversity of forest community types. High elevation forests along mountaintops and ridges are often dominated by oaks (*Quercus* spp.), northern hardwoods, or spruce (*Picea*) and fir (*Abies*). Exposure at high elevations can create rock outcrop communities or balds that lack canopy species but support grasses and ericaceous shrubs. Lower elevation forests are typically comprised of mixed hardwoods that make up the oak-hickory (formerly oak-chestnut) forest type. In protected coves, riparian corridors, or along mesic ridges, hemlock dominates with a heavy rhododendron understory (Schafale and Weakley 1990). This high diversity of community types offers a variety of habitats that support a wide array of plant and animal life, many endemic to the area. Apart from

its ecological richness, the southern Appalachian landscape has been important economically through agriculture, mining, forestry, tourism, and recreation (Kilpatrick et al. 2004).

Due to globalization and industrialization, humans have developed the capacity to threaten and destroy the high biodiversity in these forests. Through the accidental (and sometimes intentional) introduction of exotic species (*i.e.*, plants, insects, and diseases), many economically and ecologically important native species are facing extirpation or even extinction. Over the last century exotic species-induced losses have caused the decline of dominant canopy species such as chestnut, elm, fir, and beech. Such species loss due to exotic species introduction alters forest structure, composition, function, and productivity, commonly resulting in a loss of biodiversity.

The landscape of the southern Appalachians has been significantly altered by the introduction of the chestnut blight (Cryphonectria parasitica) (Anagnostakis and Hillman 1992). In the early 20<sup>th</sup> century, the chestnut blight effectively eliminated overstory American chestnut (Castanea dentata) trees in deciduous forests across the eastern United States. The species that replaced the chestnut vary with location, as there was no co-dominant species that spanned the entirety of the native chestnut range. For example, in southwestern Virginia, Quercus rubra is now the dominant species, Quercus alba has declined, and other species (Acer saccharum, Amelanchier arborea, Betula lenta, Prunus serotina and Robinia pseudoacacia) that were previously understory species are now found in the canopy (Stephenson 1986). These compositional changes were temporary, as McCormick and Platt (1980) found that, with time, a chestnut-oak forest transformed to an oak-hickory. In addition to these vegetational changes induced by chestnut mortality, wildlife was also impacted: squirrel populations crashed, woodpeckers increased (due to an increase in dead tree habitat), and seven moth species that fed on chestnut are now extinct (Opler 1978). These structural and compositional changes brought about by extensive chestnut mortality are well understood; however, very little is known concerning the specific ecosystem responses to such a drastic and sudden alteration of the landscape since many ecosystem parameters were not measured prior to the death of chestnut.

In addition to the chestnut blight, many other exotic species have altered natural forest ecosystems of the Unites States and significantly decreased the rich biodiversity of the impacted areas. The presence of the beech bark disease (*Nectria coccinea* var. *fraginata*) in hemlock sites increased the abundance of hemlock, decreased the abundance of American beech and yellow birch, and presumably decreased the production of mast, thus lowering the diversity of wildlife species (Runkle 1990, Castello et al. 1995). Likewise, Dutch elm disease (*Ophiostoma ulmi*) resulted in a 60% increase in sugar maple (*Acer saccharum*) basal area and a significant increase in shrub density in Illinois and Wisconsin, respectively (Boggess and Bailey 1964, Dunn 1986). The selective mortality caused by these aforementioned pathogens act indirectly to alter their inhabited ecosystems compositionally, structurally, functionally, and microclimatically. These ecosystem changes carry implications for the future forest biodiversity and, thus, long-term viability of these ecosystems.

Eastern hemlock (*Tsuga canadensis*), a foundation canopy tree, is a species whose loss could bring about many ecosystem responses. Hemlocks often grow in pure stands in the northeastern United States, but in the southern Appalachians they often dominate riparian and cove sites in mixed high elevation hardwood forests. In forests in which hemlocks dominate the canopy they create a shaded environment, deposit acidic litter, and mediate soil moisture. Hemlocks contribute greatly to transpiration rates throughout the year, especially in the winter and spring when deciduous trees are leafless (Ellison et al. 2005). Their presence therefore

creates a fairly stable environment with low variation in soil moisture, slow rates of nitrogen cycling, low light availability, and low seasonal variation of light (Eschtruth et al. 2006). This type of environment stabilizes stream flow and supports a number of salamanders, fish, and aquatic invertebrates, along with terrestrial dwellers such as birds, mammals, and forest carnivores that depend on hemlock stands for habitat and cover (Orwig et al. 2002, Ellison et al. 2005). Hemlock trees typically have a shallow rooting system, thin bark, and are slow-growing, making them vulnerable to disturbance. Wind, fire, drought, exotic pests, or anthropogenic disturbance can severely impact hemlock populations. For this reason, most hemlock forests today are found in protected coves and ravines, or on historically protected sites (Orwig and Foster 1998).

Since European settlement, eastern hemlock has played an important role economically as well as ecologically. Hemlock was logged heavily in the 1800s throughout the mid-Atlantic. Although hemlock was considered a low-value softwood, it was a preferred source of tannins and was used extensively in leather processing (Brown 2000). Consequentially, loggers often felled hemlock trees, stripped them of their bark, and left the log to rot. Parts of the bark have also been used historically in ointments to treat rheumatism and colds, and such ointments were even applied on the skin to stop bleeding wounds (Brown 2000). In the past century, logging of hemlock has decreased significantly and much of the previously cleared farmland has been abandoned, allowing for hemlock recovery and reforestation throughout its native range (Weckel et al. 2006).

The entire range of the eastern (*Tsuga canadensis*) and Carolina (*Tsuga caroliniana*) hemlock is currently under threat of extirpation by the introduced hemlock woolly adelgid (HWA). This insect, native to Japan and first observed in the United States in the 1950s, has quickly dispersed throughout the natural range of hemlock by wind, animal, and human vectors and can cause tree mortality within 4-10 years of infestation (McClure 1990, 1991; Souto et al. 1996). The HWA feeds on the ray parenchyma cells of young hemlock twigs and in doing so injects a toxic saliva that causes needle loss and mortality of the buds and branches (Young et al. 1995). The fate of hemlocks from these pests seems dim, as the trees show no sign of resistance. Additionally, HWA is parthenogenetic, reproduces rapidly with two generations per year, can kill hemlocks of all sizes and age classes, and seems to have no native predators within its range (McClure 1989, 1990, 1991; Kizlinski et al. 2002).

The current decline of hemlock provides a unique opportunity to examine the effect of selective tree loss on forest structure, composition, function, and microclimate as it occurs, as opposed to past pathogen and pest-induced tree mortality that could only be studied after mortality had already occurred (Orwig 2002). The loss of hemlock, a foundation species that regulates and influences understory environment and composition, will most likely alter its accompanying microenvironment to an extent not seen in other less influential tree species. Also, unlike the pathogens of other past tree species, the ability of the HWA to eliminate all ages of hemlock gives it the potential to completely eliminate hemlock from an area in a short period of time, as opposed to other exotic pathogens and pests that have only targeted a certain age group (Castello et al. 1995).

Ecosystem responses to hemlock decline have been examined extensively in the northeastern United States. Numerous studies have monitored hemlock stands infested with HWA, have simulated HWA impact by girdling hemlocks, and have simulated hemlock loss with canopy gaps in hemlock-dominated forests (Rankin and Tramer 2002, Yorks et al. 2003). These studies have found that the loss of hemlock causes an increase in understory species richness, light availability, and abundance of birch and maple (Battles et al. 1995, Orwig and Foster 1998, Eschtruth et al. 2006). Although these studies have examined ecosystem responses to hemlock mortality, these responses have not been observed and quantified in the southern Appalachians, a region with a unique climatic regime, unusually high biodiversity, and the presence of a *Rhododendron maximum* subcanopy and mixed-deciduous canopy.

In this study, we examined the effects of natural, artificially accelerated, and complete hemlock mortality due to the HWA on soil temperature, soil moisture, light availability, and species composition. We hypothesized that dying hemlock trees will result in forests that begin to show microclimate and compositional similarities to the southern hardwood deciduous forests, by 1) increased light availability, soil moisture, average soil temperature, and diurnal soil temperature variation; 2) a shift in species composition to hardwood species, such as black birch (*Betula lenta*) and yellow poplar (*Liriodendron tulipifera*); and 3) an increased growth of the dominate subcanopy species, *Rhododendron maximum*.

#### MATERIALS AND METHODS

This study was conducted at Coweeta Hydrologic Laboratory (35°03'N, 83°27'W) located on the east side of the Nantahala mountain range in western North Carolina. The 2100 ha basin spans in elevation from 700 to 1600m. The regional climate has cool summers, mild winters, and abundant precipitation. Mean annual precipitation varies from 1780 mm at lower elevation and up to 2500 mm at high elevations (Swank and Crossley 1988). Average monthly temperatures range from 3°C in January to 19°C in July. Soils are primarily inceptisols and ultisols (Swank and Crossley 1988). The forest is predominantly mixed oak with oak-pine forests along drier slopes and cove hardwoods in riparian corridors. Dominant canopy species include *Quercus alba, Q. rubra, Acer rubrum, Oxydendrum arboreum, Liriodendron tulipifera, Nyssa sylvatica, Betula lenta, Carya* spp., and *Tsuga canadensis* (Swank and Crossley 1988). There is an abundant evergreen understory up to 8m above the forest floor that is predominantly occupied by *Rhododendron maximum* (Clinton 2003).

Twelve 20m x 20m plots were established in 2004 (Fig. 1). Plots were located in riparian areas with and without hemlock present. Four plots were selected with no hemlocks. These were predominantly comprised of hardwoods, with some evergreen understory present. The remaining eight sites contain hemlock trees infested with HWA. In four of these plots the hemlock trees were girdled in August 2004 to accelerate their death and predict and analyze future ecosystem changes.

To measure the effects of hemlock loss on light levels and soil moisture, six of the twelve plots were selected for measurement, two from each treatment. Twenty light level measurements were taken at equal intervals throughout the plot and three soil moisture probes were placed randomly within each plot (Fig. 1). Networks of multiplexers and CR10X programmable dataloggers (Campbell Scientific, Logan, Utah) were connected to the sensors in each of the six plots, allowing for multiple measurements of light levels and soil moisture to be recorded simultaneously. Within each plot, dataloggers were located at the edge and data were downloaded monthly from each site. Photosynthetically active radiation (PAR;  $\mu$ mols m<sup>-2</sup>s<sup>-1</sup>) was measured in each plot using twenty Gallium Arsenide Photodiodes (Hamamatsu Corporation, Tokyo, Japan). PAR refers to the visible spectral range of light (400-700 nm) available for photosynthesis by terrestrial plants. PAR light energy was measured in millivolts every 60 seconds and logged as hourly means between the hours of 0500 and 2300 from June 2005 to August 2007. Each sensor was individually calibrated to a known quantum sensor using simple linear regression. Regression



FIG. 1. Layout of experiment plot (20m x 20m). Microclimate stations measured soil temperature. Alternating high (5m) and low (1m) photo diodes measured light intensity. Three soil moisture probes were randomly placed in each plot as well (not pictured).

coefficients were used to convert recorded millivolt signals to  $\mu$ mols m<sup>-2</sup> s<sup>-1</sup>. Twenty sensors were installed on each plot on a 2m x 2m grid alternating in height between 1m and 5m above the forest floor in order to separate the effects of the rhododendron subcanopy on changes in light levels due to loss of hemlock.

Soil moisture was measured in each plot using time domain reflectometry (TDR) with CS616 probes (Campbell Scientific, Logan, Utah). Three reflectometers were installed randomly on each plot. Each reflectometer is comprised of a pair of 30cm stainless steel rods inserted vertically into the soil to measure volumetric soil water content (%) integrated across the 30cm depth. TDR probes were calibrated for the soils found in the plots. Probes were scanned hourly and data were stored in an automated data logger.

Soil temperature was monitored in each plot at 5cm mineral soil depth using Ibutton dataloggers (Maxim Integrated Products, Sunnyvale, CA). Four temperature sensors were installed on a 5m

x 5m grid in each plot. Measurements were collected hourly over the study period.

The diameter at breast height (1.37 m, DBH) of woody vegetation in each plot was measured annually each winter using dendrometer bands and a DBH tape from 2004 to 2007. Dendrometer bands were placed on all trees greater than 15 cm DBH in October 2004 to allow the bands to settle into the bark prior to the initial measurement in December 2004. These DBH values were used with species-specific allometric equations (Martin et al. 1998) to calculate woody biomass for each tree. The following trees were not well represented in the plots and were thus placed in the "other" category: *Acer pensylvanicum, A. rubrum, A. saccarum, Amelanchier arborea, Carpinus caroliniana, Cornus florida, Fagus grandifolia, Fraxinus spp., Hamamelis virginiana, Pinus rigida, P. strobus, Quercus coccinea, Q. prinus, Robinia pseudoacacia, and Sassafras albidum.* 

#### Data Analysis

For this study we analyzed the collected data using SAS version 9.1 (SAS Institute Inc., Cary, NC). This program was used to process all data and perform statistical analyses including analysis of variance. We used least significant difference (LSD) mean separation tests to delineate treatment effects among multiple means. We evaluated statistical differences at the  $\alpha$  = 0.05 level using PROC GLM (SAS Institute Inc., Cary, NC). We used SigmaPlot® version 9.0 (Systat Software, Inc., San Jose, CA) to create figures.

#### RESULTS

#### Light Levels (PAR)



FIG. 2. Daily mean photosynthetically active radiation (PAR;  $\mu$ mol m<sup>-2</sup> s<sup>-1</sup>) averaged by treatment. Treatments include plots with hardwood only, natural hemlock forest, and girdled hemlock (*N* = 2 plots per treatment).

Light level trends from the upper and lower sensors varied among plots. In the winter and spring months, light levels were higher in the hardwood treatment due to the lack of leaf deciduous cover in trees. Comparing daily PAR values at the upper and lower sensors, the lower sensors received less light overall due to interception from low leaf cover and understory evergreen shrubs, principally Rhododendron maximum (Fig. 2). At the upper level, the girdled treatment exhibited higher PAR values than the hemlock treatments throughout the study. would be This expected as a result of the girdling. The girdling in August 2004 would presumably speed mortality of these trees, leading to greater and earlier needle loss allowing and more light However, in the penetration. lower sensors. the opposite occurred and the girdled treatment exhibited lower PAR than the hemlock treatment. again due to the distribution of Rhododendron maximum.

PAR values were averaged seasonally and compared among treatments (Fig. 3). There was no significant difference in PAR among treatments in winter or spring. At the 5m level, no difference was observed in the fall either. In summer 2005, all three treatments had significantly different (P = 0.0002) seasonal PAR. In the summer of 2006, light levels in the hemlock and girdled treatments differed from one another (P = 0.06), but neither differed significantly from the hardwood treatment. During the summer of 2007, PAR in the girdled treatment was significantly higher (P = 0.01) than both the hardwood and hemlock treatments. Comparing the summer data across years, the girdled treatment exhibited the highest PAR values for all three summers. As the summer hardwood PAR value remained fairly constant for the three years, the girdled treatment value increased slightly and the hemlock treatment PAR value increased significantly between the summers of 2005 and 2006.

At the 1m level, summer 2005 data showed a significantly higher PAR (P = 0.0009) in the hemlock plots than either the girdled or hardwood plots. In 2006, the hemlock treatment was significantly higher (P = 0.0004) in the summer and in the fall the girdled and hemlock treatments were significantly different (P = 0.06). PAR in the hemlock treatment was also significantly higher (P = 0.008) than the girdled or hardwood treatments in the summer of 2007. The summer data exhibited a similar trend to the upper level. The hardwood treatment again maintained stable light levels across the three years while the girdled treatment PAR increased slightly with time and the hemlock PAR increased between 2005 and 2006.



FIG. 3. Seasonal PAR variation among treatment plots. Treatments include plots with hardwood only, natural hemlock forest, and girdled hemlock (N = 2 plots per treatment). Error bars represent one standard error. Treatment values with the same letter were not significantly different using the LSD mean separation test at the  $\alpha < 0.05$  level.

#### Soil Moisture

Soil moisture in all plots was heavily dependent on precipitation. Daily soil moisture values averaged by plot type were graphed with daily precipitation data (Fig. 4). Soil moisture correlated very closely with precipitation events and showed effects of seasonal variability. During the majority of the year, soil moisture in both hemlock treatments was higher than that of the hardwood treatment. In the late spring of both 2006 and 2007, all treatments experienced a decline in soil moisture as hardwood species began producing new leaves. The water content in the hardwood treatment decreased at a faster rate than either hemlock treatment, experiencing the driest soils as hardwood species approached their maximum transpiration levels in early summer. The hemlock treatment exhibited the slowest rate of soil moisture dry-down following precipitation events and had the highest soil moisture content their by early summer compared with the other treatments.

Another drying event occurred in the fall that was prominent in 2005 and 2007, but not as obvious in 2006 due to missing hardwood data. This can be partially explained by the gradual loss of leaf area as the fall season progress and the consequent increase in insolation at the forest floor, resulting in higher soil evaporation rates. Again, this effect was most dramatic in the hardwood treatment and least dramatic in the hemlock treatments.

For all three treatments, highest seasonal soil moisture occurred during the winter. During this period the hardwood treatment was driest, the hemlock treatment was slightly moister, and the girdled treatment contained the highest moisture content.



FIG. 4. Daily soil moisture (% volumetric water content) averaged by treatment with daily precipitation (mm).

Soil moisture was also averaged seasonally (Fig. 5). In the spring of 2006 and 2007, none of the treatments exhibited significantly different seasonal means. This is due to high



FIG. 5. Seasonal soil moisture by treatment. Treatments include plots with hardwood only, natural hemlock forest, and girdled hemlock (N = 2 plots per treatment). Error bars represent one standard error. Treatment values with the same letter were not significantly different using the LSD mean separation test at the  $\alpha = 0.05$  level.

(December-February) or fall months (September-November) (Fig. 6). In spring and summer, the hardwood treatment had significantly higher average daily soil temperature than the hemlock and girdled treatments. The average daily soil temperature was consistently lower in the girdled than the natural hemlock treatment.

productivity from hardwoods in all treatments. In the summers of 2005 and 2007, differences between hemlock and hardwood treatments were marginally significant (P = 0.09 and P = 0.06,respectively) with the highest moisture content occurring in the hemlock treatment. In fall 2005, none of the plots were significantly different, but in fall 2006, the hardwood treatment had a significantly lower soil moisture than either hemlock or girdled treatments (P = 0.03). As mentioned, this is due to reduced transpiration during the fall and higher soil water evaporation rates. Winter data supported the trend seen in Fig. 3. In winter 2006, all three treatments had significantly different soil moisture values (P < 0.0001). The girdled treatment had the highest soil water content, followed by the hemlock and hardwood treatments. However, in winter 2007, the hardwood soil moisture was still significantly lower (P = 0.01), but the hemlock and girdled treatments were not significantly different from one another.

#### Soil Temperature

Because hemlock presence is associated with cooler temperatures, the effect of hemlock mortality on soil temperature was examined. For all years, there was higher variation in average daily soil temperature among treatment groups during the spring (March-May) and summer (June-August) months than during the winter



FIG. 6. (a) Seasonal variation in average daily soil temperature (measured at 5-cm mineral soil depth) among treatment groups. Treatments include plots with hardwood only, natural hemlock forest, and girdled hemlock. Individual points represent means of treatments (N = 4 for each treatment). Error bars represent one standard error. (b) Monthly variation in average daily soil temperature among treatment groups for 2007. (c) Spring and (d) summer variation in average daily soil temperature among treatment groups across years. Treatment values with the same letter for a time period were not significantly different using the LSD mean separation test at the  $\alpha < 0.05$  level.

Because hemlocks play a role in moderating diurnal temperature variation, the effect of hemlock mortality on the maximum daily soil temperature was also examined. Fig. 7 shows the seasonal variation in the maximum daily soil temperature among treatment groups. Like the average soil temperature, the maximum daily soil temperature was markedly higher in the hardwood treatment than in the natural and girdled hemlock treatments.



FIG. 7. Seasonal variation in maximum daily soil temperature (measured at 5-cm mineral soil depth). Treatments include plots with hardwood only, natural hemlock forest, and girdled hemlock trees. Individual points represent means within treatment types (N = 4 for each treatment). Error bars represent one standard error. Treatment values with the same letter were not significantly different for that time period using the LSD mean separation test at the  $\alpha$  < 0.05 level.

When comparing girdled and natural hemlock treatments, no significant difference was observed for any season or year, except for the first soil temperature measurement in spring 2005.

#### Species Composition

In 2004, the hardwood treatment plots were primarily comprised of *Quercus alba* (basal area 28.42 m<sup>2</sup> ha<sup>-1</sup>), *Liriodendron tulipifera* (ba 7.58 m<sup>2</sup> ha<sup>-1</sup>), and *Oxydendrum arboreum* (ba 5.20 m<sup>2</sup> ha<sup>-1</sup>) (Fig. 8). The control hemlock treatment plots were primarily comprised of *Tsuga canadensis* (ba 32.74 m<sup>2</sup> ha<sup>-1</sup>), *Rhododendron maximum* (ba 4.56 m<sup>2</sup> ha<sup>-1</sup>), and *Betula lenta* (ba 3.72 m<sup>2</sup> ha<sup>-1</sup>). The girdled hemlock treatment plots were also primarily comprised of *Tsuga canadensis* (ba 22.25 m<sup>2</sup>ha<sup>-1</sup>), *Rhododendron maximum* (ba 5.22 m<sup>2</sup> ha<sup>-1</sup>), and *Betula lenta* (ba 3.29 m<sup>2</sup> ha<sup>-1</sup>). The total mean live basal area was similar between control and hemlock treatments, but higher than that of the girdled plots. The girdled treatment groups exhibited a significantly lower total mean plot basal area than the natural hemlock or hardwood treatments during the last two years (2006 and 2007) (P = 0.0148 and P = 0.0126, respectively). This difference in the last two years may be attributed to the effects of girdling, also shown in Figure 8, where hemlock mean plot basal area significantly decreased from 22.25 m<sup>2</sup> ha<sup>-1</sup> in 2004 to 0.07 m<sup>2</sup>ha<sup>-1</sup> in 2007 (P = 0.003). The hemlock basal area in the natural hemlock and hardwood treatments did not show a significant change with time (P = 1.00 and P = 0.9991, respectively).



**Plot Treatment** 

FIG. 8. Mean live basal area by species by year. Treatments include plots with hardwood only, natural hemlock forest, and girdled hemlock (N = 4 for each treatment). The figure legend indicates each woody species by the first three letters of the genus and species, except for "other" which includes species listed in the methods section. Total treatment values with the same lowercase letter (within a year) were not significantly different using the LSD mean separation test at the  $\alpha < 0.05$  level. Hemlock basal areas with the same uppercase letter (within a treatment) were not significantly different across years using the LSD mean separation test at the  $\alpha < 0.05$  level.

TABLE 1. Mean above ground woody biomass by treatment by year. Treatments include plots with hardwood only, natural hemlock forest, and girdled hemlock (N = 4 plots per treatment).

		Μ	lean Plot H	Biomass (grams/	$m^2$ )
Year	Treatment	Live	Dead	Dead Fallen	Total
	Hemlock	28167	2620	0	30787
2004	Girdled	25680	1082	0	26762
	Hardwood	39954	1712	0	41665
	Hemlock	28381	2658	0	31039
2005	Girdled	22705	4321	31	27057
	Hardwood	40389	1730	0	42120
	Hemlock	28721	2717	27	31465
2006	Girdled	15273	11908	152	27334
	Hardwood	41027	1752	22	42801
	Hemlock	28968	2772	30	31770
2007	Girdled	15078	12361	152	27591
	Hardwood	41602	1790	22	43414

The treatment effects on the aboveground woody biomass are shown in Table 1. The total and live biomass is consistently higher in the hardwood treatment than in the girdled or natural hemlock treatments. By 2007, the girdled plots had much higher dead and dead fallen biomass than the natural hemlock or hardwood plots.



FIG. 9. Annual aboveground woody biomass increment over three years. Treatments include plots with hardwood only, natural hemlock forest, and girdled hemlock (N = 4 for each treatment). The figure legend indicates each woody species by the first three letters of the genus and species, except for "other" which includes species listed in the methods section. Total treatment values with the same lowercase letter (within a year) were not significantly different using the LSD mean separation test at the  $\alpha < 0.05$  level. Hemlock values with the same uppercase letter (within a treatment) were not significantly different across years using the LSD mean separation test at the  $\alpha < 0.05$  level.

The treatment effects on the annual aboveground wood increment for 2005, 2006, and 2007 are shown in Figure 9. The wood increment was higher in the hardwood treatment than in the hemlock treatments for all three years, although this trend was only statistically significant in 2007. Wood increments of all nonhemlock species were generally higher in 2006, across all treatments. The girdled treatment had a higher wood increment than the hemlock treatments in 2005, but showed a progressive decrease in 2006 and 2007.

## DISCUSSION

#### Light Levels

When а dominant tree species begins to decline, more light is able to penetrate the canopy as leaves fall, gradually changing the microclimate of the forest floor. In the southern Appalachians the effects of HWA on needle loss and light penetration are not always predictable since hemlock occurs in mixed forests in the presence of other hardwoods and а dense rhododendron understory. The results from light intensity at the lower sensor illustrate a trend

opposite from what was expected (Fig. 2). Considering that PAR in the girdled treatment was higher than hemlock at the upper canopy level, the switch in this trend at the lower lever is probably due to light interception from rhododendron between 1m and 5m. In a study of light responses to experimental canopy gaps, Beckage et al. (2000) found that light levels reaching the understory increased twofold when rhododendron was absent, but did not change when rhododendron was present. Therefore, the light levels recorded at the 1m level are sometimes more dependent upon the presence of rhododendron than the decline in tree health and needle loss (Beckage et al. 2000).

Light levels among treatments may vary due to aspect and sun angle as well. The sun is never directly overhead in the southern Appalachians and throughout the year the angle of the sun is changing. This affects the area that receives the most light when there is penetration through the canopy and Canham et al. (1990) found that in some cases the light was never able to reach understory levels due to the high ratio of canopy height to gap diameter. Aspect always plays a role in light dynamics and since hemlocks are usually found in coves or mesic north-facing slopes, light levels are affected by hillshade dynamics. Although an attempt was made to minimize these effects by placing hemlock and girdled plots adjacent to one another, there will always be slight variation, which could also explain the unexpected result in 1m PAR levels.

Monitoring light levels at the understory level gives insight to the conditions available for seed regeneration. Many case studies have proven that availability of light induced by experimental canopy gaps leads to a high density of seedling recruitment (Barden 1979, Beckage et al. 2000, Clinton 2003) but in the case of HWA effects, light levels will increase much less, especially when rhododendron is present, leading to different responses. In New England, declining hemlock stands are typically replaced by hardwoods such as *Betula lenta* and *Acer rubrum* (Battles et al. 1995, Orwig and Foster 1998, Eschtruth et al. 2006). As hemlocks of the southern Appalachians continue to die and light resources gradually become available it is likely that rhododendron will benefit most from hemlock decline, limiting recruitment of other canopy species (Ford and Vose unpublished).

Eventually, hemlocks that cannot survive HWA infestation will die completely and create a canopy gap with their fall. In a situation like this, other species may have a chance to take advantage of the immediate resources. In a nearby old growth forest with advanced HWA infestation, PAR measurements show a peak in light levels after a tree fall (Fig. 10). With the available light, canopy species may be able to establish seedlings, but growth and development of those seedlings have been shown to be inhibited by rhododendron for a variety of reasons including surface soil acidification due to its acidic litter (Nilsen et al. 1986). Those that do survive are typically hardwood species; very rarely is a hemlock gap filled by other hemlocks (Barden 1979, Jenkins et al. 1999, Eschtruth et al. 2006).



FIG. 10. Average PAR along a 40m transect through the center of treefall gaps (N=2) for each condition.

#### Soil Moisture

In the southern Appalachians, eastern hemlocks are typically found in riparian and mesic areas where soil moisture is high. This explains why both hemlock girdled the and higher treatments had slightly volumetric water content throughout the study period. As hemlock plays an important role in maintaining moisture levels, its decline will have a great impact on soils and hydrologic processes (Ellison et al. 2005). In winter 2006 (Fig. 5), we see that girdled treatment soil moisture is significantly higher than hemlock treatment soil moisture. Hemlock account for 30% percent of winter and

early spring evapotranspiration (Ford and Vose unpublished). As death of the girdled trees progresses, their transpiration rates decrease due to less and less annual leaf area development to maintain normal rates of transpiration (Ford pers. comm.). This has the greatest impact on total evapotranspiration in the winter months when we see significantly higher soil moisture in the girdled treatment. From winter 2006 to winter 2007, soil moisture values from the hemlock and girdled plots became much closer, indicating that the effects of natural HWA infestation were producing soil moisture conditions very similar to those experienced from accelerated hemlock death through girdling.

Furthermore, as hemlocks lose biomass through needle-fall and woody debris, less precipitation will be intercepted, leading to even higher soil water content (Ford and Vose unpublished). As the death of both HWA-infested hemlocks and girdled hemlocks progress, soil moisture is expected to continue to increase, specifically in winter months. Apart from an increase in soil moisture, the excess leaf and branch litter may result in higher infiltration of the forest floor and a rise of the water table (Ford pers. comm.).

Since hemlock populations are concentrated in riparian sites and influence hydrologic processes, future loss of the species will have serious implications for these environments. As shown in Fig. 4, the presence of hemlock slows the rate of soil moisture loss in the spring and early summer when hardwoods are producing new leaves, leading to less dramatic drying events. Similarly, with a significant precipitation event, soil moisture in the hemlock treatment does not increase as dramatically as moisture in the girdled treatment. The storage of soil moisture helps to stabilize stream flow through hemlock forests, supporting a wide and unique diversity of aquatic creatures (Ellison et al. 2005). With hemlock decline, we may see more extreme drying and soaking events which will cause more pronounced fluctuations in runoff and stream flow, potentially harming the aquatic life (Ford and Vose unpublished).

In the future, it is unlikely that these changes would be alleviated naturally since hemlock gaps will probably be filled by rhododendron or hardwood tree species (Battles et al. 1995, Orwig and Foster 1998, Eschtruth et al. 2006). If some type of evergreen restoration were applied, perhaps a species such as *Pinus strobus* could assume some of the ecohydrological processes currently maintained by hemlock by providing winter and spring evapotranspiration.

## Soil Temperature

Apart from spring of 2004, the soil temperature at 5-cm depth did not significantly differ between the natural hemlock and girdled hemlock treatments. Because the girdled hemlock treatment presumably simulates the effects of continued HWA infestation, these data suggest that soil temperature will not significantly change within the next few years of infestation in natural stands of hemlock.

Despite the absence of any girdled effect on soil temperature, the hardwood treatment had higher soil temperatures than the girdled and the hemlock treatments during the spring and summer months (April—August) for every year evaluated. These results are expected for any comparison of hardwood and hemlock-dominated forests since hemlocks are known to maintain lower temperatures. It is possible, however, that these soil temperature differences between treatments are not due to the absence of hemlock in the hardwood treatment, but rather the absence of another accompanying species, *Rhododendron maximum*. This supposition seems likely, as Clinton (2003) found mean spring and summer soil temperatures to be lower in plots with rhododendron as well. Because it is unknown whether *Rhododendron maximum* will be

impacted as hemlocks die due to HWA, it is not certain that the hardwood-only plots represent with any accuracy a post-hemlock forest. Therefore, although the results suggest that the complete elimination of hemlock will increase average soil temperature, this conclusion cannot be certain until the girdled and/or natural hemlock plots are completely devoid of living and/or dead standing hemlock trees.

Although girdling accelerates the eventual decline of hemlocks to the adelgid, such a decline was not evident through examination of soil temperature. The results show neither divergence of girdled plots from the natural hemlock stands or convergence of girdled plots with the hardwood-only treatment. Through random sampling, the girdled treatment has an average initial soil temperature that was lower than that of the natural hemlock treatment. This initial difference is most likely due to the topographic positions of the plots in regards to the slope aspect, as well as the random, close proximity of the girdled plots to streams. This initial pattern of temperature difference continues throughout the study, showing no indication of a treatment-induced increase or decrease of temperature.

The trends in the diurnal variation of soil temperature were similar across all treatments, as shown by both the maximum diurnal soil temperature and the standard error of the average temperatures (Figs. 6 and 7). Because daily temperature fluctuations are typically smaller in the understories of hemlock forests, it is expected that the diurnal variation of the hemlock stands would be lower than that of the hardwood-only plots. This inconsistency with expected conditions could be due to the depth of the soil temperature readings, where temperature ranges are typically more buffered from air temperature and solar fluctuations at deeper soil depths.

## Species Composition

The effects of girdling can be clearly seen by a significant decrease in mean live basal area for the girdled treatment. The significant decrease in total basal area in the girdled treatment in 2006 and 2007 can be attributed to hemlock mortality, where the mean hemlock basal area significantly decreased from the onset of experimentation in 2004 ( $20 \pm 10 \text{ m}^2\text{ha}^{-1}$ ) to 2007 ( $0.10 \pm 0.05 \text{ m}^2\text{ha}^{-1}$ ; P = 0.003). Such a drastic decrease in hemlock basal area was also reported in New England, in which the hemlock basal area decreased 70% over a 20 year period in a Connecticut forest (Small et al. 2005).

The annual aboveground wood increment was higher in the hardwood treatment than in hemlock treatments for all years, although this difference was not statistically significant until 2007. Although the natural hemlock treatment wood increment did not appear to significantly differ from the hardwood stands until 2007, the effects of girdling can be seen as early as 2006, when the girdled hemlock treatment had a significantly lower wood increment than the hardwood treatment. The decrease in woody biomass increment in the girdled treatment as compared to the hardwood treatment can be attributed to hemlock mortality, as wood increment from hemlock declined in the girdled treatment dramatically from 2005 to 2007. Despite the significantly lower wood increment in the girdled as compared to the hardwood treatment, these effects of girdling were not statistically significant when compared to the natural hemlock treatment, suggesting that HWA may be affecting woody production at a rate comparable to girdling.

The species that seem to be benefiting the most from hemlock mortality in the girdled and natural hemlock plots are black birch (*Betula lenta*) and tulip poplar (*Liriodendron tulipifera*), whose woody biomass increments have increased more in the natural and girdled hemlock treatments than the hardwood treatment. The accelerated mortality by girdling does not seem to affect this response, however, as a sizeable increase in woody increment for these species was seen in both the natural and girdled hemlock treatments. These results suggest that the compositional response to hemlock mortality in the southern Appalachians may be similar to that of the northeastern United States, where Orwig and Foster (1998) found *Betula lenta* seedlings and saplings to be the predominant species that grew beneath the dying hemlock canopy in New England.

Betula lenta replacement has also been observed in areas of the southern Appalachians that lack rhododendron (Ellison et al. 2005), although all of the plots in this study contain a rhododendron subcanopy. It has been predicted that the subcanopy would inhibit seedling recruitment of any species, although this study shows that a subcanopy will not inhibit the increased growth of already-established canopy species. With a subcanopy, it has also been predicted that rhododendron biomass will increase in response to the increased resource availability that accompanies hemlock mortality (Ford and Vose unpublished). An increase in rhododendron biomass has not been observed in this study. To the contrary, *R. maximum* wood increment has actually decreased to a relatively equal extent in all treatment groups. This result could be attributed to an increase in belowground or leaf biomass for *R. maximum*, or perhaps the response of *R. maximum* will be observed with future, increased hemlock mortality. Further examination of species composition trends with hemlock mortality may provide a more apparent trend in these opportunistic replacement species.

## Conclusion

Eastern hemlock (*Tsuga canadensis*) is an economically important foundation species that plays the unique and critical role of moderating and maintaining a specific microclimate in the ecosystem that it inhabits. Because of HWA, mortality of this important tree species is inevitable across the entirety of its range. Although the effects of hemlock mortality have been speculated and studied extensively in the pure hemlock stands of New England, the ecosystem responses to hemlock mortality in hemlock forests of the southern Appalachians are not as well understood. The presence of a thick rhododendron subcanopy and the mixed deciduous nature of these hemlock forests create a potential for unique ecosystem responses that may differ from those seen in New England. Through examination of forests that simulate current and future HWA damage, we have found that hemlock mortality will result in a variety of microclimatic changes. As expected, the loss of this dominant species will result in an increase in light levels reaching the forest floor, elevated soil moisture levels, and an increase in average soil temperature. However, the diurnal and annual variation in soil temperature did not respond to hemlock mortality as expected, with no change in diurnal variation observed between the hemlock and hardwood treatments.

As hemlock mortality progresses, the species composition of HWA-infected southern forests shows a general trend towards resemblance to the composition of a hardwood-deciduous forest, although this trend cannot be accurately assessed this early in the study. While the hemlocks show signs of mortality through decreased live basal area and aboveground wood biomass production, established hardwood species such as *Betula lenta* and *Liriodendron tulipifera* seem to be responding to the accompanying ecosystem responses with increased growth. With the loss of this foundation species, it seems that its accompanying biota and

climatic factors will be lost and replaced by a distinctly different forest type, the dynamics and consequential ecosystem alterations of which we can only speculate.

#### ACKNOWLEDGEMENTS

We would like to thank Brian Kloeppel, Barry Clinton, Anya Hinkle, James Costa, Greg Zausen, Jim Gruhala, and Brennan Bouma for their mentorship, assistance, and contribution to the completion and success of this project.

#### LITERATURE CITED

Anagnostakis, S., and B. Hillman. 1992. Evolution of the chestnut tree and its blight. Arnoldia 52:3-10.

- Barden, L. 1979. Tree replacement in small canopy gaps of a Tsuga canadensis forest in the Southern Appalachians, Tennessee. Oecologia **44**:141-142.
- Battles, J., N. Cleavitt, T. Fahey, and R. Evans. 1995. Vegetation composition and structure in two hemlock stands threatened by hemlock woolly adelgid. Pages 55-61 *in* K. A. McManus, K. S. Shields, and D. R. Souto, editors. Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America. U.S. Department of Agriculture, Forest Service, Newton Square, Pennsylvania, Durham, New Hampshire.
- Beckage, B., J. Clark, B. Clinton, and B. Haines. 2000. A long-term study of tree seedling recruitment in southern Appalachian forests: the effects of canopy gaps and shrub understories. Canadian Journal of Forest Research **30**:1617-1631.
- Boggess, W., and L. Bailey. 1964. Brownfield Woods, Illinois: Woody Vegetation and Changes Since 1925. American Midland Naturalist **71**:392-401.
- Brown, M. 2000. Wild East: A biography of the Great Smoky Mountains. University Press of Florida.
- Canham, C., J. Denslow, W. Platt, J. Runkle, T. Spies, and P. White. 1990. Light regimes beneath closed canopies and tree-fall gaps in temperate and tropical forests. Canadian Journal of Forest Research **20**:620-631.
- Castello, J., D. Leopold, and P. Smallidge. 1995. Pathogens, patterns, and processes in forest ecosystems. BioScience **45**:16-24.
- Clinton, B. 2003. Light, temperature, and soil moisture responses to elevation, evergreen understory, and small canopy gaps in the southern Appalachians. Forest Ecology and Management **186**:243-255.
- Dunn, C. 1986. Shrub layer response to death of *Ulmus americana* in southeastern Wisconsin lowland forests. Bulletin of the Torrey Botanical Club **113**:142-148.
- Ellison, A., M. Bank, B. Clinton, E. Colburn, K. Elliott, C. Ford, D. Foster, B. Kloeppel, J. Knoepp, and G. Lovett. 2005. Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. Frontiers in Ecology and the Environment 3:479-486.
- Eschtruth, A., N. Cleavitt, J. Battles, R. Evans, and T. Fahey. 2006. Vegetation dynamics in declining eastern hemlock stands: 9 years of forest response to hemlock woolly adelgid infestation. Canadian Journal of Forest Research **36**:1435-1450.
- Jenkins, J., J. Aber, and C. Canham. 1999. Hemlock woolly adelgid impacts on community structure and N cycling rates in eastern hemlock forests. Canadian Journal of Forest Research **29**:630-645.
- Kilpatrick, J., A. Weakley, and T. Massengale. 2004. Southern Appalachian conservation assessment. Executive Summary and Regional Overview; Open Space Institute.
- Kizlinski, M., D. Orwig, R. Cobb, and D. Foster. 2002. Direct and indirect ecosystem consequences of an invasive pest on forests dominated by eastern hemlock. Journal of Biogeography **29**:1489-1503.
- Martin, J., B. Kloeppel, T. Schaefer, D. Kimbler, and S. McNulty. 1998. Aboveground biomass and nitrogen allocation of ten deciduous southern Appalachian tree species. Canadian Journal of Forest Research 28:1648-1659.
- McClure, M. 1989. Evidence of a polymorphic life cycle in the hemlock woolly adelgid, *Adelges tsugae* (Homoptera: Adelgidae). Annals of the Entomological Society of America **82**:50-54.
- McClure, M. 1990. Role of wind, birds, deer, and humans in the dispersal of hemlock woolly adelgid (Homoptera: Adelgidae). Environmental Entomology **19**:36-43.
- McClure, M. 1991. Density-dependent feedback and population cycles in *Adelges tsugae* (Homoptera: Adelgidae) on *Tsuga canadensis*. Environmental Entomology **20**:258-264.

- McCormick, J., and R. Platt. 1980. Recovery of an Appalachian forest following the chestnut blight or Catherine Keever-you were right! American Midland Naturalist **104**:264-273.
- Nilsen, E., J. Walker, O. Miller, S. Semones, T. Lei, and B. Clinton. 1986. Inhibition of seedling survival under Rhododendron maximum (Ericaceae): could allelopathy be a cause? 1. American Journal of Botany 86:1597-1605.
- Opler, P. 1978. Insects of American chestnut: possible importance and conservation concern. Pages 83-85 in J. McDonald, editor. Proceedings of The American Chestnut Symposium. West Virginia University Press, Morgantown, West Virginia, USA.
- Orwig, D. 2002. Ecosystem to regional impacts of introduced pests and pathogens: historical context, questions and issues. Journal of Biogeography **29**:1471-1474.
- Orwig, D., and D. Foster. 1998. Forest response to the introduced hemlock woolly adelgid in southern New England, USA. Journal of the Torrey Botanical Society **125**:60-73.
- Orwig, D., D. Foster, and D. Mausel. 2002. Landscape patterns of hemlock decline in New England due to the introduced hemlock woolly adelgid. Journal of Biogeography **29**:1475-1487.
- Rankin, W., and E. Tramer. 2002. Understory succession and the gap regeneration cycle in a *Tsuga canadensis* forest. Canadian Journal of Forest Research **32**:16-23.
- Runkle, J. 1990. Eight years change in an old *Tsuga canadensis* woods affected by beech bark disease. Bulletin of the Torrey Botanical Club **117**:409-419.
- Schafale, M., and A. Weakley. 1990. Classification of the natural communities of North Carolina, third approximation. North Carolina Natural Heritage Program, Division of Parks and Recreation and NC Department of Environment, Health, and Natural Resources, Raleigh, NC.
- Small, M., C. Small, and G. Dreyer. 2005. Changes in a hemlock-dominated forest following woolly adelgid infestation in southern New England. Journal of the Torrey Botanical Society **132**:458-470.
- Souto, D., T. Luther, and B. Chianese. 1996. Past and current status of HWA in eastern and Carolina hemlock stands. Pages 9–15 *in* Proceedings of the First Hemlock Woolly Adelgid Review. USDA Forest Service.
- Stephenson, S. 1986. Changes in a former chestnut-dominated forest after a half century of succession. American Midland Naturalist **116**:173–179.
- Swank, W., and D. Crossley. 1988. Ecological Studies, Vol. 66: Forest Hydrology and Ecology at Coweeta. Springer-Verlag, New York.
- Weckel, M., J. Tirpak, C. Nagy, and R. Christie. 2006. Structural and compositional change in an old-growth eastern hemlock (*Tsuga canadensis*) forest, 1965–2004. Forest Ecology and Management 231:114-118.
- Yorks, T., D. Leopold, and D. Raynal. 2003. Effects of *Tsuga canadensis* mortality on soil water chemistry and understory vegetation: possible consequences of an invasive insect herbivore. Canadian Journal of Forest Research/Revue Canadienne de Recherche Forestiere **33**:1525-1537.
- Young, R., K. Shields, and G. Berlyn. 1995. Hemlock woolly adelgid (Homoptera: Adelgidae): Stylet bundle insertion and feeding sites. Annals of the Entomological Society of America **88**:827-835.

# A CASE STUDY OF THE BOTELER PEAK MOUNTAIN TREASURES AREA IN WESTERN NORTH CAROLINA

#### KATIE L. SUPLER

Abstract. Wilderness areas are protected, natural lands necessary for recreation, wildlife habitat, and many pharmaceuticals. In addition to being valued in terms of its human utility, wilderness holds an intrinsic value that is less quantifiable. The Wilderness Society has identified thirty-five unprotected wildlands in the Nantahala and Pisgah National Forests referred to as "Mountain Treasures Areas." Permanent protection is needed in order to keep these areas safe from the ecological effects of logging and road-building. This paper presents a case study of the Boteler Peak Mountain Treasures Area in the Nantahala National Forest. A comprehensive survey was carried out to determine the accuracy of the current U.S. Forest Service road atlas. Roads were physically ground-truthed and a large number of discrepancies were identified within the current Forest Service road atlas. The Boteler Peak Mountain Treasures Area was also being threatened by a shooting range proposal and a proposed timber sale. This paper emphasizes the need to perform a similar analysis on all thirty-five mountain treasures areas in order to ensure that they still qualify as roadless areas that can be put in front of Congress to obtain a wilderness designation to ensure protection for future generations.

Key words: Buck Creek; Clay County, NC; Forest Service road atlas; logging; mountain treasures area; Nantahala National Forest; roadless areas; The Wilderness Society.

#### INTRODUCTION

"A wilderness, in contrast with those areas where man and his own works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain." -The Wilderness Act, 1964

The Wilderness Society (TWS) is a non-profit conservation organization co-founded in 1935 by well known conservationist Aldo Leopold with the main goal of protecting the country's remaining wild lands. One of the biggest contributions of TWS was helping to get the Wilderness Act of 1964 signed into law. The growing demand of industry to exploit the natural resources in America's wild lands has made it increasingly important to assign wilderness designation to remaining unprotected areas. The Wilderness Act allowed Congress to set aside selected public and federal lands to be kept permanently unchanged by humans, limiting use and access of designated wilderness areas (TWS 2007). Wilderness areas are important for recreation, access to medicinal plants used in many pharmaceuticals, and wildlife habitat.

Today there are approximately 103,226 acres of designated wilderness in North Carolina. About two-thirds of the designated wilderness is within the Nantahala and Pisgah National Forests (McClure, 1993). The U.S. Forest Service (USFS) is currently launching a planned revision for the Nantahala and Pisgah National Forests. In response, TWS is examining the status of the unprotected wild lands in these forests. Unprotected wild areas are referred to as North Carolina's Mountain Treasures and are currently still vulnerable to future timber cutting.

Many of the North Carolina Mountain Treasures Areas encompass or would qualify as roadless areas. A roadless area is defined as having less than one-fourth of a mile of roads per 1,000 acres. Roadless areas make ideal candidates for proposed wilderness areas when the USFS plan comes under review. A wilderness area declaration would protect North Carolina's Mountain Treasures Areas from future road building and logging, preserving them for the enjoyment of future generations.

In 1996 the Southern Appalachian Assessment carried out a roads inventory that classified system roads based mostly on traffic use. Roads considered inadequate to be called system roads were not included (Fig. 1). In 1998 when the USFS created their current road atlas they included a significantly larger number of those roads that had previously been considered inadequate (Fig. 2). When the current USFS road system is compared with that of the Southern Appalachian Assessment inventory in 1996 it is obvious that most of the roads in the area were put into the system after 1996 (Figs. 1 and 2).

Roads have been shown to have major ecological effects. According to Forman and Alexander (1998), an estimated 15-20% of the United States is ecologically impacted by roads. Ten percent of the entire road length in the U.S. is contained in national forests. Roads tend to have a greater environmental impact on national forest land than most other management impacts (Furniss 2000).

Numerous studies have shown the ecological impact of roads to be a cause for major concern. Trombulak and Frissell (2000) concluded that roads have seven general effects in both aquatic and terrestrial ecosystems: mortality from road construction, mortality from collision with vehicles, modification of animal behavior, alteration of the physical environment, alteration of the chemical environment, spread of exotics, and increased use of areas by humans. Roads have been shown to modify the behavior of black bears (Ursus americanus) in North Carolina, causing them to shift their home ranges away from areas with high road densities (Brody and Pelton 1989). Roads alter the physical and chemical environments surrounding them by affecting soil density, pattern of run-off, sedimentation, and introducing heavy metals into the environment (Trombulak and Frissell 2000). Haskell (2000) found that even unpaved roads significantly depressed both the abundance and richness of the macroinvertebrate soil fauna and reduced the depth of the leaf-litter layer. Macroinvertebrates play an important role in the ability of soil to process energy and nutrients, as well as providing prey for certain salamander and bird species (Haskell 2000). It was found that these effects persisted up to 100 meters into the forest producing marked edge effects with potentially damaging consequences on the function and diversity of the surrounding forest.

Switalski (2006) conducted a review of studies that have measured road density thresholds for wildlife and examined the benefits of reducing road density. The majority of studies reviewed concentrated on charismatic megafauna including elk, wolves, bears, lynx, and wolverines. It was concluded that in order to maintain a naturally functioning landscape that would support large mammals, the road density must remain below 0.6km/km<sup>2</sup> (Switalski 2006). Semlitsch et al. (2007) looked at salamander abundance along road edges and within abandoned logging roads in the Nantahala National Forest of North Carolina. They found that plethodontid salamander abundances near roads were significantly reduced when compared with upslope sites



FIG. 1. Boteler Peak roadless area (BPRA) and Boteler Peak Mountain Treasure area (BPMTA) with the 1996 USFS System Roads.



FIG. 2. BPRA and BPMTA with the 2006 USFS system roads and trails.

away from roads. They concluded that the zone containing affected salamanders extended thirtyfive meters into the forest on either side of the low-use road (Semlitsch et al. 2007).

These studies illustrate the importance of avoiding the construction of new roads whenever possible and removing existing roads to benefit the biota of surrounding habitats. The objective of this study was to focus on one unprotected mountain treasures area in the Nantahala National Forest and perform a comprehensive survey of its existing condition. The area chosen for study is sometimes referred to as the Shooting Creek Bald Mountain Treasures Area. This area is mostly comprised of the Boteler Peak roadless area (BPRA) and, accordingly, is referred to in this study as the Boteler Peak Mountain Treasure Area (BPMTA). The BPMTA was used as a case study to determine the accuracy of the USFS 1998 road atlas in relation to the presence and condition of existing forest service system roads. This study should ultimately be applied to each existing unprotected public area in both the Nantahala and Pisgah National Forests to determine if such areas still qualify as roadless, and if so, should be put before Congress as potential wilderness areas.

#### MATERIALS AND METHODS

"There is something about wild country that resonates deeply in the American spirit." - Wallace Stegener

#### Study Area

The BPMTA is approximately 10,676 acres in size with 4,221 acres being roadless area and 917 acres of old growth forest. The BPMTA is located in Clay County, NC, fifteen miles southwest of Franklin, in the Tusquitee Ranger district of the Nantahala National Forest. United



States Geologic Survey (USGS) 7.5 minute topographic maps that include the BPMTA are the Shooting Creek, Rainbow Springs, and Topton quadrangles (Martin 2007).

The BPMTA was chosen for its location, recreation value, presence of old growth forest, and its close proximity to the Buck Creek Natural Heritage Area and a rare mountain bog called Buck Creek

FIG.3. The rough estimated location of old growth forest patches in the Boteler Peak Mountain Treasure Area (BPMTA).

Bog. The BPMTA connects the Tusquitee Bald area to the north and the Southern Nantahala

Wilderness Extension area to the south. This large connection of wild lands served as an important corridor for black bear travel (Martin 2007). In addition, the popular Chunky Gal trail traverses the BPMTA and allowes access to the mountain bog on the eastern ridge of the BPMTA. Two confirmed old growth forest sites were verified near Boteler Peak and Upper Perry Creek (Fig. 3). The first site at Boteler Peak was 794 acres of class B+ old growth and the second site near Upper Perry Creek was 79 acres of class A old growth (Martin 2007). Appendix A contains a summary of the USFS old-growth classification system.

The Buck Creek Natural Heritage Area (BCNHA) is located in the eastern corner of the BPMTA (Appendix B). The BCNHA containes a rare serpentine barren ecosystem. A serpentine barren is a natural community composed of grassland and savanna growing around outcrops of the magnesium rich mineral serpentine. Whittaker (1954) identified three traits common to all serpentine barrens: poor plant productivity, high rates of endemism, and vegetation types distinct from those of neighboring areas. The Buck Creek serpentine barren (BCSB) is the largest of numerous serpentine barrens within the Eastern Blue Ridge province (Berger et al. 2001). The BCNHA is roughly 350 acres. The olivine and serpentine of the BCNHA originated as an oceanic crustal section originating from the suture zone between the African and North American plates during orogeny over 500 million years ago (Pittillo et al. 1998). The BCSB is underlain by ultramafic rocks that were thrust upwards when the two continental plates separated. This process involved the closing of the pre-Atlantic ocean (Iapetus) and the formation of Pangaea roughly 300 million years ago (Pittillo et al. 1998). The BCSB was mined before 1932 and some cuts are still visible on the west-facing dunite outcrop. The BCSB has been periodically burned (Fig. 4) since 1995 in order to maintain the ecosystem.



FIG.4. Burned area in the Buck Creek Serpentine Barren (BCSB).

The BCSB supports many local endemic and rare species that made it a high priority for conservationists (Fig. 4). Four sensitive plants and one sensitive animal species are known to occur on the BCSB as well as thirteen locally rare plants and three rare animals (Mansberg and Wentworth 1984). The BCSB also contains a few disjunct species such as Sporobolus heterolepsis (Dropseed). Senecio plattensis (Platte ragwort), Thalictrum and macrostylum (Piedmont meadow rue). Platte ragwort is usually found in the plains states and Dropseed is most closely found in Arkansas (Mansberg and Wentworth 1984). Chlosyne gorgone (gorgone checkerspot) and Speveria

*aphrodite cullasaja* (Cullasaja aphrodite fritillary), are two extant butterfly species occurring on the serpentine barren (Finnegan 2007). Not included in Appendix A was a population of hornwort (*Megaceros aenigmaticus*) within the roadless area boundary, and several sensitive species whose survival depends on their exact location remaining unknown. It was requested by the North Carolina Heritage Program that the whearabouts of the sensitive species be kept confidential.

#### Materials and Data Collection

The USFS 1998 road atlas and 2003 road atlas data dictionary were used to determine the most recent USFS system road classifications for the roads found in the BPMTA. A total of fifteen USFS system roads were analyzed occurring in or in close proximity to the BPMTA. Parameters of most interest included the operational and objective maintenance levels and the reported mileage of roads in the BPMTA. Appendix B contains some of the most relevant definitions from the USFS road atlas. The roads within and adjacent to the BPMTA were then ground-truthed by walking, biking, or driving each road and comparing the actual physical state of the road to the road atlas data. All ground-truthing was carried out between September and November 2007. A Garmin GPSIII Plus GPS unit was used to mark the coordinate locations of each road and any interesting relevant data such as illegal four-wheel drive vehicle trails. When possible the mileage of a road was measured using a car odometer.

Information on potentially environmentally hazardous activities in the area such as logging projects was obtained with the help of Hugh Irwin, of the Southern Appalachian Forest Coalition, from the United States Department of Agriculture Environmental Assessment. Relevant GPS data such as 2006 aerial photography and topographic maps were obtained from Geocommunity (http://www.geocomm.com/). The GPS roads and trails overlay for the Nantahala Forest was obtained from Gary Wein of the Highlands-Cashiers Land Trust who obtained these files from Geocommunity. The GIS shapefiles for the BCNHA was obtained from the North Carolina Natural Heritage Program. ArcMap version 9.1 software (ESRI Inc. 2005) was used to open and analyze all GIS data.

#### Analysis

The GPS data collected was imported into ArcMap version 9.1 software (ESRI Inc. 2005) and further analyzed. The ArcMap measuring tool was used to estimate the mileage of roads that could not be quantified using a car odometer. Road density was defined as miles of road per 1,000 acres. The density of roads was calculated in three different ways. First, the road density within the roadless boundary was calculated using the ArcMap measuring tool to determine the length of road sections within the roadless area. Second, the same method was used to determine the length of road sections occurring within the BPMTA, strictly following the current boundary on the GIS files. Lastly, the road density was calculated for the BPMTA while taking into account the fact that the current boundary excludes a large portion of roadless lands and should be extended. Most roads are within less than 0.02 miles of the BPMTA boundary. Therefore, the roads are close enough to have a major ecological impact and should be included in the density calculations.

#### RESULTS

<sup>&</sup>quot;If we lose wilderness, we lose forever the knowledge of what the world was and what it might, with understanding and loving husbandry, yet become. These are islands in time -- with nothing to date them on the calendar of mankind. In these areas it is as though a person were looking backward into the ages and forward untold years. Here are bits of eternity, which have a preciousness beyond all accounting."

<sup>-</sup> Harvey Broome, co-founder, The Wilderness Society

The USFS road atlas file is given for each of the fifteen roads analyzed (USFS 1998), followed by a short summary of the actual condition of the road as it was found during ground-truthing. A summary of the USFS road atlas classification system is given in Appendix C. A level one classification road is closed to vehicular traffic. Roads are increasingly developed and maintained as the classification level increases to five (Data Dictionary 2003). Only three of the fifteen roads analyzed showed no discrepancies between the USFS road atlas file and the actual condition of the road (Tables 1 and 2). These included roads 351, 6212, and 350A. Only seven of the fifteen roads analyzed should actually be included as system roads in the road atlas and most of these were in place before 1996 (Table 2). Ten of the fifteen roads contained illegal offroad vehicle trails (Tables 1 and 2).

TABLE 1. Summary of USFS system roads classification in the study area.

Level 1	Level 2	Level 3	Level 4
6226	6212	351	348
351A	6269 section 2	351D	
351B		350 section 1	
351C		350A	
350A1		6236 section 1	
6236 section 2			
6237			
350-1			
6269 section 1			

TABLE 2. Summary of actual physical road classification based on ground-truthing.

Not a system road	Level 1	Level 2	Level 3	Level 4
6226*	350-1*	6212	351*	348*
351A*			350 section 1*	
351B*			350A	
351C*			6236 section 1	
350A1				
6236 section 2				
6237*				
351D*				

*Note:* Road 6269 is the only road not actually classified based on ground-truthing. There was one USFS road atlas unclassified road present in the BPMTA located on the left of road 351, shortly before road 351D. (\* indicates the presence of one or more illegal off-road vehicle trails).

ID: Beg	6226 Jin Termini:	SR 1340		Nam	ie: Vine	EYARD							BMP:		.0000.	EMP:	4.8000			
End	Termini:	DEAD END	0																	
	BMP	EMP	Admin Org	ср	Funo Class	Juris	Lane	Managing Org	Obj ML	Opr ML	PFSR	Prime Mint	Rte Stat	Srvo Life	State -	County		Surf Type	8ys	TSL
_	0000	4.8000	081109		L	F8	1	081109	1	1		FS	EX		NC - CI	AY.		IMP	NFSR	D

## <u>6226:</u>

The USFS classified this road as an Objective Maintenance Level (Obj ML) and Operational Maintenance Level (Opr ML) 1 (See Appendix C). The road was closed, gated, and unmarked. It appeared to possibly be managed by mowing in the beginning, but otherwise no

maintenance was apparent. The road gradually got narrower and more overgrown until it merged into an off-road vehicle trail. Multiple illegal off-road vehicle trails were observed along the length of the road.

The USFS records indicated the road was 4.8 miles long. This appeared to be accurate except that it did not take into account the off-road vehicle trail that continues at the end of the road. The road did not reach the roadless area until approximately mile 1.3 and then after 4.8



FIG. 5. A Rock Mound present along road 6226.

miles an off-road vehicle trail was followed for another 2.6 miles. There was an extensive network of off-road vehicle trails within the roadless area.

It was interesting to note the presence of rock mounds in the woods adjoining this road (Fig. 5). These mounds appeared to be the result of human construction and resemble Native American burial mounds found at similar sites in other locations (Brent Martin, pers. comm.).

ID: 351 Begin Termini: SR 1330 End Termini: BMP EMP Org 0000 5.1750 051105		Nam	e: NEL	SON R	IDGE						BMP:		.0000.	EMP:	6.1790			
BMP EMP .0000 6.1790	Admin Org 081109	CD	Funo Class C	Juris FS	Lane 1	Managing Org 081109	Obj ML 3	Opr ML 3	PFSR POT	Prime Mnt FS	Rte Stat EX	Srve Life C	State - C NC - CL/	ounty AY		Surf Type AGG	Sys NFSR	TSL C

## <u>351:</u>

The USFS classified this road as an Opr ML and Obj ML 3 which is suitable for passenger cars. This appeared accurate as the road was an open gated, gravel road with multiple house plots before the gate. There was evidence of logging along 351. Information on the existing active timber sale had not yet been located at the time of this report. Road 351 ends at a point where an old off-road vehicle trail picks up. The USFS mileage seemed to be accurate at 6.2 miles.

1	ID: 351A Begin Termini:	FDR 351		Name	: MOF	RGAN C	OVE						BMP:		.0000	EMP:	1.3000			
ł	End Termini:	Dead End	i @ Wildlife (	Opening																
	BMP	EMP	Admin Org	CD C	iace.	Juris	Lane	Managing Org	Obj ML	Opr ML	PFSR	Prime Mnt	Rte Stat	Srvo Life	State -	County		Surf Type	8ys	TSL
1	.0000	1.3000	081109		L	FS	1	081109	1	1		FS	EX	18	NC - CI	AY.		AGG	NFSR	D

## 351A:

The USFS called this an Obj ML and Opr ML 1 road but it appeared to be a grassy wildlife corridor. A grassy wildlife corridor refers to an old road bed that is completely overgrown and used as a corridor to facilitate wildlife movement. It was closed, gated, unmarked, and ended at an off-road vehicle path that eventually became too unclear to follow. The road atlas reported the road as ending at a wildlife opening. I determined that it ended in woods. The road paralleled a gravel road that appeared to lead to a building project, probably a

house. Numerous illegal off-road vehicle trails were observed along the road. The reported mileage of 1.3 miles appeared to be accurate. The off-road vehicle path was followed for about another 0.09 miles, as measured in ArcMap, before it became overgrown.

ID: 351B	Name: Bl	RCH CO	VE						BMP:		.0000.	EMP:	.4000			
Begin Termini: FDR 351																
End Termini: DEAD END																
Admin	Fund			Managing	Obj	Opr		Prime	Rte	Srvo		t-		Surf		
EMP EMP Org	CD Clace	June	Lane	org	ML	ML	PESR	MINE	stat	Line	state -	County		туре	sys	TSL
.0000 .4000 081109	L	FS	1	081109	1	1		FS	EX	18	NC - C	LAY		AGG	NFSR	D

# <u>351B:</u>

The USFS classified this road as an Obj ML and Opr ML 1 with basic custodial care. In reality, it was a linear wildlife corridor and no maintenance was apparent. The road was closed, gated, unmarked, and almost completely overgrown. It also appeared to be slightly in the wrong spot on the GPS files. The road was actually closer to 351A than the files show. Road 351B ended in forest. An overgrown off-road vehicle trail was observed at the approximate GPS location of 35.069470N and 83.701143W.

The reported mileage of 0.4 miles seemed to be accurate as measured in ArcMap.

ID: Be En	: 351C gin Termini: d Termini:	FDR 351 DEAD EN	D	Nan	ne: CH/	AIRMAK	ER						BMP:		.0000.	EMP:	1.7000			
	BMP	EMP	Admin Org	CD	Funo Class	Juris	Lane	Managing Org	Obj ML	Opr ML	PFSR	Prime Mnt	Rte Stat	Srvo Life	State -	County		Surf Type	8ys	TSL
_	.0000	1.7000	081109		L	FS	1	081109	1	1		FS	EX	1	NC - CI	AY.		NAT	NFSR	D

#### <u>351C:</u>

The USFS classified this as an Opr ML and Obj ML 1 road. It was gated, closed, and unmarked. It was a linear wildlife opening and no wider than an off-road vehicle trail. There was no maintenance apparent except for the occasional clearing of a tree blocking the trail. The road was also slightly in the wrong spot on the GPS files. In reality road 351C was much closer to road 351A. The USFS reported this road as being 1.7 miles in length. My track log in ArcMap was a little hard to follow from the GPS unit but, it reported the road as being only around one mile long. There is a lot of error associated with this track log as a result of cloud cover and GPS unit error.

ID: 351D Begin Termini:	EDR 351		Name	: PAS	SMORE	ESPUR						BMP:		.0000	EMP:	1.5000			
End Termini:	Dept End	A Midlife C	noning.																
LIM IMITIN.	Deau Lilo	@ mune c	penng																
BMP	EMP	Admin Org	CD 0	Funo Class	Juris	Lane	Managing Org	Obj ML	Opr ML	PFSR	Prime Mnt	Rie Stat	Srvo Life	State -	County		Surf Type	8y6	TSL
.0000	1.5000	081109		L	FS	2	081109	1	3	POT	FS	EX		NC - C	LAY		AGG	NFSR	D

### <u>351D:</u>

The USFS classified this road as an Opr ML level 3 which would mean it was suitable for passenger cars, but this is not the case. This road was closed to passenger vehicles and a linear wildlife corridor. It was grassy and overgrown and thinned a short distance in to no more than an off-road vehicle trail, and eventually ended where a trail picked up. The USFS also recorded this as a two lane road, which was clearly not the case. The Obj ML for this road was classified as a 1. Perhaps since this atlas was made, this road has stopped being maintained. An illegal off-road vehicle trail was observed on the road. The USFS reported this road as being 1.5 miles long. Using the ArcMap measuring tool I calculated the actual road to be 1.15 miles long not

including the trail that continues after the wildlife opening. The GPS file also had this road in a slightly inaccurate location.

ID: 350 Begin Termini: OLD US 64 End Termini: DEAD END	Name: PERRY GA	P			BMP:	.0000 EMP:	9.0140	
Admin BMP EMP Org	Funo CD Class Juris	Managing Lane Org	Obj Opr ML ML	Prime PFSR Mnt	Rte Srvo Stat Life	State - County	Surf Type S	ys TSL
.0000 3.4020 081109 3.4020 9.0140 081109	C FS C FS	1 081109 1 081109	3 3 1 1	FS FS	EX C EX C	NC - CLAY NC - CLAY	AGG NF AGG NF	SR C SR D

## <u>350:</u>

This road was classified into two different sections. The first section was an Opr ML and Obj ML 3 road and suitable for passenger cars. This appeared to be the case as it was a dirt/gravel road. It was gated but the gate was open. The GPS files make it look like 350 did not intersect the new Highway 64 west, but in reality it did. This was evident by looking at the aerial photograph of the area. This added about 0.15 miles of road onto 350. There was an illegal off-road vehicle trail observed on the road at the approximate GPS location of 35.08587N and 83.64234W.

The USFS road atlas listed the first section of road 350 as being 3.4 miles. It was not clear where the boundary was between the first and second section but when this distance was measured using a car odometer the drivable distance of 350 was 4.1 miles. There was some confusion as to what the second section of road may have been. Road 350 split into 6212 and 350-1. Road 350 was supposed to be 9.014 miles in total length with the missing second section being 5.6 miles and a level 1 road. It had been noted that road 6212 may have been absorbed into road 350 in which case the second section includes 6212 which occurred in the road atlas as a separate file. If this was the case, then the record for road 6212 will need to be removed from the USFS road atlas files.

ID: 350A Begin Termini:						BMP:		.0000 E	MP:	.9030									
End Termini:	PRIVATE	ROAD																	
BMP	EMP	Admin Org	CD	Funo Class	Juris	Lane	Managing Org	Obj ML	Opr ML	PFSR	Prime Mint	Rte Stat	Srvo Life	State - Co	unty		Surf Type	8ys	TSL
.0000	9030	081109		L	FS	1	081109	4	3	POT	FS	EX	С	NC - CLA	(		AGG	NFSR	в

## <u>350A:</u>

This road was classified as Opr ML 3 which was suitable for passenger cars, but an Obj ML of 4, which provided a moderate degree of user comfort. This classification was accurate as 350A was really just a continuation of the gravel road 350. The road ended at the junction of 350A1 and a private road which probably explained the Obj ML of four.

The reported mileage of 0.9 miles appeared to be accurate as measured in ArcMap. There was about 0.6 miles of road 350A (measured with the car odometer) that was public before it ended at the junction.

ID: 350A1			Nam	e: LOD	GE							BMP:		.0000.	EMP:	.2000			
Begin Termini:	FDR 350 A																		
End Termini:	DEAD END																		
BMP	EMP	Admin Org	CD	Funo Class	Juris	Lane	Managing Org	Obj ML	Opr ML	PFSR	Prime Mint	Rte Stat	Srvo Life	State -	County		Surf Type	8ys	TSL
.0000	.2000	081109		L	FS	1	081109	1	1		FS	EX	18	NC - CL	AY		NAT	NFSR	D

## <u>350A1:</u>

This road was classified as an Opr ML and Obj ML 1. It was a gated, closed, grassy wildlife corridor. The road was possibly maintained by mowing because the road bed was almost completely grassy. The road bed ended in a field.

The reported mileage of 0.2 miles was relatively accurate, but when measured in ArcMap it was calculated to be around 0.4 miles. This could be due to a GPS error, or the fact that the end of the road was so overgrown that it was not calculated into the distance in the USFS road atlas files.

ID B/ E/	): 6212 egin Termin nd Termini:	I: FDR 350		Nar	me: TAT	ECOV	E						BMP:		.0000.	EMP:	4.7100			
	BMP	EMP	Admin Org	CD	Funo Class	Juris	Lane	Managing Org	Obj ML	Opr ML	PFSR	Prime Mnt	Rte Stat	Srvo Life	State -	County		Surf Type	8ys	TSL
1	.0000	4.7100	081109		L	FS	1	081109	1	2		FS	EX	С	NC - GR	RAHAM		AGG	NFSR	D

## <u>6212:</u>

The USFS classified this as an Opr ML 2, which was suitable for high clearance vehicles, and an Obj ML 1. The road was gated, but the gate was unlocked. It seemed to be a fairly well



FIG. 6. Road 6212 junction with 350-1 on the right.

maintained dirt road which the USFS was calling a fire road. Road 6212 split into road 350-1 on the right after about a 20 minute walk up (Fig. 6). Analysis was only carried out up to the point at which road 6212 intersects the Chunky Gal trail. The entire road was not ground-truthed. The reported mileage of 4.71 miles seemed accurate when measured with the ArcMap measuring tool.

ID: 350-1 Begin Termini: Fi End Termini: D	DR 350 lead End		Nam	ie: THU	NDER S	TRUCK						BMP:		.0000	EMP:	2.0000			
BMP 1	EMP 0000	Admin Org 081109	CD	Funo Class L	Juris FS	Lane 1	Managing Org 081109	Obj ML 1	Opr ML 1	PFSR	Prime Mnt FS	Rte Stat EX	Srve Life IS	State - NC - Cl	County .AY		Surf Type AGG	Sys NFSR	TSL. D

## <u>350-1:</u>

The USFS classified 350-1 as an Opr ML and Obj ML 1 road. Road 350-1 was not separately gated off from where it joined road 6212 (Fig. 5). It had very large patches of huge gravel, but was a dirt road comparable to road 6212 in between the patches. It was possible that

this road was already being reconditioned to aid in a proposed logging project. The gravel looked like it had been laid recently. A probable illegal off-road vehicle trail was observed at the GPS location of 35.10543N and 83.63661W. The reported mileage of the road was two miles. However, when I used the ArcMap measuring tool it reported three miles.

IC B E	D: 6269 legin Termini ind Termini:	: FDR 350		Nar	ne: DAV	ENPOF	रा						BMP:		.0000.	EMP:	3.5000			
	BMP	EMP	Admin Org	CD	Funo Class	Juris	Lane	Managing Org	Obj ML	Opr ML	PFSR	Prime Mnt	Rte Stat	Srvo Life	State -	County		Surf Type	8ys	TSL
	.0000 2.2000	2.2000 3.5000	081109 081109		L	FS FS	1 1	081109 081109	1 1	1 2	POT	FS FS	EX EX	I	NC - CL NC - CL	AY AY		AGG AGG	NFSR NFSR	D

#### <u>6269:</u>

This road was split into two sections. The first section was classified as an Opr ML and Obj ML 1 road. It was gated, closed, and looked like a linear wildlife corridor from the gate. This road was not ground-truthed due to time constraints. The second section was an Opr ML 2 which was suitable for high clearance vehicles, but an Obj ML 1. The road was known to be used by horseback riders. The road split into roads 6269A, 6269B, and 6269C. The current status of this road needs to be confirmed.

The reported mileage for the first section of the road was 2.2 miles, and the second section was 1.3 miles, making a total of 3.5 miles. Using the ArcMap measuring tool the total road mileage was calculated to be 2.1 miles instead of 3.5 miles. This could be due to the high error of the measuring tool.

ID: 348 Begin Termin End Termini:	nl: NEW 64 : NEW 64		Na	me: OLI	D 64 HW	IY						BMP:		.0000.	EMP:	2.3240			
BMP	EMP	Admin Org	CD	Funo Class	Juris	Lane	Managing Org	Obj ML	Opr ML	PFSR	Prime Mnt	Rte Stat	Srvo Life	State -	County		Surf Type	8ys	TOL
.0000	2.3240	081109		L	FS	2	081109	5	4	POT	FS	EX	С	NC - C	LAY		BST	NFSR	^

#### 348:

This road was classified as an Opr ML 4, which provided a moderate degree of user



FIG. 7. A section of road 348.

comfort, and an Obj ML 5, which provided a high degree of user comfort. Road 348 was also listed as being a two lane road. In reality it was a single lane, paved road that is slowly becoming grown over and has a lot of potholes (Fig. 7). No maintenance was apparent. Numerous off-road vehicle trails were observed along this road. The reported mileage of 2.32 miles appeared accurate as measured with a car odometer.

ID: 6236 Name: BARNETT CREE Begin Termini: US 54 End Termini: DEAD END												BMP:		.0000	EMP:	1.5200			
BMP	EMP	Admin Org	CD	Funo Class	Juris	Lane	Managing Org	Obj ML	Opr ML	PFSR	Prime Mnt	Rte Stat	Srvo Life	State -	County		Surf Type	8ys	TOL
1.1080	1.1080 1.5200	081109 081109		Ĺ	FS FS	1	081109 081109	3	3	POT	F8 F8	EX EX	÷	NC - CL NC - CL	AY AY		AGG AGG	NFSR NFSR	D

# <u>6236:</u>

This road was classified into 2 different sections. The first was an Opr ML and Obj ML



FIG. 8. The entrance to road 6236.

3, which was suitable for passenger cars. The second section was an Opr ML and Obj ML 1. This seemed to be accurate as one was able to drive up to the point at which the road was gated and split into trail 381 (as numbered on a 1991 topographic map) on the right. This trail is not labeled on the ground. The level one section was gated, closed, and was a grassy wildlife corridor (Fig. 8). It was really overgrown with no maintenance apparent and the road ended where a trail through the forest continued. The reported mileage of the first section was 1.11 miles and the second was 0.41 miles. This appeared to be accurate using the ArcMap measuring tool.

ID: 6237 Begin Termini:	: US 64 FH	28	Nam	19: BRU	ICE RID	GE						BMP:		.0000.	EMP:	3.8300			
End Termini:	DEAD EN	D																	
BMP	EMP	Admin Org	CD	Funo Class	Juris	Lane	Managing Org	Obj ML	Opr ML	PFSR	Prime Mnt	Rte Stat	Srvo Life	State -	County		Surf Type	8ys	TSL
.0000	3.8300	081109		L	FS	1	081109	1	1		FS	EX	1	NC - CI	AY		NAT	NFSR	D

# <u>6237:</u>

This road was classified as an Opr ML and Obj ML 1. It was a gated, closed, grassy wildlife corridor (Fig. 9). Road 6237 ended in a field that was marked as a game protection area.



There was an illegal off-road vehicle trail leading into two fields located at the approximate GPS location of 35.06950N and 83.64421W. The reported mileage of the road was 3.83 miles. This seemed accurate when measured in ArcMap.

The results of the road density calculations indicate that there is approximately 2.26 miles of road within the BPRA resulting in a total road density of 0.54 miles per 1,000 acres (Table 3). Strictly following the current BPMTA boundary there was about 6.29 miles of road within the BPMTA resulting in a total road density of 0.59 miles per 1,000 acres. If all the roads within less than 0.2 miles of the BPMTA boundary are included there is roughly 29.33 miles of road resulting in a total road density of 2.75 miles per 1,000 acres

FIG. 9. A section of road 6237.

(Table 3) however, this density would be much less once the BPMTA boundary were extended because it would include a larger acreage of roadless area than the current calculation takes into account.

In November of 2007 it became known that there was a Shooting Range proposed in Upper Perry Creek, within the BPMTA (Fig. 10). This would involve the construction of a 1,300 foot access road, the complete clearing of up to three acres of land, and the building of restroom facilities (White 2007).

In August of 2007 the Department of Agriculture proposed the "Thunderstruck Project" timber sale in the northeast corner adjacent to the BPMTA (Fig. 10). The project area would comprise 3,586 acres with 335 acres of timber harvested from nine different areas (Tilley 2007). Part of the project area is traversed by a portion of the Chunky Gal hiking trail. The proposed project would begin in 2008 and take approximately five years to complete. The road activities involved in the project include reconditioning 2.0 miles of road 350-1, constructing 2.0 miles of new classified road, and constructing 0.5 miles of temporary haul road (Tilley 2007).

N within BFAA       Road       Mileage         6226       2.24         6237       0.02         Total Mileage       2.26         Road Density (miles of road/1000 acres)       0.54         B) Within BPMTA (following current boundary line)       Mileage         Road       Mileage         351       0.28         351B       0.4         6226       2.33         SR 1349       0.3         6237       2.03         6236       0.95         Total Mileage       6.29         Road Density (miles of road/1000 acres)       0.59         C) Within BPMTA (including all roads within <0.2       0.3         mi of the boundary line)       551         351B       0.4         6226       4.8         Section of SR 1349       0.3         6237       3.83         6236       1.52         Section of SR 1307       1.2         351A       1.3         6212       4.71         350       4.1         Half of 348       1.4	A) Wishin DDDA	
Road         Mileage           6226         2.24           6237         0.02           Total Mileage         2.26           Road Density (miles of road/1000 acres)         0.54           B) Within BPMTA (following current boundary line)         Mileage           Road         Mileage           351         0.28           351B         0.4           6226         2.33           SR 1349         0.3           6237         2.03           6236         0.95           Total Mileage         6.29           Road Density (miles of road/1000 acres)         0.59           C) Within BPMTA (including all roads within <0.2	A) WUMIN DFKA	Milange
	Koau	Mileage
0.220 $2.24$ $6237$ $0.02$ Total Mileage $2.26$ Road Density (miles of road/1000 acres) $0.54$ B) Within BPMTA (following current boundary line)       Mileage         Road       Mileage $351$ $0.28$ $351B$ $0.4$ $6226$ $2.33$ SR 1349 $0.3$ $6237$ $2.03$ $6236$ $0.95$ Total Mileage $6.29$ Road Density (miles of road/1000 acres) $0.59$ C) Within BPMTA (including all roads within <0.2 mi of the boundary line)	(22)	2.24
6237 $0.02$ Total Mileage $2.26$ Road Density (miles of road/1000 acres) $0.54$ B) Within BPMTA (following current boundary line) $0.54$ Road       Mileage         351 $0.28$ 351B $0.4$ 6226 $2.33$ SR 1349 $0.3$ 6237 $2.03$ 6236 $0.95$ Total Mileage $6.29$ Road Density (miles of road/1000 acres) $0.59$ C) Within BPMTA (including all roads within <0.2 mi of the boundary line)	6226	2.24
Total Mileage       2.26         Road Density (miles of road/1000 acres)       0.54         B) Within BPMTA (following current boundary line)       Mileage         Road       Mileage         351       0.28         351B       0.4         6226       2.33         SR 1349       0.3         6237       2.03         6236       0.95         Total Mileage       6.29         Road Density (miles of road/1000 acres)       0.59         C) Within BPMTA (including all roads within <0.2	6237	0.02
10an Mileage       2.25         Road Density (miles of road/1000 acres)       0.54         B) Within BPMTA (following current boundary line)       Mileage         Road       Mileage         351       0.28         351B       0.4         6226       2.33         SR 1349       0.3         6237       2.03         6236       0.95         Total Mileage       6.29         Road Density (miles of road/1000 acres)       0.59         C) Within BPMTA (including all roads within <0.2 mi of the boundary line)	TT - ( 1 ) ('1	2.24
Road Density (miles of road/1000 acres) $0.54$ B) Within BPMTA (following current boundary line)       Mileage         351 $0.28$ 351B $0.4$ 6226 $2.33$ SR 1349 $0.3$ 6237 $2.03$ 6236 $0.95$ Total Mileage $6.29$ Road       Mileage         C) Within BPMTA (including all roads within <0.2 mi of the boundary line)	I otal Mileage	2.20
B) Within BPMTA (following current boundary line)       Mileage         351       0.28         351B       0.4         6226       2.33         SR 1349       0.3         6237       2.03         6236       0.95         Total Mileage       6.29         Road Density (miles of road/1000 acres)       0.59         C) Within BPMTA (including all roads within <0.2 mi of the boundary line)	Road Density (miles of road/1000 acres)	0.54
B) winn BFMTA (jolowing current boundary line)       Mileage         351       0.28         351B       0.4         6226       2.33         SR 1349       0.3         6237       2.03         6236       0.95         Total Mileage       6.29         Road       0.59         C) Within BPMTA (including all roads within <0.2 million of the boundary line)	D) With in DDMTA (6. 11-11-11-11-11-11-11-11-11-11-11-11-11-	
Koad         Mileage           351         0.28           351B         0.4           6226         2.33           SR 1349         0.3           6237         2.03           6236         0.95           Total Mileage         6.29           Road Density (miles of road/1000 acres)         0.59           C) Within BPMTA (including all roads within <0.2	B) within BPMIA (Jouowing current boundary line)	NC1
351 $0.28$ $351B$ $0.4$ $6226$ $2.33$ $SR 1349$ $0.3$ $6237$ $2.03$ $6236$ $0.95$ Total Mileage $6.29$ Road Density (miles of road/1000 acres) $0.59$ C) Within BPMTA (including all roads within <0.2 mi of the boundary line)	Road	Mileage
351 $0.28$ $351$ B $0.4$ $6226$ $2.33$ $SR 1349$ $0.3$ $6237$ $2.03$ $6236$ $0.95$ Total Mileage $6.29$ Road Density (miles of road/1000 acres) $0.59$ C) Within BPMTA (including all roads within <0.2	251	0.29
3315       0.4 $6226$ 2.33         SR 1349       0.3 $6237$ 2.03 $6236$ 0.95         Total Mileage       6.29         Road Density (miles of road/1000 acres)       0.59         C) Within BPMTA (including all roads within <0.2 mi of the boundary line)	551 251D	0.28
0.220       2.33         SR 1349       0.3         6237       2.03         6236       0.95         Total Mileage       6.29         Road Density (miles of road/1000 acres)       0.59         C) Within BPMTA (including all roads within <0.2 mi of the boundary line)	551D (226	0.4
SR 1349       0.3         6237       2.03         6236       0.95         Total Mileage       6.29         Road Density (miles of road/1000 acres)       0.59         C) Within BPMTA (including all roads within <0.2	0220 SP 1240	2.33
6237 $2.03$ $6236$ $0.95$ Total Mileage $6.29$ Road Density (miles of road/1000 acres) $0.59$ C) Within BPMTA (including all roads within <0.2 mi of the boundary line)	SK 1349	0.3
6236 $0.95$ Total Mileage $6.29$ Road Density (miles of road/1000 acres) $0.59$ C) Within BPMTA (including all roads within <0.2 mi of the boundary line)	6237	2.03
Total Mileage $6.29$ Road Density (miles of road/1000 acres) $0.59$ C) Within BPMTA (including all roads within <0.2 mi of the boundary line)	6236	0.95
Road Density (miles of road/1000 acres) $0.29$ C) Within BPMTA (including all roads within <0.2 mi of the boundary line)	Total Mileage	6 29
C) Within BPMTA (including all roads within <0.2 mi of the boundary line)       Nileage         351       5.51         351B       0.4         6226       4.8         Section of SR 1349       0.3         6237       3.83         6236       1.52         Section of SR 1307       1.2         351D       1.46         351A       1.3         6212       4.71         350       4.1         Half of 348       1.4	Road Density (miles of road/1000 acres)	0.59
C) Within BPMTA (including all roads within <0.2 mi of the boundary line)       Road       Mileage         351       5.51         351B       0.4         6226       4.8         Section of SR 1349       0.3         6237       3.83         6236       1.52         Section of SR 1307       1.2         351D       1.46         351A       1.3         6212       4.71         350       4.1         Half of 348       1.4	Road Density (nines of road/rooo acres)	0.39
C) within DFMTR (including all rotats within <0.2 million of the boundary line)       Nileage         Road       Mileage         351       5.51         351B       0.4         6226       4.8         Section of SR 1349       0.3         6237       3.83         6236       1.52         Section of SR 1307       1.2         351D       1.46         351A       1.3         6212       4.71         350       4.1         Half of 348       1.4	C) Within RPMTA (including all roads within $< 0.2$	
Road         Mileage           351         5.51           351B         0.4           6226         4.8           Section of SR 1349         0.3           6237         3.83           6236         1.52           Section of SR 1307         1.2           351D         1.46           351A         1.3           6212         4.71           350         4.1           Half of 348         1.4	(1) within DI MITA (including all rodus within $(0.2)$	
Xoad         Mileage           351         5.51           351B         0.4           6226         4.8           Section of SR 1349         0.3           6237         3.83           6236         1.52           Section of SR 1307         1.2           351D         1.46           351A         1.3           6212         4.71           350         4.1           Half of 348         1.4	Pond	Milanga
351       5.51         351B       0.4         6226       4.8         Section of SR 1349       0.3         6237       3.83         6236       1.52         Section of SR 1307       1.2         351D       1.46         351A       1.3         6212       4.71         350       4.1         Half of 348       1.4	Koau	Willeage
351B       0.4         6226       4.8         Section of SR 1349       0.3         6237       3.83         6236       1.52         Section of SR 1307       1.2         351D       1.46         351A       1.3         6212       4.71         350       4.1         Half of 348       1.4	351	5.51
6226       4.8         Section of SR 1349       0.3         6237       3.83         6236       1.52         Section of SR 1307       1.2         351D       1.46         351A       1.3         6212       4.1         350       4.1         Half of 348       1.4	351B	0.4
Section of SR 1349       0.3         6237       3.83         6236       1.52         Section of SR 1307       1.2         351D       1.46         351A       1.3         6212       4.71         350       4.1         Half of 348       1.4	6226	4.8
6237       3.83         6236       1.52         Section of SR 1307       1.2         351D       1.46         351A       1.3         6212       4.71         350       4.1         Half of 348       1.4	Section of SR 1349	0.3
6236       1.52         Section of SR 1307       1.2         351D       1.46         351A       1.3         6212       4.71         350       4.1         Half of 348       1.4	6237	3.83
Section of SR 1307       1.2         351D       1.46         351A       1.3         6212       4.71         350       4.1         Half of 348       1.4	6236	1 52
351D     1.46       351A     1.3       6212     4.71       350     4.1       Half of 348     1.4	Section of SR 1307	12
351A       1.3         6212       4.71         350       4.1         Half of 348       1.4	351D	1.46
6212     4.71       350     4.1       Half of 348     1.4       Total Mileage     29.3	351D 351A	13
350     4.1       Half of 348     1.4       Total Mileage     29.3	6212	4 71
Half of 3481.4Total Mileage29.3	350	4.71
Total Mileage 29.3	Ualf of 348	4.1 1 <i>4</i>
Total Mileage 29.3	11a11 UI 340	1.4
	Total Mileage	29.3
Road Density (miles of road/1000 acres) 2.75 (this density would actually be much lower if the	Road Density (miles of road/1000 acres)	2.75 (this density would actually be much lower if the
BPMTA acreage is expanded)		BPMTA acreage is expanded)

TABLE 3. Total mileage of roads and calculated road density within the BPRA and the BPMTA.

*Note:* Roads SR 1349 and SR 1307 are state roads and are not included in the USFS road atlas. However, they contribute to the road density and have ecological effects on the BPMTA.

•


FIG. 10. Proposed environmental hazards affecting the BPMTA. This includes the proposed shooting range at Perry Creek and the Thunderstruck Timber Sale Project.

### DISCUSSION

#### "In wildness is the preservation of the world." - Henry David Thoreau

The principal objective of this study was to present a case study of a mountain treasures area in need of wilderness designation. One aspect that aids in obtaining a wilderness designation is that the area qualify as roadless. When the existing USFS road atlas was compared to the actual physical state of the roads in the study area it was found to be incorrect in the majority of its system road classifications (Tables 1 and 2). The fact that so many level 1 roads found in the atlas are not suitable as system roads indicates that the USFS road atlas that was put into place in 1998 likely "grandfathered" in many old unmaintained and unneeded roads as system roads. These roads need to be reconsidered in terms of need, environmental impacts, and maintenance feasibility. Given realistic road budgets it seems unlikely that the USFS will be able to maintain these roads as system roads. Keeping roads on the system for the sole reason that they may be of use someday is not acceptable given their ongoing and significant environmental impacts (Irwin 2006). These impacts include physical changes on the landscape, constraints on the movement of species, and providing avenues for illegal off-road vehicle use (Table 2).

In the BPMTA alone there is more road mileage than can be realistically maintained by the USFS. Updating the current road atlas and removing these roads from the system is a necessary step the USFS needs to take. Proposed roads to be taken off of the system include all those listed as a non-system road in Table 2.

Based on my estimated road density calculations BPRA no longer qualified as a roadless area because it had about 0.54 miles of road per 1,000 acres instead of the required 0.25 miles or less. The only road mileage actually occurring inside the roadless boundary was from roads 6226 and 6237, both of which are linear wildlife openings that should not be classified as system roads in the USFS road atlas. If both roads were officially decommissioned and removed from the road atlas, BPRA would continue to qualify as a roadless area. It is discouraging to think about how many similar situations must exist within the other Mountain Treasure Areas.

The proposed shooting range in Perry Creek and the "Thunderstruck Project" timber sale both pose significant threats to the BPMTA. The construction of the shooting range would be very invasive to the BPMTA in terms of land clearing, new access road construction, and increased noise levels. Shooting practices would also have an ecological effect on the area. The lead from shotgun casings has been shown to persist in the environment for extended periods of time with negative effects on vegetation (Mozafar et al. 2002). This includes both the soil and the surrounding stream systems and groundwater.

The stands proposed for logging are within the BPMTA and could potentially disrupt the wildlife connector between the Southern Nantahala Wilderness Extension and the Tusquitee Bald Area. The proposed stands are also in close proximity to the BCNHA and the Chunky Gal trail. Logging across the Chunky Gal trail will have a negative impact on recreation in the area. This is a popular trail with a trail guide that is sold by the USFS in some of the ranger stations (Irwin 2007). A project that will potentially carry on over five years will deter the public from enjoying this beautiful area. The potential negative impacts on the rare species found in the BCNHA are unknown. Logging in such a unique environment would not be in the best interest of ecosystem health or the public to whom this land belongs.

Several of the proposed logging stands contain trees of very old ages, upwards of 118 years with some up to 153 years (Irwin 2007). Given the rarity of old-growth habitat any remaining old growth areas should be protected. A few proposed stands also appear to be rich cove forests and rare boulderfield forest that are uncommon and should be conserved (Irwin 2007). Research has shown that harvesting old growth and mature forest will release more carbon than can be sequestered by young forests (Harmon et al. 1990, Dixon et al. 1994, and Houghton et al. 1999). The USFS should consider the impact of the policies and actions on carbon emissions and should be attempting to reduce their carbon footprint by allowing old growth forests to remain and act as sources of carbon sequestration.

The "Thunderstruck Project" would include the construction of new and temporary roads in undeveloped areas within the BPMTA. The negative effects of roads are most profound in wild lands and the USFS should concentrate on removing system roads that are no longer maintained instead of constructing new roads. Total road density within the BPMTA should be decreased.

In the future, all Mountain Treasure Areas would benefit from a similar analysis reporting on their present conditions. If any of these areas are going to be put before of Congress as possible wilderness areas it needs to be determined whether they still in fact qualify. An analysis of this type would be improved with the use of a GPS unit that records mileage, and has less error associated with it on overcast days. This would cut down on the need to use the ArcMap measuring tool to determine mileage, which also has a high degree of error associated with it. Continued research into the ecological impacts of roads in the area would provide insight, as well as a comprehensive survey of the biodiversity present in the area. It was also brought to our attention that the roadless area boundary was drawn in away from many of the surrounding roads, putatively, to protect from noise. However, the current boundary line excluded a large portion of roadless land that will need to be included in a protected area. The boundary of the roadless area should be extended to include as much roadless land as possible.

In conclusion, the importance of confirming the current physical condition of the Mountain Treasure Areas cannot be ignored. Ground-truthing the BPMTA provided insight into just how outdated the USFS system road atlas is. This will prove detrimental to obtaining a wilderness declaration for many Mountain Treasure Areas that would qualify as roadless if the road atlas was updated to only include the minimum number of roads that will be realistically needed and maintained. The utilitarian and intrinsic value of wilderness should not be taken for granted. The replication of similar projects in the future will aid in the procurement of more public lands as wilderness, for the benefit of all Americans.

### ACKNOWLEDGMENTS

I thank Brent Martin for taking me on as an intern with The Wilderness Society and providing all the direction for this project. I thank Gary Wein for the necessary GIS data and skills. I thank Hugh Irwin for providing the Mountain Treasures Areas GIS files and information on the Thunderstruck Project. I thank Dr. Anya Hinkle and Dr. J for her time editing.

#### LITERATURE CITED

- Berger, S., D. Cochrane, K. Simons, I. Savov, J.G. Ryan, and V.L. Peterson 2001. Insights from rare earth elements into the genesis of the Buck Creek Complex, Clay County, NC. Southeastern Ecology **40**:201-212.
- Brody, A. J. and M.R. Pelton. 1989. Effects of roads on black bear movements in Western North Carolina. Wildlife Society Bulletin 17:5-10.
- Data Dictionary Sub-Team: Travel Routes Road User Board. 2003. Travel Routes: National Data Dictionary ROADS. Version 1.3.
- Dixon, R. K., A. M. Solomon, S. Brown, R. A. Houghton, M. C. Trexier, and J. Wisniewski. 1994. Carbon pools and flux of global forest ecosystems. Science 263:185-190.
- ESRI Inc. 2005. ArcMap 9.1. Redlands, CA.
- Finnegan, J. 2007. GIS data. North Carolina Natural Heritage Program. 5 Nov. 2007. < <u>fttp://nhpout:ardswomo@149.168.1.198/></u>.
- Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecological Systems 29:207-231.
- Furniss, M. J. 2000. Roads analysis: informing decisions about managing the National Forest transportation system. Watershed Management and Operations Management, USA.
- Harmon, M. E., W. K. Ferrell, and J. F. Franklin. 1990. Effects of carbon storage of conversion of old-growth forests to young forests. Science 247:699-702.
- Haskell, D. G. 2000. Effects of forest roads on macroinvertebrate soil fauna of the southern Appalachian mountains. Conservation Biology **14**:57-63.
- Houghton, R. A., J. L. Hackler, and K. T. Lawrence. 1999. The U.S. carbon budget: contributions from land-use change. Science **285**:574–578.
- Irwin, H. 2007. Letter in response to the Thunderstruck Project Environmental Assessment. Southern Appalachian Forest Coalition, USA.
- Mansberg, L., and T. R. Wentworth 1984. Vegetation and soils of a serpentine barren in western North Carolina. Bulletin of the Torrey Botanical Club **111** (3):273-286.
- Martin, B. 2007. North Carolina's mountain treasures: the unprotected wildlands of the Nantahala and Pisgah National Forests. The Wilderness Society, USA.
- McClure, T. J. 1993. North Carolina's mountain treasures: the unprotected wildlands of the Nantahala and Pisgah National Forests. The Wilderness Society, USA.
- Mozafar, A., R. Ruh, P. Klingel, H. Gamper, S. Egli, and E. Frossard. 2002. Effect of heavy metal contaminated shooting range soils on mycorrhizal colonization of roots and metal uptake by leek. Environmental Monitoring and Assessment 79:177-191.
- Pitillo, J.D., R. D. Hatcher, Jr., and S. W. Buol 1998. Introduction to the environmental and vegetation of the southern Blue Ridge Province. Castanea 63(3):202-216.
- Semlitsch, R. D., T. J. Ryan, K. Hamed, M. Chatfield, B. Drehman, N. Pekarek, M. Spath, and A. Watland. 2007. Salamander abundance along road edges and forests. Conservation Biology 21:159-167.
- Switalski, A. 2006. How many is too many: a review of road density thresholds for wildlife. Wildlands CPR Winter Solstice 14:6-8.
- The Wilderness Society. 2007. Washington, D.C. 26 Nov. 2007 < http://wilderness.org/ourissues/wilderness/>.
- Tilley, T. 2007. Environmental Assessment: Thunderstruck Project. Tusquitee Ranger District, Nantahala National Forest, USA.
- Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18-30.
- United States Forest Service Roads Atlas. 1998. Travel Routes.
- White, M. A. 2007. Clay County Shooting Range Scoping Letter. Tusquitee Ranger District. File Code: 1950.

Whittaker, R.H. 1954. The ecology of serpentine soils. Ecology 35:258-259.

#### APPENDIX A: A summary of the USFS old growth classification system.

The forest service old growth classification system considers classes A, B+, and B sites to be old growth. Class C and candidate sites are not considered old growth. A summary of the class characteristics is shown.

**Class A:** hard core old-growth: old growth forests where no significant signs of human disturbance to the forest canopy or under-story could be determined. Canopies are dominated by older trees generally over 150 years of age. One hundred and fifty years is considered an appropriate coarse filter for old-growth candidacy as this corresponds to a period when logging was limited to areas near early settlement sites.

**Class B+:** contains both hard and soft core old growth: old-growth forests that have both class A and class B characteristics. Sites in this class tend to be large, with numerous forest communities, making it difficult to categorize the whole site. Uncut forests with canopy trees at or above 150 years may be present in these sites, yet the effects of disturbances such as blow-downs, American chestnut blight, or fire may be present in other forest communities within the site.

**Class B:** soft core old growth: old-growth forests exhibiting one of two different conditions: 1) the canopy is dominated by old-growth trees, yet signs of past human disturbance to the forest canopy or under-story were found (generally a half century ago or longer). These stands have often been heavily impacted by American chestnut blight. Culling may also have occurred. 2) no sign of past human disturbance could be confirmed, yet the forest canopy is dominated by younger forest. These stands can range from 100 to 150 years in age and were possibly affected by natural disturbances.

**Class C:** forests with obvious signs of past human disturbance, yet containing appreciable old trees in the canopy or higher tree diversity than surrounding forests. Forests in this class are suitable for oldgrowth recovery. Some sites in this class are small. Others form buffers for class A, B+, or B oldgrowth. Forests in this class usually did not have extensive field work done in them due to time constraints.

**Candidate Sites:** are considered worthy of a site visit due to a nomination, steep topography, or lack of access. These sites can show up as large uninventoried stands in USFS data.

Appendix B: Location of Natural Heritage Areas in and near the BPMTA, and some of the rare element occurrences present.



#### **APPENDIX C:** A summary of the relevant USFS road atlas terms found in the data dictionary.

Admin\_Org: The USFS unit where the route segment physically resides or the primary USFS unit served by the route segment.

**Begin\_Termini:** A description of where the route begins.

BMP: Beginning measure point of the route. Measured in miles.

County: State and County/Borough/Parish/Township in which the route segment physically resides.

EMP: Ending measure point of the route. Measured in miles.

**End\_Termini:** A description of where the route ends.

**Functional Class (Func Class)**: The way a road services land and resource management needs, and the character of service it provides.

A- arterial class: provides service to large land areas and usually connects with other arterial roads or public highways.

**C- collector**: provides service to smaller land areas than an arterial road. It ususually connects forest arterial roads to local forest roads or terminal facilities.

**L- local**: Connects terminal facilities with forest collector or arterial roads or public highways. Usually local roads are single purpose transportation facilities.

**ID**: The official identifier of the route. In general the ID should be the same identifier that is signed on the ground.

**Juris:** Jurisdiction. The legal right to control or regulate use of a transportation facility. Jurisdiction requires authority, but not necessarily ownership. The authority to construct or maintain a road may be derived from fee title, an easement, an agreement, or some other similar method. (FS – Forest Service)

Lanes: The number of lanes the travel way has.

**Managing\_Org:** The USFS unit (region/forest/district) that has long-term responsibility for the management of the route segment.

Name: The common name of the route.

**Objective Maintenance Level (Obj ML):** The maintenance level to be assigned at a future date considering future road management objectives, traffic needs, budget constraints, and environmental concerns. (SUV is considered high clearance vehicles)

(a typical low standard timber sale road is usually operated at a higher maintanence level during the sale than afterwards. Typically these roads have an operational maintanence level of 2 and an objective maintanence level of 1)

- 1- Basic Custodial Care (closed) : Assigned to intermittent service roads during time they are closed to vehicular traffic
- 2- High Clearance Vehicles : assigned to roads operated for use by high clearance vehicles
- **3-** Suitable for Passenger Cars: Assigned to roads operated and maintained for travel by a prudent driver in a standard passenger car.
- 4- Moderate degree of user comfort: assigned to roads that provide a moderate degree of user comfort and convenience at moderate travel speeds
- 5- High degree of user comfort : assigned to roads that provide a high degree of user comfort and convenience.
- C- convert use : convert use of the facility to another use such as a trail.
- **D- decommission**: assigned to roads that have been or are to be decommissioned.

**Operational Maintenance Level (Opr ML):** The maintenance level currently assigned to the road considering today's needs, road condition, budget constraints and environmental concerns; in other words it defines the level to which the road is currently being maintained. (If a road is being operated at a maintenance level of 1, it should also have a service life of I-intermittent term service or IS- Intermittent Stored Service).

- 1- Basic Custodial Care (closed) : Assigned to intermittent service roads during time they are closed to vehicular traffic
- 2- High Clearance Vehicles : assigned to roads operated for use by high clearance vehicles
- **3-** Suitable for Passenger Cars: Assigned to roads operated and maintained for travel by a prudent driver in a standard passenger car.
- 4- Moderate degree of user comfort: assigned to roads that provide a moderate degree of user comfort and convenience at moderate travel speeds
- 5- High degree of user comfort : assigned to roads that provide a high degree of user comfort and convenience.

**PFSR Classification:** A public Forest Service Road (PFSR) is a designated public road under Forest Service jurisdiction that meets the definition of 23 U.S.C. Section 101. The PFSR classification indicates the status of PFSR designation. (DSG – designated PRSR; POT – potential PFSR)

**Primary Maintainer (Prime Mnt):** The agency or party having primary (largest share) financial responsibility for maintenance. (FS – Forest Service).

**Route:** A road or trail that is signed and managed as a unique entity. Management can change along its length but it is singularly identified. This term is also used in GIS to denote a linear feature composed of one or more arcs or parts of arcs.

Route Status (Rte Stat): Current physical state of being of the route segment.

**CV – Converted:** A route that was no longer needed and has been converted to another use.

**DE – Decommissioned:** A route that was no longer needed and has been removed from service.

**EX – Existing:** A route that physically exists.

PL - Planned: Planned route identified in a completed NEPA document, with a

record of decision.

Service Life (Srvc Life): The length of time that a facility is expected to provide a specified service.

C – Long Term Service: Coninuous or annual recurrent service.

I – Intermittent Term Service: A road which is closed to vehicle traffic between

periods of use. The closed period must exceed one year.

IS - Intermittent Stored Service: Intermittent service road, closed to traffic.

The road is in a condition that there is little resource risk if maintenance is not Performed (self-maintaining).

**S** – **Short Term Service:** Short term use (including temporary roads).

Surface Type: The wearing course; usually designed to resist skidding, traffic abrasion, and the disintegrating effects of weather.

AC – Asphalt: Asphaltic Concrete.

AGG – Crushed Aggregate or Gravel: Crushed or screened graded material.

**BST – Bituminous Surface Treatment:** Built up surface of asphalt emulsion and aggregate, not a dust palliative.

**CSOIL – Compacted Soil:** Compacted Native Material.

**FSOIL – Frozen Soil:** Template has been cleared and rough shape completed but can't be used until frozen conditions exist.

IMP - Improved Native Material: Imported or processed material (pit run,

select burrow, or admixture added to the surface soil and compacted).

NAT – Native Material: No imported or processed materials.

**OTHER – Other:** Other surface type – specify in remarks.

**P** – **Paved:** Unknown manufactured hard surface.

PCC - Portland Cement Concrete: Portland Cement Concrete.

**System (SYS):** A network of travel ways serving a common need or purpose, managed by an entity with the authority to finance, build, operate and maintain the routes. (NFSR – National Forest System Road).

**Traffic Service Level (TSL):** A description of the road's significant traffic characteristics and operating conditions. A – Free Flowing Mixed Traffic: Free flowing, mixed traffic; stable, smooth

surface. Provides safe service to all traffic.

**B** – **Congested During Heavy Traffic:** Congested during heavy traffic, slower

speeds and periodic dust; accumulates any legal-size load or vehicle.

**C – Flow Interrupted – Use Limited:** Interrupted traffic flow, limited passing facilities, may not accommodate some vehicles. Low design speeds. Unstable surface under certain traffic or weather.

**D** – **Slow Flow or May be Blocked:** Traffic flow is slow and may be blocked by management activities. Two-way traffic is difficult, backing may be required. Rough and irregular surface. Travel with low clearance vehicles is difficult. Single purpose facility.

# ANAEROBIC DIGESTION OF MUNICIPAL SOILID WASTE AS SUPPLEMENTARY SOURCE OF BIOGAS FOR THE JACKSON COUNTY GREEN ENERGY PARK

## ANNA VANDENBERGH

Abstract. The Jackson County Green Energy Park (JCGEP) has capped a landfill that reached its maximum capacity and is currently drawing biogas to be used as fuel for artisan studios (in the near future) and heating boilers. The biogas (50% methane 50% carbon dioxide) coming from the capped landfill is currently copious but their supply can only last approximately 20-25 years. In addition there are potential for problems with having enough biogas to run the studios and boilers at the same time. By creating a supplemental "clean" supply of biogas for the park, an anaerobic digester (AD) could be beneficial for securing a productive future for the park. An AD system would not only supplement the biogas it would also lessen the amount of the organic fraction of municipal solid waste (OFMSW) going into the new landfill. The end product from an AD system not only includes a fairly clean source of biogas but also a liquid fertilizer and a nutrient rich digestate which can be sold or used by the JCGEP. All in all an AD system will work at the JCGEP but it is a major effort that involves county and community participation. This paper discusses anaerobic digestion as a process and as a system for producing biogas, and issues surrounding digester systems in hopes of supplying a foundation of research for the JCGEP.

Key words: anaerobic digesters; biogas; landfill; methane; municipal solid waste

### INTRODUCTION

As fuel prices increase and the threat of global warming resounds across the nation there is increased incentive and pressure to utilize alternative energy sources. The JCGEP in Dillsboro, North Carolina, is responding to this need and pressure. The JCGEP is utilizing a landfill that has reached its capacity and is in the process of using the biogas produced by the decaying waste as fuel for various artisan workshops and greenhouses. Fig. 1 shows a schematic of the park with both future and existing buildings. Currently the blacksmithing studio, greenhouses, and a tenant-leased building have been built (in some cases renovation of existing buildings). The blacksmithing studio and the tenant leased building are using biogas for heat and fuel. For such a small town to set precedent by becoming "green" before many other larger and certainly capable cities is admirable. Although the biogas is currently being used infrequently by the park it is flared off when not needed (producing  $CO_2$  and water vapor) which prevents approximately 222 tons of methane from escaping into the atmosphere every year.

Methane is a significant greenhouse gas due to its ability to absorb and trap heat, with 27 times the heat-trapping efficiency of carbon dioxide. The gas coming from the landfill is expected to reach its peak in 20-25 years, which brings interesting questions to the table. Will this make the park obsolete after that time? Will those artisan studios, workshops, and greenhouses be fueled by other sources if they can no longer be fueled by the biogas? With the park, once fully up and running, be able to pull enough biogas from the landfill to run all the studios and boilers for which it provides fuel? The possible solution to these concerns and

questions could be supplementing the biogas by adding an anaerobic digester (AD) to the park. Of course an AD would not only supplement the park's fuel reserve but also divert the organic fraction of municipal solid waste (OFMSW) from the new landfill.

The municipal solid waste (MSW) stream in North Carolina is a variable mix of paper, glass, metals, plastics, food waste, and many other materials. The MSW stream is currently being reduced by recycling programs for glass, paper, metals, and some plastics. Of those products being recycled, paper is the only organic material accounted

for currently. Private composting diverts some of the food waste from landfills but a significant portion still makes it into landfills.



FIG. 1. The Jackson County Green Energy Park footprint for both existing and future buildings most of which will require fuel from the landfill.

According to the Environmental Protection Agency (EPA) in 2005 the United States generated 29.2 million tons of food waste, of which only 2.4% was recovered by composting (EPA 2005). Yard trimmings also make up a significant portion of the waste stream at 13.1% in 2005 and 12.9% in 2007 (Fig. 2). Both of these materials are considered in the organic fraction of MSW and have a potential to be used for an AD system. Jackson County, NC, produces significant amounts of waste. In 2005 alone, Jackson County produced 52,674 tons of solid waste, of this 18,000 tons were managed for by recycling (NCDENR 2006). The county is home to a hospital, a number of k-12 public schools, Western Carolina University, a paper plant,



FIG. 2. The MSW stream for the US. Food scraps make up a significant portion of the waste stream at 12.4%. (EPA, 2006).

restaurants. and numerous many residences all of which produce digestible waste. Close to 25% of MSW generated in Jackson County could be digested in an AD system and used as fuel at the JCGEP. It costs approximately \$55 per ton to throw away MSW in Jackson County (Parker 2007). By reducing MSW an AD system will save the county and its residents money and reduce the amount of waste going into the new landfill.

Food waste going into the landfill is decomposed by bacterial communities, some of which produce methane. Anaerobic digestion is defined as "the conversion of organic matter into carbon dioxide, methane, and sludge by employing bacteria in an oxygen-depleted environment" (Ostrem 2004). The methane produced from this process is relatively clean and has the potential to be stored. A liquid and sludge digestate is also formed during anaerobic digestion which can be sold, given away, or used by the park as fertilizer.

In this paper, I will further discuss the complex process of anaerobic digestion, the capacity of an AD system, the pretreatment of OFMSW, the parameters for running a successful anaerobic digester for producing methane, the end products of anaerobic digestion, feasible digester systems, and potential sources of waste material. This will hopefully provide a foundation for deciding whether or not such a system will work in Jackson County.

# MATERIALS AND METHODS

My objective was to find recent research relating to anaerobic digestion of MSW in the United States. This was particularly difficult because the research for treating MSW in the United States is new and not yet published. One of the main and probably the best sources I worked with was a master's thesis on anaerobic digestion for treating OFMSW written by Karena Ostrem in 2004. Another crucial resource was a feasibility study of anaerobic digestion of MSW and agricultural waste in Northern Ireland published in 2002. The North Carolina Department of Energy and Natural Resources (NCDENR) solid waste reports and the EPA's report on MSW also provided valuable information on the MSW generation in Jackson County and the US.

### **RESULTS/ DISCUSSION**

## Anaerobic Digestion of Organics

Anaerobic digestion is a complex process comprising of four main chemical reactions: hydrolysis, acidogenesis, acetagenesis, and methanogenesis. Digestion occurs at different rates for all carbon-containing materials. OFMSW contains a wide variety of materials such that it requires "an intricate series of metabolic reactions to be degraded" (Ostrem 2004) (Fig. 3). Hydrolysis occurs first with the organic material and specialized hydrolic and/or fermentive bacteria. In this process soluble organics are broken down into insoluble organics and soluble monomers. For example proteins are converted to amino acids and starches are converted into simple sugars (Ostrem 2004). This can be a very slow process, dependent on the complexity of the organic material entering the system (also called feedstock). The resulting material then goes through acidogenesis which produces short chain acids, ketones, and alcohols. These acids, ketones, and alcohols then go through the next stage of digestion, acetagenesis. Acetagenesis breaks down carbohydrates and produces acetate, carbon dioxide, and hydrogen gas (Ostrem 2004). In this step it is crucial that there is a population of hydrogen scavenging bacteria to consume the hydrogen and reduce the partial pressure of the system. The partial pressure must be low enough to ensure the proper thermodynamics that result in the conversion of the acids from acidogenesis. This causes the pH to decrease which in turn provides a stable environment for the acidophilic bacteria. Lastly, methanogenesis occurs when the pH becomes more neutral. The slow growing, methanogenic bacteria, turn what is left in the system into biogas by way of converting alcohol into methane. It is very crucial during this stage for the system to be above a pH of 6 to guarantee survival of the methanogenic (both aceticlastic and hydrogen utilizing)



FIG. 3. This diagram depicts the steps and products of anaerobic digestion (Ostrem, 2004).

bacterial populations (Ostrem 2004, Ostrem et al. 2004, Carucci et al. 2005, and Liu et al. 2007). The result is biogas (methane, carbon dioxide, and trace amounts of other gases), a liquid and sludge digestate.

# Products of Anaerobic Digestion

After anaerobic digestion has completely broken down organic matter main materials three are available for further use: a liquid digestate, sludge and biogas. The digestate, biogas generally contains high levels of methane and some carbon dioxide. Between 80- $150m^{3}$ of biogas can be

produced by approximately one ton of organic waste material (Ostrem 2004). This biogas can be introduced directly into the current fuel stream at the JCGEP. Another way to use this biogas would be to remove the carbon dioxide, trace amounts of other gases (hydrogen sulfide and ammonia), and store it much like natural gas (Ostrem 2004) According to Ostrem (2004) the fuel equivalents of 100m<sup>3</sup> of biogas would be significant (Table 1).

The digestate produced is both in the liquid and sludge form. The liquid digestate can be released into the sewage system although it is biologically active and contains high levels of nutrients. The liquid digestate can be used for pretreatment of the waste (discussed later in this

TABLE 1. Fuel type and fuel amounts equivalent to  $100m^3$  of biogas produced by an AD system (Ostrem 2004).

Fuel Type	Fuel Equivalent
Gasoline	15 gal
Electricity	170 kWh
Heat	250 kWh

paper). It can also be sold, given back to the community, or used in the green houses as a liquid fertilizer. The sludge digestate is also very biologically active and nutrient rich. It initially has high moisture content and is slightly odorous. The sludge digestate can be "dewatered", removing 30% of the water in the sludge making it easier to transport. The sludge digestate can also be sold, given back to the community, and or used by the JCGEP for use in the

greenhouses and on-site landscaping. There are, however, potential problems with contamination of the digestate that will be discussed later in this paper.

# Pretreatment of Organics

For an AD system to have a high production it is very beneficial to first pre-treat the waste before adding it into the system. The first and probably one of the most crucial

pretreatments is separation of potential contaminants like glass, metal, and plastics (i.e nonorganics). This can be done mechanically or physically (different systems use different means of removing contaminants). Next shredding or pulping the material to reduce the particle size also helps to increase the productivity of the AD system. The reduction in the particle size creates a pulp or a sludge that has higher surface areas which is advantageous for the digester bacteria and also helps to reduce over all retention time (Gunaseelan 1997, Ostrem 2004). Gunaseelan (1997) reports that the particle size reduction is beneficial but unnecessary and uneconomical to reduce the particles to below 0.088 mm. Dilution is also a useful pretreatment that is especially necessary for the anaerobic digestion of high solids characterized by the OFMSW. This allows for free movement of bacteria throughout the system. Suspending the waste in water is also a way to remove some contaminants (i.e plastics that float can be removed from the surface). One way to increase production is to use the liquid digestate produced by the system for dilution. Initially this will not be applicable until the system has run and produced LD. According to Nguyen et al. (2005), it is possible that micro-aeration of the waste helps to increase methanogenic activity because methanogenesis is established early (time wise) before becoming completely anaerobic. Other types of mechanical pretreatment depend on the type of the system, which will be discussed later in this paper.

Chemical and thermal pretreatments can also increase productivity of the system by initially increasing the amount of soluble compounds. An alkali treatment, like NaOH, can be added to boost the pH and help degrade the insoluble fats. Together with raising the initial temperature of the system, this can help to increase the rate of hydrolysis which tends to be slower than acidogenesis and acetagenesis. Temperature will be explored later as a parameter that can be altered to affect the reaction rates within an AD system.



#### Parameters for a Successful Anaerobic Digester

One of the key parameters for running a successful digester is pH (Fig. 4). The pH of anaerobic digestion changes naturally throughout the digestion process. It is crucial that the digester remains in the range of 5-8 to ensure bacterial growth and survival. During hydrolysis there is a potential for acid accumulation if the pH of the starting solution is even slightly acidic. A buffer must be added to the system to drive the methanogenic bacteria to begin forming. These sensitive bacteria require a more neutral pH to flourish in the system. Methanogens optimal pH range is between 7.0—7.2 but will still function at a range of 6.7-7.4 (Ostrem 2004).

Temperature is also an important parameter in maintaining a successful an AD (Fig 5). A digester system is generally either set up for thermophilic or mesophilic bacteria. Thermophilic bacteria are very sensitive and conditions must be kept at an optimum range with little contamination. Because OFMSW has a high potential for contaminants and would require more energy to be put into the system a thermophilic digester is not recommended for the JCGEP. Alternatively mesophilic digesters would be much more suitable. Mesophilic bacteria are more robust and respond more favorably with changing conditions but degrade material much slower than thermophilic bacteria. The optimal temperature for mesophilc bacteria is somewhere between 20–35°C.



FIG. 5. Temperature affects an anaerobic digester systems ability to produce biogas. The first peak in this diagram is mesophilic bacterial methane production and the second peak is thermophilc bacterial methane production (Liu et al. 2007).

Monitoring the carbon-to-nitrogen ratio is important in maintaining health of the AD system. Carbon enters the system through most of the materials being digested, but paper is considered the main source of carbon in an AD. The nitrogen in the system mainly comes from protein rich materials like food wastes. Too much nitrogen causes the ammonia to build up, makes the system become too basic and lowers the quality of the digestate. The addition of more carbon leads to a much faster consumption of nitrogen and in turn lowers the amount of methane produced (Mahony and O'Flaherty 2002).

Retention time is key to getting viable products from an AD. A longer retention time leads to a more complete degradation of the waste materials and better end products. This time ranges from 3—30 days depending on choice of quality digestate and biogas. Processes with shorter retention times have less biogas produced and less overall degradation. Having a shorter retention time is more suitable for facilities handling copious amounts of waste (Ostrem 2004). For the JCGEP, having a moderate-long retention time would be feasible if the system was both large and a continuously fed system.

### Feasible Systems

There are two main processes of AD systems that are useable for digestion of OFMSW: continuous process and batch process. Continually fed digesters maximize efficiency by

constantly digesting something. The waste is loaded either multiple times in one day or each day (Gunaseelan 1997). A batch digester on the other hand is only loaded once. Material is placed in a batch digester and sealed for the length of the digestion process. Both systems have advantages and disadvantages. I would suggest that the JCGEP to have a continuous system since waste may come into the park irregularly and because Jackson County is relatively small with modest amounts of waste.

There are also single stage or multiple stage digesters. In single stage digesters every step of the digestion process occurs in a single tank. This can be a little more complicated to operate because the pH must be monitored regularly. The multiple stage system sets optimal conditions



FIG. 6. The Kompogas system developed in Switzerland can digest 5,000-100,000 metric tons of waste per year (Ostrem 2004).

for each stage within each Most commonly tank. two staged systems are where set up methanogenesis occurs in one tank and all other reactions take place in another (Wang et al. 2002). The disadvantage of this type of system is that it has a larger therefore footprint, requiring a larger area, and initial cost of the system is higher than the single stage digester. One system that would be recommended would be

the Kompogas<sup>®</sup> system designed in Switzerland (Fig. 6). It is a single

staged digester that can process from 5,000-100,000 metric tons of waste per year (Ostrem 2004). The system also has turbines inside the digester that help to mix the waste and create a more homogenous system (Mahony et al. 2002). Only one of the cylindrical tanks would be needed, processing about 10,000 metric tons per year. Another feasible system is the HIMET system. This was developed by Gas Technologies, Incorporated and is a multiple stage process. The waste is loaded into the first chamber and goes though hydrolysis, acidogenesis, and acetagenesis with a retention time of 1-3 days. Then the waste goes into a second tank where methanogenesis occurs with a retention time of 7-10 days (Ostrem 2004). Their much smaller tank size and high methane biogas make them an optimal choice for the JCGEP. Electrigaz<sup>®</sup> is a newer company that tailors its AD systems to each client. A system capable of digesting all of Jackson County's food waste would cost approximately \$2,103,602 and produce 1,887,102m<sup>3</sup> per year (Electrigaz 2007).

### **Conclusions**

In conclusion, the JCGEP could benefit from having an AD system. The next step in this process would be finding the funding for such a system. Another important step would be raising public awareness to this new addition to the park through newspaper articles and advertisements. Because it takes a high level of community involvement, it is crucial to survey residents as well as businesses to find out if they would be willing to sort out food waste from their normal waste stream. Getting the county involved in a pick-up system for the food waste within city limits might increase the willingness of the community to get involved. Overall, supplementing the biogas at the park is a huge benefit of an AD system. Saving space in the landfill and creating new jobs is also beneficial, not only to the park but also to the residents of Jackson County.

#### ACKNOWLEDGEMENTS

I would like to thank my mentor Tim Muth and Carrie Blaskowski of the JCGEP. I would also like to thank Dr. Anya Hinkle and Dr. Jim Costa of the Highlands Biological Station.

#### LITERATURE CITED

- Carucci, G., F. Carrasco, K. Trifoni, M. Majone, and M. Beccari. 2005. Anaerobic digestion of food industry wastes: Effect of codigestion on methane yield. Journal of Environmental Engineering **131**:1037-1045.
- Environmental Protection Agency (EPA). 2005. Municipal solid waste in the United States: 2005 facts and figures. USEPA 2005.
- Environmental Protection Agency (EPA). 2006. Municipal solid waste in the United States: 2006 facts and figures. USEPA 2006.
- Gunaseelan, V. N. 1997. Anaerobic digestion of biomass for methane production: A review. Biomass and Bioenergy 13:83-114.
- Liu, C., X. Yuan, G. Zeng, W. Li, and J. Li. 2007. Prediction of methane yield at optimum pH for anaerobic digestion of organic fraction of municipal solid waste. Bioresource Technology **99**: 882-888.
- Mahony, T., and V. O'Flaherty. 2002. Feasibility study for centralised anaerobic digestion for the treatment of various wastes and wastewaters in sensitive catchment areas. Ireland Environmental Protection Agency, R&D series 16.
- North Carolina Department of Environment and Natural Resources (NCDENR), Division of Waste Management. 2006. North Carolina solid waste management annual report: July 1<sup>st</sup> 2005-June 30<sup>th</sup> 2006. NCDENR: http://www.wastenotnc.org/swhome/AR05-06.pdf
- Nguyen, P. H. L., P. Kuruparan, and C. Visanathan. 2005. Anaerobic digestion of municipal solid waste as a treatment prior to landfill. Bioresource Technology **98**:380-387.
- Ostrem, K. M. 2004. Greening waste: Anaerobic digestion for treating the organic fraction of municipal solid waste. Masters thesis, Columbia University New York, NY.
- Ostrem, K. M., K. Millrath, and N. J. M. Themelis. 2004. Combining anaerobic digestion and waste to energy. 12<sup>th</sup> North American Waste to Energy Conference **12**.
- Parker, Chad. 2007. Solid waste. Jackson County, North Carolina. http://solidwaste.jacksonnc.org
- Wang, J. Y., H. L. Xu, and J. H. Tay. 2002. A hybrid two-phase system for anaerobic digestion of food waste. Water Science and Technology 45:159-165.

## HYBRIDIZATION IN THE FERN GENUS DRYOPTERIS

### SALLY S. WHISLER AND THOMAS M. GOFORTH

Abstract. In this study, we investigated a group of ferns in a high elevation acidic cove which appeared to include new hybrids. Intermediate Wood Fern (*Dryopteris intermedia*) and the mountain wood fern (*D. campyloptera*) are the two established species in the study. Samples were analyzed for morphological characters and sorted into groups of similar morphology. Ordination analysis was performed with PC-ORD v. 5 to examine the relative similarity between samples. A group of *D. intermedia* was found with very consistent morphologies. The majority of the samples appeared to be *D. campyloptera* with a large range of morphologies. Two other groups were found, one which is most likely a hexaploid hybrid backcross between *D. intermedia* and *D. campyloptera*. Another group of hybrids was not easily attributed to the phenotypes in *D. intermedia* or *D. campyloptera*.

*Key words: Dryopteris campyloptera; Dryopteris intermedia; hybridization; non multidimensional scaling ordination; polyploid formation.* 

### INTRODUCTION

One important way in which ferns differ from flowering plants is that they have a free living gametophyte generation (Fig. 1). When the spore is dispersed from the parent plant, it travels by wind and forms a free-living gametophyte which supports the sexual organs, holding the egg and the sperm. When species of the same genus occur together, it provides the opportunity for gametophytes of each species to develop next to each other, allowing sperm of one species to fertilize the egg of a different species gametophyte. This process, called hybridization, is one of the evolutionary drivers in the creation of new species in ferns (Moran 2004). Hybrids can form whenever two gametophytes are very close to each other. However, the hybrids that are produced are typically sterile, due to the lack of homologous chromosome pairs. To persist in the habitat, the sterile hybrid species must go through polyploidy to become fertile. The formation of polyploid individuals usually starts with a mistake in the meiosis process where the number of chromosomes for each spore is not reduced in the usual manner. These spores with twice the usual number of chromosomes give rise to gametophytes in which the gametes also each have two or more sets of chromosomes rather than one set. If this gametophyte selffertilizes, the offspring produced will have twice the numbers of chromosomes as the parent (Moran 2004). Hybrids that have formed fertile, polyploid offspring are more evolutionarily significant than their sterile predecessors because they reproduce; they can evolve independently of the parent plants and can establish a range beyond the parent range. Often, hybrids can be differentiated by morphology and sometimes a sterile hybrid can be differentiated from a fertile polyploid hybrid.

In studies of comparative morphology, non-multidimensional scaling (NMS) is a useful tool for examining the relationship between samples and for grouping samples by similarity. This is an ordination based analysis method which assigns a coordinate value to each specimen based on its characters, then plots all the samples on a multi-dimensional graph and compares the

similarities of the samples by their location and distance on the graph. NMS ordination is considered the most accurate choice for examination of data without a preconceived specific



FIG. 1. Life cycle of ferns (Milinski 2004).

explanatory hypothesis of sample relationships (McCune and Grace 2002). This method is useful to differentiate morphological variation among samples of unknown lineage.

The processes of hybridization and polyploidy examined in this study involve species in the genus Dryopteris that occur together. From South Carolina west to the Mississippi River and north to southern Canada, there are 12 known fertile species in the Dryopteris genus: six diploid, five tetraploid, and one hexaploid. At this time, only one fertile hexaploid species, D. clintoniana, has been identified. One diploid species, inferred in the genetic profile of the fertile tetraploids D. cristata and D. carthusiana has never been found (FONA 1993). Dryopteris species ranges vary by latitude and elevation, as well as by regional geology and soil conditions. Some species occur together in common habitats, providing opportunities for hybridization.

This study examines a *Dryopteris* population near the Blue Ridge Parkway in the Appalachian Mountains of North Carolina. The research site was initially identified as having probable hybrids that involve *D. intermedia*, *D. campyloptera*, *D. expansa*, *D. carthusiana*, *D. cristata*, and the hypothetical diploid species *D. semicristata*. The site is at the extreme southern range limit of *D. campyloptera* and near the southern range limit of *D. intermedia*, *D. carthusiana and D. cristata*. Dryopteris expansa has not been documented in the region. In this paper, we will report on the findings from morphological examination of 99 samples from this *Dryopteris* population. We will identify the samples that belong to one of the parent species, document *Dryopteris* hybrids in the study population, and determine the characters in the hybrids that distinguish them from the parent species.

#### METHODS

#### Study Site

The study area is located on a northwest facing forested slope on National Park Service land along the Blue Ridge Parkway in Jackson County, North Carolina, at approximately 1700 meters in elevation. The site has varied density tree canopy, very acidic and organically rich A horizon soil (Burton Series), and substrates of biotite granite gneiss and biotite schist. The site generally corresponds to a Red Spruce-Fraser Fir forest (Herb Subtype to Birch Transition Herb Subtype) as described in Classification of the <u>Natural Communities of North Carolina, Fourth Approximation</u> (Schafale 2002). The most abundant canopy species is *Picea rubens* with scattered *Betula alleghaniesis, Betula papyrifera, Abies fraseri, Aesculus octandra*, and *Fagus* 

grandifolia. Canopy cover varies from 60-90%. The herb layer includes *Dennstaedtia* punctilobula, Athyrium asplenioides, Thelypteris noveboracensis, Huperzia lucidula, Aster divaricatus, and Rubus spp. The pH varies from 4.9 to 5.1 across the study site.



FIG. 2. Photo of a Dryopteris individual in the



FIG. 3. Map of study area from Jackson County Quadrangle with inset showing location of the site within North Carolina.

# Data Collection

The study plot was selected as a rectangle approximately 75 meters long and 25 meters wide on a forested northwest facing slope (Fig. 2). *Dryopteris* species occur in the plot in dense and dispersed colonies and as scattered individual plants. Over two collection days (10 September 2007 and 17 September 2007) 99 specimens were collected from the site. First, four *Dryopteris* individuals in close proximity and with varying morphologies were located. A yard staple with a plastic tag was placed in the ground as close to the first chosen plant as possible, marked with the ID number of the plant, both in sharpie and etched on the tag. In addition, a flag was placed around the base of the plant and another flag on a tree above the plant to mark the location. The most representative frond from the plant was collected from the parent plant at the base of the stipe. The reflex and twist angles of basal pinna were measured and recorded on the sheet. This protocol was repeated with the other three fronds in the location, after which a new group of four was chosen.

Pressed fronds were measured and scored for morphological characters contained in the description protocol (Table 1). Prior to collection, a list of morphological characters was created as a description protocol for the sample. The protocol was based on taxonomic references in FONA (1993), Lellinger (1985), Weakley (2006), Thorne and Thorne (1989), Radford et al.

(1968) and Lellinger (pers. comm.). Characters were included for a broad range of *Dryopteris* species that may have had a historical genetic influence on this population. During morphological analysis, characters were added to and removed from the description protocol to fully capture variation within the samples. The measurements were recorded in a spreadsheet of 99 fronds described by 36 morphological characters. For input into PC-ORD v. 5 (McCune and Grace 2002), the data set was translated into binary code, with 23 morphological characters evaluated as a presence-absence.

Character	State		
Frond dissection	Number pinnate-pinnatifid: 2, 21, 3, 31, 4		
Frond length (mm)	cont., mm		
Stipe length (mm)	cont., mm		
Stipe length/frond length	cont., ratio		
Blade Length (mm)	cont., mm		
Blade width (mm)	cont., mm		
Blade length/blade width	cont., ratio		
Basal pinna shape	1-deltate, 2-lanceolate		
Basal pinna length (mm)	cont., mm		
Longest pinna number (from blade base)	count		
Blade broadest at base	yes-1, no-2		
Basal pinna length/Blade Width	cont., ratio		
Asymmetrical pinna pairs	Number count = or > $10\%$ asymmetry		
Blade glands	yes-1, no-2		
Sorus glands	yes-1, no-2		
Trichomes	yes-1, no-2		
Scale color	clear-1, tan-2, brown-3		
Scale center stripe	yes-1, no-2		
Scale irregular darker in center	yes-1, no-2		
Scale darker at base	yes-1, no-2		
1st basal basiscopic pinna pinnule much closer to	yes-1, no-2		
2nd acroscopic pinnule			
Basal pinna pinnules	opposite-1, alternate-2		
1st basal basiscopic pinnule twice as wide as 1st	yes-1, no-2		
acroscopic			
1st basal basiscopic pinnule not much wider than 1st	yes-1, no-2		
Basal ninna basisconic first ninnule length	cont mm		
Basal pinna basiscopic second pinnule length	cont mm		
First hasiscopic pinnule length/second hasiscopic	cont. ratio		
pinnule length			
Basal pinna acroscopic first pinnule length	cont., mm		
First basiscopic pinnule/first acroscopic pinnule	cont., ratio		
Equal number of basiscopic and acroscopic pinnules	yes-1, no-2		
on basal pinna			
Uneven number of pinnules on every pinna pair	yes-1, no-2		
Sorus location	marginal-1, medial-2, sub-mar-3, sub-med-4		
Evergreen	yes-1, no-2		
Number of vascular bundles	count		
Blade shape estimate	ovate lanceolate-1, lanceolate-2, ovate-3		

TABLE 1. Morphological features examined on all samples, (cont. = continuous).

### Data Analysis

Analysis of the data set was done using PC-ORD v 5.0. In PC-ORD, we used the Non-Multidimensional Scaling (NMS) ordination and cluster analysis to determine groupings among the samples. The accepted method for NMS analysis (McCune and Grace 2002) in PCORD was conducted as follows: autopilot mode was used and the Sorenson (Bray-Curtis) distance measure was selected. The entire data set was put through all three levels of the autopilot mode, and all three of these analyses recommended a three-dimensional solution with an acceptable stress level of 16.21. NMS manual ordination was then performed with a three axis solution using the Sorenson (Bray-Curtis) distance measure.

Agglomerative cluster analysis was performed in PC-ORD to analyze similarity between frond samples by using hierarchical grouping based on the development of a dissimilarity matrix using algorithms to combine groups with the lowest dissimilarity values (McCune and Grace 2002). The Sorensen (Bray-Curtis) distance measure was used. This cluster analysis produced low dissimilarity values for a 6 group solution. The two and three dimensional scatter plot graphs and the cluster dendrograms were used to visually evaluate the suitability of groups.

We examined the characters important in determining membership in the groups through a repeated process of sorting. Characters which had similar results in most of the group members were recorded as influential in determination of group membership. The sample fronds were physically placed in the indicated groups and examined visually to confirm the accuracy of the groups dictated by PC-ORD.

#### RESULTS

# Initial Morphological Findings

In the morphological examination of the samples, *D. intermedia* samples were easily identified due to the high length-to-width ratio narrow shape of the blade. Upon further examination, the presence of glandular trichomes confirmed their identification as *D. intermedia*. The morphologies also indicated a large amount of variation within the group identified as *D. campyloptera*. Generally, wider and more deltate blades with exaggerated basiscopic pinnules on the basal pinna identified the *D. campyloptera* samples. There were several samples that appeared to have a mixture of characters expected in *D. intermedia* and *D. campyloptera*. Surprisingly, glandular trichomes were not found on any of the possible hybrid samples. Glandular trichomes were expected to be displayed in sterile hybrids involving *D. intermedia* (Thorne and Thorne 1989, FONA 1993). The initial morphological examination also identified important characters for differentiating *D. intermedia* and *D. campyloptera*. Specifically, the pinnules on the basal pinna pair showed repeating patterns in the relative width and length of the first basiscopic and first acroscopic pinnules. Also, the relative lengths of the first basiscopic and second basiscopic pinnules appeared important.

## Initial Ordination

The initial ordination on the main data set, with 99 samples and 23 characters, indicated that 6 groups were appropriate, as seen on the 3D scatter plot below (Fig. 4). The 6 groups were fairly tightly clustered, particularly the samples representing *D. intermedia* (yellow). Samples

that were initially identified as *D. campyloptera* appear in several of these groups, (light blue, dark blue, red and magenta) as morphological variation within the group of *D. campyloptera* was large. The green group appears to include hybrids as do individuals included in the magenta and red groups.



FIG. 4. 3D scatter plot of samples representing similarity. Colors represent the groups found in cluster analysis.

FIG. 5. Cluster dendrogram, showing which samples were placed in each group.

The determining characters in distinguishing between *D. campyloptera* samples and hybrids were confirmed through the initial ordination. The characters representing the size of the frond, which is mostly a function of the age of the individual, seem to be less influential on the identification of the sample. Blade shape was determined by the location of the longest pinna pair and the ratio of blade length to blade width. Blade shape is an important characteristic, as the literature indicates that *D. intermedia* has a more narrow acuminate-lanceolate blade shape and *D. campyloptera* has a wider, oblong-ovate blade shape. These characters are important to examine outside of the ordination analysis, but are not useful in dictating group membership between *D. campyloptera* and hybrids due to the relatively small differences in blade shape and the subjective nature of shape assessment. Color variation in stipe scales was also shown to be less informative because of the fairly random distribution of markings, not correlated with other morphological patterns. The presence of a variety of markings on the stipe scales was originally

considered very significant because only *D. expansa* is described as having stipe scale stripes. The presence of stripes on some stipe scales was then taken as an indication that there was genetic influence from *D. expansa* in the population (FONA 1993).

Based on morphological description and analysis and on published sources, the most definitive taxonomic characters among the study ferns are: (1) presence or absence of glandular trichomes; (2) frond shape; (3) basal pinna shape; and (4) size relationships between pinnules on the basal pinna pair. These characters are shown for each group in Table 2.

	Dryopteris intermedia	Dryopteris campyloptera	Hexaploid D. campyloptera × D. intermedia	<i>Dryopteris</i> sp. (possible hybrid)
Lamina glandular trichomes	+			
Frond shape lanceolate	+			
Frond shape deltate/lanceolate			+	+
Frond shape deltate		+		
Basal pinna lanceolate	+			
Basal pinna deltate/lanceolate			+	+
Basal pinna broadly deltate		+		+
First basal basiscopic pinnule longest		+		+
First basal basiscopic pinnule twice as long as opposite		+		+
First basal basiscopic pinnule twice as wide as opposite acroscopic pinnule		+		

TABLE 2. Summary of definitive morphological characteristic for each Dryopteris study group.

As seen in Fig. 6, the blade of *D. intermedia* is much narrower and more lanceolate than the blade of *D. campyloptera*. The first basiscopic pinna is shorter than the second basiscopic pinnule and the basiscopic pinnules are less than two times the length of the acroscopic pinnules. *Dryopteris campyloptera* is defined by exaggerated basiscopic pinnules on the basal pinna, with the first basiscopic pinnule much longer than the second and 3 to 5 times longer than the first acroscopic pinnule. The blade shape is much wider and more ovate-deltate in shape. Hybrid 1 represents the possible hexaploid cross between *D. intermedia* and *D. campyloptera*. Hybrid 2 represents the samples that do not have a close resemblance to any of the previous groups.



FIG. 6. Blade shape and basal pinna configurations for representative fronds of each of the four morphological groups.

## Ordination with Reduced Characters

We found that distilling the character list to those that specifically address basal pinna shape, frond shape, presence of glandular trichomes, the comparative lengths and widths of the first basiscopic and the first acroscopic pinnules on the basal pair and the comparative lengths of the first basiscopic and second basiscopic pinnules allowed preliminary conclusions to surface. The results shown in Figs. 7-8 the relation between the samples based on characters addressed above. Cluster analysis produced four tightly clustered groups, *D. intermedia*, *D. campyloptera*, the probable hexaploid hybrid of *D. intermedia*  $\times$  *D. campyloptera*, and a group of individuals



FIG. 7. Cluster graph of Reduced Character Ordination showing effects of "Basal Pinna Deltate" character. The graph on top right shows the scatter plot of all the samples, with the larger symbols representing the effect of the character. The other two graphs show the determining effect of this character on the position of the *D. campyloptera* samples.

that did not easily fit into any of the above categories. As shown in Fig. 7, the group of *D. campyloptera* is defined partially by basal pinna of a distinctly deltate shape. Since the membership in the fourth group is very small, consisting of only two samples, an outlier analysis was performed on the data set to see if these two samples were skewing the data. However, the result did not show these two samples were outliers. Therefore. they are considered their own group, an undefined hybrid Dryopteris species.



FIG. 8. Scatter plot of the ordination with the reduced character list. The colors represent the four morphological groups.

### the parents of *D. campyloptera*.

### Description of Ferns

Nine samples were identified as D. intermedia. These samples display glandular trichomes sparsely to densely spread over the blade and stipe. Other defining characters of the D. intermedia samples are blade shape and basal pinnule arrangement. In these nine samples, the blades were much longer and narrower than other fronds in the study, characteristic of a lanceolate shaped blade. Also, the basal pinna pair display an ovate shape rather than the deltate shape in *D. campyloptera*. The first basiscopic pinnules were shorter than the second basiscopic pinnules. The first basiscopic pinnules were less than two times longer than and less than two times wider than the first acroscopic pinnules. These characters defined these nine samples as D. intermedia, one of

Fifty-two of the samples appear to be *D. campyloptera*. There is significant variation in morphology within the *D. campyloptera* group, with a wide range of blade shapes and basal pinnule arrangements. Although the shape of the fronds varied significantly, overall the fronds exhibited a more ovate or ovate-lanceolate shape than the *D. intermedia* samples. The basal pinna were mostly deltate in shape, one of the classic characters of the species (FONA 1993). The basal pinnule arrangement exhibited variation as well, but many fit the classic description of the species with first basiscopic pinnules much longer than the second pinnules and more than twice the length and width of the first acroscopic pinnules. The exaggerated first basiscopic pinnule and the length of the first pinna pair at times caused the blade to appear ovate-deltate, with a very broad base. Overall, the *D. campyloptera* samples appeared much broader and lusher, characters present in the other parent, *D. expansa*.

Thirty-seven samples represent a possible backcross of *D. campyloptera* with *D. intermedia*. These samples displayed characters of both species in frond shape, basal pinnule configuration and basal pinna shape. The most interesting character in this group was the complete lack of glandular trichomes. Trichomes have been documented in sterile triploid products of this backcross and were expected in this sample group. The lack of glandular trichomes suggests that these are in fact hexaploid hybrids, the result of a polyploidy event in one or more of the triploid hybrids. The blade shape of these samples is much wider and more ovate than the *D. intermedia*. Also, many had deltate shaped basal pinna, another characteristic distinguishing this species from *D. campyloptera*. However, the configuration of pinnules on the basal pinna pair had traits distinct to both groups, namely first basiscopic pinnules which were shorter than the second basiscopic pinnules, but more than twice as long and wide as the first acroscopic pinnules. An interesting characteristic was seen on many of these samples. The first

basiscopic pinnule was often closer to the second acroscopic pinnule than the first acroscopic pinnule. This unusual pinnule arrangement was recorded by Thorne and Thorne (1989) as being common in *D. intermedia*  $\times$  *D. campyloptera* crosses. Seventeen specimens in the group of potential *D. intermedia*  $\times$  *D. campyloptera* hybrids have characters suggestive of a hexaploid hybrid of *D. intermedia and D. campyloptera*. Documentation of this hybrid has not found elsewhere. The hybrid has morphology intermediate between its parents but lacks glandular trichomes of the triploid *D. intermedia*  $\times$  *D. campyloptera* criteria crited in the literature (Thorne and Thorne 1989, Montgomery 1982). Twenty specimens in the group of potential *D. intermedia*  $\times$  *D. campyloptera* hybrids have characters similar to *D. campyloptera* but not consistent with the hexaploid described above. The morphological divergence from *D. campyloptera* in this group is low to moderate, generally relating to size relationships of basal basiscopic and acroscopic pinnules. Some of these specimens may ultimately be classified as *D. campyloptera*.

Two samples remain identified as *Dryopteris* spp. These are hybrids that display characters outside of the range of variation attributable to a single species. The characters that distinguished these two species appear to be unusually long basal pinnae, with the first basiscopic pinnule shorter than the second basiscopic pinnule, a character of *D. intermedia*. However, one of the samples in this group has a first basiscopic pinnule twice the length of the first acroscopic pinnule, whereas in the other sample, the first basiscopic pinnule is less than twice the length. These two samples may simply represent the outer limits of natural variation that occurs within a species.

# DISCUSSION

This report suggests preliminary morphological groupings of *Dryopteris* species and possible hybrids in the study population. Within the study sample of 99 ferns, approximately two thirds of the specimens display characters that are strongly consistent with taxonomic characters for two species, *D. intermedia* and *D. campyloptera*. In all published sources, the characters of *D. intermedia* are described as being narrowly variable. Nine specimens in this study are identified as *D. intermedia* with little variation between individual plants. *Dryopteris intermedia* is the only species in the study sample with lamina glandular trichomes and lanceolate fronds. *Dryopteris campyloptera* is described as highly variable in several morphological characters and often morphologically indistinguishable from *D. expansa* (Thorne and Thorne 1983). Within the collected samples of *D. campyloptera*, significant variation was found. *D. campyloptera* is a fertile tetraploid cross between *D. expansa* and *D. intermedia*. In all published descriptions of *D. campyloptera*, three characters are sited as diagnostic. The lamina is described as without glands, the first basiscopic pinnule of the basal pinna is longer than adjacent pinnules, and the first basiscopic pinnule.

Stipe scales are described as various shades of tan or with irregular basal or central darkening. Several plants in the study sample that have *D. campyloptera* characters also have strong central stripes that are described in published sources as diagnostic only of *D. expansa*. Some plants with *D. campyloptera* characters have medium to faint scale central stripes. Most literature sources suggest that only DNA analysis can be used to distinguish between *D. campyloptera* and *D. expansa*. The documented North American southern range limit for *D. expansa* is slightly south of the Canadian border. More investigation is necessary to explain the significance of stipe scales, particularly in light of the fact that they are susceptible to color variation from environmental factors (Lellinger pers. comm.).

Our results confirmed our hypothesis that there are individuals in this population that are not identified as *D. intermedia* or *D. campyloptera*. Thirty seven ferns have morphological characters strongly to mildly different from *D. intermedia*, *D. campyloptera*, and *D. expansa*. *D. carthusiana*, *D. triploidea* (a triploid cross between *D. intermedia* and *D. carthusiana*), and *Dryopteris intermedia* × *D. campyloptera* (a sterile triploid) have not been identified in the study sample. Both triploids are documented as having glandular trichomes. The lack of glandular trichomes is a strong indication of polyploid formation in this population and the probable existence of a new fertile hexaploid species.

The formation of new species is an important area of investigation in botany. With present and future challenges to the world's biodiversity, an understanding of the mechanisms behind speciation is increasingly necessary. With the current rates of species extinction and the increased rates predicted from climate change, preserving the mechanisms of species creation may become important to reestablish species that can withstand more volatile conditions. Ferns have retained their unique life cycle for millions of years, in the process creating new types of species suited for current conditions. The role that ancient ferns and fern spores played in the creation of fossil fuels (Moran 2004) is a prime example of the timeless utility of this group of organisms.

# Further Study

Further study is necessary of the ferns in this community to understand the underlying genetic makeup and ascertain the presence or absence of a new hexaploid hybrid species. Examination of the spores is needed to assess the fertility of the plants in the study. Spores need to be collected from each plant in the study and examined for size, shape, color and texture. Sterile hybrids, namely triploid hybrids in this case, will have shriveled, darkened spores that are abortive. A hexaploid hybrid should have a majority of functional spores and a percentage of abortive spores as well. To confirm the viability of the spores and therefore the fertility of the plant, viability trials need to be conducted. These will entail sowing spores collected from plants suspected to be hybrids and evaluating what percentage produce viable gametophytes and sporophytes.

In addition, continued morphological study is needed. Evaluation of individuals of *D. intermedia* and *D. campyloptera* is needed in communities where the two species occur in allopatry. There are other areas of similar elevation and soil conditions near the current field site than can be used as a source for additional frond samples. More individuals on the current study slope should be evaluated for unusual morphology. In addition, fronds of many individual plants seemed to vary. The variation within the individual is an important source of error, since the study is based exclusively on morphology. A statistical analysis on variation between frond morphology within an individual plant would be a useful comparison to determine whether there is significantly more variation within our study sample fronds.

Growing the spores in the lab environment is an important tool to examine morphological variation under controlled environmental conditions. Plants grown under controlled conditions will allow for quantification of plasticity in morphology. In addition, the spores could be experimentally crossed in a laboratory, and the morphologies of these hybrids could be compared to those found at the study site. Finally, DNA analysis should be performed on select specimens to determine if there is significant genetic evidence for the presence of a new species. DNA and morphology should be used together in the pursuit of deeper understanding of lineage and trait expression in these ferns.

#### **ACKNOWLEDGEMENTS**

I would like to thank David Lellinger, the University of North Carolina Herbarium and the National Park Service.

### LITERATURE CITED

- McCune, B. and J. B. Grace. 2002. Analysis of Ecological Communities. Glenden Beach, Oregon: MjM Software Design.
- Milinski, R. G. 2004. Kingdom Plantae Division: Pterophyta; Fern Life Cycle. Retrieved December 2, 2007 from http://www.esu.edu/~milewski/intro\_biol\_two/lab\_2\_moss\_ferns/images/fern\_life\_cycle.gif
- Montgomery, J. D. and W. H. Wagner Jr. 1993. Dryopteris. In: Flora of North America Editorial Committee, eds. 1993+. Flora of North America North of Mexico. 12+ vols. New York and Oxford. USA Vol. 2, pp. 280-288.
- Lellinger, D. B. 1985. A Field Manual of the Ferns and Fern-Allies of the United States and Canada, Smithsonian Institution Press, Washington, DC. USA
- Montgomery, J.D. 1982. Dryopteris in North America: Part II The Hybrids. Fiddlehead Forum 9(4):23-30.
- Moran, R. C. 2004. The Natural History of Ferns. Timber Press, Inc, Portland, Oregon. USA.
- Schafale, M. P. 2002. Classification of the Natural Communities of North Carolina, 4<sup>th</sup> Approximation. North Carolina Natural Heritage Program, Division of Parks and Recreation, North Carolina Department of Environment, Health, and Natural Resources, Raleigh, NC.
- Radford, A. E., H. E. Ahles, and C.R. Bell. 1968. Manual of the Vascular Flora of the Carolinas. University of North Carolina Press, Chapel Hill, NC. USA
- Thorne, F. and L. Thorne. 1989. Henry Potter's Field Guide to the Fern Hybrids of the Northeast. Academy Books, Rutland, Vermont, USA.
- Weakley, A. S. 2006. Flora of the Carolinas, Virginia, Georgia, and surrounding areas; working draft of August 2006. University of North Carolina Herbarium, Chapel Hill, NC.

# PERENNIAL STREAM IDENTIFICATION AND MAPPING IN THE BIG CREEK WATERSHED

# MATTHEW C. WHITEHEAD

*Abstract.* The Town of Highlands water treatment plant is located along Big Creek. Water from Big Creek and its tributaries flow directly into pumps to be treated then pumped throughout the town. The zone around Big Creek falls in the Watershed II Critical Area (WS-II-CA). Under current ordinances the only streams protected with a naturally vegetated buffer are those that appear on US Geological Survey (USGS) maps. This does not protect any of the tributaries that flow into Big Creek. Currently there are several such tributaries unmapped by both the USGS and the Town of Highlands Zoning Department. In this project, the tributaries were mapped and analyzed for the Town of Highlands to use for zoning administration. The North Carolina Division of Water Quality (NCDWQ) will use this information and determine the accuracy of the analysis. Ultimately this information will be used by the Town of Highlands, backed by the NCDWQ, to change an ordinance so it will protect perennial streams as well as current USGS blue line streams.

Key words: Big Creek; GIS; perennial stream; stream buffers; watershed management

## INTRODUCTION

A watershed is a network of streams that flow to the same point. What affects the headwaters a tributary will likely move its way downstream into some type of collection basin like a lake or large stream. If pollution or sediment problems occur at the headwaters it is only a matter of time before they reach further downstream. The complexities of the geomorphilogical and biological interactions in a stream are delicate and are often affected by erosion. This is why it is so important for municipalities to protect not only large rivers but also their tributaries and headwaters. Sedimentation upstream can have detrimental effects on both the local biology and health of the stream and the drinking water supply of the town. It is necessary for towns such as Highlands to protect not only its own well-being but also the well-being of the delicate river ecosystem.

Sedimentation is a huge threat to water quality and biodiversity in a watershed system. Erosion and poor management practices are the number one cause of the pollution (Gage et al. 2004). Policy largely determines the extent to which sediment affects streams. Zoning and protection legislation can directly affect the health of a stream. A much higher biodiversity is found in forested river systems then developed river systems (Gage et al. 2004). A naturally vegetated buffer law or ordinance is a good way to protect streams from heavy erosion. A buffer does several things to protect the stream. Woody vegetation traps nitrates, prevent erosion, cools the area, and deposits organic material in the stream used by aquatic insects and other organisms (Correll 2005). The larger and more continuous the buffer the more it protects a stream.

Big Creek is an example of a watershed. This stream appears on USGS maps of the Highlands area. It is located just outside the city limits but within the extraterritorial jurisdiction

zone. This means that ordinances of the Town of Highlands concerning streams apply to the Big Creek Watershed. The Big Creek Watershed is in the Watershed II Critical Area (WS-II-CA). According to Section 209 of the Zoning Ordinance of the Town of Highlands, "within the WS-II-BW Watershed Overlay District, a minimum fifty (50) foot vegetative buffer for development activities is required along all perennial waters indicated on the most recent versions of USGS 1:24,000 (7.5 minute) scale topographic maps. Desirable artificial stream bank or shoreline stabilization is permitted." This protects Big Creek itself but it does not protect any of its tributaries. Steps need to be taken to ensure the health of the stream ecosystem and the water quality of Highlands.

In this project I map all existing perennial streams that flow into Big Creek upstream of the Highlands Water Treatment Plant's intake locations. I analyze the stream to determine whether the tributaries are perennial or intermittent using the guidelines provided to me by the NCDWQ. My observations and pictures also were used to determine the current state of the Big Creek Watershed. Ultimately, the information from the project will be used by the Highlands Zoning Administration to help pass a revision to ordinance 209A.6 to include all perennial streams. A member of the NCDWQ will verify the work to be able to back the town with its decision. The information will also be used by the NCDWQ to propose an update to USGS maps to include verified perennial streams.



## MATERIALS AND METHODS

For the mapping project in the Big Creek Watershed, I received the necessary tools and training from both the Town of Highlands GIS department and the NCDWQ. The Town of Highlands provided me with the necessary equipment including a Trimble® Model XM GPS unit with a Zephyr Antenna, a compass, a digital camera, flagging tape, waders, a hard hat, and a computer with ArcGIS<sup>®</sup> 9.1 (ESRI 2005) and Manifold<sup>®</sup> System Release 8 (MNL 2007) installed. I was trained by the GIS department in how to use the Trimble<sup>®</sup> Model XM, Manifold<sup>®</sup> System Release 8, Light Detection and Ranging (LiDAR) data, and ArcGIS<sup>®</sup> 9.1. The NCDWQ provided me with a kick net, soil auger, and the NCDWQ -Stream Identification Form, Version 3.2 along with training on how to properly fill out the worksheet and how to

identify a perennial stream. With these provided materials I began my mapping an analysis of

FIG. 1. This is a map of LiDAR calculated streams (in red) and existing USGS blue line streams (in blue). This was used to help determine tributary location.

the Big Creek Watershed.

To begin the project I used Manifold<sup>®</sup> to analyze LiDAR data from the Big Creek Watershed area. The LiDAR data gave me an accurate elevation map for the area of study. With this elevation model I was able to run a watershed tool that would predict where streams might be. I created one-acre watersheds by finding where 42 tiles of the LiDAR data converged. Each tile of LiDAR data was 100m<sup>2</sup> so 42 tiles represented roughly one acre. Where the elevation converges to a point represents a natural valley and drainage way that would be a likely location for a stream. This gave me a starting point to locate tributaries to Big Creek.

Once I had mapped possible stream locations I set out to physically locate the tributaries and begin my analysis and mapping. With a map of LiDAR created streams I worked my way down Big Creek starting at Randall Lake until I reached the Highlands Water Treatment Plant. I looked carefully on each bank for any incoming tributaries. The LiDAR calculated stream map was used as a guide to locate tributaries.

Once located, I used flagging to mark the stream and took a GPS point so I would be able to locate the stream again for mapping and analysis. I walked up each tributary to check for any other tributaries. With the new GPS points I made a map in ArcGIS<sup>®</sup> 9.1 as a reference to relocate the streams.



FIG. 2. A sample North Carolina Division of Water Quality - Stream Identification Form; Version 3.2. This stream (#7011) was perennial because it scored a 34.5.

Analyzing the stream came next. I used a form given to me by the NCDWQ to determine whether the stream was perennial, intermittent, or ephemeral. The form was a scoring system that analyzed geomorphology, hydrology, and biology. As instructed, I did my analysis at the headwaters of the stream and only analyzed no more than a 20 foot transect along the stream. If a stream scored a 30 or above on the NCDWQ - Stream Identification Form, Version 3.2 it was recorded as perennial (Fig. 2). There were additional conditions under which a stream was recorded as perennial. Streams that had crayfish, larval amphibians, fish or clams present were recorded as perennial. If there were only crayfish and clams then a score of 18 in the geomorphology section of the NCDWQ - Stream Identification Form, Version 3.2 was required to be considered perennial. If a stream contained more than one benthic macroinvertebrate species that require water for its entire lifecycle the stream was recorded as perennial.

After the origin of the stream was

found and verified as perennial, it was flagged and a GPS point was taken. Upstream and downstream photos were also taken for record keeping purposes. Starting at the origin I mapped each tributary using the GPS device. To accurately follow the thalweg of the stream I made sure

to take a point any time the stream changed directions. This ensured the map I produced would be as accurate as possible. Once all the streams were mapped I used Manifold<sup>®</sup> to produce a map of all the tributaries in the Big Creek Watershed.

# **RESULTS AND DISCUSSION**



FIG. 3. A picture at the headcut of stream 7014. The road at the headcut is responsible for sediment deposition in the stream.

After running the LiDAR data I found that there were 22 tributaries that ultimately flowed into Big Creek. None of these predicted streams appear on current USGS maps of the area. I found that all of the 22 tributaries were in fact locations of stream beds. Some of the stream beds had flowing water while others did not. Since the year had been particularly dry it was hard to tell whether some of these streams would have had flowing water during a typical year. There were no other streams found that the LiDAR data had not picked up

in its watershed analysis. It is important to note that the LiDAR calculated streams were very accurate to their

actual location along Big Creek. As far as accuracy is concerned I think that LiDAR data is a very good indicator of where streams are located and would be good to use in future stream mapping projects.

Using the NCDWQ – Stream Identification Form, Version 3.2, I found that 19 of the 22 streams located qualified as perennial streams. The remaining 3 streams did not score high



FIG. 4. A construction site that is responsible for sedimentation of Big Creek and its tributaries



FIG. 5. Closer photograph of the erosion sit illustrated in Fig. 4.

enough of the form and did not fit into any the other previously stated categories to be considered perennial streams. Results could have varied if the area was not under an extreme drought. On a typical year, with normal rain, it is very possible that all 22 streams would have been considered perennial. Not every stream classified as perennial scored a 30 or above on the Stream Identification Form. Those that did not were classified as perennial due to the aquatic life found in the streams. The presence and diversity of aquatic insects, such as caddisflies, mayflies, and stoneflies, caused several streams to be classified as perennial despite scoring



FIG. 6. This picture shows silt screens that have been set up to prevent sedimentation of tributary 7023. A lot of sediment was still present in the stream.

under a 30 on the Stream Identification Form.

Pictures were taken at each site for documentation. Through observation of both the pictures and visual inspection of the stream sites, many of the streams were located in close proximity to roads, construction sites, and houses. There was a positive correlation between sediment deposition in the streams and proximity to developed areas. Tributaries 7006, 7007, 7009, 7014, 7020, and 7021 had large amounts of sediment and were very close to development. All of this sediment ultimately works its way down into Big Creek. Another correlation involving sedimentation is its effect on biology. Streams that scored a 3 (strong) on recent alluvial deposit had much less biological diversity then streams with less sediment. Macrobenthos numbers and diversity were very low in streams with high sedimentation.

Streams that classified as perennial were mapped using the GPS unit and used to produce a map for the Town of Highlands. This map along

with my Stream identification Forms, pictures, and analysis will be used to determine whether ordinance 209A.6 should be changed to require a 50 foot buffer around perennial streams in the WS-II-CA zone. Currently ordinance 209A.6 states that there is a required 50 foot buffer around current USGS blue line streams in WS-II-CA. The current USGS blue lines only cover a fraction of the perennial streams in the Highlands Plateau. I found 19 perennial streams starting at Randall Lake and ending at the Highlands Water Treatment Plant that flowed directly into Big Creek. Sediment that is deposited in these streams negatively impacts biodiversity. Water from these streams also gets pumped into the Highlands Water Treatment Plant. High sediment content is damaging to the pumps and lowers water quality. It is clear that with this evidence that it is necessary to protect the watersheds for both environmental and public health reasons.



FIG. 7. Final map of Big Creek from Randall Lake to the water plant intake pumps. The yellow lines are perennial streams that were mapped but do not currently appear on USGS maps. The origins of these streams are marked with blue flags. The blue lines represent streams found on USGS maps.

#### ACKNOWLEDGEMENTS

I would like to thank Matt Shuler, the Town of Highlands GIS technician, for training and assistance with mapping. I would also like to thank Richard Betz, Town of Highlands Administrator, for help with town ordinances. Finally, would to thank Periann Russell of the NC Division of Water Quality for the necessary training and materials to complete my project.

#### LITERATURE CITED

Correll, D. L. 2005. Principles of planning and establishment of buffer zones. Ecological Engineering. **24**:433-439 ESRI Inc. 2005. ArcMap 9.1. Redlands, California, U.S.A.

Gage, M. S., A. Spivak, and C. J. Paradise. 2004. Effects of land us and disturbance on benthic insects in headwater streams draining small watersheds north of Charlotte, NC. Southeastern Naturalist **3**:345-358

Manifold Net Ltd. 2007. Manifold System Release 8.0. Carson City, Nevada, U.S.A.

NC Division of Water Quality. 2007. Identification Methods for the Origins of Intermittent and Perennial streams, Version 3.2. North Carolina Department of Environment and Natural Resources, Division of Water Quality. Raleigh, NC.

Town of Highlands. 11 July 2007. Zoning Ordinance: Zoning Certificates, Appendix A.

# CAROLINA INSTITUTE FOR THE ENVIRONMENT CANOPY DYNAMICS AND UNDERSTORY REGENERATION AT TREE FALL SITES: EFFECTS OF HEMLOCK LOSS IN THE HENRY WRIGHT PRESERVE

# JASON E.H. BAKER, KATHERINE A. BETZ, MELISSA A. BURT, BRIAN R. HOUSEMAN, BRIAN M. LEVO, ANDREA L. MARTIN, SANDRA SKOLOCHENKO, KATIE L. SUPLER, ANNA R. VANDENBERGH, SALLY S. WHISLER, MATTHEW C. WHITEHEAD. ANYA E. HINKLE<sup>1</sup> AND JAMES T. COSTA<sup>1</sup>, PROJECT FACILITATORS.

<sup>1</sup>*Highlands Biological Station*, 265 N. Sixth Street, Highlands, NC, 28741.

Eastern hemlock (Tsuga canadensis) and Carolina hemlock Abstract. (*Tsuga caroliniana*) populations are declining across their natural range due to the infestation of the hemlock wooly adelgid (Adelges tsugae Annand). Death of hemlocks and the subsequent tree-falls create canopy gaps and decomposing logs that may act to alter the forest ecosystem. In this study we examined the effects of hemlock mortality and tree-fall due to the hemlock wooly adelgid (HWA) on light availability, crown density, and understory recruitment. We hypothesized that the area under fallen hemlock trees will provide an immediate increase in canopy openness that will encourage recruitment, as compared to other areas of this forest. We also predicted that fallen hemlock will act as nurse logs to encourage the recruitment and growth of a variety of early successional species that may not be characteristic of old growth hemlock forests. We used canopy photography and visual assessment of decomposition and understory recruitment at tree-fall sites to examine these ecosystem changes at the Henry Wright Preserve in Highlands, NC. We have found that the loss of this dominant species will not affect the light levels reaching the forest floor or seedling recruitment on or around the fallen tree. We speculate that the lack of ecosystem responses at these tree-fall sites may be due to the abundance of rhododendron (Rhododendron *maximum*), which inhibits light penetration and seedling recruitment. It is likely that in the short term the hemlocks will be replaced by greater rhododendron abundance rather than large canopy trees.

*Key words. eastern hemlock; hemlock woolly adelgid; nurse log; old growth forest;* Rhododendron maximum; *seedling recruitment; tree-fall gaps;* Tsuga canadensis.

## INTRODUCTION

Within a forest there are typically several ecosystems present that are shaped by the geography and microclimate of a particular area. Foundation tree species shape their own ecological communities, controlling the biota present and the functions of that ecosystem (Ellison et al. 2005). The southern Appalachians support a diversity of forest community types. High elevation forests along mountaintops and ridges are often dominated by oaks (*Quercus* spp.), northern hardwoods, or spruce (*Picea*) and fir (*Abies*). Exposure at high elevations can create rock outcrop communities or balds that lack canopy species but support grasses and ericaceous shrubs. Lower elevation forests are typically comprised of mixed hardwoods that make up the oak-hickory (formerly oak-chestnut) forest type. In protected coves, riparian
corridors, or along mesic ridges, hemlock dominates with a heavy rhododendron understory (Schafale and Weakley 1990). This high diversity of community types offers a variety of habitats that support a wide array of plant and animal species, many endemic to the area. Apart from its ecological richness, the southern Appalachian landscape has been important economically through agriculture, mining, forestry, tourism, and recreation (Kilpatrick et al. 2004).

Due to globalization and industrialization, humans have increased their capacity to threaten and destroy the high biodiversity in these forests. Through the introduction of exotic species (*i.e.*, plants, insects, and diseases), many economically and ecologically important natives are facing extirpation or even extinction. In the northeastern United States, exotic species-induced losses have increasingly occurred over the last century and have caused the decline of dominant canopy trees such as chestnut, elm, fir, and beech. Such species loss alters forest structure, composition, function, and productivity, commonly resulting in a loss of biodiversity.

The landscape of the southern Appalachians has been significantly altered by the introduction of the chestnut blight (Cryphonectria parasitica) (Anagnostakis and Hillman 1992). In the early 20<sup>th</sup> century, the chestnut blight effectively eliminated overstory American chestnut (Castanea dentata) trees in deciduous forests across the eastern United States. The species that replaced the chestnut varies with location, as there was no co-dominant species that spanned the entirety of the native chestnut range. For example, in southwestern Virginia, red oak (Q. rubra) is now the dominant species, white oak (Q. alba) has declined, and other species such as sugar maple (Acer saccharum), service berry (Amelanchier arborea), sweet birch (Betula lenta), black cherry (Prunus serotina) and black locust (Robinia pseudoacacia) that were previously understory species are now found in the canopy (Stephenson 1986). These compositional changes were not permanent, however, as McCormick and Platt (1980) found that, with time, a chestnut-oak forest transformed to an oak-hickory. In addition to these vegetative changes induced by selective chestnut mortality, wildlife was also impacted: woodpecker abundance increased due to an increase in dead tree habitat, squirrel populations declined, and seven moth species that fed on chestnut are now extinct (Opler 1978). These structural and compositional changes brought about by extensive chestnut mortality are well understood. However, very little is known concerning the specific ecosystem responses to such a drastic and sudden alteration of the landscape since many ecosystem parameters, such as light penetration and soil pH, were not measured prior to the death of chestnut.

In addition to the chestnut blight, many other exotic species have altered natural forest ecosystems of the United States and significantly decreased the rich biodiversity of the impacted areas. The presence of beech bark disease (*Nectria coccinea* var. *fraginata*) in hemlock sites increased the abundance of hemlock, decreased the abundance of American beech and yellow birch, and presumably decreased the production of mast, thus lowering the diversity of wildlife species (Runkle 1990, Castello et al. 1995). Likewise, Dutch elm disease (*Ophiostoma ulmi*) resulted in a 60% increase in sugar maple basal area and a significant increase in shrub density in Illinois and Wisconsin, respectively (Boggess and Bailey 1964, Dunn 1986). The selective mortality caused by these aforementioned pathogens act indirectly to alter their inhabited ecosystems' compositions, structures, functions, and microclimates. These ecosystem changes carry implications for the future forest biodiversity and, thus, long-term viability of these ecosystems.

Eastern hemlock, a foundation canopy tree, is a species whose loss could precipitate many ecosystem responses. Hemlocks typically grow in pure stands in the northeastern United States, but in the southern Appalachians they often dominate riparian and cove sites in mixed high elevation hardwood forests. Hemlocks create a shaded environment, deposit acidic litter, mediate soil moisture, and greatly contribute to transpiration rates throughout the year, especially in the winter and spring when deciduous trees are leafless (Ellison et al. 2005). Their presence therefore creates a fairly stable environment with low variation in soil moisture, slow rates of nitrogen cycling, low light availability, and low seasonal variation of light (Eschtruth et al. 2006). This type of environment stabilizes stream flow and supports a number of salamanders, fish, aquatic invertebrates, birds, and mammals that depend on hemlock stands for habitat and cover (Orwig et al. 2002, Ellison et al. 2005). Hemlock trees typically have a shallow rooting system, thin bark, grow slowly, making them vulnerable to disturbance. Wind, fire, drought, exotic pests, and anthropogenic disturbance can severely impact hemlock populations. For this reason, most hemlock forests today are found in sheltered coves and ravines, or on historically protected sites (Orwig and Foster 1998).

Since European settlement, eastern hemlocks have played an important role economically as well as ecologically. Hemlocks were logged heavily in the 1800s throughout the mid-Atlantic. Although hemlock was considered low-value softwood, it was a preferred source of tannins and was used extensively in leather processing (Brown 2000). Consequentially, loggers often felled hemlock trees, stripped them of their bark, and left the log to rot. Parts of the bark have also been used historically in ointments to treat rheumatism and colds, and such ointments were even applied on the skin to stop bleeding (Brown 2000). In the past century, logging of hemlock has decreased significantly and much of the previously cleared farmland has been abandoned, allowing for hemlock recovery and reforestation throughout its native range (Weckel et al. 2006).

Eastern and Carolina (*Tsuga caroliniana*) hemlocks are currently under threat of extirpation by the introduced HWA. This insect, native to Japan and first observed in the eastern United States in the 1950s, has quickly dispersed throughout the natural range of hemlock via wind, animal, and human vectors and can cause tree mortality within 4-10 years of infestation (McClure 1990, 1991, Souto et al. 1996). HWA feeds on the ray parenchyma cells of young hemlock twigs and in doing so injects a toxic saliva that causes needle loss and mortality of the buds and branches (Young et al. 1995). HWA poses a threat to the non-resistant hemlocks because it is parthenogenetic, reproduces rapidly with two generations per year, can kill hemlocks of all sizes and age classes, and seems to have no native predators within its range (McClure 1989, 1990, 1991, Kizlinski et al. 2002).

Mortality of eastern hemlock due to the HWA results in tree-fall gaps, leaving decomposing logs on the forest floor. The presence of such gaps and the accompanying logs alter the light availability and species composition in those areas. Light availability in the understory, usually a limiting resource to recruitment, drastically and immediately increases with the creation of canopy gaps (Beckage et al. 2000). In New England hemlock stands, higher light levels due to hemlock mortality result in significantly higher seedling densities, especially sweet birch (Orwig and Foster 1998). Fallen logs may influence habitat conditions for centuries and even millennia (Franklin et al. 1987) and have been shown to provide habitat for decomposers and other plants, as well as a variety of animal species. In fact, "nurse logs" act as a regeneration niche, providing nutrients and an elevational advantage to successional vegetation (Gray and Spies 1997).

The loss of hemlock will most likely alter its accompanying microenvironment to an extent not seen in other less influential tree species. Also, unlike the pathogens of other past tree species, the ability of the HWA to eliminate all ages of hemlock gives it the potential to completely eliminate hemlock from its natural range in a short period of time. On the other hand, many other exotic pathogens and pests only target a certain age group (Castello et al. 1995).

Ecosystem responses to hemlock decline have been examined extensively through numerous studies which have monitored hemlock stands infested with HWA. These studies have simulated HWA impact by girdling hemlocks, and have studied canopy gaps in hemlock-dominated forests (Rankin and Tramer 2002, Yorks et al. 2003). These studies have found that hemlock loss causes an increase in understory species richness, light availability, and abundance of birch and maple (Battles et al. 1995, Orwig and Foster 1998, Eschtruth et al. 2006). Although these studies have examined ecosystem responses to hemlock mortality, these responses have not been observed and quantified in the southern Appalachians, a region with a unique climatic regime, unusually high biodiversity, and with the presence of a rhododendron subcanopy and mixed-deciduous canopy.

This study examines ecosystem responses at the Henry Wright Preserve (hereby referred to as the Wright Tract) in an old-growth forest already infested by HWA in Highlands, NC. Specifically, we examined the effects of hemlock mortality and tree-fall due to the HWA on light availability, crown density, and understory recruitment. We hypothesize that the area under fallen hemlock trees will provide an immediate increase in canopy openness that will encourage recruitment, as compared to other areas of this forest. We also predict that fallen hemlock will act as nurse logs to encourage the recruitment and growth of a variety of early successional species that may not be characteristic of old growth hemlock forests.

#### MATERIALS AND METHODS

#### Study Area

This study was conducted at the Wright Tract, a cove forest of large old-growth eastern hemlock in the southern Appalachians of North Carolina. The canopy of the preserve consists primarily of eastern hemlock, sweet birch, red maple (*Acer rubrum*), tulip poplar (*Liriodendron tulipifera*), red oak, mountain holly (*Ilex montana*), fraser magnolia (*Magnolia fraseri*), and black gum (*Nyssa sylvatica*). The forest at the Wright Tract is a relict of a once-expansive tract of primeval hemlock forest that spanned from Highlands, NC to Whiteside Mountain in Cashiers, NC (Zahner 1994). As the surrounding land was sold to the Champion Paper Company of North Carolina in the 1940s, this parcel was retained by Henry Wright and remains one of the last pristine hemlock stands in this region (Shaffner 2004).

#### Canopy Gap Analysis

The extent of tree-fall gap effect was assessed by evaluation of canopy gap openness at 10 tree-fall sample sites and 11 control sites in the surrounding forest (Fig. 1). The canopies were evaluated using photography with a digital camera (Coolpix 4500, Nikon) and 180° hemispherical (fisheye) lens (FC-E8, Nikon) using standard and accepted protocol (Barthod et al. 2007). The control photographs were taken along a trail at 3-minute intervals, totaling 11 sites.



FIG. 1. Tree-fall sites at the Henry Wright Tract in Highlands, NC.

Each photograph was taken at a height of 5 feet using a level to ensure consistency among areas of varying slope. All control photographs were taken in duplicate on Sept. 5, 2007 under sunny weather conditions.

Canopy openness was assessed at 10 tree-fall sites using the same photography protocol. Photographs were taken at 20-foot intervals adjacent to each fallen log, from the base to the crown. A photograph was taken from the crown end of each log regardless of interval. Logs were of various species and stages of decomposition. Log photographs were taken on two separate occasions: Day 1 (Sept. 13, 2007) and Day 2 (Sept. 18, 2007). Photographs of Logs 1-5 were taken on Day 1 under rainy weather conditions and those of Logs 6-10 were taken on Day 2 under sunny weather conditions.

Photographs were analyzed for canopy openness using the software Gap Light Analyser (GLA v2.0, Institute of Ecosystem Studies, New York, USA). The threshold for analysis was set at 128 (50% on a 0-256 grayscale) and the output recorded was "Percent Canopy Openness." Using this

method, percent canopy openness was determined for each photograph. The effect of tree fall on canopy openness was assessed using a Wilcoxon Sign-Ranks Test (Zar 1984). All statistical analyses were performed using JMP IN 4.0.4 (SAS Institute Inc. 2001, (Canham et al. 1990, Pacala et al. 1994, Fraser et al. 2001).

# Temporal Trends in Hemlock Crown Density

We performed a visual canopy assessment to evaluate changes in hemlock crown density from Boggess et al. (2006) to our study in 2007. The crown density survey we employed utilizes a modified defoliation scale created by Eschtruth et al. (2006), and is the same methodology used in Boggess et al. 2006. The canopy classification ranges from a value of "1" that indicates little or no defoliation, to a value of "3" which indicates about 50% canopy loss, to a canopy class of "5", which represents a completely defoliated tree. The survey team consisted of three members who photographed the tree canopies, and individually assessed each hemlock's canopy class. An average value was then calculated from the individual assessments and recorded as well as the canopy classifications from Boggess et al. (2006) (Table 1). In addition to canopy class and tree identification, a "Yes" or "No" was recorded to distinguish the hemlocks that have been treated for HWA. Treated trees were marked with paint upon treatment. Select 2006 canopy photos (Boggess et al. 2006) were compiled with our photos in Appendix A, to serve as a direct visual

comparison of crown difference between the studies. We chose only a few pairs of photos, which effectively emphasize the range of crown density changes.

### Nurse Log Recruitment and Decomposition

The level of decomposition of each nurse log was assessed using a 5-class system of log decomposition developed by (Fogel et al. 1973). Each log was also characterized by its cover type. The percentages of moss, dog hobble (*Leucothoe axillaris*), rhododendron, overgrown evergreen, deciduous saplings/seedlings, and blackberry (*Rubus spp.*) were estimated in increments of 25 percent. The number of seedlings and saplings rooted in the nurse log itself was also recorded (Table 2).

# Lateral and Base Plot Recruitment

To assess seedling recruitment and forest regeneration in the wake of a tree-fall, we selected a subset of five out of the ten photographed tree-fall sites. For each tree, we set up three plots in each tree-fall gap and three comparative plots in the same area. The plots were arranged as depicted in the surrounding forest (Fig. 2). A 1m x 1m lateral plot was delineated on each side of the trunk. The distance of each lateral plot from the stump base was selected using a random number table. Each corresponding 1m x 1m comparative plot was 5m from the lateral plot and at a bearing derived using a random number table. This process was repeated with the second comparative lateral plot.

The stump plot and corresponding comparative plots were measured and evaluated with a similar procedure. At the tree stump, a  $3m \times 3m$  plot was demarcated with a corresponding  $3m \times 3m$  comparative plot selected at a random bearing and random distance from the stump. The random distance and bearing were both chosen using a random number table.



FIG. 2. Lateral and stump plot locations.

Each 1m x 1m or 3m x 3m square plot was measured using a meter tape and the corners were marked using flags. Within the plot set up, all seedlings determined to be woody canopy species were identified, counted, and recorded. Dog hobble and rhododendron were excluded from these counts on the basis that they are not hardwood canopy species. Any saplings present in the plots were recorded separately. Other canopy species present around the tree-fall were noted, along with general conditions such as slope, weather, time and date. The location of each lateral plot along the log, the bearing of the comparative lateral plot and the distance and bearing of the comparative stump plot were all recorded.

To determine whether the number of seedlings and saplings found in the tree-fall plots were significantly higher than those found in the comparative plots, the Chi Square formula was used. The Chi Square formula is as follows:

# $X^{2} = \frac{\sum (Observed Frequency - Expected Frequency)^{2}}{Expected Frequency}$

This test is designed to demonstrate if the observed frequencies within a sample are significantly different than those expected, based on the Chi Square curve in which the slope is determined by the degrees of freedom. The degrees of freedom (1) were chosen based on the sample size of the study (Zar 1984).

### Soil pH Analysis

A sampling location was selected at the stump and top of logs 1, 6, 8, 9 and 10. A 20 cm hole was dug and approximately 30 g of soil was collected and stored in a sealed glass jar. The samples were then dried in an Isotemp oven (Fisher Scientific, USA) at 90° Fahrenheit for a week. Each dried sample was filtered through a metal sieve, breaking up the large particles and making the sample more homogenous in texture. The processed soil was placed in a plastic tube and a 2:1 de-ionized water to soil ratio was used. The initial pH of the de-ionized water was 5.1. The tube was agitated (shaken not stirred) for 1 minute. After allowing the soil-water mixture to settle, the pH was measured with a pH meter (Oakton 110), three times and an average recorded.

#### RESULTS

# Canopy Gap Analysis

A significant tree fall effect was observed when considering only the maximum photographs for each log examined on Day 2 (Wilcoxon Sign Ranks Test, Z = 2.60563, P = 0.0078, Fig. 3). The average percent canopy openness for all control site photographs is presented as "control average." "Log max" represents only the photographs from locations with the highest average percent canopy openness for each log.



FIG. 3. The effect of tree fall on percent canopy openness. Error bars represent one standard error. Canopy openness marked by an asterisk was significantly different at the  $\alpha = 0.05$  level using a Wilcoxon Sign-Ranks Test.

Photographs were taken at set intervals along the log. In order to assess the consistency of canopy openness across the chosen intervals, the average openness for all trees at each interval of the log was examined (Fig. 4). This graph incorporates all log data (Day 1 and Day 2) and averages the canopy openness for each range of log length. There was no significant variation among sites on the log when considering the averages of all logs examined (ANOVA, P = 0.7168).



FIG. 4. Variation in canopy openness across logs. Error bars represent one standard error.

## Temporal Trends in Hemlock Crown Density

When the Boggess et al. (2006) defoliation analysis was compared to data we collected, it was found that four of the nine hemlock trees examined have declined in crown density (Table 1). However, of the other five hemlock canopies researched, two displayed no further decline in density and three showed increases in density. One of the two trees treated for HWA showed an increase in crown density, while the other treated tree exhibited a slight decrease. Overall, there was no significant change in crown density between 2006 and 2007. The canopy photographs located in Appendix A visually demonstrate these changes in canopy density. Big Daddy Hem and Lightning displayed a decline in crown density, Uncle Hemi displayed an increase in crown density, and no change was seen in Baby Hemi.

TABLE 1. List of hemlock canopies surveyed. Contains defoliation classes (1=least defoliation,<br/>5=most defoliation) from 2006 study (Boggess et al. 2006) and our 2007 study. Status of<br/>HWA treatment has been indicated.

Tree #	Tree Name	2006 Canopy Class	2007 Canopy Class	Treated for HWA (Yes/No)
1	Big Daddy Hem	1	2	Yes
2	Fat Albert	3	4	No
3	Lightning	3	4	No
5	Croaking Hem	5	5	No
6	Beeka	3	2.3	No
7	Wishbone	2	1	No
9	Uncle Hemi	4	1.6	Yes
11	Earl	4	5	No
15	Baby Hemi	3	3	No

# Nurse Log Recruitment and Decomposition

Five nurse logs were examined for vegetation cover type (Table 2). The extent of log decomposition and seedling/sapling recruitment were also examined for the 5 nurse logs (Fig. 5). It was found that the majority of vegetation growing on nurse logs was moss, dog hobble, and rhododendron. Only Log 1 contained saplings, and Log 8 was the only log that did not have any vegetation coverage.

TABLE 2. Nurse log recruitment by vegetation type.							
Coverage Characteristics	Log #						
(percent)	1	6	7	8	9		
Moss Coverage	25-50 %	0-25%	25-50%	0	75-100%		
Dog Hobble Coverage	0	75-	75-100%		50-75%		
		100%					
Rhododendron Coverage	0	0-25%	25-50%	0	25-50%		
Deciduous Saplings/Seedlings	0-25%	0	0	0	0		
Blackberry Coverage	0	0	0	0	0-25%		

TABLE 2. Nurse log recruitment by vegetation type



FIG 5. Seedling and sapling recruitment as a function of log decomposition rating. On a scale of 1 to 5 with 1 being the least decomposed. No logs were analyzed with a decomposition rating higher than 3.

The log decomposition rating was compared to the number of seedlings or saplings found to be rooted in each nurse log (Fig. 5). Most seedlings were rooted in log rated as Class "2.5". The lowest number of seedlings was found in the decomposition Class "1" log.

# Lateral and Base Plot Recruitment

Seedling and sampling recruitment was assessed at lateral and base plots set around the same fallen logs examined for the nurse log study (Appendix B). We looked at the distribution of seedlings/saplings within the various study plots (Fig. 6). The average number of seedlings/saplings within each study plot was 1.36. Most of the seedling/saplings observed were within the stump plots and comparative stump plots. At log 6 there were actually more seedlings and saplings in the comparative plot than at the stump of the log itself. At log 9 there were more seedlings and saplings found at the stump than in its comparative plot. The comparative stump plots averaged 3 seedlings/saplings per plot, whereas the stump plots averaged two seedlings. There were more seedlings/saplings within both lateral plots than the comparative lateral plots. The comparative lateral plots averaged 0.2 seedlings/saplings, whereas cumulatively, the lateral plots averaged 1.6 seedlings/saplings.



FIG. 6. Seedling and sapling recruitment within the study plots.

Soil pH Analysis

The pH of the soil did not differ significantly between the top and bottom of the log, with the exception of Log 1 and Log 10. The soil at the top of Log 1 was higher, while the soil at the bottom of Log 10 had higher pH. The variation between logs was small, with an average pH of 4.052 across all samples.

Log	Sample Location	Avg pH
1	Bottom	3.64
6	Bottom	3.71
8	Bottom	3.72
9	Bottom	3.78
10	Bottom	5.01
1	Тор	4.53
6	Тор	3.75
8	Тор	3.77
9	Тор	3.94
10	Тор	4.67
	Overall Average:	4.05

TABLE 3. Results from soil pH analysis. Three trials were performed on each sample.



FIG. 7. Average pH at each sampled log.

# DISCUSSION

# Canopy Gap Analysis

Upon consideration of average canopy openness over the extent of the logs studied, openness at tree-fall sites did not significantly differ from that of the surrounding forest. These results suggest that light penetration at the understory does not significantly increase at the site of a fallen tree as expected. Perhaps this derivative from our expected results was due to the age of the fallen trees examined. With time, logs will decompose and allow for the recruitment and increased growth of other accompanying species. Perhaps the logs examined for canopy openness were of an age at which recruitment and increased growth had already occurred to an extent that would inhibit light penetration to the understory.

It is also likely that the similarity in canopy openness between tree-fall sites and the remaining forest may be due to the presence of the evergreen subcanopy shrub *Rhododendron maximum*. This species, which is prevalent at the Wright Tract, has been shown in another southern Appalachian forest to also prevent the tree-fall-induced increase of light levels (Beckage et al. 2000). Perhaps further, specific examination of rhododendron abundance at the individual tree-fall sites would better explain these observed trends in canopy openness.

The only instance in which the canopy openness significantly differed from the surrounding forest was when considering only day 2 of the study and only the photograph that showed the greatest canopy openness for each log. Perhaps the difference found when examining this select subset of data was due to the cofounding effects of weather on canopy openness. Weather during the control-group photography was sunny and could be more easily compared to the sunny weather on day 2 of log photography than day 1, in which the weather was rainy and cloudy. This cofounding effect of weather may have inhibited the appearance of a significant increase in average canopy openness at all tree-fall sites. Future studies should include photograph taken on similar days as to minimize the effects of this confounding variable.

The significant increase in canopy openness only seen when considering the "maximum openness" photograph for each log may be explained by examination of the variation in canopy openness across an individual log. The percent canopy openness did not significantly vary, however, across the length of the log, suggesting that a tree-fall will uniformly influence canopy openness across the length of the log. Additionally, the variation in canopy openness (as shown by standard error values) within each log length interval did not seem to vary by intra-log location, also suggesting that tree-falls will influence canopy openness at one random location on each log.

# Temporal Trends in Hemlock Crown Density

Both increases and decreases in crown density were seen upon comparing data collected for this study with Boggess et al (2006). However, overall more trees under consideration displayed increased needle loss. This decline is thought to reflect the degradation in tree health brought upon by the HWA. However the short time scale of data collection is not expected to reflect degradation from the HWA and continued annual data collection using this method is needed to confirm a declining trend. The reality that one of the two trees treated for HWA showed canopy increase, while the other tree exhibited a slight decrease, only reinforces the uncertainty of a visual canopy analysis over this time frame. Treated hemlocks typically demonstrate fitness improvement assuming the adelgid is the only terminal strain on the tree. However, this improvement is likely to be gradual over a number of years.

Additionally, when comparing both sets of photos to the defoliation classification scale, it appears that subjective interpretation may generate biased results. For instance, the field team assessing the crown densities in the 2006 study likely held a different interpretation of the characteristics of a '3' classification than the team in our study. This further reduces the scientific value of this analysis method as a measure of hemlock fitness over this brief duration.

#### Nurse Log Recruitment and Decomposition

No trends were immediately apparent from the data presented in regards to nurse log recruitment. When log decomposition was plotted against number of seedlings or saplings rooted in the log we observed the general trend that the more decomposed logs had more seedlings present. However, it was unexpected that the class "3" decomposed log had fewer seedlings present than the decomposition class of "2.5". This could be due to seedling dispersal rates in the area and barriers to dispersal preventing seedlings from establishing on the class "3" log. The observed lack of seedling recruitment on the decomposition class "1" log was in agreement with our hypothesis that less decomposed logs would have fewer numbers of seedlings and saplings present.

In the future a larger sample size and more specific categories would provide a better framework for more conclusive results. A larger sample size would probably include all five classes of log decomposition and provide a more varied sample of decomposition.

#### Lateral and Base Plot Recruitment

There were no significant differences between the number of seedlings/saplings found in the stump and seed plots with their comparative plots. These results did not support our hypothesis; we expected to find more seedlings/saplings in the log plots than in the comparative plots. Although studies in New England hemlock forests have found a significant increase in numbers of sweet birch seedlings within canopy gaps (Ellison et al. 2005: Orwig and Foster 1998), these trends are not apparent in the Wright tract. This could be partially explained by the presence of dense rhododendron and dog hobble in this forest. Rhododendron and dog hobble inhibit the availability of light resources to reach the forest floor. Beckage et. al (2000) found that in experimental canopy gaps, light levels at the understory increased twofold in the absence of rhododendron, but did not increase when rhododendron was present. Furthermore, the rhododendron deposits a thick acidic litter which also inhibits new seedling establishment (Nilsen et al. 1986). In this case, the small size of the study area and limited sampling may have inhibited our ability to see any clear patterns in seedling recruitment. It is possible that looking at a larger area at the lateral and stump plots and sampling a greater number of tree-fall sites would provide more viable data to clarify any trends.

#### Conclusion

Eastern hemlock is an important foundation species that plays the unique and critical role of moderating and maintaining a specific microenvironment and species composition in its ecosystem. Because of HWA, mortality of this influential tree species is inevitable across the entirety of its range. Although the effects of hemlock mortality have been speculated and studied extensively in the pure hemlock stands of New England, the ecosystem responses to hemlock mortality in hemlock forests of the southern Appalachians are not as well understood. The presence of a thick rhododendron subcanopy and the mixed deciduous composition of these hemlock forests create a potential for unique ecosystem responses that may differ from those seen in New England.

Through examination of tree-fall sites that simulate the future result of HWA damage, we have found that hemlock mortality in this region may not result in significant ecosystem changes. The loss of this dominant species will not affect the light levels reaching the forest floor or seedling recruitment on or around the fallen tree. We speculate that the lack of ecosystem responses at these tree-fall sites may be due to the abundance of rhododendron, which inhibits light penetration and seedling recruitment. In the near future HWA will fell many of the great hemlocks in this tract, and we do not expect rapid replacement from other canopy species. The effect of hemlock mortality on the abundance of rhododendron, however, has not been examined in this forest. It is likely in the short term the hemlocks will be replaced by greater rhododendron abundance rather than large canopy trees.

#### ACKNOWLEDGEMENTS

We would like to thank Gary Wein for his assistance with collecting GPS points at the study site, the Community Bible Church for allowing us to access the Wright Preserve from their property and Western Carolina for the supply of de-ionized water and contribution of funds.

#### LITERATURE CITED

Anagnostakis, S., and B. Hillman. 1992. Evolution of the chestnut tree and its blight. Arnoldia 52:3-10.

- Barthod, S., Z. Cerovic, and D. Epron. 2007. Can dual chlorophyll fluorescence excitation be used to assess the variation in the content of UV-absorbing phenolic compounds in leaves of temperate tree species along a light gradient? Journal of Experimental Botany 58:1753.
- Battles, J., N. Cleavitt, T. Fahey, and R. Evans. 1995. Vegetation composition and structure in two hemlock stands threatened by hemlock woolly adelgid. Pages 55-61 in K. A. McManus, K. S. Shields, and D. R. Souto, editors. Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America. U.S. Department of Agriculture, Forest Service, Newton Square, Pennsylvania, Durham, New Hampshire.
- Beckage, B., J. Clark, B. Clinton, and B. Haines. 2000. A long-term study of tree seedling recruitment in southern Appalachian forests: the effects of canopy gaps and shrub understories. Canadian Journal of Forest Research **30**:1617-1631.
- Boggess, L. M., E. C. Bolas, L. P. Chestnut, D. A. Eitelberg, K. M. Hines, E. B. Hoekstra, G. Y. Kimmel, K. R. McLeod, E. K. Meineke, A. M. Nagle, B. A. Purvis, A. E. Hinkle, and J. E. Costa. 2006. Carolina Environmental Program Capstone Project: A baseline study of the effects of hemlock loss in the Henry Wright Preserve and Kelsey Tract. Highlands Biological Station, Highlands, NC.
- Boggess, W., and L. Bailey. 1964. Brownfield Woods, Illinois: Woody Vegetation and Changes Since 1925. American Midland Naturalist **71**:392-401.
- Brown, M. 2000. Wild East: A Biography of the Great Smoky Mountains. University Press of Florida.
- Canham, C., J. Denslow, W. Platt, J. Runkle, T. Spies, and P. White. 1990. Light regimes beneath closed canopies and tree-fall gaps in temperate and tropical forests. Canadian Journal of Forest Research **20**:620-631.
- Castello, J., D. Leopold, and P. Smallidge. 1995. Pathogens, patterns, and processes in forest ecosystems. BioScience **45**:16-24.
- Dunn, C. 1986. Shrub layer response to death of *Ulmus americana* in southeastern Wisconsin lowland forests. Bulletin of the Torrey Botanical Club **113**:142-148.
- Ellison, A., M. Bank, B. Clinton, E. Colburn, K. Elliott, C. Ford, D. Foster, B. Kloeppel, J. Knoepp, and G. Lovett. 2005. Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. Frontiers in Ecology and the Environment 3:479-486.
- Eschtruth, A., N. Cleavitt, J. Battles, R. Evans, and T. Fahey. 2006. Vegetation dynamics in declining eastern hemlock stands: 9 years of forest response to hemlock woolly adelgid infestation. Canadian Journal of Forest Research 36:1435-1450.
- Fogel, R., M. Ogawa, and J. Trappe. 1973. Terrestrial decomposition: a synopsis. College of Forest Resources, University of Washington, Seattle, Washington, USA.
- Franklin, J. F., H. H. Shugart, and M. E. Harmon. 1987. Tree death as an ecological process: The causes, consequences, and variability of tree mortality. BioScience 37:550-556.
- Fraser, G., R. Fournier, J. Trofymow, and R. Hall. 2001. A comparison of digital and film fisheye photography for analysis of forest canopy structure and gap light transmission. Agricultural and Forest Meteorology **109**:249-263.
- Gray, A. N., and T. A. Spies. 1997. Microsite controls on tree seedling establishment in conifer canopy gaps. Ecology **78**:2458-2473.
- Kilpatrick, J., A. Weakley, and T. Massengale. 2004. Southern Appalachian conservation assessment. Executive Summary and Regional Overview Open Space Institute.
- Kizlinski, M., D. Orwig, R. Cobb, and D. Foster. 2002. Direct and indirect ecosystem consequences of an invasive pest on forests dominated by eastern hemlock. Journal of Biogeography **29**:1489-1503.
- McClure, M. 1989. Evidence of a polymorphic life cycle in the hemlock woolly adelgid, *Adelges tsugae* (Homoptera: Adelgidae). Annals of the Entomological Society of America **82**:50-54.
- McClure, M. 1990. Role of wind, birds, deer, and humans in the dispersal of hemlock woolly adelgid (Homoptera: Adelgidae). Environmental Entomology **19**:36-43.
- McClure, M. 1991. Density-dependent feedback and population cycles in *Adelges tsugae* (Homoptera: Adelgidae) on *Tsuga canadensis*. Environmental Entomology **20**:258-264.
- McCormick, J., and R. Platt. 1980. Recovery of an Appalachian forest following the chestnut blight or Catherine Keever-you were right! American Midland Naturalist **104**:264-273.
- Nilsen, E., J. Walker, O. Miller, S. Semones, T. Lei, and B. Clinton. 1986. Inhibition of seedling survival under *Rhododendron maximum* (Ericaceae): could allelopathy be a cause? American Journal of Botany **86**:1597-1605.

- Opler, P. 1978. Insects of American chestnut: possible importance and conservation concern. Pages 83-85 *in* J. McDonald, editor. Proceedings of The American Chestnut Symposium. West Virginia University Press, Morgantown, West Virginia, USA.
- Orwig, D., and D. Foster. 1998. Forest response to the introduced hemlock woolly adelgid in southern New England, USA. Journal of the Torrey Botanical Society **125**:60-73.
- Orwig, D., D. Foster, and D. Mausel. 2002. Landscape patterns of hemlock decline in New England due to the introduced hemlock woolly adelgid. Journal of Biogeography **29**:1475-1487.
- Pacala, S., C. Canham, J. Silander Jr, and R. Kobe. 1994. Sapling growth as a function of resources in a north temperate forest. Can. J. For. Res./Rev. can. rech. for **24**:2172-2183.
- Rankin, W., and E. Tramer. 2002. Understory succession and the gap regeneration cycle in a *Tsuga canadensis* forest. Canadian Journal of Forest Research/Revue Canadienne de Recherche Forestiere **32**:16-23.
- Runkle, J. 1990. Eight years change in an old *Tsuga canadensis* woods affected by beech bark disease. Bulletin of the Torrey Botanical Club **117**:409-419.
- Schafale, M., and A. Weakley. 1990. Classification of the natural communities of North Carolina, third approximation. North Carolina Natural Heritage Program, Division of Parks and Recreation and NC Department of Environment, Health, and Natural Resources, Raleigh, NC.
- Shaffner, R. P. 2004. Heart of the Blue Ridge: Highlands, North Carolina. Faraway Publishing, Highlands, NC.
- Souto, D., T. Luther, and B. Chianese. 1996. Past and current status of HWA in eastern and Carolina hemlock stands. Pages 9–15 *in* Proceedings of the First Hemlock Woolly Adelgid Review. USDA Forest Service.
- Stephenson, S. 1986. Changes in a former chestnut-dominated forest after a half century of succession. American Midland Naturalist **116**:173–179.
- Weckel, M., J. Tirpak, C. Nagy, and R. Christie. 2006. Structural and compositional change in an old-growth eastern hemlock (*Tsuga canadensis*) forest, 1965–2004. Forest Ecology and Management 231:114-118.
- Yorks, T., D. Leopold, and D. Raynal. 2003. Effects of *Tsuga canadensis* mortality on soil water chemistry and understory vegetation: possible consequences of an invasive insect herbivore. Canadian Journal of Forest Research **33**:1525-1537.
- Young, R., K. Shields, and G. Berlyn. 1995. Hemlock woolly adelgid (Homoptera: Adelgidae): Stylet bundle insertion and feeding sites. Annals of the Entomological Society of America 88:827-835.
- Zahner, R. 1994. The Mountain at the End of the Trail: A History of Whiteside Mountain. private publisher, Highlands, NC, USA.
- Zar, J. H. 1984. Biostatistical Analysis, 2 edition. Prentice Hall, Inc., Inglewood Cliff, New Jersey, USA.

APPENDIX A. Hemlock canopy photographs at various old-growth hemlock trees for 2006 and 2007.



PHOTO 1: Lightning (2006)



Рното 2: Lightning (2007)



PHOTO 3: Big Daddy Hem (2006)



PHOTO 4: Big Daddy Hem (2007)



Рното 5: Uncle Hemi (2006)



PHOTO 6: Uncle Hemi (2007)



Рното 7: Baby Hemi (2006)



Рното 8: Baby Hemi (2007)

SITE ID	LOG 1	LOG 6	LOG 7	LOG 8	LOG 9
Date	10/10/2007	10/10/2007	10/10/2007	10/10/2007	10/10/2007
Time	12:19 PM	1:30 PM	2:15 PM	2:32 PM	3:00 PM
Weather Conditions	low wind, clear skies, sunny	low wind, clear skies, sunny	low wind, clear skies, sunny	low wind, clear skies, sunny	low wind, clear skies, sunny
Length of log (ft)	66	20	49	34	37
Seedling count- lateral plot #1 (1x1m)	0	0	0	0	0
Sapling count- lateral plot #1 (1x1m)	0	0	3 Dog Hobble	0	0
Seedling count- lateral plot #2 (1x1m)	1 llex montana, 3 Bentula lenta	0	0	1 Betula lenta	0
Sapling count- lateral plot #2 (1x1m)	0	0	0	0	0
Seedling count- stump plot (3x3m)	0	0		0	0
Sapling count- stump plot (3x3m)	0	1 Clethra acuminata	0	1 Clethra acuminata	8 mature Magnolia fraseri
Comparative Seedling count- lateral plot #1 (1x1m)	0	0	0	0	0
Comparative Sapling count- lateral plot #1 (1x1m)	0	0	0	0	0
Comparative Seedling count- lateral plot #2 (1x1m)	0	0	Dog Hobble	0	0
Comparative Sapling count- lateral plot #2 (1x1m)	0	1 Dog Hobble	0	0	0
Comparative Seedling count- stump plot (3x3m)	0	11 Clethra acuminata	plentiful Rubus and Smilax	0	2 Clethra acuminata, 1 Castanea dentata
Comparative Sapling count- stump plot (3x3m)	0	0	0	1 llex montana	0
Distance of lateral plot #1 from stump (ft)	18	13	39	21	N/A
Distance of lateral plot #2 from stump (ft)	43	12	45	7	N/A
Distance of comparative lateral plot #1 from log (m)	5	5	N/A	N/A	N/A

APPENDIX B. Seedling and sapling recruitment at lateral and base plots.

#### Illustrations

Front cover: John James Audubon "Carolina Parakeet (*Conuropsis carolinensis* L.)" reproduced in Magee, J. (2007) The art and science of William Bartram. Pennsylvania State University Press. University Park, PA, USA. Introduction page: "Hemlock (*Tsuga canadensis* L.): twig with mature seed cones." Page 37 in Coker, W. C, and H. R. Totten (1934) Trees of the Southeastern states. University of North Carolina Press, Chapel Hill, NC, USA. Acknowledgements page: Laura Louse Foster "Boott's Fern (*Dryopteris Boottii* [Tudkerm.]Underw.)—A hybrid between *D. spinulosa* var. *intermedia* and *D. cristata*." Page 79 in Cobb, B (1956) A field guide to the ferns. Houghton Mifflin Company. Boston, MA, USA. Back cover: William Bartram. "Franklinia (*Franklinia altamaha* W. Bartram ex Marshall)" reproduced in Magee, J. (2007) The art and science of William Bartram. Pennsylvania State University Press. University Park, PA, USA.

