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HIGHLANDS BIOLOGICAL STATION
HIGHLANDS, NORTH CAROLINA

Illustrations

Front cover: “*Liriodendron tulipifera*” Hand-colored engraving by William Paul Crillon Barton (1786-1856)
Vegetable Materia Medica of the United States, 2nd ed., Philadelphia: Carey, 1825

INTRODUCTION

This collection of internship research papers by the students of the 2008 UNC Institute for the Environment–Highlands Field Site program epitomizes the diversity of environmental concerns and issues facing the Highlands Plateau and the equally diverse interests of the students and the varied techniques they have employed to better understand our environmental impact. From policy and management to educational and scientific approaches, their studies are innovative and reveal sometimes surprising aspects of the human footprint on the southern Appalachian landscape -- records of shrew distributions reckoned with discarded bottles, insights gleaned from tree rings on the age and persistence of unique community types or on the ghost of nutritional environment past, restored golf course riparian zones as native plant repositories, GIS-based assessments of new conservation land that may be targeted by area land trusts, contributions to the future of the nascent Highlands Greenway, and more. This volume also reports the results of the students' capstone research project: analysis and proposed remedies for a heavily impacted stream. They did not have to travel far for this study: it meanders through the Station's botanical garden! This once healthy stream presented -- unfortunately -- a study in unintended consequences. Off-site road treatments resulted in inexorable sedimentation and habitat destruction, a process of degradation accelerated in the normally high-rainfall Highlands environment.

The Highlands Biological Station has served as a field site of the The Institute for the Environment (IE) at UNC-Chapel Hill since 2001. The Blue Ridge Escarpment of the southern Appalachians affords unrivalled opportunities to study the ecology and evolution of the region's rich biota, its complex history of land use, and increasing threats to southern Appalachian natural systems. Together the projects reported here underscore our philosophy as an IE field site: hands-on engagement toward a better understanding of human impacts on the southern Appalachian environment. We could not achieve this for our students without help, however. We are immensely grateful to the many individuals who came to share their expertise and enthusiasm, and are especially appreciative of the time and talent shared by the students' mentors: Patrick Brannon (Highlands Biological Station), Hugh Dillingham (Upper Cullasaja Watershed Association), Sharon Taylor and Paul Carlson (Land Trust for the Little Tennessee), Chelcy Ford and Jennifer Knoepp (Coweeta Hydrologic Lab), Brent Martin (The Wilderness Society), Hillrie Quinn (Highlands Plateau Greenway), and Gary Wein (Highlands-Cashiers Land Trust). We thank Steve Foster of Watershed Science, Inc. for sharing his expertise in the capstone study, guiding the students through the theory and techniques of impacted stream assessment in a truly home-grown project.

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Jim Costa, Site Director
Anya Hinkle, Associate Site Director

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2008 IE-HFS INTERNSHIP MENTORS

David Bost and Maggie Caswell worked with Patrick Brannon of the Highlands Nature Center

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AN EXAMINATION OF SHREW SPECIES' DISTRIBUTIONS ALONG THE BLUE RIDGE ESCARPMENT USING DATA FROM DISCARDED BOTTLES

DAVID M. BOST AND MAGGIE CASWELL

Abstract. Small mammal remains were collected from discarded bottles at 96 sites along major roads in the Blue Ridge escarpment of North Carolina, South Carolina, and Georgia to examine elevational distributions and habitat preferences of individual shrew species. Remains were found in approximately 4% of the open bottles searched, and specimens were found at greater than 56% of the sites. A total of 132 specimens of small mammals were collected representing five species of shrew and three species of rodents. Results are consistent with previous studies suggesting that the northern short-tailed shrew (*Blarina brevicauda*) and the smoky shrew (*Sorex fumeus*) are abundant and widespread, while the masked shrew (*S. cinereus*) and the southeastern shrew (*S. longirostris*) are allopatric along the elevational gradient. Distributional data on rodent species captures are also provided.

Key words: Blue Ridge escarpment, bottles, mammals, shrews, *Blarina brevicauda*, *Sorex cinereus*, *Sorex fumeus*, *Sorex longirostris*, southern Appalachians.

INTRODUCTION

The Blue Ridge escarpment marks the southeastern edge of the Appalachian Mountains through North Carolina, South Carolina, and Georgia. Elevation decreases quickly from north to south as the landscape shifts from mountain to piedmont. For example, the elevation in the Highlands Plateau region changes from 4118 ft (1255 m) at Highlands, NC to 1027 ft (313 m) at Walhalla, SC but is separated by a distance of only 31.25 miles (50.29 km). This rapid transition means that the ranges of high elevation species of small mammals, such as the masked shrew (*Sorex cinereus*), and low elevation species, such as the southeastern shrew (*S. longirostris*), may occur in relatively close proximity (Johnson 1967, Mengak et al. 1987). Although some species of shrews are found throughout the region, the masked shrew and the southeastern shrew are contiguously allopatric. The masked shrew has been found to be associated with mesic hardwood forests between 2017 and 5249 ft (615 to 1600 m), whereas the southeastern shrew occurs in mostly xeric forests at elevations of 656 to 3028 ft (200 to 923 m; Ford et al. 2001).

Discarded bottles were first used to collect small mammal data in the 1960s in England (Morris and Harper 1965, Clegg 1966). Rodents and shrews may enter bottles looking for food, water, or shelter, or may be attracted to the scent of the contents, and often become entrapped due to the slippery surface or angle of the bottle. Animals may also drown if the bottle becomes partially filled with rainwater (Benedict and Billeter 2004). Pagels and French (1987) used discarded roadside bottles to delineate the ranges of the northern short-tailed shrew (*Blarina brevicauda*) and the southern short-tailed shrew (*B. carolinensis*) in Virginia. Using that study as a model, we sought to use

animals trapped in bottles to delineate the elevational distributions of shrews along the Blue Ridge escarpment as a continuation of a study by Burt (2007).

MATERIALS AND METHODS

We collected bottles from 96 sites along roadsides at overlook and pull-off areas, including 14 sites in Macon County, NC; 15 sites in Jackson County, NC; 11 sites in Transylvania County, NC; 31 sites in Oconee County, SC; 10 sites in Pickens County, SC; and 15 sites in Rabun County, GA (Fig. 1). We searched on highways in these counties for sites that were in the potential range of *S. cinereus* and *S. longirostris* and also where these two species' ranges could overlap, including NC Hwy 281, SC Hwy 11, SC Hwy 130, SC Hwy 288, US Hwy 64, US Hwy 76, and US Hwy 178. These highways were chosen for their wide range of elevation. Our highest elevation site was at 4160 ft (1268 m) in Macon County, NC, and our lowest elevation site at 797 ft (243 m) in Oconee County, SC, an elevation change of 3363 ft (1025 m).

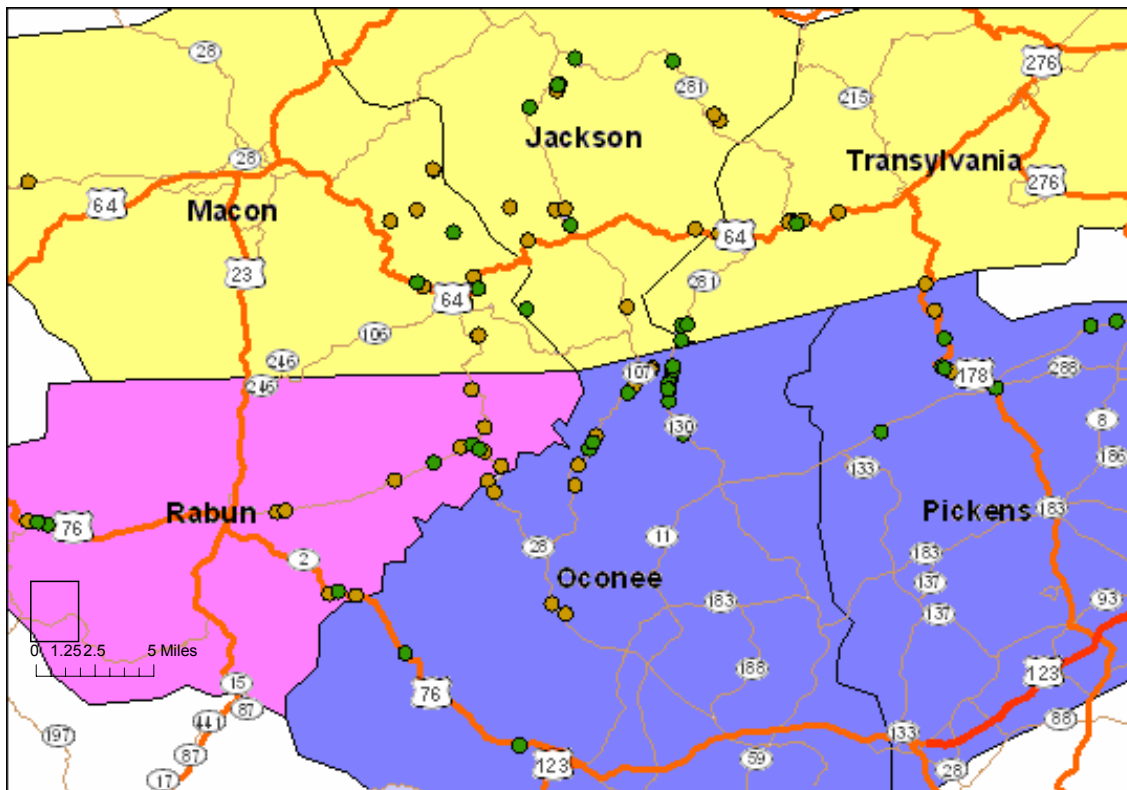


FIG. 1. Map of study sites examined with North Carolina counties in yellow background, South Carolina counties in blue background, and Georgia county in purple background. Orange circles indicate sites with specimens found in bottles. Green circles indicate sites with no specimens found in bottles.

Sites were chosen in areas of high traffic, primarily at overlook and pull-off areas likely to support a high concentration of discarded bottles. The area investigated of each site varied, based on its slope steepness and the thickness of its vegetation. The search area averaged 100 m in breadth and in depth, or as far into the woods as bottles could be found. Latitude, longitude, and elevation data at each site were recorded with a Garmin

eTrex Legend[®] HCx GPS. We also recorded a general description of the site's dominant habitat.

At each site bottles were collected and examined for animal material. We recorded the number of bottles found with lids (i.e. closed) and those without (i.e. open), as well as the number of bottles containing animal remains and the number of specimens found. The bottles that contained animal material usually had water, dirt, insects (e.g. carrion beetles, millipedes, worms, etc.), and a foul odor. Remains were extracted and placed into a Ziploc bag with collection site data. Skulls were returned to the Highlands Biological Station where, with the aid of a microscope, they were identified to species on the basis of dentition and other cranial characteristics (Caldwell and Bryan 1982). The location of each site and species was mapped using ArcGIS[®] 9.3 (ESRI 2008).

RESULTS

A total of 5921 bottles were examined, most of which were located far from the shoulder of the road down the steep slope into the woods. Only 3316 of these bottles were open (62.7%) and served as potential traps, with an average of 34.54 open bottles at each site. Specimens were collected from 132 (3.98%) open bottles that contained specimens at 54 sites (56.3%) with mean of 2.6 specimens (range = 0 to 16) per site. Most of the bottles that contained specimens were facing upslope and filled with water. Multiple specimens were frequently collected in individual bottles (mean = 1.89; range 0 to 12 skulls, 0 to 3 species), although these were usually from larger bottles. Many of the bottles found in the study sites were buried and had been in place for a long period of time, as indicated by their design and labeling. There were a variety of bottles found including 2 liter soda bottles and glass milk bottles.

A total of 248 mammalian specimens were collected (Table 1), constituting five species of shrews and three species of rodents. Two salamander specimens were also collected: a southern red-backed salamander (*Plethodon serratus*) and a southern gray-cheeked salamander (*P. metcalfi*). The most common small mammal species found was the northern short-tailed shrew, *Blarina brevicauda*, (n=152 or 61.29% of captures) located at 41 (42.71%) of the sites. *Blarina brevicauda* was also the most widely distributed at mean site elevation of 760.8 ± 39.0 m and range of 361 to 1223 m (Fig. 2a), and were found in a variety of different habitats including mesic hemlock-hardwood, xeric hardwood and pine forests.

Other species of shrews found were the smoky shrew, *Sorex fumeus* (n=41 or 16.53% of captures), the pygmy shrew, *S. hoyi* (n=5 or 2.02% of captures), the masked shrew, *S. cinereus* (n=9 or 3.63% of captures), and the southeastern shrew, *S. longirostris* (n=4 or 1.61% of captures). *Sorex fumeus* was also widely distributed and was found at 20 (20.83%) of the sites (Fig. 2b) at a mean elevation of 893.2 ± 52.1 m (range = 448 to 1223 m). This species was primarily found in mesic hemlock-hardwood forests. *Sorex hoyi* was found at 3 (3.13%) of the sites (Fig. 2b) at a mean elevation of 1049.0 ± 87.7 m (range = 882 to 1179 m) and was found in primarily mature, mesic hemlock forests.

Although relatively few samples were collected, masked shrews and southeastern shrews appeared to be allopatric in the region. *Sorex cinereus* was found at 9 (9.38%) of the sites (Fig. 2c) at a mean elevation of 1092.3 ± 37.1 m (range = 881 to 1192 m) and occurred exclusively in mesic, mixed hemlock-hardwood forests. Conversely, *Sorex*

longirostris was found at 4 (4.17%) of the sites (Fig. 2c) at a much lower mean elevation of 574.5 ± 60.0 m (range = 458 to 728 m) in mainly xeric mixed hardwood and pine forests.

The three species of rodents (Fig. 2d) collected were the white-footed mouse, *Peromyscus leucopus* (n=27 or 10.89% of captures), the deer mouse, *P. maniculatus* (n=5 or 2.82% of captures), and the woodland vole, *Microtus pinetorum* (n=3 or 1.21% of captures). *Peromyscus leucopus* was found at 10 (10.42%) of the sites at a mean elevation of 643.5 ± 56.9 m (range = 395 to 894 m). *Peromyscus maniculatus* was found in 7 (7.29%) of the sites at a mean elevation of 945.9 ± 55.7 m (range = 702 to 1192 m). Both *Peromyscus* species were found in a variety of habitats including mesic hemlock-hardwood, xeric hardwood and pine forests. *Microtus pinetorum* occurred in 3 (3.13%) of the sites at a mean elevation of 799.0 ± 226.6 m (range = 395 to 1179 m) and in xeric and mesic forests.

TABLE 1. A total of 248 mammalian specimens were collected at a total of 96 sites.

Species Collected	Common name	Total Captured	% Total Captures	# of Site Occurrences	% Total Sites
Soricidae					
	Northern Short-tailed				
<i>Blarina brevicauda</i>	Shrew	152	61.29	41	42.71
<i>Sorex cinereus</i>	Masked Shrew	9	3.63	9	9.38
<i>S. fumeus</i>	Smoky Shrew	41	16.53	20	20.83
<i>S. hoyi</i>	Pygmy Shrew	5	2.02	3	3.13
<i>S. longirostris</i>	Southeastern Shrew	4	1.61	4	4.17
Muridae					
<i>Microtus pinetorum</i>	Woodland Vole	3	1.21	3	3.13
<i>Peromyscus leucopus</i>	White-footed Mouse	27	10.89	10	10.42
<i>P. maniculatus</i>	Deer Mouse	7	2.82	7	7.29

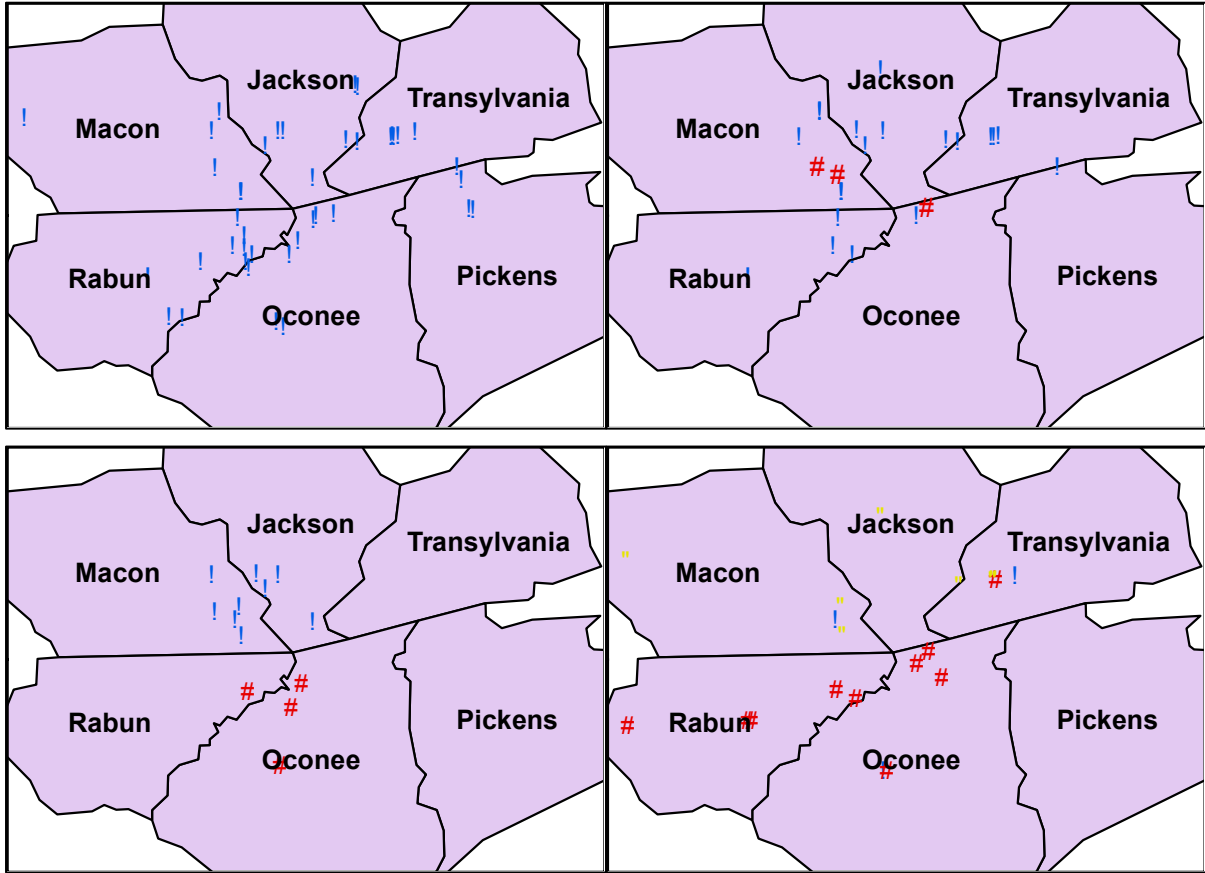


FIG. 2. Distribution of mammals based on specimens collected in bottles: (a) *Blarina brevicauda*; (b) *Sorex fumeus* (blue circle) and *S. hoyi* (red triangle); (c) *Sorex cinereus* (blue circle) and *S. longirostris* (red triangle); (d) *Microtus pinetorum* (blue circle), *Peromyscus leucopus* (red triangle), and *P. maniculatus* (yellow square).

DISCUSSION

The southern Appalachians represent the epicenter of soricid diversity in North America (Berman et al. 2007). The unique climate and geography of the southern Blue Ridge escarpment allow for many different species to overlap at the edge of their ranges. Because shrews have high water requirements, areas with high annual rainfall tend to have high shrew species diversity (Berman et al. 2007). Shrews forage in leaf litter in search of food and water, relying more heavily on their senses of smell and touch than sight. This makes them more susceptible to entering discarded bottles hidden in leaf litter or partially buried in soil (Benedict and Billeter 2004).

Northern short-tailed shrews (*Blarina brevicauda*) may be more likely to become trapped in bottles due to their use of echolocation, as bottle openings may resemble tunnels (Gould et al. 1964). Their high capture rate could also be influenced by their size, which is generally larger than species of *Sorex*, making it more difficult to escape bottles once entered. *Blarina brevicauda* was observed in a variety of habitats, including both mesic and xeric hardwood forests as well as mixed hardwood and pine forests, consistent with its status as a generalist species. As such, *B. brevicauda* does not have specialized habitat or resource requirements and is widely distributed in a variety of habitats and elevations (see Fig. 2a). *Sorex fumeus*, the second most abundant species of

capture, has also been observed in a variety of habitats, though it's in greatest abundance in northern hardwood and cove hardwood communities (Laerm et al. 1999).

Sorex longirostris is also a generalist, and can live in a variety of habitats. *Sorex cinereus*, on the other hand, is specialized to live at higher elevations, and moisture is a primary factor affecting its distribution (Laerm et al. 1999). Hardwood forest habitats tend to have higher soil moisture, and are more often found at higher elevations, which are generally wetter and cooler. Though insufficient numbers of specimens of the masked shrew and the southeastern shrew were obtained to delineate these species' elevation restrictions, results were consistent with delineations made by Ford et al. (2001). Although an overlap in the latitudinal distribution of the two species has been observed, masked shrews and southeastern shrews have never been captured at the same site. The southernmost record for masked shrew is the Walhalla Fish Hatchery in northwestern Oconee County, South Carolina (Laerm et al. 1995), a hemlock-rhododendron streamside community at an elevation of approximately 760 meters. Conversely the northernmost record for the southeastern shrew is the Coweeta Hydrological Laboratory of Macon County, North Carolina, in a xeric oak-pine-grassy meadow habitat at an elevation of 716 meters (Laerm et al. 1999). The occurrences of *S. longirostris* in more xeric environments at higher elevations and *S. cinereus* in more mesic environments at lower elevations indicates habitat segregation along with contiguous elevational allopatry (Laerm et al. 1999, Ford et al. 2001).

An examination of discarded bottles can be a useful source of small mammal distributional data, especially for shrews (Pagels and French 1987). This method is less labor intensive than conventional methods such as pitfall- or snap-trapping (Gerard and Feldhamer 1990, Taulman and Thill 1992). Discarded bottles are already in place and function continuously, so distributional gaps may be filled in a very short period and reduce the necessity of overnight trapping (Pagels and French 1987). Although bottles may not be a reliable indicator of actual species abundances (Gerard and Feldhamer 1990) and may be ineffective in short-term studies involving activity patterns (Taulman and Thill 1992), geographic distributional information from bottles may be limited only by the area sampled and the diversity of the small mammal fauna (Pagels and French 1987).

Discarded bottles could serve as a conservation threat in areas where species of concern are likely to be trapped. Although only about 4% of discarded bottles in our study collected animals, which is consistent with the findings of Benedict and Billeter (2004), the abundance of small mammals that become entrapped along highways is alarming. Pagels and French (1987) estimated a mortality rate of 24 small mammals per kilometer, but this rate has been determined to be as high as 183 animals per km in certain areas (Benedict and Billeter 2004). In steep mountainous terrain, bottles often roll down the slope where they go undetected by road cleanup crews. Thus, the accumulation of bottles along the roadways should be of great concern in the southern Appalachians where shrew diversity is especially high.

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QUANTIFYING THE DECLINE IN TRANSPIRATION OF *TSUGA CANADENSIS* AND PREDICTING WATER BUDGET IMPLICATIONS OF SUCCESSION IN SOUTHERN APPALACHIAN FORESTS

JOSEPH B. DAVIS

Abstract. Eastern hemlock (*Tsuga canadensis* (L.) Carr.) is declining throughout the eastern United States as a result of infestation of the hemlock woolly adelgid (HWA). As a principal species in riparian cove habitats in the southern Appalachians, its loss will have impacts on the hydrologic budget in these systems. To estimate the impact on the hydrologic budget, we quantified transpiration over five years for *T. canadensis*, and over two years for co-occurring species *Acer rubrum*, *Betula lenta*, and *Rhododendron maximum*. Further, to understand the impacts of climate on transpiration, we compared transpiration to photosynthetically active radiation (PAR) and to vapor pressure deficit (VPD). Given the loss of *T. canadensis* from the ecosystem, we modeled implications on transpiration from two resulting succession scenarios, one in which *R. maximum* dominates, and one in which *A. rubrum* and *B. lenta* dominate. Transpiration was shown to decline since 2004 for *T. canadensis*, and no such decline was observed for the other species from 2006. The decline in transpiration was not shown to be a result of a changing climate conditions from the same study period. Using data from other studies, we modeled the succession of *R. maximum* following the loss of *T. canadensis* leaf area from the canopy. Also, we modeled the succession of *A. rubrum* and *B. lenta* resulting from a shift in sapwood area from *T. canadensis* to these species. Under both post-mortality scenarios, the transpiration component of the hydrologic budget increased. Although actual post-mortality scenarios are difficult to predict, the loss of *T. canadensis* will result in changes in the function of this ecosystem.

Key words: hydrologic budget; sap flux density; sapwood; succession; *Tsuga canadensis*.

INTRODUCTION

A foundation species is a single species that defines much of the structure of a community by creating locally stable conditions for other species, and by controlling fundamental ecosystem processes (Dayton 1972). Foundation tree species have shown a decline throughout the world due to a number of factors, including introductions and outbreaks of nonindigenous pests and pathogens, spread of native pests, over-harvesting, and deliberate removal of individual species from forests (Ellison et al. 2005). Eastern hemlock (*Tsuga canadensis*) is a foundation species due to its role in modulating water and nutrient cycling, and microclimate.

In the southern Appalachians, eastern hemlock grows in mixed stands in narrow riparian corridors and moist coves, often with dense understories of *R. maximum*. The combination of deep shade and acidic, slowly decomposing litter results in a cool, damp

microclimate, slow rates of nitrogen cycling, and nutrient-poor soils (Jenkins et al. 1999). Streams flowing through hemlock forests support unique assemblages of salamanders, fish, and freshwater invertebrates that are intolerant of seasonal drying (Snyder et al. 2002).

Hemlock woolly adelgid (*Adelges tsugae* Annand, HWA), an invasive exotic insect, is causing eastern hemlock decline and mortality throughout the extent of its range. HWA was first found in North America in British Columbia in 1924 and later in Oregon in 1928 (Annand 1928). HWA was found in the southern Appalachians in Virginia in the early 1950s. HWA attaches to the base of hemlock needles and feeds on stored sugars in xylem ray parenchyma (Young et al. 1995). Healthy eastern hemlock trees retain needles up to four years; however, in HWA-infested trees, the tree does not produce new buds or foliage after infestation (Stadler et al. 2005). The decline of eastern hemlock is already having pronounced impacts on ecosystem processes (Orwig and Foster 1998, Ellison et al. 2005, Ford and Vose 2007, Daley et al. 2007); of these, impacts on hydrologic budget are predicted to be long-term and significant.

The hydrologic budget is an accounting of all the water entering (precipitation), exiting (stream flow and evapotranspiration), and being stored in a hydrologic unit, such as a drainage basin (or watershed). Transpiration, one component of evapotranspiration, typically constitutes 30-40% of the water budget in southern Appalachian systems (Swift et al. 1975). Transpiration rates are affected by phenology (Oren and Pataki 2001), climate, and differences between sapwood area and leaf area (Wullschleger et al. 1998, Meinzer et al. 2005). Species that grow in areas with constant access to water have the potential to transpire longer or at greater rates compared to species located in areas without stable access to water (Dawson 1993), and evergreen species have the potential to transpire year-round. Eastern hemlock is one of the principal riparian and cove species in the southern Appalachians and commonly the only evergreen canopy species in mesic sites (Brown 2004, K. Elliott, unpublished data).

Stand structure and species composition is expected to change following the loss of eastern hemlock, and the change in structure and composition is predicted to be different for eastern hemlock stands in the northeast and southern Appalachians (Ellison et al. 2005). *Betula lenta* is the primary species replacing *T. canadensis* in the northeast, as it represents 75% of the replacement species following the loss of *T. canadensis* from HWA-infestation (Daley et al. 2007). In the southern Appalachians, *A. rubrum* and *B. lenta* are located in association with *T. canadensis* in riparian and cove forests and may be the primary canopy species replacing eastern hemlock. However, in stands with a dense subcanopy of *R. maximum*, post-hemlock mortality seedling recruitment of any species into the canopy will likely be low (Clinton and Vose 1996, Beckage et al. 2000, Nilsen et al. 2001).

Sap flux density is a measurement of the velocity of water moving per unit of sapwood through trees, and it is a way to make inferences about canopy transpiration. Within a given system and climate, healthy individuals within a species maintain a constant ratio of leaf area and sapwood area. In a tree that declines by losing leaf area over time—if the age of the foliage that is lost is random, and if the decline is slow enough so that changes in sapwood area keep pace with changes in leaf area—sap flux density may not decline over time, although total water use by the tree (sap flow) would decline. In eastern hemlock trees infested with HWA, the ratio of new to old foliage

declines (Stadler et al. 2005) because the tree does not produce new buds or foliage after infestation. Under any given humidity or light level, young foliage has a higher transpiration rate and photosynthetic rate than older foliage (Ford and Vose 2007). Therefore, as eastern hemlock trees decline from HWA infestation, we would expect sap flux density to decline over time because the remaining (older) foliage on the tree has lower transpiration rates than younger foliage (that the tree likely is not producing), and because the decline is likely too rapid for sapwood area changes to keep pace with leaf area changes. Because the mean foliage age of a post-infestation tree is greater than the mean foliage age of a pre-infestation tree, we expect that, for any given light level or humidity level, sap flux density will decline over time in *T. canadensis*, but not for other canopy tree species. We also expect that as eastern hemlock foliage is lost, light levels incident on the sub-canopy species' foliage will increase (e.g., more light for *R. maximum*), and that for any given light or humidity level, that transpiration will increase over time.

Our goals were (1) to evaluate changes in sap flux density of infested eastern hemlock trees over five years, and also evaluate the changes in sap flux density of three co-occurring species (*R. maximum*, *A. rubrum*, *B. lenta*); (2) to evaluate the relationship between transpiration and climate of all species for changes over time; and (3) to model impacts of changes in sap flux density for three proposed likely succession scenarios following the loss of *T. canadensis* (Fig. 1).

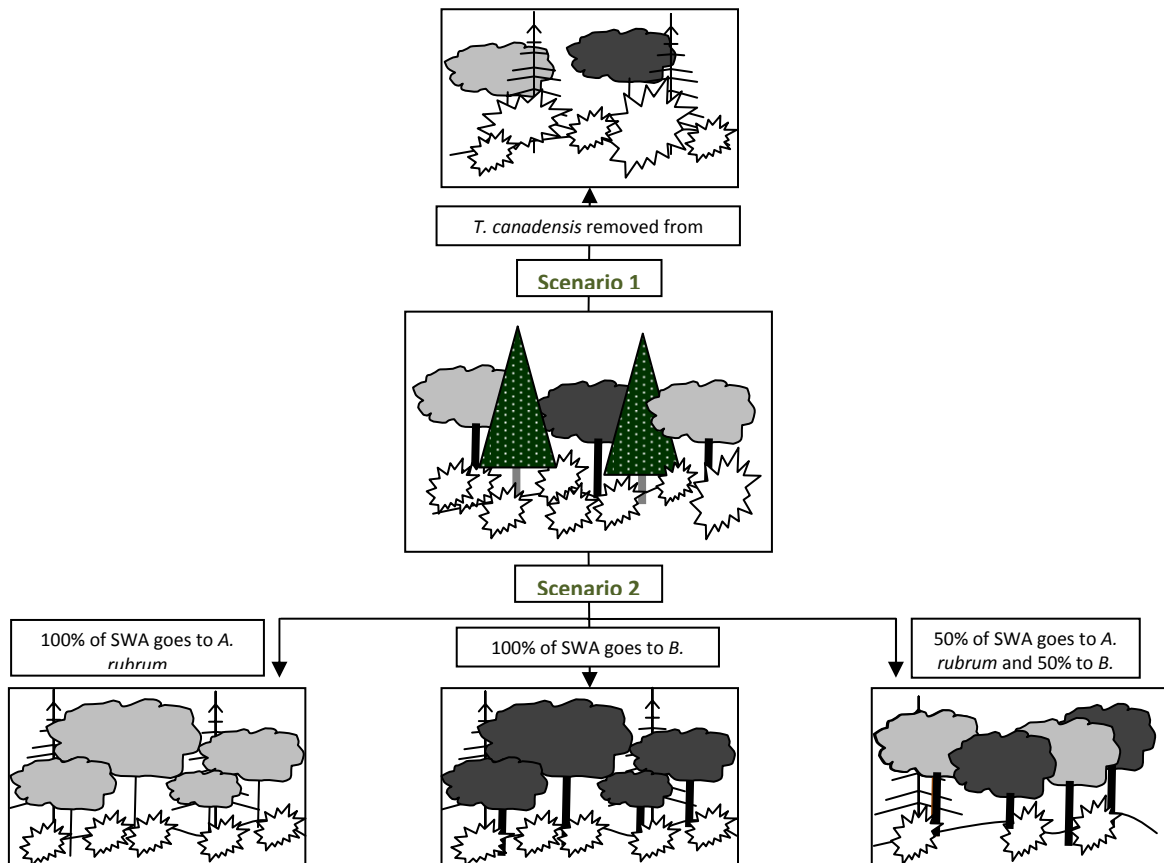


FIG. 1. Diagram showing succession scenarios predicted in this study. Scenario 1 depicts the effects of the loss of *T. canadensis* leaf area from the canopy, and an increase in transpiration of *R. maximum*. Scenario 2 depicts the effects of replacing the sapwood area of *T. canadensis* completely by *A. rubrum*, completely by *B. lenta*, or half by *A. rubrum* and half by *B. lenta*.

In order to test for changes in sap flux density among species we targeted the time of year when we expected sap flux density to be the greatest. For *T. canadensis* we tested for differences in spring sap flux density over time (between the years 2004 and 2008), and for the other three species, we tested for changes in sap flux density during the growing season (between 2006 and 2007). We hypothesized that *T. canadensis* sap flux would decrease over time, and that sap flux for the other species would not change over time. We also tested for changes in sapwood area of *T. canadensis* trees by evaluating the relationship between diameter and sapwood area during 2004-2005 and 2008-2009. We tested for changes in the regression coefficients between light and sap flux density, and humidity and sap flux density of all species and years to detect changes in the relationship between transpiration and climate. We hypothesized that the regression coefficients would decline over time for *T. canadensis*, stay the same over time for *A. rubrum* and *B. lenta*, but increase over time for *R. maximum* (specifically for the relationship between overstory light and sap flux). Lastly, to estimate potential impacts on transpiration following *T. canadensis* mortality, we created two succession scenarios: one in which *R. maximum* is the only species after *T. canadensis* mortality, and one in which hardwood canopy species replace *T. canadensis*. We hypothesized that there would be an increase in the transpiration component of the water budget under both post-mortality scenarios, and that transpiration of hardwood species would be greater than that of *R. maximum*.

MATERIALS AND METHODS

Site Description and Plot History

This study took place at the USDA Forest Service Southern Research Station, Coweeta Hydrologic Laboratory, located in the Nantahala Mountain Range of Western North Carolina. Climate in the Coweeta basin is classified as humid temperate with cool summers and mild winters (Swift et al. 1988). Average annual temperature in the basin is 13°C and average annual rainfall is 178 cm. The plots used for the study were established in low elevation (730-1040 m) cove hardwood forests. Two long-term sap flux plots (H3 and H4), located on Shope Fork Creek, were used for sap flux density analysis. Two other plots used, intensive hemlock study plots (IH3 and IH6), were located on Ball Creek and Shope Fork Creek, two fourth-order streams that drain Coweeta basin (Elliot and Swank 2007). Sap flow plots were initially set up in 2004 to monitor hemlock sap flow over time with HWA infestation; intensive hemlock plots were set up to quantify changes in carbon and nutrient cycling, forest structure and species composition, and microclimate. Species composition in the long-term sap flux plots is dominated by eastern hemlock (*T. canadensis*), rosebay rhododendron (*R. maximum*), and sweet birch (*B. lenta*). Other species include *Quercus* spp., *Carya* spp., *Nyssa sylvatica*, and *Liriodendron tulipifera*.

The presence of hemlock woolly adelgid was first noticed along the main roads in the Coweeta basin in the fall of 2003 and in Macon county, NC in 2002 (USDA Forest Service 2002 as in Nuckolls et al.). Little or no infestation was found in the rest of the basin in 2003, but significant infestation throughout the basin was observed by 2005 (K. Elliot, unpublished data).

Climate Data

Climate Station 01 (CS01) is an open-field climate station located at the entrance of Coweeta Hydrologic Lab in the bottom of the watershed. Variables used in this study, such as solar radiation, air temperature (T), and relative humidity (RH), were measured every 1 min and logged 15- and 60-min means. We used data from CS01 based on the assumption that open-field climate conditions represented overstory canopy conditions. Solar radiation was used to calculate photosynthetically active radiation (PAR $\mu\text{mol m}^{-2} \text{s}^{-1}$) by assuming that 50% was in the 400-700 nm wavelength (Landsberg and Waring 1997) and using the conversion factor of 4.608 $\mu\text{mol quanta/J}$ (from ambient T, saturated vapor pressure [e_s] was calculated according to Lowe [1977]). Actual vapor pressure (e_a) was calculated from fractional RH and e_s . Air vapor pressure deficit (VPD, kPa) was calculated as the difference between e_s and e_a : $\text{VPD} = e_s(T_a) - e_a$. Soil moisture was measured at 0-30 cm soil depth at two locations in the sap flow plots, and at two locations in the intensive hemlock plots starting in 2005. Additional soil moisture measurements were made seasonally in the intensive hemlock plots in five spatial locations during 2004-2006 (Nuckolls et al., unpublished data).

Calculating Flow

Thermal dissipation probes (Granier 1985), inserted in the outer 0-2 or 0-3 cm of sapwood, were used to estimate sap flux density ($\text{g H}_2\text{O m}^{-2} \text{sapwood s}^{-1}$). Dataloggers calculated the temperature difference every 30s and gave 15min averages. Temperature difference between the upper and lower probes was converted to sap flux density using equations given by Granier (1985). Two replicate sets of probes were inserted into each tree every spring (separated by more than 90 degrees).

Sapwood area (SWA, m^2) was estimated from diameter at breast height (DBH) versus sapwood area relationships developed on 12 hemlock trees. Relationships were developed in early spring 2005 by drilling a hole into the stem 0-1 m above ground height and connecting a reservoir of solution of water and dye which perfused the hydroactive xylem. After at least 1 L of solution was taken up, trees were cored at ~ 1.3 m height (above the perfusion point), and the sapwood radius was measured as the radial length of dyed xylem. From these data, the area of active sapwood was determined (Ford and Vose 2007). The same measurement technique was repeated in the fall of 2008 for 7 hemlock trees. We fit linear regressions for both years and tested for differences in the regression coefficients using ANOVA PROC GLM (SAS) and compared the slopes and intercepts among years. Sap flow (g s^{-1}) was calculated as the product of Js and SWA.

Quantifying Changes in Transpiration

To quantify changes in transpiration, sap flux density was measured from 2004-2008 using days 142-165 (representative of the growing season) from hours 600-2000. Although many size classes were being monitored, we only used large size class trees: DBH 47.7-67.5cm (5 replicate trees). We plotted sap flux density over time and tested for differences over time using a repeated measure ANOVA PROC MIXED (SAS). Three other species were also monitored starting in 2006: *A. rubrum*, *B. lenta*, and *R. maximum*.

For these species, we only had enough data to test for changes in sap flux density from years 2006 and 2007.

To compare transpiration to climate, we plotted daily sap flux density against daily PAR or daily VPD and fit a linear regression to the relationship for each of the four species. We took each regression coefficient and tested for differences over time using tree as a replicate and year as a repeated measure (ANOVA PROC MIXED) for each species. The same PAR and VPD data were used when comparing sap flux density of *A. rubrum*, *B. lenta*, and *R. maximum* as were used to compare sap flux density of *T. canadensis*.

Simulating the loss of T. canadensis

Two simulations were modeled: (1) complete loss of hemlock with no canopy recruitment, but increased resources for *R. maximum*, and (2) complete loss of hemlock with sapwood area taken over by either all *A. rubrum* or all *B. lenta*, or half *A. rubrum* and half *B. lenta*. For the first simulation, we estimated the effect of hemlock loss on *R. maximum* transpiration by modeling how the canopy leaf area would change incident PAR using days 142-285 in 2005. We chose these days because there was no understory light data available until 2005. To model a decline in leaf area, we calculated light extinction coefficients ($-k$) for healthy hemlock stands. From two intensive hemlock plots (IH3 and IH6), we used understory daytime PAR (initial Q_i) averaged for each day over the study period gathered by an array of photodiodes in plots IH3 and IH6 (B. Clinton, unpublished data). We calculated canopy leaf area index (excluding *R. maximum* or any subcanopy species) for both stands based on diameter versus leaf area allometric relationships (B. Kloeppel, unpublished data). Using overstory PAR (as Q_o) from CS01, we calculated $-k$ for a number of days when average daily PAR was greater than 1000 $\mu\text{mol photons m}^{-2} \text{s}^{-1}$ to indicate how much light normally penetrates into the stand with hemlock present based on Beer-Lambert Law equation (Vose et al. 1995).

$$\ln\left(\frac{Q_i}{Q_o}\right) = -k(LAI) \quad (1)$$

We then calculated the leaf area index (LAI) of the two stands excluding all the *T. canadensis* (LAI_S). Then, using the known $-k$, the calculated new LAI_S, and the overstory PAR from CS01, we estimated what Q_i would be. We used regression equations from 2006 PAR versus sap flux density for *R. maximum* and calculated the new sap flux density (i.e., $\hat{J}_s$) in a post-mortality scenario.

For the deciduous canopy succession simulations, we used the IH3 and IH6 stands, and replaced the SWA of *T. canadensis* in 2004 by the SWA of other canopy species (*A. rubrum*, *B. lenta*). Using climate data from days 142-285 in 2006, we developed regression equations for each tree in each species (*A. rubrum*, *B. lenta*) between sap flux density and overstory PAR, overstory VPD, and percent soil moisture. Of the 10 trees sampled, P values ranged from <0.0001 to <0.01 , and R^2 values ranged from 0.68 to 0.90. Using these equations, we estimated $\hat{J}_s$ for each tree for seven days in 2004 (days occurred during spring, summer and fall) given the climatic conditions measured on those days (VPD, PAR and soil moisture). These sap flux densities were averaged across days, then across replicate trees for each species: *A. rubrum* ($\hat{J}_{SA}$), *B. lenta* ($\hat{J}_{SB}$), and *T. canadensis* ($\hat{J}_{ST}$). For ease of comparison, we defined canopy stand sap

flow as the sum of water use by *A. rubrum*, *B. lenta*, and *T. canadensis*. These three species represented 79% and 74% of the canopy leaf area in these two stands. A baseline scenario of normal flow under healthy conditions for each stand was calculated by multiplying known total sapwood areas estimated from allometric equations (B. Kloeppel, unpublished data, Ford and Vose 2007) for each species in stands IH3 and IH6 by $\hat{J}_{SA}$, $\hat{J}_{SB}$, $\hat{J}_{ST}$.

Baseline Scenario: calculate stand flow with *T. canadensis* still living

$$\text{Total stand flow} = \hat{J}_{SA} * (SWA_A) + \hat{J}_{ST} * (SWA_T) + \hat{J}_{SB} * SWA_B \quad (2)$$

Scenario 1: All SWA goes to *A. rubrum*

$$\hat{J}_{SA} = \hat{J}_{SA} * (SWA_A + SWA_T) + \hat{J}_{SB} * SWA_B \quad (3)$$

Scenario 2: All SWA goes to *B. lenta*

$$\hat{J}_{SB} = \hat{J}_{SA} * SWA_A + \hat{J}_{SB} * (SWA_B + SWA_T) \quad (4)$$

Scenario 3: 50% SWA to *A. rubrum*, 50% to *B. lenta*

$$\hat{J}_{\text{half/half}} = \hat{J}_{SA} * (SWA_A + (0.5 * SWA_T)) + \hat{J}_{SB} * (SWA_B + (0.5 * SWA_T)) \quad (5)$$

We then ran contrasts among $\hat{J}_{SA}$, $\hat{J}_{SB}$, and $\hat{J}_{ST}$ to test for significant differences with tree as a repeated measure using ANOVA (PROC MIXED SAS).

RESULTS

Changes in Sap Flux Density Over Time

Over the study period, sap flux density in *T. canadensis* showed a decline (Fig. 2). A significant year effect ($F_{4,15} = 3.25$, $P=0.03$) in the model indicated that sap flux density was not consistent across years. These data supported our hypothesis that sap flux density decreased over time for *T. canadensis*. A significant difference was observed between 2004 and all other years (P values ranged from 0.0045 to 0.0546); however, changes in sap flux density from years 2005-2008 were not significant.

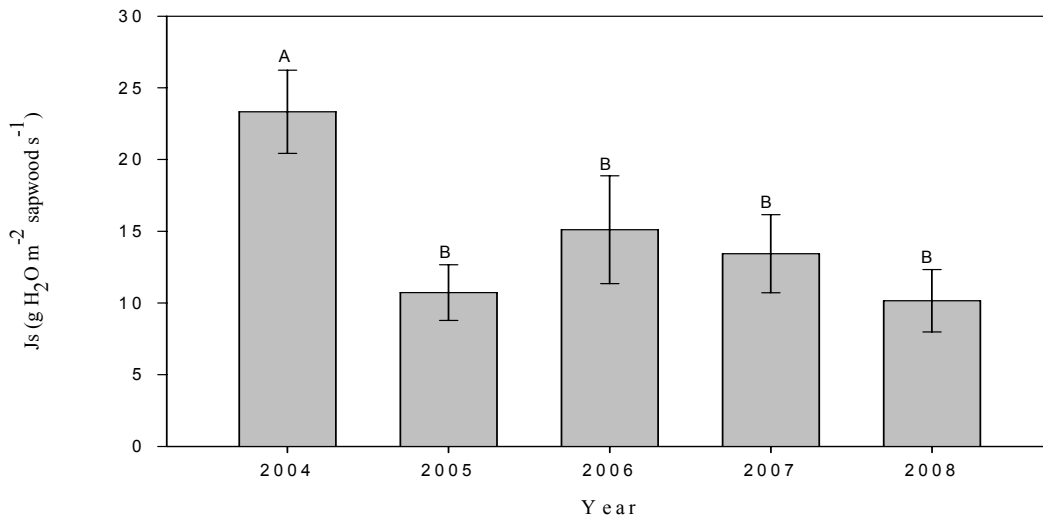


FIG. 2. Mean sap flux density (J_s) of *T. canadensis* trees from days 142–165 for each year. Different letters represent a significant difference among years.

Concurrent with this change in sap flux density for *T. canadensis*, we found that sapwood area was also declining over time (Fig. 3). The regression equation of the natural log of SWA versus the natural log of DBH in 2005 is: $0.8415 + 1.5291x$ and in 2008 is: $-2.0114 + 2.0039x$. This indicates that while *T. canadensis* sap flux density declined significantly over the study period, sap flux density in other canopy and subcanopy species did not decline (Fig. 4).

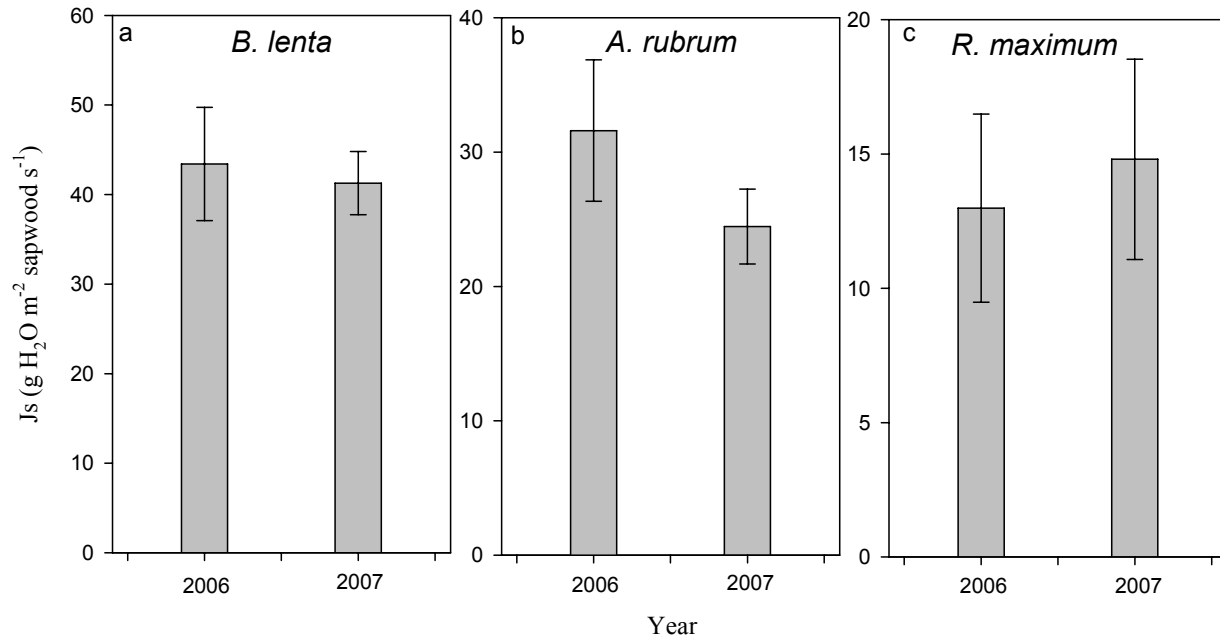


FIG. 4. Average J_s of (a) *B. lenta*, (b) *A. rubrum*, and (c) *R. maximum* over the study days (142-165) for years 2006 and 2007. Error bars represent one standard error of the mean.

Changes in Sap Flux Density in Relation to PAR and VPD

Over the study period, the regression coefficients between *T. canadensis* sap flux density and PAR did not show a decline (Fig. 5a), but the regression coefficients for sap flux density and VPD declined ($F_{4,15} = 4.86$, $P = 0.01$, Fig. 5b). The change in transpiration relative to humidity was greater than the relationship between light. These results partially support our hypothesis that for any given light or humidity level that sap flux density would decline over time for *T. canadensis*. In contrast, the relationships between sap flux density and climate among the other three species over the two years did not change (Fig. 6). While our data supported the hypothesis that for any given light or humidity level that sap flux density in *A. rubrum* and *B. lenta* would not change over time, our results did not support the hypothesis that for any given overstory light level, that sap flux density for *R. maximum* would increase over time.

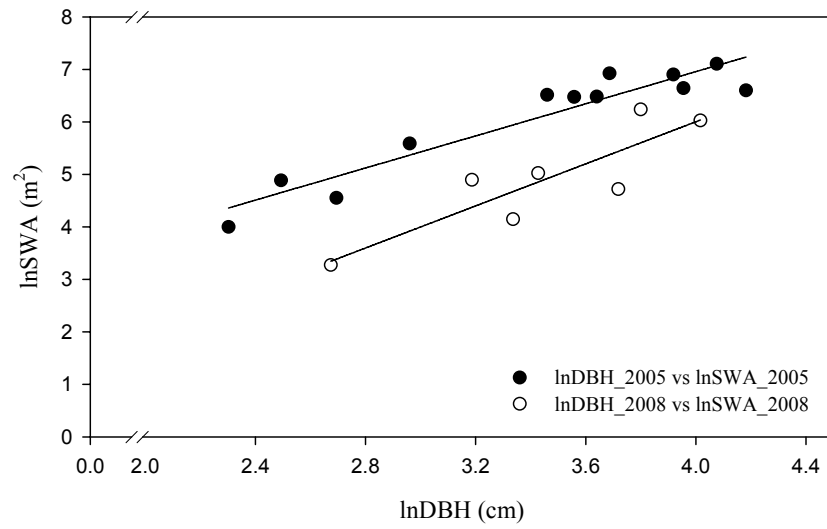


FIG. 3. Relationship between the natural log of active sapwood area (SWA) and the natural log of diameter at breast height (DBH) for 12 *T. canadensis* trees in 2005 and 7 in 2008.

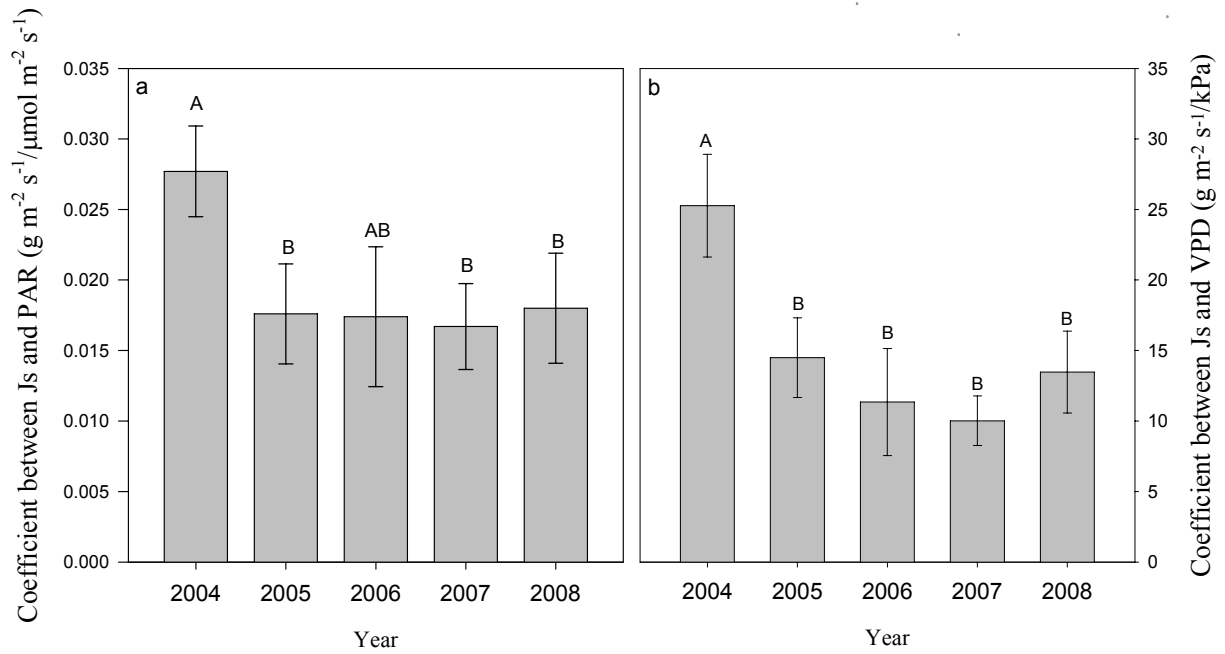


FIG. 5. Mean regression coefficients between *T. canadensis* Js and (a) PAR and (b) VPD. Error bars represent one standard error of the mean. Different letters represent significant differences among years.

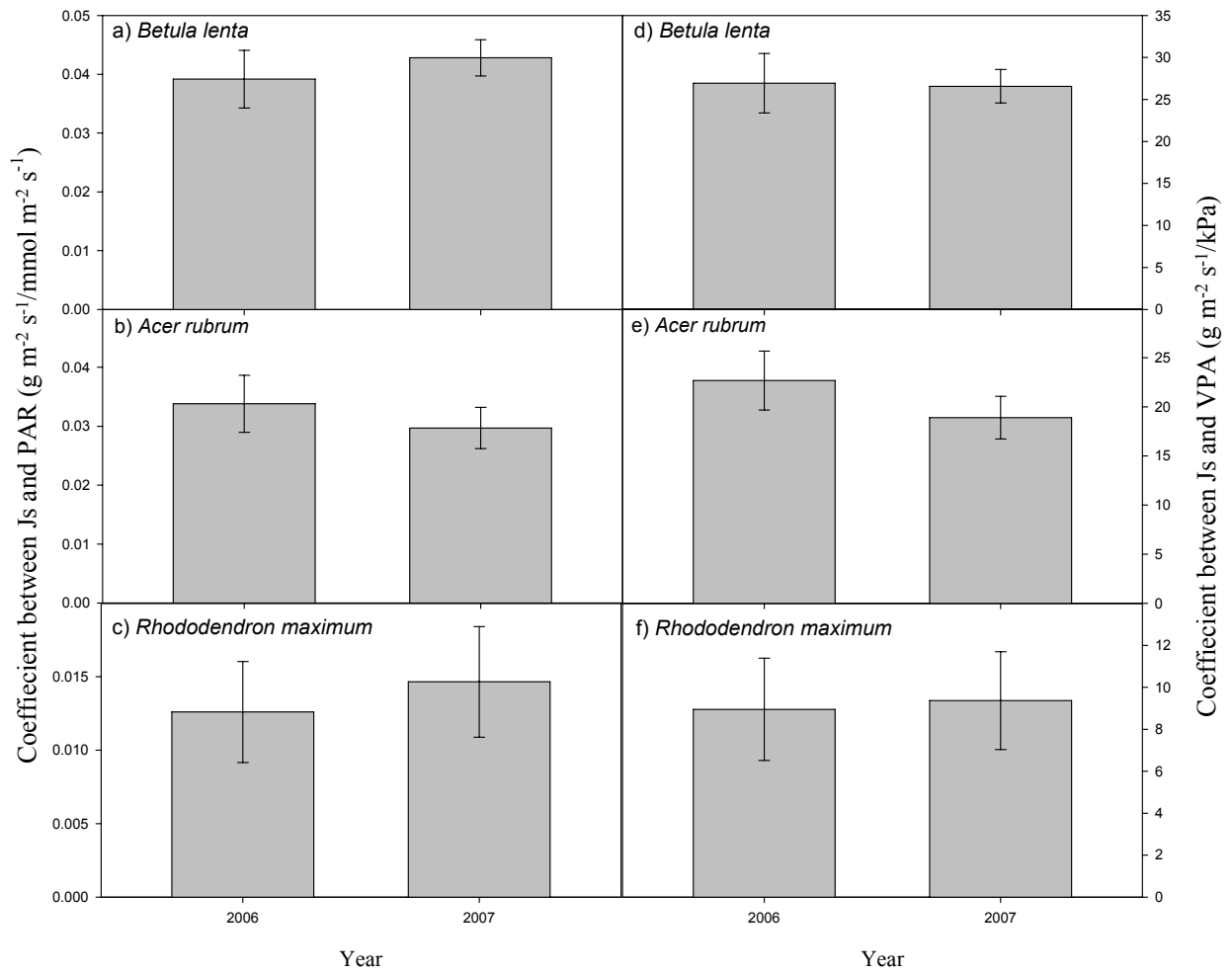


FIG. 6. Mean values of regression coefficients between (a) *B. lenta*, (b) *A. rubrum*, and (c) *R. maximum* sap flux density (Js) versus PAR; and (d) *B. lenta*, (e) *A. rubrum*, and (f) *R. maximum* sap flux density versus vapor pressure deficit (VPD) for days 142–165 in 2006 and 2007. Bars represent one standard error. No significant differences were detected for any species or years.

Scenario 1: Succession of *R. maximum*

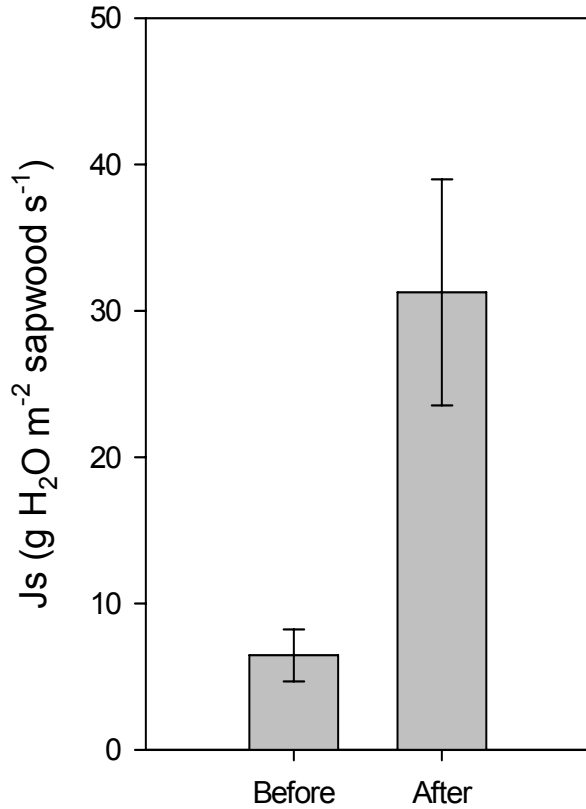


FIG. 7. Simulation 1 projecting the increase in sap flux density (J_s) of *R. maximum* resulting from a decrease in leaf area (LAI) of *T. canadensis*, and an increase in average daily available light (Q_i). Bars represent the average J_s of *R. maximum* before and after the canopy leaf area of *T. canadensis* was removed; bars represent one standard error.

The loss of *T. canadensis* leaf area from the canopy resulted in an increase in light level in the subcanopy (Q_i) and a subsequent increase in sap flux density of *R. maximum*. Before the loss of *T. canadensis*, mean canopy LAI was $5.39 \text{ m}^2 \text{ m}^{-2}$, and mean Q_i was $21.69 \mu\text{mol m}^{-2} \text{ s}^{-1}$. Following the loss of *T. canadensis* from the canopy, mean canopy LAI was $1.56 \text{ m}^2 \text{ m}^{-2}$ and mean Q_i was $366.30 \mu\text{mol m}^{-2} \text{ s}^{-1}$. Mean extinction coefficients for the two stands were 0.75 in IH6 and 0.74 in IH3. This is in agreement with our hypothesis that sap flux density of *R. maximum* would increase following the loss of *T. canadensis*. In plot IH3, *T. canadensis* represented 77% of the total leaf area index in the stand, and in plot IH6, *T. canadensis* represented 63% of total leaf area index. Excluding *T. canadensis* leaf area from the stand resulted in an increase in Q_i by ~17-fold. From 2006 PAR versus J_s *R. maximum* regression equations, we estimated that there would be a ~4.8-fold increase in *R. maximum* J_s following the loss of *T. canadensis* (Fig. 7). Although transpiration will increase for *R. maximum* in a post-mortality scenario, the overall flow is less than that

of a healthy hemlock stand. Predicted flow of *R. maximum* was 4.788 g s^{-1} , whereas healthy flow of *T. canadensis* in 2004 was 14.78 g s^{-1} .

Scenario 2: Succession of *A. rubrum* and *B. lenta*

Using the baseline scenario under healthy hemlock conditions (in 2004), the average total sap flow of the two stands (sum of $\hat{J}_{SA}$, $\hat{J}_{SB}$, and $\hat{J}_{ST}$) was 25.14 g s^{-1} . If all the sapwood area from *T. canadensis* was replaced by *A. rubrum*, the resulting total sap flow of the stand would increase by about 38.3%. If all the sapwood area from *T. canadensis* was replaced by *B. lenta*, the total flow of the stand would increase by about 71.2%. If half of the sapwood from *T. canadensis* went to *A. rubrum*, and half went to *B. lenta*, there would be a 54.8% increase in total flow of the stand.

DISCUSSION

Decline of T. canadensis Transpiration

The sap flux density of hemlock trees in this study declined over time, indicating the combined effects of needle loss and the remaining needle physiology of those infested by HWA. Although changes in sapwood area occurred over time, transpiration was still observed to decline. This indicates that the change in sapwood area is not keeping pace with the change in needle loss. When hemlock trees lose needles as a result of HWA infestation, there is an increase in available light in the understory. As the amount of available light increases in the understory and transpiration of hemlock trees decreases, transpiration of subcanopy species is expected to be affected. Although our study did not show a significant increase in sap flux density for *R. maximum* from 2006 to 2007, this trend is expected over a longer time period. Because the largest shift in sap flux density of eastern hemlock was from 2004 to 2005, there may have been a corresponding increase in sap flux density of *R. maximum* during this time; however, data limitations precluded us from testing these years.

Post-mortality Succession

Following the loss of hemlock from the canopy, we simulated two likely scenarios. In the first scenario, if the subcanopy of *R. maximum* is dense, post-hemlock mortality seedling recruitment of any species into the canopy will likely be low (Clinton and Vose 1996, Beckage et al. 2000, Nilsen et al. 2001). If transpiration of *T. canadensis* trees is replaced by *R. maximum*, it is predicted that, over the long-term, there will be a decrease in riparian forest transpiration because *R. maximum* has a low leaf conductivity to water vapor (Nilsen 1985, Lipp and Nilsen 1997). We found that with the loss of hemlock leaf area, light levels increased almost 17-fold, and we estimated that *R. maximum* would increase transpiration by over 4-fold. Although *R. maximum* transpiration increased, this increase was not enough to make up for the loss of *T. canadensis*' contribution to transpiration. Estimated sap flow of *R. maximum* during days 142-285 in 2005 was found to be 4.78 g s^{-1} while sap flow of *T. canadensis* under healthy conditions during several days of the growing season in 2004 was 14.78 g s^{-1} .

If *R. maximum* does not dominate the subcanopy in HWA-infested eastern hemlock stands, early successional species (*B. lenta*) are expected to increase first, followed by later successional species (*A. rubrum*) (Orwig and Foster 1998). As leaf and sapwood area shift from hemlock to deciduous trees, it is predicted that there will be an overall increase in riparian forest transpiration, and profoundly decreased rates of winter and early spring transpiration (Ford and Vose 2007). Average growing season sap flux density was $35.76 \text{ g m}^{-2} \text{ s}^{-1}$ for *A. rubrum*, $53.51 \text{ g m}^{-2} \text{ s}^{-1}$ for *B. lenta*, and $15.09 \text{ g m}^{-2} \text{ s}^{-1}$ for *T. canadensis*. Because *T. canadensis* is a coniferous species, transpiration occurs throughout the year. Deciduous trees do not transpire during this time because they have not yet put on new leaves. Despite this difference, total annual sap flow is expected to increase following the loss of *T. canadensis*. For example, mean winter flow of *T. canadensis* in 2004 (days <80 and >300) was 4.75 g s^{-1} . If this value is added to growing season flow of *T. canadensis*, the resulting yearly flow is about 29.75 g s^{-1} . When this

value is compared to average annual sap flow of *B. lenta*, 43 g s⁻¹, average annual sap flow will increase if *B. lenta* replaces *T. canadensis*. Using this rationale for calculated sap flux increases of other succession circumstances (both *A. rubrum* or *B. lenta* succession), annual transpiration would be greater than that of yearly *T. canadensis* including winter transpiration.

Regardless of what hardwood species come in after hemlock mortality, the seasonality and timing of stand sap flow will change. However, the magnitude of change of stand sap flow will greatly depend on species. For example, some studies have found that diffuse porous trees use a greater amount of water than ring-porous trees (Wullschleger et al. 2001). These authors predicted that total transpiration of the stand is dominated by species with the largest sapwood area. Diffuse porous trees, such as *A. rubrum* and *B. lenta*, typically have a greater amount of sapwood area compared to ring-porous trees, such as oak. Following the loss of *T. canadensis*, diffuse porous species will have a greater transpiration rate than co-occurring ring-porous species.

Other Studies on Ecosystem Function

Studies have shown that with the loss of foundation species from an ecosystem, there are great changes within the function of that ecosystem. Our study estimates that as leaf area of *T. canadensis* declines, there will be a greater abundance of light available to the subcanopy. As PAR increases, transpiration of the understory species increases. Other studies show a change in ecosystem function following the loss of a foundation species. A study of the effects of HWA infestation on forest carbon cycling showed that soil CO₂ efflux declined by about 20% after one year of infestation (Nuckolls et al., unpublished data). This suggests rapid declines in hemlock productivity from HWA infestation. A study of water use by *T. canadensis* and *B. lenta* showed that transpiration during the growing season is greater in early successional black birch trees compared with late successional eastern hemlock trees (Daley et al. 2007). Timing and magnitude of water use as a result of eastern hemlock replacement is apparent, as their results show a 30% increase in stand water transpiration from June through October. Our study also estimates an increase of stand transpiration with the succession of *B. lenta*.

Transient and long-term losses in ecosystem function have also been observed with native insect infestations. For example, stream export of nitrogen in the form of nitrate increased in the Coweeta basin as a result of defoliation of a mixed hardwood stand by the fall cankerworm (*Alsophila pometaria* Harris) (Swank et al. 1981). As cankerworm populations peaked, 33% of the total leaf mass was consumed, resulting in elevated concentrations of nitrogen in the form of nitrates throughout the year. Further study of the decline of *T. canadensis* from HWA infestation might consider testing for similar changes in nitrogen cycling. Infestation of a native insect, the southern pine beetle (*Dendroctonus frontalis* Zimm.), has been shown to decrease stem circumference and sap flux density of loblolly pine (Wullschleger et al. 2004). This study showed that the success of attacking adult beetles was not affected by a disruption of tree water balance. At the time when xylem function began to fail (as observed by a decrease in sap flow), progeny of attacking beetles would have already departed the trees, leaving the phloem and cambium so thoroughly girdled that mortality was inevitable (Wullschleger et al. 2004).

Future Research

In this study, we predicted increases in sap flux density for three species following the simulated loss of *T. canadensis*. These values are simply projections, and there is no definite evidence that these scenarios will actually occur. It is important to continue monitoring changes in sap flux density to better predict a post-mortality scenario in the future. To better understand the relationship between decreases in sap flux density of *T. canadensis* and increases in sap flux density of other species, a greater set of data over more years is needed. Although an increase in sap flux density of *R. maximum* over the two years was not seen, future data may show a significant increase. To better model the post-mortality affects of *T. canadensis* on succession, climate data (PAR, VPD, and soil moisture) from a greater number of days is necessary. Although climate data used in this study represented a span of three seasons, a more accurate prediction would be made possible from a greater number of days.

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LITERATURE CITED

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RIVER CORRIDOR RESTORATION: PLANNING A RIPARIAN BUFFER ZONE FOR THE CULLASAJA CLUB

HANNAH S. EARLY

Abstract. The Cullasaja River is listed on the state of North Carolina's impaired waters list. This is largely due to a loss of riparian buffer zones from increased development and impoundment in golf course communities near Highlands, NC. This paper documents the current state of the buffer zone on one such golf course community, the Cullasaja Club, and outlines detailed recommendations for changes in the Club's current golf course maintenance routine. These recommendations have general applicability to riparian zone mitigation in other montane golf courses.

Key words: aerial photography; Cullasaja Club; Division of Water Quality; impaired waters; native species; riparian buffer zone.

INTRODUCTION

The Cullasaja River and its watershed are part of the Little Tennessee River Basin located in western North Carolina in southern Macon County (Jones and Henson 1999). The headwaters are on the Highlands Plateau, flowing for 4.8 miles from Ravenel Lake to Mirror Lake. These waters are classified by the Division of Water Quality (DWQ) as High Quality Waters, specifically, Water Supply II (WS-II) and as important trout waters by the North Carolina Wildlife Resource Commission (making its complete classification Water Supply - II, Trout [WS-II, Tr]). Near Highlands, NC, the river flows through the golf course community of Wildcat Cliffs to Ravenel Lake, which is in another golf course community, the Cullasaja Club. The river then flows through the Cullasaja Club and drops over Highlands Falls into a third golf course community, the Highlands Falls Country Club. Throughout these three golf course communities, the river is multiply dammed to create ponds used for irrigation of the country club properties. The two largest impoundments, one being Ravenel Lake directly above the Cullasaja Club, have top-spill dams over which there is little or no flow during dry periods (NCDENR 2002).

Portions of the Cullasaja River have been listed on the Section 303(d) impaired waters list of The Federal Water Pollution Control Act, which is more commonly referred to as The Clean Water Act. A 303(d) list is published by each state every two years via an extensive process including the publishing of a draft, a period for public comment, and then time for approval by the DWQ. Conservatism is applied to the act of listing waters on the 303(d) list because listing will have strong regulatory implications on new and current development and will likely require changes for town regulatory documents and plans. It is not unlikely for a river to be commonly regarded as "impaired" once even a single segment has made the list. This is the case with the Cullasaja River, as currently only two segments, consisting of less than 2 miles, are officially listed as impaired. This does not mean that the river is not impaired at other segments but only that the State of

North Carolina has not conducted the analysis of the Cullasaja River or completed the listing process for that segment.

The officially impaired segments are located upstream in relation to the Cullasaja Club, and evidence of impairment is present on Cullasaja Club property. It is good practice on the part of the Cullasaja Club to make plans for a stream restoration project before formal listing on the impaired waters list. The Club recognizes the value in protecting the river as a resource and the mutual benefit for the Club and the community in reviving the health of the Cullasaja River as it runs through Cullasaja Club property.

With a listing on the 303(d) list and designation as important trout waters, the Cullasaja River is looked upon today with particular interest by several state agencies and interest groups. Upon development of the Club, however, there was no requirement to consult with DWQ or the NC Wildlife Resource Commission and there was less concern in general of the environmental impacts of construction. Rerouting of the original stream path was likely a large part of the golf course construction plan. Construction of a golf course community in the same location today would require consultation and approval by DWQ and also the Wildlife Resource Commission concerning trout. Golf course communities constructed in the area more recently, such as Highlands Cove and Mountaintop Golf and Lake Club, were required to maintain a 30-foot riparian buffer zone surrounding streams and were prohibited from re-routing the natural course of the stream as part of the design of their golf courses. No aerial photography of the property before construction has been located, but Hugh Dillingham who serves on the Board of Directors of the Cullasaja Club, is Chairman of the Green Committee at the Club, and is President of the Board of Directors for the Upper Cullasaja Watershed Association (UCWA) and Tom Nelson, the Club's Golf Course Superintendent, agree that before the construction of the Cullasaja Club golf course, much of the area was a highland mountain bog. The original course designers had the river channelized and redirected in order to establish the greenways and fairways of the course, modifications that are particularly evident at Fairways #2 and #8 (Fig. 1). Dillingham and Nelson feel strongly that length was also added to the river at construction to create the meandering path that exists today.

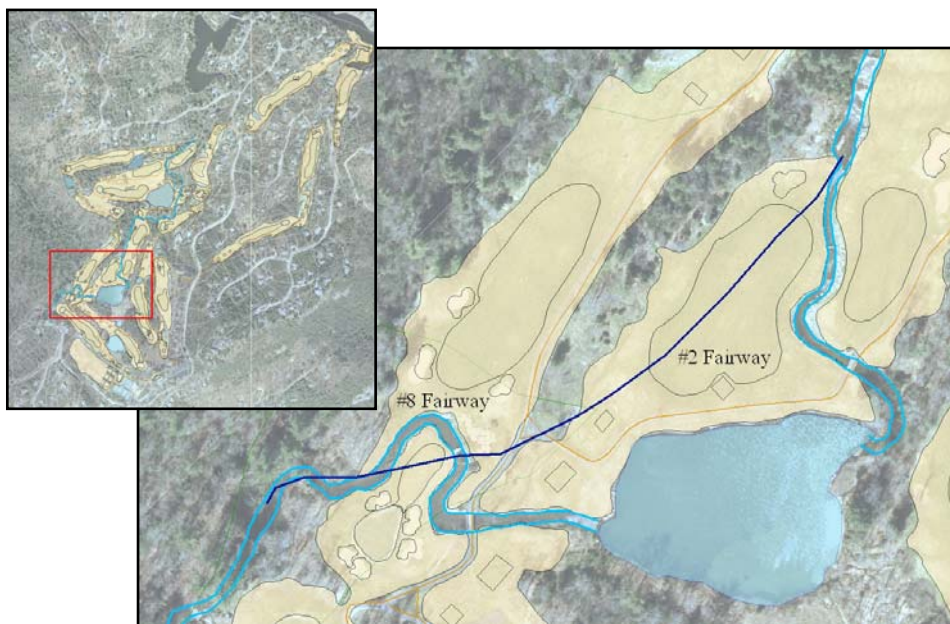


FIG. 1. Speculated historic river flow in dark blue. Example of added length to river at construction as the channel was diverted to create meanders and an irrigation pond.

Evidence of impairment on Cullasaja Club property can largely be attributed to dam-related issues. The dam directly upstream of the Club at Ravenel Lake prevents downstream colonization of fish and benthic macroinvertebrates and upstream migration of fish, lowers water levels below the dam and thus increases localized temperatures, and changes food type availability due to trapping of coarse particulate organic matter and input of phytoplankton from impoundments. There is also a cumulative lack of organic microhabitat such as leaf packs and sticks (NCDENR 2002). Slowed flow speed from added length to the course of the river contributes to an overall temperature increase. Slowed speed, added length, and irrigation pond impoundments combine to increase exposure time to sunlight, thus perpetuating the cycle of warming.

One of the primary goals of this project was to enhance mapping of the Cullasaja Club golf course, to include information about the stream. Current maps of the course are strictly golf-centered and fail to map the water (Fig. 2). In order for the Club to begin planning for river restoration, they need to be able to quantify how many linear feet of the river exists on their property, the square footage of areas along the river bank, and what riparian zone plant species will suit the needs of both the river and the golf course. I enhanced the Cullasaja Club's map to provide detailed coverage of the Cullasaja River, conducted analysis of current stream bank conditions, and provide comprehensive recommendations for a riparian buffer zone plan. My recommendations are intended, in part, to serve as an interim buffer zone strategy until the implementation of a future stream restoration project. A portion of the recommendations have the potential to be immediately incorporated into the long-term maintenance plan, while other recommendations involve areas of the stream where extensive restructuring of the bank is

expected under a future stream restoration project. With the time-line for implementation of a future stream restoration project unknown, recommendations have been made regardless of this distinction. While maps in this project focus specifically on the Cullasaja Club, recommendations have general applicability for maintenance on other golf courses with impaired waters.



FIG. 2. Existing Cullasaja Club golf course map lacks coverage of river and most bodies of water.

MATERIALS AND METHODS

To facilitate mapping of the golf course to include stream coverage, I utilized the original surveyor's CAD file. The CAD file had to be traced and converted to shapefiles using ArcMap in ArcGIS® 9.3 (ESRI 2008). I then imported other data layers including color aerial photography, property lines, and contour lines. Using aerial photographs, coverages of the stream bank and bodies of water were created in ArcMap and I then conducted some ground-truthing GPS work with a Trimble® GeoXM™ hand unit and range pole.

To quantify and categorize areas along the river bank, I divided river segments into three classifications depending on the presence of vegetation on the river bank: presence of vegetation on both banks, one bank, or neither. Buffer zones of 30 and 15 feet were then applied. I then created polygons extending from the river bank to the edge of the buffer zones in order to calculate areas in square feet. These polygons were also divided into three categories according to the height necessary to maintain a line of sight during golf play. The buffer zone plan was completed by selecting the most applicable polygon for all areas along the river. Ideally, all polygons would be those extending from the river bank to the 30 foot buffer edge, but in areas where this encroached upon important elements of the golf course, polygons extending to the 15 foot buffer were selected.

RESULTS AND DISCUSSION

An enhanced map of the Cullasaja Club provides a detailed coverage of the Cullasaja River (Fig. 3), as well as highlighting the condition on the vegetation along its banks (Fig. 4). River coverage was created using aerial photography because I did not have access to post processing software. The margin of error in the data I manually collected with the GPS unit was generally 3-5 feet off from the aerial photography, therefore accurate enough for the intended purposes of this project. This error could be attributed to error in either the accuracy of the manual data collection, of the aerial photography, or both.

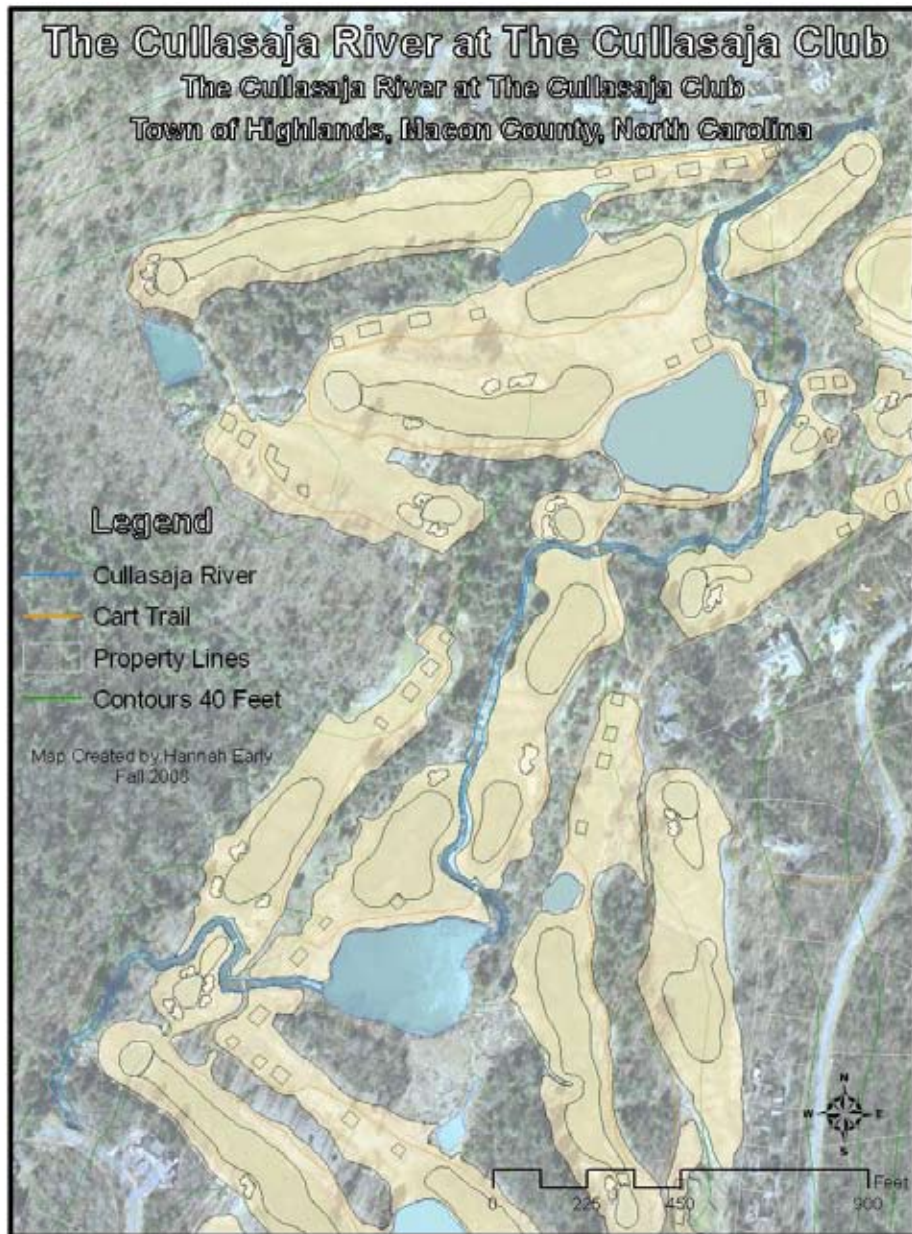


FIG. 3. Enhanced coverage to include the Cullasaja River and other bodies of water.

Table 1 summarizes how many total linear feet of the river exist on the property and how many linear feet belong to each vegetation classification. Numbers are approximate because the segments were hand drawn before being measured by GIS software.

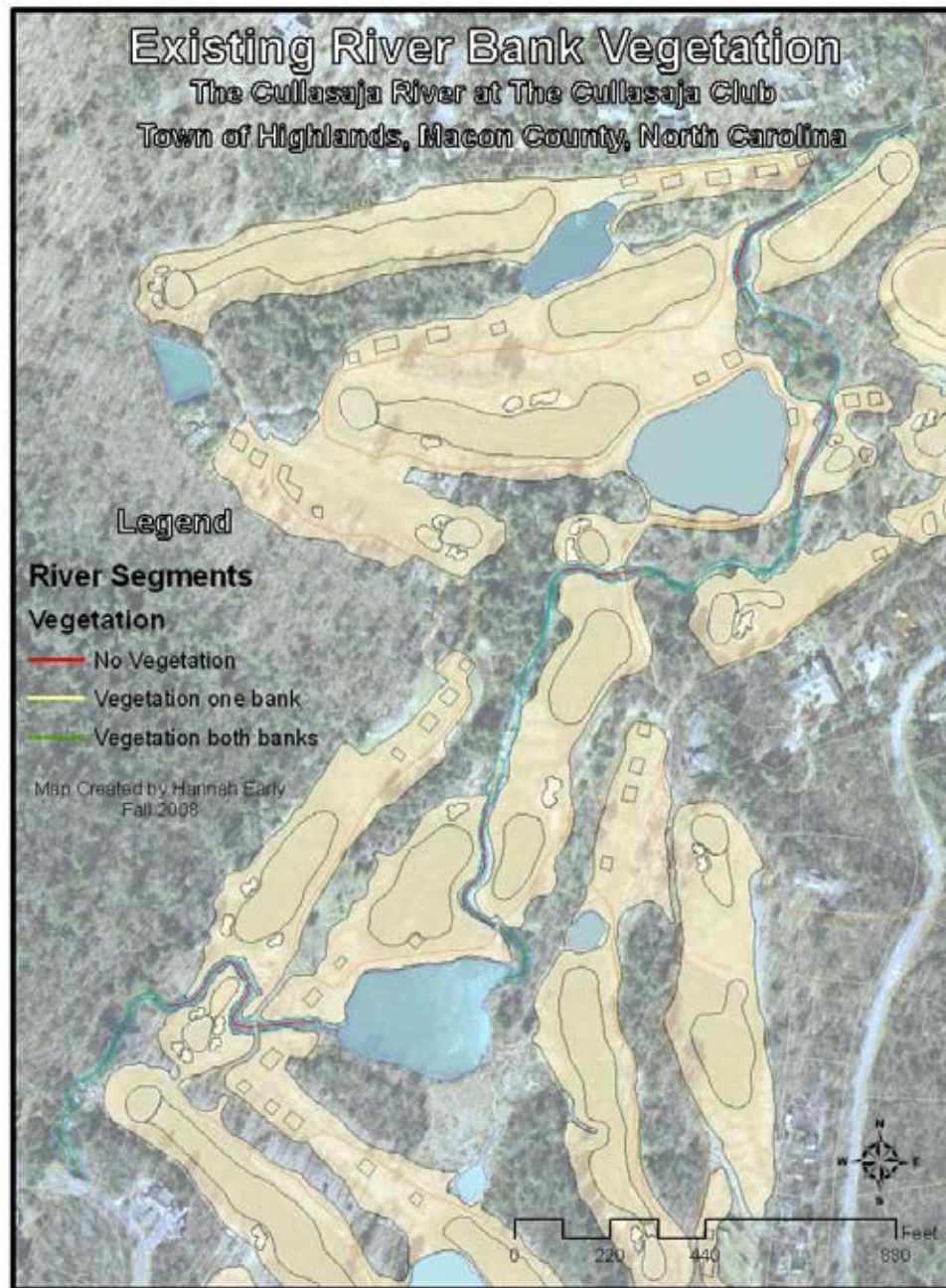


FIG. 4. Map created to classify existing bank vegetation: Green = veg on both banks; Yellow = veg on 1 bank; Red = no veg on either bank.

TABLE 1. Summary of length in feet of each river segment.

Segment number	River Segment Classification	Approximate Linear Footage
1	Yellow	309.11
2	Red	278.11
3	Yellow	58.65
4	Green	206.03
5	Yellow	115.58
6	Red	266.64
7	Green	192.85
8	Yellow	163.2
9	Green	144.26
10	Red	181.06
11	Green	304.7
12	Yellow	253.28
13	Red	349.97
14	Green	171.94
15	Red	598.66
16	Green	579.06
Total veg on both		1598.84
Total veg on one bank		899.82
Total no veg		1674.44
Total Apprx. Linear Footage		4173.1

Of the over 4100 feet of river running through the Cullasaja Club, only about 38% is vegetated on both banks. This means that almost 62% of this river length is currently being mowed to the bank on at least one side and 40% is mowed to both banks. The primary recommendation in this paper's riparian buffer zone plan is to eliminate all mowing directly to the riverbank (Table 1).

Recommendations for a Riparian Buffer Zone Plan

It is critical that any plan presented for a riparian buffer zone not compromise the functioning of the golf course. There are several locations along the river where implementation of a 30 foot buffer would severely encroach upon greens, tee boxes, and other features central to the game (Fig. 5). My recommendations are an attempt to find a balance between the 30 foot buffer ideal and the traditional golf course aesthetic.

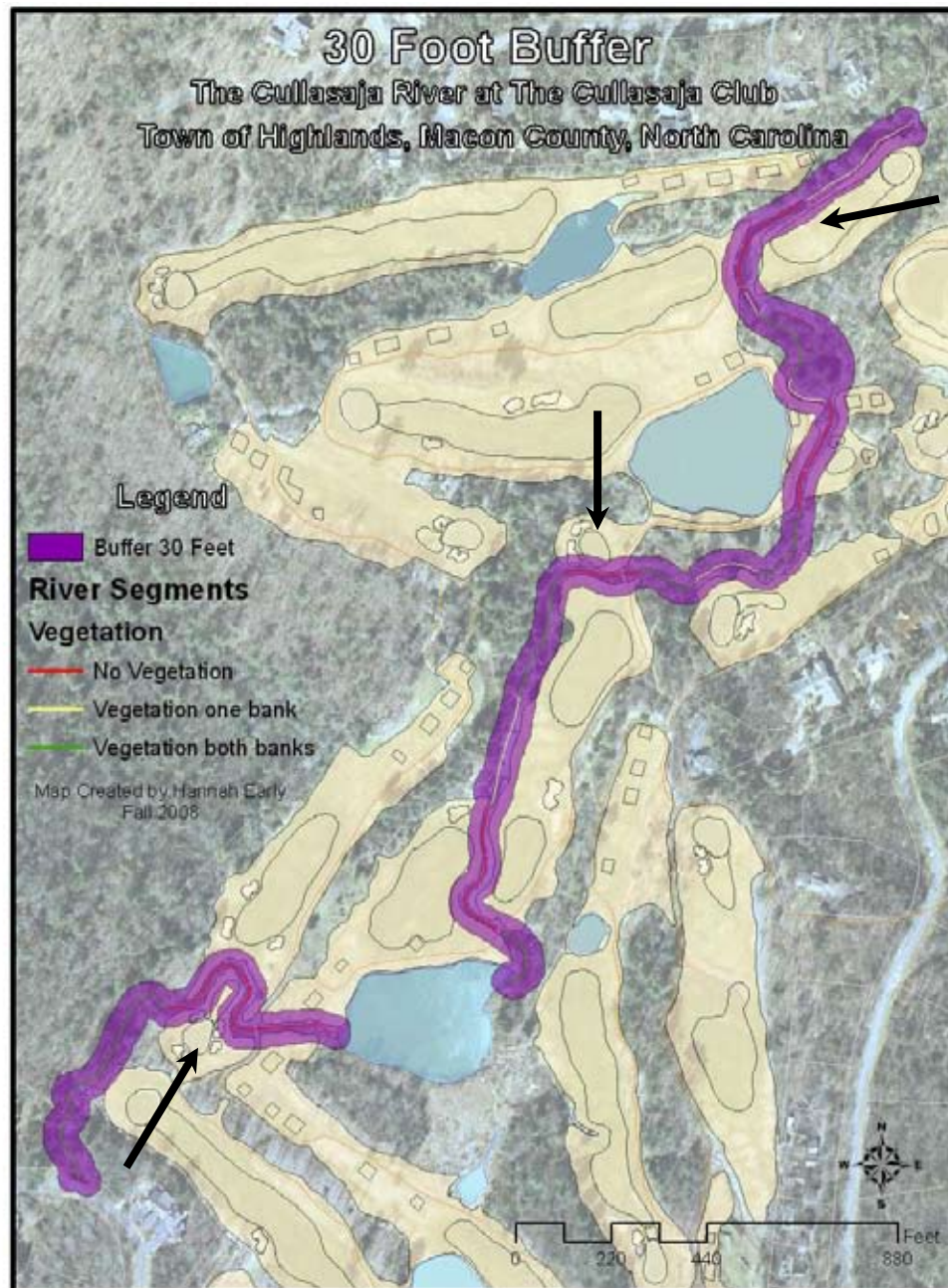


FIG. 5. Map displays the conflict between the 30ft buffer ideal and maintenance of golf course function. Arrows indicate areas where buffer zone intrudes upon important golf game elements.

My primary recommendation is to eliminate all mowing to the bank of the river. A species list provided in the Appendix is divided into three height categories, including a low-lying species category for areas of special concern on the golf course where the river crosses the line of play. Here a line of sight must be maintained in order not to interfere with golf play. While the traditional golf course aesthetic is to maintain a highly manicured turf that provides a seamless visual down the fairway, I suggest that planting attractive low-lying species will enhance the aesthetic as well as provide an important

filtering service for the river. The species list includes some wildflowers for color and as a means to quell potential Cullasaja Club member disapproval, as such changes may make member support difficult to obtain. In these areas of particular concern where a 30 foot buffer is not a viable option, I have produced an alternative 15 foot buffer to be applied in these problem areas (Fig. 6).

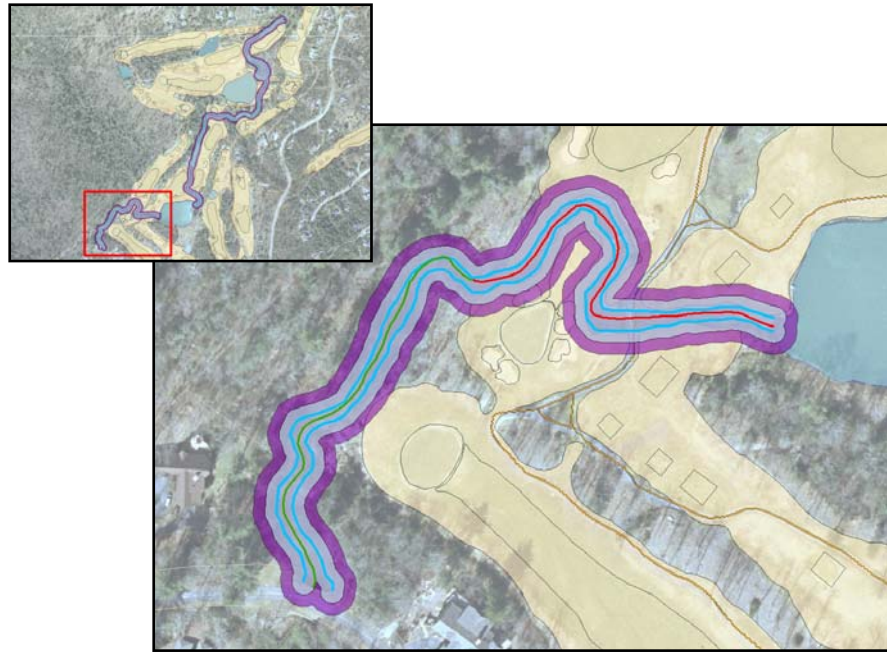


FIG. 6. Application of 15ft buffer (grey) instead of 30ft buffer (purple) on hole #8.

To conclude the project, areas within the buffer zone were divided into the following three categories: out of play, mid height, and low-lying (Fig. 7). The categories were determined on basis of necessary height to maintain a line of sight in a golf game. The species listed in the Appendix for the out of play category includes taller species of trees and shrubs that can thrive with little to no maintenance to allow these areas to return to woods. The mid-height category consists of grasses and shrubs that grow no higher than 5 feet or could be easily maintained to that height. The low-lying category consists of ground covers and flowers that reach no more than 2 feet. Several of the out of play regions are not part of the river's buffer zone, but will eliminate instances of unnecessary mowing near the river or bodies of water. Areas were then selected depending on appropriateness of a 15- or 30-foot buffer. The resulting map accounts for the entire river corridor (Fig. 8). Areas not part of the buffer zone vegetation categories are already adequately serving as a riparian buffer zone. For estimated square footage, see Table 2.

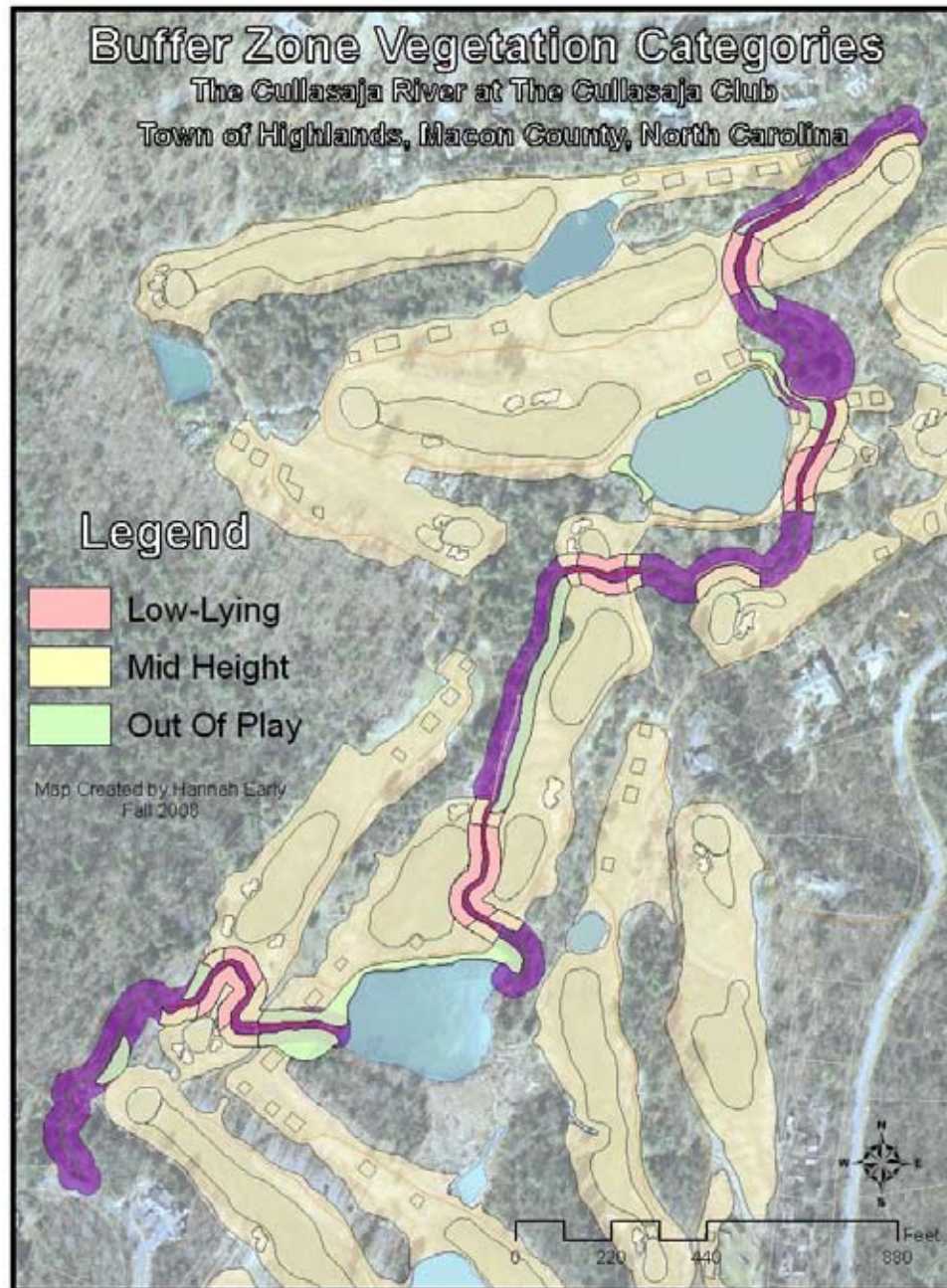


FIG. 7. Buffer zone vegetation categories shown with 30 foot buffer.

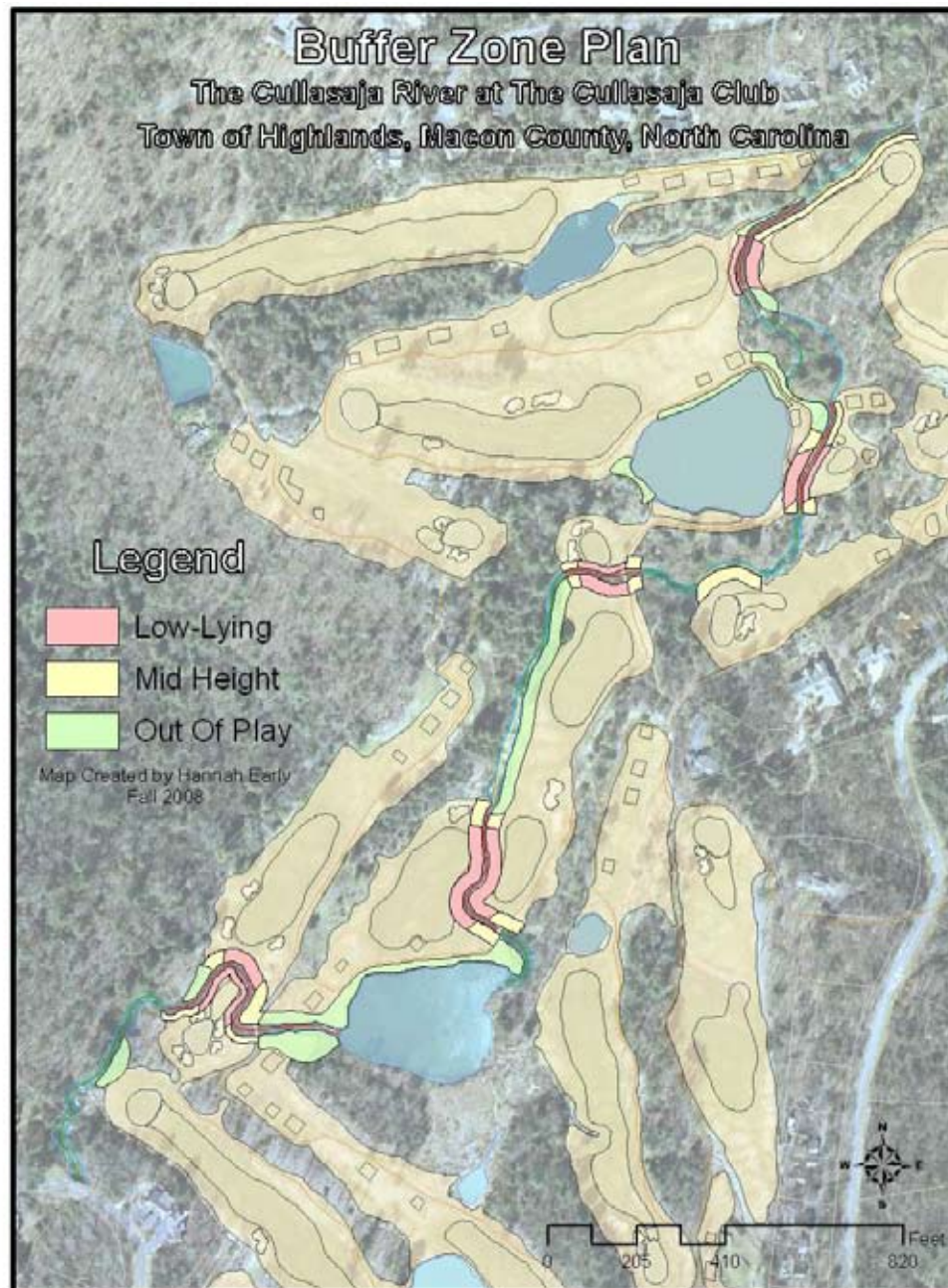


FIG. 8. Complete buffer zone plan divided by plant height requirements.

TABLE 2. Area in square feet for each polygon in the Buffer Zone Plan. “River Right” and “River Left” are applied in terms of facing downstream.

Low-Lying (red)		Area in square feet Mid Height (yellow)		Out of Play (green)	
River Right	River Left	River Right	River Left	River Right	River Left
2158.38	3439.73	1653.14	6752.12	1524.04	1945.57
3857.33	2118.15	581.12	1597.74	5602.78	17050.75
1722.55	3493.39	1048.17	943.21	4959.05	9477.87
7880.74	7168.81	633.65	5154.12	3041.11	3797.99
3574.68	4045.12	1917.12	1058.08	18042.01	
		2039.53	818.36	2379.29	
		3443.53	1006.16		
		1382	2213.13		
			1359.04		
			1444.21		
Total	39458.88	Total	35044.43	Total	67820.46
			All category total		142323.77

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APPENDIX

Recommended native species to plant as part of buffer zone. Categorized by height (Out of Play, Mid-Height, and Low-Lying).

Out of Play (over 5 feet)	Species	Common Name	Type	Flower Color
	<i>Alnus serrulata</i>	Alder	herb	
	<i>Amelanchier arborea</i>	Serviceberry, Juneberry,		
	<i>Betula lenta</i>	Shadbush	small tree	
	<i>Betula allegheniensis</i>	Cherry Birch	tree	
	<i>Betula nigra</i>	Yellow Birch	tree	
		River Birch	tree	
	<i>Impatiens capensis</i>	Spotted Touch-Me-Not,	herb	deep orange to red
		Jewel Weed		
	<i>Impatiens pallida</i>	Touch-Me-Not, Jewel Weed	herb	light yellow to cream
	<i>Kalmia latifolia</i>	Mountain Laurel	large shrub	
	<i>Lobelia cardinalis</i>	Cardinal Flower	herb	vivid red
	<i>Lyonia ligustrina</i>	Male-berry, Male-blueberry	shrub	
	<i>Rhododendron calendulaceum</i>	Flame Azalea	shrub	brilliant orange, yellow, or red
		Mountain rosebay,	shrub/small	
	<i>Rhododendron catawbiense</i>	purple laurel	tree	pink to purple
		Rosebay Rhododendron,	shrub/small	
	<i>Rhododendron maximum</i>	Great Laurel	tree	pink to whitish
	<i>Rhododendron minus</i>	Piedmont Rhododendron	shrub	pink to white
	<i>Salix nigra</i>	Black Willow	tree	
	<i>Salix sericea</i>	Silky Willow	shrub or small tree	
	<i>Vaccinium constablaei</i>	Mountain Blueberry	shrub	
	<i>Vaccinium stamineum</i>	Squaw-Huckleberry, Gooseberry	shrub	
	<i>Vernonia noveboracensis</i>	Iron Weed	herb	
Mid-Height (up to 5 feet)	Species	Common Name	Type	Flower Color
	<i>Ceanothus americanus</i>	New Jersey Tea	shrub	
	<i>Eupatorium maculatum</i>	Joe-Pye Weed	herb	
	<i>Fothergilla gardenii</i>	Dwarf Fothergilla	shrub	
	<i>Gaylussacia baccata</i>	Buckberry, Black Huckleberry	shrub	
	<i>Hypericum prolificum</i>	Shrubby St. John's Wort	shrub	
	<i>Leiophyllum buxifolia</i>	Mountain Myrtle	shrub	
	<i>Leucothoe fontanesiana</i>	Dog Hobble, Drooping leucothoe	shrub	
	<i>Rudbeckia heliopsisidis</i>	Black Eyed Susan	herb	yellow
Low-Lying (up to 2 feet)	Species	Common Name	Type	Flower Color
	<i>Antennaria solitaria</i>	Pussytoes	ground cover	
	<i>Aster paternus</i>	White-Topped Aster	herb	
	<i>Chrysanthemum leucanthemum</i>	Daisies	herb	white
	<i>Chrysogonum virginianum</i>	Green-and-Gold	ground cover	
	<i>Clintonia umbellulata</i>	Blue Beadlily	ground cover	white

<i>Dryopteris intermedia</i>	Fancy Fern	fern	evergreen
<i>Gaultheria procumbens</i>	Wintergreen	ground cover	
<i>Hexastylis</i> spp.	Little Brown Jugs	ground cover	
<i>Iris cristata</i>	Dwarf Crested Iris	ground cover	bluish to violet
<i>Mitchella repens</i>	Partridge Berry	ground cover	
<i>Onoclea sensibilis</i>	Sensitive Fern	fern	
<i>Osmunda cinnamomea</i>	Cinnamon Fern	fern	
<i>Osmunda claytoniana</i>	Interrupted Fern	fern	
<i>Osmunda regalis</i>	Royal Fern	fern	
<i>Pachysandra procumbens</i>	Allegheny Spurge	ground cover	evergreen
<i>Phlox divaricata</i>	Woodland Phlox	ground cover	
<i>Phlox stolonifera</i>	Creeping Phlox	ground cover	
<i>Phlox subulata</i>	Moss Phlox	ground cover	
<i>Podophyllum peltatum</i>	May apple	herb	dangling white flower
<i>Polystichum acrostichoides</i>	Christmas Fern	fern	
<i>Shortia galacifolia</i>	Oconee Bells	ground cover	white or pinkish
<i>Sisyrinchium angustifolium</i>	Blue-Eyed Grass	ground cover	
<i>Solidago rugosa</i>	Wrinkle-Leaf Goldenrod	herb	yellow
<i>Tiarella cordifolia</i>	Foam Flower	ground cover	
<i>Vaccinium macrocarpon</i>	Cranberry	ground cover	
<i>Vaccinium palidum</i>	Lowbush Blueberry	shrub	
<i>Woodwardia areolata</i>	Netted Chain Fern	fern	

PROMOTING A LINKED LANDSCAPE IN HIGHLANDS THROUGH THE DEVELOPMENT OF PUBLICATIONS AND SUBDIVISION ORDINANCES FOR THE HIGHLANDS PLATEAU GREENWAY

BRYCE KOUKOPOULOS

Abstract. As the Town of Highlands, North Carolina grows, development spreads, and the land values rise, residents and policy makers of the Town are searching for ways to preserve connective open space in Highlands. Formed in 2005, The Highlands Plateau Greenway is in the early stages of development. As trails are constructed and the Greenway system grows, the Highlands Plateau Greenway will provide recreation and alternative transportation opportunities to the public, in addition to facilitating the preservation of the natural and cultural heritage found along the trails. Planning for the Highlands Plateau Greenway includes communicating with the public about the opportunities for use and areas of interest along greenway trails, as well as incorporating considerations pertaining to the Greenway into town policies that can facilitate the acquisition of land and expansion of the trail system. This paper describes the development of publications and subdivision ordinances for the Highlands Plateau Greenway.

Key words: greenway; Macon County, N.C.; subdivision ordinance; Town of Highlands; town planning.

INTRODUCTION

The Highlands Greenways Committee, now the Highlands Plateau Greenway Board of Directors, was formed in 2005 and began creating the Greenways Master Plan for the Town of Highlands, North Carolina. The plan facilitates the development of existing and proposed trails that highlight botanical points of interest, historic sites, important birding areas, scenic overlooks, and other areas of natural beauty. To date, the Highlands Plateau Greenway has become an incorporated non-profit organization and has constructed over five miles of paved and natural trails. Development of the Greenway is still underway. There is work to be done to advertise the Greenway, acquire land, plan and construct future trails, maintain existing trails, and increase membership and funding. This project focused on two such needs, advertising and land acquisition.

One facet of the effort to assist the short-term growth of the Highlands Plateau Greenway is the development of publications and interpretive Greenway guides available to visitors and residents of Highlands. The existing Highlands Plateau Greenway brochure available to the public includes membership information and a map that features existing and proposed trails. The existing and proposed portions of the Greenway connect many areas of historical and ecological interest in Highlands. As land is acquired, nature trails are constructed, and the Greenway expands into a linked system, the Greenway is anticipated to be an important asset for residents as well as a tourist attraction. The first component of this project involved the development of interpretive publications that will

serve as guides for the Highlands Plateau Greenway to enhance the educational experience of the public on the trails.

The other focus of this study is on the long term development and growth of the Highlands Plateau Greenway through land acquisition. This portion of the project deals with ordinances and development codes for the Town of Highlands for subdivisions, and, specifically, how the Highlands Plateau Greenway can be included in the planning process for open space dedication by developers. Historically, town planners have been responsible for such town infrastructure elements as roads, sewers, and sidewalks that support residential, commercial, and industrial development. It is now widely advocated that it should also be the responsibility of local government to plan for greenways as an element of infrastructure (Timson 2005). If this is to be realized, greenways need to be a part of the planning process.

The Town of Highlands is beginning the transition away from a system of incongruent specialized ordinances that deal with policies on cluster development, subdivisions, zoning, etc. to a unified code. The envisioned code will restructure the Town's development policies, including the zoning and subdivision ordinances, into a single consistent document. The transition, directed by consultants, could potentially continue for several years. A concern of the Highlands Plateau Greenway Board of Directors is that reluctance of the Planning Board and the Town Board to consider greenway amendments to the current ordinances prior to this change will postpone or even hinder the growth and development of the greenway system during the transition time. The Highlands Plateau Greenway hopes to incorporate provisions regarding the Greenway into the Town's Subdivision ordinance before the unified code is assembled. In this study I researched and amended subdivision ordinances for the Town of Highlands to help plan for the Highlands Plateau Greenway.

Across the country, city planners have linked the benefits of connective open space, responsible development, economic growth, and community building (Arendt 2004). Through effective planning in respect to subdivision and greenway development, Highlands can preserve the charm that many other towns and cities are trying to recreate. Cities like Charlotte and Raleigh are now looking at open space reclamation and post-development remediation. Conservation is a part of "smart growth." Towns cannot rely on haphazard conservation efforts or hope that developers will volunteer open space dedications. It is far more difficult and costly for an administration to propose to "downzone" an existing development, or reduce densities within an existing subdivision, than it is to designate open space in the initial planning process (Arendt 2004). Highlands has an opportunity now to plan for a linked landscape that will include parks and Greenway trails. To facilitate the growth of connected, functional open space, the Town of Highlands is considering incorporating the Highlands Plateau Greenway into a wider range of policies that define conditional zoning ordinances, minimum lot size requirements, sidewalk regulations, tree ordinances, watershed regulations, and subdivision ordinances. This project focused on the subdivision ordinances regarding lot size and setback requirements, buffer requirements, and open space dedication requirements pertaining to the Highlands Plateau Greenway.

MATERIALS AND METHODS

Publications

Two publications, a booklet and a compact brochure, were created using Microsoft Publisher to provide the public with educational information about the Greenway's nature trails and historic districts. Much of the information included in the publications was derived from secondary sources and existing literature about the natural and cultural history of the town of Highlands and the greater Highlands Plateau.

The Greenway system was organized into five segments: the Kelsey Trail, the Coker Rhododendron Trail, the Mill Creek Trail behind the Recreation Park, Sunset Rock Road, the Botanical Garden at the Highlands Biological Station, and the Business District. The distances for each nature trail, including those in the Botanical Garden, were measured in feet using a wheel and converted to miles. The measured distances were compared to and verified by distances derived from GIS data in ArcGIS® 9.3 (ESRI 2008). The GPS points were collected from the Greenway's previous Institute for the Environment intern, Brian Levo, in 2007. Forest communities for the nature trails were based on Michael Schafale and Alan Weakley's "Classification of the Natural Communities of North Carolina, Third Approximation" (Schafale and Weakley 1990). They were classified by observing the dominant species found in the canopy and understory along the trails. A list of native trees and shrubs was drawn from an account of native plant species found on the Highlands Plateau, compiled by Robert Zahner. A brief synopsis of the Highlands Plateau Audubon Society's Important Bird Areas project and a list of examples of migrants, permanent residents, summer residents, and winter residents were compiled. These examples were derived from the Highlands Plateau bird checklist, also available through the Highlands Plateau Audubon Society.

Historic sites in proximity to the Greenway were organized into four districts: the Highlands Biological Station, Main Street and the Business District, the North Historic District, and Cullasaja Drive. A numbered list of historic structures was compiled from research conducted by Randolph Shaffner at the Highlands Historical Society. This list includes the construction date, home ownership, and preservation status for historic structures along portions of the Greenway. The location of each structure was labeled with its corresponding number on a Historic Sites version of the Highlands Plateau Greenway map. In addition to this list, a brief narrative about each historic district was included.

A focus group was assembled to advise the content and format of the publications. The group included Dr. Gary Wein and Julie Schott from the Highlands-Cashiers Land Trust, Randolph Shaffner from the Highlands Historical Society, and Dr. Anya Hinkle from the Highlands Biological Station. The brochure and booklet were also presented to the Highlands Plateau Greenway Board of Directors for review and comments. The two groups offered comments based on guiding questions about the amount, breadth, and organization of the information presented in the publications.

Subdivision ordinance

Amendments were proposed for the Highlands Subdivision ordinance to include language regarding the Highlands Plateau Greenway in policies regarding lot size exceptions, setback requirements, and buffer areas in subdivisions. Research was also conducted to propose requirements for open space donation through mandatory dedication or payment-in-lieu of dedication options for subdivisions. The requirements including payment-in-lieu of dedication impact fees were omitted from the final proposal to the Town Board. Much of the content and language of the amendments was modeled after recent amendments made to the Highlands Zoning ordinance, as well as ordinances from the towns of Davidson, Durham, and Cary, North Carolina. In some cases, the amendment proposed was a simple inclusion of the Highlands Plateau Greenway into existing language featuring open spaces in parks and public schools.

Within the amendments presented to the Town Board, lot size exceptions (Section 409.3, Paragraphs B and D), and buffer areas for public open spaces (Section 413) featured the aforementioned inclusion of the Highlands Plateau Greenway. The language for the setback requirements (Section 410, Paragraph C) and buffer areas in respect to open space requirements (Section 411) were formulated specifically for the Highlands Plateau Greenway, with the guidance of Hillrie Quin, president. The amendments to buffer area requirements pertaining to watershed protection (Section 412) were modeled after the language in the Highlands Zoning ordinance about buffer areas, Section 209 A.6, Paragraph B.

Models for the requirements for open space donations, including impact fees, were found in the towns of Durham and Cary. Excerpts from the ordinances of these towns were found in examples from the 2005 Blue Ridge Greenways Conference (Timson 2005). Amendments defining the “nature of land to be dedicated,” “minimum required payment formula,” and “allocation and use of fees” were modeled after such examples.

The proposed amendments to the Subdivision ordinance, excluding the requirements for open space donations and payment-in-lieu-of option, were presented to the Highlands Town Board on November 5, 2008. Payment-in-lieu-of dedication requirements were omitted to simplify the proposal and focus on the changes already made in the Zoning ordinance. The Highlands Plateau Greenway Board of Directors intends to build upon these changes in the future and propose further changes to town ordinances, including required open space dedication specifically for the Greenway. A summary of the town ordinances from Davidson, Durham, Cary, and Pembroke were presented to the Highlands Plateau Greenway Board of Directors on December 2, 2008 in preparation for submittal to the committee overseeing the transition to a unified code.

RESULTS

Publications

Three miles of nature trails on the Greenway were measured along with 2.7 miles of paved sidewalks, adding over five miles of existing and proposed trails within the Highlands town limits. Forest community classes along the nature trails were

consolidated into three categories: Eastern hemlock forest, high elevation granitic dome, and mixed hardwood forest. Eastern hemlock and mixed hardwood communities described the vegetation on the Kelsey Trail and the Mill Creek Trail. The Coker Rhododendron Trail is described as an old-growth hemlock forest, and is relatively undisturbed when compared to the rest of the Greenway. Sunset Rock Road winds through a mixed hardwood community that leads to a rock outcrop community at the high elevation granitic dome at the top.

A booklet guide featuring maps and information about the Greenway system's nature trails, native vegetation, birds, areas of historical interest, volunteering opportunities, and membership was drafted for the Greenway. The Kelsey Trail, Coker Rhododendron Trail, Mill Creek Trail, Sunset Rock, and the Highlands Botanical Garden are featured individually. Each trail page includes a description of the trail, a summary of the forest communities found on the trail, trail distance in miles, the relative level of difficulty, and a thumbnail view of the location on the Greenway map. A list of historic structures along the Greenway was compiled and featured in the booklet with a corresponding numbered map (Appendix A). A compact version of the brochure features a Greenway map and abbreviated information about the nature trails and volunteering opportunities. (Both publications are included as an electronic appendix [Appendix B]).

Subdivision ordinance

The amendments proposed for the subdivision ordinance of Highlands (Appendix C) match the amendments passed in 2007 for zoning, but are tailored to fit the format and requirements for subdivisions. Lot size exceptions and setback exceptions allow property to be subdivided below the minimum lot size requirements if the property is being clustered to preserve "common open space," which includes greenways. The lot size requirement is reduced by the amount of land dedicated to open space. When a subdivision is clustered to provide open space, fifty percent of the land to be subdivided must be dedicated to open space available for public use (Appendix C). This ordinance includes the Highlands Plateau Greenway as an option for open space, making it possible for subdividers to meet lot size requirements after land is dedicated to the Highlands Plateau Greenway.

The ordinance regarding easements in buffer areas for commercial and industrial developments ensures that land dedicated to the Highlands Plateau Greenway as part of the buffer will not exceed the Town's standard open space requirements. The ordinance regarding buffers between Greenway trails and perennial streams ensure that the Highlands Plateau Greenway is in compliance with the 1989 North Carolina Water Supply Watershed Protection Act (N.C. GS 143-214.5 1989). This ordinance restricts development within stream buffers, except for greenway trails where no practical alternative exists. In this case, the trails are developed according to storm water Best Management Practices (NC DWQ 2007) to minimize impairment of the stream, including a twenty-foot vegetative buffer

A summary of development ordinances from the North Carolina towns of Durham, Cary, and Davidson serve as examples of similar municipalities that have effectively incorporated greenways into their codes and ordinances (Appendix D).

DISCUSSION

Whether in rural, suburban, or urban settings, greenways have introduced social, health, environmental, and economic benefits to communities and municipalities across the country. They attract visitors and highlight natural, cultural, and historical attractions. As well as providing alternative, sustainable, transportation, greenways promote physical health and foster community among residents (Searns and Vogel 2002). The publications created in this study will help guide visitors through the Highlands Plateau Greenway and highlight historical and natural areas of interest. The purpose of the brochure is to provide a quick user guide that will give the public information about the trail segments within the Greenway system and provide a map that shows where the Greenway connects natural, historical, and commercial areas of town (Appendix B). The booklet provides more detailed information about the natural history of each trail, the historic sites in Highlands, birding areas, and general information about the Highlands Plateau Greenway, including membership and opportunities to volunteer (Appendix B).

The proposed amendments to the subdivision ordinance were designed to lead to increased connectivity of the existing greenway sections by easing the process of land dedication to the Greenway for developers and property owners. If passed, the amendments will facilitate land acquisition for the Highlands Plateau Greenway in subdivisions by minimizing obstacles to dedication because of development requirements, including requirements regarding lot sizes, setbacks, and buffers. Because of the transition to a unified code of ordinances, these amendments are likely to be postponed until the ordinances are restructured and joined with zoning and other development policies. Throughout the transition, the Planning Board is committed to keeping the Highlands Plateau Greenway included in the review and approval process for new subdivision proposals.

Further work is needed to fully incorporate the Highlands Plateau Greenway into the political foundation and infrastructure of the Town of Highlands. Future revisions of the subdivision ordinance could include dedication requirements or payment of impact fees-in-lieu-of dedication for new developments in Highlands. These requirements would greatly increase land contributions and funding for the Highlands Plateau Greenway, as well as ensure connectivity within the trail system.

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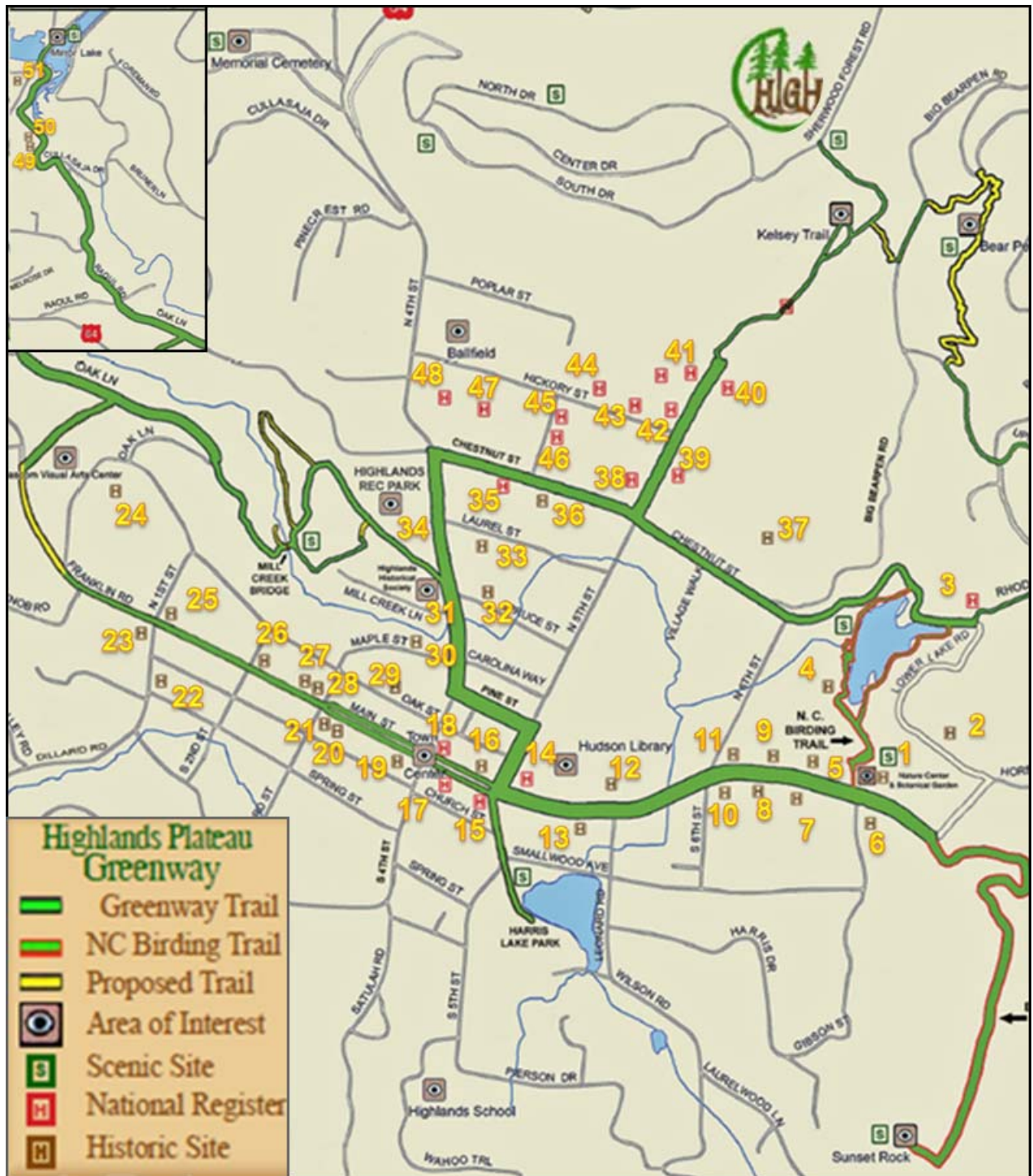
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Map of Historic Sites along the Highlands Plateau Greenway, featured in the brochure.



**Highlands Biological Station
and Horse Cove Rd Road**

1. 930 Horse Cove Road, Nature Center & Botanical Garden, 1941 **A**
2. 516 Lower Lake Road, Robert Foreman, 1920 **B**
3. 266 Lower Lake Road, David Watson, Joe Webb, 1925 **N**
4. 265 6th Street, Weyman Memorial Laboratory, 1931, 1958 **B**
5. 888 Horse Cove Road, Ewing-Pierson-Valentine House, 1881 **B**
6. 10 Gibson Street, Cook- Nickerson House
7. 859 Horse Cove Road, Harris-Van Huss House "Harvilla," 1885 **B**
8. 815 Horse Cove Road, Bascom-Nall, 1881 **B**
9. 858 Horse Cove Road, Hill-Dimick-Billstein House, 1880, 1931 **B**
10. 110 S. 6th Street, Hill-Staub House, 1878 **A**
11. 111 Horse Cove Road, Sargent House, 1931 **B**
12. 594 Main Street, Hutchinson-Frost-Hall-Farnsworth House, 1878 **A**

**Main Street and
Business District**

13. 601 E. Main Street, Reinke House-Highland Hiker-Joe Webb, 1935 **A**
14. 530 Main Street, Episcopal Church of the Incarnation, 1896 **N**
15. 471 Main Street, First Presbyterian Church, 1885 **N**
16. 474 Main Street, Smith "Gray Cottage" Wolfgang's, 1893 **A**

17. 445 E. Main Street, Central House-Old Edwards Inn, 1878 **N**
18. 420 Main Street, Highlands Inn, 1880 **N**
19. 399 Main Street, Bill's Soda Shop, 1883, 1939 **A**
20. 315 Main Street, Methodist Church, 1909 **A**
21. 305 Main Street, Blue Ridge Masonic Hall, 1893 **A**
22. 151 Helen's Barn Avenue, Helen's Barn, 1935 **A**
23. 31 Dillard Road, Dobson-Raoul Home, 1879 **A**
24. 65 Oak Street, Crane Home, "Crane Stable," 1926 **A**
25. 108 Main Street, Merchant-Davis-Patterson House, 1879, 1926 **A**
26. 220 Main Street, Methodist-Baptist Church, 1885, 1904 **A**
27. 260 Main Street, Partridge-Rice House, 1883 **A**
28. 270 Main Street, Boynton-Norton-Phelps House, 1881 **A**
29. 362 Oak Street, Highlands Playhouse, 1934 **A**
30. 96 Maple Street, Highlands Jail, 1918 **A**

North Historic District

31. 524 N. 4th Street, House-Trapier-Wright House, 1877 **A**
32. 432 Spruce Street, WT "Potts House, Mountain Findings", 1909 **B**
33. 459 Laurel Street, McAfee-Marett House, Fibber's thrift, 1910 **B**
34. Bug Hill, 1908-1918
35. 483 Chestnut Street, McKinney House, 1904 **N**

36. 539 Chestnut Street, Grant House, "Spring Dale," 1890 **B**
37. 10 Big Bear Pen Road, Hughs House, 1925 **B**
38. 750 N. 5th Street, Rideout-Whittle Cottage, 1883 **N**
39. 747 N. 5th Street, Marett-Reeve Cottage, 1939 **N**
40. 827 N. 5th Street, Diffendorfer-Heacock-Melvin Cottage, 1889 **N**
41. 856 N. 5th Street, Edwards House, 1891 **N**
42. 832 N. 5th Street, Johnson Cottage, 1931 **N**
43. 650 Hickory Street, Johnson-Gillaspie Cottage, 1940 **N**
44. 608 Hickory Street, Sheldon-Wade-Northrop House, 1886 **N**
45. 85 4½ Street, Nall House, 1950 **N**
46. 55 4½ Street, Rice-Potts House-Fairview Inn-4½ Street Inn, 1910 **N**
47. 537 Hickory Street, Smith-Froneberger- Wood House, 1890, 1918, 1956 **N**
48. 425 Hickory Street, Downing-Stewart-Michael House, 1890 **N**

Cullasaja Drive

49. 445 Cullasaja Drive, VeRelle House, Joe Webb, 1925 **B**
50. 443 Cullasaja Drive, Crosby House, Joe Webb, 1925 **B**
51. 251 Cullasaja Drive, Strong House, Joe Webb, 1939 **B**

N—National Register

A—Top priority for preservation

B—Worthy of preservation

APPENDIX B

Booklet guide and brochure for the Highlands Plateau Greenway (electronic).

APPENDIX C

Proposed amendments of subdivision ordinance for Greenways in the Town of Highlands, North Carolina.

October 15, 2008

Changes to existing ordinance are underlined.

ARTICLE 300: PROCEDURE FOR REVIEW AND APPROVAL OF PLATS

Section 306. Final Plat.

306.2 Contents required.

The original reproducible copy of the final plat shall be prepared in accordance with standards acceptable to the Register of Deeds of Macon County and/or Jackson County, at a scale of not less than two hundred (200) feet to one (1) inch, and shall conform substantially to the preliminary plat as approved. The plat shall also conform to the provisions of North Carolina General Statutes, Section 47-30, as amended. The final plat shall be prepared by a registered land surveyor and shall contain the following information:

Excerpt (I) The location and dimensions of all rights-of-way, utility or other easements, riding trails, natural buffers, existing or proposed portions of the Highlands Plateau Greenway, pedestrian or bicycle paths, and areas to be dedicated to public use, with the purpose of each stated.

ARTICLE 400: REQUIRED IMPROVEMENTS & MINIMUM STANDARDS

1. Lot Size Exceptions

Section 409. Lot Sizes and Standards, Exception in Order to Increase Size, and Exception in Order to Cluster.

409.3 Lot size exception in order to cluster development.

"Common open space" means a portion of a development site that is permanently set aside for public or private use, is held in common ownership by all individual owners within a development, and restricted from development as provided herein. Common open space may include wetlands, upland recreational area, wildlife areas, historic sites, and areas unsuitable for development in their natural state. Common open space shall not be construed to mean the space between buildings, or the area within twenty-five (25) feet around each structure or any impervious surface.

(B) Property may be subdivided without respect to the minimum lot size required by the Zoning Ordinance for the purpose of clustering development, as defined herein. The purpose of such an option is to preserve significant natural features on the parcel of land to be subdivided, and to provide for more open space, tree cover, recreation areas, greenway trails, and scenic vistas in a subdivision, while at the same time maintaining the overall dwelling unit density in a particular zoning district.

(C) Building setbacks on lots in a cluster subdivision shall conform to the Zoning Ordinance. Minimum lot width and lot size shall not apply, except that the total number of clustered lots in the subdivision shall not exceed the total number of lots allowed for single-family detached development in either the underlying Zoning District or the Watershed Overlay District, whichever is more restrictive.

(D) Common open space created by the cluster development shall comprise at least fifty-percent (50%) of the total property to be subdivided, and shall be located as much as the natural terrain permits in one contiguous area. Common open space may not contain any

structures unless explicitly approved by the Board of Commissioners. Common open space may be dedicated to public or private use:

(1) If common open space is dedicated to public use--such as to the Town of Highlands, the State of North Carolina, or any other public entity--it shall be made available to and accessible to the public. The approval of a cluster subdivision plat does not constitute or affect the acceptance by the Town or the public of the dedication of any open space, and shall not be construed to do so. The Board of Commissioners may, however, in its discretion, and by separate resolution, explicitly accept any such dedication, and may also accept the responsibility to maintain such open space.

(2) If common open space is dedicated to private use, an agreement shall be prepared, and recorded with the final plat, specifying the ownership and responsibility for maintenance of the open space. Provisions for the perpetual ownership and maintenance of common open space may be accomplished by an agreement with a property owners' association, ~~or~~ a land trust, the Highlands Plateau Greenway, or by other method or means approved by resolution of the Board of Commissioners.

2. Setbacks

Section 410. Building Setback Lines.

The requirements of the Town of Highlands Zoning Ordinance, where applicable, shall govern the location of the minimum building setback lines, subject to the following exceptions: (A) In all zoning districts except the B-3 Zoning District, the required setback of any building in a clustered subdivision from the right-of-way of any street, other than a subdivision street, shall be one hundred (100) feet. (B) In the B-3 Zoning District, no building shall be erected within five (5) feet of the property line of an adjoining lot within a cluster development. (C) When a portion of the property is dedicated to the Highlands Plateau Greenway, the minimum lot size may be reduced by the amount of land dedicated.

3. Buffer Areas

Section 411. Easements.

411.3 Buffer strips.

A buffer strip at least ten (10) feet in width may be required adjacent to a major street or a commercial or industrial development. This strip shall be reserved for the planting of trees and shrubs by the subdivider. The buffer applied, in the case of portions of land dedicated to the Highlands Greenway, shall not exceed existing open space requirements for subdivisions.

Section 412. Compliance with North Carolina Water Supply Watershed Protection Act.

(A) Any land which is subdivided in accordance with these subdivision regulations, and which is also located, in whole or in part, within any watershed classified as a surface water supply, shall conform to the standards of the North Carolina Water Supply Watershed Protection Act (G. S. 214.5, or House Bill 156).

(B) Trails and paths 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 Appendix D of the Highlands Zoning Ordinance. 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. Surfaces of trails and paths may be a maximum of ten (10) feet in width, and may consist of asphalt or any other impermeable or permeable surfaces. These trails and paths 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.

Section 413. Public Open Spaces and Sites for Public Facilities.

Due consideration shall be given to the allocation of suitable areas for parks, playgrounds, schools, Greenway trails, or other facilities to be dedicated for public use.

APPENDIX D

Summary of ordinances pertaining to greenways in the Towns of Durham, Cary, and Davidson, North Carolina.

Town of Durham, Durham County

Unified Development Ordinance (UDO)

Article 3: Applications and Permits

- Greenways are included in the preliminary plat requirements for proposed subdivisions regarding options for property dedications for open space and recreation facilities. [3.6.6(C)(8)][3.7.4(C)(11)]
- Greenway plans are included with the town's Comprehensive Plan and transportation plan, among others, as criteria that preliminary plats proposed to the Planning Board must conform to. [3.6.7(D)(3)] [3.6.8(E)(1)]
- If a proposed subdivision contains land that is included in an adopted greenway plan, the review of the preliminary plats may only be delayed 45 days, during which reservation and site acquisition may occur. [3.6.7(E)(1)]

Article 6: District Intensity Standards

- The promotion of interconnected greenways is included as a purpose of conservation subdivision design [6.2.4(A)(6)]
 - Conservation subdivision submittal requirements include a site analysis map to identify significant natural features and priority conservation areas, in addition to the general requirements for subdivision review. [6.2.4]

Town of Cary, Wake County

Land Development Ordinance (LDO)

Chapter 3: Review and Approval Procedures

- Greenways are included as a special use for flood hazard area. [3.12.2(A)]

Chapter 4: Zoning Districts

- Greenway corridors that are a part of the adopted greenways plan are classified as prioritized primary open space within conservation residential overlay districts. [4.4.3(F)(4)]
- Greenways will be used instead of sidewalks to meet pedestrian connectivity needs within conservation residential overlay districts. Construction of primary greenways is required at the time of development for new developments inside conservation residential sections. [4.4.3(F)(7)]

Chapter 7: Development and Design Standards

- Greenways are permitted in vegetated buffer areas, where no practicable alternative exists. [7.2.14(C)(2)]
- Greenways are permitted in special flood hazard areas. [7.5.3(B)(3)]
- Considerations for greenways are included in standards for pedestrian facilities. [7.10.4(B)(3)] [7.1-.4(A)(2)]

Chapter 8: Standards for Subdivisions and Uses Requiring Site Plans

8.1.2 Dedication Land for Parks and Greenways

- The subdivider of land for residential and non-residential purposes is required to dedicate land or pay a fee in lieu thereof for public park and/or greenway development. [8.1.2(A)]

- Land granted for greenway development will be required for areas identified in an adopted greenways plan. [8.1.2(A)(2)]
- Exceptions to required greenway dedication are made for multi-family dwelling units. [8.1.2(A)(3)]
- Considerations for greenways are included in the requirements for the nature of park land dedications. [8.1.2(C)]
- If a proposed development interferes with a proposed greenway site in an adopted greenways plan, a strip of greenway land through this area shall be dedicated to the Town, at a minimum of 30 feet, ranging from 30 to 50 feet in width. [8.1.2(D)(3)]
- Greenway land dedications will be reviewed and approved as part of the preliminary plat of new developments. [8.1.2(E)]
- Payment of fees in lieu of land dedication.
 - Payment of fees in lieu of land dedication may be at the request of the developer or at the request of the Town if the land is not suitable for greenway development or the needs of the greenway can be met elsewhere. [8.1.3(A)]
 - Payment of fees will be reviewed and approved as a part of the preliminary plat. [8.1.3(B)]
 - Payment of fees shall occur before construction of lots in the subdivision to which the fees relate. [8.1.3(C)]
 - The amount of the fee will be based on an appraisal of the fair market value of the land to be annexed, zoned, platted, or developed, at the developer's expense, or documentation of the fair market value that is approved by the Town. [8.1.3(D)]
 - Use of funds received by the town only for the acquisition or development of greenways and open space. [8.1.3(F)]

Town of Davidson, Mecklenburg County

Planning Ordinance

Section 4.1 Planning Areas

- Within a conservation easement subdivision, the developer must provide for greenway space by either deed or plat map if it includes proposed greenway space. [4.8.11.2]
- If a developer dedicates and builds a 10-foot wide greenway through the subdivision, one acre less is required per dwelling unit. A 5-foot wide greenway grants a bonus of ½ of an acre less per dwelling unit. [4.8.14.3]

Section 8.0 Development Proposal Submittal Requirements

- Greenway locations must be included in the master plan schematic design. [8.3(D)]
- Public access easements shall be provided for greenways within preliminary plats. [8.9(K)(4)]

Section 11.0 Streets and Greenways

These sections detail design and construction standards within greenways master plans

- General design principles. (11.5)
- Greenway engineering and design principles. (11.6)
- Greenway acceptance policy. (11.7)

Section 15.0 Stream Buffer Overlay District

- Greenway trail construction is permitted in managed-use zones stream buffers where natural topography and vegetation are preserved. [15.2.2][15.2.3]

Section 16.0 Watershed Protection Overlay District

- Greenway construction is permitted in vegetative buffer areas. [16.7.4(A)]

LAND TRUST CONSERVATION: GIS ANALYSIS FOR THE DELINEATION OF NON-ENCROACHMENT AREAS OF A FLOODPLAIN ORDINANCE

ANDREA KRUTULIS

Abstract. The National Flood Insurance Program conducted a Flood Insurance Study in Macon County, North Carolina in 2007. As a result, new floodplain management ordinances were passed by Macon County, which will assist in the preservation of habitat within the Little Tennessee watershed. The recommended a ban on the construction of residential structures in a newly-designated non-encroachment zone along the Little Tennessee River. Using GIS, a county wide map of the nonencroachment zone was created to identify properties within the non-encroachment area for conservation value. The map will serve as a useful tool for the Land Trust for the Little Tennessee (LTLT) to use to prioritize potential land purchases and conservation easements. The LTLT anticipates that the new floodplain ordinance will result in increased property sale and conservation easement opportunities for the organization with significant conservation benefits for the Little Tennessee River watershed.

Key words: flood insurance study; floodplain conservation; floodplain management; floodway; non-encroachment.

INTRODUCTION

Water quality of the Little Tennessee River watershed, like many across the nation, is threatened by rapid development. The destruction of riparian habitats bordering the watershed increases runoff into the Little Tennessee River, which introduces sediment and other pollutants into the river system and degrades habitat. The Little Tennessee watershed is an overall healthy ecosystem containing many rare and endemic species, including various fish and freshwater mussels (Etnier and Starnes 1993). Disturbance created by floodplain development can severely compromise the health of the ecosystem. In addition, development on the floodplain results in the risk of flood damage to structures and high costs expended by government agencies and landowners for disaster relief. For these reasons, federal, state and local governments are providing incentives for floodplain preservation.

County policies for floodplain management can be valuable in protecting watershed health. In 2008, Macon County adopted a new management policy, based upon a county-wide study conducted by the National Flood Insurance Program (NFIP) - a part of the Federal Emergency Management Agency (FEMA) - which was released in 2007 (FEMA 2007). The aim of the NFIP is to prevent and reduce damage associated with major flood events and to reduce costs expended by FEMA in relief efforts. These studies, termed Federal Insurance Studies (FIS), are provided to county governments who must accept them to be eligible for federal flood insurance (FEMA 2007).

Using the FIS, the NFIP attempts to assess the damage that would be associated with varying severities of flood events. Flood events of certain magnitudes have varying chances of being equaled in a given year. Those higher in damage potential have a smaller chance of occurring annually. For instance, the 100-year event has a 1% chance of being equaled in any given year (FEMA 2007). The NFIP has adopted a standard for floodplain management, managing for the 100-year flood event level of intensity (FEMA 2007). For the FIS, computer models calculate water levels for 100-year floods on each individual stream, based on stream flow characteristics. These calculations help identify flood-prone areas which are especially susceptible to extreme flood damage.

Localities that are susceptible to extreme damage during flood events are termed non-encroachment zones in the FIS (FIS 2007). A non-encroachment area, also called a floodway in the FIS, the area region along the stream channel in which construction of residential structures is prohibited (FIS 2007). The NFIP created this designation because “encroachment on floodplains such as that caused by placement of structures and fill reduces flood-carrying capacity, increases flood heights and velocities, and increases flood hazards” (FIS 2007:3). The prohibition of construction in floodways is enforced so that the 1% annual chance flood event can occur without considerable increases to flood heights, resulting in increased destruction and expenses (FIS 2007).

Federal insurance through NFIP is affordable insurance designed in part to meet the escalating costs of private insurers. Although it is beneficial for county governments and its residents to be insured through the NFIP, the suggested policy of the floodway produced by the FIS can have negative implications for landowners. By reducing the development potential on a parcel of land, the overall property value is expected to decline. For this reason landowners may choose to sell their land. An alternative may be to place a conservation easement on their land in return for tax benefits, which may attract landowners who are already limited in development possibilities. A conservation easement is an agreement with a landowner to forgo development for conservation purposes. Non-profit organizations, such as The Land Trust for the Little Tennessee (LTLT), can help facilitate the process of designating land for conservation, with the overall goal of protecting large tracts of contiguous land for the preservation of cultural and biological diversity. One goal of LTLT is use of conservation easements in order to increase connectivity of conserved floodplain land. LTLT needs a way to visualize parcels in the floodway. A GIS layer of the floodway overlain on a layer of Macon County parcels would be a way for LTLT to identify parcels that might be priority targets for conservation, based connectivity between parcels and critical or prime habitat areas. The purpose of this project is to create a county-wide map of parcels within the floodway of Macon County, NC to aid LTLT in identifying areas of conservation potential.

MATERIALS AND METHODS

The floodway map was created using ArcGIS® version 9.3 (ESRI 2008). In the FIS, cross sections were assigned roughly every 4000 feet on each major stream involved the study, and made into a GIS layer which I obtained from the Macon County mapping department. At each particular cross section, a distance to either side of the center of the stream is provided in the FIS, and this designates the floodway boundary (FEMA 2007:33-77). According to the FIS, the center of the stream is arbitrary and may

therefore be determined by sight. To visually mark the center of the stream at each cross section, I created a point layer to edit. I overlaid this layer on top of the cross section layer and the most recent aerial photo of Macon County, also obtained from the mapping department. I placed a point in the center of the stream on each individual cross section. I created a line layer to visually display the floodway boundaries, which are given in the FIS as distances on either side of the center point of each cross section (FEMA 2007: 33-73). At a particular cross section which now has a center point overlaid on top of it, I made a line of particular distance (given in the FIS) to the left of the center point and another line of a different distance (also given in the FIS) to the right of the center point. This was done for each individual cross section produced by the FIS. The distances of the non-encroachment boundaries were each found in the FIS (FEMA 2007: 33-37). After each line was made on the cross sections of each stream, I created a polygon layer which would be edited to display the final non-encroachment zone. I connected all of the outside edges of the floodway boundaries farthest away from the center point which resulted in a polygon displaying the contiguous non-encroachment zone on each stream studied in the FIS. Finally I obtained a layer depicting the boundaries of the 100-year flood which was produced by the FIS and obtained by the Macon County mapping department.

I next created a GIS layer depicting current land for sale for LTLT to use in identifying areas which may potentially be purchased by the organization for conservation. This layer may also be used to monitor the effects of the non-encroachment zone on land sales. A local realtor from Prudential Markham Bankston Realty ran a search on the Multiple Listing Service (MLS) for waterfront properties. I summarized selected information on each property from the search results in a database file created in Microsoft Excel, which included MLS number, parcel ID number, address, list price, acreage, owners name, area, type of land, and topography. I obtained a GIS layer of Macon County parcel data from the Macon County government website. In the layer of Macon County parcels there is a parcel ID associated with each waterfront parcel contained within the attribute table. In this layer, I searched the attribute table for each parcel ID number of the parcels found in the waterfront property search. I made a new layer of the selected parcels, which visually displays the current waterfront land for sale. In this new layer of properties for sale, I then joined the attribute table with the database file I created in Microsoft Excel with the common field of parcel ID number. The layer of the non-encroachment zone I created could then be overlaid on top of this layer to see any properties for sale which contain floodway areas. The attribute table could then be examined to see the sale information for each property.

RESULTS

The county-wide map created in ArcGIS® allows the user to visualize the location of the floodway relative to individual parcels (Appendix, Figs. 1 and 2). A complete county-wide map, too large to display in its entirety here, can be found in the electronic appendix, but Figs. 1 and 2 present examples that show the features of the larger GIS map that displays the non-encroachment zone. The map also allows the user to identify parcels of land for sale that are located in the non-encroachment zone (Fig. 3).

Out of seventy-five waterfront parcels of land currently for sale on the Multiple Listing Service, seventeen parcels of Macon County land were found in the floodway zone.

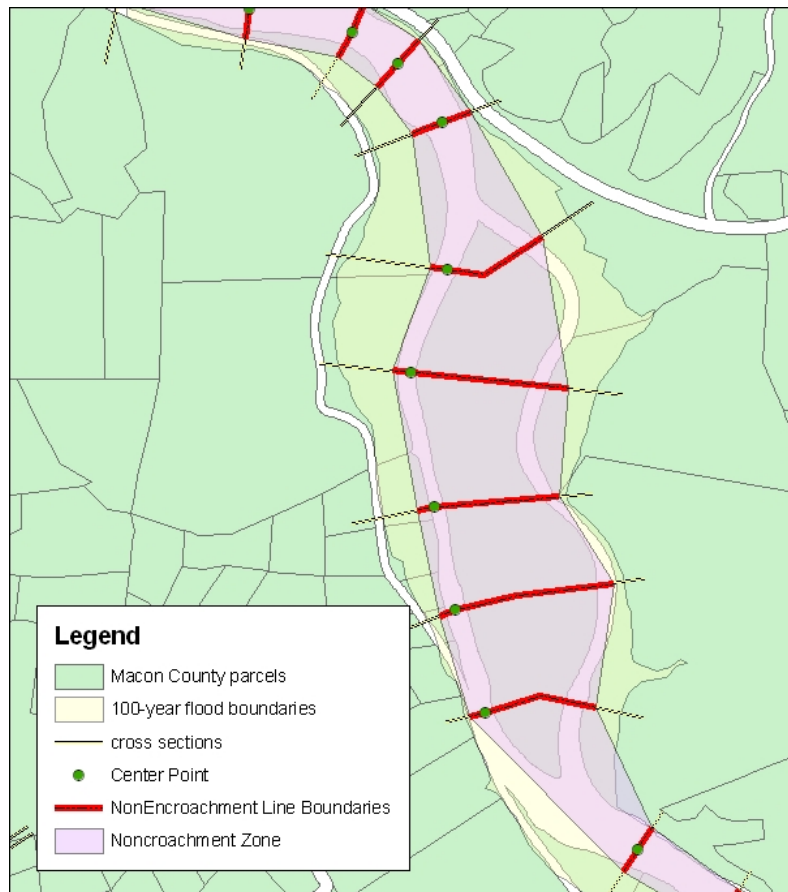


FIG. 1. Reach of the Little Tennessee River in Macon County, NC showing labeled cross sections, 100-year flood boundaries, center points, non-encroachment line boundaries, and non-encroachment area.



FIG. 2. An example of Macon County parcel data showing the non-encroachment area.

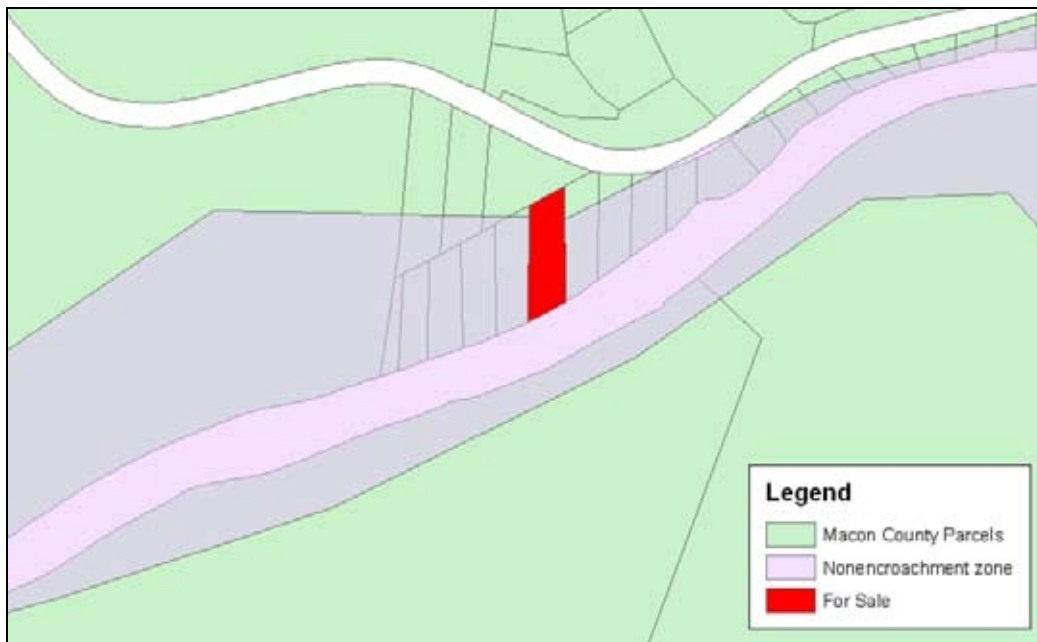


FIG. 3. An example of Macon County parcel data showing the non-encroachment area and a sale parcel falling in the non-encroachment area.

DISCUSSION

The mapping of non-encroachment zones in Macon County assists LTLT in identifying areas that can be easily targeted for conservation. It is the hope of LTLT that an increase in land and easement holdings will provide a more contiguous protection of the watershed. Landowners that have lowered property values will be targeted by LTLT. The GIS layers created in this study will help in determining the conservation value of those targeted properties. The benefit of owning or holding an easement on a piece of property with a large non-encroachment area may be greater, especially if it is adjacent to existing LTLT holdings. When a potential land or easement holding becomes available, LTLT must act in order to acquire the property or establish a conservation easement. A rapid evaluation of the conservation value of the property must be performed, and the GIS-based analysis presented here provides the means to perform an effective and efficient assessment.

Non-profit organizations such as LTLT often lack sufficient funding to purchase large tracts of desirable land. It therefore behooves non-profits to be conscious of changing market conditions that favor land acquisition. This will allow for the creation of conservation easements and direct management of prime habitat. LTLT is also hopeful that the tax benefits offered by conservation easements might entice a greater number of landowners to conserve and manage property suitable for the preservation of biological diversity. The costs and benefits of the floodway policy, as related to conservation, are currently unknown as it was only accepted by Macon County in 2008. It is likely that the new NFIP policy will prove beneficial to conservation organizations such as LTLT, and ultimately to the quality of the Little Tennessee watershed.

ACKNOWLEDGEMENTS

I thank Sharon Taylor and the staff of LTLT. Thanks also to Josh Pope at the Macon County mapping department for assistance with ArcGIS and to Mark Bankston at Prudential Markham Bankston Reality for conducting a search on the Multiple Listing Service.

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APPENDIX

County-wide map showing Macon County parcels, non-encroachment zones, and Macon County parcels for sale (electronic).

SOIL AND TREE RING CHEMISTRY CHANGES IN AN OAK FOREST

QUENTIN D. READ

Abstract. Changes in soil chemistry due to historic large-scale disturbances, e.g. pollution inputs, storm damage, and logging, have previously been shown to cause similar changes in the nutrient concentrations found in tree rings. Repeated soil sampling in a reference watershed at the Coweeta Hydrologic Laboratory (Otto, NC) in 1970, 1990, and 2004 showed significant decreases in cation concentrations and soil pH. It was hypothesized that historic wood nutrient concentrations could be used as a surrogate to estimate earlier soil cation concentrations. We hoped to exploit a relationship between recent soil and wood chemistry measurements to predict older soil chemistry values based on dendrochemical analysis. Oak trees (*Quercus alba* and *Q. prinus*) located in the reference watershed adjacent to long-term soil sampling plots were cored and analyzed for cation concentrations in 5-year increments. No significant relationship was found between the soil and wood chemical compositions for any given time. This indicates either that cation availability in the soil has not yet become a limiting factor for tree growth at this site, or that trees can access a source of nutrient cations other than the soil exchangeable cation pool.

Key words: acidification; aluminum; calcium; dendrochemistry; disturbance; magnesium; phosphorus; pollution; *Quercus alba*; *Quercus prinus*; soil; tree rings.

INTRODUCTION

Dendrochemistry background

Trees distinguish themselves among organisms for their longevity. Furthermore, their secondary xylem is visibly divided into yearly increments. The science of dendrochemistry was developed in order to describe and quantify correlations between the internal chemistry of trees on an annual basis and the chemical conditions prevailing in the surrounding environment, including pH, cation availability, and pollution inputs. The original goal of most dendrochemistry research was to track the effects of pollution across a long timescale as manifested in pollutant concentrations in tree rings. Whether or not the correlation between tree and environmental chemistry is valid depends on several assumptions. First, we must assume that the conditions under which the xylem was laid down actually have a consistent effect on the chemical composition of the xylem. A second necessary assumption is that the ions within the xylem are relatively static; that is, that they are not radially transported throughout the tree in later years.

Disturbances such as logging have a significant effect on ecological conditions that affect tree growth. Removal of large trees releases understory plants, including saplings, from suppression due to increased sunlight and decreased competition for water and nutrients, thereby promoting plant growth. Despite the fact that some material is removed in the form of commercial timber, nutrient concentrations in the soil increase

because a large amount of slash, consisting of residual plant matter such as leaves and small branches, is left to decompose and contributes nutrients to the soil. This occurs in several phases starting with throughfall beneath slash and followed by decaying leaves and twigs, then by larger branches and roots. We hypothesized that a past logging event would be detectable by a spike in yearly growth increment in tree cores of now-mature trees, as well as by a concurrent increase in cation concentrations in the wood (Knoepp and Swank 1997).

The initial goal of this particular study was to determine if the relationship between cation concentrations in wood and the pH and cation concentrations in the soil could be described quantitatively. If so, soil concentrations could be extrapolated backward to before the period when soil was actually sampled by using cation concentrations from older growth rings. This extrapolation could be used to predict the soil nutrient response to past disturbances within the watershed.

History of the Coweeta basin

The study site is located in Coweeta Hydrologic Laboratory (Otto, North Carolina), a USDA Forest Service Experimental Forest established in 1934. The landscape at Coweeta consists of a large basin with highly dissected topography; many small ridges divide the basin into numerous watersheds, each of which drains into a stream (in this case, Ball Creek). All the streams eventually drain into Coweeta Creek.

The watershed under study, reference watershed WS18, has a long, well-documented history of large-scale ecological disturbances. In 1835, during the lifetime of some of the oaks in the sampled population, a hurricane destroyed many of the trees in the Coweeta basin, and settlers farmed some of the land at higher elevations when the flat lands began to yield less crop. Most importantly, the majority of the basin was logged in 1919, removing all timber with a diameter greater than 15 inches. Shortly thereafter, the U.S. Forest Service bought the land and established the research facility; Watershed 18 remained a reference watershed and was not further disturbed. However, in the 1930s, chestnut blight struck the area. All mature chestnut trees, which had previously comprised over one-third of the dominant hardwood overstory, succumbed to the plague. All these disturbance episodes were followed by a period of higher recruitment among deciduous trees (Douglass and Hoover 1988).

The spike in growth and recruitment after the logging event is clearly visible in the dendrochronological record at the site; annual growth increment responded with a sharp increase in the years immediately following the event, then gradually decreased to previous levels after several decades (Fig. 1).

Acid deposition and leaching

The advent of fossil-fuel-based industry and transportation increased acid deposition from the atmosphere into the soil. Oxides of sulfur and nitrogen are discharged by the burning of coal and oil; some of it is incorporated into precipitation and ends up in the soil. As the acidic solution moves downward through the soil, the sulfate and nitrate anions increase the acidity of the soil. The anions also bind to naturally occurring base cations, such as potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}), as well as

aluminum (Al). While K, Ca, and Mg are essential nutrients required for healthy plant growth, Al is toxic to plants. When base cations bind with anions, they are leached out of the soil and are no longer available for uptake by plants. Unfortunately, nutrients like Ca may be depleted by this process, but Al is practically inexhaustible in the environment of the study area due to the composition of the bedrock minerals. As acid deposition increases, the ratio of Al to Ca in the soil also increases (Shortle et al. 1995). Studies have shown that a ratio above 1 is the threshold for deleterious effects on plant growth, because at that level, root cation exchange sites begin adsorbing Al at the expense of Ca (Lawrence et al. 1995).

Dendrochemical analysis

Stemwood chemistry of various tree species has previously been used to reconstruct historical chemical conditions in the surrounding soil. For example, Guyette et al. (1992) conducted a dendrochemical study to examine the effects of atmospheric acid deposition in central Missouri. They used Mn concentrations in eastern redcedar (*Juniperus virginiana*) to predict historical soil pH. They concluded that there was a significant correlation between the soil pH and the wood Mn concentration. Mn is well-suited to track pH changes, since it is not overly affected by leaching and has a low mobilization factor; that is, it requires a significant decrease in pH to be taken up by tree roots.

Dendrochemical techniques have some limitations. Secondary xylem undergoes major chemical changes as it senesces and transforms from sapwood to heartwood. In mature oaks, roughly thirty of the most recent rings are still functional sapwood, while the rest has become heartwood (Cronquist 1982). Radial translocation of nutrients may invalidate the dendrochemical technique of measuring historic cation concentrations in tree rings. As wood ages, cations are often drawn out of it and transferred to new growth; a local minimum in cation concentration is often observed at the transitional zone between heartwood and sapwood (Penninckx et al. 2001). If cations are easily transmitted transferred across rings, the concentration in wood from a given year will no longer be correlated with environmental conditions in the year when it was produced.

METHODS

Soil pH and cation concentrations

Cation concentrations and pH data were available for each of the eight soil plots for both 1970 and 1990, and soil samples were also available at each of the soil plots in 2004 and had been previously analyzed for exchangeable cation concentration. (For more detailed sampling methods, see Knoepp and Swank 1994.) Soil pH for the 2004 samples was measured by mixing 5 g of soil with 10 mL of 0.01 M CaCl₂, letting it sit for thirty minutes at room temperature, and then measuring the pH with an electrode probe. This measurement was repeated for the A, B, and B2 soil horizons for three to five locations in each of the soil plots, and the values for each horizon on each plot were averaged for statistical analysis.

Increment core analysis: ICP

Fifteen white and chestnut oaks (*Quercus alba* and *Q. prinus*, respectively) were cored using a 5.5 mm increment corer in 1993 by Coweeta staff; two cores were collected from each tree. At that time, ring widths were measured for each of the two cores for all trees. Cores were sectioned into 5 year increments for cation concentration for all the trees providing data through 1993. We collected additional cores to update the data set for the following 15 years (1994-1998, 1999-2003, and 2004-2008 segments) as follows. A core was collected from each sample tree at breast height using an increment corer 5.5 mm in diameter. The cores were allowed to dry and then sectioned into five-year segments along the growth ring boundaries with a razor blade. All segments were weighed, placed in a crucible, and ashed in a muffle furnace for eight hours at 550°C. After wood sections were completely reduced to ash, they were digested in 5 mL of a 20% nitric acid solution (HNO₃) and brought to a volume of 25 mL with deionized water. Inductively coupled plasma spectrometry was used to assess the cation concentrations present within the wood for Ca, K, Mg, and Al.

We chose white oak and chestnut oak, prevalent tree species in the watershed, for several reasons. Oaks have ring-porous wood, meaning that larger-diameter vessel element cells are predominantly produced during the early part of the growing season, while smaller tracheids appear later during the summer (Zimmermann and Brown 1971). Because of this phenomenon, there is a distinct demarcation between growth rings from successive years, facilitating analysis. In addition, radial translocation of cations is minimal in oaks compared to other tree species, for example red spruce (Shortle and Smith 1995). These factors make oaks ideal for dendrochemistry studies.

Data analysis

The majority of the wood chemistry samples were collected and analyzed in 1996. Unfortunately, the data were generated by a commercial lab whose data output systems contained errors. Information needed to correct the problem was unavailable, as were the original samples. Therefore, the units for reported elemental concentrations in the wood were uncertain. As a result, we compared the ratios of the elements to one another among the trees, examining Ca:Al, Ca:Mg, and Ca:P. Normalizing the values in this way makes the units irrelevant. Furthermore, the cation concentrations from before approximately 1920 were highly variable; they were only used qualitatively. The masses of the samples collected for the years 1994-2008 were too small to get an accurate value for aluminum concentrations, so [Al] values for 1995-2005 wood chemistry are not included in this study.

We used a paired T-test to test for significant differences among years for soil and wood chemistry as well as tree annual growth increment. Regression analysis showed no significant relationships between soil exchangeable cation concentrations or soil pH and wood cation ratios, so prediction of past soil chemistry composition could not be conducted.

RESULTS

Soil chemistry

A significant decrease in soil pH (Fig. 2) and soil Ca (Fig. 3) occurred between 1970 and 2004, as determined using a paired T-test (MEANS procedure, SAS software). Results are shown in Table 1. The change was most pronounced in the upper (A) soil horizon for [Ca] and in the lower (B) horizon for the pH value. Soil plots located on ridge tops also differed significantly from those along streams: namely, ridgetop plots had a lower pH and a lower [Ca] throughout the time interval studied.

Between 1970 and 1990, soil [Mg] decreased significantly in surface soils ($P=0.019$), while increasing significantly at depth ($P=0.014$). However, there was no significant change in [Mg] between 1990 and 2004 (Fig. 4). The ratio of Ca:Mg in the soil remained stable between 1970 and 1990, but decreased significantly within both horizons between 1990 and 2004.

Changes in soil chemistry over time were also analyzed separately for soils in ridgetop and streamside locations; each location had a group of four plots. pH decreased significantly in soils of both slope positions, but did not change significantly in the A horizon between 1970 and 1990. [Ca] did not decrease significantly in ridge soils, but it did in the A horizon of stream soils between 1970 and 1990 ($P=0.002$). [Mg] increased in the B horizon of ridge soil plots between 1970 and 1990 ($P=0.012$) but decreased in the A horizon of stream soils during that time ($P=0.002$). Ca:Mg ratio did not significantly change in either ridge or stream plots.

Wood chemistry

Paired T-tests analysis showed annual growth increment was significantly greater in 1920 than in 1970 or 1990 ($P=0.032$, 0.064). There was no significant change in Ca:Al ratio between 1920 and 1990 (Table 2 and Fig. 5); Ca:P ratios decreased significantly between 1990 and 2004 ($P=0.006$, Fig. 6). Ca:Mg ratios decreased significantly from 1970 to 1990 ($P=0.003$) but then increased from 1990-2005 ($P=0.026$, Fig. 7). As with the soil values, ridgetop trees had significantly different chemistry than streamside trees: Ca:Al and Ca:Mg ratios were significantly greater in streamside trees ($P=0.001$, 0.008), but Ca:P ratios were greater in ridgetop trees ($P=0.003$).

Looking at trends separately in the ridge and stream trees, it is apparent that most of the significant change took place in the ridge trees. When analyzed separately, the decrease and subsequent increase in wood Ca:Mg ratio was significant in the ridge trees ($P=0.034$) but not in the stream trees. However there was a trend toward a decrease in Ca:Al ratio in the stream trees from 1920-1970 ($P=0.055$).

Fungal stains were documented on some of the extracted cores; coloring ranged from light to dark. The effect of the staining on wood chemistry is uncertain. If fungi had mobilized minerals in the wood or was analyzed along with the wood sample, the nutrient concentration values would have been affected. Infection by fungus may have added to the increased variability in older wood chemistry (see Figs. 6 and 7, for example); values prior to about 1900 became very noisy and unreliable (data not shown), possibly due to staining and the decrease in samples from this time period.

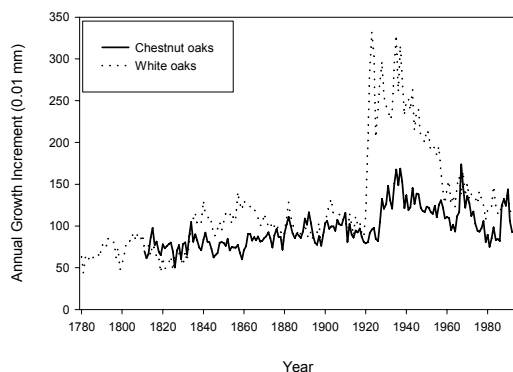


FIG. 1. Mean annual growth increment for two oak species in Coweeta Hydrologic Laboratory (Otto, NC), Watershed 18, 1780-1993.

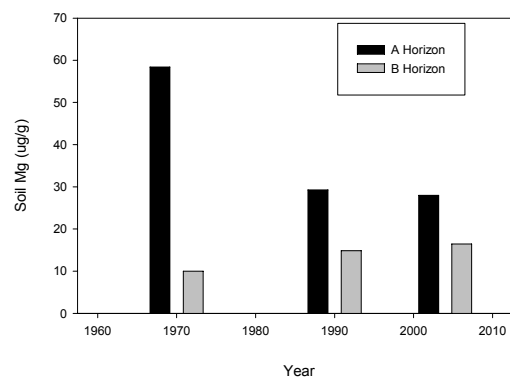


FIG. 4. Mean soil [Mg] change over time, 1970-2004.

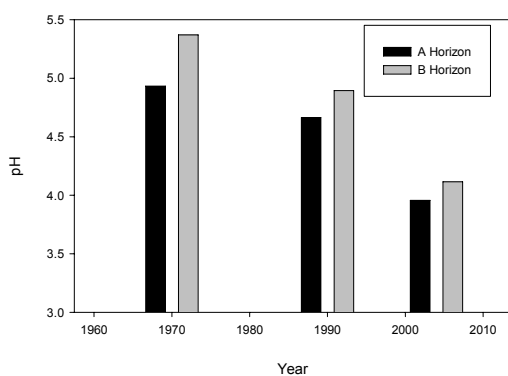


FIG. 2. Mean soil pH change over time in WS18, 1970-2004.

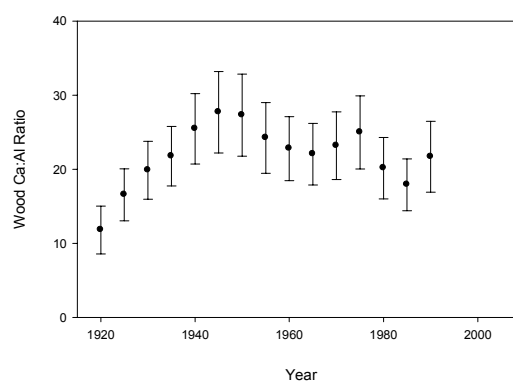


FIG. 5. Mean wood Ca:Al ratio ± 1 standard deviation, 1920-1990.

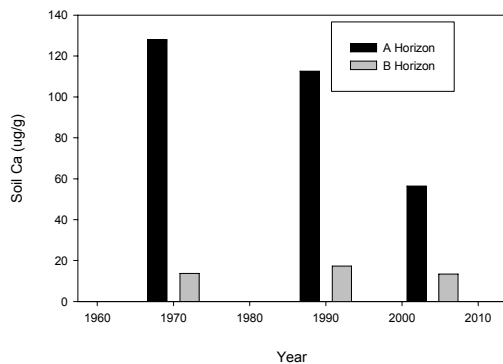


FIG. 3. Mean soil [Ca] change over time, 1970-2004.

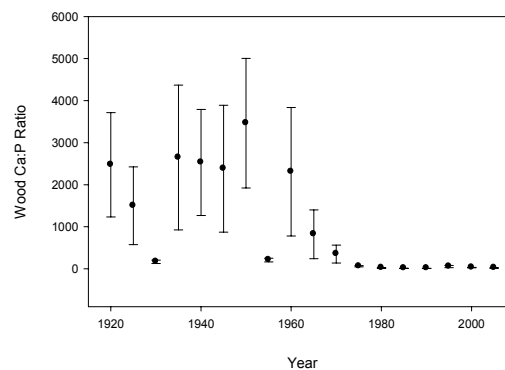


FIG. 6. Mean wood Ca:P ratio ± 1 standard deviation, 1920-2005.

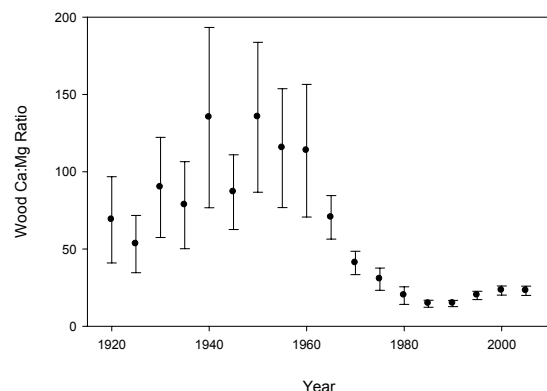


FIG. 7. Mean wood Ca:Mg ratio $\pm$ 1 standard deviation, 1920-2005.

TABLE 1. Statistical test results for soil chemistry.

	All soil		Ridge soil		Stream soil	
<u>Ca</u>	T value	P> T	T value	P> T	T value	P> T
1970-1990 horizon A	6.86	0.0002	-2.2	N.S.	2.38	0.0978
1990-2004 horizon A	2.12	0.072	22.78	0.0002	5.33	0.0129
1970-1990 horizon B	-1.19	N.S.	9.57	0.0024	8.62	0.0033
1990-2004 horizon B	1.26	N.S.	73.81	<.0001	15.86	0.0005
<u>pH</u>	T value	P> T	T value	P> T	T value	P> T
1970-1990 horizon A	0.31	N.S.	4	0.028	10.16	0.002
1990-2004 horizon A	8.94	<0.0001	1.25	N.S.	1.85	N.S.
1970-1990 horizon B	12.39	<0.0001	-1.82	N.S.	-0.46	N.S.
1990-2004 horizon B	33.58	<0.0001	0.25	N.S.	1.9	N.S.
<u>Mg</u>	T value	P> T	T value	P> T	T value	P> T
1970-1990 horizon A	3.04	0.019	0.94	N.S.	9.6	0.0024
1990-2004 horizon A	0.27	N.S.	-0.62	N.S.	1.33	N.S.
1970-1990 horizon B	-3.24	0.0142	-5.49	0.0119	-1.14	N.S.
1990-2004 horizon B	-0.55	N.S.	-0.64	N.S.	-0.07	N.S.
<u>Ca:Mg Ratio</u>	T value	P> T	T value	P> T	T value	P> T
1970-1990 horizon A	-0.74	N.S.	0.54	N.S.	-1.71	N.S.
1990-2004 horizon A	2.75	0.0287	2.45	0.0917	1.91	N.S.
1970-1990 horizon B	0.64	N.S.	1.91	N.S.	-0.18	N.S.
1990-2004 horizon B	2.32	0.0532	1.65	N.S.	1.58	N.S.

TABLE 2. Statistical test results for wood chemistry.

	All trees		Ridge trees		Stream trees	
<u>Annual Growth Increment</u>	T value	P> T				
1970-1990	0.35	N.S.				
1970-1920	2.38	0.032				
1990-1920	2.01	0.0645				
<u>Ca:Al Ratio</u>	T value	P> T	T value	P> T	T value	P> T
1920-1970	0.99	N.S.	-0.02	N.S.	-4.08	0.0552
1970-1990	1.01	N.S.	-1.94	0.0812	1.18	N.S.
<u>Ca:P Ratio</u>	T value	P> T	T value	P> T	T value	P> T
1920-1970	1.64	N.S.	1.66	N.S.	1.18	N.S.
1970-1990	1.56	N.S.	1.3	N.S.	2.4	0.0619
1990-2005	-3.16	0.0061	-2.52	0.0329	-1.61	N.S.
<u>Ca:Mg Ratio</u>	T value	P> T	T value	P> T	T value	P> T
1920-1970	1.1	N.S.	0.36	N.S.	1.26	N.S.
1970-1990	3.48	0.0028	2.46	0.0338	1.82	N.S.
1990-2005	-2.45	0.0263	-2.49	0.0344	-1.06	N.S.

DISCUSSION

The response of forest soils to disturbance events is consistent and predictable. A Coweeta watershed that was logged during the 1970's showed a significant increase in soil exchangeable cation concentrations immediately following the event. The concentrations stayed elevated for a substantial amount of time, dropping slowly over the next two decades (Knoepp and Swank 1997). It is very likely that a similar response occurred in the soils of WS18, starting in 1919. We expected to see a sharp increase followed by a steady decrease in the wood cation concentrations after 1920 to confirm this prediction. However, wood cation concentrations showed no significant change during that period.

Soil pH decreased significantly from 1970 to 2004 (Table 1). During this period, calcium concentration in the A (uppermost) horizon of the soil also dropped. Despite this, no concomitant decrease in tree ring calcium concentrations was observed (Table 2). We expected to find that Ca:Al ratio in tree rings would decrease with decreasing soil pH, but linear regression failed to yield a significant R^2 value; none of the other wood elemental ratios we examined were significantly related to soil chemistry.

The lack of correlation between wood and soil chemistry values is probably due to the characteristics of the local environment and its pollution history. Soil pH and calcium values recorded in the watershed are typical for Coweeta Hydrologic Laboratory: current pH values range between 4 and 5. While cation concentrations have declined, constant concentrations in wood suggest that cations are not limiting growth. Industrialization in the vicinity of the site has historically not been as extensive as other locations in the US, leading to relatively low deposition of sulfate, nitrate and other forms of pollution.

Many of the dendrochemical studies that have found correlations between soil chemistry and wood chemistry were conducted in highly polluted areas. For example, Anderson et al. (2000) studied lead (Pb) concentrations in black oak (*Q. velutina*) stemwood in the immediate vicinity of a lead smelter in Alabama. Unsurprisingly, Pb concentrations were markedly higher in stemwood from trees that had been exposed to a high level of pollution. Other studies were done in highly industrialized areas of North America and Europe, such as *Fagus sylvatica* in Belgium (Penninckx et al. 2001), *Acer saccharum* in Ontario (Houle et al. 2007), and *Liriodendron tulipifera* in urban Ohio (McClenahan and Vimmerstedt 1993). In these areas, sulfate concentrations in atmospheric deposition are much greater than in the southeastern U.S., resulting in a more pronounced soil cation decrease; this deficiency in the soil would make itself seen in xylem concentrations.

When data from all years were averaged and considered together, the chemistry of the ridge trees appeared to be more closely related to the chemistry of ridge soil than to the stream soil, although the relationship was not significant. This possible relationship provides some support for the idea that had the study been conducted in an area with a higher pollution load or with an initially more depleted nutrient pool, there may have been a detectable relationship between the chemical changes in wood and soil. However, the relationship was not significant when looking at each year individually, making the initial objective of predicting past soil nutrient concentrations impossible to assess quantitatively.

This study suggests that soil extractable calcium concentrations have not fallen beyond the point at which they become limiting to oak growth; the trees may be taking up just as much soil calcium as in previous years, despite the fact that extractable Ca has declined (Fig. 3). If this is not the case, the trees may be accessing other sources of calcium. One interesting possibility for such a calcium source, mineral weathering mycorrhizae, is suggested by van Schöll et al. (2007). Hyphae from ectomycorrhizae, which are fungi living on and around the surfaces of tree roots, can penetrate small mineral grains that are not otherwise easily weathered, forming microscopic tunnels. If the tree is experiencing a nutrient deficiency, the fungi release organic acids that help mobilize the otherwise inaccessible cations. Blum et al. (2002) also raised the possibility that mycorrhizal weathering of the common mineral apatite, $\text{Ca}_5(\text{PO}_4)_3(\text{OH}, \text{F}, \text{Cl})$, can be a vital Ca source in forest ecosystems, specifically the northern hardwood forest of North America; since the calcium is taken up directly from the minerals into the roots, it is not part of the soil exchangeable cation pool.

Physiological responses to stress by trees may also contribute to confounding results: Bukata and Kyser (2008) found that in the northern red oak (*Q. rubra*), nutrient concentrations within xylem can be highly erratic and unrelated to the bioavailability of the nutrients themselves. During historic periods of stress, concentrations of essential cations, including Ca and K, were found to increase, but chemically similar non-nutrients, such as rubidium and strontium, did not change their behavior, indicating a physiological response within the tree rather than an actual change in bioavailability.

Smith and Shortle (1996) observed that ratios of aluminum to other cations are not necessarily a useful part of wood chemistry analysis. Aluminum tends to be excluded from plant uptake at the absorbing tip of the tree root; the steeply increasing pH at the interface decreases aluminum availability for uptake to a large degree. They recommend avoiding quantitative analyses of aluminum availability to plants due to this property.

In conclusion, despite a clear decrease in soil nutrients over the past four decades at our Coweeta study site, nutrient concentrations in oak growth rings have not decreased in the same

way. The lack of a correlation between soil and wood cation concentrations at this site makes it impossible to estimate historic elemental concentrations in the soil using older tree ring values, at least in the two species studied. Conducting a similar study at a more polluted site, or one with lower soil pH and cation concentrations, would yield more convincing results and allow historic projections to be made. Research on susceptibility of wilderness areas to SO₄ deposition (Elliott et al. 2008) suggests that Linville Gorge Wilderness Area would be a promising spot for further research.

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QUALITY-SOIL AND FARMLAND LOCATIONS IN JACKSON AND MACON COUNTIES, NORTH CAROLINA, AND THEIR IMPLICATIONS FOR LAND CONSERVATION

CHRIS TIFFANY

Abstract. Local land trusts are interested in conserving farms, as they usually contain the most productive soils. These soils are grouped into three categories with separate standards for soil quality. Maps were generated to display the distribution of each soil type in Jackson and Macon counties. Local farms were located in the field and their location recorded using a GPS device. Each farm was pinpointed on aerial photographs of Jackson and Macon counties. Farmland maps were generated for each county based on the spectral data of the previously located farms. Quality-soils and farmland data were combined to display the acreage of farmlands containing quality soils. It was concluded that both counties have a substantial amount of quality-soil farmlands.

Key words: ArcGIS; Feature Analyst; locally-important soils; prime soils; quality soils; Raster Calculator; statewide-important soils.

INTRODUCTION

Land trusts are interested in preserving not only pristine ecosystems, but also working lands such as forest lands and farmlands. In particular, farmlands are often targeted by developers as sites prime for residential or commercial development. One aim of land trusts is to conserve parcels of high quality farmland before they can be bought by developers. In Jackson and Macon counties, local land trusts such as the Highlands-Cashiers Land Trust (HCLT), located in Highlands, North Carolina, and the Land Trust for the Little Tennessee (LTLT), located in Franklin, North Carolina, are working to protect local farmlands that are at risk for development.

Historical accounts of local farming give evidence as to how well soils in the region are suited to agriculture. For centuries, various communities in Jackson and Macon counties have relied on the productivity of quality farmlands. As early as 1540 the Cherokee were harvesting corn, beans, squash and pumpkins in the city of Cullasaja, just southeast of present day Franklin, NC. (Macon Historical Society 1987). Subsistence farming was very important to white settlers, including Joseph W. Dobson, who in 1835 established a thriving apple orchard just southwest of Franklin in the valley of Cartoogechaye (Shaffner 2004). In 1840, a local farmer named Silus McDowell touted the town of Highlands as ideal for growing apples, grapes, melons, peaches, pears and quinces. This view was also shared by Samuel Kelsey who, in 1875, tended to a hundred-acre farm on the Highlands plateau, which included apples, potatoes, cabbages, turnips, lettuce, radishes, peas, parsnip and beans (Shaffner 2004). There are still various row crops produced in the region, as well as Christmas trees, a high-value cash crop, grown mainly in Jackson County. From these accounts, it is evident that high quality farmlands are important within Jackson and Macon counties and are worth conserving.

An assessment that takes into account the quality and productivity of soil is one of many variables that land trusts use when determining whether a parcel of land is worth conserving.

The HCLT has not yet generated any digital or paper maps that illustrate the distribution of quality soils. This report establishes, with a series of digital maps, the current distribution of quality soils in both Jackson and Macon counties, and determines the total acreage of land on which these soils are present. Further, this report also assesses the locations of agricultural farms and determines the extent to which these farms possess quality soils. The conclusions established by this report will aid local land trusts in the future assessment and acquisition of quality-soil farmlands.

MATERIALS AND METHODS

Classification of Soils

Soil classification is based on numerous variables. The highest-order variables when determining a soil's classification include a soil's location in regard to elevation and distance from a flood plain, drainage patterns, and permeability of the soil. Macon County lists 42 different highest-order soil "classifications," as does Jackson County. The next order in soil identification is based on the steepness of slope, mineralogy, and the ability of soil types to mix and form soil complexes. Based on all of these variables, 92 soil types are recognized for Macon County (USDA 1998a) and 101 soil types are recognized for Jackson County (USDA 1998b).

Some soils are more suitable than others for the purpose of agriculture and are commonly referred to as quality soils. The three categories of quality soils are prime soils, locally-important soils, and statewide-important soils. The United States Department of Agriculture defines prime soils as soils that are best suited to food, feed, forage, fiber and oilseed crops (USDA 1998a). These soils have conditions that are favorable to high crop yields such as receiving a dependable amount of moisture, favorable temperatures during growing season, few permeable rocks, non-excessive erosion or saturation, and infrequent grow season flooding. In other words, these soils must meet federal standards for proper landscape, mineralogy, elevation, moisture and climate (USDA 1998a). Statewide-important soils are soils that are recognized for producing high-value crops, but do not meet the requirements to be considered prime soils based on their steepness of slope, permeability, susceptibility to erosion, or low water capacity on a statewide scale (USDA 2008). Lastly, locally-important soils are recognized for producing high-value agriculture, despite lacking qualities associated with prime soils. Soils data for this report was taken from the 1998 United States Department of Agriculture Soil Survey of Jackson County, NC (USDA 1998b), and Macon County, NC (USDA 1998a).

Rendering Quality-Soils and Farmland Maps

Digital maps for this report were generated using ArcGIS® 9.3 (ESRI 2008), a computer software program which takes various types of data and distributes it across a spatial coordinate plane, rendering digital maps. The quality-soils in Jackson and Macon counties were placed into one of the three categories: prime soils, statewide-important soils, and locally-important soils (USDA 1998a). A quality-soils database was initiated by creating a Microsoft Excel file that displayed only quality soils and their new classification (1=prime, 2=locally-important, 3=statewide-important). Digital data containing the soils distributions for all of Jackson and Macon counties were obtained from the Highlands-Cashiers Land Trust. The digital data was joined with the newly created quality-soils database file in ArcGIS to generate a series of maps

for Jackson and Macon counties that displayed only the distribution of quality-soils for each county.

The quality-soils digital maps for Jackson and Macon counties were loaded onto a Trimble® GeoXM™ GPS device. This enabled the GPS user to determine the exact location coordinates of patches of quality-soils in both counties. The first in-field goal of the project was to locate quality-soil sites in Jackson and Macon counties and determine whether or not these sites were being utilized for agriculture. The second goal was to locate agricultural farmlands in Jackson and Macon counties and mark them using the GPS device. Farmlands were considered to be of interest to this report if they were larger than 1 acre, as estimated by visual inspection. Agricultural plots less than 1 acre were considered private or residential farms and were removed during post-processing.

The extent of farm acreage in Jackson and Macon counties was mapped using Feature Analyst 4.2 (Visual Learning Systems 2007), which is a tool used in ArcGIS that supervises classifications of spectral data. Farmland areas recognized in Jackson and Macon County aerial photography were used as seeds (polygons) for Feature Analyst searches. Farmlands were mapped from georegistered Landsat Enhanced Thermal Mapper Plus (ETM+) satellite data from 1999 (30m resolution) and 2001 (60 m resolution). Using the farmland seeds, Feature Analyst selected cells from the ETM+ data that have similar spectral signatures. This application was run ten times for each county, ensuring that most of the major farmlands would be selected by the Feature Analyst application. The extent to which farmlands contained quality soils was determined by an ArcGIS application called Raster Calculator (ESRI 2008). This application superimposed quality-soils distribution data with farmland distribution data to find parallels in their spatial location.

RESULTS

Digital quality-soils maps created using ArcGIS display the distributions of all three distinct quality-soil classifications for both Jackson and Macon counties (Fig. 1). Locally-important soils are the most abundant and most widely distributed soil classification in both counties. This is not surprising given that this soil type extends to any soil that has the capacity to support agriculture on a local scale. Prime soils are the least common soil classification within Jackson and Macon counties. This is expected, because this soil classification has an extremely restrictive set of parameters.

Fig. 1 shows the distribution of the three classifications of quality soils throughout the two counties. Jackson County contains 7,409 acres of prime soils, 12,727 acres of statewide-important soils, and 47,390 acres of locally-important soils (Table 1). While in the field, 15 agricultural farms in Jackson County were located that were visibly larger than one acre in total area. After plotting the farm locations on a quality-soil distribution map, it was determined that 10 of these farms contained soils of one or more of the three distinct quality-soil classifications.

Macon County contains 12,382 acres of prime soils, 11,860 acres of statewide-important soils, and 67,689 acres of locally-important soils (Table 1). While in the field, 11 agricultural farms in Macon County were located that were visibly larger than one acre in total area. After plotting the farm locations on a quality-soil distribution map, it was determined that 7 of these farms contained soils of one or more of the three distinct quality-soil classifications.

Fig. 2 displays the distribution of farmland across Jackson and Macon counties, in which there were 33,628 acres of farmland in Jackson County and 53,233 acres of farmland in Macon

County. The primary agricultural crop in Jackson County is Christmas trees (Fig. 3, Appendix). Christmas tree farms in Jackson County comprised 11,021 acres of farmland, totaling 48.59% of all Jackson County farmland. The primary agricultural crops in Macon County were row crops, including tomatoes, corn and squash (Appendix). Fig. 4 displays the distribution of quality-soil farmlands in Jackson and Macon counties, or rather the amount of farmlands which contained one or more of the three quality-soil classifications. It was determined that in Jackson County, there were 8,456 acres of farmland which contained one or more of the quality-soil types, while in Macon County, 52,273 acres of farmland contained one or more quality-soil types (Table 2).

There were several sources of error while generating farmland maps, including Feature Analyst's inability to distinguish farmlands from non-farmlands. This was a particular problem for Jackson County. ETM+ data used for this report was 60 meters, which is very coarse compared to the 30 meter pixel resolution of Macon County ETM+ satellite. For each run of Feature Analyst, the application determined a certain percentage of forested land to be farmland. Digital polygons that were determined to be forested lands were removed, as well as polygons less than one acre in area.

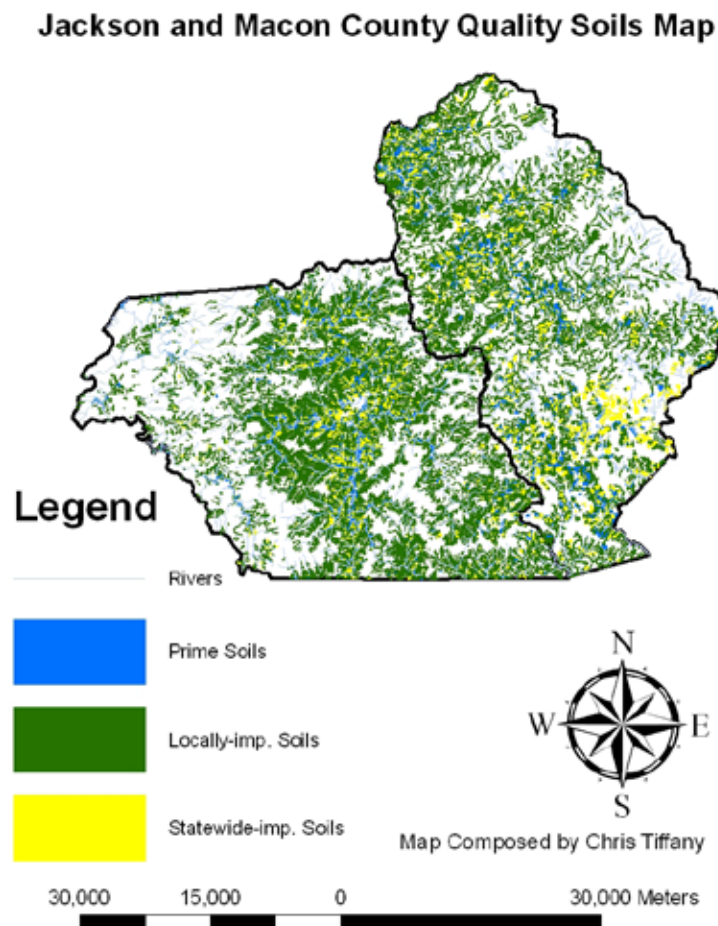


FIG. 1. Distribution of quality soils in Jackson and Macon counties, NC.

TABLE 1. The quantities of quality soils in Jackson and Macon Counties and the percentage of total acreage.

Classification	Acreage	% Acreage of County
<i>Jackson County</i>		
Prime Soils	7,409	2.53%
Locally-Imp. Soils	47,390	16.15%
Statewide-imp. Soils	12,727	4.34%
Total	67,527	23.02%
<i>Macon County</i>		
Prime Soils	12,382	3.72%
Locally-imp. Soils	67,689	20.36%
Statewide-imp. Soils	11,860	3.57%
Total	91,932	27.65%

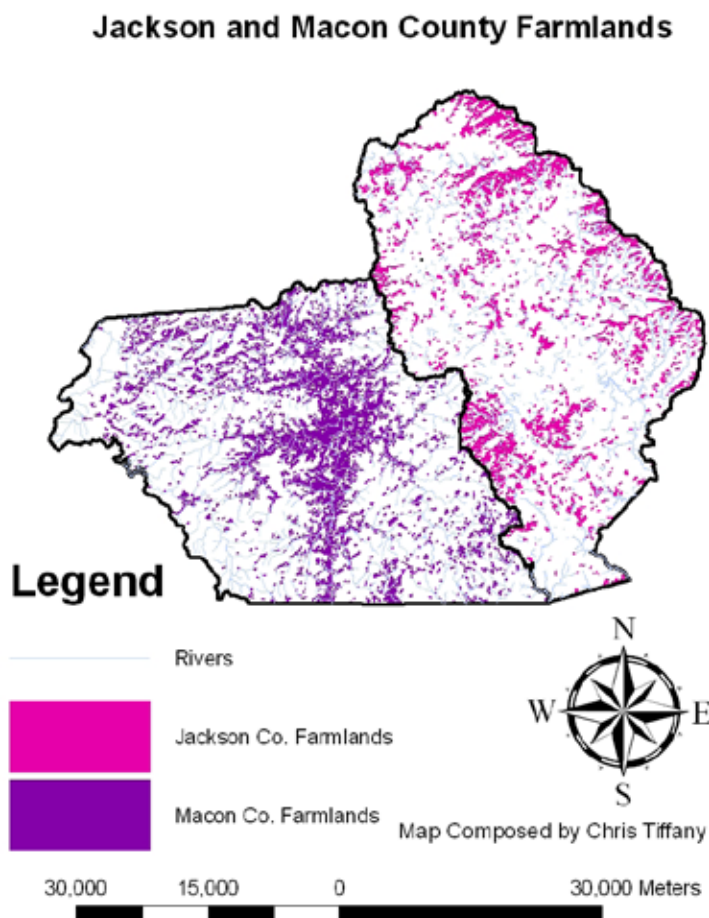


FIG. 2. Map displaying the distribution of all farmlands across Jackson and Macon counties, NC.

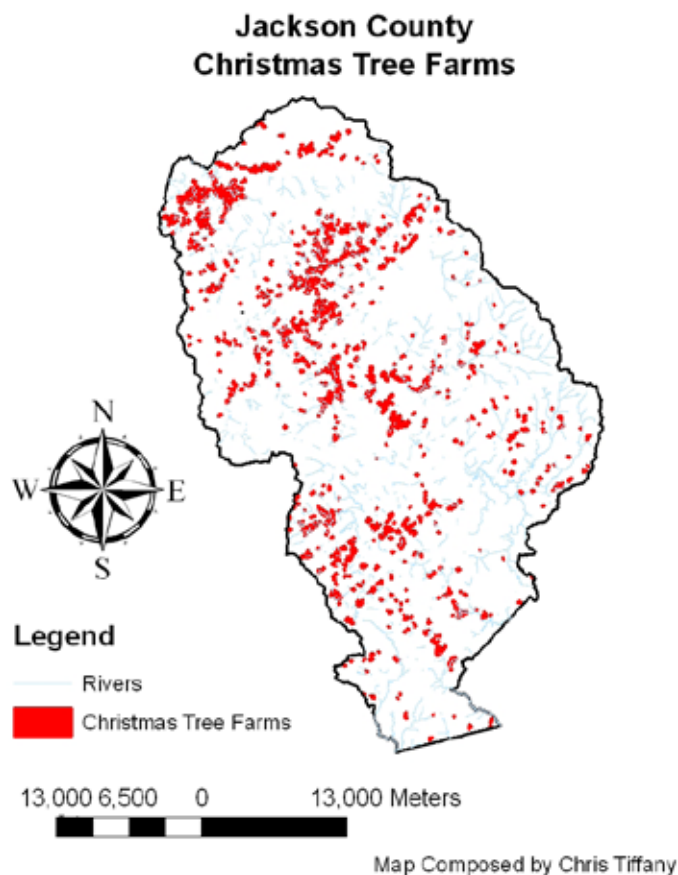


FIG. 3. Map displaying the distribution of Christmas tree farms in Jackson County, NC.

Jackson and Macon County Quality Soil Farmlands

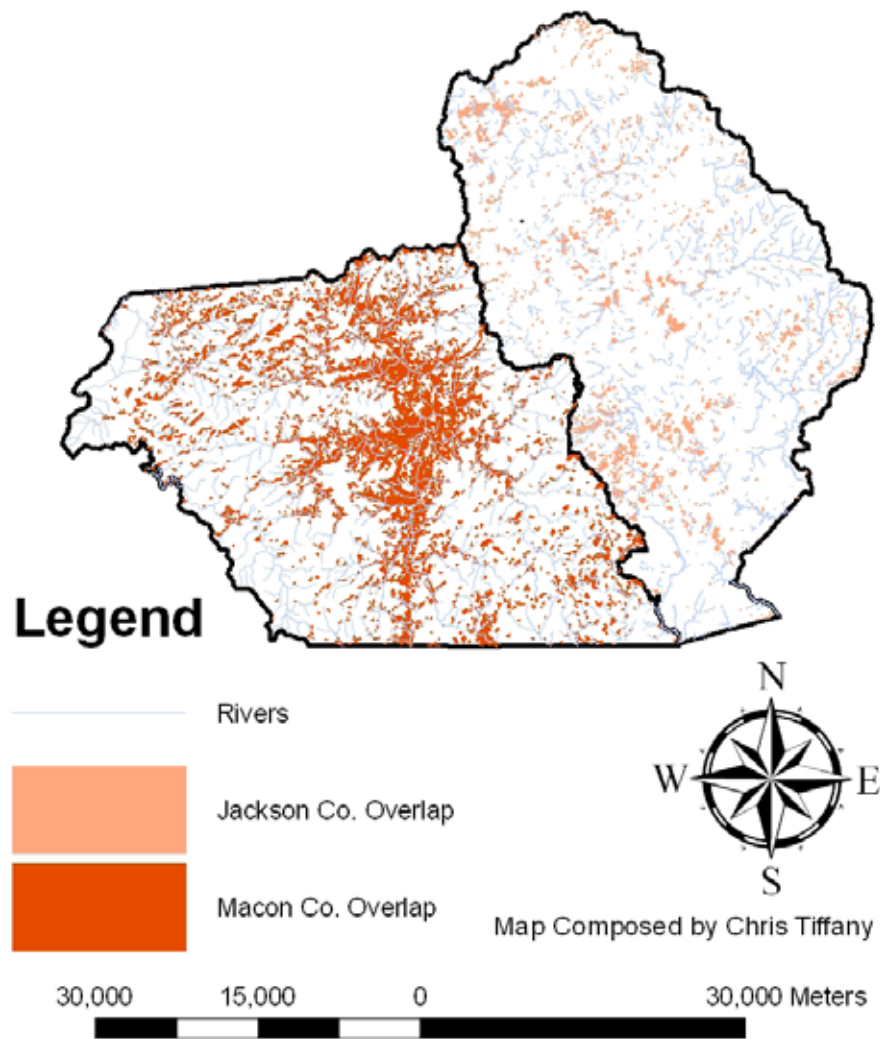


FIG. 4. Map displaying the distribution of quality-soil farmlands in Jackson and Macon counties, NC.

TABLE 2. Amount of acres in which farmlands and quality soils overlap in Jackson and Macon counties, NC.

County	Farmland (acres)	Quality Soil (acres)	Quality Soil Farmland (acres of overlap)
Jackson	33,628	67,527	8,456
Macon	53,233	91,932	52,273
Total	86,861	159,459	60,729

DISCUSSION

Local land trusts' attempts to preserve farmland properties should focus on examining farms that contain all three categories of quality soils. Although locally-important soils are the most abundant category of quality soil (Fig. 1), local land trusts must not give preference to this category of soil when selecting farmlands to assess. From a conservation perspective, locally-important soils are not as significant as prime soils or statewide-important soils because their conditions are not best suited to agriculture (USDA 2008). In addition, land trusts must not give preference to prime soils while selecting farmland properties to conserve. Collectively, there are only 11,512 acres of prime-soil farmland in Jackson and Macon counties, compared to 60,729 acres of farmlands that contain any or all three of the quality soil classifications (Table 2). Focusing conservation efforts on farmlands containing only prime-soils would severely limit the amount of farmlands that local land trusts could potentially acquire.

There are sufficient differences between Jackson and Macon counties in terms of farmland quantity. Macon County is 13% larger than Jackson County in total acreage, and contains a much larger proportion of quality-soil farmlands than does Jackson County. This is understandable, since Jackson County contains fewer rivers and flood plains than Macon County and more land characterized by steep mountainous slopes, which have fewer quality-soils. Presently, there exist 52,273 acres of quality-soil farmlands in Macon County, compared to only 8,456 acres of quality-soil farmlands in Jackson County. In addition, Macon County farmlands are almost wholly comprised of quality-soils, due to its abundance of rivers and floodplains and its valley slopes with gentler gradients. On a strictly quantitative basis, land trusts that want to acquire quality-soil farmland will find abundant acreage for this particular aim in Macon County.

This report establishes that there are quality-soil farmlands in both Jackson and Macon counties. It has been determined that Macon County contains significantly more quality-soil farmlands than Jackson County, mainly because it is topographically more suitable for soils that support high-value agriculture. Many of the row crops found to be growing in Macon County today are the same crops that were once found on local historical subsistence farms, signifying the continuing importance of farming practices in the county. Quality-soil farmlands in Jackson County are still very important to conserve, particularly because many of these farmlands contain high-value Christmas tree farms. Local land trusts have a particular interest in conserving quality-soil farmland because these lands are also of interest to developers. With the expansion of new homes and businesses in western North Carolina, local land trusts must try to quickly acquire remaining farmland properties for conservation before they become developed. The results from this report may be used to guide the HCLT and other local land trusts in future land assessments, ultimately protecting the high-value farmlands of Jackson and Macon counties from development.

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APPENDIX

Photo gallery of various Christmas tree farms in Jackson County, NC, and row crops in Macon County, NC.

APPENDIX

Photo Gallery



Example of a Christmas tree farm in Jackson County, NC. Photo taken October 12, 2008.



Example of a Christmas tree farm in Jackson County, NC. Photo taken October 12, 2008



Example of row crops in Macon County, NC. Photo taken October 6, 2008.



Example of row crops in Macon County, NC. Photo taken October 6, 2008.

MONTANE CEDAR GLADES OF MACON COUNTY, NORTH CAROLINA: RED CEDAR AGES AND GEOGRAPHIC BOUNDARIES AT THREE SITES

GRAHAM B. ZIMMERMAN

Abstract. Montane cedar glades are rare *Juniperus virginiana*-dominated rock outcrop plant communities of the southeastern United States. I measured and analyzed *J. virginiana* ages and radial growth rates by collecting and measuring increment cores at three montane cedar glades in Macon County, North Carolina. I also mapped the boundaries of each site using GPS and GIS technology. Maximum confirmed age was 170 years; an age estimation of 178 years was obtained from an incomplete core. Mean radial growth rate was 1.3 mm/yr ($N = 30$, $\sigma = 0.5$ mm/yr). These values indicate stable conditions and slow growth in montane cedar glade communities. Linear regression analysis confirmed a significant relationship between diameter at breast height (in cm, y) and age (in years, x) across the three sites ($y=0.1367x+8.8682$, $R^2 = 0.581$, ANOVA $P < 0.001$). Mapping efforts demonstrated the restriction of montane cedar glades to sites with southern aspect, steep slope, and rocky soil. This paper provides a preliminary study of age and growth rate values of *J. virginiana* in the montane cedar glade habitat.

Key words: age estimation; dendrochronology; eastern red cedar; GIS; GPS; increment core; *Juniperus virginiana*; Macon County; mapping; montane cedar glade; North Carolina; southern Appalachians.

INTRODUCTION

Montane cedar glades are rare plant communities dominated by eastern red cedar, *Juniperus virginiana*. They occur on south-facing rock outcrops in the southern Appalachian Mountains, including locations in Macon County, North Carolina. Montane cedar glades are little-studied and have not yet been included in the North Carolina natural community classification system (Small and Wentworth 1998).

Juniperus virginiana is a small to medium sized, dioecious, evergreen conifer of the family Cupressaceae (Weakley 2008). It reaches a maximum height of 15 m and a maximum diameter of 60 cm, with the oldest individuals reaching around 300 years of age. Its growth form ranges from columnar to pyramidal. The leaves of *J. virginiana* are small and scalelike, lying flat and densely against the twig and ranging in color from bluish to yellowish green. The bark has a shredded texture and ranges in color from brown to reddish brown; however, with sufficient weathering, it can become gray. The female cones are glaucous, blue, berrylike, and are eaten and dispersed by many birds and mammals, with consumption serving to aid germination (Harlow and Harrar 1950, Radford et al. 1968, Horncastle et al. 2004).

Juniperus virginiana occupies both a wide geographic range and a wide variety of habitats. It can be found across eastern North America, from southeastern Canada to the Gulf Coast and from the Great Plains to the Atlantic Coast (Harlow and Harrar 1950). *Juniperus virginiana* is able to tolerate most of the extremes of temperature, moisture, growing season, elevation, and soil quality occurring within this range (Harlow and Harrar 1950, Lawton and Cothran 2000). However, it does best in dry, highly exposed habitats such as rock outcrops,

barrens, and old agricultural fields, where it acts as a pioneer species (Harlow and Harrar 1950, Radford et al. 1968, Small and Wentworth 1998). Despite its hardiness, *J. virginiana* is intolerant of both fire and competition from hardwood species (Small and Wentworth 1998).

Juniperus virginiana dominates a suite of plant communities known as cedar glades, barrens, and woodlands which occur on areas of thin, rocky soil in the southeastern United States (Harlow and Harrar 1950, LeGrand 1988, Small and Wentworth 1998, Baskin and Baskin 2003). In the “classic,” non-montane glades, this soil is of calcareous substrate, most commonly limestone; however, these communities can also be found on dolomite, diabase, and gneiss (LeGrand 1988, Small and Wentworth 1998, Baskin and Baskin 2003). These areas are characterized by extreme variation in soil moisture and temperature and high levels of irradiance (solar exposure), harsh conditions which result in a unique species assemblage primarily composed of lichens, mosses, and annual C₃ forbs and C₄ graminoids, depending on individual site location and soil characteristics (Baskin and Baskin 2003). These include several species and subspecies endemic or nearly endemic to these communities (Baskin and Baskin 2003). *Juniperus virginiana* is the most common of the comparatively few tree and shrub species making up the open canopies found in places where the soil is thick enough to support woody plants (Baskin and Baskin 2003).

Montane cedar glades differ from their lowland relatives in that topography becomes an important factor in determining suitable community habitat. Occurrence of montane cedar glades is restricted to moderate to steep upper slope rock outcrops with a southern aspect and moderate exposure. The steepness of the sites serves to inhibit soil accumulation as well as enhance soil drainage, resulting in a thin, xeric soil character. Southern aspect and moderate exposure increase temperature range and have further drying effects on the soil. Montane cedar glades appear most often on biotite gneiss and sometimes on or near hornblende gneiss. Growth of *J. virginiana* individuals on these sites is limited to small patches of soil of varying depth within a matrix of bare rock. Species assemblage is similar to lowland cedar communities but also includes several rare or endemic southern Appalachian species such as *Carex biltmoreana*, *Amelanchier sanguinea*, *Prosartes maculata*, and *Senecio millefolium* (Small and Wentworth 1998).

Small and Wentworth (1998) published one of the only extensive quantitative studies of montane cedar glades (based on seven sites in Alexander, Jackson, and Macon Counties), but did not include any investigation of *J. virginiana* age data. I collected and analyzed *J. virginiana* increment cores in order to determine tree ages at three montane cedar glade sites in Macon County. I also used GPS technology to collect geographic data for map creation and future remote sensing applications. My study intends to contribute to our understanding of the montane cedar glade plant community.

MATERIALS AND METHODS

I collected increment cores, diameter-at-breast-height (DBH) measurements, and GPS data at three montane cedar glade sites in southern Macon County (see Fig. 1 for locations). I collected cores from 10 trees at a site located on the Pinnacle, 11 from a site at High Knob, and 9 from a site at Doubletop Mountain. I used a handheld GPS unit to collect waypoints at each sampled tree and to map an approximate boundary of each site.

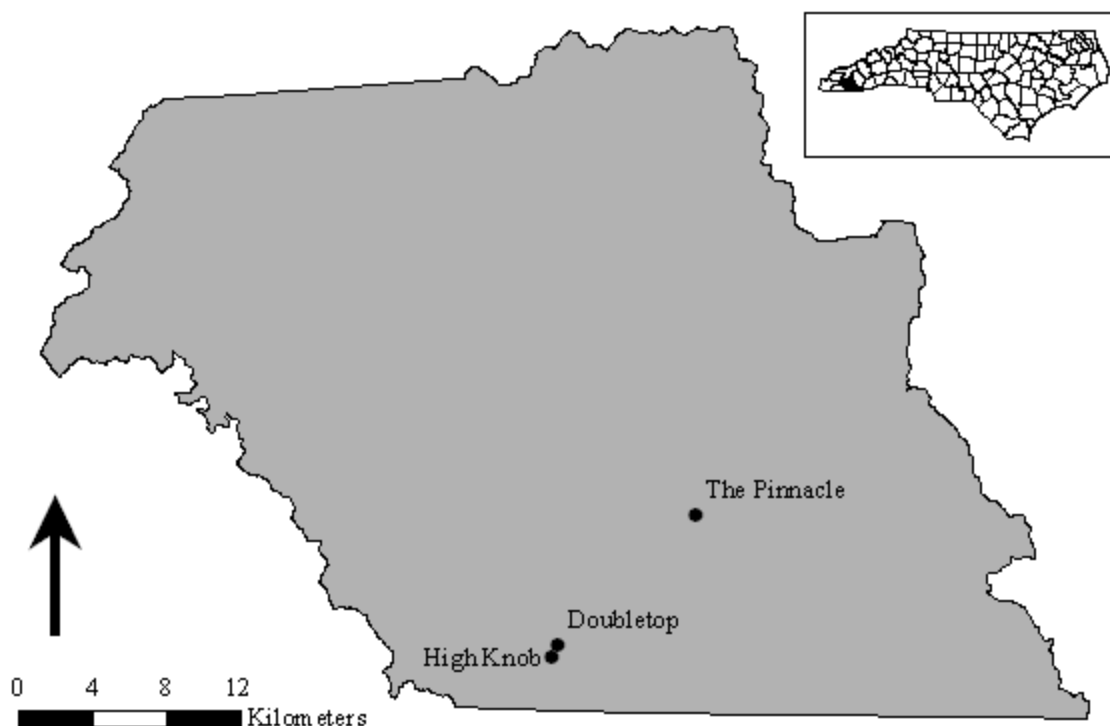


FIG. 1. Location of montane cedar glade study sites within Macon County, North Carolina.

I took DBH measurements of each tree with a Ben Meadows® DBH-circumference measuring tape. I used a 12-inch Mattson® increment borer to extract one core per each tree, also at breast height. Each core was taken at a horizontal angle and depth intended to include pith or near-pith in the sample (Phipps 1985). Extracted cores were individually labeled and stored in plastic drinking straws. Trees were selected for coring based on size and accessibility. Some large trees (DBH > 40 cm) could not be reliably cored because their heartwood had softened or rotted and could not be extracted. Despite this exclusion, several collected cores (N = 6) were incomplete due to failure to extract pith/near-pith. Larger trees were also avoided because the increment borer became lodged in them on several occasions, with extraction proving excessively laborious and time-consuming. I did not core the smallest trees (DBH < 6.5 cm) in order to avoid causing them injury. Some trees were not cored because extensive branch growth on the lower trunk inhibited operation of the borer. Other trees were excluded because of their location on hazardous portions of the sites. I attempted to spread my sampling across each site, but no formal random sample selection methods were used. My core data do not represent random population sampling due to these constraints.

I prepared each core for analysis by manually sanding the end grain of one side with three grades of progressively smaller-grit sandpaper, as per Phipps (1985). Once a polished surface was achieved, the core was examined under a dissecting microscope at sufficient magnification to discern individual cells. I counted the number of true and false rings appearing on each core; identification of true (annual) and false rings was performed according to Phipps (1985) and advice from Jess Riddle (pers. comm.). I also measured the counted length of each core sample using a ruler, from cambium to pith or near-pith.

I analyzed the core data using Microsoft® Excel software. Individual, site, and overall radial growth rates were calculated using core length and number of true rings. I also calculated

individual, site, and overall ratios of true rings to false rings. These calculations did not require any extrapolation of incomplete core data. I estimated true ring numbers (T) for incomplete cores (N = 6) using counted true rings (t), DBH, total measured core length (L), length of core containing the oldest 20 true rings as recommended by Rozas (2003) (d), and site-specific mean difference between DBH and core length of intact cores (D). Site-specific mean difference between DBH and intact core lengths accounted for the contribution of bark and phloem to DBH measurements. The extrapolation equation used was $T=t+20*(0.5*DBH-L-D)/d$. By estimating true ring numbers for the incomplete cores, I was able to use them in the production of a scatter plot, linear regression trendline, and ANOVA test of the relationship between DBH and tree age.

I collected GPS data at each site with a Garmin® GPS 72 handheld GPS unit, marking the site boundary and sampled tree locations with points. Each point was taken as the average of approximately 30 measurements in order to improve accuracy. These points were imported into ArcGIS® v.9.3 (ESRI 2008) software using Minnesota Department of Natural Resources DNRGarmin© software. Using ArcGIS, I separated tree points from boundary points, created polygons from the boundary points, measured the location, perimeter and area of each boundary polygon, and created aerial photograph maps. I created aspect and slope maps using 6-m Macon County LIDAR elevation data. I created soil maps using North Carolina soil survey polygon data.

RESULTS AND DISCUSSION

General site descriptions

Though the three sites all qualify as montane cedar glades due to *J. virginiana* dominance, each is distinguished from the others by differences in moisture, exposure, slope and species composition. The Pinnacle is the driest of the three sites, with few if any notable seeps. High Knob is the wettest, with a large number of seeps distributed across the site. Doubletop has an intermediate number of seeps, primarily distributed along the steeper reaches of the site. The channels eroded into the rock outcrops by the seeps at High Knob and Doubletop indicate that they have been stable components of the sites for a long time. The Pinnacle and Doubletop are more exposed than High Knob, which is located along one ridgeline of a cove. The Pinnacle and High Knob were significantly steeper than much of the Doubletop site. High Knob has a significant heath component dominated by *Kalmia latifolia* along its transition into the surrounding forest. Doubletop has a significant pine component within the site consisting of *Pinus pungens* and *Pinus rigida*. The Pinnacle has neither of these components.

Ages and growth rates

Age and radial growth rate values from my increment core analysis are reported in Table 1. The confirmed true ring counts of incomplete cores were included in the calculation of these age values; estimated ages were not used. The oldest sampled tree, at 170 years of age, occurred at the Pinnacle site. Minimum growth rates of 0.6 mm/yr occurred at the Pinnacle and Doubletop sites. A maximum growth rate of 2.8 mm/yr occurred at the High Top site. High Top also had the highest mean growth rate, 1.7 mm/yr with a standard deviation of 0.5 mm/yr. Mean growth rate across the three sites was 1.3 mm/yr with a standard deviation of 0.5 mm/yr. Fig. 2 provides a graphical representation of mean growth rate by site and in total.

TABLE 1. Site-specific and overall ages and radial growth rates: minimum, maximum, median, and mean values.

Site ID	Minimum		Maximum		Median		Mean		Rate σ (mm/yr)
	Age (yr)	Rate (mm/yr)	Age (yr)	Rate (mm/yr)	Age (yr)	Rate (mm/yr)	Age (yr)	Rate (mm/yr)	
Pinnacle	51	0.6	170	1.5	103	0.9	105	1.0	0.3
High Knob	17	1.0	103	2.8	45	1.7	50	1.7	0.5
Doubletop	49	0.6	110	1.4	66	1.2	71	1.1	0.3
Overall	17	0.6	170	2.8	67	1.2	75	1.3	0.5

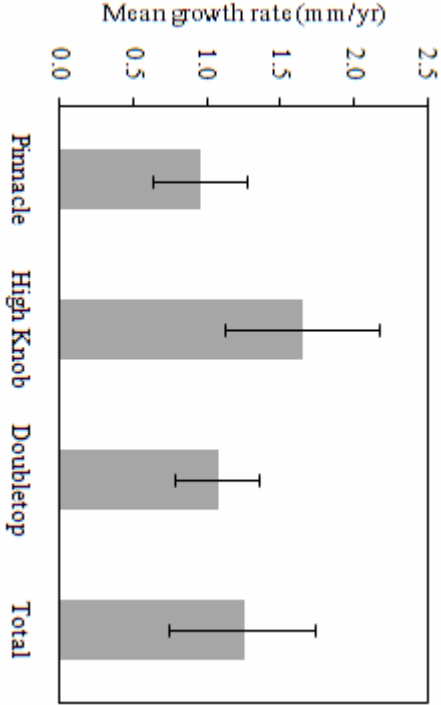


FIG. 2. Mean radial growth rates $\pm$ 1 standard deviation.

TABLE 2. Estimated ages of trees with incomplete core samples.

Core #	Site ID	DBH (cm)	Core age (yr)	Estimated age (yr)
1	Pinnacle	40.6	102	159
5	Pinnacle	26.4	134	178
6	Pinnacle	19.8	58	64
8	Pinnacle	28.4	115	139
17	High Knob	15.2	36	38
28	Doubletop	26.4	89	84

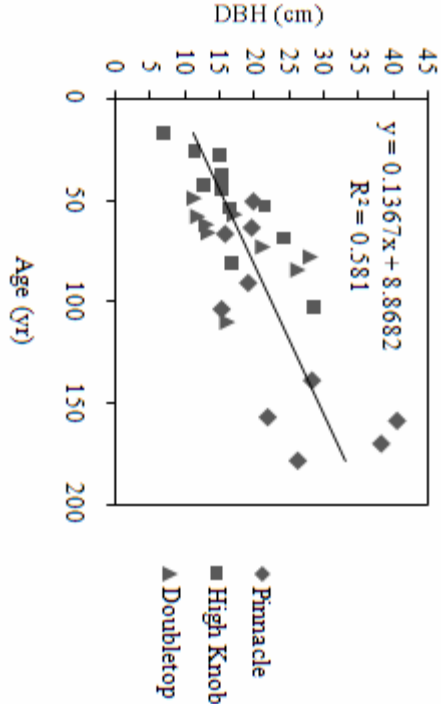


FIG. 3. DBH versus age with linear regression trendline.

TABLE 3. Site location, perimeter, and area.

Site ID	Latitude N	Longitude W	Perimeter (km)	Area (ha)
Pinnacle	35°5'30.65"	83°20'41.561"	1.301	5.582
High Knob	35°1'10.749"	83°25'37.241"	0.828	1.193
Doubletop	35°1'32.069"	83°25'23.492"	0.630	2.118

Age values indicate that montane cedar glades are stable rather than seral (successional) communities and maintain suitable growth conditions for *J. virginiana* over an extended period of time. Fire events and competition with colonizing hardwoods are two readily conceivable threats to individuals inhabiting these sites, given their dry, exposed nature and direct contact with hardwood forest (Small and Wentworth 1998). However, the oldest sampled tree on each site was at least 103 years old, an age probably not uncommon given my observation of the abundance of trees of similar size on each site. This indicates that threats from fire and hardwoods to individuals within the boundaries of the sites are probably minimal. Fire may have difficulty starting and spreading in montane cedar glades due to their open canopy as well as extensive bare rock coverage and lack of leaf litter (the products of vigorous erosional processes resulting from steep slope and high exposure). The near-absence of hardwood species within the sites is probably maintained by harsh temperature and moisture conditions and thin, unsuitable soils (Small and Wentworth 1998). These factors are stable and derive from aspect, exposure, and slope of the sites. Without a hardwood component with which to compete, *J. virginiana* individuals within the sites are at little risk of mortality or fitness reduction due to shading. The situation along the transitional perimeters of the sites may be different. Contact with hardwood forest in this transitional zone increases the impact of shading and may facilitate the spread of fire. Small and Wentworth (1998) come to similar conclusions regarding the dynamics of montane cedar glades, but note that the fire regime in these communities is still unknown.

Growth rate values show considerable variation among sites and individuals. Variation among sites seems to follow my qualitative observations of site moisture: High Knob is the wettest site, based on seep frequency, and has the highest growth rate, while the relatively dry Pinnacle ranks last. However, given the high degree of standard deviation overlap between the sites (see Fig. 2), it is unlikely that this is a statistically significant relationship. Larger sample numbers would be needed for a more thorough investigation. The high variation of growth rate within each site, demonstrated by site minimums, maximums, and standard deviations, indicates that conditions vary widely from tree to tree. This may be caused by variation between soil depth and moisture from tree to tree. Since trees within the site grow on small patches of soil which vary in extent, depth, and drainage, the observed variation between individual growth rates is expected. To give some perspective on these growth rates, Lawton and Cothran (2000) cite limestone cedar glade trees of 30-60 cm in diameter and 140-175 years of age as slow growing. My data indicate that montane cedar glade trees reach that age class at a diameter range of only 20 to 40 cm. Thus, *J. virginiana* in montane cedar glades appears to be exceptionally slow-growing, even within the context of the extreme conditions present in cedar glade communities as a whole.

Age estimation and diameter-age relationship

Table 2 contains the estimated age values of the incomplete increment cores, calculated by extrapolation. A maximum estimated age of 178 years occurred at the Pinnacle site. The estimated age of the Doubletop individual was 84 years, a reduction from the 89 true rings counted on its core sample. This reveals the limitations of my extrapolation method. Fig. 3 plots DBH measurements versus age for each specimen. I used estimated ages for specimens with incomplete core samples. A linear regression trendline and ANOVA test were applied to the total of the data points from the three sites ($y=0.1367x+8.8682$, $R^2 = 0.581$, ANOVA $P < 0.001$).

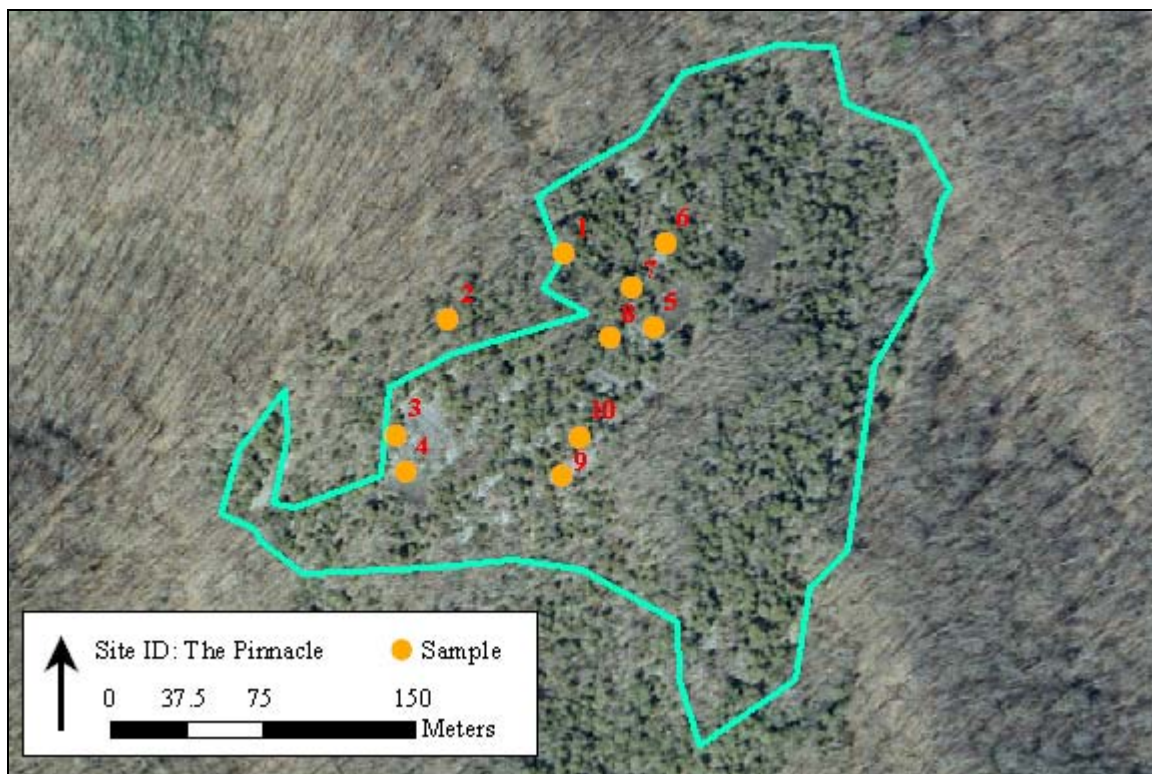


FIG. 4A. The Pinnacle: site boundary and sampled trees. Map numbers correspond to sample numbers.

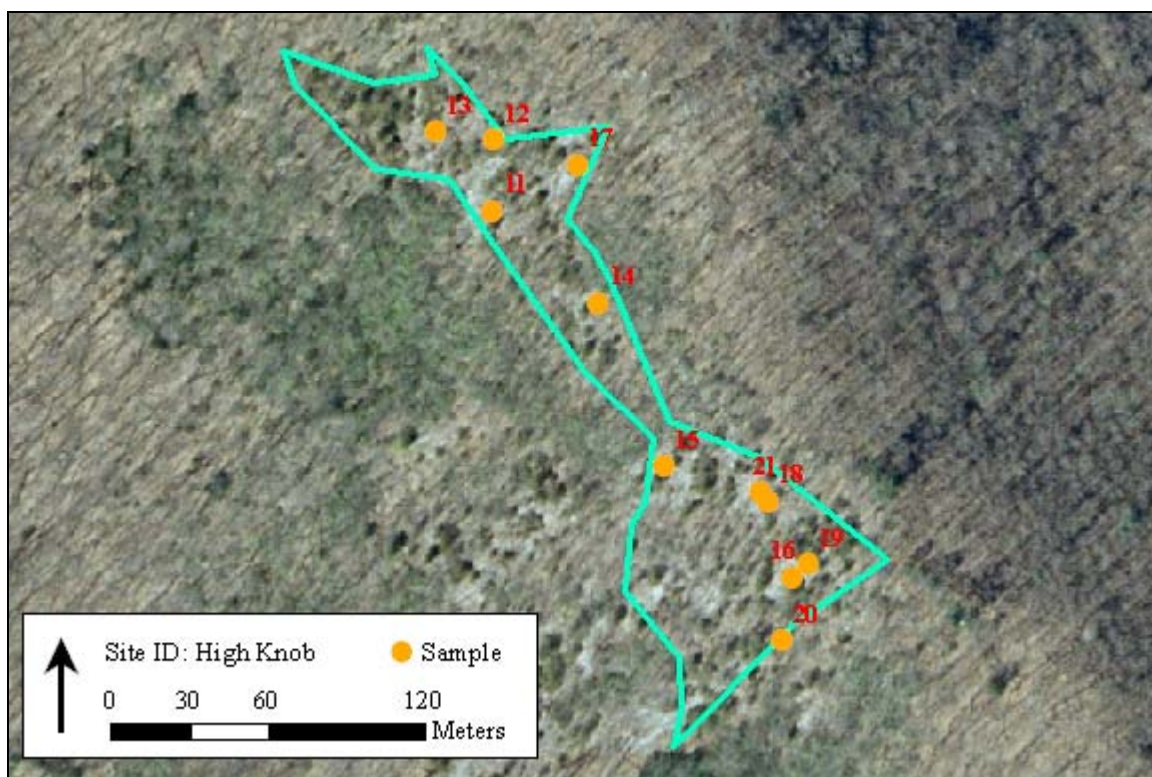


FIG. 4B. High Knob: site boundary and sampled trees. Map numbers correspond to sample numbers.

My age estimation method provided plausible results through the use of a likely oversimplified extrapolation equation. Estimated ages of incomplete cores did not conflict with ages of complete cores when viewed within the context of DBH measurements. However, an important caveat is the failure of my extrapolation method to provide a logical estimated age for the incomplete specimen collected at the Doubletop site. The reduction of the age of this specimen after extrapolation is likely due to extraction of the core from an axis of significantly greater length than the DBH measurement of the tree. This could occur if the trunk cross-section at breast height was significantly non-circular. Using more than one core per tree could counter this possibility. Another possibility is that the site-specific variable used to account for contribution of bark and phloem to tree DBH proved to be a significant overestimation for that particular individual. Ideally, an individual measurement of bark and phloem would be incorporated into each extrapolation, eliminating that potential source of error. However, I found that the process of collecting cores from these trees often fragmented, damaged, or destroyed the bark and phloem layer of the core, making accurate measurement impossible. Whatever the case, this outcome clearly shows that the extrapolation method I used has definite limitations. Rozas (2003) found that tree age estimation methods including elements of cross-dating, growth rate models, and graphical ring extrapolation proved significantly more accurate than methods, such as the one used here, relying only on geometric center extrapolation and inner ring growth rates. Geometric-center and inner-ring methods were sufficient to estimate ages of *Fagus sylvatica* and *Quercus rober*, two European hardwood species, to within a range of 10% to 20% of accuracy (Rozas 2003). I used the simplest method because it was within the constraints of my experience and resources. Given my small sample size and the preliminary nature of this work, I elected to include my estimated age values in my analysis of the relationship between DBH and tree age. Given a larger sample size, I would have excluded them.

The relationship between DBH measurements and tree age proved to be significant (ANOVA $P < 0.001$). However, the determination coefficient ($R^2 = 0.581$) of the linear regression indicates that approximately 58.1% of variation between individuals can be explained by the DBH-age relationship, while the remainder is due to unknown variables and inherent randomness. Other variables that factor into the DBH-age relationship probably include local and site-wide exposure and aspect, local and site-wide soil properties, tree gender, and intra- and interspecific competition for light (Vasiliauskas and Aarssen 1992, Lawton and Cothran 2000). Another possibility is that the relationship between DBH and tree age is not linear; it may be better described by a logarithmic or power trendline. However, in the interest of simplicity, I decided to examine the relationship in terms of linear regression. The DBH-age linear relationship equation I found could provide the means to make rough estimates of *J. virginiana* age in montane cedar sites without collecting and analyzing increment cores. However, given the limited sample size upon which this regression is based as well as its determination coefficient, such estimates would be restricted in application to preliminary surveying necessarily followed by more thorough investigation.

Site mapping

Centroid latitude and longitude and boundary polygon perimeter and area measurements for each site are included in Table 3. The Pinnacle was the largest site, with an area of 5.582 ha, and High Knob was the smallest site, with an area of 1.193 ha. Figs. 4a, 4b, and 4c are maps consisting of true color aerial photographs overlaid with boundary outlines and sampled tree

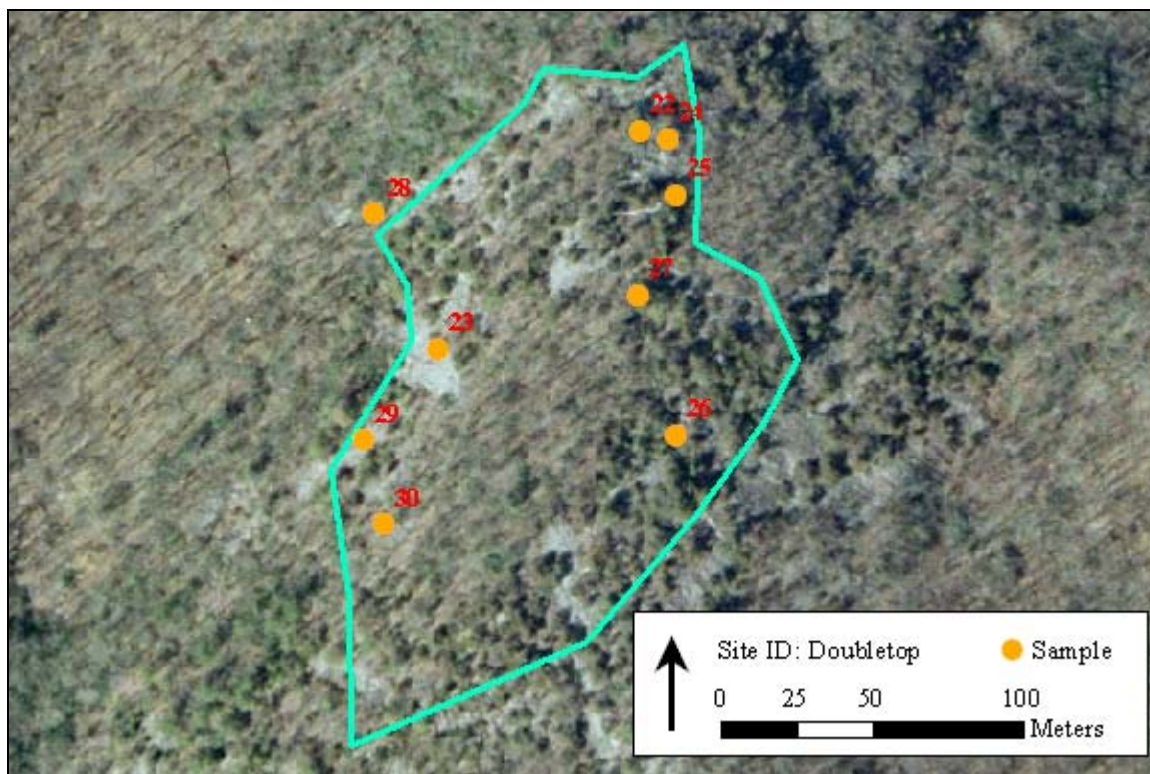


FIG. 4C. Doubletop: site boundary and sampled trees. Map numbers correspond to sample numbers.

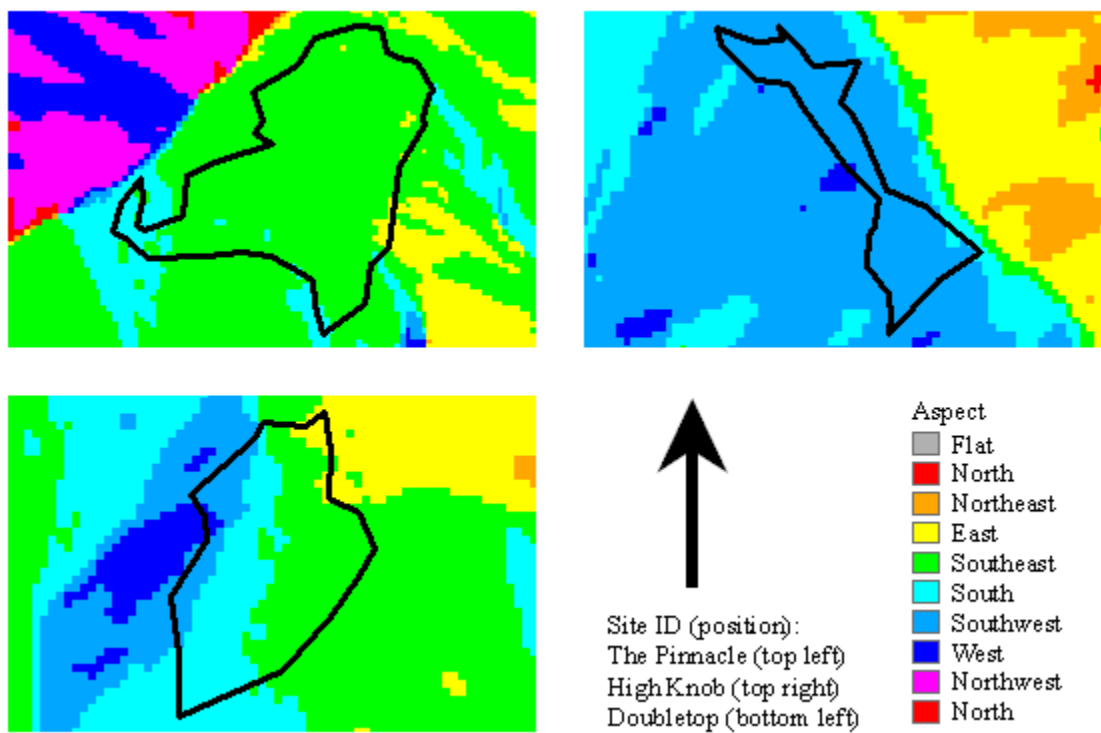


FIG. 5A. Aspect of each site with boundary overlays.

points. The Pinnacle and Doubletop maps show inclusion of pockets of hardwood forest within the site boundaries. The Pinnacle map also shows an unintentional clumping of sampled specimens. The points are labeled according to core number. Fig. 5a presents an aspect map of each site overlain with site boundaries. The Pinnacle has a primarily southeastern aspect, High Knob has a primarily southwestern aspect, and Doubletop has a mix of southwestern, southern, and southeastern aspects. Fig. 5b is a map of slope overlain with site boundaries. The Pinnacle and High Knob were dominated by slopes of 32° or greater while Doubletop included both a section of gentle slope (0-23°) and a section of steeper slope (23° or greater). Fig. 5c is a map of soil type overlain with site boundaries. All three sites were dominated by Cleveland rock outcrop soils according to North Carolina soil survey data.

The aerial photography boundary maps created for each site proved to be fairly accurate in their border delineations with regard to the area sampled. Measurement of perimeter and area using ArcGIS provided a precise interpretation of site shape and extent. These maps confirm the restriction of the montane cedar glade sites to rock outcrop areas, with shape and extent determined by the location of bare rock. The aspect maps confirm the restriction of montane cedar glades to areas of southern, southwestern, and southeastern aspect. The slope maps confirm the restriction of montane cedar glades to areas of high slope, though much of the Doubletop site was situated on an area of significantly lower slope than that found at the Pinnacle and High Knob. And the soil maps confirm restriction of montane cedar glades to thin, rocky soils, in this case Cleveland rock outcrop soils. The aerial maps were also useful for checking the distribution of my sampling; collection at the High Knob and Doubletop sites was well-distributed relative to the unintentional clustering revealed by the Pinnacle map. On all aerial maps, additional areas of montane cedar glade are visible outside the site boundaries; these areas were not mapped due to my restriction of collection activities to the largest patches at each site. The Pinnacle and Doubletop maps reveal islands of hardwood forest within the sites. These patches occur on areas with relatively gentle slopes and pockets of deeper soil. A lack of hardwood saplings along their borders indicates that they are not colonizing the surrounding montane cedar glade matrix.

Problems and improvements

I have several reservations regarding my increment core data. The first is sample size; 30 data points would be more ideal for each site rather than as a total. Second, instead of attempting to estimate ages from incomplete cores, it would have been better to reattempt core collection on those trees. Age estimation would only be used if collection of a complete core proved difficult after repeated attempts. Third, the extrapolation method I used for age estimation may be overly simplified, is my own creation, and may not be considered valid by the standards of the dendrochronology community. It has not been tested against verified tree ages. Furthermore, if the method produced invalid results, they have skewed my test of the relationship between DBH and tree age. Fourth, I counted and recorded false rings on each core but elected not to perform any analysis of the data due to lack of confidence in the counts. I did not use a set standard to determine whether intra-annual structures were sufficiently defined to be counted as false rings; because of this, my false ring counts are probably not consistent.

Possible expansion of this investigation lies in randomizing data collection, refining and expanding core analysis techniques, and collecting data on other variables possibly affecting *J. virginiana* ages and growth rates. Randomized data collection would enable investigation of population structure, allowing analysis of *J. virginiana* reproduction and population dynamics

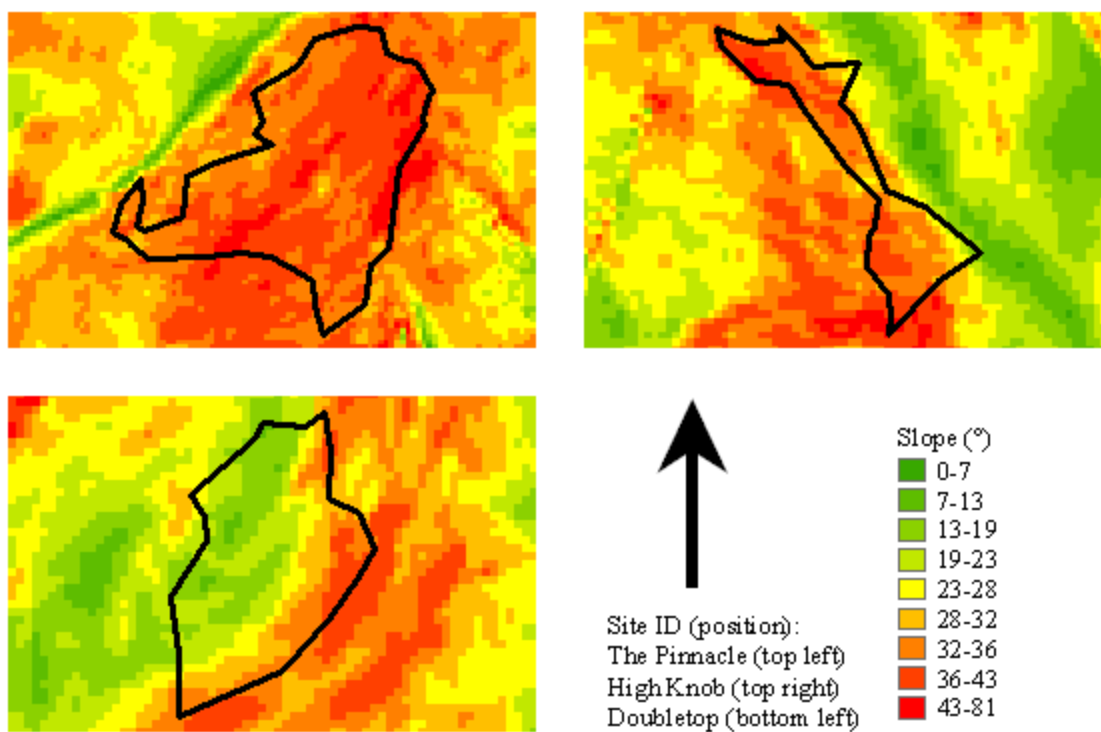


FIG. 5B. Slope of each site with boundary overlays.

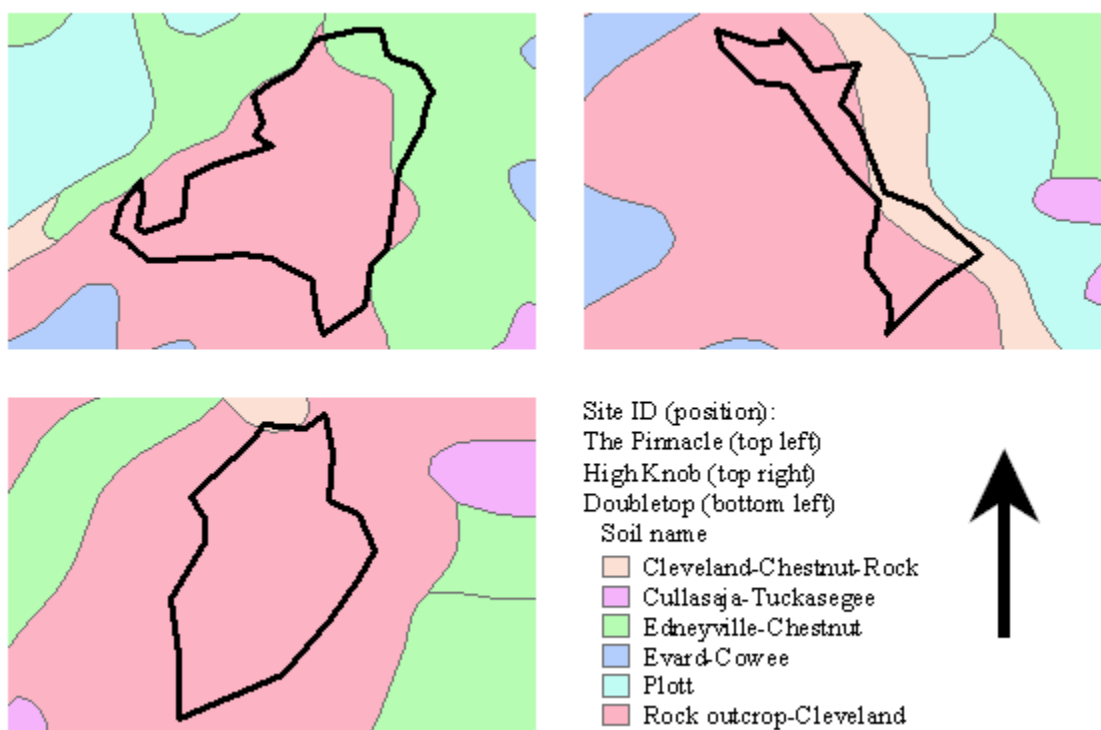


FIG. 5C. Soils of each site with boundary overlays.

similar to investigations performed by Vasiliauskas and Aarssen (1992), Small and Wentworth (1998), Lawton and Cothran (2000), and Quinn and Meiners (2004). I performed my core analysis without the benefit of previous experience or specialized equipment. With a proper dendrochronology lab, techniques such as cross-dating and individual increment measurement could be employed to yield age data of greater depth, breadth, and accuracy. Tree sex, distance between neighbors, and soil temperature, moisture, depth, and chemistry are a few of the variables that could be measured for each individual and included in future work (Vasiliauskas and Aarssen 1992, Small and Wentworth 1998, Lawton and Cothran 2000, Quinn and Meiners 2004).

Conclusion

The old ages and slow growth rates of *J. virginiana* on these sites warrant comparison of montane cedar glades to other old-age rock outcrop woodland communities around the world. Larson et al. (2000) performed an intercontinental study of ancient forests on cliffs which included sampling of *J. virginiana*, among other species. These communities are extremely stable, with stunted, slow-growing trees reaching ages in excess of 1000 years (Larson et al. 2000). Old age and slow growth rates were correlated with increasing verticality of growth substrate; trees growing directly on vertical cliff faces were the oldest and grew the slowest of all sampled specimens (Larson et al. 2000). Similarly, the oldest trees I sampled occurred on the steepest and most cliff-like site, the Pinnacle. Larson et al. (2000) also found that ancient cliff forests exhibited continuous rather than pulsed regeneration. A similar regeneration pattern is likely present in *J. virginiana* populations on montane cedar glades. Furthermore, those authors state that, due to their rocky nature and inaccessibility, ancient cliff forests serve as refuges from fire and economic exploitation. The rocky nature of the sites I studied and the fire-intolerance of *J. virginiana* suggest that montane cedar glades act similarly to ancient cliff forests as refuge communities. Because of their protected nature, such communities may act as centers of persistence and dispersal into the surrounding environment for species such as *J. virginiana* (Larson et al. 2000). If this “seed source” phenomenon also applies to montane cedar glades, it increases their conservation priority.

Whatever the course of future investigations, it is certain that our understanding of montane cedar glade communities will benefit greatly from further study. These communities harbor a unique flora including several rare and endemic species. They may also act as reproductive refuges and repositories of genetic diversity for *J. virginiana*. Montane cedar cliffs could be at risk of degradation or extirpation if altered temperature and precipitation patterns brought by climate change enable hardwood invasion or increase frequency or intensity of fire events, because both of these factors have the potential to degrade and destroy the community. However, given that these factors are probably excluded by topography as much as or more than by climate, such a scenario may be unlikely. Despite this, montane cedar glades could become the focus of future conservation efforts which would be aided by further investigation of these communities.

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APPENDIX

Full *J. virginiana* increment core data from the Pinnacle, High Knob, and Doubletop montane cedar glade sites. True ring counts denote ages of complete cores. For estimated ages of incomplete cores, see Table 2 in the main body of the paper.

APPENDIX

Summary data for cores taken from 30 *Juniperus virginiana* trees at three montane cedar glades in Macon County, North Carolina. DBH = diameter at breast height, C = circumference.

Core #	Site ID	DBH (cm)	C (m)	Core length (cm)	True rings	False rings	Incomplete
1	Pinnacle	40.6	1.3	12.9	102	9	*
2	Pinnacle	38.4	1.2	17	170	8	
3	Pinnacle	19.3	0.6	7.2	91	10	
4	Pinnacle	16.0	0.5	7	67	10	
5	Pinnacle	26.4	0.8	8.8	134	16	*
6	Pinnacle	19.8	0.6	7.3	58	7	*
7	Pinnacle	20.1	0.6	7.9	51	7	
8	Pinnacle	28.4	0.9	9.6	115	10	*
9	Pinnacle	15.5	0.5	5.8	104	5	
10	Pinnacle	22.1	0.7	10.3	157	22	
11	High Knob	16.5	0.5	7.1	54	13	
12	High Knob	28.7	0.9	10	103	7	
13	High Knob	12.7	0.4	5.5	43	6	
14	High Knob	6.9	0.2	3.4	17	3	
15	High Knob	15.2	0.5	6.6	45	6	
16	High Knob	24.4	0.8	11.7	69	12	
17	High Knob	15.2	0.5	6.4	36	6	*
18	High Knob	15.0	0.5	7.7	28	6	
19	High Knob	21.6	0.7	9.4	53	12	
20	High Knob	16.8	0.5	8.2	81	5	
21	High Knob	11.4	0.4	5.6	26	4	
22	Doubletop	16.3	0.5	7.6	110	4	
23	Doubletop	11.9	0.4	3.7	58	6	
24	Doubletop	11.4	0.4	5.7	49	7	
25	Doubletop	21.3	0.7	9.6	73	9	
26	Doubletop	13.5	0.4	6.4	66	6	
27	Doubletop	28.2	0.9	10.6	78	15	
28	Doubletop	26.4	0.8	12.9	89	8	*
29	Doubletop	17.3	0.5	6.7	57	11	
30	Doubletop	13.2	0.4	6.1	62	7	

THE UNIVERSITY OF NORTH CAROLINA
INSTITUTE FOR THE ENVIRONMENT CAPSTONE RESEARCH PROJECT
CRUSHED STONE DEPOSITION:
AN ANALYSIS OF SEDIMENTATION AND STREAM HEALTH

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Abstract. Sedimentation is the deposition of particulate matter in a body of water via erosion and water transport. It contributes substantially to pollution problems in many bodies of water including streams. Aquatic animals living in these impacted streams, particularly salamanders and aquatic invertebrates, are negatively affected by sedimentation through disruption of habitat. In this paper, the sedimentation problem of Mill Creek (Highlands, NC) was examined. The problem has increased over the last several years due to expansion and maintenance of an unpaved road located in the Mill Creek watershed. Erosion resulting from storm events has washed crushed stone from the roadbed of Sunset Rock Road into the creek. We photographed and mapped the road, emphasizing areas of significant deposition and locations of remediation features constructed by the Town of Highlands. We also analyzed four separate creek reaches exhibiting varying degrees of sedimentation. The reaches were photographed, mapped, and surveyed to determine slope and bed sediment characteristics. Finally, each reach was surveyed for aquatic macroinvertebrates. We determined that the impacted stream reaches have an altered streambed composition with more uniform particle sizes compared to the unimpacted reaches, creating a more compacted bed that offers a poorer habitat for aquatic animals. We evaluated the water and sediment control structures and practices implemented by the Town of Highlands and provided specific recommendations that will aid in alleviation of the erosion problem and restore healthy stream conditions.

Key words: crushed stone; erosion; gravel; macroinvertebrates; pavement; pebble; road management; sedimentation; stream remediation.

INTRODUCTION

The UNC Institute for the Environment's Fall 2008 Highlands Field Site program has chosen as its group capstone project an issue which adversely affects the Highlands Biological Station (HBS). Mill Creek, a stream running through the grounds of HBS, was once a prime spot for salamanders, but has become almost uninhabitable for them. The problem: sedimentation. Our task: to assess the situation in as many ways as possible and determine what steps need to be taken to address this problem.

Sedimentation has created an unsightly mess in the Botanical Garden at HBS and rendered the area unusable for salamander programs at the Station because the habitat no longer

supports for salamander populations (Appendix A). Salamanders, which typically comprise a large proportion of aquatic animal biomass in southern Appalachian streams, are especially sensitive to anthropogenic environmental disturbances, including stream sedimentation (Brannon and Purvis 2008).

Sedimentation is a process in which large amounts of particles are transported by and deposited in waterbodies. The most significant pollutant in streams, both in North Carolina and the nation as a whole, is sediment (U.S. Environmental Protection Agency 2002); many types of aquatic life are negatively affected by the increased deposition of small particles which often accompanies human activities like construction, road-building, agriculture, and silviculture. Many aquatic organisms have very specific requirements for streambed composition. A high proportion of the streambed of mountain streams should be composed of gravel, cobble, and boulder that are not deeply embedded into the substrate; this configuration provides sheltered interstitial spaces between the rocks. Salamanders require these spaces to live, since they spend much of the time hiding and foraging there, and use them for egg laying (Lowe et al. 2004). In addition, the insects and other aquatic macroinvertebrates require heterogeneous, uncompacted bed material to thrive. This is largely because heterogeneous substrate permits the accumulation of organic input such as decomposing leaves, supporting the macroinvertebrate food web. With sedimentation, the bed becomes compacted such that larger rocks in the bed can no longer provide interstitial spaces for salamanders and other animals due to the embedded matrix of fine particles. Without the necessary habitat requirements, salamanders and aquatic invertebrates are highly compromised or unable to survive in sedimented stream reaches (Welsh and Olivier 1998).

In addition to its effect on aquatic organisms, sedimentation also adversely affects the physical behavior of the stream system. As the channel is filled with particulate matter, stream flow is often diverted or attenuated. In this case, a small waterfall on Mill Creek on the HBS property has been choked off by sediment buildup above the waterfall and the flow has been diverted around it. Not only does this reduce the aesthetic value of the stream, it also further disrupts habitat for aquatic plants and animals.

Erosion will occur when moving water picks up soil particles and carries them downhill. Crushed stone roads on steep slopes are especially susceptible to erosion because high-velocity water is capable of transporting a greater size and volume of material. Areas where flowing water leaves particulate matter behind are known as depositional environments; typically these have lower slopes and velocities, allowing suspended particles to settle, and larger particles to decelerate and come to rest on the stream bed. In order to avert the worst effects of erosion, many road building and maintenance techniques have been developed to either prevent harmful runoff or divert it elsewhere.

Since 2006, sedimentation has steadily worsened in Mill Creek, which runs from the Sunset Rock area through a parcel of private land and down through the grounds of the Highlands Biological Station into Lindenwood Lake. The stream was previously used in educational programs about local fauna such as salamanders, but is now so choked with crushed stone that aquatic animal populations have declined steeply. This is due to the recent widening and resurfacing of Sunset Rock Road, an unpaved road which leads from Horse Cove Road up to Sunset Rock. The road, which travels up a fairly steep slope, is paved with crushed stone, some of which is washed downhill with each large storm event and deposited in certain areas of the creek and in ephemeral or intermittent tributaries (Appendix B).

Sunset Rock Road has existed for decades, but was only recently improved and widened. Large quantities of crushed stone are brought up regularly to replace material lost to weather-driven erosion. While this maintenance is necessary to keep the road open for vehicular traffic, constant input of material has been detrimental to Mill Creek's health. Erosion and sediment control measures are necessary to alleviate this problem. While certain techniques have already been implemented, more are required to restore and maintain the quality of the aquatic habitat over the long term.

MATERIALS AND METHODS

GIS Mapping

A Trimble® GeoXM™ handheld GPS unit and a range pole-mounted antenna were used to collect points along Sunset Rock Road. Before the Town began construction of water and sediment control structures, sites with major erosion and crushed stone deposits from runoff from the road were recorded. After construction, points were collected at each new sediment trap or wing ditch. Using ArcGIS® 9.3 (ESRI 2008), these points were connected in a new shapefile to map the road, including eroded sections and new construction. Points were named by their distance (ft) from the top of Sunset Rock Road and called "stations."

In order to illustrate and quantify the crushed stone contributing most significantly to the sediment problem at the Highlands Biological Station, we created maps and measured the perimeter and surface area of the crushed stone deposits using the Trimble® GeoXM™ handheld GPS unit with range pole and ArcGIS software. Three impacted areas between Sunset Rock and HBS were mapped. Our maps include contour data obtained from Macon County, road data obtained from the North Carolina Department of Transportation, and stream data obtained from the North Carolina Department of Environment and Natural Resources.

Stream Reaches Selected for Study

Stream reaches at four locations on Mill Creek were defined for this study. The reaches were chosen based on location relative to the crushed stone sources and deposits, surrounding topography, and stream condition. In stream order, Reach 1 is farthest upstream and well above the crushed stone deposits. The steep topography at Reach 1 creates a riffle, a stream feature characterized by a constant current and broken water surface. Reach 2 is an unimpacted run that is located immediately upstream of a large crushed stone deposit that enters Mill Creek below Sunset Rock Road. While runs have constant currents, they are distinguished from riffles by smooth, clear surfaces and lower slopes. Reach 3 is on the grounds of the HBS, just below the waterfall located immediately downstream of Horse Cove Road. This riffle is the impacted site of interest. It is located along a commonly used nature trail and was formerly used for the Nature Center's salamander programs. Reach 4 is the farthest downstream run and has not yet been directly impacted.

Pebble Count

At each reach, the Wolman pebble count procedure (Wolman 1954) was performed to determine sediment particle size distribution. A length of each reach was selected and divided

into transects for sampling. Reach 1 had a length of 5 meters with individual transects every 0.5 meters. Reaches 2 and 4 had lengths of 10 meters with individual transects every meter. Reach 3 had a length of 13.5 meters with individual transects every 1.5 meters. At each transect, ten particles were sampled. Particles were randomly selected by averting the eyes and picking up the first particle touched by the tip of the index finger.

The intermediate axis (Fig. 1) of each particle was measured in millimeters with a ruler and recorded. This process was repeated until a total of 100 measurements were collected at each reach. Size class distribution graphs and D_{50} and D_{84} measurements, which represent the 50th and 84th percentile of size class distribution, were created using the Reference Reach Spreadsheet (Mecklenburg and Ward 2004), available through the Ohio Department of Natural Resources. The D_{50} and D_{84} of each reach were plotted on the graphs to illustrate size class distributions.

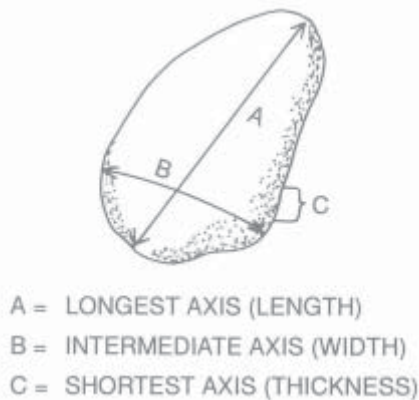


FIG. 1. Schematic of particle measurement from Stream Restoration Handbook (Doll et al. 2003).

Pavement-Subpavement Analysis

Pavement-subpavement analysis was conducted at each of the four reaches as described in the Stream Restoration Handbook (Doll et al. 2003). A bottomless five-gallon bucket was placed in the stream in a fairly fast-flowing riffle area and slightly embedded into the sediment. The top veneer of rock (pavement) was removed, and the two largest stones were measured along their intermediate axes. The pavement layer was then wet-sieved through a series of sieves with openings measuring 63, 45, 31.5, 16, 12.5, 6.3, and 4.75 mm in size. The contents of each sieve were bagged separately. The subpavement layer within the bucket was excavated to a depth twice the length of the intermediate axis of the largest piece of the pavement layer, unless bedrock or a boulder was struck before reaching that depth. This material was also wet-sieved through the same sieves and bagged. All samples were allowed to dry and then weighed by size class. The percentage by weight of each size class relative to all material in its layer were calculated.

Slope Survey

We used a tripod-mounted transit level, a survey rod, and a measuring tape to survey the longitudinal profile of the streambed at each of the four reaches, recording elevation differences at distance increments. Slope values were calculated as a percentage for each profile using the formula $\text{slope} = [(\text{total rise})/(\text{total run})] \times 100$.

Aquatic Macroinvertebrates Survey

Leaf packs were created by putting fifty red maple leaves into a mesh onion bag and tying it shut. Five leaf packs were submerged into the channel at each reach and left there from November 5 until December 3. The leaf packs were removed from the stream and the leaves were washed thoroughly. The organisms found were counted, identified, and classified taxonomically. Categories included the insect taxa caddisflies (order Trichoptera), stoneflies (order Plecoptera) and mayflies (order Ephemeroptera). Other groups included dragonflies (order Odonata), black fly larvae (order Diptera: Simuliidae), and unidentified worms. Salamanders were tallied as well.

RESULTS

Sunset Rock Road

Significant channels of erosion were observed along Sunset Rock Road during an initial reconnaissance of road conditions in September 2008. Material from these erosion channels was deposited by the natural flow of water in the Mill Creek streambed and ephemeral channels in the surrounding forest. At that time, there were very few structures implemented to slow the velocity of water running over the road. Because slowing the speed of flowing water will decrease its ability to carry material such as crushed stone, we suggested sites for the Town of Highlands to install wing ditches and sediment traps. Initial construction of sediment control features such as sediment traps and wing ditches was carried out in October 2008 (Fig. 2).

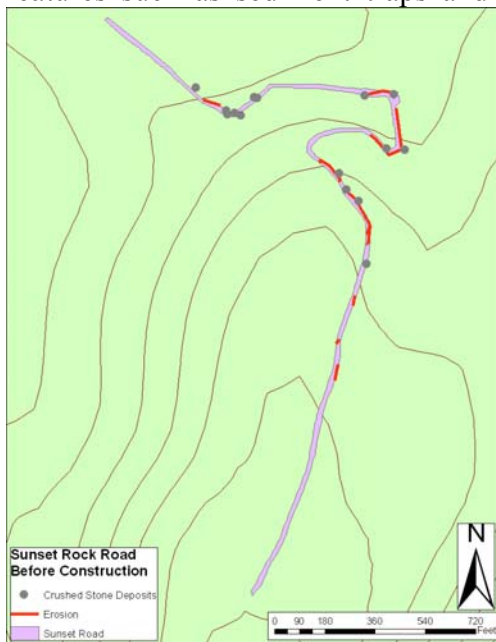


FIG. 2. Sunset Rock Road before Town of Highlands improvements.

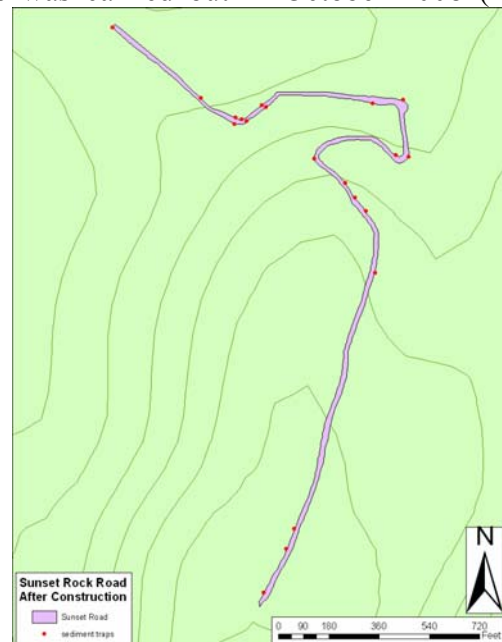


FIG. 3. Sunset Rock Road after Town of Highlands improvements.

The newly constructed sediment traps by the Town along Sunset Rock Road were generally located in areas identified in Fig. 2 where there was extensive erosion of the roadbed (Fig. 3).

Maps of Crushed Stone Deposits

The source of crushed stone deposited on HBS property is road failure at station 2395 on Sunset Rock Road (Appendix C). From this station, crushed stone is being transported by an ephemeral tributary across private property (Playmore) where it enters Mill Creek. Crushed stone is then moved downstream under Horse Cove Road and onto the HBS property with each storm event. Three major crushed stone deposits were mapped and represent the majority of stone that has been transported from the road (Fig. 4, Table 1). The upper deposit, a dry deposit along an ephemeral channel within the forested area, is the smallest of the three with an area of 131.8 m². The middle deposit is the largest, with an area of 293.3 m². It includes both a dry portion along the ephemeral channel and a wet portion within the streambed. The lower deposit is situated within Highlands Biological Station property and is a wet deposit confined entirely to the streambed. Total surface area of the three crushed stone deposits is 674.4 m².

TABLE 1. Crushed stone deposit measurements.

Deposit ID	Perimeter (m)	Area (m ²)
Upper	76.3	131.8
Middle	116.2	293.3
Lower	117.3	251.3
Total	-	676.4

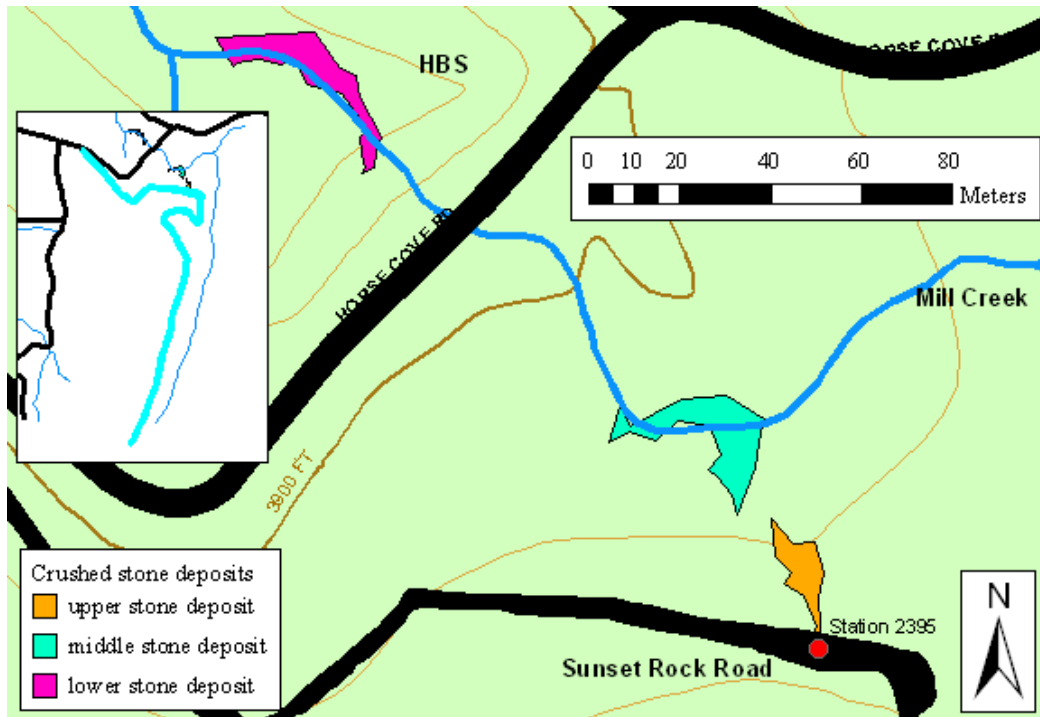


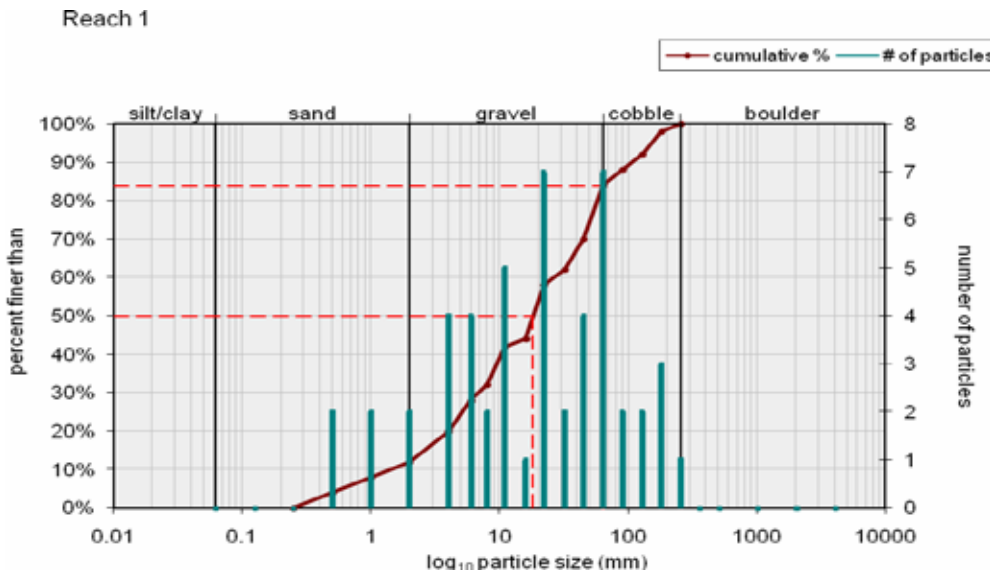
FIG. 4. Crushed stone deposits relative to Sunset Rock Road.

Pebble Count

Significant variation in the pebble size class distribution was found between each of the four stream reaches. Reach 1 was mainly comprised of gravel and cobble, Reach 2 was sand and silt/clay, Reach 3 was gravel, and Reach 4 was sand, gravel, and cobble. Reach 4 was the only reach to have boulder and bedrock. Table 2 shows information for each reach including the particle size that falls on each percentile and the percentage of each class type. Fig. 5 shows the total number of particles by size and the cumulative percent total for each reach.

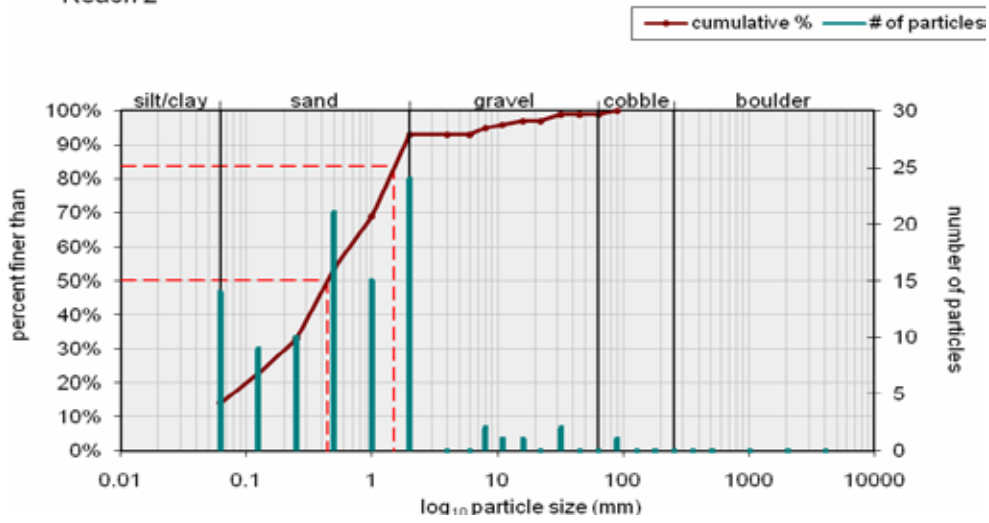
TABLE 2. Size and type distribution for pebble counts.

	Reach 1	Reach 2	Reach 3	Reach 4
Cum. (%)				
D16	2.8	0.072	6.5	1.5
D35	8.8	0.27	11	13
D50	18	0.44	16	25
D65	36	0.83	20	41
D84	64	1.5	30	90
D95	150	8	64	360
Type (%)				
Silt/Clay	0%	14%	0%	1%
Sand	12%	79%	5%	20%
Gravel	72%	6%	90%	55%
Cobble	16%	1%	5%	19%
Boulder	0%	0%	0%	5%



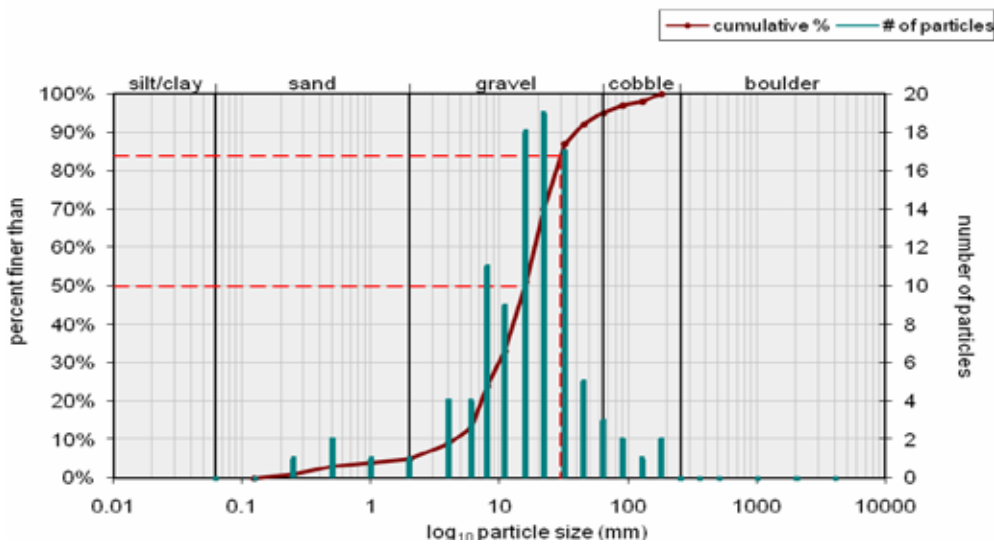
5A.

Reach 2

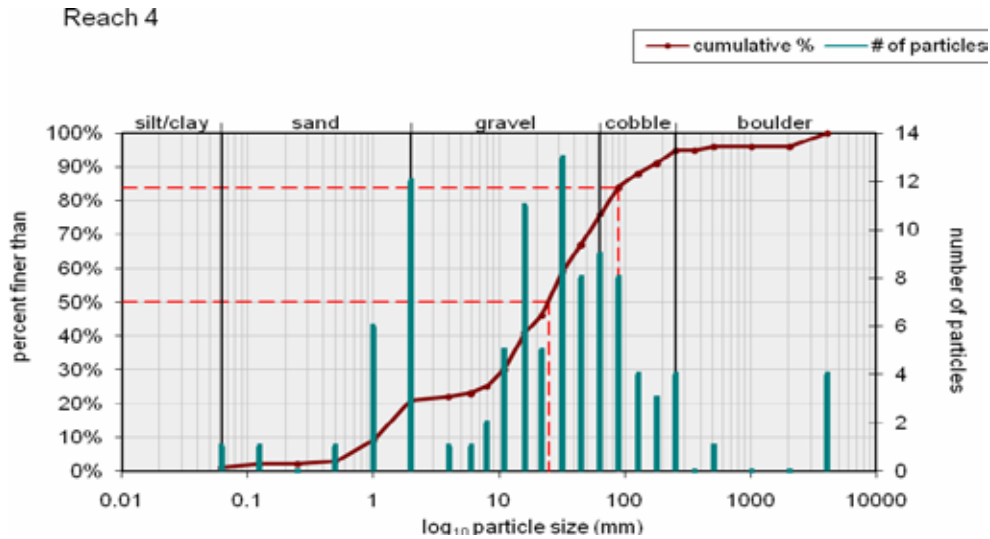


5B

Reach 3



5C

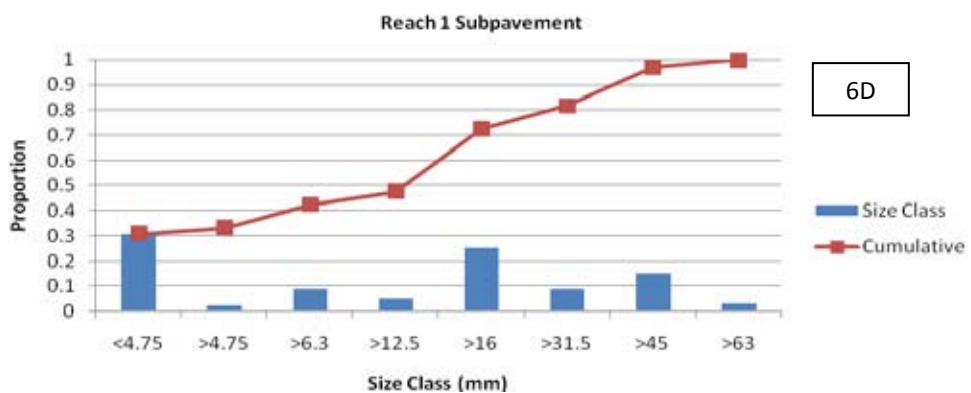
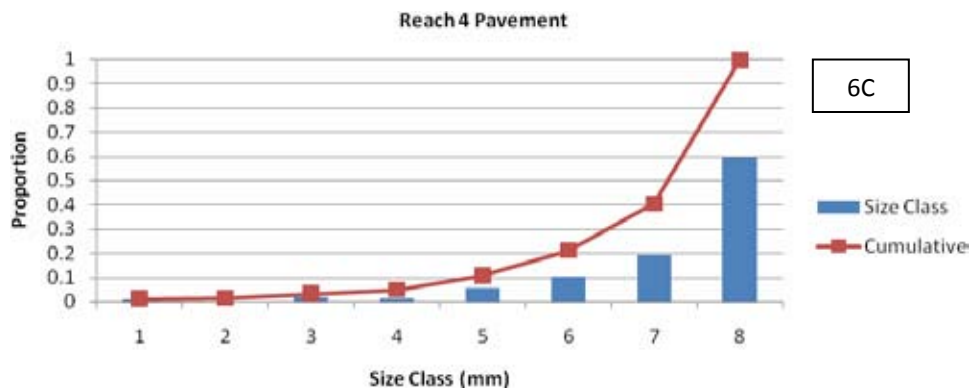
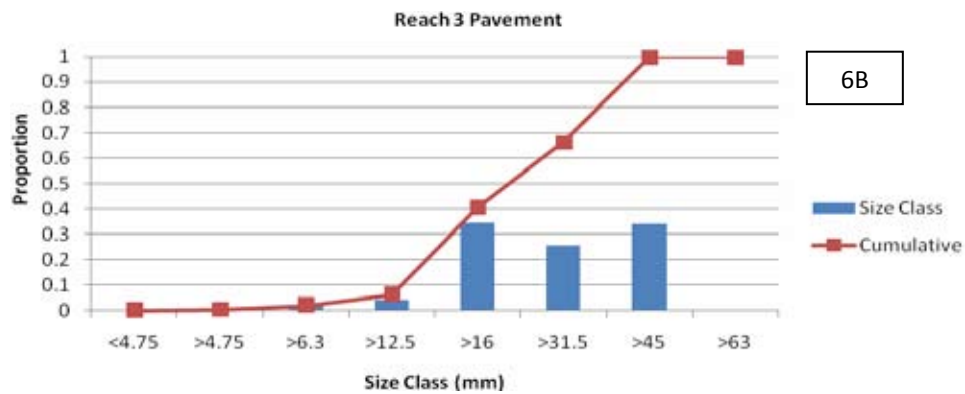
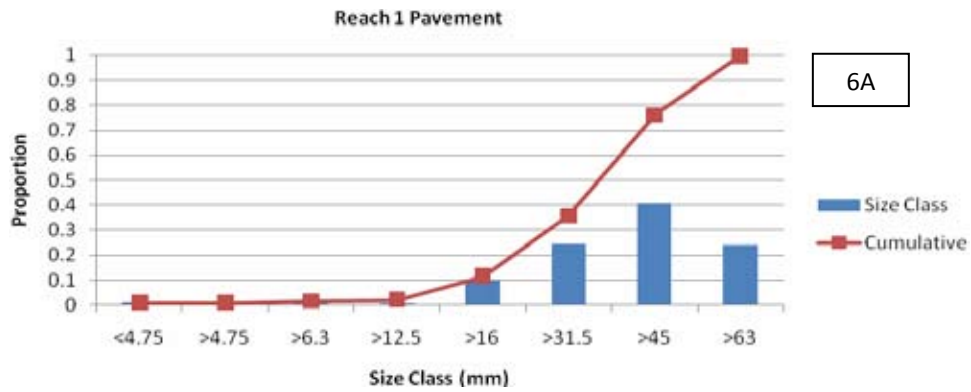


5D

FIG. 5A-D. Sediment distribution curves for Reaches 1-4.

Pavement/Subpavement Analysis

A noticeable difference in size class of streambed sediment was observed between impacted and unimpacted reaches. At Reach 1, the cumulative proportion axis is fairly level until size class > 16 mm, where a steep rise in the slope of the axis occurs. This signals an abundance of pavement rocks larger than 16 mm at Reach 1. Approximately 98% of pavement collected at Reach 1 had an intermediate axis larger than 16 mm, with the largest proportion of pavement recorded (40%) between 45-63 mm (Fig. 6A). Subpavement at Reach 1 had a less drastic increase in the slope of its cumulative axis, showing a more even allocation between size classes. The largest proportion of subpavement at Reach 1 (31%) was in size class < 4.75 mm (Fig. 6B). At Reach 2, there were no distinguishing characteristics between pavement and subpavement and analysis yielded no pebbles larger than size class 4.75 mm. At Reach 3, pavement also had a steep rise in the slope of its cumulative axis after size class > 16 mm. Approximately 93% of pavement collected at Reach 3 had an intermediate axis larger than 16 mm, with the largest proportion of pavement recorded (34%) between 16-31.5 mm (Fig. 6C). Subpavement at Reach 3 was more evenly distributed by class size, compared to Reach 3 pavement particles. The largest proportion of subpavement at Reach 3 was 24% in size class > 45 mm (Fig. 6D). Neither pavement nor subpavement classes at Reach 3 had any recorded rocks in size class > 63 mm. At Reach 4, 95% of pavement collected had an intermediate axis larger than 16 mm, with the largest proportion recorded (59%) being > 63 mm (Fig. 6E). The largest proportion of subpavement at Reach 4 was 30% in size class < 4.75 mm (Fig. 6F).



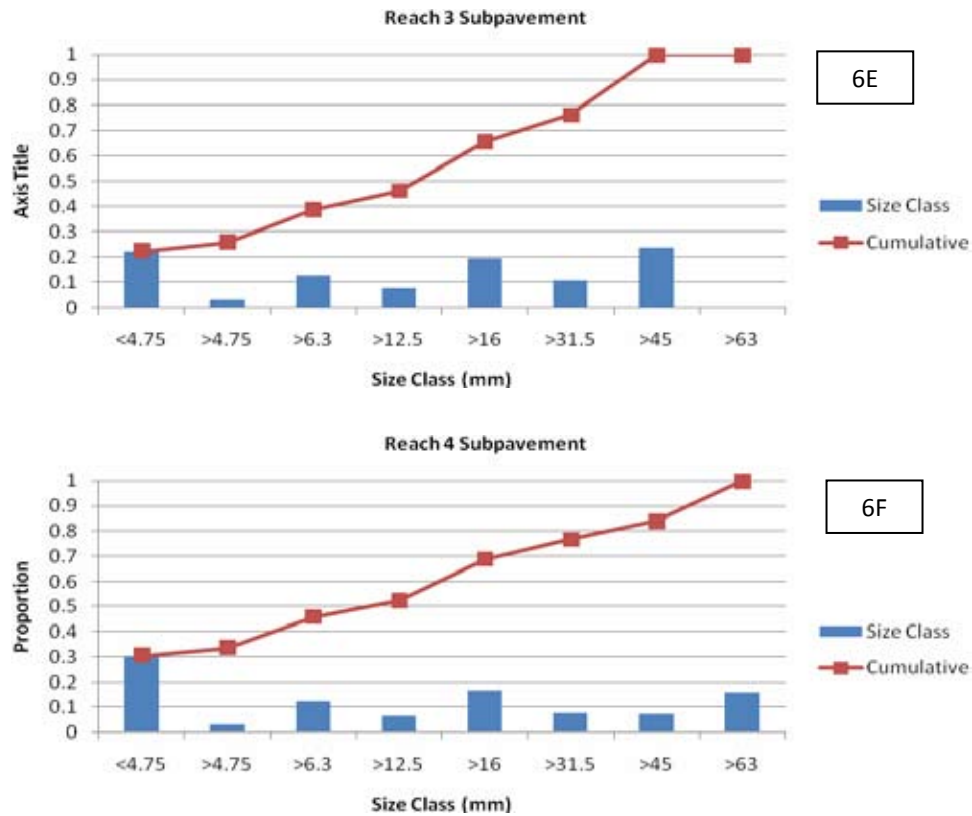


FIG. 6. Size class distributions, displayed both cumulatively and as individual classes, for pavement–subpavement analyses for Reaches 1, 3, and 4. Pavement: A, B, and C respectively; Subpavement: D, E, and F respectively.

Slope

According to the methods established for the slope survey outlined in the materials and methods section of this paper, slopes of Reaches 1–4 varied from 1.7% to 4.0% (Table 3, Fig. 7). In general, as distance from the headwaters increased and the valley in which the channel is located widened, slope tended to decrease. Riffle areas tended to have steeper slopes than runs.

TABLE 3. Slope percentage values.

Reach #	Slope
1	3.5%
2	1.7%
3	4.0%
4	2.6%

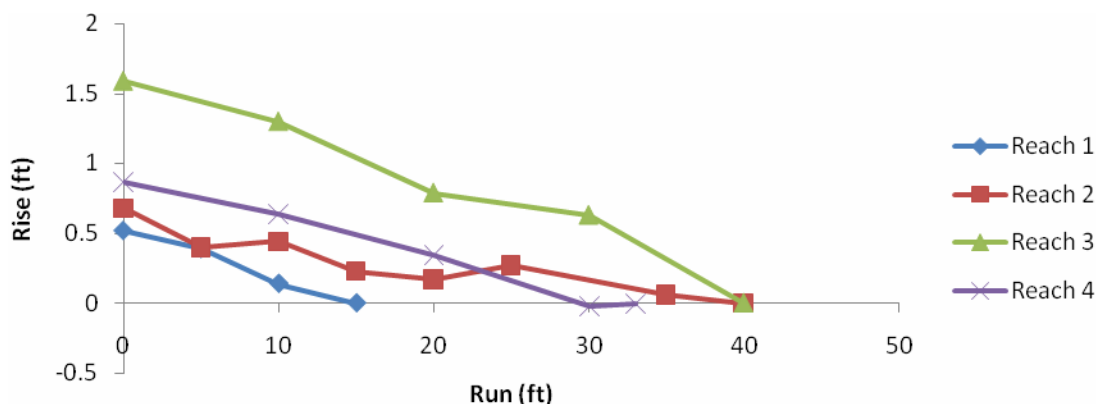


FIG. 7. Longitudinal profiles of the four reaches.

Aquatic Macroinvertebrate Survey

We found and identified a diversity of aquatic macroinvertebrates. Table 4 displays the diversity found in each reach. The most abundant taxa found were Trichoptera, Plecoptera, and Ephemeroptera. The abundance of each of the three groups in Reaches 1 through 4 is shown in Fig. 8. Our findings indicate that trichopterans were the most clearly negatively affected by sedimentation, with abundance depression occurring at Reaches 2 and 3. Abundances of plecopterans and ephemeropterans appeared to be affected by factors other than sedimentation. Abundances of plecopterans experienced a steady increase from Reach 1 to Reach 4. Ephemeropterans experienced a sharp decrease from Reach 1 to Reach 2 and 3, but did not significantly increase in number at Reach 4.

Fig. 9 shows that the total abundance of macroinvertebrates was greater in Reaches 1 and 4 than in Reaches 2 and 3. Reaches 1 and 4 had abundance values of 210 and 355, respectively, and Reaches 2 and 3 had abundances of 136 and 155.

TABLE 4. Aquatic macroinvertebrate survey results by taxon.

	Reach 1	Reach 2	Reach 3	Reach 4
Caddisflies (Trichoptera)	99	42	18	60
Stoneflies (Plecoptera)	17	64	131	283
Mayflies (Ephemeroptera)	87	10	2	5
Dragonflies (Odonata)	2	0	0	0
Black fly larvae (Diptera)	1	8	0	0
Other larvae	1	7	4	5
Worms	3	5	0	2
Total Macroinvertebrates	210	136	155	355
Salamanders	3	10	7	9

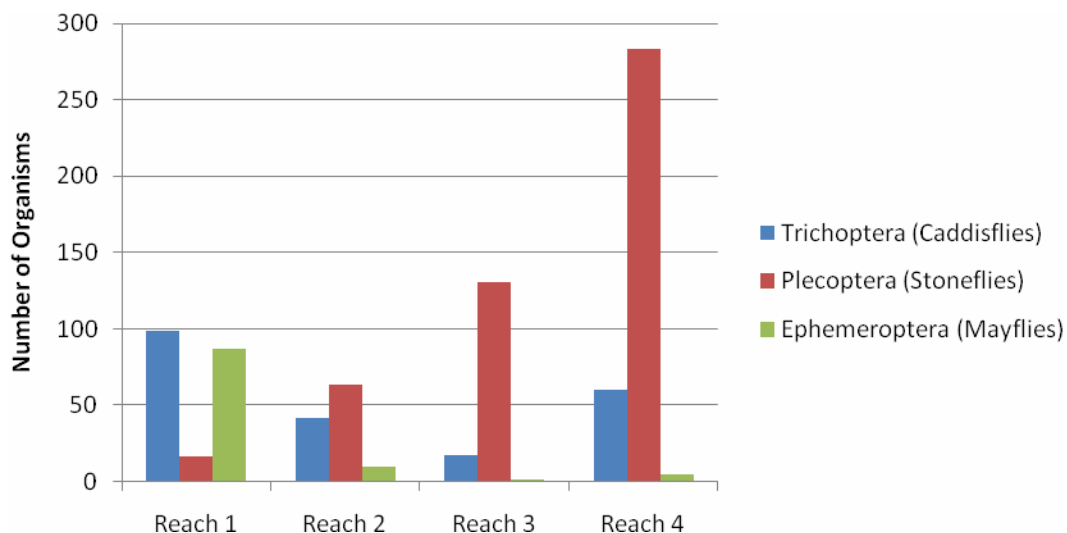


FIG. 8. Abundance values for three of the most common insect taxa at all four Reaches.

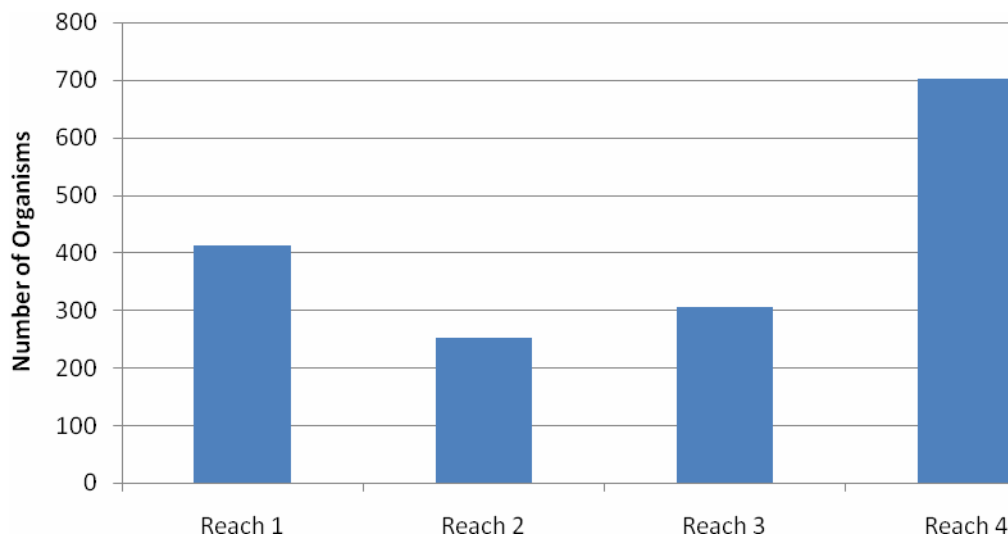


FIG. 9. Total macroinvertebrate abundance at all four Reaches.

DISCUSSION

Our results indicate that sedimentation is having a major impact on Mill Creek, and that the effect is primarily due to the deposition of roadbed material transported from Sunset Rock Road. Both the pebble count and the pavement/subpavement analysis support the claim that crushed stone deposition and subsequent compaction of sediment from Sunset Rock Road is making Mill Creek less habitable for aquatic organisms by altering streambed structure. While subpavement compositions did not differ substantially between sites, the composition of the pavement layer at Reaches 2 and 3 was more skewed toward smaller size classes than at Reaches 1 and 4. This is shown by the D_{50} and D_{84} values from the pebble count as well as the size class distribution from the pavement/subpavement analysis (Table 2, Figs. 5 and 6). Small size class material ($<4.75\text{mm}$) had naturally accumulated at Reach 2 due to its low slope (Table 3); it was located above the impacted area. Despite the steeper slope at Reach 3, accumulation of particles

in the >16mm class was observed there due to its location directly below the upper and middle crushed stone deposits.

Diversity and abundance of aquatic macroinvertebrates, particularly the three insect orders Ephemeroptera, Plecoptera and Trichoptera (collectively known as EPT), are frequently used as measures of stream health (Barbour et al. 1999). Providing additional support to the pavement analysis results, the results of the simplified macroinvertebrate survey of Reaches 1-4 suggest that sedimentation at Reaches 2 and 3 had a negative effect on overall macroinvertebrate abundance by degrading and eliminating interstitial space habitat. Reach 2 was naturally sandy, while small sediment particles from the road filled the interstitial spaces of the larger, native stream sediment in Reach 3. Trichopterans appear to be the most sensitive to habitat loss via sediment deposition. The trichopteran abundance data indicates that crushed stone sedimentation has negatively impacted the aquatic community of Mill Creek, but a more thorough EPT survey would provide more detailed data on sedimentation impact. In addition to leaf packs, sampling protocols that employ a variety of collection techniques using equipment such as kick nets and dip nets would ensure a wider sampling of the macroinvertebrate population (Barbour et al. 1999).

The source of the sediment input into Mill Creek has been clearly documented at Sunset Rock Road. Our photographs and maps show that erosion has taken place, moving crushed stone downhill and into the streambed. Photography shows that sediment deposition within Mill Creek on Highlands Biological Station property became a problem starting in 2006, corresponding with when the road was widened and resurfaced. The maps can be used to precisely locate the worst erosion sites along Sunset Rock Road, as well as to quantitatively assess the extent of the erosion as well as the areas of the crushed stone deposits. Quantifying the issue in this way helps to determine how to allocate resources to the remediation effort.

The Town of Highlands Street Department has implemented water and sediment control structures consisting of wing ditches, sediment traps, and water bars on Sunset Rock Road. These structures are intended to divert water at regular intervals, particularly upslope of the primary deposition site, in order to prevent a buildup of velocity and volume capable of transporting crushed stone downstream. In the future, we recommend that crushed stone be physically removed from stream reaches on Highlands Biological Station property. In addition, a sediment trap should be constructed above HBS at Horse Cove Road to prevent the extensive crushed stone deposits above the road from being deposited on the HBS property. In conclusion, the remediation features implemented by the Town of Highlands are an important first step in addressing the significant deposition problem off of Sunset Rock Road. These remediation features will be most effective in conjunction with routine maintenance. Appendix C contains a detailed evaluation of each remediation feature including recommendations for potential improvements and suggestions for a routine maintenance plan.

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APPENDIX A

Photos of impact due to crushed stone erosion, 2004 to 2008



Mill Creek at the Highlands Biological Station (2006).



Mill Creek at the Highlands Biological Station (2008).



Mill Creek at the Highlands Biological Station (2006).



Mill Creek at the Highlands Biological Station (2008).



Mill Creek waterfall at the Highlands Biological Station (2004).



Mill Creek waterfall at the Highlands Biological Station (2008).

APPENDIX B

Photos of crushed stone impact along and below Sunset Rock Road.



Mill Creek where it meets the crushed stone deposit directly below Sunset Rock Road at station 2395.



An erosional channel beside Sunset Rock Road at station 2130 before implementation of water and sediment control practices.



A closer look at the erosional channel at station 2130.



Station 2395 before implementation of water and sediment control structures.

APPENDIX C

Water and sediment control structures, including sediment traps, wing ditches, and culverts were installed and/or maintained along the reach of Sunset Rock Road. Construction was accomplished using a tracked excavator and new structures were lined with the same crushed stone from the road, seeded and topped with straw mulch. The length of Sunset Rock Road from Ravenel Memorial Rock at the top to the stop sign at the base of the road is 3,355 ft. Throughout, the road is unpaved and topped with crushed stone. Station numbers represent the distance in feet from Ravenel Memorial Rock. Photographs and descriptions of the individual practices at each station are as follows:



Station 145

Sediment trap at station 145 appears reasonably sized for the amount of deposition that can be expected at this elevation and slope.



Station 315

Sediment trap at station 315 is located in an area where storm water is conveyed by sheet flow along the surface of the roadway and therefore this trap may not provide much remediation.



Station 390

Sediment trap at station 390 is located, similar to the previous trap, in an area where waters appears in sheet flow with little discrete conveyance of stormwater.



Station 1335

Sediment trap at station 1335 is placed just up-slope of an area of discrete conveyance and therefore has the potential to intercept some discharge and sediment transport before it reaches said area of discrete conveyance.



Station 1575

Sediment trap at station 1575 appears well placed to intercept significant discharge and sediment transport. However, after the first rain event since its construction (a small rain event the weekend of November 14-16), this trap has begun to allow sediment to pass through the system and be transported downslope. This structure may benefit from an expansion of width and depth as well as reinforcement with larger stone.



Station 1630

Sediment trap at station 1630 appears well placed and reasonably sized for the drainage area it serves. This structure may benefit from reinforcement with larger stone.



Station 1685

Sediment trap at station 1685 appears well placed, occurring before the grade of the road shifts to the other side in the curve. The wing ditch at the entrance to the sediment trap is partially blocked. Its functionality would likely be improved if the entrance was smoothed and leveled to promote discharge of stormwater into the structure.



Station 1800

There is currently no sediment control structure here. The slope of the road directly above this location has steepened and the location is just prior to the initiation of a sharp curve where there is evidence of significant discharge. Recommendations for this location include an angled culvert to divert water across the road from right to left (orient facing down slope/down road) with a sediment trap on the left where the culvert would discharge. An alternate suggestion is to regrade the road to slope toward the outside of the curve and then construct a sediment trap to capture the redirected flow.



Station 2060

Sediment trap at station 2060 would be more beneficial if a culvert or water bar was added to bring water across the road. Current conditions of the road grade appear to prevent proper functioning of this system since the trap does not appear to intercept flow.



Station 2130

Sediment trap at station 2130 appears well placed to intercept a significant amount of discharge and sediment as evidenced by significant deposition as a result of the first small rain event since construction. This structure would likely benefit from an expansion of width and depth as well as reinforcement with larger stone. Its location in an area of significant drainage suggests that this trap should be part of a diligent, routine inspection and maintenance plan to avoid exceeding the capacity of the system.



Station 2330

Sediment trap at station 2330 appears well placed and the cross-road barrier is working to divert flow into the trap. In a storm event however, the barrier appears insufficient to prevent water from bypassing this station.



Station 2395

This station is located at the primary point of crushed stone transport into the stream below. The street department has created a barrier of crushed stone and some larger stone along the edge of the road here. Due to the construction of a number of sediment traps up-slope from this site, having no outlet to divert water from the road surface here may function well in interruption of sediment transport. This site should be inspected after the next big rain event to determine the success of the barrier and if the addition of a sediment trap or alternative remediation strategy would be beneficial.



Station 2761

Sediment trap at station 2761 intercepts the discharge of a culvert. Routine clearing of the culvert is suggested for maintaining the success of this trap.



Station 2830

This is the location of a culvert that intercepts discharge from the left side of the road. As recommended for all other culverts on the road, routine clearing of the culvert is necessary for the success of this feature. The sediment trap on the right side of the road may benefit from be lined with larger stone. This station would likely benefit from the construction of wing ditch on the right side of the road to intercept discharge from the right side of the road. The wing ditch could utilize the same sediment trap as the culvert discharge.



Station 2880

Sediment trap at station 2880 appears well placed to transport water from the ephemeral channel entering the road from the left and passing under the road in a culvert. Routine clearing of the culvert is necessary for the success of this feature. The trap may benefit from an expansion of width and depth as well as reinforcement with larger stone. A low spot at the rear of the trap was eroded to form a gap after the first rain event since construction.



Station 3010

Sediment trap at station 3010 appears to be intercepting discharge fairly well. The steep entry may lead discharge to erode and cut into the road. The trap may benefit from reinforcement with larger stone.

