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2010 Internship Research Reports

Highlands Biological Station

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INTRODUCTION

The mountains around us and the people they have inspired have served as a sort of touchstone for us this semester. There is perhaps no better place than Highlands to do so — consider the remarks of author Bradford Torrey writing about a visit to Highlands the 1890s, in his book *A World of Green Hills*, published in 1898: [p. 90]

> *In truth...botany and Latin names might almost be said to be in the air at Highlands. A villager met me in the street, one day, and almost before I knew it, we were discussing the specific identity of the small yellow lady's-slippers,—whether there were two species, or, as my new acquaintance believed, only one, in the woods round about. At another time, having called at a very pretty unpainted cottage,—all the prettier for the natural color of the weathered shingles,—I remarked to the lady of the house upon the beauty of Azalea Vaseyi, which I had noticed in several dooryards, and which was said to have been transplanted from the woods. I did not understand why it was, I told her, but I couldn't find it described in my Chapman's Flora. "Oh, it is there, I am sure it is," she answered; and going into the next room she brought out a copy of the manual, turned to the page, and showed me the name. It was in the supplement, where in my haste I had overlooked it. I wondered how often, in a New England country village, a stranger could happen into a house, painted or unpainted, and by any chance find the mistress of it prepared to set him right on a question of local botany.*

Naturalists before and since Torrey have reveled in this landscape in different ways, recognizing its very special nature. William Bartram set the tone from the summit of the Nantahalas in the 1770s, beholding, he wrote, "with rapture and astonishment, a sublimely awful scene of power and magnificence, a world of mountains piled upon mountains." Horace Kephart came to the area 135 years later, seeking a "back of beyond," what George Ellison has called a "place of refuge." It was the balm of wildland, rugged terrain, and people with a sense of place that Kephart sought, it has been such a place for many others besides Kephart — certainly for the Cherokee historically, and certainly for many of us today.

The Smokies changed radically between the nine-year period between the first publication of Kephart's book *Our Southern Highlanders* in 1913 and the revised edition in 1922, in ways that resonate with the theme of the IE program:

> *Nine years have passed since this book first came from the press, my log cabin on the Little Fork of Sugar Fork has fallen in ruin. The great forest wherein it nestled is falling too, before the loggers' steel. A railroad has pierced the wilderness. A graded highway crosses the country. There are mill towns where newcomers dwell…*

Those changes continued at an ever-accelerated pace since then, and the greater southern Appalachian landscape today is a mosaic of public and private land, wild, farmed, and built land, land supporting astounding biodiversity and land that has been compromised. This is a land with a fascinating history that reflects a rich interplay of geology, ecology, and human culture. It is no longer "back of beyond," but it is as instructive as it is beautiful to study this land.

It is our hope that our students will take what they have learned about how a rich confluence of circumstances creates "place" and apply this knowledge to achieve a deeper appreciation of the "places" they will call home in the future.

ACKNOWLEDGEMENTS

On behalf of the IE-HFS class of 2010, we would like to thank the many individuals who took the time out of their already busy professional lives to help develop and guide the students' courses and projects this year. Thanks to internship mentors Jenny Sanders (Little Tennessee Watershed Association), Brent Martin and Jack Johnston (The Wilderness Society), Curtis Smalling (North Carolina Audubon Society), Jason Love (Coweeta Hydrologic Laboratory), Timm Muth (Jackson County Green Energy Park), and Kathy Mathews (Western Carolina University). Other individuals that assisted with the internships included Ed Schwartzman and James Aaron (NC Department of Environment and Natural Resources), Jennifer Love and Debbie Gibbs (Macon County Schools), Woody Malot and Amy Jenkins (Rabun Gap-Nacoochee School), Bill McLarney and Jason Meador (Little Tennessee Watershed Association), Doug Landwehr (Highlands Plateau Audubon Society), Lauren Bishop (Western Carolina University), Reid Conway (State Energy Office), Adrian Boutwell (Waste Reduction Partners), Bob Cashner (University of New Orleans), Dave Penrose (Watershed Science, Inc.), Fred Benfield (Virginia Tech University), and Jeff Zahner (Chattooga Gardens). We also thank Brennan Bouma and Lindsay Leonard of the IE for their assistance in organizing and overseeing the internships.

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Jim Costa and Anya Hinkle
IE-Highlands Field Site Directors
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A HERPETOLOGICAL INVENTORY AT THREE SITES IN THE SOUTHERN APPALACHIANS

ERIK AHL AND CAROLINE HAMPTON

Abstract The number of reptiles and amphibians is diminishing worldwide, with habitat destruction and fragmentation as the main cause of decline. The protection of these species depends upon long term studies of herpetofauna and an understanding of species-habitat interactions. Land managers now regard herpetofauna as an important part of land management plans, and the southeastern United States is one of the richest spots in the world for herpetofauna diversity. For this project we inventoried three sites in the southern Appalachians for herpetofauna: Rabun Gap – Nacoochee School, Tessentee Creek Bottomland Preserve, and the Buck Creek Serpentine Barrens. These sites have unique ecological and geological features, are currently being managed, and had never been inventoried for herpetofauna before. Coverboards were placed at all three sites and checked weekly over an approximately one month period. A leaf litter bag technique was used in streams at each site to inventory salamanders. The purpose of this study was to document the diversity of reptile and amphibian species within these three unique sites to provide a baseline for further studies of these areas.

Key words: Buck Creek; coverboards; herptofauna; inventory; leaf litter bags; Rabun Gap-Nacoochee School; reptiles; salamanders; Serpentine Pine Barrens; Tessentee Creek Bottomland Preserve.

INTRODUCTION

Since the 1980s, scientists have noted drastic declines in amphibians and reptiles, known collectively as herpetofauna (Phillips 1994). Studies of these species and their complex and varied roles in ecosystems shed light on the importance of herpetofauna and their vital role in ecosystem function. As products of two distinct lineages separated millions of years ago, reptiles and amphibians are quite different and play significant ecological roles. Many reptiles and amphibians are important predators within their food webs, regulating the number of small mammals and invertebrates, while also falling prey to higher trophic levels of predatory fauna. Salamanders specifically contribute more energy to the food chain than either birds or mammals (Gibbons and Buhlmann 2001). Consumption of plants by reptiles such as turtles in aquatic environments can help to maintain a healthy ecosystem. Reptiles and amphibians are also especially susceptible to changes in their environment, making them potentially valuable as indicators of environmental health.

Worldwide declines in both amphibians and reptiles have been well documented and emphasize the need for long term studies to both track declines and better understand the causes of decline (Alford and Richards 1999). Among vertebrate taxa, amphibians are the most threatened (Rohr et al. 2008). In 1999 the organization Partners in Amphibian and Reptile Conservation outlined six factors contributing to the decline of these species, including habitat destruction, disease and parasitism, pollution, global climate change, non-native invasive species, and unsustainable use (Gibbons et al. 2000). The pathogenic chytrid fungus in particular has been called the most deadly invasive species on the planet, and since 1980 has driven 67 frog species in the genus *Atelopus* to extinction (Rohr et al. 2008). Habitat destruction has been identified as the greatest threat to biodiversity and has serious implications for the future of herpetofauna, since herps often depend on forested habitats, or forest peripheries like streams and wetlands (Wilcove et al. 1998).

The southeastern United States is the area of greatest diversity for all amphibians and reptiles in this country except lizards; more turtle species are known to occur there than anywhere else in the world. The southern Appalachians constitute a biodiversity hotspot, boasting the richest diversity of salamander species in the world (Gibbons and Buhlmann 2001). The high diversity of herpetofauna in this region will only be protected from impending threats if herpetofauna are identified and monitored. It is important to inventory areas of interest to record species diversity, population sizes, habitat quality, and connectivity.

Historically, management plans have focused on game species, and were intended to manage habitats in ways that were tailored to human interests (i.e., fishing, hunting, logging, etc.) (Gibbons and Buhlmann 2001). Management practices have changed in recent decades to reflect a goal of maintaining biodiversity, and the effects of land management practices on herpetofauna in particular has become a concern (deMaynadier and Hunter 1999). It was the purpose of this study to inventory amphibians and reptiles at three distinct locations in northern Georgia and western North Carolina that had not been previously studied. These three areas included the grounds at Rabun Gap – Nacoochee School in Rabun County, Georgia, and Tessentee Bottomland Preserve and the Serpentine Barrens at Buck Creek in Macon and Clay counties, respectively, in North Carolina. This inventory of herpetofauna will serve as a baseline for future inventories and contribute to the land management plans for each of these locations.

MATERIALS AND METHODS

Study Sites

Rabun Gap - Nacoochee School (RGNS) is a private preparatory school located in Rabun County, Georgia. The grounds are comprised of about 1300 acres of diverse habitat including wetlands, ponds, fields and forest. The inventory conducted at this site will be shared with the school as part of a larger plan to develop a long-term sustainable management program.

Tessentee Bottomland Preserve is a 64-acre tract of bottomland and river bluff land at the junction of Tessentee Creek and the Little Tennessee River. Owned and managed by the Land Trust for the Little Tennessee, this area provides opportunities for study and restoration efforts (LTLT). Because of the diverse habitat types, from wetlands to upland mixed oak-pine forests, to bottomland Giant River Cane stands, this site was an obvious choice for study.

The serpentine barren at Buck Creek is a unique area in terms of geology and flora. Generally considered low in biotic diversity, serpentine barrens tend to harbor unusual species of flora and fauna in contrast to surrounding areas (Gatrelle 2001). Prone to fire and comprised mainly of pine stands and grassland, this area has a geology dominated by olivine-serpentine outcrops and nutrient-deficient soils, lending to the possibility of interesting herpetofauna species (Mansberg and Wentworth 1984).

Methods

Our herpetological inventories included several search methods. At each site we used coverboards, a method of studying herps that is used widely by researchers (e.g., Harpole and Haas 1999, Pittman and Dorcas 2006, Wilgers and Horne 2006). Coverboards create a shaded but warm protected place for snakes and other herps to seek shelter. Our coverboards were constructed with 24 pieces of galvanized roofing tin cut into rectangular pieces approximately 70×100cm. When checking the coverboards, each one was quickly lifted and any debris underneath it was agitated. When a herp species was found under the coverboard, attempts were made to hand catch the animal, and snout-vent length and total length were recorded. Identification was done in the field using the guides Amphibians and Reptiles of the Carolinas and Virginia by Martof et al. (1980), Reptiles and Amphibians of Eastern/Central North America by Conant and Collins (1991), and The Amphibians of Great Smoky Mountains National Park by Dodd (2004).

As a method of catching stream salamanders and juvenile salamanders, we set out leaf litter bags in streams and tributaries at each site. The leaf litter bags were constructed of nylon mesh "deer exclosure" netting with openings of $2.5cm^2$. The bags were approximately $50cm^2$ (Jung et al. 1999). Each site had two transects of leaf litter bags, and the bags were checked once. When depositing the leaf litter bags, they were filled more than ¾ full with various fallen leaves from the stream edge, and submerged in the water at intervals about three meters apart. The bags were secured in the stream bed by placing rocks on top of them. When the bags were recovered, a 5 gallon bucket was filled with stream water and the rocks were removed from the bag as it was quickly lifted from the stream into the bucket. We submerged the bag while agitating the leaf litter with our fingers and rubbing the bag up and down, finally pulling the bag out of the bucket and allowing all water to drain into the bucket. The debris from the bag and water in the bucket were poured through a fine sieve net, and then the remaining debris in the net was sifted through by hand.

We recorded the percent of the bag that was submerged, which salamander species were found, whether they were larval or adult, their snout-vent length and total length at Rabun Gap-Nacoochee School and Tessentee Creek Bottomland Preserve. At Buck Creek we also included the number of *Plecoptera* of the genus *Tallaperla*, snails and crayfish found in each bag. The use of coverboards and leaf litter bags was accompanied by more casual inventory methods, conducting opportunistic searches by flipping terrestrial rocks and decomposing logs in minimal impact fashion (Pike et al. 2010), and flipping rocks in river beds. We were able to catch several individuals this way, and we noted species that we were not able to catch. At each site we also conducted a night search using headlamps, using the same opportunistic methods. When we were able to catch species and record measurements, we recorded snout-vent length, as well as total length in mm.

At Tessentee Creek Bottomland Preserve, 24 pieces of galvanized roofing tin had been placed in three transects of eight by Jason Love in May and June 2009, and these were checked periodically and the findings recorded. The first transect was located in an edge habitat between early successional forest and a field. The second transect was along the path through a red cedar savannah, an area characterized by native grasses and flowers. The third transect was in a second-growth mixed pine/hardwood forest.

The coverboards at Tessentee Creek were checked four times on a weekly basis from 9/10 – 10/11. A night search was conducted on 10/4. Our inventory also included a search of the wetland on the property and a rocky bluff. Thirteen leaf litter bags were placed at this site on

10/29, with seven in a tributary of Tessentee Creek at a low flow site and six in a tributary of the Little Tennessee River in a low flow area. The bags were recovered on 11/8.

Coverboards had been placed at the Rabun Gap-Nacoochee School by Jason Love in August, with three transects of eight coverboards. The first transect was placed on the edge of an open field, bordered by a stand of trees. The second transect was placed in a mixed oak/pine forest, and the third was along the edge of a small pond that was a former rock quarry filled with water. Coverboards were checked four times on a weekly basis from 9/10 – 10/11. A night search was conducted on 10/11 at Indian Lake, the small recreational lake on the school grounds. Other areas searched on the property included the wooded area surrounding a cemetery, and a degraded wetland surrounded by cow pasture. In addition, a search was done under the highway 441 bridge that passes over Betty's Creek on the RGNS property to seek out a *Cryptobranchus alleganiensis alleganiensis* (Eastern hellbender) individual that had been found there in 2009. Twenty leaf litter bags were placed in two transects on 11/8. Ten bags were placed along Betty's Creek, and another 10 were placed at the seep by the school alumni center. All bags were recovered on 11/15.

We placed 24 coverboards at the Buck Creek Serpentine Barrens on 9/17. The first two transects were at low and mid-level elevation on either side of Buck Creek with slopes of 10-15%, where pitch pine and white oak are the dominant tree species, and the understory is dominated by grasses, many of them rare for this part of the country (more typical of the Midwest). Each of these transects had seven coverboards in place. A third transect was placed at a higher elevation with similar vegetation. Ten coverboards were placed in this transect, following the ridge line with a slope of approximately 10%. The coverboards at Buck Creek were checked five times on a weekly basis from 9/17 – 10/15. A night search was conducted on 10/19 for about one hour. Opportunistic searches were conducted several times around the coverboard transects, and the tributary to Buck Creek that runs through the barrens close to our second transect was searched for salamander species. Twenty leaf litter bags were deposited at the Buck Creek Serpentine Barrens on 11/8. Ten were deposited in this tributary to Buck Creek, and ten were placed in Buck Creek. These bags were recovered on 11/19.

Analysis

The three sites at which the inventories were conducted were located in different counties: Buck Creek in Clay County, North Carolina, Tessentee in Macon County, North Carolina, and RGNS in Rabun County, Georgia. All species found at the North Carolina sites were compared to the county inventories found on the Carolina Herp Atlas website for Macon and Clay counties (http://www.carolinaherpatlas.org). The information is based on reports submitted by observers in the field and not to be considered a complete listing of all species per county, but it served as a growing database with which to compare our findings. A list of herp species recorded for Rabun County was acquired from John Jensen at the Georgia Department of Natural Resources, and our species list for Rabun County was compared to this document. These resources were used to establish whether the species that we found had previously been recorded in these locations. The global (G) and state (S) conservation status of each species was also checked with the website Nature Serve (http://www.natureserve.org). A number system of 1 through 5 was used to reflect the level of concern: 1 = critically imperiled, 2 = imperiled, 3 = vulnerable, 4 = apparently secure, and 5 = secure.

The species diversity at each site was calculated using the Shannon-Wiener Diversity Index. Scores for this index tend to fall between 1.5, indicative of low species richness and evenness, and 3.5, indicative of high species richness and evenness. However, values are not limited to this range and can vary widely among locations. The formula used to calculate the Shannon-Wiener Diversity Index, H, is shown below.

$$H = -\sum_{i=1}^{S} (p_i (\ln p_i))$$

In this equation, S is the number of species found, and p_i is the relative abundance of each species, calculated as the proportion of individuals of a given species to the total number of individuals in the community.

RESULTS AND DISCUSSION

Our surveys yielded a total of 14 species of reptiles and amphibians (Table 1). A species list supplemented with notes and measurements is presented in Appendix A. *Eurycea wilderae* (Blue Ridge two-line salamander) was found at all three sites, the only species in common to all sites and representing more than 50% of the individuals found at some sites (Fig. 2). This is a very common species throughout the southern Appalachians, so it is unsurprising that this species was so well represented. However, the lack of diversity is unusual and suggests that our samples are not exhaustive for the communities at these sites. At each site the number of amphibians found far exceeded the number of reptiles, reflective of the species composition in the southern Blue Ridge, where species richness of frogs, toads, turtles, snakes and lizards decreases as altitude increases (Taylor 2001).

TABLE 1. Recorded species and number of individuals by site.

Site	Scientific name	Common name	Count
Tessentee Creek	*Diadophis punctatus edwardsii*	Ringneck snake	1
	Coluber constrictor constrictor	Northern black racer	1
	Lampropeltis getula getula	Eastern kingsnake	1
	Eurycea wilderae	Blue Ridge two-lined salamander	13
	Desmognathus ocoee	Ocoee salamander	7
	Bufo woodhousii fowleri	Fowlers toad	1
TOTAL			24
Rabun Gap NS	*Nerodia sipedon*	Northern watersnake	1
	Sceloporus undulatus	Eastern fence lizard	1
	Eurycea longicauda guttolineata	Three-lined salamander	1
	Eurycea wilderae	Blue Ridge two-lined salamander	5
	Cryptobranchus alleganiensis	Eastern Hellbender	1
	Rana clamitans	Green frog	2
TOTAL			11
Buck Creek	*Crotalus horridus*	Timber rattlesnake	1
	Sceloporus undulates	Eastern fence lizard	1
	Desmognathus monticola	Seal salamander	6
	Desmognathus ocoee	Ocoee salamander	1
	Eurycea wilderae	Blue Ridge two-lined salamander	9
	Plethodon shermani	Red-Legged salamander	3
TOTAL			21

The low species count is also reflected by the scores for Shannon-Wiener Diversity Index (Table 2), which fell below the range of scores that is expected when using the index. This doesn't necessarily reflect poor richness in diversity but may be a result of the short duration of our study. Index scores did show a difference between the sites studied: Buck Creek scored the highest in diversity followed by Tessentee Creek and then RGNS. Even though Tessentee and Buck Creek yielded the same numbers of species, evenness differed between sites resulting in a lower score for Tessentee. RGNS had the same count of species as Buck Creek and Tessentee, but with a lower total and Shannon-Wiener score.

TABLE 2. Shannon-Wiener Diversity Index by site.

Site	Shannon-Wiener Diversity Index
Rabun Gap NS	1.04
Tessentee Creek	1.22
Buck Creek	1.43

This herpetological inventory contributes to Jason Love's previous inventory, and providing baseline data that others can use in the future. Other herpetological inventories that we consulted that were performed in the southern Appalachians yielded many more species (King 1939, Huheey and Stupka 1965, Taylor 2001). Though these surveys were over greater areas, their results indicate that long-term inventories at our sites should yield more herp species.

The study was limited by several factors, including time, season and number of coverboards/leaf litter bags used. Past studies that used coverboards have recommended that vegetation be cleared from under the coverboards, and the coverboards should be undisturbed after their placement for a significant period of time so that snakes will accept them as a part of the habitat. Because snakes are so sensitive to disturbance, the coverboards should be checked with less frequency, closer to once a month than once a week (Pittman and Dorcas 2006). Placing more coverboards would also be an effective method of finding more herp species, especially at RGNS, which has 1300 acres. The time of year of our study was also less favorable for herps, especially for snakes who are only active during the day when it is warmer. We experienced daytime temperatures averaging 50˚F, with temperatures even lower at night, inhibiting our findings on night searches.

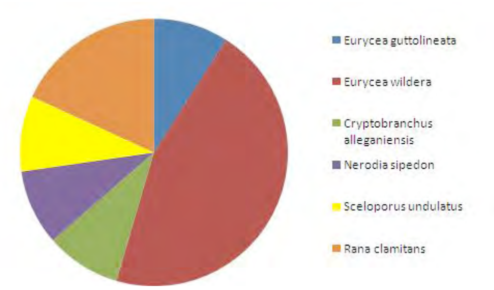

FIG. 1. Relative abundance of species found at Rabun Gap Nacoochee School.

The inventory of Tessentee Creek Bottomland Preserve has been going on longest of the three inventories we conducted, and we collected more herp species here than at any other site. This is probably partially because the preserve has such a diversity of habitats in a continuous landscape, but also suggests that a long term inventory done with coverboards yields a higher and more accurate count of snake species, and presents more opportunities for observing amphibians and reptiles in the greater area. Each snake species that we found while conducting the inventory at Tessentee Creek had already been found and recorded at this site by Jason Love. *Diadophis punctatus* (northern ringneck snake) was found in the same habitat type before, the second-growth mixed pine/hardwood forest transect. The recovery of *D. punctatus* again confirms the continued survival of the species here. Multiple *Coluber constrictor* (northern black racer) individuals have been found before in the red cedar savannah, so our data confirms this species continues to populate the area. *Lampropeltis getula* (eastern kingsnake) was also found in the red cedar savannah transect. The *L. getula* recorded previously was an adult, while the individual found during this inventory was a juvenile, indicating that *L. getula* is still breeding in this area. All three snake species recovered are common in North Carolina and have a conservation status of G5, globally secure. We recommend that future inventories at this site include herp searches in as many different types of habitat as possible, since more than ten different habitat types have been described at the preserve. Further searches should include the bluff lands in particular, with rocky outcroppings that could be good for species like the timber rattlesnake, skinks, and lizards, as well as the wetland complex, which could harbor water snakes, turtles, and a diversity of amphibians.

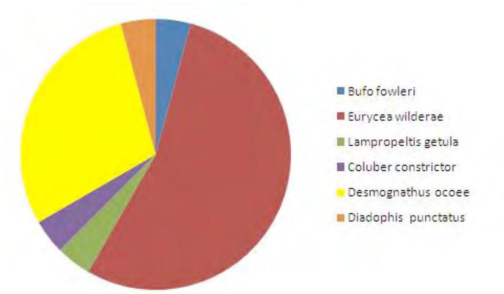

FIG. 2. Relative abundance of species found at Tessentee Creek.

Rabun-Gap Nacoochee School was the site with the greatest amount of acreage (approximately 1300 acres), but the fewest species were found here. A longer inventory period would likely yield more results, and because of the size of the property, creating a matrix of habitat patches to study would be more reflective of the diversity that can probably be found there. Because the coverboards had been placed for the first time only two weeks prior to checking them, we would recommend a longer study period with the coverboards. Future inventories of RGNS should include more searches at Indian Lake and the surrounding wetland habitat. The coverboard transect by the alumni center should be moved, since the adjacent field is mowed regularly, creating a major disturbance for reptiles and amphibians. In general, RGNS is more disturbed and fragmented than the other two sites, and this may have been another reason that so few species were found here. *Cryptobranchus alleganiensis alleganiensis* (eastern hellbender) had been found under the highway 441 bridge at Betty's Creek in July 2009 by Jason Love. The measurements recorded for the two individuals only differed by about 2 cm. Considering the small home range of *C. a. alleganiensis,* it is probable that the individual found in 2010 was the same one found in 2009. The continued presence of this individual indicates that Betty's Creek is a fairly clean stream, free of heavy sedimentation or pollution. *Cryptobranchus a. alleganiensis* is very habitat specific, and requires cool clean water with minimal sedimentation and a rocky/cobble bottom. A proposed widening of highway 441 at the location of this bridge may be impacted by the presence of this individual, which has a rounded global status of T3, vulnerable, and a state status in Georgia of S2, imperiled. We did not find any salamanders in our leaf litter bags placed in Betty's Creek, possibly because the creek flow is too fast and the water is too high for them.

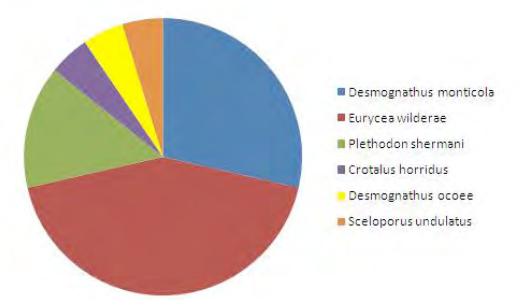

FIG. 3. Relative abundance of species found at Buck Creek.

The geology of Buck Creek Serpentine Barrens creates such a unique fire dependent community of plants that further study of herpetofauna at this site would be advisable. Due to the nature of the shallow soils, this is a variable habitat that is very moist in rainy periods and very dry in the absence of rain. The acidity of the soil also creates runoff into the tributaries and seeps in the barrens, with potential for unusual species (Mansberg and Wentworth 1984). Though we were able to easily find and record salamanders in the tributary to Buck Creek on multiple occasions, we did not find any salamanders in the leaf litter bags that we placed here. This may be due to the placement of this transect next to the road through the barrens, which is more polluted due to runoff from the gravel road. Another factor that may have affected our litter bags was the high amount of rainfall prior to our checking the bags, which increased the flow of the tributary.

Crotalus horridus (timber rattlesnake) was collected at the Buck Creek Serpentine Barrens. *Crotalus horridus* has a global status of G4 but a state status in North Carolina of S3, vulnerable. This species prefers open, early successional habitats much like the barrens. The occurrence of this species at this site should be investigated further for more data since the long term global trend of this species is moderate decline (25-50%), and this is one species for which habitat destruction due to shading over and development is having a major impact. Areas with optimal habitat types like the serpentine barrens should be further investigated for a better understanding of the species-habitat interactions on the landscape.

Reptiles and amphibians around the world now face many threats, and with their sensitivity to pollution and various forms of ecosystem degradation and destruction, their value as biomarkers is to be given priority. Because of the numerous threats to biodiversity and the diminishing numbers of amphibians and reptiles, inventories will play a vital role in future conservation efforts. Inventories not only serve to document abundance and diversity of herpetofauna but can contribute to ecosystem assessment and better land management practices. Long term studies can help us understand more about the interactions between species and their habitat on a landscape and make us better equipped to deal with stressors. Short term inventories can contribute a great deal to long term studies, especially in areas like these that have not been previously inventoried. The data from this study will provide the groundwork for others to build upon and compare findings. As more inventories are carried out, more can be deduced about varying ecosystems and the species that comprise them. With this knowledge we can begin to develop sustainable conservation plans as well as rehabilitation plans for those systems already stressed or threatened.

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Appendix A

Herpetofauna inventory data (tins, leaf litter bags, hand capture) by site and species found (digital archive on attached CD).

Appendix B

Image of site map for Rabun Gap – Nacoochee School, including coverboard transect locations. Constructed in ArcMap (digital archive on attached CD).

Appendix C

Image of site map for Buck Creek Serpentine Barrens, including coverboard transect locations. Constructed in ArcMap (digital archive on attached CD).

IMPLEMENTATION OF A WASTE VEGETABLE OIL CLEANING SYSTEM FOR THE PRODUCTION OF BIOFUEL

KYLE E. ANDERSON

Abstract. The production of vegetable oil based fuel is an expanding industry with potential that is largely untapped. Vegetable oil fuels are cleaner-burning and more sustainably produced than petroleum-based fuels, and can be produced in both the commercial and domestic spheres. Here I describe some basic implications the use of vegetable oil as a fuel source, and report on the design and construction of a small waste vegetable oil refining system at the Jackson County Green Energy Park in Dillsboro, North Carolina.

Key words: alternative fuel; biodiesel; dewatering; Vegetable oil; WVO.

INTRODUCTION

Vegetable Oil as Fuel

Derived from pressing oil-rich plants, vegetable oil is a common product with many uses both culinary and industrial. Although the possible application of vegetable oil as a fuel source has long been known, it has historically been eclipsed by cheap petroleum as a primary liquid combustion fuel. However, as evident environmental, social, and economic costs of a fossil fuel-based economy have increased and become increasingly clear, the development of alternative sources of energy has become a priority in post-industrial societies, and after years of obscurity vegetable oil is emerging as a promising energy source that is free of many of the problems associated with petroleum fuel (Tickell 2003, Pahl 2005).

Many aspects of vegetable oil support its use as an alternative to fossil fuels. Burning vegetable oil does not inherently contribute to atmospheric carbon levels: the carbon released by combusting fuel is equivalent to or less than the atmospheric carbon absorbed by growing plant stock. Burning fossil fuels, by contrast, releases carbon that has been sequestered underground, adding new carbon to the atmospheric system, increasing “greenhouse” gas levels thought to be responsible for the global climate change phenomenon (Tickell 2003).

Unlike fossil fuels, vegetable oil is a renewable resource. Fossil fuels will certainly become more scarce as worldwide deposits dwindle, and some models suggest that worldwide petroleum production potential has already peaked (Lynch 2002). What reserves remain are largely under foreign soil, often in nations with historically tenuous relationships with the USA, casting the future availability of petroleum fuel into further doubt. Vegetable oil can be produced indefinitely as long as cropland is available, and domestically, supporting the nation’s economy and increasing the security of its fuel supply (Tickell 2003).

Vegetable oil may be generated as restaurant waste or as virgin oil from crops. Mustard, corn, sunflower, soybeans, and peanuts are efficient oil-producing plants that are cultivated in the United States. Vegetable oil production can occur without directly impacting food supplies, as virgin oil can be garnered from land currently left fallow, or as a by-product (Tickell 2003).

Transitioning from petroleum oil fuels to vegetable oil fuels is often simple and inexpensive. Furnaces, diesel engines, and other combustion systems can often run on vegetable oil with only slight and technically simple modifications. The first diesel engine was built in 1897 to run on peanut oil, and almost all diesel engines can run on 100% vegetable oil as long as the fuel is heated to achieve viscosities similar to diesel fuel. This can be achieved in automobiles by installing a second fuel tank with coolant-heated fuel lines; the automobile is started on diesel fuel and run until the engine-heated coolant warms the vegetable oil fuel lines, at which point the fuel system can be switched to supply only vegetable oil (Tickell 2003, Pahl 2005).

The complication of adapting machines to accommodate highly viscous vegetable oil can be avoided by engineering the fuel into "biodiesel". Biodiesel is vegetable oil that has been mixed with methanol (a thin alcohol) and a catalyst, causing glycerol (a thick alcohol) to separate from the oil. The resultant fuel achieves viscosities similar to petroleum-diesel, and can be used as diesel fuel without altering equipment or operation (Alovert 2005).

The use of vegetable oil fuels over petroleum fuels cuts or eliminates net emissions of carbon dioxide, sulfur dioxide, soot, lead, carbon monoxide, hydrocarbons, and carninogenic aromatic hydrocarbons, although it may increase nitrous oxide emissions of some engines. Vegetable oil and biodiesel contain less energy by volume than petroleum diesel, however, lowering performance and fuel efficiency by about 5% each. Biodiesel and vegetable oil have a higher clouding temperature than petroleum diesel, and must be mixed with petroleum diesel or kerosene to avoid gelling in cold weather. Biodiesel acts as a detergent and lubricant which may extend the usefulness of an engine (Pahl 2005).

Most technology for the burning or modification of vegetable oil is very simple, allowing private individuals to manage their own fuel supplies and allowing small companies dealing with vegetable oil to start up without prohibitive investments in capital and specialized labor, and small coops and "backyard" producers are common in the United States (Tickell 2003, Alovert 2005). Although small producers may rely on steady sources of waste fryer oil from restaurants, some large commercial operations purchase virgin oil (Pahl 2005)..

Project

In line with the grassroots history of vegetable oil fuel, this paper will discuss the design, construction, and function of a small waste vegetable oil processor at the Jackson County Green Energy Park (JCGEP), located in Dillsboro, North Carolina. Built on an abandoned industrial site adjacent to a landfill, the JCGEP is a county project with the task of exploiting methane created in the landfill to create jobs and educational opportunities in an environmentally sustainable way. Towards this end, the JCGEP uses methane to heat a foundry, blacksmithing forge, glass blowers' "glory hole" furnaces, and a large greenhouse. By offering the use of its facilities to the public at bargain rates, the JCGEP acts as an incubator for local artisans and horticulturalists (Muth 2010).

Because the methane supply drawn from the landfill is prone to occasional inconsistencies, a fuel oil tank is standing by to supply the greenhouse boiler in the event of a "hiccup." Ordinarily fueled with diesel, biodiesel, or kerosene, experimentation has shown that the boiler will tolerate the inclusion of vegetable oil fuel at concentrations of at least 5%, reducing fuel costs and carbon emissions. The planned wood- and vegetable oil-fired pottery kiln could also consume large quantities of both vegetable oil and waste products derived from it.

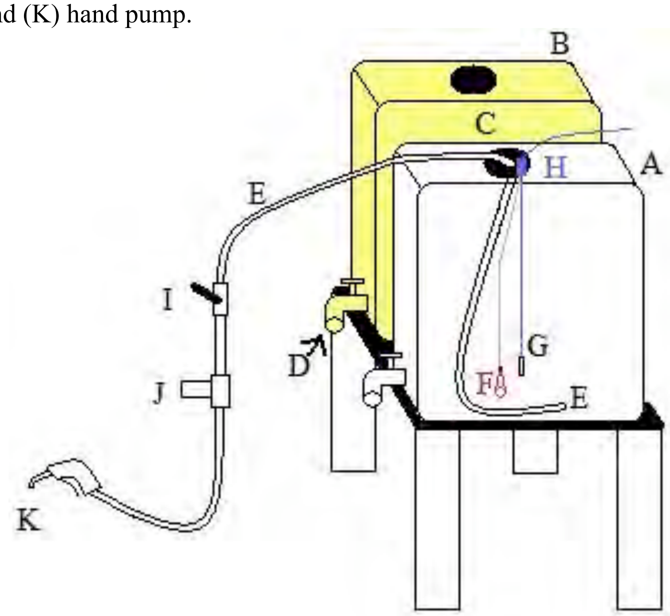
Waste vegetable oil is gathered from donations and solicited waste fryer grease from restaurants. Because oil fryer oil is laden with water and impurities that may cause clogging or damage from incomplete combustion of fuel, a processor was designed to clean raw vegetable oil. The processor was to use heat to settle water and impurities out before filtering the oil to 10 microns, requiring few material inputs and minimal effort of operation.

METHODS AND MATERIALS

Design

The waste vegetable oil cleaning system was designed to remove water and other impurities from fryer oil with an emphasis on ease of operation, simplicity of design, and low cost. As vegetable oil fuel technology lends itself to a grassroots, internet savvy culture, online forums and search engines were vital in exploring different system designs. In particular, the closely-moderated "Alt Fuels Furnace" Yahoo.com group was the most comprehensive and reliable source of information found regarding fueling furnaces and boilers on vegetable oil and biodiesel. Youtube.com was also a valuable resource for existing small processor designs. Research was performed especially to identify failures in other experimental systems. The McMaster-Carr industrial part catalog was used to identify a suitable thermostat, immersion heater, and fuel pump (McMaster-Carr 2010).

FIG 1. Processor design. (A) primary processing tank, (B) secondary settling tank, (C) ported lid, (D) drain spout, (E) outlet line, (F) immersion heater, (G) thermostat thermometer, (H) thermostat, (I) on/off valve, (J) inline fuel filter, and (K) hand pump.



Construction

This project required a posthole digger, spade, blunt tamping object, tape measure, level, chainsaw, drill, drill press, reciprocating saw, four by four and three by three square steel tubes left over from greenhouse construction, six by six inch treated wood posts, dry cement, two cubic 275 gallon "tote" tanks, PVC primer and "blue" glue, one inch PVC pipe, one inch elbow and union connections, silicone sealant, and metal pipe bracers. Other than the steel tubing, which was recycled scrap, and cubic tanks, which were purchased used, all the materials were bought at Lowes Hardware.

Six post holes were dug 20 inches deep, set four feet apart (center to center) in a three-by-two formation. Four-foot long 6” x 6” posts were placed in the holes. Dry cement was gradually poured around the post, using a level to ensure the post was vertical and a tape measure to keep the edges of all the posts set parallel to each other. Cement was tamped firmly around the post, and left to sit for a day.

Posts were trimmed to a level height and notched using a chainsaw. Four by four inch square steel tubes were bolted into the notches of opposite posts, bracing pairs of posts together. Three 3” x 3” square steel tubes were bolted parallel 15 inches apart on the 4” x 4” tubes, creating a shelf. The tubes were trimmed to length using a reciprocating saw.

Two cubic 275-gallon plastic tanks were mounted on the shelf, each equipped with a lid and drainage spout. Using a drill press and a hole saw bit, a 1.23” circular porthole was drilled into the lid, through which a 1” PVC pipe was set with union fittings set on either side of the lid, set as tightly together as possible. The breach in the lid was sealed with silicone.

Using metal braces, a one inch PVC pipe was fixed vertically to a wooden post. Elbow fittings were use to guide the line to the top of the settling tank, where it could connect with its ported lid. All plumbing connections were treated with primer and “blue” PVC glue.

As time and money become available to improve the system to its design specifications, additional port holes will be drilled in the lid, through which an immersion heater and thermometer will hang from and externally-mounted thermostat, and an on/off valve a ten-micron inline filter, and a hand pump will be plumbed into the outlet pipe.

Operation

In its current state, the processor functions as a basic settling tank system. Raw waste vegetable oil is poured into the tank through a strainer, and allowed a week or more to settle. Oil discolored by water and impurities will be drained off the bottom out of the lower spout, and the clear oil will be removed from either the lower spout or upper outlet line, and filtered in a ten micron “sock” filter.

As envisioned, the completed system will admit raw waste vegetable oil through a strainer into the tank, removing the largest waste particles. Next, the lid is mounted, submerging the immersion heater, temperature sensor, and outlet hose in the oil. The thermostat is set to maintain a temperature in the tank of 140 degrees Fahrenheit, increasing difference in density between oil and suspended water molecules, increasing the rate at which water and impurities settle to the bottom of the tank (Alovert 2005). The operator uses the drain to remove the discolored wastewater-laden oil from the bottom of the tank, and switches open the outlet hose valve. The height of the tank above the nozzle creates a gravity feed in the outlet hose that siphons clear oil out of the tank, through the inline filter, and out the spout. The unused tank can be filled with raw waste vegetable oil to begin settling until the modified tank is available.

The only tasks required of the operator are filling the tank, programming the thermostat, draining impurities, and switching the outlet valve. The only energy consumed by the system is the electricity used to power the thermostat and immersion heater. The only material inputs after construction will be inline filter cartridges.

DISCUSSION

Although the vegetable oil system is incomplete as originally envisioned, it still provides a consolidated settling system that will likely be adequate to meet the greenhouse boiler's limited demand for clean oil. The heating aspect of the system will likely be installed by spring 2011, raising output levels to meet demand for oil after a planned pottery kiln comes online.

While the increased use of vegetable oil as a fuel source will cut fuel polluting emissions as well as fuel costs at the JCEP facility, this processor will not constitute a defining effort of vegetable oil-based fuels in North Carolina. In the state, commercial biodiesel operations alone have an annual production potential of nearly 45,000,000 gallons annually and it is likely that backyard vegetable oil processors and biodiesel reactors also produce significant amounts of fuel (National biodiesel board 2010).

Nonetheless, it is difficult to build a vegetable oil processor without some level of creativity and innovation. This processor achieves an uncommonly simple operational procedure through the inclusion of self-regulatory systems, such as the heater/thermostat system and the fully contained, gravity fed filter scheme. Although the system may produce only around a thousand gallons of fuel annually, the use of fuel in a boiler and a kiln will help increase public appreciation for the practicality and versatility of vegetable oil as a fuel.

ACKNOWLEDGMENTS

I'm grateful to Timm Muth, director of the Jackson County Clean Energy Park, who contributed vital support and technical expertise to the project. I also acknowledge the efforts of online communities of anonymous vegetable oil users, whose efforts to disseminate information contributed considerably to this project's success. Especial thanks to James Costa and Anya Hinkle for creating the excellent program at Highlands Biological Station.

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APPLYING A GIS-BASED APPROACH TO MAPPING POTENTIAL CEDAR CLIFF HABITATS USING TRAITS OF A *JUNIPERUS VIRGINIANA* POPULATION AT CEDAR CLIFF MOUNTAIN, NORTH CAROLINA

WILLIAM C. COMBS

Abstract. Characterizing and mapping rare communities are important parts of biological conservation. In this study, I describe the habitat characteristics and composition of a cedar cliff community at Cedar Cliff Mountain in Jackson County, North Carolina. Using these data, I analyzed the extent and stability of the cedar population within the study area and used the site characteristics to create metrics to inform a habitat probability model. Although analysis of the Cedar Cliff Mountain site determined that the community was a mature, stable community and displayed no immediate risk of deterioration, further analysis is needed to validate these results. The predictive model was only moderately successful and could not be adequately verified due to restricted site access. The results suggest that future studies are needed to better delineate community characteristics, and that increased access to predicted sites is key to model verification and improvement.

Key words: *cedar cliff community*; *habitat assessment*; *predictive modeling*; *GIS*; *raster calculator*; *rock outcrop community*.

INTRODUCTION

Rock outcrop plant communities, an understudied land feature in the southern Appalachians, present some of the rarest assemblages found in the region. The general isolation of these plant communities creates an insular effect as the surrounding habitat is unfavorable and greatly reduces recruitment and dispersal of associated plants; such isolated and unique habitats often contain rare or uncommon species outside of their normal range (Wiser et al. 1996). These outcrops are characterized by extreme temperatures, high erosion levels (Small and Wentworth 1998), and drought (Oosting and Anderson 1937) owing to their minimal canopy and shallow soils; such periodic disturbance as fire is also noted at these sites (Small and Wentworth 1998). Fortunately, such unique sites have historically been deemed low in economic value and thus have been largely avoided as natural resources (Wiser et al. 1996).

Among the unique communities found in rock outcrop habitats are the recently described cedar cliffs. Though still an unlisted community type in North Carolina (Schafale and Weakley 1990), they are noted for a canopy dominated by eastern red cedar (*Juniperus virginiana*). This species is known for its ability to flourish in dry, shallow soils where sunlight is abundant and drought is common (Vasiliauskas and Aarssen 1992, USDA Plant Guide 2002). Cedar cliff communities occur on high-elevation, circumneutral rock outcrops, as opposed to the more regionally common acidic granite outcrops, and are characterized by a southern to southwestern aspect, medium to steep slopes and a mixed cedar-hardwood forest in the more dense and moist ridgeline soils (Pittillo 1994, Small and Wentworth 1998, Weakley 2008). Cedar cliffs are often associated with unusually high levels of diversity that include many endemic and disjunct species (Wiser et al. 1996, Small and Wentworth 1998); examples of rare or unusual species at some sites included *Opuntia compressa* (Prickly Pear), *Amelanchier sanquinea* (Roundleaf Serviceberry), *Krigia montana* (Dwarf Dandelion) and *Carex biltmoreana* (Biltmore Sedge) (Pittillo et al. 1994, Small and Wentworth 1998). At such sites, the presence of basophilic plants, like *Lonicera flava* (Yellow Honeysuckle) and *Celtis occidentalis* var. *georgiana* (Hackberry), indicates that pH levels are more basic, or circumneutral, than granite rock outcrops, allowing such unusual communities as cedar cliffs to arise (Pittillo et al. 1994, Small and Wentworth 1998). Though diverse, these plant communities are fairly nutrient deficient because of the high erosion rates experienced on the bare bedrock. Vegetation grows very slowly as soil mats accumulate very slowly to replace eroded ones, often leaving many older trees stunted and shorter than their relatives in more nutrient rich habitats (Oosting and Anderson 1937). Periods of rapid or normal growth in the upland forest, which has higher soil retention due to less severe slopes, are often explained by openings in the canopy where solar radiation becomes more abundant (Oosting and Anderson 1937).

The purpose of this study was to describe the characteristics and dynamics of a cedar community and to use this information to inform a predictive model to locate where other such sites may exist. The first portion of this study involved data collection and analysis of a cedar cliff community on Cedar Cliff Mountain in Jackson County, NC. This site was examined for dominance, age, recruitment and density of main canopy species, as well as related habitat characteristics that influenced the presence of *J. virginiana* within the rock outcrop. These data were then used to inform a GIS-based habitat probability model, similar to one used in a prior study of Chinese cedar (Tie et al. 2007), in order to identify additional sites within the county that may have cedar cliff communities.

MATERIALS AND METHODS

Study Area

Cedar Cliff Mountain is a North Carolina Natural Heritage site managed by the Plant Conservation Program of the North Carolina Department of Agriculture. It is located off N.C. Highway 281 across from Cedar Cliff Lake and Bear Lake Reserve. While the full site is 290,851 m^2, only 13,808 m^2 centered on the main cliff face was sampled as it represented the largest cedar population on the site. The entire site and study area can be seen in Fig. 1. Described as a high elevation granitic dome, the study site contains diverse species of flora and fauna; unique species like *Opuntia compressa* (Prickly Pear) and *Talinum teretifolium* (Fameflower), both rare in Jackson County, as well as the significantly rare *Hexaletric spicata* (Crested coralroot) and *Sedum glaucophyllum* (Cliff Stonecrop) are present at the site (Pittillo et al. 1994). The cliff's classification as a granitic dome does not indicate granite bedrock at the site, but rather a similar surface fracturing to granite; the bedrock is largely biotite schist and gneiss (Pittillo et al. 1994). Trees within the study area on main face include, in addition to *Juniperus virginiana*, Virginia pine (*Pinus virginiana*), and hickory (*Carya* sp.) along with saplings of birch (*Betula sp.)* and oak (*Quercus sp.*). The study area at Cedar Cliff Mountain has a south to southwest aspect and dry mesic soils of the Cleveland Chestnut Rock Outcrop (CpD, CpF) and Rock Outcrop Cleveland (RkF) complexes (Pittillo et al. 1994). These complexes are characterized by well-drained soils, gentle to steep slopes, shallow soil depth, and high exposure to wind, all of which have contributed to the lack of intensive logging, due to minimal desirable lumber, at the site (USDA 1997). Evidence of fire (burn marks) and lightning (tree scars) also indicate that the study area experiences fire disturbance.

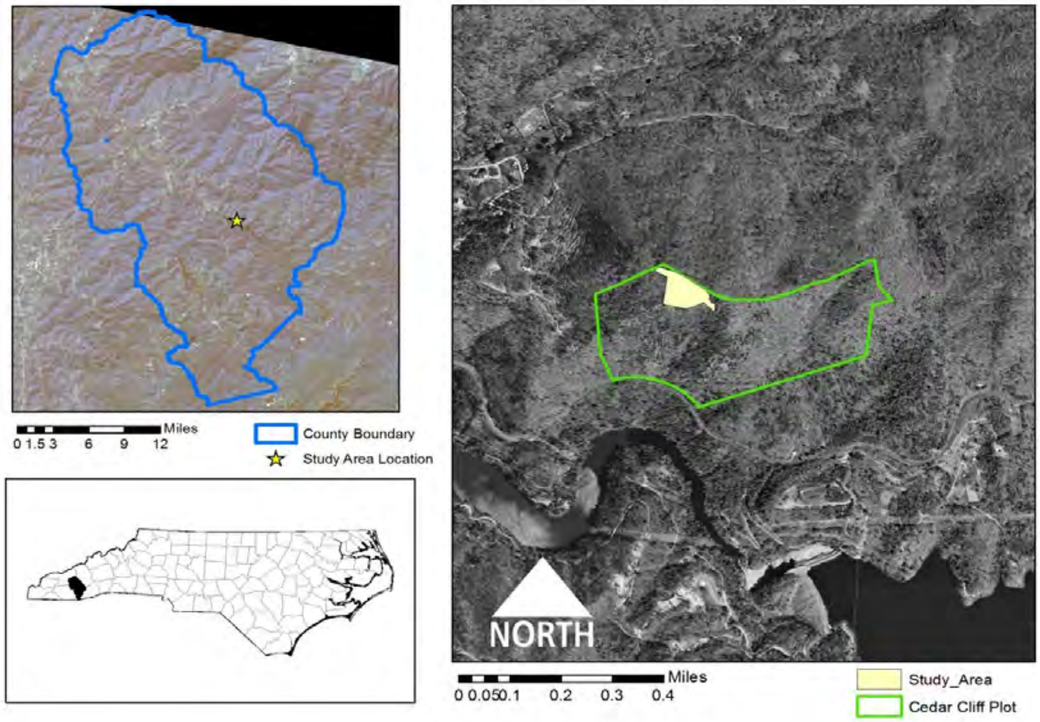

FIG.1. Location of study area in Jackson County with aerial map of site and study area.

Data Collection

The first portion of the study required collection of data on physical and biological features within the study area at Cedar Cliff Mountain. A Trimble® Recon® handheld GIS unit with Bluetooth® connection to a Trimble® GPS Pathfinder® ProXH™ receiver, mounted on a survey pole to improve satellite geometry, was used to collect geolocated points for living and dead cedar trees within the study area; an average of the 30 collected GPS points for each tree was recorded in order to maximize accuracy. Dead cedars were only sampled within the ridgeline forest, as this was the area of highest cedar mortality and also the area of greatest interaction between the cedar-dominated cliff face and the pine-dominated ridgeline. These trees were then measured for diameter at breast height (DBH) and the majority were examined for presence of lightning scars; six trees were not examined for lightning scars due to difficulty of secondary examination during the onset of the fall season. Two 70 m transects, one at the ridgeline and one approximately 10 m down slope at the outcrop's edge, were then sampled in order to conduct point-centered quarter analysis of the main area of overlap between the evergreen species *J. virginiana* and *P. virginiana,* as well as the hardwood *Carya* sp., to examine density and dominance. Radial plots were also constructed at a selection of cedar trees in an attempt to characterize the average recruitment of cedar and pines within the whole study area. Heights of cedar and pine saplings were recorded within each plot; a maximum of five heights per species per plot were collected. Cores for a sample of cedar trees and pine trees were collected to provide age estimates for some of the larger trees within the study area.

The second portion of the study involved the use of GIS analysis to evaluate habitat characteristics of the study area and to use them to construct a probability model to predict the occurrence of possible cedar cliff habitats within the county. I used ESRI's database software

ArcGis® v. 9.3.1 (ESRI 2008), as well as the Feature Analyst v. 4.3, an ESRI extension, to organize the data layers and attributes needed to build the model.

Analysis of Field Data

In order to characterize the cedar cliff community within the study area, both quantitative and observational analyses were employed. DBH measures for both live (n=111) and dead cedars (n=26) were compiled into separate tables using Microsoft® Excel software and the means, standard deviations and ranges were calculated for each data set (Appendix A). GIS analysis of cedar GPS points grouped trees in quartiles by DBH so that size distribution of sampled cedar trees could be quantitatively, and visually, examined within the study area. This permitted the determination of clustering and habitat preference within the site. Percentages comparing presence or absence of lightning scars were also calculated for a majority of the live cedar trees (n=105) to assess the likely importance of lightning as a disturbance mechanism in this outcrop community (Appendix A). Dead cedar DBH values and GPS points, as well as observations of the entire study area, were analyzed to examine mortality among cedars within the ridgeline forest and to compare results with community dynamics in other portions of the study area. Following proscribed procedures for quantitative analysis of the point-centered quarter method (Mitchell 2007), metrics for density and dominance were calculated for the three tree species noted along the two transects constructed at the field site (Appendix B). Analysis of the two meter radial plots (n=14) gave an estimate of the relative recruitment between cedars and pines; these data were also used to compare average heights of saplings in plots where recruitment was noted (Appendix C). Cedar (n=10) and pine (n=4) cores were analyzed using ring count analysis in order to determine their ages. The ages for both species were then compared to provide a basic description, in conjunction with observational analysis of the site, of the relative ages of the two populations within the study area.

Construction of Habitat Probability Model

The first step in construction of the habitat probability model involved importing relevant data layers into ArcGIS. These layers included a digital elevation model (DEM) derived from LiDar data (NCDOT 2007), Enhanced Thematic Mapper plus Satellite Imagery (ETM+) data (USGS 2001), tree height data determined by Doug Newcomb of the USFWS, county and land parcel layers for Jackson County (Jackson County Mapping Department), soil data identified from the Soil Survery Geographic (SSURGO) database (USDA NRCS 1997), as well as GPS points of live and dead cedars collected at the study area. All imported layers were either projected or transformed into North American Datum 1983 projected coordinate system. Tree height data for Jackson County was extracted from the tree height layer, using Extract tool found within the ArcGIS Spatial Analyst Toolbox, and added to the map as a new layer.

Next, raster layers for slope, aspect and curvature were calculated from DEM data using the Surface toolkit within the Spatial Analyst toolbox. In order to allow for pixel by pixel analysis, the Jackson County soils layer was rasterized using the Spatial Analyst toolbar and added to the map as a new layer. Two, four, six and eight meter buffers were then constructed using the Buffer tool in the Analysis toolbox around the live cedar GPS points in order to calculate mean and standard deviation for elevation, slope, aspect, and curvature. The four buffers were used to create an empirically based, range of values that described the widest optimal range of each observed site characteristic associated with cedar growth within the study area. The means and standard deviations at each buffer radius were then used to calculate maximum and minimum values for optimal range, denoted R_{max} and R_{min}, respectively. R_{max} and R_{min} were calculated as for each site characteristic as:

(1) $R_{max} = M_{max} + S_{max}$
(2) $R_{min} = M_{min} - S_{min}$

where M_{max} = highest mean, S_{max}=standard deviation of highest mean, M_{min}= lowest mean, and S_{min}= standard deviation of lowest mean.

For the soil type layer, optimal soil types were selected as those within the study area that had cedar trees growing in them. In order to determine an optimal tree range, information such as outcrops' limiting effect on tree size (Oosting and Anderson 1937, Vasiliauskas and Aarssen 1992, Small and Wentworth 1998), standard *J. virginiana* height ranges (Vasiliauskas and Aarssen 1992, USDA 2002) and personal observation of tree height at the site, a height range of 0 to 40 feet was chosen to isolate cedar trees from other species. Due to the coarse 60 meter resolution of the ETM+ data, the largest buffer of eight meters was selected for use as a training set in Feature Analyst 4.3 so that a maximum amount of cedar-associated spectral values could be sampled to isolate such values from other spectral signatures for Jackson County.

Once all of the optimal ranges and values had been determined for the seven site characteristics, each layer was reclassified using Spatial Analyst so that an interpretable raster calculation could be performed. This process involved assigning to all optimal ranges or values a new, interpretable value for the model; all others were given a null value to avoiding confounding results. In order to allow certain variables to have more influence on the model, characteristics of more importance were given higher values than those of less importance. Note that importance was not quantitatively calculated, but rather a qualitative hierarchy was identified based on noted characteristics influencing or indicating cedar cliff presence, such as soil type, aspect, elevation (Oosting and Anderson 1937, LeGrand 1988, Vasiliaukas and Aarssen 1992, Pittillo et al. 1994, Small and Wentworth 1998), and the usefulness of ETM+ spectral data and known land-cover values in land classification (Göttlicher et al. 2008, Mohammadi et al. 2010). Since tree height, slope and curvature values could become easily confounded with other community types or land covers, these values were given less weight in the model. Table 1 includes data on the seven characteristics, including total range of values in Jackson County, optimal values for cedar cliff sites, and the assigned model values for each characteristic.

Once reclassified, the model values for the seven characteristics were added using the Raster Calculator in Spatial Analyst and the resulting layer was added to the map. In order to separate sites by likelihood of cedar cliff habitat, the qualitative hierarchy of characteristic importance was employed. Pixels with values of 1,111,000 or greater (i.e., sites with optimal values for at least the four most important characteristics) were grouped and considered sites with the highest cedar habitat probability, while pixels with values of 111 or less (sites with optimal values for at most the three least important characteristics) were grouped and considered sites with the lowest habitat probability. Two other groups, with value ranges of 111-11,111 and 11,111-1,110,999.99, were considered to have low-to-moderate and moderate-to-high probabilities, respectively, of having a cedar cliff community. The final model was analyzed to determine total number of patches, average patch size, and range of patch sizes using the 8-neighbor rule;

the 8-neighbor rule considers both diagonal and adjacent cells to be neighbors rather than only adjacent cells, as per the 4 neighbor rule.

TABLE 1. Optimal value and model value for seven site characteristics included in habitat probability model.

Site Characteristics	Full Range/Values	Optimal Range/Values	Model Value
Soil Type	(USDA 1997)	CpD, CpF, RkF	1,000,000
ETM+	N/A	N/A	100,000
Aspect	0 - 360°	173.8 - 280.1	10,000
Elevation	460.79 - 1408.2 m	997.2 + m	1,000
Tree Height	0 - 247 ft	0 - 40 ft	100
Slope	0 – 84.7°	16.5 – 41.0°	10
Curvature	-143.0 – 120.5°	-0.8 – 1.5°	1

Notes: Full range and optimal range/values were not included for the ETM+ data as Feature Analysts 4.3 only selects pixels with comparable spectral values to the training values. The output of the classification in Feature Analyst thus only provides the number and location of comparable values and not the actual values themselves.

RESULTS

Cedar Cliff Mountain

Statistical analysis of DBH measures for both live (n=111) and dead (n=26) *J. virginiana* indicated that live cedars were, on average, larger than dead cedars (μ=8.0 in and μ=5.7 in, respectively; Table 2) and also displayed less variation as indicated by standard deviations and DBH ranges (Table 2). Within the study area, the majority of sampled trees (n=87, 78%) were situated on the cliff face, though a smaller proportion (n=24, 22%) were sampled further down the ridgeline into the hardwood forest. GIS analysis found that the largest group (n=49, 44.1%) of trees had DBH measures of 5.78 to 8.75 inches in the second quartile, with the third quartile (n=38, 34.2%), first quartile (n=18, 16.2%) and fourth quartile (n=6, 5.5%) following in proportion (Fig. 2). Mapping of the dead cedars (Fig. 3) found that they were nearly equal in proportion when comparing totals of fallen (n=15) and standing (n=11). However, while the variation in size between standing (s=2.4) and fallen (2.7) dead cedars was similar, fallen trees were larger (μ=6.9) than standing trees (μ=4.0), on average (Appendix A). Of the 105 cedar trees sampled for lightning scars, 78 of them (74%) had indications of at least one lightning strike. Figs. 2 and 4 depict the findings for DBH and lightning strikes, respectively.

TABLE 2. DBH values for living and dead red cedar (*J. virginiana)* on Cedar Cliff Mountain, NC.

Tree Status	Sample Size	Mean DBH (μ)	Standard Deviation (s)	Minimum	Maximum	Range
Living	111	8.0 in	2.4 in	2.8 in	14.7 in	11.9 in
Dead	26	5.7 in	3.0 in	1.5 in	14.9 in	13.4 in

Analysis of the point-centered quarter plots found that *P. virginiana* had the highest relative density on both transects (90.6% and 71.9%, respectively; Table 3) and, although second in density on the second transects (22.9%; Table 3), *J. virginiana* was unrepresented in the first transects. Despite low relative density values for both transects, *J. virginiana* attained a comparable dominance value (41.5%; Table 3) to *P. virginiana* (58.0%; Table 3). Complete results for the point-centered quarter analysis for all three tree species can be found in Table 3, with all recorded values found in Appendix B.

TABLE 3. Point-centered quarter analysis for three dominant tree species in two transects at Cedar Cliff Mountain, NC.

Species	Relative density	Dominance	Mean distance	Absolute density	Total cover
A) Ridgeline Forest			2.25 m	1975 trees/ha	6.5 m^2 per ha
Carya sp.	9.4%	1.5%			
J. virginiana	0.0%	0.0%			
P. virginiana	90.6%	98.5%			
B) Forest Edge at Outcrop			2.125 m	2214 trees/ha	5.95 m^2 per ha
Carya sp.	3.1%	0.5%			
J. virginiana	22.9%	41.5%			
P. virginiana	71.9%	58.0%			

Radial plot analysis determined that *J. virginiana* had higher levels of recruitment in the sample plots than *P. virginiana* as determined by percentage of plots with recruitment (64% and 55%, respectively; Table 4) and average saplings per plot (μ=2.6 and μ=1.4, respectively; Table 4). Also, when measuring average height of a maximum of five saplings per plot, *J. virginiana* saplings were taller on average (μ= 42.4 in; Table 4) than *P. virginiana* saplings (μ=30.3 in; Table 4). Complete results for the radial plot analysis of recruitment are displayed in Table 4, with all recorded values found in Appendix C.

TABLE 4. Recruitment analysis for radial plots.

Species	Plots with recruitment	Average saplings per plot	Total Saplings	Relative Recruitment	μ of Average Sapling Heights
J. virginiana	9	2.6	37	66%	42.4 in
P. virginiana	7	1.4	19	34%	30.3 in

Of the cores collected for cedars (n=10) and pines (n=4), six of the cedar cores were unreadable, either due to knotting or incomplete coring, while all of the pine cores were easily analyzed. Coring analysis of readable samples from *J. virginiana* (n=4) and *P. virginiana* (n=4), determined that the oldest cored cedar was at least 168 years old, while the oldest cored pine was at least 70 years old; on average, cedars were over 100 years older than pines. It should be noted that owing to small sample size and bias in sampling technique yield these values as not statistically significant, but are only mentioned here as an example of a possible age difference between populations of *J. virginiana* and *P. virginiana* on Cedar Cliff Mountain. Table 5 presents all cored tree ages and statistics for both species.

TABLE 5. Coring analysis data of *J. virginiana* and *P. virginiana* on Cedar Cliff Mountain, NC.

Species	Age 1 (yrs)	Age 2 (yrs)	Age 3(yrs)	Age 4 (yrs)	Mean
J. virginiana	130	166	135	168	149.8
P. virginiana	32	47	33	70	45.5

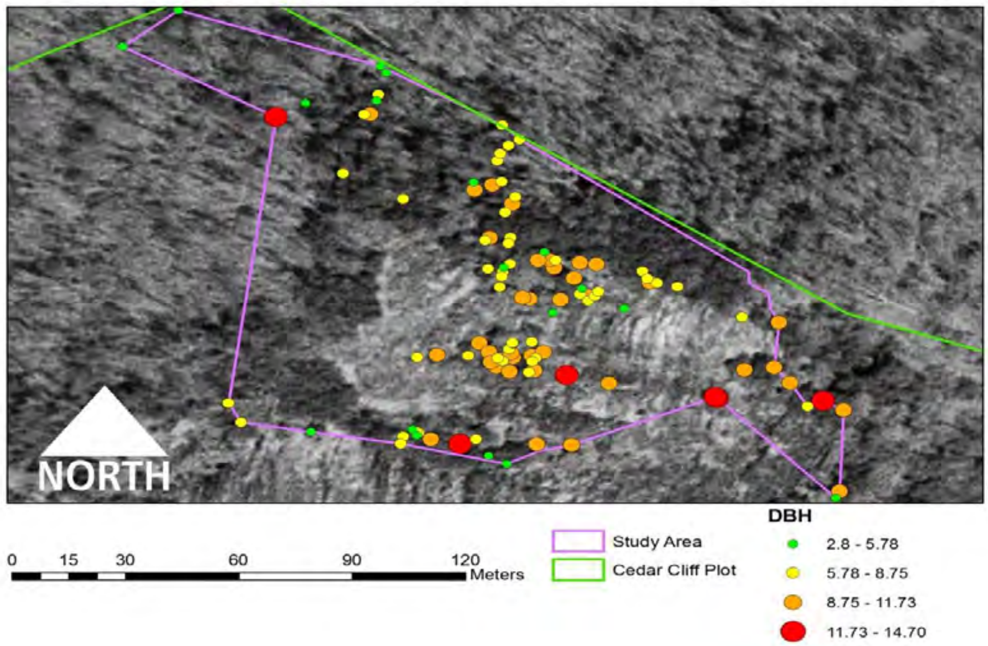

FIG. 2. Quartile depiction of live *J. virginiana* DBH ranges within the study area. Most individuals within each quartile are found near or on the outcrop face, with a group of individuals from various quartiles represented in the woodland further down the ridgeline to the west.

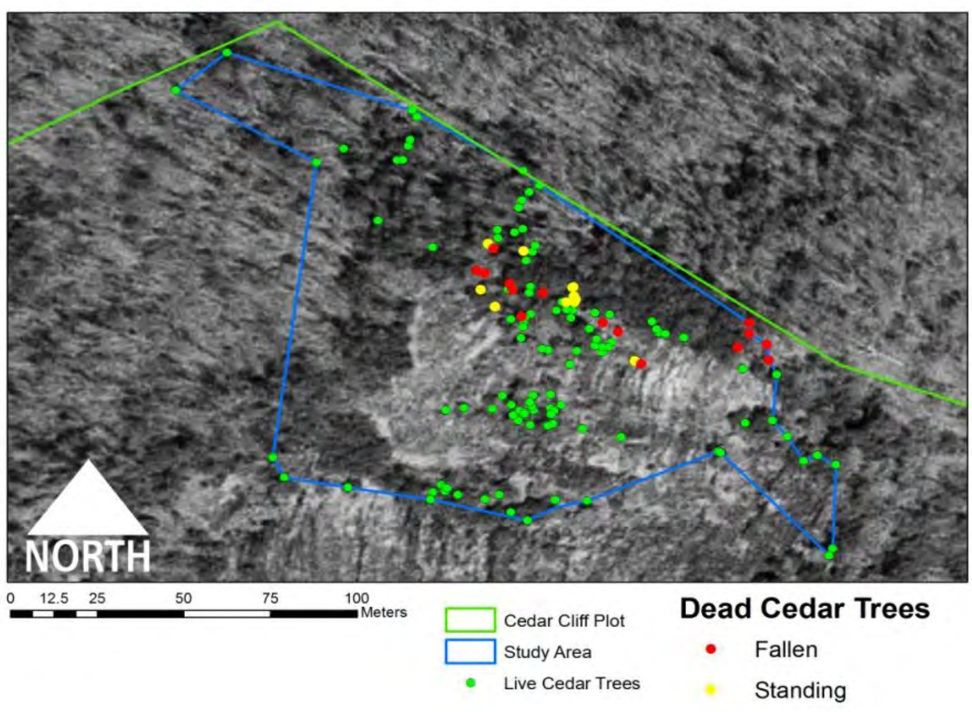

FIG. 3. Depiction of dead *J.virginiana* sampled along ridgeline at Cedar Cliff Mountain. Size difference of points denoting live and dead individuals does not represent actual size difference, but is used to increase visibility of dead cedars.

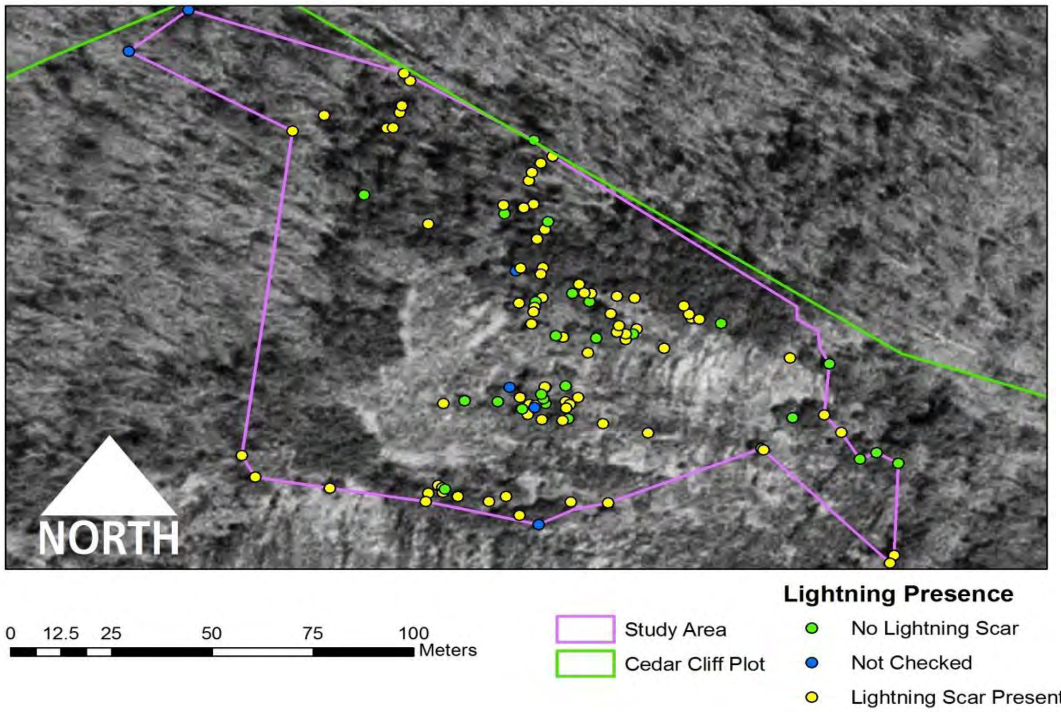

FIG. 4. Distribution of lightning disturbance across a majority (n=105) of sampled *J. virginiana* within the study area at Cedar Cliff Mountain. Nearly three quarters (74%) of all examined trees displayed some form of lightning scarring, while the remainder displayed no visible evidence of lightning disturbance.

Cedar Cliff Habitat Probability Model for Jackson County, NC

In order to consider the model viable for use, the model had to pick up the study area within its highest probability value range and also had to provide the surrounding hardwood forest with, at most, a moderate valuation (Fig. 5). The habitat probability model for cedar cliff habitat found that only 0.03% of pixels (n=134) had a high model probability (Value ≥ 1,111,000) of indicating a cedar cliff community. This result indicates that approximately 430, 800 m^2 of all of Jackson County (1,260,227,235 m^2) had optimal values for most characteristics, or at least all four key characteristics. The model also found that 91.17%, or around 1,149,000,000 m^2, was least likely (values ≤ 11,000) to support a cedar cliff community. The remaining two categories, low-to-moderate and moderate-to-high probability of representing a cedar cliff community, only accounted for 8.80%, or about 110,770,000 m^2, of Jackson County's area. The resulting map (Fig. 6) displays points where the model predicts there is a high probability of a cedar cliff community being present. Using the 8-neighbor rule, 47 different patches were identified with a model-predicted high probability of representing a cedar cliff community; the smallest of these sites (n=22) had an area close to 3,200 m^2, while the largest patches (n=4) were approximately 28,900 m^2.

Eight of the larger predicted sites were visited to verify the success of the model (Table 6). It should be noted that limited access to these locations restricted my analysis to observation with binoculars. Of the sites I visited, only one (Fig. 6) had a clear cedar community present along a south facing rock outcrop, while three had cedar present but needed closer examination to determine if a cedar community was truly present. The remaining three sites showed no indication of either cedar or a cedar cliff community. I was unable to verify the existence of a community at one site, Flat Creek, due to a gate that blocked visibility of the site.

TABLE 6. Visual analysis of model-predicted sites selected for ground truthing.

Predicted Cedar Site	Cedar Present	Verified Community	Field Notes
Wade St./High Hampton	No	No	*P. strobus* and *P. pungens* dominant
Lonesome Valley/Laurel Knob	Yes	Possible	Possible community on northernmost portion of outcrop
Round Hill/Merrie Woode	Yes	Possible	Possible small community, mostly *Pinus* spp.
Twin Creeks	Yes	Yes	Clear dominance of *J. virginiana* along westernmost ridge of outcrop
Flat Creek	N/A	N/A	N/A
Shepard's Rd.	No	No	Mostly hardwood species, few *Pinus* spp.
Parachute Ridge	No	No	Mostly hardwood species
Thorpe Rd.	Yes	Possible	Possible community along ridgeline

Notes: Sites were chosen based on perceived level of access due proximity to major roadways. Access to the Flat Creek site was blocked off resulting in the null values noted in the table.

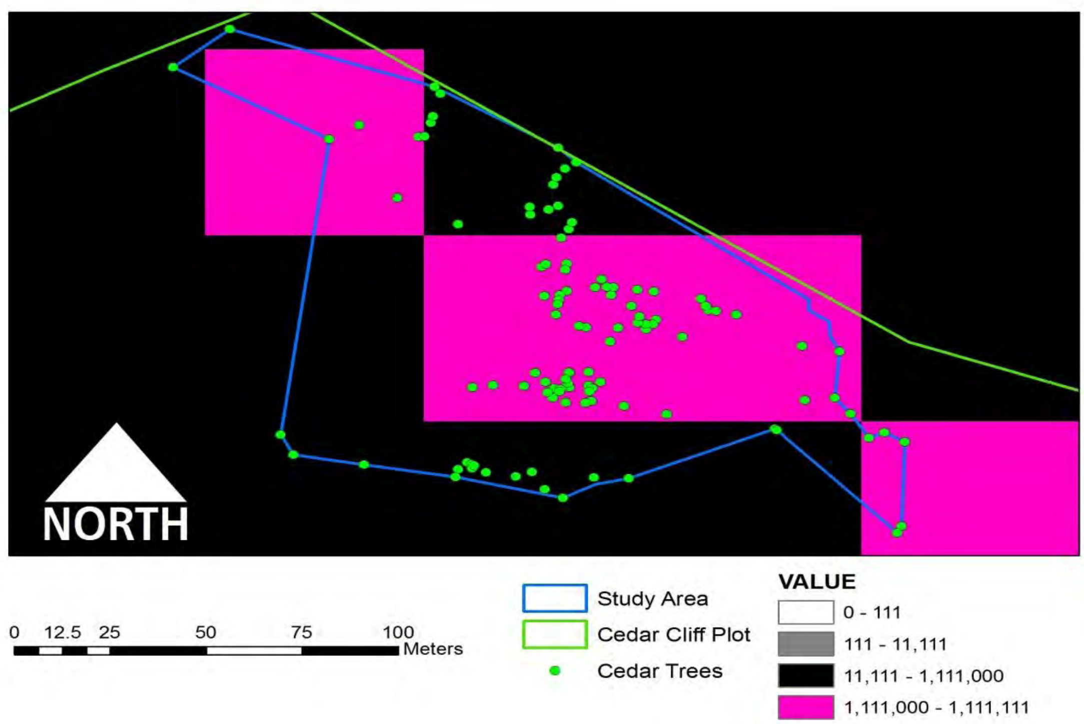

FIG. 5. Results of raster calculation depicting the study area with a value within the highest probability bracket of potential cedar cliff habitat. This result indicates the likelihood that the model is accurate enough to pick up similar sites.

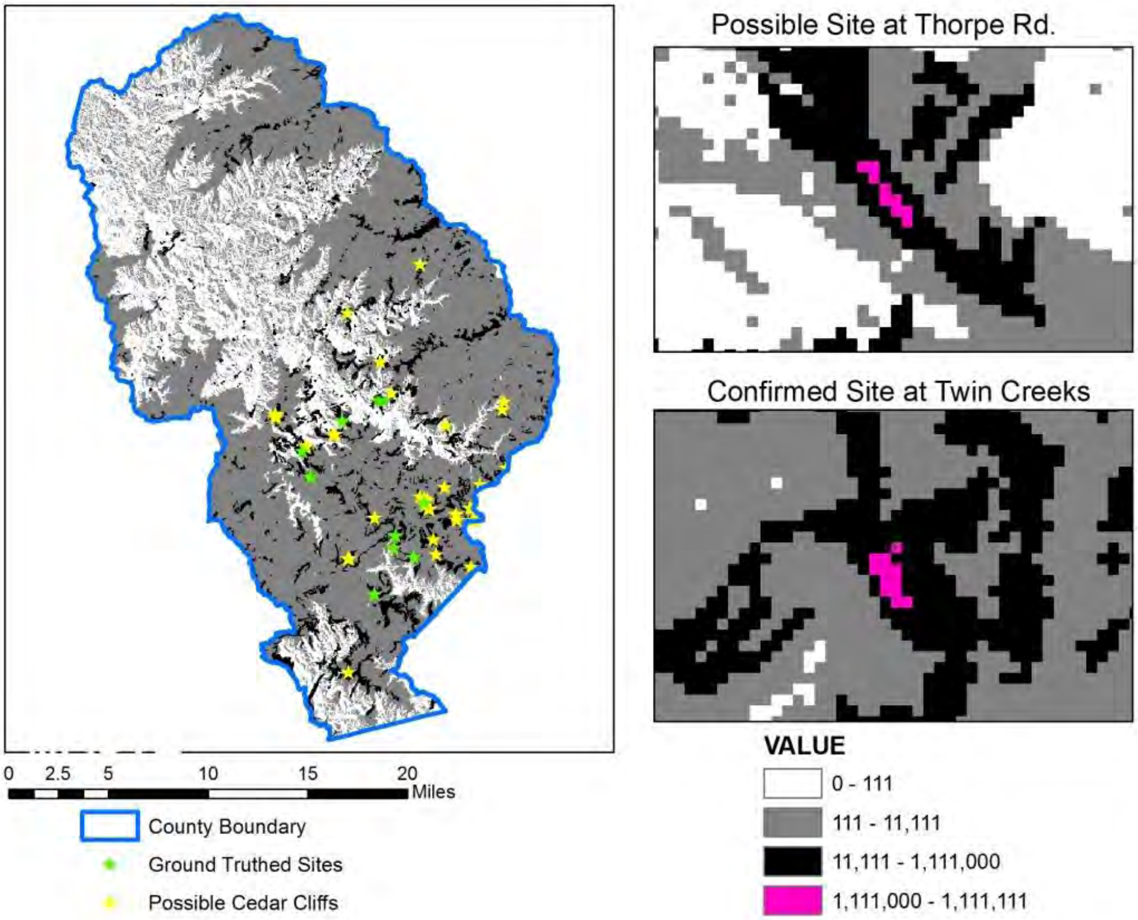

FIG. 6. Locations of model-predicted cedar cliff communities and sites visited for ground truthing. Two sample sites are detailed to illustrate a positive result, and a highly likely positive result pending further field analysis.

DISCUSSION

Community Dynamics on Cedar Cliff Mountain

DBH data confirmed that the cedar population on the main face of Cedar Cliff Mountain represents a mature community, as a majority of the largest individuals in the sample, are present within this portion of the study area. It is important to note that a significant portion of the cedars in this study (n=24, 21.6%) were observed further down the ridgeline into the hardwood forest; this is unusual as cedars do not compete well with hardwoods (Buehring et al. 1971). This may indicate a wider historical range of the current cedar community, which is mostly restricted to the main face; the largest live cedar sampled in this study (DBH= 14.7 in) was recorded in this portion of the study area and could possibly be a relic of an older cedar population at the site. However, DBH values in this portion of the study area also decrease (Fig. 3) as cedars are sampled further into the forest, which also indicates a more recent effort to recruit into that section of forest. Greater *J. virginiana* clustering (Fig. 3) was expected within the main cliff face as the higher incident radiation, minimal hardwoods, low moisture and shallow soils there constitute prime habitat for cedars (Oosting and Anderson 1937, Buehring et al. 1971, LeGrand 1988, Small and Wentworth 1998). The high incidence of lightning scars among sampled cedars also indicates that this community experiences high levels of disturbance, adding to their slow, irregular growth rates.

When analyzing the interaction between *J. virginiana* and *P. virginiana*, and *Carya* sp. to a smaller extent (Table 3), results indicated that despite major pine dominance within the ridgeline forest and along the outcrop edge, the population of *J. virginiana* seems to be flourishing. The point-centered quarter analysis determined that, despite lacking any representation along the first transect, the second transect at the outcrop edge indicates that *J. virginiana* exhibits comparable dominance values (41.5%) to *P. virginiana* (58.0%). The radial plot analysis had even more promising results for the cedar community, indicating that of all sampled recruitment, *J. virginiana* had more and larger saplings than *P. virginiana* within the study area (Table 4). This indicates that although cedar is decreasingly present as trees are sampled further into the less suitable ridgeline forest, their relative dominance and overall recruitment within their prime habitat, the main cliff face, are evidence of a healthy, and possibly growing, cedar cliff community.

Habitat Probability Model

The habitat probability model was moderately successful in identifying possible sites when ground truthing was performed. Of all the checked ground sites, half of the sites appeared to have populations of *J. virginiana*, but only one had a visually verifiable community (Twin Creeks). The other half of the predicted sites yielded mixed results, with some sites presenting either hardwood or evergreen dominated forest lacking in *J. virginiana*. Restricted access at one site, Flat Creek, prevented visual confirmation of community type; limited access was an issue at every site that was visited. The high demand for homes with views and ridgeline parcels in the area has greatly restricted access to analyze high elevation plant communities. In order to more fully determine the accuracy of the model, access to the predicted sites would be needed.

A few trends were noticed among the model-predicted sites during GIS analysis. The largest trend is that all of the predicted sites were clustered within the southeastern portion of Jackson County (Fig. 6). Another interesting pattern is that the proximity of the sites seems to decrease as one moves from the southeastern corner of the county to the northwest (Fig. 6). It also appears that there is a gradient among preferable site characteristics, moving from the values of the least determined importance to the more important values; this finding is visible in the model-predicted communities at Thorpe Rd. and Twin Creeks. This finding seems to indicate that these communities do not have a random distribution, but rather arise as a result of overlap between the model's seven, and likely more in actuality, preferable habitat characteristics and follow an environmental gradient across the county.

In light of these findings, there are many aspects of the model that would likely benefit from adjustments and further refinement. One major issue that compromised the effectiveness of my model was the quality of the data. Issues with resolution, such as the ETM+ and tree height data's coarse resolution (60 m and 20 m, respectively), reduced the level of accuracy that could be obtained for site characteristics. As the canopy area of cedar trees is smaller than these values, it would be hard to avoid confounding cedars with nearby species. Another key issue to address is the manner in which site characteristics are assigned importance. Rather than arbitrarily designating importance values to characteristics based on perceived importance, a quantitative study would allow values to be assigned importance by true relation to the requirements of *J. virginiana* in rock outcrop habitats.

Ultimately my model only enjoyed a moderate rate of success as determined by ground truthing. However, the model's true accuracy and predictive ability can only be assessed by visiting all model-predicted sites. Furthermore, while the seven characteristics used in the model seemed to provide a fair characterization of cedar cliff habitat, more comprehensive sampling and a group of study areas would better inform and increase its predictive ability.

Habitat Mapping as a Conservation Tool

While my model requires modification and improvement, it is important to recognize that such models have an important role as a conservation tool. The first step in any conservation effort involves the mapping and ground truthing of potential habitat for species at risk; the extent of the issue must be determined before action can be taken. In their 2007 study, Tie et al. used a similar habitat mapping approach in order to create a potential reserve that could protect *Cryptomeria fortunei* (China Cedar). Through habitat mapping, they created three functional zones, denoted as the core zone, buffer zone, and experimental zone, in order to prioritize potential habitat and to minimize disturbance in high priority areas. Another study used GIS habitat mapping in order to determine potential habitat on a U.S. military reservation for the grassland bird *Lanius ludovicianus* (Loggerhead Shrike); *L. ludovicianus* has been declining since the 1940s (Lauver et al. 2002). Once the predicted habitat was verified, the Department of Defense was able to protect the bird species through maintenance of the confirmed grasslands habitats. Both of these studies represent key examples of how a GIS-based mapping approach provided the necessary information in order to take the next step in conservation, namely, habitat protection.

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APPENDIX A

DBH and lightning values for live cedars within study area and complete table of DBH values and standing status for dead cedars along ridgeline (digital archive on attached CD).

APPENDIX B

Point-centered quarter analysis results for transects one and two (digital archive on attached CD).

APPENDIX C

Radial plots taken within the study area (digital archive on attached CD).

COMMUNITY OUTREACH IN HIGHLANDS, NORTH CAROLINA TO PROTECT PRIORITY BIRD SPECIES

TRUDIE HENNINGER

Abstract. An Audubon North Carolina sponsored project in Highlands, NC, known as the "Treasure Highlands" project, has focused on effectively communicating to members of the Highlands community about ways they can help protect priority bird species, in hopes that they will become more involved in the conservation process. The research focused primarily on providing educational materials for landowners in Highlands on how to protect priority bird species including the importance of maintaining canopy closure, vegetation structural complexity, the use of native plants and control of invasive plants, and reducing human related dangers to birds. This information is being compiled into multiple formats including in a booklet, website, and video segment for the community's use. This project also contributed to the citizen science aspects of the "Treasure Highlands" project by field testing and simplifying citizen science vegetation protocols aimed at relating vegetation within the town of Highlands to other data.

Key words: canopy structure; citizen science; community conservation; Highlands, NC; invasive plants; landscaping; native plants; priority bird species; structural complexity; Treasure Highlands; vegetation protocol.

INTRODUCTION

As the world's population increases and people continue to develop more land, the habitat and diversity of important species are being depleted and destroyed. Demands for resources and forest and agricultural products on local, national, and global levels drive forest depletion (Drummond and Loveland 2010). Worldwide, more forests are declining than increasing (Drummond and Loveland 2010). Declining forests cause habitat loss, which is the most pressing threat to the survival of plant and animal species (Wilcove 1998). Habitat destruction can be largely attributed to agriculture, livestock grazing, mining, logging, infrastructure development, and urban and commercial development (Wilcove 1998). Commercial timber production, the expansion of residential and other development, and mountaintop mining have mostly been responsible for the decline of forest habitat in the eastern United States (Drummond and Loveland 2010). Importantly, declining forest habitat due to urban and commercial development is most often a permanent change (Drummond and Loveland 2010). As noted by Gaston (2010), "in the absence of a detailed understanding of what each species does in an ecosystem, it would be foolish to allow the loss of any one of them." As more forest habitats are destroyed there is a greater need for more research and protection of threatened or endangered species.

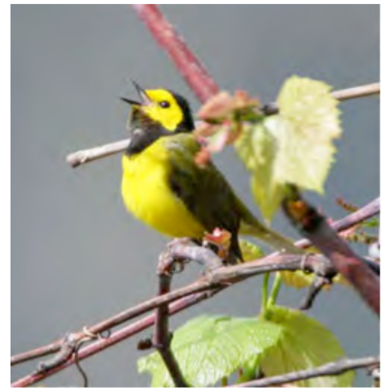
Years of conservation efforts have shown that it is critical to get the community involved and interested in protecting threatened or endangered species. However, involving the community is one of the biggest challenges of conservation efforts (Marcovaldi and Marcolvaldi 1999). Conservation programs that involve local communities have had more long-term success protecting endangered or threatened species than conservation programs that have not involved local communities. For example, the marine turtle conservation program Projecto TAMAR-IBAMA in Brazil has been successful due to the involvement of local fishing villages in helping protect the habitat of endangered marine turtles (Marcovaldi and Marcolvaldi 1999). Communities that are involved in the protection of species are more likely to support environmental policies and conservation plans for that particular species (Wilcove et al. 1998). Furthermore, areas where the community is involved in the conservation of a species are likely to have higher diversity (Bajracharya et al. 2005). In order to successfully conserve and protect threatened or endangered species there should be emphasis on involving the local community.

The National Audubon Society (NAS) is a non-profit organization with a mission to "conserve and restore natural ecosystems, focusing on birds, other wildlife, and their habitats for the benefit of humanity and the earth's biological diversity" (Audubon North Carolina 2010). The NAS projects typically involve communities in order to promote the conservation of bird species. The NAS also involves communities in citizen science research programs through which data is collected about bird species and habitats. Audubon North Carolina (ANC) is a state office of the National Audubon Society that spearheads identification and conservation of Important Bird Areas in North Carolina. Important Bird Areas are designated areas worldwide that need to be conserved due to their importance for birds (National Audubon Society 2010b). Highlands is a unique mountain town known for its high species diversity in many taxonomic groups including birds. Highlands has been classified as an Important Bird Area by Audubon North Carolina as it provides essential bird habitat for priority bird species. There are approximately 200 breeding species of birds in North Carolina, and about 80 of those species breed in the Highlands Plateau, including approximately 20 species listed as high priority for North Carolina and the southern Appalachians by the NAS, the North Carolina Heritage Program or Partners in Flight including *Dendroica caerulescens (*Black-throated Blue Warbler), *Dendroica virens* (Black-throated Green Warbler), *Regulus satrapa* (Golden-crowned Kinglet), *Wilsonia citrina* (Hooded Warbler), *Sitta canadensis* (Red-breasted Nuthatch), *Wilsonia canadensis* (Canada Warbler), and *Parula americana* (Northern Parula) (Fig. 1). Some of these species have confirmed or suspected sub-species that are endemic to the southern Appalachians. These include *Vireo solitarius alticola (*Blue-headed vireo), *Junco hyemalis carolinensis (*Dark-eyed Junco*)*, and *Dendroica caerulescens cairnsi* (Black-throated Blue Warbler*)*, *Poecile atricapilla practicus* (Black-capped Chickadee), *Dendroica virens waynei* (Black-thraoted Green Warbler), *Certhia americana nigrescens* (Brown Creeper), *Bonasa umbellus monticola* (Ruffed Grouse), *Sphyrapicus varius appalachiensis* (Yellow-bellied Sapsucker), *Loxia curvirostra pusilla* (Red Crossbill), *Troglodytes troglodytes pullus* (Winter Wren), *Thryomanes bewickii altus* (Bewick's Wren), *Aegolius acadicus acadicus* (Northern Saw-whet Owl) (Lee 2004). Unfortunately, bird habitat in Highlands, NC has been jeopardized by logging and development of housing and recreation in the area. The addition of golf courses, residential neighborhoods, and business districts cause dramatic changes in bird communities (Minor and Urban 2009). Previous research in Highlands, NC has shown that such logging and development has altered the composition and structure of the Highlands bird communities and habitats since the 1800s (Chin 2009).

ANC is implementing a project, called Treasure Highlands, aimed at educating the Highlands community about the priority birds in the area, involving community members in protecting and creating habitats for the birds, as well as having community members help gather data on the bird species in the area. For this phase of the project research on landscaping for birds and photography of Highlands will be used in the creation of a Treasure Highlands website, booklets, and video segments to provide easy-to-understand instructions, pictures, diagrams, and additional helpful links on how landowners can landscape their yards as successful bird habitat. This project also has a citizen science component that involves field testing and simplifying citizen science vegetation protocols.


Black-throated Blue Warbler
Dendroica caerulescens


Black-throated Green Warbler
Dendroica virens


Hooded Warbler
Wilsonia citrina


Golden-crowned Kinglet
Regulus satrapa


Northern Parula
Parula americana


Red-breasted Nuthatch
Sitta canadensis


Canada Warbler
Wilsonia canadensis

Fig. 1. Images of priority bird species in Highlands, NC. All photos used with permission by Dr. Steven Bullock

METHODS AND MATERIALS

Study Area

This study was conducted in Highlands at the Highlands Biological Station located at 265 North Sixth Street Highlands, NC 28741. Highlands, NC is in the southern Appalachian Mountains of western North Carolina at 35°3′15″N 83°12′8″W. Highlands has a high elevation, with an average elevation of 4,118 feet. Due to its high elevation, Highlands has cool temperatures and abundant rainfall, with an average of approximately 80 inches of rainfall per year (Chin 2009). Highlands is renowned for its high diversity of plants and animals due to the climate, rainfall, and elevation. Birds are particularly abundant in Highlands, which is well known for a variety of warblers and species associated with hemlock forests. The town of Highlands is home to about 80 breeding species of which twelve are endemic subspecies of birds (Lee and Browning unpublished).

Methods

The vegetation protocol data sheet was obtained from Heather Lumpkin, a graduate student from the University of Wisconsin who has been looking at relating bird density to housing density in western North Carolina (Lumpkin, H. pers. comm. 2010). The vegetation protocol was tested at the following five locations: a densely forested landscape from the parking lot road behind the Highlands Biological Station, an open grass area at the Highlands Civic Center, and three randomly chosen nearby developed neighborhoods in Highlands. These locations were chosen to ensure the vegetation protocol data sheet was applicable to different densities of vegetation. From one point at each location the cover type was recorded as forest, pasture, old-field, distance, blacktop or rock, house, lawn, or row crop every 5 meters along a 40 meter transect. The percent coverage of herbaceous plants, shrubs, sub canopy, and canopy was then recorded every 5 meters along a 40 meter transect. The cover type and percent coverage across the 40 meter transects was estimated by standing at one point and estimating the distance. This was done in the North, East, South, West, Northeast, Southeast, Southwest, and Northwest directions from the point location. A compass was used to determine the directions. The vegetation protocol data sheet was then edited to better suit the needs of Audubon and to simplify them for the citizen participants.

Using the Google search tool I researched how to landscape yards for birds. The information gathered on landscaping for bird habitats was explored for recurring themes on how landowners can help protect birds in their backyards. Pictures of exemplary landscaped bird habitat were taken at the house of Doug and Barbara Landwehr, landowners in Highlands, NC. Pictures of Highlands, including Dry Falls, Bridal Veil Falls, Bust Your Butt Falls, and Sunset Rock were taken and compiled by myself and fellow student Gabe Hobson. Curtis Smalling, mountain region biologist and North Carolina Important Bird Area Coordinator for Audubon North Carolina, and I identified four main themes that we wanted to share with Highlands landowners. These include the importance of maintaining a canopy closure, vegetation structural complexity, the use of native plants and control of invasive plants, and reducing human related dangers to birds such as pesticide use.

The information on landscaping for birds was then synthesized, simplified, and organized under the four main themes to include what each theme is, a description of each theme, and why each theme is important, as well as links to further information and diagrams. This information was summarized and expanded into a narrative for a short video segment. This information was also edited and arranged by Curtis Smalling for publication in booklet form and on the Treasure Highlands website.

RESULTS AND DISCUSSION

The field tests of the vegetation protocol data sheet helped determine what needed to be simplified and clarified The vegetation protocol will be used to provide additional information for other surveys that might occur. Particularly, the vegetation protocol data sheet will provide additional information to point counts done by citizen scientists at permanent point locations in Highlands (Appendix A). It was determined that another definition other than forest was needed to describe the vegetation in a neighborhood, that it was hard to see the herbaceous plant material past ten meters when standing at one point and that it would be helpful to have definitions for each of the plant types on the protocol data sheet. The distances on the vegetation protocol data sheet were shortened from 40 meters to 30 meters. The percent scale was changed to a presence/absence scale. An additional cover type of "landscaped" was added to the definitions for our cover types. The updated and simplified vegetation protocol data sheet is provided in Fig. 2. A space was also added to provide a name. The simplified vegetation protocol data sheet will make it easier for more citizen scientists to complete. The vegetation protocols will be used to relate vegetation within Highlands to other data such as priority bird species densities, and generating the mapping necessary to establish permanent monitoring points for those surveys as well as other ecological monitoring efforts.

Name ________________

Point Count Habitat Datasheet

Point Name ____________________ Point Number __________________ Date___________

	North				East				South				West			
Distance	5	10	20	30	5	10	20	30	5	10	20	30	5	10	20	30
Cover type																
Herbaceous																
Shrub																
Subcanopy																
Canopy																

	Northeast				Southeast				Southwest				Northwest			
Distance	5	10	20	30	5	10	20	30	5	10	20	30	5	10	20	30
Cover type																
Herbaceous																
Shrub																
Subcanopy																
Canopy																

FIG. 2. Edited vegetation survey protocol data sheet

The research done for this project found that in order to contribute to the survival of bird species, landowners should maintain structural complexity of vegetation, maintain a canopy structure, use native plants and control invasive plants, and reduce dangers to birds. Structural complexity includes different layers of vegetation from the ground up to the uppermost canopy layer. Structural complexity of vegetation is important especially for birds because birds use different layers of vegetation for different activities such as feeding, nesting, collecting materials for their nests. Structural complexity also gives birds protection when they are searching for food, as they are able to more easily hide from predators in the different layers from the ground up to the canopy. Some strategies for increasing habitat complexity including first placing low growing plants near the ground should be placed under shrubs. Brush piles of limbs and sticks could also be placed on the ground level. Low growing shrubs should then be placed under taller growing shrubs and trees that make up the canopy layer. If habitats have little or no structural complexity very few bird species can be sustained.

A healthy canopy layer should be maintained as bird habitat, and the removal of mature trees is discouraged. The canopy layer is an important component of the structural complexity of vegetation. The canopy is made up by the tallest trees, of multiple tree species, that are above all other lower vegetation. The plants that make up the canopy should be of significant height, and if possible above the roof of the landowner's home. Trees that make up the canopy in the Highlands area include *Quercus* spp. (oaks), *Acer* spp. (Maples), *Carya* spp. (hickories), *Magnolia* spp. (magnolias), *Tilia* spp. (basswood), *Betula* spp. (Birches), *Robinia pseudoacacia* (black locust), *Fraxinus Americana* (white ash), *Oxydendrum arboretum (*sourwood), *Fagus grandifolia* (beech), *Nyssa sylvatica* (black gum), *Juglands nigra* (black walnut), *Castanea dentata* (chestnut), *Catanea pumila (*chinquapin), *Prunus serotina* (black cherry), and *Liriodendron tulipifera* (yellow poplar) (Highlands Greenway 2008b). Many birds use the canopy as protection from predators as well as a supply for food and a place to build nests.

Native plants should be used and invasive plants should be removed and controlled. Some examples of native small trees and shrubs in the Highlands area include *Catanea pumila (*chinquapin), *Liriodendron tulipifera* (yellow poplar), *Pinus strobus, Pinus echinata or P. taed,* (pines), (*Abies* spp. (firs), *Tsuga* spp. (hemlocks), *Cornus florida* (flowering dogwoods), *Ilex* spp. (hollies), *Rhododendron* spp. (rhododendrons), and *Hamamelis virginiana* (witch hazel) (Highlands Greenway 2008b). Native plants are important to bird species for many reasons. Birds are better adapted to food sources from native plants and often will first choose to eat from native plants over non-native plants (Craves 2009). Native plants usually provide birds with places to build nests. Furthermore, native plants can provide birds with food year round as they bloom at different times of the year, and are better suited to survive the climate where they are naturally found. Native plants further provide birds with food by providing habitat for insects that birds consume.

In contrast, invasive plants are plants that were introduced to the southern Appalachians that do not naturally grow there. Exotic plants can be invasive and outcompete native plants and destroy critical wildlife habitats. Some of the many exotic invasive plants in Highlands include *Morus alba* (white mulberry), *Lonicera maackii* (Amur honeysuckle), *Lonicera morrowii* (Morrow's honeysuckle), *Lonicera fragrantissima* (sweet-breath-of-spring), *Rubus phoenicolasius* (wineberry), *Herdera helix* (English ivy), *Lonicera japonica* (Japanese honeysuckle), and (*Pueraria montana* (kudzu) (Highlands Greenway 2008a). Exotic invasive plants can quickly overtake areas, reducing the diversity of plants that are critical to bird survival. Appropriate action for landowners concerned about bird habitat would be to remove exotics from their yards and replace them with native plants.

There are various dangers to birds caused by humans. One major threat to bird populations is domestic cats, which are responsible for hunting and killing many birds. House and feral cats are estimated to kill hundreds of millions of birds per year in the United States (American Bird Conservancy 2010). Landowners can prevent birds from unnecessarily encountering wild predators by keeping their cats indoors. Raccoons, skunks and rats can also be predators of birds and bird eggs. By keeping the lids on garbage cans, keeping compost piles covered, and keeping pet food inside, landowners can help birds by not attracting raccoons, skunks to their habitat (PRBO Conservation Science 2010).

Another major threat to bird populations is the use of pesticides on lawns and gardens. The use of pesticides can harm the health of birds and even kill birds. Pesticides can also severely deplete the food sources of birds by killing the insects that they survive on. Furthermore, collisions into windows of buildings can be a significant cause of bird mortality. Windows can sometimes reflect the outdoor habitat which birds will mistakenly fly into and get fatally injured. The Audubon website provides homeowners with solutions to prevent bird collisions with windows including placing feeders more than 30 feet from a window, using white or light colored window screens that are kept closed as often as possible, placing decals on or in front of windows, using bug screens over windows, or using a bird net across the window (National Audubon Society 2010a). Even when trying to help birds, humans can put birds' health at risk. By providing unclean bird feeders humans can contribute to the spread of diseases amongst birds. It is important for landowners to keep bird feeders clean such as by wiping the excess droppings each day from the actual seed. Also replace old seed that accumulates at the bottom of some feeders.

This information for landowners is provided an informational booklet, in video segments, and on the Treasure Highlands website that outlines ways that landowners can provide habitat for birds despite increasing urbanization and development. The Treasure Highlands website will be a convenient resource for residents and visitors to find outdoor activities, volunteer opportunities and other resources so that they can be involved in the protection of birds. The website will link volunteers with Treasure Highlands and its local partners in Highlands. Partners to be engaged in this project include Highlands/Cashiers Land Trust, Highlands Biological Station and Nature Center, Jackson-Macon Conservation Alliance, Upper Cullasaja Watershed Association, Highlands Audubon Society, Highlands Greenway Association, Nantahala National Forest, and Center for Life Enrichment. Other organizations may include the Laurel Garden Club, Mountain Garden Club, NC Bartram Trail Association, Nantahala Hiking Club, Over the Hill Hikers, and Land Stewards of Highlands. The Treasure Highlands project will encourage participation in the protection of birds through public meetings, resources on its website and printed materials. Treasure Highlands will inform the public of its resources using posters, mailings, and print ads.

This project focused on providing resources to the community of Highlands in order to encourage involvement in the conservation and protection of priority bird species. As bird species decline nationwide, the need to protect them becomes more imperative. Previous research in Highlands shows that changing forest habitat has affected the bird species present in Highlands (Chin 2009). Birds play an important role in southern Appalachian ecosystems and it is necessary that efforts are made to protect them. The conservation of priority bird species in Highlands will most likely be more successful with the involvement and support of the community. According to GIS analysis from ANC within the Highlands Plateau Important Bird Area, about 35 percent of the land area is in privately owned and embedded within a matrix of national forest (Smalling, C. pers. comm. 2010). The Highlands community has an opportunity to contribute to the conservation of priority bird species. We hope that the Treasure Highlands website, booklets, and video segments, as well as the simplified vegetation protocol, will be successfully used by the community and can then be implemented in other towns and cities to help protect and preserve important bird species across the United States.

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APPENDIX A

Point count detailed information, important bird areas bird census sheet, map of point locations in Highlands, NC, and important bird areas bulls-eye data, digital archive on attached CD.

PHYSICAL DESCRIPTIONS AND ASSOCIATED ECOLOGICAL ANALYSES OF WESTERN NORTH CAROLINA *STEWARTIA OVATA* POPULATIONS

GABRIEL P. HOBSON AND MICHAEL T. HOUSER

Abstract. *Stewartia ovata* is a rare woody species of the Theaceae family known for its silky white flowers. While much is known about the species in cultivation, little is known about its natural habitat. Our study identified, mapped, and collected physical and ecological data on all known populations of *S. ovata* in western North Carolina. Using data on slope aspect, slope inclination, elevation, and associated species we attempted to identify characteristics indicative of the species' natural habitat. The study found that populations in western NC occupied habitats characterized by north-facing slopes of inclinations between 17° and 33° and an elevation range of 1,500 to 2,000 feet.

Key words: basal area; conservation; GIS; mountain camellia; rare plants; rare species; southern Appalachian; Stewartia ovata; *Theaceae; western North Carolina.*

INTRODUCTION

Conservation of rare and outstanding elements of floral diversity is a goal that merits special consideration as land-use decisions are made, and may carry important implications for the sustainability of entire ecological communities (North Carolina Natural Heritage Program 2010). The species *Stewartia ovata* (Cav.) Weatherby, also commonly referred to as mountain camellia, is one such rare and outstanding element among the rich flora of western North Carolina. Said to embody the Japanese principle of *wabi-sabi*, or the intuitive appreciation of understated beauty (Hsu et al. 2008), members of the genus *Stewartia* have long been coveted by horticulturalists for their large white flowers as well as unique bark patterns and stately foliage.

A member of the Theaceae or tea family, the genus *Stewartia* consists of both evergreen and deciduous species that enjoy a surprisingly wide geographic distribution from eastern Asia to eastern North America. Only two species occur naturally in the United States, *S. malachodendron* and *S. ovata,* both of which are deciduous and tend to occur only in sparse populations throughout the southeastern US (Spongberg and Fordham 1975). Despite this limited present-day distribution in North America, fossil evidence from Europe dating to the middle Oligocene suggests widespread, ancient origins for the genus (Spongberg 1974). Spongberg (1974) also remarks that the current distribution between eastern North America and eastern Asia, coupled with such fossil evidence, may suggest that the genus is an Arcto-Tertiary relict. Today, wild populations of *Stewartia* (and particularly *S. ovata*) are uncommon in the southeastern US, a trend that is especially true in the higher elevations of western North Carolina. Populations of *S. ovata* are most abundant in the Cumberland Plateau of Tennessee and Kentucky (Weakley 2008). Although distributions of the two species overlap, the aesthetic beauty and rarity of *S. ovata* in particular has made it quite popular among horticulturalists, despite plants being difficult to procure and requiring delicate attention in order to establish and maintain in cultivation.

Stewartia ovata ranges from the southern Appalachians and adjacent piedmont of Georgia and the Carolinas west to Alabama, Kentucky and Tennessee (Spongberg 1974). It also occurs in two disjunct populations on the coastal plain of Virginia, where it was originally discovered in 1678 by Reverend John Clayton near Williamsburg (Baldwin 1969). The species is characterized by silky white flowers usually measuring 2.5in across and consisting of five petals (Fig. 1). The leaves measure 2-5in in length and are alternately veined ovate with an acuminate tip, having fine serrations of 0.5-1cm spacing between teeth and a finely pubescent lower surface. Seeds have winged margins and are contained in woody capsules that may remain on the branches well into the winter months. Trees may reach a height of 18-20ft, often consisting of multiple trunks or stump sprouts displaying a unique, scaly bark pattern. In the wild, they may grow at an angle towards the base of the slope on which they are found.

FIGURE 1. **Stewartia ovata.** a, flowering branchlet of forma *grandiflora* × 1/2; b, flower of forma *ovata*, × 1/2; c, apically dehiscent capsule with 5 persistent styles and persistent calyx, × 1 1/2; d, seed with winged margin and finely rugose surface, × 3.

FIG. 1. *Stewartia ovata* (Spongberg 1974).

Very little is known about the natural habitat of *Stewartia ovata.* While there is information available pertaining to its cultivation, we are aware of no published papers or data that relate to the physical and ecological environment in which *S. ovata* naturally occurs. Furthermore, since this is a particularly rare species in western North Carolina, it is important to record as much information as possible about its ecology in the wild. Such knowledge could prove integral to future conservation efforts or attempts to locate additional populations. It is for these reasons that our study examines the physical and ecological characteristics associated with *S. ovata* populations in the western NC region. Data presented will include physical characteristics such as site elevation, aspect, and slope. Diameter at breast height (DBH) measurements and data on associated species will yield basal area, density, and dominance measurements. Additionally, detailed maps will illustrate the geographic distribution of trees throughout the region along with spatial analyses depicting elevation, slope, aspect, and hydrologic features on a broader scale.

Through our research we hope to create a basic understanding of the biotic and abiotic characteristics indicative of *Stewartia ovata* habitat. We intend for this study to serve as a reference for botanists and ecologists interested in the species and as a starting point for further studies on the natural habitat of the genus *Stewartia* and the species *S. ovata* in North America.

METHODS AND MATERIALS

Study Areas

This study focuses on western North Carolina *Stewartia ovata* populations in Graham, Macon, and Swain counties. Additionally, geographic coordinates and elevation data for populations in Clay and Cherokee counties were obtained from the North Carolina Natural Heritage Program (NCNHP). All data for populations occurring in Graham, Macon, and Swain Counties were collected by the authors of this paper. The locations of these populations were provided by local *Stewartia* expert Jack Johnston or were found by searching on foot, often with the assistance of Johnston. Elevations in the southern Blue Ridge range from 1,084 to 6,643ft above sea level. When scouting for new populations, search efforts were focused on mesic coves and riparian zones below 2,800ft elevation as no natural populations have been recorded above this range (Johnston, J., pers. comm.)

Macon County populations were found in Blue Valley south of Highlands near the Georgia border. Swain County populations were found along the Little Tennessee River near the Macon County line as well as between the southeastern end of Fontana Lake and Sawmill Creek. Graham County populations were found just east of Fontana Dam along the southern extent of the lake. The Cherokee County populations, whose locations were accessed through Ed Schwartzman of the NCNHP, are located near Hiwassee Lake and Appalachia Lake. Clay County populations, also obtained from Schwartzman, occur north of US Hwy. 64 near the Cherokee County line. Geographic distributions of all populations are mapped in Fig. 2. Additional spatial analyses conducted with ESRI® ArcGIS™ are digitally archived in Appendix A.

All populations surveyed in this study are located within the Nantahala National Forest. None are part of old growth stands and all of the sites were likely clear-cut between the mid-1800s and early 1900s. No surveyed sites appeared to have been logged or extensively disturbed by human activity in recent years.

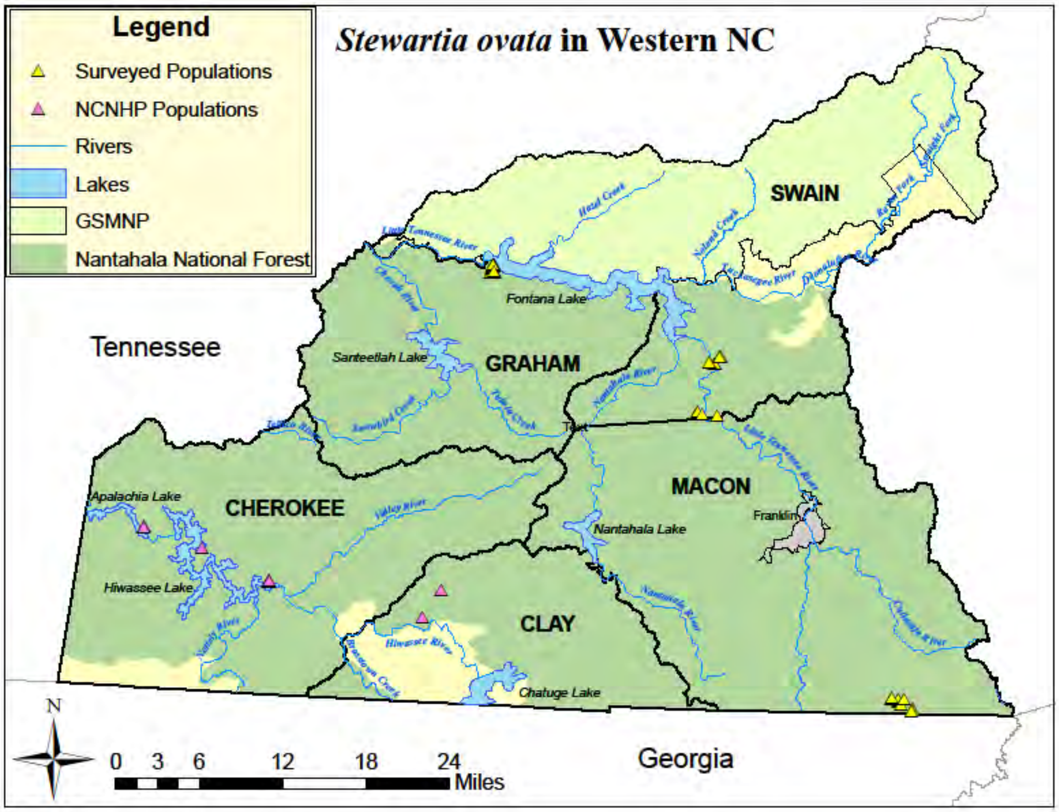

FIG. 2. Geographic distribution map of known *S. ovata* populations in western North Carolina.

Data Collection

Under the direction of Jack Johnston, known populations of *Stewartia ovata* in Graham, Macon, and Swain counties were accessed on foot from local roads and U.S. Forest Service (USFS) access roads. New populations were sought out in riparian and mesic cove environments below 2,800ft elevation. Once populations were identified, geographic coordinates were recorded with a hand-held Garmin eTrex Legend® HCx global positioning system receiver. Site IDs were assigned by county and number following the format NCGR 001, indicating the first population recorded in Graham County, NC. Some populations were divided into subpopulations following the format NCGR 002-2. Determinations of population status were made on the basis of how locally clustered trees were and how geographically distinct they were from other populations. Such determinations were often made with the help of Johnston. Forty-two populations were recorded in our study, excluding the Cherokee and Clay County populations. Of these, geographic coordinates and elevation data were recorded for all, local aspect data were recorded for 23, and local slope data were recorded for 22 populations. Seven populations were then randomly selected to collect DBH data on *S. ovata* and their associated species. Collection of field data began in early September 2010 and ended in early November of the same year.

In order to assess the physical characteristics of sites, local aspects and slopes were measured. Due to the time constraints inherent in this project, data could not be collected for all recorded populations. A Silva® Guide™ Model 426 compass was used to determine the aspect in degrees of slopes on which *S. ovata* populations were present. A Suunto® PM-5 clinometer was used to measure slope in degrees of gradients on which populations were present. Measurements were taken in a central location deemed representative of the whole population.

A DBH tape was used to measure the diameters of *Stewartia ovata* individuals and woody associate species within the seven randomly selected sites. Due to the nature of *S. ovata* trees, which often do not grow vertically or straight and may have numerous stems per individual, DBH measurements were not always taken at the standardized 1.3m above ground. Rather, these measurements were taken for each stem as close to 1.3m from the base as possible. Similarly, DBH protocol had to be altered to allow for the erratic growth patterns of woody associates such as *Rhododendron maximum*. Because *S. ovata* and such ericaceous species do not normally achieve large diameters, our exclusion size was also lowered to 1cm DBH below which we did not sample stems. Dense understory vegetation and steep slopes at some sites made travel challenging, and establishing straight transects or square vegetation survey plots would have been difficult. We therefore centered our analyses of associate species and basal areas on single *S. ovata* individuals. Using a Tajima® transect tape, we measured circular plots with a radius of 15ft (4.57m) within which to conduct our vegetation surveys.

Data Analysis

We began our analyses by tabling and graphing our recorded physical characteristics to reveal general trends. Summary statistics for these measurements were also calculated. Statistical analysis was conducted on the aspect data following Zar (1999) using Rayleigh's Test for circular uniformity. Slope inclination data was analyzed using the Kolmogorov-Smirnov goodness-of-fit test to look for clustering around certain values within the observed range of our dataset (Zar 1999). Finally, forest composition parameters for the seven sampled populations were calculated using formulas from Bower (1997). We calculated basal area, relative dominance, and stem densities at each plot to characterize the physical structure of forest communities containing *Stewartia ovata* as well as to provide insight into interactions among the observed tree species. Basal area (BA), or the total area of the forest floor covered by a species, was determined using the following formulas. Basal areas were calculated for each species in a plot, totaled for all species in a plot, and totaled for all species across all plots.

Basal Area by Stem: $BA_{stem1} = \pi\left(\frac{dbh}{2}\right)^2$

Basal Area for Species X: $BA_{speciesX} = \sum BA_{stem1}, BA_{stem2}, BA_{stem3}, \ldots$

Total Basal Area: $BA_{Total} = \sum BA_{speciesX}, BA_{speciesY}, BA_{speciesZ}, \ldots$

The second composition parameter to be tested was relative dominance, or the percent basal area of each species relative to the total basal area of all tree species. Basal areas for a species were summed across all plots, then divided by the sum of total basal areas from each plot and multiplied by 100 to yield the relative dominance of that species compared to all other species observed among our seven plots. The following formula was used:

$$\text{Relative Dominance for Species X} = \left(\frac{\sum BA_{speciesX\,for\,all\,plots}}{\sum BA_{totals\,for\,all\,plots}} \right) 100$$

Plot densities were then calculated using the following formula:

$$\text{Plot Density} = \left(\frac{Total BA\, in\, Plot}{Total Plot Area\, or\, 4.57m^2} \right) 100$$

Analysis with GIS

The mapping and landscape analysis component of this project was completed using ESRI® ArcGIS™ 9.3.1 (2009) digital mapping software. The X-Y coordinates of surveyed populations were recorded using a Garmin eTrex Legend® HCx GPS receiver. The receiver also collected elevation data for each of the 42 sites that were then graphed individually and by 250ft range classes to better observe any apparent trends. An average and standard deviation were also included. These coordinates, along with those acquired from NCNHP, were imported into ArcMap™ and projected onto a general geographic base map of the region. Using a NCDOT digital elevation model (DEM) of our five county study area, we mapped the locations of all populations to illustrate their distribution across the landscape with respect to elevation, particularly their upper range limit of 2,800ft.

Additional landscape analyses were run on the DEM data to reveal general geographic trends on a larger landscape scale. The Spatial Analyst Aspect Tool was run in ArcMap™ to produce a map of aspect ranges from which the aspect at each site was determined and graphed. Hillshade was also run to better evaluate the topography and shading of the landscape. More detailed versions of these maps were made for Graham, Macon, and Swain Counties and digitally archived in Appendix A. Soil maps for the three counties were also loaded from which the soil type for each population was manually determined by checking the soil type at that point on the map (Appendix A).

RESULTS

Slope aspects, as determined by a GIS analysis of all 47 mapped populations, appears to show a greater preference for north and northwestern slopes (Fig. 3). However, analysis of local slope aspects for our 23 sites does not indicate such a trend. These data were plotted around a 360° compass diagram and are presented in Fig. 4. We obtained a mean aspect of 196.13° ± 99.49° (Mean ± SD). Following Zar (1999), there was no significant aspect preference detected using Rayleigh's Test for circular uniformity (N=23, Tabled $z_{(0.05,\,23)} = 2.963$, z=0.554, p>0.5).

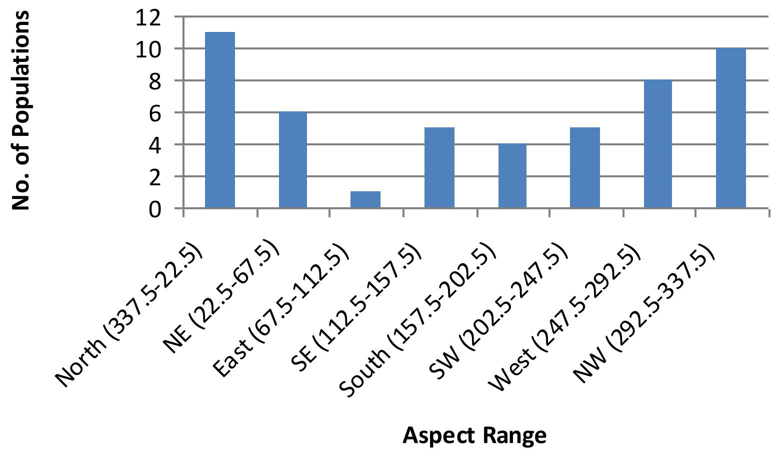

FIG. 3. Slope aspects for all populations in western NC as determined by ArcGIS spatial analysis.

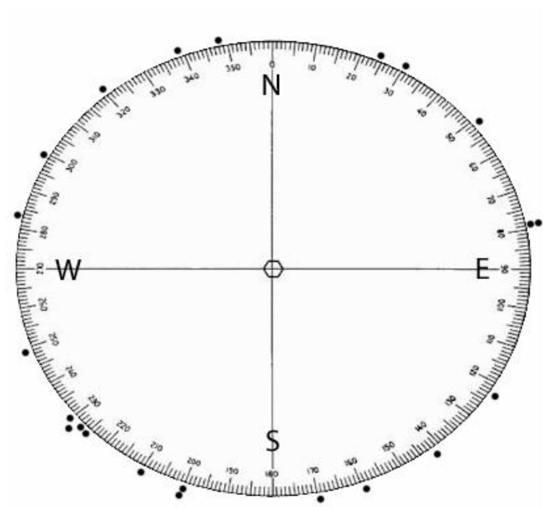

FIG. 4. Compass headings taken at 23 *S. ovata* populations were plotted on a compass diagram. The diagram shows the distribution of slope aspects, which were shown to have no significant bias when the Rayleigh's Test for circular uniformity was applied.

Slope values for the 22 sites sampled were plotted on a bar graph representing inclination at each site in degrees (Fig. 5). A mean slope of 22.55° ± 7.28° (Mean ± SD) was observed. Using the Kolmogorov-Smirnov goodness-of-fit test, we looked for clustering around certain slope values within the observed range of our dataset (Zar 1999). Again, we found that there was no preference for slope in *S. ovata* sites (N=22, Tabled $D_{(0.05,\ 22)}$=0.28087, D_{max}=0.20356, 0.2>p>0.5).

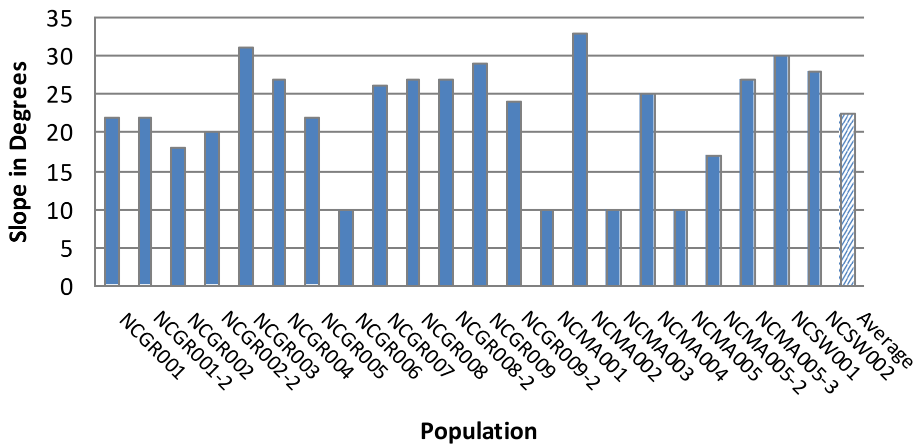

FIG. 5. Local slope in degrees for 22 *S. ovata* populations. This graph shows a uniform distribution of slopes with no correlation among values as determined by the Kolmogorov-Smirnov goodness-fit-test. Nevertheless, it is apparent that most populations occurred on slopes between 15-30° inclination. Average was 22.55±7.28.

DBH data for individual *S. ovata* specimens were plotted on a bar graph in size ranges of 10cm, showing that small specimens occur more often than larger specimens (Fig. 6).

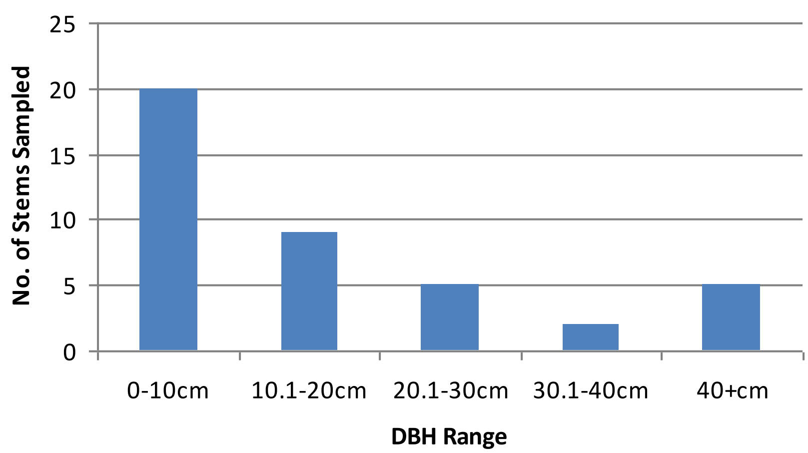

FIG. 6. Range distribution of DBH measurements for *S. ovata* individuals.

TABLE 1. Associated species in *S. ovata* plots. Species occurrences are indicated by shaded blocks for each site where the species was present.

Plots	*Tsuga canadensis*	*Acer rubrum*	*Oxydendrum arboreum*	*Rhododendron maximum*	*Stewartia ovata*	*Halesia tetraptera*	*Kalmia latifolia*	*Liriodendron tulipifera*	*Betula lenta*	*Cornus florida*	*Hamamelis virginiana*	*Magnolia tripetala*	*Pinus strobus*	*Betula alleghaniensis*	*Carya tomentosa*	*Clethra acuminata*	*Fagus grandifolia*	*Magnolia fraseri*	*Nyssa sylvatica*	*Pinus echinata*	*Quercas alba*	*Quercas rubra*
NCGR 001			■		■	■				■				■								■
NCGR 004	■	■	■		■	■		■	■			■										
NCGR 007	■	■	■	■			■	■					■				■		■	■		
NCMA 001	■	■		■			■									■						
NCMA 002	■		■	■					■						■			■				
NCSW 001	■			■	■	■		■			■											
NCSW 002	■	■			■		■			■	■	■	■								■	

A graph of relative dominance across all plots showed that *Tsuga canadensis, Rhododendron maximum,* and *Liriodendron tulipifera* (respectively) occupied the greatest proportions of observed species basal areas (Fig. 7). Species only found associated with a single population were considered outliers, despite some specimens being quite large and accounting for a relatively large proportion of total observed basal area.

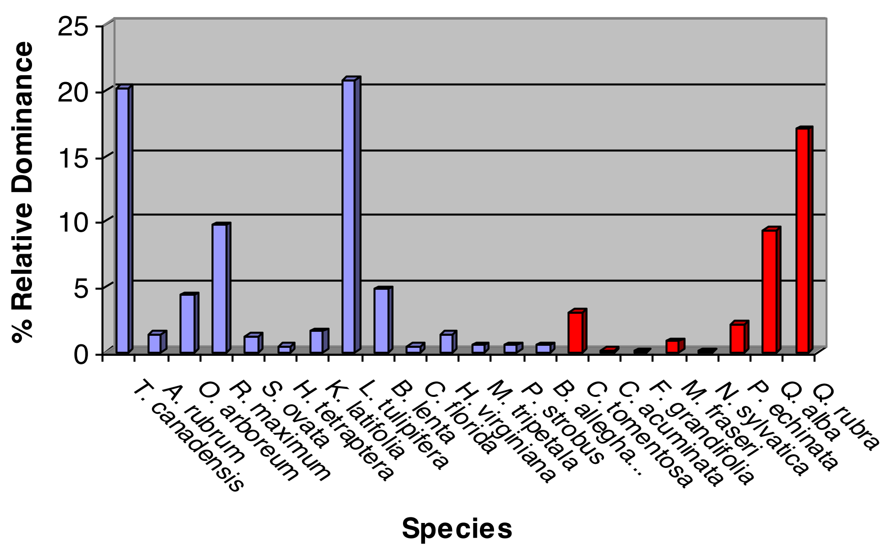

FIG. 7. Total basal area of associated species as percentages of total basal area of all species across all seven plots. Species found in only one of seven plots are shown in red.

A graph of stem density for each plot shows that NCSW 001 had the highest density while NCGR 004 had the lowest (Fig. 8).

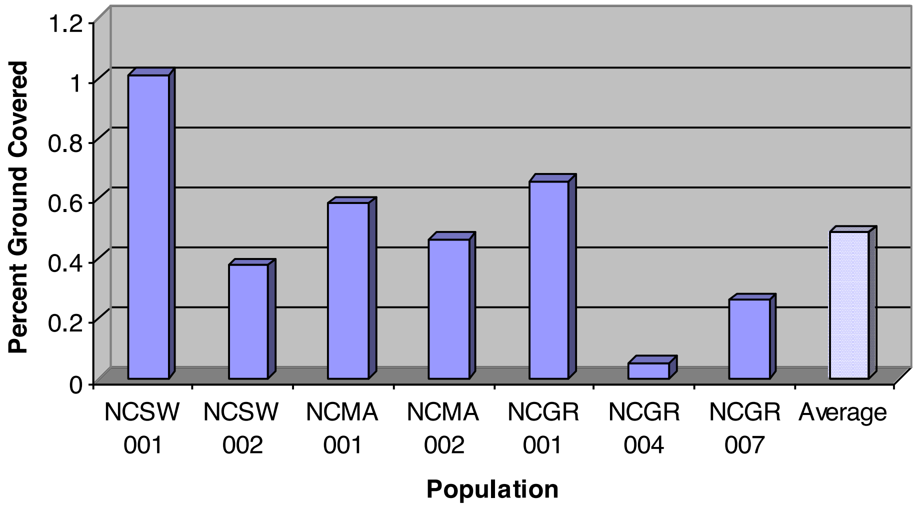

FIG. 8. Plot density was graphed for each individual site as the percentage of ground covered by the basal area of all species in that plot. Average plot density is 0.42%.

Elevation data was both graphed and mapped for all known NC populations. The data shows that the majority of populations occur between 1500ft and 2000ft in elevation (Fig. 9 and 10). The Macon county populations occur at a higher altitude than other populations increasing the average to1980.35 ± 322.05ft.

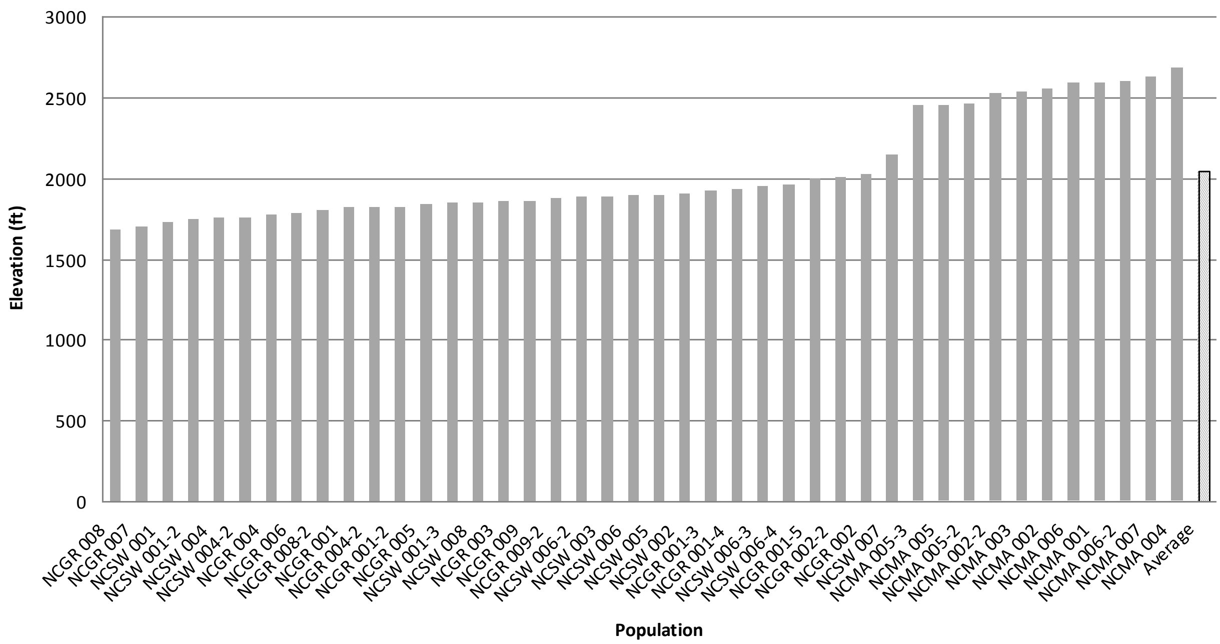

FIG. 9. Elevation data for all western NC *S. ovata* populations.

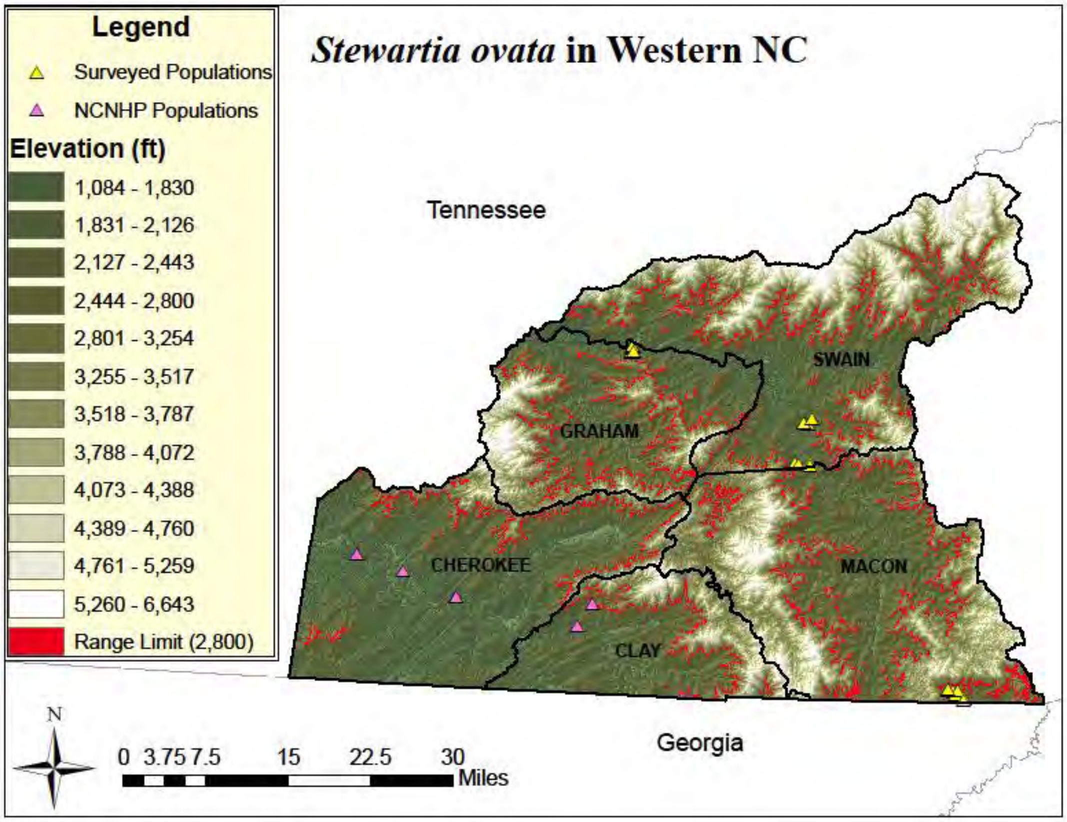

FIG. 10. Map of all known western NC *S. ovata* populations in relation to elevation distributions throughout the region, including the upper limit of their habitat depicted in red.

DISCUSSION

Slope aspect data collected showed no significant correlation to the presence of *Stewartia ovata*. This may be due to the small sample size or error in attempting to determine local aspect with the compass. When aspect data are interpreted from an ArcGIS Spatial Analyst aspect map and graphed on a bar chart it appears that there is a trend for *S. ovata* preferring more northern slopes. This may be a reflection of the species' preference for moist soils (Hsu 2008), as northern facing slopes receive less solar radiation and provide for more mesic conditions. A GIS spatial analysis approach to discerning such trends may prove more conclusive than local estimations of aspect because a broader perspective can often reveal topographic trends that are not visible on the ground. For example, although some local aspects recorded with a compass at sites were south-facing, many of these were also shaded by a close north-facing slope on the opposite side of a ravine or streambed. Even specimens not located immediately adjacent to such a shading slope could also be protected from full southern sun by a higher elevation land feature out of sight of the immediate area where measurements were taken.

When slope inclination data was statistically analyzed no significant correlation was found. However, because of the great variation in slope inclination throughout the region and the presence of populations primarily within the 17-33° range, we believe that *S. ovata* individuals are most likely to be on slopes near the observed average of 22.5°. The preference of trees for this slope range concurs with the generally accepted belief that the species prefers moist, yet well-drained soils (Johnston, J., pers. comm.). It should be noted that some populations were observed on relatively flat ground, although these were generally considered outliers from which no slope data was recorded. This indicates that *S. ovata* can occur on all slope inclinations between 0-35°. Nevertheless, the majority of these areas still appeared to be well-drained, often being located near the lip of a small ravine or the base of a hill.

When DBH values of *S. ovata* stems were graphed in size classes there was a clear trend of decreasing numbers with increasing size. This is likely due to slow growth rates and increasing mortality rates as the plants age. Causes for mortality may be attributed to disturbance events such as trees falling on top of plants, fire, or anthropogenic causes such as logging and development. Another explanation could be that increased mortality in the larger size classes is a result of anthropogenic disturbances endured during the early growth stages of those trees, such as early to mid-20th century logging in the southern Appalachians. It is also possible that the growth patterns of *S. ovata* leave it at risk for premature death. Many trees observed in the field had somewhat gnarled growth patterns and were often growing out an angle from the slopes on which they were observed. This is particularly true of older trees, possibly indicating that their preference for slopes may put them at risk of being pushed over by erosion and down-hill tree fall, resulting in higher occurrences of young trees and stump sprouts.

A table of associate species occurrences across the seven plots surveyed (Table 1) revealed that *Tsuga canadensis, Liriodendron tulipifera, Oxydendron arboreum,* and *Rhododendron maximum* were the most common associates. This result is likely due to prevalence of those species in the region, particularly in moist riparian areas where many *S. ovata* populations were found. Relative dominance statistics also showed that these species, as well as *Betula lenta* were the most dominant within plots. Again, these are very common species in the region and are not likely to be significant indicators that *S. ovata* is specifically associated with these species. It should be noted that Jack Johnston, in his many years of working with the species, has observed that *Juglans nigra* will cause the death *S. ovata* when they occur near each other. *Juglans nigra* contains the toxin juglone which is known to be toxic and potentially deadly to sensitive plants (Dana and Lerner 1994).

Plot density results showed that stem coverage for all species in each plot totaled between 0.1% and 1% of total plot area. The variation was large between plots and did not seem to show a discernable trend. This indicates that stem density does not play a large role in *S. ovata* occurrence. However, it should be noted that the species prefers full sun or partial shade, but will not tolerate complete shading (Spongberg and Fordham 1975). This means that particularly dense areas with full shading are unlikely locations for *S. ovata* to occur. Due to their preference for moist soils and co-occurrence with *T. canadensis,* it will be interesting to note how its loss will affect *S. ovata* populations in the coming years. It is likely that tree fall will kill some individuals but perhaps just as likely that the canopy gaps created may provide an opportunity for growth, should opportunistic associates such as *R. maximum* not overtake them.

Elevation data showed that the average elevation for all known populations in western NC was 1,980.35ft consistent with expected values between 1,500 and 2,000ft elevation. Most of the populations occurring above 2,000ft were observed in Macon County as part of the Blue Valley populations. This suggests that *S. ovata* is most likely to be found between 1,500 and 2,000ft elevation in western NC. However, populations will occur below 1,500ft and as high as their observed upper range limit of 2,800ft.

Our research has revealed many characteristics of the preferred natural habitat of *Stewartia ovata* in western North Carolina. Based on our findings, we propose that the characteristics of the species' preferred habitat include (but are not limited to) northern facing slopes of inclinations between 17 and 33° as part of mesic cove environments near water bodies. Additionally, they are likely to be found between elevations of 1,500 and 2,000ft although elevations slightly outside this range may also be viable locations. It appears very unlikely that populations will be found near or above 2,800ft elevation, in particularly xeric or exposed environments, or near potentially toxic species such as *Juglans nigra*.

Considering the lack of published research and information available pertaining to the natural ecological conditions associated with *Stewartia ovata*, the present study represents a first step toward characterizing the habitat requirements of *S. ovata.* Future studies on the natural habitat of *S. ovata* would benefit from collecting more complete data sets on each of the known populations rather than a subset. Considering the observed preference of the species for acidic soils (Hsu 2008), an examination of local soil chemistry within populations could be beneficial. Additional study parameters such as canopy coverage and leaf area index could help to better understand the complete set of physical and ecological characteristics indicative of viable *S. ovata* habitat.

This study has produced a baseline understanding of the natural habitat of *Stewartia ovata*. These outcomes, while useful, leave room for further studies that can add to the results of this paper. The importance of the conservation of rare species such as *S. ovata* makes research such as this integral to future conservation efforts.

ACKNOWLEDGEMENTS

We would like to thank Brent Martin, our mentor, for his support throughout the entirety of this project. We would also like to thank Jack Johnston for his unwavering enthusiasm and the many hours he selflessly devoted to spending time in the field with us. Thanks to Ed Schwartzman of the NC Natural Heritage Program for his contributions and advice. Finally, we would like to thank Anya Hinkle and James Costa of the Highlands Biological Station and Gary Wein of the Highlands-Cashiers Land Trust for their guidance and criticisms that guaranteed the success of this project.

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APPENDIX A

Table of all sampled populations, chart of soil type occurrences, and ArcGIS spatial analysis maps of *Stewartia ovata* populations in Graham, Macon, and Swain Counties of western North Carolina (digital archive on attached CD).

AN EVALUATION OF THE STREAM VISUAL ASSESSMENT PROTOCOL FOR THE LITTLE TENNESSEE RIVER WATERSHED

KENAN JERNIGAN AND NIKKI LILES

Abstract. Stream and riparian habitat are essential factors in the health of riverine flora and fauna, which are a part of the complex interactions that occur in stream ecosystems. Knowing how riparian and stream habitat change over time is important to understanding the health of these systems for both the survival of plants and animals and for human health. The Little Tennessee River has many branches that cover a vast area stretching from Rabun County in north Georgia through Macon and Swain counties in North Carolina and into Tennessee, which makes its existence and health vital to a large population of people. The Little Tennessee Watershed Association (LTWA) carries out biomonitoring throughout the Little Tennessee River basin to address water quality issues in Little Tennessee River and its tributaries. In response to land use pressures resulting from residential and commercial development and agriculture, the LTWA is implementing a program using a simple assessment tool known as the Stream Visual Assessment Protocol (SVAP) to collect stream quality data within the watershed based on physical characteristics. The LTWA will use this information to enhance the spectrum of approaches for protecting and improving stream health. As a pilot project of this program, we assessed ten sites within the upper Little Tennessee watershed to gain an understanding of current conditions. In addition, we determined the feasibility of using the protocol with the general public and suggest possible improvements to the protocol.

Key words: Little Tennessee Watershed Association; Little Tennessee River; riparian habitat; stream habitat; Stream Visual Assessment Protocol (SVAP); Upper Little Tennessee Watershed.

INTRODUCTION

Diversity and quality of stream and riparian habitat are important indicators of the overall health of a stream. Stream health directly correlates with habitat complexity (Gorman and Carr 1978). Aquatic animals prefer habitat that offers some sort of instream cover for protection of their eggs, feeding requirements, and many other reasons. Habitat diversity is very important because each aquatic species prefers a distinct type of cover (Gorman and Carr 1978). Land use in and around the riparian buffer and the interface between the stream and the surrounding land can greatly affect the habitat complexity and in turn, the diversity of aquatic wildlife. Many fish and insect species prefer habitat below overhanging vegetation. The removal of such vegetation decreases fish populations (Jones et al. 1999). Riparian vegetation also produces detritus that provides up to 90 percent of the organic matter necessary to support headwater stream communities (Cummins and Spangler 1978). The removal of riparian vegetation reduces the amount of available organic matter in addition to decreasing the strength of the buffer that helps to filter out sediment, pollutants, and harmful nutrients from agriculture (Jones et al. 1999). It also decreases the amount of canopy cover that helps to keep the water temperature stable. Such sedimentation, pollution, and nutrient enrichment decrease the diversity of aquatic communities (Jones et al. 1999).

The Little Tennessee River flows 135 miles from Rabun County in north Georgia through Macon and Swain counties in North Carolina and into Tennessee, where it joins the Tennessee River. The 1,100 square mile watershed is considered one of the most intact in the eastern United States. With about 88% of the region covered with mountain forest, protecting many of the headwater streams, the watershed boasts some of the highest levels of aquatic diversity and endemism in the Southeast (Desmond 2003). However, like all developed watersheds, the Little Tennessee faces a growing number of threats to its health, namely the large amount of livestock grazing and farming in or near riparian zones and/or floodplains and increasing development pressure from residential and commercial development. Livestock manure deposition in or near flood plains, riparian grazing, and instream livestock bathing have negative effects on aquatic communities. Riparian grazing and instream livestock activity has been observed as a major cause of stream sedimentation, and manure presence causes respiratory stress to fish and macroinvertebrate communities by forming a coating on their gill structures (Strand and Merritt 1999). The increase in nitrogen levels due to livestock manure and urine can also adversely affect the respiration of aquatic organisms. It is because of these threats that streams need to be monitored with visual assessment in addition to biological assessment in order to better pinpoint the causes of habitat loss, lack of aquatic biodiversity, and overall lack of stream health. The information obtained from using the SVAP protocol will be helpful in formulating a mitigation plan for problem areas in the watershed.

The Little Tennessee Watershed Association (LTWA) is a non-profit organization founded in 1993 when concerned individuals met to discuss the health of the Little Tennessee River. The mission of the LTWA is to protect and restore the waters of the upper Little Tennessee Watershed to maintain aquatic biodiversity and habitat conditions, as well as water quality for the use of people living in the area. The LTWA works in conjunction with local governmental agencies, environmental non-profits, and volunteers to execute numerous projects and initiatives under their Water Quality and Water Quantity programs. One of the main tasks that the LTWA performs is biomonitoring (LTWA 2003). Indeed, the LTWA has data from 1990, before the organization was founded, collected by the Biomonitoring Program Director, Dr. William McLarney. These data include samples of fish and, in some cases, benthic macroinvertebrates at 154 sites in the Upper Little Tennessee Watershed. Dr. McLarney used the Index of Biotic Integrity (IBI) to collect data at each of these sites, resulting in a 20-year dataset used to help monitor threats over time and better understand changing conditions within the Upper Little Tennessee watershed (McLarney 2007). Such long-term data also help LWTA advocate for changes to local governmental policies and practices that protect the watershed and improve water quality.

In this paper, we will report results from visual assessments of ten sites in the upper Little Tennessee Watershed. We conducted sampling using the Stream Visual Assessment Protocol (SVAP), which was modified for use within the Little Tennessee River basin. This assessment is useful for, among other things, determining changes in streams after a disturbance, understanding conditions for resource use, and forming resource inventories and reports (Bjorkland et al. 2001). Scientists developed the first draft of SVAP in 1996 after a survey was conducted by the Natural Resources Conservation Service's (NRCS) Water and Climate Center, in which they asked NRCS state biologists about stream ecological assessments and the need for technical support. After finding that biologists desired to be more active in stream ecological assessments and wanted additional technical support, a tiered system of assessment methods was developed. The simplest method created in this system was the SVAP, which is a conglomeration of existing assessment procedures (Bjorkland et al. 1998). This protocol was designed as a quick assessment to be used by individuals who are unfamiliar with conducting stream assessments. NRCS workers perform the assessment with landowners in order to both assess the stream and teach the landowner about the conservation of aquatic resources (Bjorkland et al. 2001).

As it pertains to the Little Tennessee, criteria for the assessment included 13 categories important to the overall health of the stream environment. In addition to reporting the results of the stream assessment, we will also discuss areas of improvement for the protocol in order to create a single standardized visual assessment protocol. This LTWA SVAP will soon be used by landowners and other citizens throughout the watershed to help pinpoint problem areas of poor physical habitat quality.

METHODS AND MATERIALS

General Procedure

We collected data from ten sites within the upper Little Tennessee watershed over the course of two months, using a modified version of the Stream Visual Assessment Protocol (SVAP). Sites included locations on Tellico, Watauga, Rabbit, Ellijay, Skeenah, Tessentee, Mud, Betty, and Mill Creeks (Fig. 1)

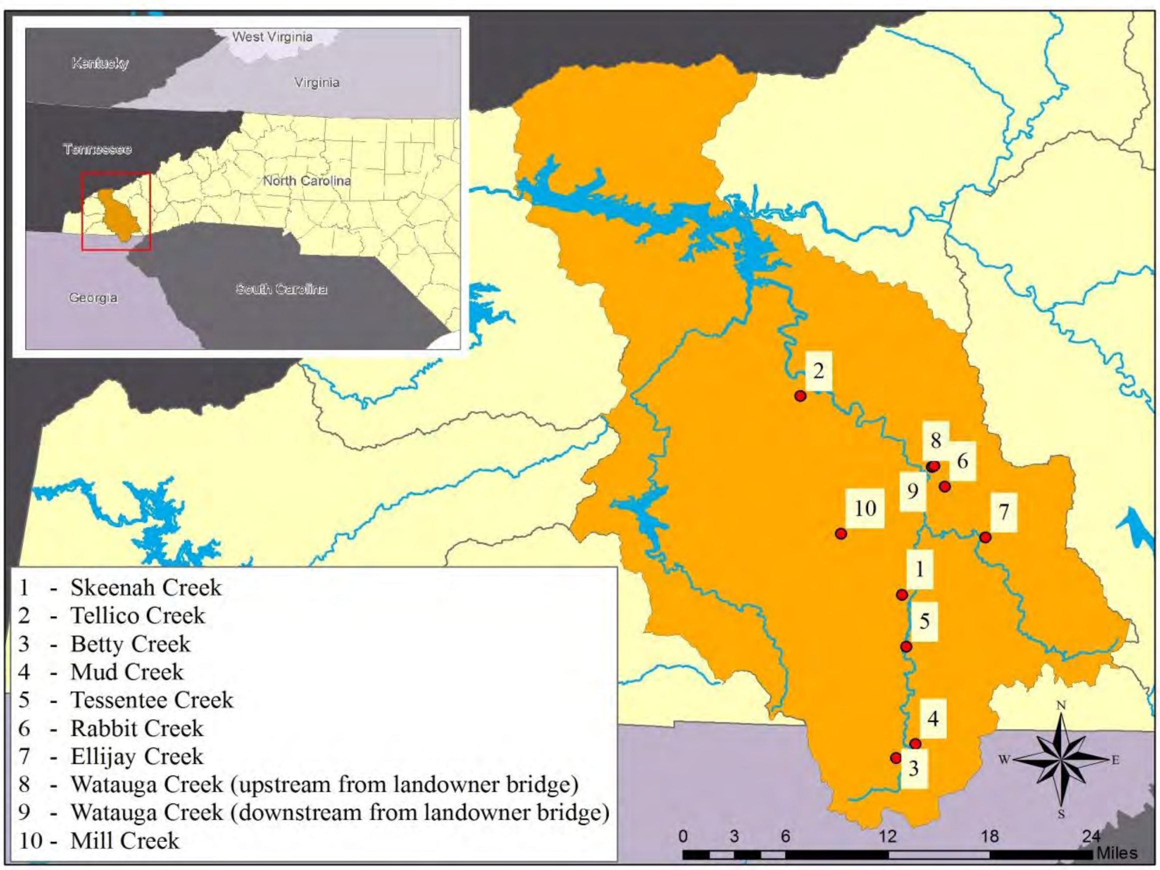

FIG. 1. Map showing SVAP site locations in the Little Tennessee River watershed.

At each site, we entered the stream wearing waders provided by the LTWA, and walked the designated reach carefully observing our surroundings. We specifically evaluated the channel condition, possible hydrologic alteration, riparian zone, bank stability, water appearance, nutrient enrichment, barriers to fish movement, instream fish cover, pools, insect and invertebrate habitat, canopy cover of stream reach, manure presence, and riffle embeddedness using a hard copy SVAP guide provided by LTWA. These guides included pictures for most categories to help the user determine a proper score for the stream. We gave each category a score from 1 to 10, with 10 being the best and 1 being the worst, and recorded the information on modified data sheets, which were printed on *Rite in the Rain*® all-weather paper (Appendix A). We also recorded date, time, dominant substrate, weather conditions, and general observations, noted on the modified data sheets. Finally, we used a digital camera to take photographs of most of the sites and logged the GPS coordinates at the entrance to each stream reach and a track of the reach using a Garmin 60CS GPS unit.

Criteria for Assessment

We assigned scores for stream condition based on the following information:

Channel Condition: This category refers to the sinuosity of the stream and whether or not the stream has been straightened. If a stream describes a nearly perfect straight line, it has been channelized. You can often spot these reaches on topo maps, where they are shown in magenta (W. McLarney, Biomonitoring Program Director, LTWA, pers. comm.). Older channelized streams may be characterized by grassy instead of woody vegetation along stream banks (Bjorkland et al. 1998). Streams with channels that were natural, with no structures, dikes, or down-cutting, received a score of 9 or 10. To receive a score of 6 to 8, there had to be evidence of recovery from past channel alteration. All dikes or levees were set back so that the stream had suitable access to the flood plain. If the stream reach was braided, had less than fifty percent of riprap and/or channelization, showed aggradation (stream bottom or flood plain raised in elevation because of deposition of material), and was restricted from the flood plain, then it received a score of 3 to 5. Streams with more than 50% of the area with riprap and/or channelization, that had active down-cutting or widening, as well as being restricted from the flood plain by dikes and levees, received a score of 1 or 2 (LTWA 2009).

Hydrologic Alteration: Natural hydrologic conditions are important to maintaining the shape and function of the stream channel, which is important for maintaining the physical habitat for flora and fauna. Natural conditions include bankfull flows (Fig. 2) and access to the flood plain for flooding events (Bjorkland et al. 2001). So, streams earned either a 9 or 10 when there were no dams, dikes, or areas of water withdrawal along a reach. Additionally, there were no structures limiting the stream from reaching the flood plain, with no evidence of

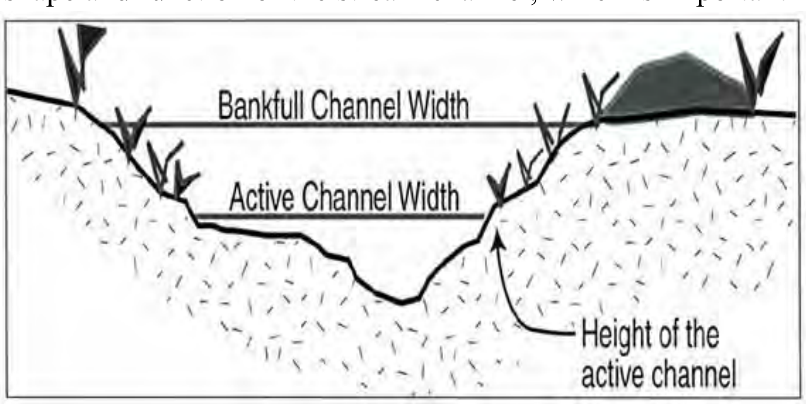

FIG. 2. Bankful and Active Channel Depiction (Taylor and Love 2003)

the channel incision. Streams that flooded once every three to five years with no channel incision and habitat that was not negatively impacted by water withdrawals received a score of 6 to 8. If flooding occurs once every six to ten years with the stream having limited channel incision, or if withdrawals from the stream negatively affects stream habitat during low flow periods, the stream received a score of three to five. To receive a 1 or 2, the stream had to experience no flooding, be deeply incised, or have structures that prevent the stream from having flood flow. Alternatively, the stream would also receive these scores if withdrawals had caused the loss of low flow habitat or if floods only occurred on a one-year rain event or less cycle (LTWA 2009).

Riparian Zone: This zone is the area extending from the edge of the active channel (Fig. 2) out onto the flood plain on both sides of the stream (Bjorkland et al. 1998). If this zone had natural vegetation extending at least two active channel widths, which is the width of the stream at bankfull discharge, on either side, then the stream received a score of 9 or 10. Scores of 7 and 8 were given to streams that only had natural vegetation extending one active stream length on either side of the stream, or if there was only one active channel width of vegetation within the entire flood plain. If the vegetation extended half the active channel length the stream received a score of 5 or 6. Streams with vegetation extending only a third of the stream length on either side, or if the riparian zone function was significantly compromised because of its condition, then a score of 3 or 4 was assigned. Streams deserving of a 1 or 2 had natural vegetation extending less than a third of the active channel length on either side of the stream. Additionally, these streams would not show regeneration of vegetation or the filtering function was severely compromised (LTWA 2009).

Bank Stability: This element refers to the possibility of soil from the upper and lower portions of stream banks being deposited in the stream. Although some bank erosion is normal, excessive erosion is unhealthy and indicates degraded riparian zones and areas of instability (Bjorkland et al. 2001). Streams with stable banks, which were low (at flood plain level), with at least 33% of the surface area in outside bends protected by roots extending to the base flow elevation, received a 9 or 10. Scores of a 6, 7, or 8 were given to streams that had less than 33% of the surface area in outside bends protected by roots that extended to the base flow elevation. If the stream had banks that were usually high, meaning that flood events were restricted to one year out of five, or even less, with actively eroding outside bends, characterized by falling mature trees, then it was assigned a 3, 4, or 5. These streams may have also had slope failures. Streams were assigned a 1 or 2 if they had the same conditions as the last section, in addition to having straight areas in or near the reach, with outside bends actively eroding, with many mature trees falling over into the stream annually, and much evident slope failure (LTWA 2009).

Water Appearance: This category refers to the turbidity, the amount of suspended particles and organic matter, of the stream (Bjorkland et al. 1998). If the stream was either very clear or tea colored, which allowed objects to be visible 3 to 6 feet below the water, with no evidence of oil sheen on the surface or film on inundated rocks or other objects, then it was given a score of 9 or 10. Streams receiving a 6, 7, or 8 had somewhat cloudy water with objects visible at 1.5 to 3 feet below the surface of the water. Water in these streams may have had a slightly green appearance, but still had no oil sheen present on the water's surface. Streams that were considerably cloudy most of the time, with objects visible at 0.5 to 1.5 ft below the surface received a 3, 4, or 5. These streams may have also had slow areas that in some cases appeared pea-green, had inundated objects covered with green film, and possibly smelling of ammonia. Streams received a 1 or 2 if they were extremely cloudy or muddy most of the time. Objects in these streams were only visible at less than 0.5ft. The water moved slowly and was possibly bright green in color with obvious pollutants. These streams may have had floating algal mats, surface film, oil sheen, or foam, or may even have had a chemical, oil, or sewage scent (LTWA 2009).

Nutrient Enrichment: Among other factors, this element was determined by the amount and types of vegetation in the water. Having too much decaying vegetation in the stream promotes the development of excess algal and macropyhte growth (Bjorkland et al. 2001). Streams with a clear appearance along the reach with no macrophytes, and little algal growth were assigned a 9 or 10. If the stream was only fairly clear and possibly slightly green with moderate algal growth on stream substrate, then it received a score of a 6, 7, or 8. If the water in the stream moved slowly with the presence of green macrophytes, other than *Podostemum*, with significant algal growth, then the stream received a 3, 4, or 5. Lastly, streams receiving a score of 1 or 2 were green, gray or brown in color with dense areas of macrophytes that impeded the water's progress. These streams also had severe algal blooms, which created thick algal mats in the stream (LTWA 2009).

Barriers to fish movement: The presence of fish and their reproduction is important to the riverine environment, so the presence and absence of barriers is important to stream health assessments (Bjorkland et al. 1998). Therefore, streams with no barriers received a score of 9 or 10. Streams that had, or were suspected of having, seasonal withdrawals that consequently were a barrier to fish movement received a 6, 7, or 8 depending on the severity of the situation. If drop structures, culverts, dams or other diversions that had more than a one-foot drop within three miles of the reach were present, then the stream received a 3, 4, or 5. This information was usually determined by driving upstream and downstream of the stream reach. Streams in which drop structures, culverts, dams, or other diversions were greater than one foot within the reach were assigned a score of 1 or 2 (LTWA 2009).

Instream Fish Cover: This category refers to the amount of fish habitat that is available in the stream, which is important to the stability of fish communities (Bjorkland et al. 2001). Types of instream fish cover specifically mentioned in the LTWA's SVAP included logs and large woody debris, pools, riffles, undercut banks, overhanging vegetation, boulders, thick root mats, and dense macrophyte beds. However, the protocol does allow for the counting of other sources of fish cover by having an "other" category. Streams with more than seven cover types were given a 9 or 10, while those with 6 to 7 cover types available were given a 7 or 8. Streams with 4 to 5 cover types received a 5 or 6, while those with 2 to 3 cover types were given a 3 or 4. Streams with one to no cover types were given either a 1 or 2 (LTWA 2009).

Pools: Pools are deep or shallow areas of slow moving water that can provide cover for fish (Bjorkland et al. 1998).Streams abundant in pools that had more than thirty percent of their bottoms obscure because of their depth, or had pools that were at least 3ft deep received a score of 9 or 10. If pools were not abundant and 2ft deep with 10 - 30% of their bottoms obscure because of their depth, then they received a score of 6, 7, or 8. Streams with shallow pools that had 5 to 10% of their bottoms obscure because of their depth that were less than 2ft deep were given scores of 3, 4, or 5. If pools were absent, or the entire bottom was discernible then the stream received a 1 or 2 (LTWA 2009).

Insect/Invertebrate Habitat: Stable substrate is important to the colonization of insect and invertebrate habitats in streams (Bjorkland et al. 2001). Insect and invertebrate habitat was defined as being fine woody debris, leaf packs, submerged logs, boulders, undercut banks, cobbles, and coarse gravel. However, the SVAP does allow for the addition of other undefined insect cover types by listing "other" as an option. Streams with at least five good quality habitats were given a 9 or 10. Streams with 3 to 4 good quality habitats received 6, 7, or 8. If the stream only had 1 to 2 good quality habitats then it received a 3, 4, or 5. Streams with one to zero habitat types were given a 1 or 2 (LTWA 2009).

Canopy Cover of Stream Reach: This element refers to the amount of sunlight that reaches the water's surface. Too much light will increase stream temperature and promote algal growth (Bjorkland et al. 1998). Therefore, streams with more than 75% of the water surface shaded in the reach and within 2-3 miles of the reach received a 9 or 10. If the stream was shaded more than 50% in the reach or 75% in the reach and poorly shaded within 2-3 miles of the reach, then the stream received a 6, 7, or 8. Streams in which the reach was only shaded 20-50% were given a 3, 4, or 5. If less than 20% of the water within the reach was shaded, then the reach received a 1 or 2 (LTWA 2009).

Manure Presence: Human and animal waste changes the chemical make-up of the stream such that the trophic scale of the aquatic biological community is altered. Additionally, untreated human waste is an extreme health risk (Bjorkland et al. 2001). If there was no evidence of livestock in or near the riparian zone, then the stream received a 9 or 10. If there was evidence of livestock access to the riparian zone, for example cattle gates leading into the water, then the stream was given a score of 6, 7, or 8. When there were waste storage structures located on the flood plain of the stream and there was evidence of occasional manure in the stream, a score of 3, 4, or 5 was given. In the worst case, a stream received a 1 or 2 if there was evidence of a significant quantity of manure on the banks or in the stream, or if untreated human waste was being discharged directly into the stream (LTWA 2009).

Riffle Embeddedness: Scores for this category were determined by kicking substrate located above a riffle in the stream and counting the amount of time it took for the sediment to clear from the point of disturbance. If no cloud of sediment was produced and the water remained clear, the stream received a score of 9 or 10. Streams where the sediment cloud persisted for 2 seconds were given a 7 or 8. If the sediment persisted for five seconds, the stream received either a 5 or 6, while streams with sediment persisting for 8 seconds received a 3 or 4. Steams where large sediment was completely buried in fine sediment, and riffles, which were once naturally present, were now absent received a 1 or 2 (LTWA 2009).

After we surveyed the ten stream reaches, we shared information using a comparison data sheet (Appendix A) and discussed findings, determining whether we missed any outstanding factors, or whether any scores should be changed. In cases where scores were changed, we crossed out previous assessments and wrote in the new scores beside the earlier mark. We averaged category scores by the number of observations, then to create an overall visual assessment rating, scores were averaged among observers. Based on the SVAP score for each stream reach, we classified the streams on scale of *very poor* to *excellent*, where *very poor* scores 1 to 2.2, *poor* scores 3.1 to 5.3, *fair* scores 6.1 to 7.0, *good* scores 7.7 to 8.5, and *excellent* scores 9.6 to 10. Gaps between the scoring tiers were reserved for judgment of the observer, so we could use or own judgment on whether to round up or down based on the overall visible condition of the stream. We depicted these rankings on maps (Appendix A).

Analysis

The LTWA is concerned about usability of this protocol by the public. In order to evaluate the efficacy of this protocol, we looked at differences among categories. We calculated the variance between our scores for each category in order to see which category is the most difficult to agree upon using the following equation:

$$\sum \frac{2\sqrt{(x_n - \mu)^2}}{n}$$

x_n = individual observer value
μ = Mean value of the that category for the stream
n = sample size

We averaged these variance values to produce a mean of the variances for each category. Although the variance would be more effective with more observer scores, this analysis would help us to pinpoint and discuss possible problem areas of the protocol.

RESULTS

The results show that two (20%) of the streams surveyed have a rating of *poor*, seven (70%) have a rating of *fair*, and one (10%) has a rating of *good*. These scores are shown in Table 1. The site locations are depicted in Fig. 1.

Tellico Creek scored the highest with an overall score of 7.25. The channel was altered very little, and its riparian zone was intact, diverse, and free of pollution sources such as manure or agricultural runoff. The water seemed clear with little sign of excess nutrient enrichment, and there were many opportunities for fish and macroinvertebrate habitat, with the exception of a deficit in deep pools. This is an example of a *good* stream for the watershed. Mud Creek scored the worst with an overall score of 4.75. Its primary substrate consists of silt and sand, and the channel is relatively straight with little elevation change. Just below a shallow culvert, sits a concrete drop-off which poses a large barrier to fish movement. Riparian zones on over half of each bank are mostly bare providing no buffer for the agricultural runoff from the two adjacent fields. What little vegetation exists has low diversity and appears to be fairly recently planted. The streambed was littered with trash, and there are not many opportunities for fish and macroinvertebrate habitat. This is an example of a *poor* stream that would benefit from plans for mitigation.

TABLE 1. Stream visual assessment protocol scores for ten stream reaches in the watershed.

Site	Numerical Score	Reach Rating
Skeenah Creek	6.63	FAIR
Tellico Creek	7.25	GOOD
Betty Creek	5.7	FAIR
Mud Creek	4.75	POOR
Tessentee Creek	4.8	POOR
Rabbit Creek	6.85	FAIR
Ellijay Creek	6.5	FAIR
Watauga Creek	6.7	FAIR
Watauga Creek	6.1	FAIR
Mill Creek	6	FAIR

Notes: All sites were surveyed by two observers except site 1 (Skeenah Creek), which was surveyed by four, and site 5 (Tessentee Creek), which was surveyed by three observers. These results are visualized in maps found in Appendix A.

The mean score for each category was calculated. These means ranged from 4.92, for riparian zone, to 8.24, for insect/invertebrate habitat. We calculated variance among scores for each site and averaged per category observed to draw conclusions as to which criteria are the most objective and difficult to judge. For most sites, n(number of observers)=2, except n=4 at Skeenah Creek and n=3 at Tessentee Creek. Variance ranged from 0.15, for nutrient enrichment, to 0.65, for water appearance, with a mean of variance for all categories of 0.37.

TABLE 2. Variance among observer scores for each category.

Category	Variance among scores
Channel Condition	0.33
Hydrologic Alteration	0.56
Riparian Zone	0.37
Bank Stability	0.38
Water Appearance	0.65
Nutrient Enrichment	0.15
Barriers to Fish Movement	0.21
Instream Fish Cover	0.55
Pools	0.30
Insect/Invertebrate Habitat	0.33
Canopy Cover	0.29
Manure Presence	0.26
Riffle Embeddedness	0.38
Total Mean Variance	0.37

DISCUSSION

The LTWA SVAP seems to be a successful tool for creating a quick and easy-to-follow survey of southern Appalachian stream and riparian habitat quality. By design, it yields consistent numerical results which, when combined with biological sampling data, can be helpful in pinpointing exact sources of problems with water quality in a stream. Most categories on the protocol are easy to score and provide effective feedback for areas that must be addressed when considering quality of instream habitat.

The LTWA protocol worked toward pinpointing problem areas in the watershed, but several improvements can be made for it to be more affective and simpler to follow for volunteer landowners and the general public. For SVAP to be a uniform protocol, it must be outlined in one legible and easy-to-follow document that can be given to all participating parties. In the LTWA SVAP, there are simple typographical errors that can easily be fixed.

The artistic depictions for each scoring category are helpful for the SVAP evaluator. Drawings and paintings provide better reference than photographs because areas of importance to the observer can be highlighted, and minor, distracting details can be left out. These depictions give an observer a better idea of the elements on which they need to concentrate in a way that cannot be conveyed by words or photographs (Hodges 2003). Some categories however, were lacking in these drawings. For example, the bank stability category had no pictures, but asked the evaluator to determine whether or not 33% of banks in outside bends were protected by roots. Without some sort of image to which they can refer, this is difficult to judge. SVAP should also consider using fractions instead of percentages in their descriptions as it would likely be easier for the average citizen to judge. Hydrologic alteration, manure presence, and riffle embeddedness were only missing one or two pictures each, yet having these would be helpful for an observer in giving a proper score.

Our results indicate that some of the categories of SVAP generally produce more variable scores than others. Using more evaluators for each stream reach could help in reducing, or at least pinpointing the cause of variance in SVAP, but the variances found in our data should be taken into account when considering the final version of the LTWA SVAP. The highest variances were found in water appearance, hydrologic alteration, and instream fish cover.

Water appearance is probably the most subjective category in the protocol which would explain the high variance of 0.65, almost double the mean total variance, between evaluator scores. Perhaps this is difficult to judge because many of the streams evaluated never got beyond 3 feet deep, forcing the evaluator to make a guess. With a protocol aimed at non-experts, guesses like these are not necessarily educated and will cause high variation in scores.

Hydrologic alteration is a controversial category. In order to properly assess it, one must acquire some basic knowledge of the flooding history of the stream. A landowner may have this knowledge, but typically a volunteer will not, hence a variance of 0.56, 0.19 above the mean total variance, between observer scores. Although this is an important factor of the overall stream health, errors in scoring may skew the overall SVAP score to inaccuracy. It is because of this that we suggest the hydrologic alteration category be removed from the LTWA protocol, but making it an optional category based on the evaluator's local knowledge should be considered.

The high variation in scores of instream fish cover (0.55) can be explained by evaluators using different scoring systems. Detailed scoring instructions should be included in the protocol in order to standardize the scoring methods of evaluators. These instructions should include a half point system for counting a type of fish and insect/invertebrate habitat that is found but not common within a reach. It should also explain whether the scorer should start at zero and add points based on good qualities, or start at 10 and subtract points for bad observed qualities. This standardization will make the SVAP a much more effective tool for the LTWA.

Many of the streams in the Little Tennessee River basin have an abundance of thick mats of foam that could possibly indicate phosphate enrichment (Fig. 3). Nutrient enrichment is difficult to evaluate in mountain streams because the water generally moves quickly and such foam mats can be created by turbulence when no nutrient enrichment has occurred. Also due to the fast moving water, the green, algal tint that would normally indicate nutrient enrichment is not always displayed. Many times, these harmful nutrients can occur in Appalachian streams but rarely settle long

FIG. 3. Foam in Mill Creek near Memorial-Patton United Methodist Church.

enough to create visible indicators (C. Pringle, Distinguished Research Professor, Odum School of Ecology, University of Georgia, pers. comm.). Due to the ambiguity of this category for visual assessment, we suggest it also be removed from the LTWA SVAP, with an option for considering it a factor in visually obvious enrichment scenarios. Perhaps steps may be taken toward yearly or bi-yearly chemical analysis of streams in the watershed to evaluate nutrient enrichment.

Once revised and standardized, the LTWA Stream Visual Assessment Protocol will be a much more effective tool in judging stream health. It will provide local landowners and the general public with a chance to actively pinpoint problem areas and eventually increase the quality of the water in their watershed. Participating citizens will be able to take pride in the steps they took toward better water quality in one of the most intact and species-rich watersheds in the eastern United States.

Acknowledgments

Special thanks to Dr. William McLarney, Jenny Sanders, and Jason Meador of the Little Tennessee Watershed Association for all their help and effort in our training and improving our understanding of the riverine environment. Thanks to Gary Wein from the Highlands-Cashiers Land Trust for help with GIS and providing the necessary background data for our maps. Thanks also go to the Highlands Biological Station, especially Dr. Anya E. Hinkle and Dr. James T. Costa.

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APPENDIX A

Color-coded SVAP ratings per site – 8 separate maps (digital archive on attached CD).

APPENDIX B

Revised SVAP Data Sheet for field use (digital archive on attached CD).

APPENDIX C

SVAP Comparison Data Sheet for field use (digital archive on attached CD).

APPENDIX D

Older version of LTWA SVAP information pamphlet for evaluators (digital archive on attached CD).

SHEDDING LIGHT ON ENERGY CONSERVATION AND SUSTAINABILITY AT THE HIGHLANDS BIOLOGICAL STATION

SEAN M. MURPHY

Abstract. In order to prevent further global climate change, the burning of fossil fuels should be slowed through conservation efforts, such as energy efficiency initiatives and renewable energy projects. As the DELTA intern at the Highlands Biological Station, I worked to write a Strategic Energy Plan, conduct a Detailed Energy Assessment, organize a behavioral change program, prepare feasibility studies for solar thermal and heat pump systems, and compile funding opportunities relevant to such projects. The result of this semester's work included identification of a range of opportunities for energy and water conservation. Highlands Biological Station now has the momentum and information it needs to begin implementing identified sustainability projects with an energy plan as a future roadmap.

Key words: behavioral change; DELTA intern; energy assessment; energy efficiency; funding; heat pump; Highlands Biological Station; renewable energy; solar thermal; Strategic Energy Plan; sustainability.

INTRODUCTION

The United States is addicted to fossil fuels. Currently in the U.S., oil, coal, and natural gas generate over 85% of total energy demand, including over 60% of electricity, and over 99% of transportation fuels. Even with the addition of emergent renewable energy technologies and increases in efficiency, this fossil fuel dependence is expected to grow over the next twenty years (US DOE 2010). Globally the outlook is similar with demand for energy increasing annually by 1.7% through 2030. This increase is driven by increases in population at a rate of 1.3 to 2% per year and by a greater per capita demand for energy worldwide as more people climb out of poverty each year. The picture for 2030 appears to be a world with 9 billion inhabitants, a 67% increase in global energy demand from 2000, and a rapidly changing climate (Bilgen et al. 2004). Global climate change has been caused by the burning of fossil fuels and the subsequent release of carbon dioxide and other greenhouse gases. Weaning ourselves from our carbon-based fuel habit is of greater importance than simply avoiding an increase in future demand and price; it is a necessity to prevent runaway changes to our climate (Hohmeyer and Trittin 2008).

Locally there exist additional incentives to conserve energy, water, and other resources, such as direct financial savings and educational benefits. There are numerous strategies for financial savings, most readily by reducing heating and cooling temperatures and replacing incandescent bulbs with compact fluorescent lights. Owners of schools, residential buildings, and even commercial buildings have the opportunity to teach occupants about ways they can act more sustainably in their daily lives (Energy Star 2010). Institutions of higher education have taken a lead in energy efficiency, renewable energy, and energy education by collecting renewable energy fees for campus projects, increasing campus sustainability events, and even offering more energy related courses. The University of North Carolina at Chapel Hill has created an internship program specifically targeted at energy. The Developing Energy Leaders

Through Action (DELTA) internships are being sponsored jointly by the State Energy Office and by the University system (UNC IE 2010).

I served as a DELTA intern for the fall 2010 semester at the UNC Institute for the Environment Highlands Field Site located at the Highlands Biological Station (HBS). The purpose of my project was to assist HBS in reducing its fossil fuel consumption and the associated negative effects on the environment. Specifically, I have been responsible for researching and implementing sustainability projects that include writing a Strategic Energy Plan, conducting a Detailed Energy Assessment, organizing a behavioral change program, conducting feasibility studies for solar thermal and heat pump systems, and compiling information on funding opportunities relevant to these projects (UNC IE 2010). This paper will provide an overview of these six energy saving projects, the results I gathered, and how these results can help HBS move forward to a more sustainable tomorrow.

MATERIALS AND METHODS

Strategic Energy Plan

The first step towards saving energy at the Highlands Biological Station was to prepare a Strategic Energy Plan (SEP). An initial meeting with Lauren Bishop, the Energy Manager at Western Carolina University, identified the opportunity to write a SEP for the Highlands Biological Station (Bishop, L. pers. comm.). Tutorials and sample SEP documents were found on the NC State Energy Office (SEO) website (NC SEO 2010). These resources and correspondences with Ms. Bishop helped me to prepare a first draft of the SEP with the sections of Executive Summary, Baseline Utility Consumption, Existing Conditions, Organizational Cultural Change Projects, Supply Side, Demand Side, and Energy Declaration.

The initial SEP draft was discussed and revised several times through meetings with the directors of the Highlands Biological Station (James Costa and Anya Hinkle), feedback from Ms. Bishop, and a meeting with Reid Conway, the energy engineer for the western region of the NC SEO. Changes made during this process include reducing redundancy, increasing specificity of goals and objectives, and being as brief as possible without compromising the content (Conway, R. pers. comm.). All parties read and signed the energy declaration, including James Costa, HBS Executive Director; Anya Hinkle, HBS Associate Director; Guy Cook, HBS Maintenance; Cynthia Soderstrom, HBS Business Office Manager; and Sean Murphy, HBS DELTA SEO Intern. The finalized SEP was submitted to the NC SEO on November 8, 2010.

Energy Assessment

Lauren Bishop also recommended that I conduct Detailed Energy Assessments on multiple Highlands Biological Station buildings. The American Reinvestment and Recovery Act of 2009 distributed money to state governments specifically for energy assessment projects. The NC State Energy Office has been financing these assessments for state-sponsored entities such as NC public schools (Bishop, L. pers. comm.).

The first step toward conducting these energy assessments was to identify the HBS buildings that we wanted to have assessed. It was decided that the Valentine House, Nature Center, and Coker Laboratory would be assessed following consultation with the HBS directors. The Valentine House was chosen due to its high usage and old age. The Nature Center was selected due to its high visibility and interaction with the public. Coker Laboratory was included because it is slated for renovation soon and any additional guidance towards energy savings could be incorporated in the renovation designs.

Requests for Technical Assistance were submitted to the NC State Energy Office for these three Detailed Energy Assessments. These requests contained basic data about each building, including the year built, total square footage, previous 12-months bills, and contact information to be passed on to the energy consulting company. I was then contacted by Adrian Boutwell of the Waste Reduction Partners, a local energy auditing company. Prior to his visit, I was required to complete an Administrative and Energy Conservation Measures Survey for each of the three buildings. This survey required basic building information, including average occupancy, fuel sources used, heating and hot water system information, and detailed utility data for the past 12-months. On October 8, 2010, Adrian Boutwell conducted the Detailed Energy Assessments for the Valentine House, Nature Center, and Coker Laboratory.

Behavioral Change Initiatives

Lauren Bishop, WCU Energy Manager, suggested increasing the visibility of sustainability efforts at the Highlands Biological Station by hanging educational signs. These signs would highlight opportunities for energy and water conservation through simple behavioral changes such as using cold water when washing clothes (Bishop, L. pers. comm.). The first step towards designing these signs was to identify areas where signs would be useful and effective at HBS.

I conducted a visual assessment of the HBS facilities and determined five areas to target: building exits, laundry washers and driers, printers, showers, and sinks. Research was then done on the Association for the Advancement of Sustainability in Higher Education, US Department of Energy, Energy Star, and the US Environmental Protection Agency websites to gather specific data for the signs (AASHE 2010, Energy Star 2010, US DOE 2010, US EPA 2010). A sustainability logo was designed for the top of each sign using HBS and web graphics, and the signs were formatted using Adobe Photoshop Editor. The most cost effective and permanent way to hang the signs was researched, and it was found that 5 in. by 7 in. picture frames would be most appropriate. A total of 48 sites at HBS were identified by walking through each building and tallying appropriate locations.

Solar Thermal Hot Water System

Anya Hinkle and James Costa, Highlands Biological Station Directors, recommended that I research the feasibility of a solar thermal hot water system for the Valentine House. This building was chosen because of its high hot water demand and large roof surface area unobstructed by tree shade. Basic information on existing conditions, such as occupancy, water usage, and costs were calculated using past year's utility data for the building and information found on the water heater unit. This information was provided to three local solar thermal companies, Winter Sun Construction, Solar World, and Sundance Power Systems. Each company provided a cost estimate and some detail about components of the system. These three sources of information were summarized and compiled into a feasibility report.

Heat Pump Heating System

I next researched the feasibility of a geothermal heat pump heating system for Coker Laboratory. This building was chosen because it is in the design phase of renovation and is close to Lindenwood Lake, which would be used as the heat sink for the system. Basic information about heat pump systems was first researched using the US Department of Energy and US Environmental Protection Agency websites (US DOE 2010, US EPA 2010). Utility data for Coker Laboratory for the past 2.5 years was compiled into an Excel spreadsheet.

Funding Opportunities

In order to implement future energy efficiency and renewable energy projects at the Highlands Biological Station, outside funding must be secured. I researched the Association for the Advancement of Sustainability in Higher Education, NC State Energy Office, US Department of Energy, Energy Star, and US Environmental Protection Agency websites for grant information. These websites contained resources and links to the following grant listing websites: NC Open Book, Community Resource Information System, NC Green Power, Grants.gov, Database of State Incentives for Renewables & Efficiency, Z. Smith Reynolds Foundation, The Community Foundation of Western North Carolina, Land-of-Sky Regional Council, Waste Reduction Partners, US Department of Agriculture, Wachovia Grants, Highlands Community Foundation, The Cannon Foundation, Environmental Support Center, The Kresge Foundation, David, Helen, and Marian Woodward Fund, John W. and Anna H. Hanes Foundation, Percy B. Ferebee Endowment, and Progress Energy (AASHE 2010, Energy Star 2010, NC SEO 2010, US DOE 2010, US EPA 2010). All of these websites were researched and I summarized funding sources applicable to HBS and renewable energy and energy efficiency projects.

RESULTS AND DISCUSSION

Strategic Energy Plan

The finalized Strategic Energy Plan (SEP) is a 6-page detailed report that describes the Highlands Biological Station's energy use with information about the past year and provides a roadmap for energy planning during the next 12 months (Appendix A). The SEP begins with an Executive Summary that contains the key elements and goals that the plan aims to achieve. Next is the Baseline Utility Consumption that contains a table with utility information for the previous four fiscal years (Table 1). The Existing Conditions section then briefly describes the history of the Biological Station. The next three sections describe specific efforts at energy conservation and are broken down into the past 12-month's activities and the next 12-month's activities. The Organizational Culture Change Projects section discusses projects that do not directly relate to demand for or supply of energy, such as displaying behavioral change and educational material at HBS. The next section is Supply Side that deals with the supply of energy to HBS such as verifying electric and water meter readings. The Demand Side section describes ways that HBS can reduce its demand for energy, for example, replacing old exit signs with new L.E.D. exit signs. The final section is the Energy Declaration that was signed by all relevant parties at HBS and states HBS's commitment to the sustainable use and conservation of electricity, fossil based fuels, and water.

TABLE 1. Comparison of HBS utility consumption and cost over the past four fiscal years. This table can be found in the HBS SEP (Appendix A).

Fiscal Year	Total Utility Cost $	$ / kWh	$ / gsf	Btu / gsf	% Change - Btu / gsf	Water gal / gsf	% Change - Water gal/ gsf
06-07	$24,379	$0.0759	$0.83	47,899		26.75	
07-08	$26,451	$0.0767	$0.97	46,038	-3.89%	12.94	-51.6%
08-09	$24,096	$0.0770	$0.88	50,742	5.93%	8.40	-68.6%
09-10	$27,954	$0.0881	$1.04	50,446	5.32%	8.20	-69.4%

Notes: kilowatt-hour (kWh), gross square feet (gsf), British thermal unit (Btu).

The importance of SEPs is comprehensively discussed on the NC State Energy Office website. Of primary importance, having an up-to-date SEP allows organizations such as HBS to apply for federal stimulus funds. Another main aspect of the plan is to help groups track their goals and progress from year to year. HBS should actively pursue both of these objectives with their SEP as well as use it as a roadmap for seeking additional funding for energy efficiency, renewable energy, and water conservation projects (NC SEO 2010).

Energy Assessment

Adrian Boutwell of Waste Reduction Partners completed an energy assessment report for Valentine House, Nature Center, and Coker Laboratory on October 20, 2010 (Appendix B). This document includes a brief background of the Highlands Biological Station, a description of the facilities assessed, historical usage data of all utilities, an analysis of current utility use, and energy saving recommendations. Additionally, an executive summary section provides detailed recommendations for low-cost and no-cost opportunities and two capital investment projects. These low-cost and no-cost recommendations, all under $600/project, include items such as replacing seven outmoded exit signs with LED exit signs, disconnecting electricity to the water cooler in the Nature Center, and installing aerators on two lavatory faucets in Coker Laboratory. The two capital investment projects are upgrading the gas furnaces in Valentine House ($7,000) and replacing T-12 lamps and ballasts with T-8 lamps and ballasts throughout all three buildings ($3,562). For each recommendation the investment cost, cost savings per year, and payback period in years is provided (Boutwell 2010).

As seen in the Energy Assessment Report, many of these opportunities are low-cost or no-cost improvements with payback periods under 2 years (Appendix B). Due to current funding constraints at HBS, the energy efficiency projects with low investment costs should be implemented first. Additionally, the payback period and cost savings per year figures for each project can be used to further prioritize projects for maximized savings.

Behavioral Change Initiatives

The 48 behavioral change signs were printed, framed, and hung throughout the Highlands Biological Station campus (Fig 1). We expect reductions in electricity, propane, and water use, but there are no results to report at this time other than the increased visibility of sustainability at HBS. The utility bills each month will be used to make comparisons over time as this behavioral change program continues. It will be most accurate to compare a month's utility consumption to the same month of previous years, since large month-to-month variances are found.

The educational benefits of this paper's research to those who use HBS extend from the behavioral change program to the new sustainability initiatives page on the HBS website.[1] These are inexpensive ways that HBS can inform users of the Biological Station's efforts toward greater energy efficiency and sustainability. A London-based study found that while gas and electricity consumption are highly variable, when occupants knew that their consumption of utilities was being monitored, consumption fell significantly (Levine et al. 2007). The increased awareness of energy, propane, and water consumption at HBS, due to the posting of behavioral change signs, can also be expected to reduce demand for these utilities. Another study focusing on behavioral change initiatives to a middle-class, rural community found that participant involvement was dependent on a feeling of ownership, and that the term "green" was likely to alienate people. With this in mind, HBS should include guests and staff in the future involvement of sustainability initiatives and frame these programs using clear and descriptive wording (Trier and Maiboroda 2009).

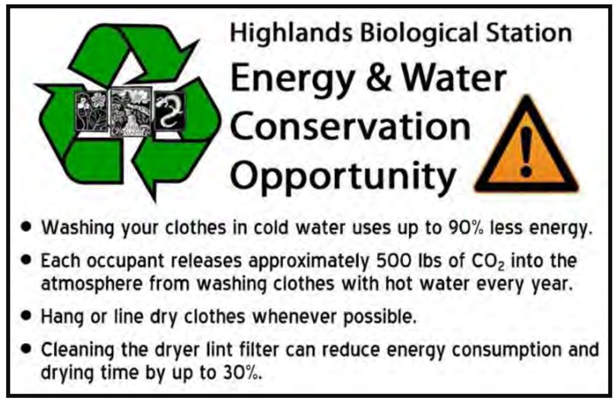

FIG. 1 Example of a behavioral change sign framed and hung at HBS highlighting energy and water conservation opportunites.

Solar Thermal Hot Water System

Solar thermal systems can be used to heat water and are especially applicable in residential buildings due to high hot water demands. Solar panels on the roof contain piping that connect to coils within a water heater tank. This closed-loop piping contains an antifreeze fluid, which has a high thermal transferring capacity. The antifreeze liquid is heated in the panel on the roof and then pumped to the water tank where it heats fresh water for domestic building use (US DOE 2010).

The first step was to gather basic information on existing conditions, such as occupancy, water usage, and costs, which include: 10 occupants, 260 days/ year, 76,590 gallons/ year of total water demand, 35,000 gallons/ year of hot water demand, 120°F temperature of hot water, and \$500/ year spent heating water. The research done for the Valentine House solar thermal system is summarized in a feasibility report given in Appendix C. It was found that 96 ft^2 of solar panels would be needed on the south-facing roof slope to generate enough hot water given current demand level. The existing 80-gallon water heater tank would be kept as a storage tank for the solar thermal system. The average life of this system is 30-40 years and is priced at \$6,000 to \$10,000. The projected savings are \$500/ year making the payback period 12-20 years. Assuming a cost of \$8,000 and a payback period of 16 years, there will be about 20 years of system life after "paying itself off" in avoided utility costs. This results in a lifetime avoided cost of about \$10,000 for the solar thermal hot water system.

[1] http://www.wcu.edu/hbs/energy.htm

When funding becomes available, a more detailed assessment and plan for the solar thermal system should to be done. A local, reputable solar thermal company will need to be chosen for the job, and I would recommend choosing an energy performance contracting (EPC) company. EPC is a way to finance large, capital-investment renewable energy projects, such as solar thermal systems. Prior to any construction, a detailed assessment would be performed for the future system to determine the expected savings. The solar company would pay the entire initial cost of installation, but would share in the savings that the renewable project creates. Through this process, the solar company recoups its investment incrementally until the full installation price is paid. This strategy ensures that the consumer would neither see an increase in utility rates nor need a large initial investment, but would only begin to see the full savings from the installed renewable system after the solar company had been fully paid (Yik and Lee 2004). EPC is becoming a more widely know and used source of funding, as shown by energy efficiency improvements made in public grade schools in Missouri (Butler 2009). The major setback for EPCs is that agencies sometimes believe they are too complicated, misunderstand what projects could be funded, and do not realize the benefits. Further study is needed to see if EPCs are applicable for HBS as it is financed with state funding (Nail et al. 2004).

Heat Pump Heating System

A heat pump system can be used to heat and cool buildings. The system requires a heat sink, which is usually a well deep in the ground or the bottom of a lake. The heat sink maintains a more constant temperature year-round, making it cooler in the summer and warmer in the winter compared to air temperatures. The lake source system connects a heat pump unit in the building to the bottom of the lake with piping. The closed-loop piping contains coils in the lake bottom to increase dispersal and absorption of heat between the fluid within the piping and the heat sink lake. The relatively warmer temperature of the lake in the winter can be used to heat the fluid in the piping and the building. The opposite is true to provide cooling in the summer (US DOE 2010).

It was initially estimated that on average the building is occupied by 10 people, 20 hours/ week, 260 days/ year, and that 1,800 gallons of propane are consumed yearly resulting in a cost of $2,300/ year. A conversation with Jerome Hay (Sud Associates, PA, Asheville, NC), the engineer working on the Coker Laboratory renovation, provided me with more guidance about the specific information needed for him to make a decision about whether or not to

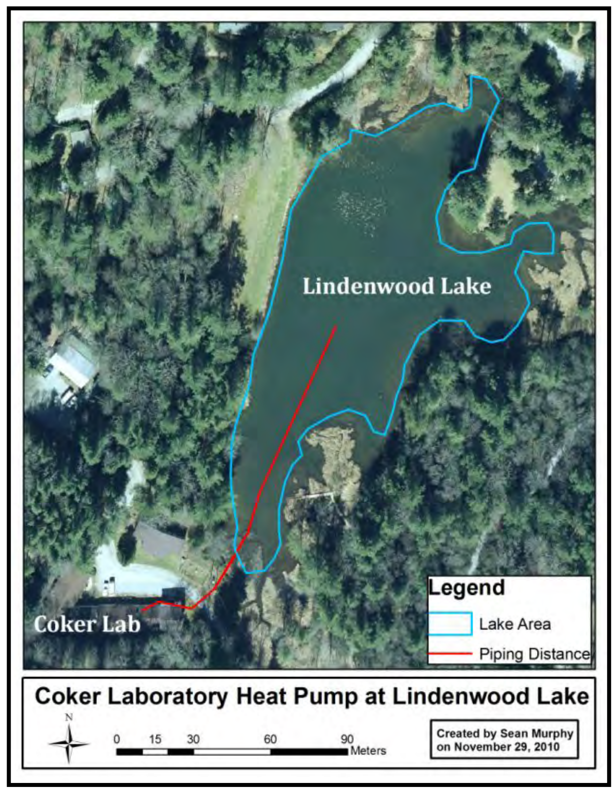

FIG. 2. Map estimating the piping distance (144 m) from Coker Lab to the deepest part of Lindenwood Lake and the volume of lakewater (14,300 m^3 or 3,777,660 gallons). The calculate geometry function was used to calculate the length of the line and area of the polygon drawn in ArcMap®.

incorporate a heat pump system into the renovations. Basic flow, volume, temperature, depth, and distance measurements were needed about the state-owned Lindenwood Lake (Hay, J., Vice President and Engineer, Sud Associates, pers. comm.). Using an HBS canoe, tape measure, and thermometer, the average depth, maximum depth, water temperature, and water flow of the lake were found to be 1.5 m, 2.5 m, 8.5°C, and 17,300 gallons/day respectively. ArcGIS® 9.3 was used to calculate the distance from Coker Lab to the deepest part of the lake (144 m) and the volume of the lake (14,300 m^3 or 3,777,660 gallons) by multiplying the average depth and area of the lake (Fig. 1) (ESRI 2008).

ClimateMaster, James M. Pleasants Company, and Froehling & Robertson are companies that specialize in heat pump systems and were all contacted to obtain cost estimates and system details. The research done for the Coker Laboratory heat pump system was summarized as a feasibility report (Appendix D). It was found that a 5-ton heat pump unit would be needed to provide enough heating for the 6,400 ft^2 of Coker Lab and the attached administrative building. This pump unit would be connected to 144 m of piping to the deepest part of Lindenwood Lake where a closed-loop system of black plastic coils would be sunk. Due to this shallow depth of only 2.5 meters and 4+ meters being preferable to provide insulation from the outside air, additional coils might be needed to increase the efficiency of the system. Dehumidification of the renovated Coker Laboratory could by accomplished by using a glycol solution running through the pipes, which could be incorporated into the same heat pump unit. Further research and information for incorporating dehumidification into this system is needed and could be provided by the James M. Pleasants Company (Hatchett, T., Regional Sales Representative, James M. Pleasants Company, pers. comm.).

The average system life of this heat pump is 25 years for the inside unit and at least 50 years for the loops in the lake. The heat pump system is priced at $6,000 to $8,000, and the projected savings are $1500/year, making the payback period 4-6 years. Assuming a cost of $8,000 and a payback period of 6 years, there will be about 20 years of system life after "paying itself off" in avoided utility costs. This will results in a lifetime avoided cost of about $30,000 for the heat pump heating system.

Additional research is needed to look into the ecological integrity of the lake with an added heat pump system, specifically the thermal pollution and the interaction between the plastic coils and organisms in the lake. More information will also be needed concerning the lake water temperature year-round and what resulting efficiencies and savings can be expected. If both of these studies have positive results, maintaining the lake's natural ecology and lake bottom temperatures remaining fairly constant through the year, it is recommended that this heat pump project should be incorporated into the Coker Laboratory renovations.

Funding Opportunities

Four grants for renewable energy or energy efficiency projects applicable to Highlands Biological Station were identified (Table 2). Details of these funding opportunities were summarized and communicated to the HBS leadership.

TABLE 2. Summary of available grants relevant to HBS for renewable energy or energy efficiency projects.

Organization	Grant Name	Grant Size	Deadline
The Kresge Foundation	Challenge Grant	$100,000 to $2,500,000	rolling basis
Wachovia Bank	The David, Helen and Marian Woodward Fund	$6,500 to $25,000	May 1 and Nov 1
Wachovia Bank	Percy B. Ferebee Endowment	$3,000 to $15,000	Sep 30
The Cannon Foundation, Inc.	The Cannon Foundation	$5,000 to $150,000	Jan 5, Apr 5, Jul 5, and Oct 5

It is my recommendation to apply for all available grants to maximize the number of energy saving projects that can be completed. These sustainability opportunities will remain nothing more than a list without the backing of funding to make them a reality. As additional funding becomes available or as grants are received, large capital investment projects should be considered. While these more expensive projects often have longer payback periods, the per-year savings after this period and for the remainder of the product life can be much larger. An example of this is how a heat pump system can save $30,000 over its lifetime, while each compact-fluorescent light (CFL) can only save $40 over its lifespan (Appendix D) (US DOE 2010).

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APPENDIX A

Strategic Energy Plan for the Highlands Biological Station for the 2009-2010 fiscal year (digital archive on attached CD).

APPENDIX B

Energy Assessment Report for the Highlands Biological Station prepared by the Waste Reduction Partners for Valentine House, Coker Laboratory, and Nature Center (digital archive on attached CD).

APPENDIX C

Feasibility Report for a solar thermal hot water system for the roof of Valentine House (digital archive on attached CD).

APPENDIX D

Feasibility Report for a heat pump heating system for Coker Laboratory using Lindenwood Lake as a heat sink (digital archive on attached CD).

USING PHENOLOGY GARDENS TO MONITOR CLIMATE CHANGE IN THE SOUTHERN APPALACHIANS

EMMA L. NASH

Abstract. In order to better understand past climatic change and to predict the effects of future change, it is useful to consider how climate affects biological systems. Thus, phenology, the study of the occurrence, timing, and interaction of biological events in plants and animals, has become increasingly important as indicator of a changing climate. Phenological monitoring also has great potential as an educational tool for teaching all ages about the effects of climate change on organisms and ecosystems. The present study sought to establish a network of phenological gardens and create a manual that would facilitate the accurate and uniform observation and collection of data from the phenology gardens. Prototype phenology gardens, consisting of a set of native and non-native plant species, were designed for four sites in Macon County, North Carolina and nearby Rabun County, Georgia. Signage, brochures, and a teacher's manual were created to accompany the gardens, to educate and encourage participation in phenological monitoring. The implementation of these gardens will contribute to the solidification of a regional phenology network that can provide long-term data for local, regional and national use.

Key words: citizen science; climate change; Coweeta Hydrological Laboratory; Highlands Biological Station; Mountain View Intermediate School; phenology; Rabun Gap Nacoochee School; school garden(s); Southern Appalachian Phenology Network.

INTRODUCTION

The 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC 2007) documents significant observed changes in both temperature and precipitation patterns over the past century. In addition to reporting observed change, the IPCC predicts a continued increase in global average temperature in the next century. While the general trends in climate change are understood and undeniable, it is unclear how shifting climatic variables will affect ecosystem function and species composition at a regional scale. In order to better understand past climatic change and to predict the effects of future change, we must understand how climate affects biological systems. Thus, phenology, the study of the occurrence, timing, and interaction of biological events in plants and animals, has become increasingly important (Parmesan 2006).

Monitoring phenology has a range of potential benefits for our understanding of the environment from both an ecological and economic perspective. Studying phenology and its relationship to climate change could increase the predictability of ecosystem productivity in response to altered greenhouse gas concentrations in the atmosphere, which will improve the accuracy of our predictions of climate in the future. In addition, phenological studies can provide further information on inter-specific interactions and population dynamics (Cleland et al. 2007). Of particular concern in this case is a scenario in which the phenophases (respective phenological timing) of two species, that share an important interaction, could become decoupled due to varied response to a changing climate. This is known as a phenological mismatch and could have significant impact on ecosystem processes and species survival (Strode 2003, Amano et al. 2010). A third benefit of studying phenology is our potential ability to indentify sylvicultural and agricultural species that are at risk in a changing climate, as opposed to those which may respond well to a changing climate (Cleland et al. 2007). The study of phenology bridges interests and can provide valuable information to multiple fields of study.

The study of phenology in recent years has taken on many forms. Studies can be roughly divided into two categories: small scale and large scale. Small-scale studies focus on observations of individual plants and attempt to determine patterns at the local scale , while large-scale studies use satellite information to determine regional and continental-scale patterns (Cleland et al. 2007). Both of these categories have positive and negative attributes, and literature on the subject stresses the importance of using the two approaches cooperatively. For example, satellite data can be used to incorporate species-specific data into a community level index (Amano et al. 2010), while species-specific studies can be used to ground-truth satellite data (Cleland et al. 2007). Both small- and large-scale studies are valuable tools in observing and predicting phenological and climatic changes.

There is a particular need for the collection of long-term data sets in the southern Appalachian region, as we are uncertain how mountain ecosystems will be affected by climate change. In the southern Appalachian, numerous organizations, from research centers to schools perform small-scale phenological studies. For example, Coweeta Hydrological Laboratory, the Great Smoky Mountains Institute at Tremont, and the Appalachian Highlands Science Learning Center at Purchase Knob each have independent phenology monitoring programs. In recent years, efforts have been made to organize these independent projects into a Southern Appalachian Phenology Network. Dr. Howard Neufeld, Appalachian State University, is initiating these efforts. The Highlands Biological Station became interested in joining the Southern Appalachian Phenology Network in the summer of 2010, and organized a project to establish phenology-monitoring sites at the Biological Station in Highlands, NC, and partner sites at lower elevations in Macon County, North Carolina and Rabun County, Georgia. My project represents the first step of this initiative, designing and implementing phenology monitoring gardens and data collection forms. A manual and supporting educational resources were created in order to ensure the accurate and uniform observation and collection of data from these phenology gardens, and facilitate their use as an educational resource for area schools and the general public.

METHODS

Garden prototype

Prototype phenology gardens and monitoring sites were created for four sites in the Blue Ridge escarpment area of the southern Appalachians (Table 1). These sites were chosen to represent a range of elevation in the interest of future comparison of phenology among sites.

Table 1. Location and elevation of the four sites chosen for gardens in the project.

Site	Location	County	Latitude	Longitude	Elevation (ft)
Coweeta Hydrological Laboratory	Otto, North Carolina	Macon	35°3'30"N	83°26'0"W	2480
Highlands Biological Station	Highlands, North Carolina	Macon	35°3'30"N	83°12'0"W	3900
Mountain View Intermediate School	Franklin, North Carolina	Macon	35°9'30"N	83°21'30"W	2000
Rabun Gap Nacoochee School	Dillard, Georgia	Rabun	34°57'30"	83°23'0"W	2200

Notes: Latitude, longitude, elevation were determined using topographic maps (TVA 1946)

Species selection for the gardens was determined based on a series of criteria. The ultimate goal was to have as many of the same species as possible at multiple sites so that phenological data could be compared across sites. Two lists were used: The National Phenology Network's (NPN) list of plant calibration species (USA-NPN 2010), and Project Budburst's '10 Most Wanted Species in America' list (Project Budburst 2010). The NPN list of plant calibration species includes 20 species that have broad distributions and are used to calibrate observations of other species with more narrow distributions. These lists present species of nationwide importance, not necessarily of regional importance, thus, native species were also prioritized in the garden design. Once it was determined that a mix of both nationally important and native species were to be included, physical site characteristics were evaluated. For example, Mountain View Intermediate School was built on recently cleared land and its available land was in full sun with poor soil conditions; therefore, it was important that selected species could thrive in these conditions. The final consideration was the coordination of species life cycle event timing with the standard school calendar.

Layout for the gardens varied by site. The Highlands Biological Station phenology garden was planted in a bed within the Botanical Gardens that was previously prepared. The layout was determined based on plant height, with the tallest plants in back and the shorter plants in front. In addition, the non-native species were placed in a central location so that they could be differentiated from the native species. The Mountain View Intermediate School Garden was designed by Deborah Gibbs to incorporate the landscaping requirements of the school. A portion of the garden at Rabun Gap Nacoochee School Garden was already planted around a walking trail located at the base of the school property. The lilac was planted at the head of the walking trail in close proximity to the sign.

Materials were created to accompany the gardens to educate and encourage participation in phenological monitoring. The need for these materials varied from site to site, and materials were primarily designed for sites with high public activity. Templates for an informational garden sign and brochure were designed using Microsoft Word 2008 for Macintosh. These materials were designed to be used primarily at Highlands Biological Station and Rabun Gap Nacoochee School, but could be adapted for other sites.

Teacher's manual

A teacher's manual was created to provide materials to assist teachers, students, and citizen scientists in the observation and reporting of phenological data. The goal of this manual was to present information in a way that would promote consistency so that data could be compared in the future. Data from the gardens are to be reported to the National Phenology Network; therefore, the materials created for the teacher's manual are based on the observation and data reporting guidelines presented in the National Phenology Network's Nature's Notebook (USA-NPN 2010).

RESULTS

Garden prototype

TABLE 2. Cumulative species list for all four sites and criteria evaluated for species selection.

Species	Nationally Important (NPN*; PB**)	Native to southern Appalachian Region	Suitable to Growing Conditions	Appropriate for the Public School Calendar
Acer rubrum	Yes NPN & PB	Yes	Yes	Yes; spring buds, fall senescence
Aster patens		Yes	Yes	Yes; fall flowering
Eupatorium purpureum		Yes	Yes	Yes; fall flowering
Iris cristata		Yes	Yes	Yes; spring flowering
Juniperus virginiana	Yes NPN	Yes	Yes	
Narcissus sp.		No	Yes	Yes; spring flowering
Panicum virgatum	Yes NPN	Yes	Yes	
Rhododendron calendulaceum		Yes	Yes	Yes; spring flowering
Solidago sp.		Yes	Yes	Yes; fall flowering
Syringa patula	Yes* NPN & PB	No	Yes	Yes; spring flowering[1]
Tradescantia virginiana	Yes** PB	Yes	Yes	Yes; spring flowering

Notes: National Phenology Network (NPN); Project Budburst (PB); * *Syringa patula* was used because *Syringa vulgaris* is regionally susceptible to a stem borer; however *S. vulgaris* is the species listed on the NPN and PB lists; ***T. ohioensis* is the species listed on the PB list, however I chose to use *T. virginiana* because it is a native species and should yield comparable results.

A set of eleven species was selected for establishing the gardens at the four sites. The species set (Table 2) consists of both woody and herbaceous perennials and annuals, including a deciduous tree, a coniferous tree, two shrubs, a grass, and six herbaceous species.

The garden at the Highlands Biological Station was planted between November and December 2010. The garden contains nine of the eleven species, and there are plans to include the remaining two species in the spring. A diagram of the Highlands Biological Station Phenology Garden layout is presented in Figure 1. The figure presents plans for the final garden, however at this point the monitoring tower and two species – *Aster patens* and *Eupatorium purpureum* – have not yet been incorporated into the garden. The goal is to have these elements in place in the coming year. At Mountain View Intermediate School planting began in November 2010 and, thus far, two species have been planted with plans to complete the garden with eight additional species. Rabun Gap Nacoochee School had five species growing on campus and plans to plant at least one more in the spring. Coweeta Hydrologic Laboratory had previously existing monitoring system that included two species on the list and plans to plant at least one more in the spring. When gardens are complete, all sites will be able to monitor at least one individual of three species: *Acer rubrum*, *Syringa patula*, and *Rhododendron calendulaceum*. All sites will be able to monitor at least two nationally important and two regionally important species.

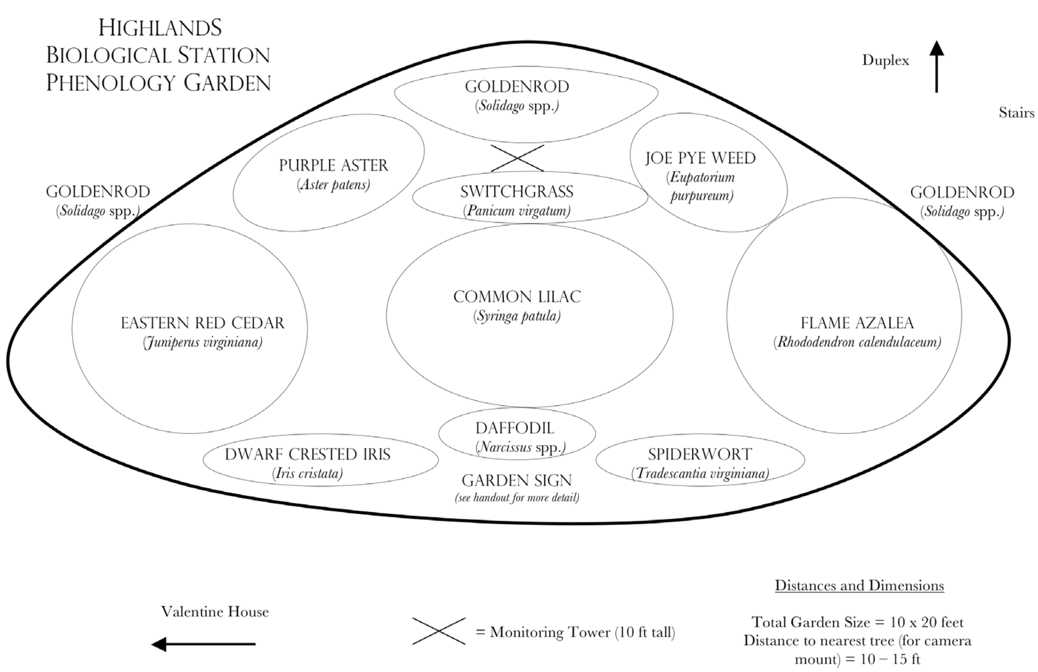

FIG. 1. Diagram of the Highlands Biological Station Phenology Garden.

In addition, sign and brochure templates were created and are presented in Appendices A and B. The sign depicts the name of the garden and a brief description.

The brochure presents information on the history of phenology, its relationship to climate change, and information on how the citizen scientist can contribute to phenological monitoring. In addition to basic information on phenology, the brochure presents a modified observation report log that can be filled out and reported to the National Phenology Network.[1]

Teacher's manual

The teacher's manual contains introductory information on plant phenology, and basic guidelines on how to observe and report phenological events such as flowering, budding, leaf-out, and leaf senescence. In addition to this general information, the manual contains species-specific guidelines on how to observe and report the phenology of species in the gardens, together with datasheets for recording observations. These guidelines and worksheets are formatted to be compatible with the National Phenology Network's "Nature's Notebook" so that observations can be easily reported to the National Phenology Network. "Nature's Notebook" is an online resource coordinated by the phenology network for observers nationwide to record observations. The materials were supplemented with information from Project Budburst's observation resources, which include observation guidelines and educational activities.[2] The manual (Appendix C) will be used by teachers at Mountain View Intermediate School and Rabun Gap Nacoochee School in the coming school year and could be easily adapted for use at other schools or by citizen scientists.

DISCUSSION

This project resulted in the successful creation of four phenology gardens that have been specialized to fit the needs of each site. The creation of these gardens will allow for the beginnings of a regional phenology network that can collect long-term data for local, regional and national use. These four gardens have common species of both national and regional importance that should allow for valuable comparison of phenological data among sites. While some sites have fewer species than others, the network will collectively gather data on several individuals from each of eleven species. This will allow sites to not only compare data, but also obtain useful data from other sites in the network. In addition to the implementation of phenology gardens, the creation of brochures and signs will increase public awareness and increase citizen science participation in the region. This can further contribute to the collection of consistent, long-term phenological data. Scientists have found great value in long-term historical data sets and effort should be made to contribute to current data sets. A 2008 study conducted in Massachusetts reviewed a 150-year record of plant flowering dates beginning in 1852 with the observations of Henry David Thoreau. The results of this study support the advancement of spring flowering dates with recent climate change and emphasize the importance of long-term data sets (Miller-Rushing 2008).

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[1] usanpn.org
[2] http://neoninc.org/budburst/resources.php

The teacher's manual provides materials for students, teachers, and citizen scientists, and facilitates the process of observing and recording phenological data. The incorporation of phenology into educational and scientific material has been successfully implemented elsewhere. For example, a project coordinated by the University of California, Santa Barbara incorporates a Teacher's Guide that provides materials for educators to teach phenology in elementary, middle, and high school classrooms in California (Haggerty 2008). In addition, Project Budburst is a campaign focused on promoting citizen science through phenology and climate change. Project Budburst also provides a source for online observation reporting.[2]

Although this project successfully achieved its goals of designing and implementing phenology gardens, signs, brochures, and a teacher's manual, it was limited in several ways. The project was confined to the space of one semester, and this time constraint resulted in a diminished ability to obtain species and plant the gardens. The project was also limited by lack of funds. This restricted the scope of the project both in terms of the number of plants purchased and number of gardens planted. I recommend the expansion of gardens established in the current project and the creation of new gardens at sites in the future.

The Highlands Biological Station phenology garden will be further elaborated by the addition of sensors, cameras, and electronic weather instruments (mounted on the Monitoring Tower identified in Figure 1). This "e-garden" is being developed as a prototype, with the eventual goal of developing the capacity for web-based comparisons among phenology gardens. In the future, additional gardens are planned for the North Carolina Arboretum in Asheville, NC, and Western Carolina University in Cullowhee, NC. The expansion of this project and similar projects has the potential to have significant scientific payoff in the future as data accumulate.

Climate change is a powerful force in the alteration of plant distribution and diversity because temperature, precipitation, and related climatic factors are often the drivers for the occurrence and timing of biological events (Parmesan 2006). The study of phenology is fundamental to the prediction and prevention of species extinction and loss of biodiversity due to climate change. Accordingly, the expansion and solidification of a Southern Appalachian Phenology Network has enormous potential for collecting scientifically useful data and for educating the public about climate change and its ecological effects. The gardens established in this project represent an important first step towards the development of such a regional network.

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[2] http://neoninc.org/budburst

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APPENDIX A

Sign template for the Highlands Biological Station Phenology Garden
(digital archive on attached CD)

APPENDIX B

Brochure template for the Highlands Biological Station Phenology Garden
(digital archive on attached CD)

APPENDIX C

Phenology Garden Teacher's Manual:
An introduction to teaching, observing and recording phenology
(digital archive on attached CD)

PHYLOGENETIC RELATIONSHIPS OF THE FLOWERING PLANT GENUS *SABATIA* (GENTIANACEAE) BASED ON *ATPI-H* GENE SEQUENCES: A COMBINED ANALYSIS

MICHELLE RUIGROK

Abstract. Previous systematic research on the flowering plant genus *Sabatia* (Gentianaceae) concluded that five well-resolved clades exist within *Sabatia*. However, relationships among these clades were poorly resolved. In this study, the *atpI-atpH* (*atpI-H*) intergenic, noncoding region of chloroplast DNA was sequenced and added to the previous datasets in order to construct a phylogenetic tree with better resolution than the previous models. The *atpI-H* dataset was analyzed alone and combined with the previous data to quantify its contribution to the phylogenetic tree. Maximum Parsimony (MP) and Bayesian analyses were performed and compared. Systematists have divided *Sabatia* into two sections and five subsections. Our results largely support this taxonomy with a few exceptions. Molecular results also reveal a correlation between chromosome number, biogeography and floral polymery with phylogenetic and evolutionary relationships. Additional datasets are needed to further resolve the interspecific relationships of *Sabatia*.

Key words: atpI-atpH; *floral polymery; flowering plant*; *Gentianaceae; plant systematic; phylogeny;* Sabatia; *taxonomy*

INTRODUCTION

For centuries, naturalists have described the relationships between species based on morphological characteristics and biogeography. The study of classification and evolutionary relationships of species is known as *systematics* (Hillis et al. 1996). Today, molecular systematics investigates the interspecific and intraspecific relationships among related taxa by analyzing DNA sequences to supplement observations based on other forms of empirical data, including morphological features. A well-resolved phylogeny is a valuable asset in conservation planning. In cases where a hybridization program is required to save a species from inbreeding, the preservation of that species' genetic material is important. Thus, an accurate species-level classification based on phylogenetic relationships can help managers choose the most genetically similar species to hybridize with the species in danger in order to main as much genetic diversity as possible (Avise and Nelson 1989).

The purpose of this study was to analyze the interspecific relationships of the 18 species in the flowering plant genus *Sabatia* of the Gentian family [Gentianaceae]. Although plants belonging to the genus *Sabati*a were described earlier, the genus *Sabbatia* was first proposed by Adanson in 1763 after Italian botanist, Liberato Sabbati (Wilbur 1955, Perry 1971). In 1814, Pursh, in describing *Sabatia,* changed the spelling of the genus. Since then, *Sabatia* has been treated several times, including by Grisebach (1839, 1845), Gray (1878), Blake (1915), Wilbur (1955), and Perry (1971). This paper draws from the taxonomy of Wilbur (1955) and Perry (1971).

Sabatia species are native to Eastern North America, Canada, Mexico and the Caribbean. Most species are found on the coastal plains of the southeastern United States and prefer wetland habitats (Wilbur 1955, Wood 1982, Mathews unpublished). Only five species grow in the Appalachian region and elsewhere outside of the coastal plain, including *S. angularis, S. brachiata, S. campanulata, S. capitata* and *S. quadrangula* (Perry 1971). *Sabatia* is threatened due to habitat loss as wetlands are under increasing development pressure on the coastal plain.

The majority of the species of *Sabatia* have 5-merous flowers; however, six species are polymerous, with 7-12 sepals, petals and stamens (Wilbur 1955, Perry 1971, Mathews unpublished). Chromosome numbers within *Sabatia* vary from n=13 to n=38, and both aneuploidy and polyploidy could be involved in speciation in *Sabatia* because related species have distinct chromosome numbers (Perry 1971, Mathews and Mansion unpublished).

Previous research, focusing on the evolution of floral traits and patterns of speciation in *Sabatia,* attempted to reconstruct the phylogenetic history of the group using DNA sequence data (Mathews and Mansion unpublished). Mathews and Mansion sequenced three non-coding chloroplast DNA (cpDNA) regions - the *trn*D-T intergenic spacer, *trn*-S-G-G, and *trn*L-F - as well as an internal transcribed spacer (ITS) region of nuclear DNA. Phylogenetic analyses of these data, using parsimony, concluded that five well-supported clades exist within *Sabatia*. However, relationships among these clades were poorly resolved. Thus, the purpose of the present study was to analyze the interspecific relationships within the genus *Sabatia* and construct a phylogenetic tree with higher resolution and statistical support than previous models. To do so, the *atpI-atpH (atpI-H)* region of cpDNA, an intergenic and highly variable noncoding region (Shaw et al. 2007), was amplified, sequenced, and analyzed both alone and combined with previous data sets.

MATERIALS AND METHODS

Sampling and DNA extraction

The starting material for this study was total DNA previously extracted from leaf samples using a DNEasy Plant Mini Kit (Qiagen Inc., Valencia, CA). The leaf samples were collected in the field prior to this study. In addition, I performed eight new total DNA extractions on leaf and stem material that had been stored in silica gel desiccant using a modified small-scale CTAB (cetyltrimethylammonium bromide) extraction method (Doyle and Doyle 1987). The protocol required 30-50mg of fresh or herbarium leaf tissue.

Eighteen species of *Sabatia* were sampled for the *atpI-H* analysis **(**Table 1**)**. *Eustoma exaltatum* (L.) Salisb*., Gyrandra brachycalyx* Standl. and L.O. Williams and *Gyrandra speciosa* Benth., were selected as outgroups for the study. *Gyrandra* is sister genus to *Sabatia* and *Eustoma* is sister genus to *Gyrandra+Sabatia* (Mansion and Struwe 2004). *Gyrandra speciosa* was excluded from the combined analysis because it was not analyzed in the previous study. In cases where more than one sample of leaf tissue was available, multiple accessions of these species were analyzed.

DNA amplification and sequencing

The *atpI-H* intergenic region of cpDNA was selected for study for its high variability and primer universality (Shaw et al. 2007). Samples were amplified by PCR using an Eppendorf Mastercycler Pro or an Eppendorf Mastercycle Gradient in 25µl reactions: 12.5µl PCR Master Mix including Taq polymerase and dNTPs (Promega), 8.5µl dH_2O, 1µl Bovine Serum Albumin (BSA, 1mg/ml), 1µl of DNA, and 1µl each of the *atpI* forward (TAT TTA CAA GYG GTA TTC AAG CT) and *atpH* reverse *(*CCA AYC CAG CAG CAA TAA C) primers (Shaw et al. 2007). In some reactions, 1.25µl of $MgCl_2$ was added to the mixture, and the other proportions adjusted to maintain 25µl reactions, in order to optimize PCR. The PCR cycling parameters were as follows: one cycle of five minutes at 80°C and 30 cycles of one minute at 95°C, one minute at 50°C, four minutes at 65°C, followed by five minutes at 65°C, and then held at 4°C until ready for analysis.

PCR products were run on a 1% agarose gel stained with ethidium bromide in order to identify the quality of the product. Successful reactions were cleaned using the QIAquick PCR purification kit (Qiagen Inc., Valencia, CA) and prepared for sequencing reaction using 5µl reactions with a BigDye® Terminator 3.1 Cycle Sequencing Kit (Applied Biosystems, Foster City, CA). Each sample consisted of 2µl Big Dye, 1.6µl of 1.0µM primer, 0.4 µl of water, and 1.0µl of DNA template. Sequencing reactions were purified with Centri_Sep™ spin columns (Princeton Separations, Adelphia, NJ), dried down with a Vacufuge (Eppendorf), and resuspended in 10µl of formamide. Samples were then automatically electrophoresed and analyzed on a 4-capillary AB3130 Genetic Analyzer.

TABLE 1. Origin of the plant material used.

Species of *Sabatia*	Collection location
angularis (L.) Pursh	Tennessee
arenicola Greenm.	Texas
bartramii Wilbur	Alabama
brachiata Ell.	N/A
brevifolia Raf.	Alabama
calycina (Lam.) Heller	Alabama
campanulata (L.) Torr.	Alabama
campestris Nutt.	Texas
capitata (Raf.) Blake	Tennessee
difformis (L.) Druce	New Jersey
dodecandra (L.) B.S.P.	N/A
gentianoides Ell.	Alabama
kennedyana Fern.	N/A
macrophylla Hook	Alabama
quadrangula Wilbur	Georgia
stellaris Pursh	Alabama

Sequence editing, alignment and phylogenetic analyses

DNA sequences were edited by eye using Sequencher® 4.7 (Gene Codes Corp., Ann Arbor, MI). Sequences amplified by forward and reverse primers were automatically assembled in Sequencher and compared to one another for accuracy. Ambiguous bases were identified by comparing the chromatogram peaks to the automated base calls produced by the Applied Biosystems data collection software. Edited sequences were exported in FASTA format to ClustalX 2.0.10 (Higgins et al. 1996) for alignment. Recognition of gaps as independent insertion or deletion events may influence the resulting phylogenetic hypotheses (Simmons and Ochoterena 2000). Thus, in the *atpI-H* dataset, sixteen unique shared indels, or insertions and deletions, were coded as a binary matrix for presence or absence. For taxa that were sequenced for the *atpI-H* analysis but not for the previous study, missing data were entered for the unsequenced regions. Where species with different accessions were sequenced, we added *atpI-H* data to the alternate accession. This was the case for *S. angularis, S. bartramii, S. brevifolia,* both accessions of *S. calycina,* both accessions of *S. campanulata, S. difformis, S. dodecandra, S. gentianoides, S. kennedyana, S. macrophylla,* both accessions of *S. quadrangula, S. capitata,* and *S. stellaris.*

We ran multiple phylogenetic analyses, including Maximum Parsimony (MP) and Bayesian analysis, on the *atpI-H* data alone and combined with the previously sequenced gene regions in order to explore each dataset's contribution to the combined dataset and to check for conflicting results. The phylogenetic trees of the Mathews and Mansion study (unpublished) were used to look at the contribution of the previous data to the combined data. Further, we analyzed the datasets separately in order to quantify the level of resolution in the new dataset (*atpI-H*), particularly because new taxa were added to the analysis.

MP analysis searches for the shortest tree(s). The underlying principle is that the tree(s) with the minimum number of changes to explain the data are the most likely. The aligned sequences were loaded into PAUP* 4.0b10 (Swofford 2003) in Nexus format for phylogenetic analyses. For each MP analysis, heuristic searches were performed with 100 random repetitions of taxon addition and Tree-Bisection-Reconnection (TBR) swapping. To test the strength of support for each clade, one hundred bootstrap replications were run using the same heuristic search settings for both sets of data.

Bayesian analysis of phylogenies is similar to Maximum Likelihood (ML) in that both analyses require a model of evolution (nucleotide substitution), which is used to search for the trees that are most consistent with the model and the data (Hall 2001). Bayesian inference is based on posterior probabilities, which are probabilities that are estimated based on a chosen model (prior expectations), given prior observation of the data. Unlike ML, however, which searches for a single tree, Bayesian inference searches for the best set of trees from which a consensus tree is computed (Hall 2001).

The program FindModel (Posada and Crandall 1998), a web implementation of Modeltest, was used on each dataset separately to determine the best-fit model of evolution according to the Akaike information criterion (AIC). Bayesian phylogenetic analyses were conducted using the program MrBayes 3.1., which uses the Metropolis-coupled Markov Chain Monte Carlo tree search method (Ronquist and Huelsenbeck 2003). Two separate simultaneous analyses were performed.

The datasets were partitioned into nucleotides and binary-coded indels, with each gene region also treated as a separate partition in the combined dataset, in order to specify different models of evolution for each partition in the analysis. Four chains (three hot and one cold) were run for 1,500,000 generations, using a random starting tree, and sampled every 100 generations. Likelihood convergence was reached when the average standard deviation of split frequencies was less than 0.01. Once convergence was reached, a consensus tree was computed after discarding the first 3,750 trees (the first 25% of all of the trees saved).

RESULTS

DNA sequencing and alignment

In total, we analyzed the *atpI-H* cpDNA region of 16 of the 18 species of *Sabatia* and three outgroup species. *Sabatia tuberculata and S. grandiflora* were excluded from analysis due to poor amplification and sequencing. *Gyrandra speciosa* was excluded from the combined data set analysis because it was not sequenced in the previous studies. Base pairs (bp) 612-635 and 659-698 of the *atpI-H* sequences were excluded from analysis due to ambiguity of alignment. The length of the aligned *atpI-H* dataset was 1,473 bp. When combined with the previous data sets, the total aligned length was 4,252bp.

Maximum parsimony and bootstrap analysis

The *atpI-H* MP analysis consensus tree (Fig. 1), combined data MP analysis consensus tree (Fig. 2), *atpI-H* Bayesian analysis consensus tree (Fig. 3), and the combined data Bayesian analysis consensus tree (Fig. 4) are shown. Bootstrap values and prior probabilities for the *apI-H* analysis are shown in Fig. 3. Bootstrap values and prior probabilities for the combined dataset analysis are shown in Fig. 4. Chromosome number for each species is also listed in parentheses in Fig. 4 for reference.

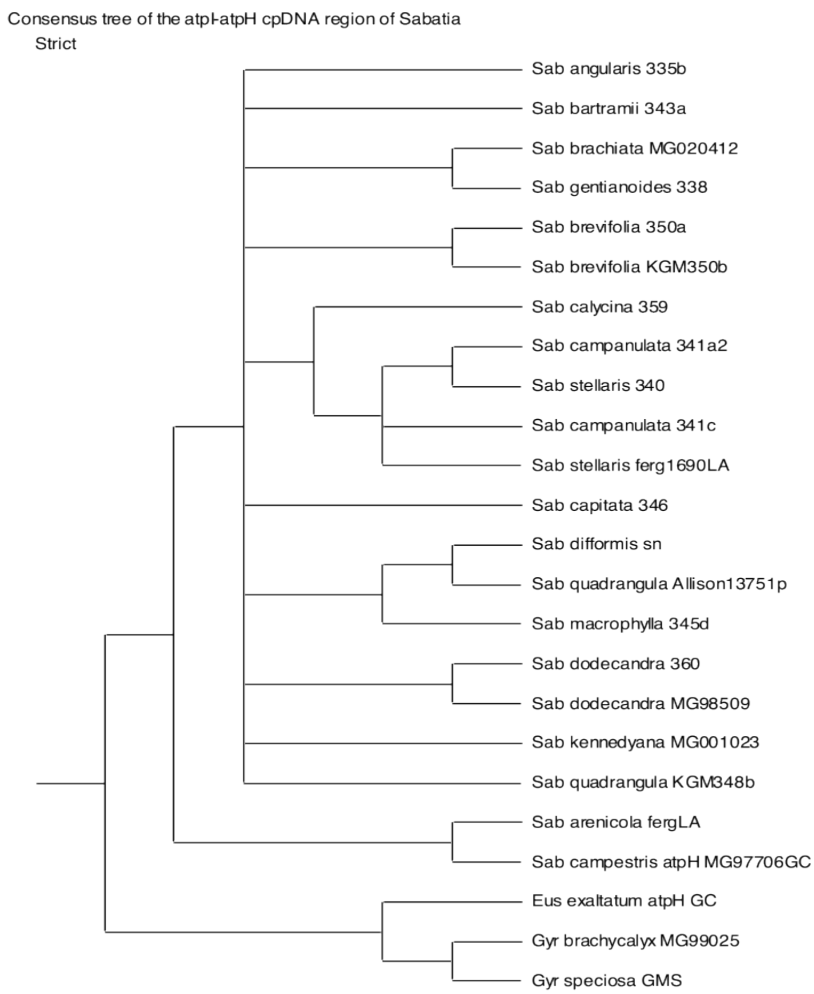

FIG. 1. Maximum Parsimony analysis strict consensus tree for the *atpI-H* dataset.

Sixteen coded indels were added to the *atpI-H* dataset. Maximum parsimony (MP) analysis produced 37,545 most parsimonious trees and 79 parsimony informative characters for the *atpI-H* dataset, with CI = 0.8960, RI = 0.8500 and RC = 0.7616. MP analysis for the combined data set produced three most parsimonious trees with 189 parsimony informative characters. For the combined data consensus tree, CI = 0.8588, RI = 0.7315, and RC = 0.6282. A strict consensus tree was developed for each analysis from the most parsimonious trees.

The *atpI-H* MP consensus trees supported the monophyly of *Sabatia* (bootstrap [BS] value = 74%), with ten resolved clades within the genus. One clade includes *S. brachiata and S. gentianoides*. Another includes *S. calycina, S. campanulata, and S. stellaris* (BS = 85%) with *S.*

campanulata and *S. stellaris* as sister species nested within this clade (BS = 100%). *Sabatia difformis, S. quadrangula, and S. macrophylla* are resolved in a clade (BS = 96%) with *S. difformis* and *S. quadrangula* nested as sister species (BS = 100%). A *S. arenicola* + *S. Campestris* clade is resolved (BS = 100%) at the base of the *Sabatia* clade. Several branches of the tree are unresolved, however, including *S. angularis, S. bartramii, S. capitata, S. kennedyana,* and *S. quadrangula.*

Relationships within the combined dataset consensus tree largely correspond with those obtained from the *atpI-H* MP analysis. Support for the monophyly of *Sabatia* was very strong (BS values = 100%). This tree also contained the *S. arenicola* and *S. campestris* clade at the base of the *Sabatia* clade (BS value = 100%) as well as the *S. calycina, S. campanulata, and S. stellaris* clade (BS = 62%) within which BS support for the sister species classification of *S. campanulata* and *S. stellaris* was 100%. Further, the *S. difformis, S. quadrangula, and S. macrophylla* clade (BS = 99%) was also generated. Within this clade, *S. difformis* and *S. quadrangula* are sister species with 97% BS support.

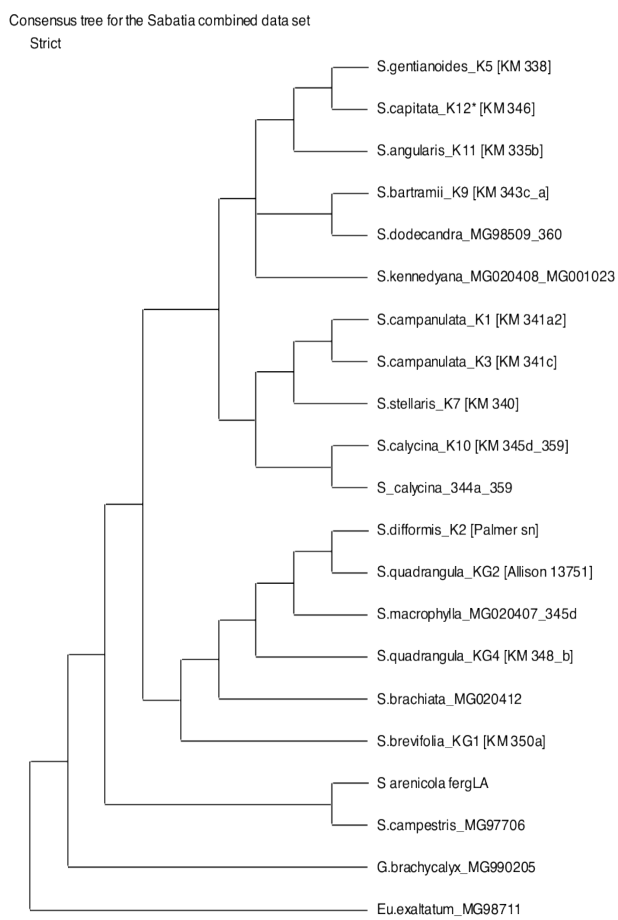

FIG. 2. Maximum Parsimony analysis strict consensus tree for the combined dataset.

Some results from the combined dataset consensus tree differed from the *atpI-H* dataset, including a clade containing *S. angularis, S. bartramii, S. dodecandra, S. gentianoides, S. capitata,* and *S. kennedyana* (BS = 62%) which was not present in the *atpI-H* consensus tree.

Within this clade, *S. bartramii* and *S. dodecandra* were sister species (BS = 87%) and *S. gentianoides* and *S. capitata* were sister species (BS = 69%). The *S. brachiata* and *S. brevifolia* lineages were unresolved.

Bayesian analysis

The best-fit model chosen by FindModel for the *atpI-H* aligned data matrix without the coded indel binary matrix was the GTR: General Time Reversible Plus Gamma with invariant sites, gamma shape parameters and empirical-based frequencies. For the binary matrix, we selected a standard model used for restriction site data which uses equal rates of change and no reversals allowed.

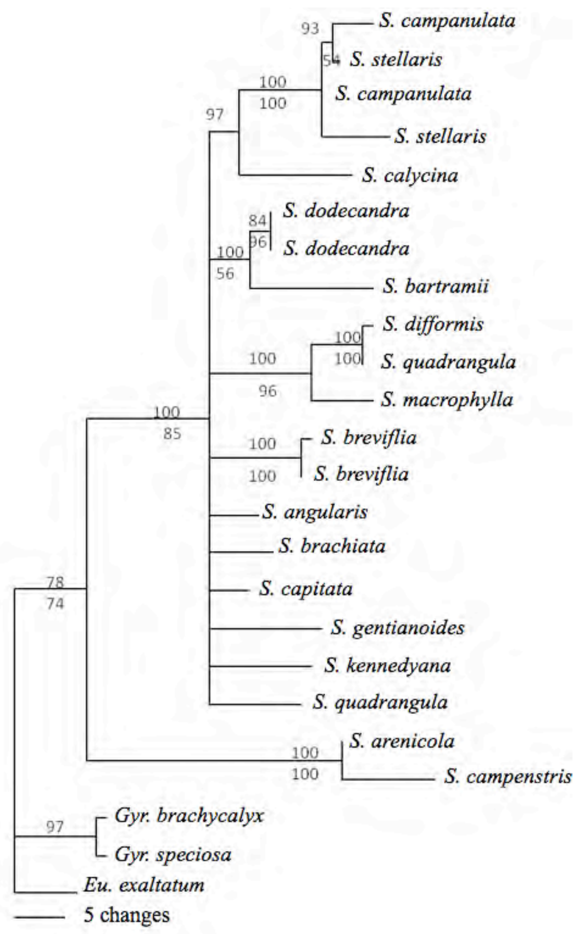

FIG. 3. *atpI-H* Bayesian analysis consensus tree. Bootstrap values >50% are shown under the branches. The space is left blank where bootstrap values >50% were not given. Prior probabilities are shown above the branches.

Bayesian analysis for the *atpI-H* data resolved ten clades within *Sabatia.* The Bayesian consensus tree and the MP tree do not conflict with each other in terms of tree topology, but they have different resolution in two areas. The Bayesian consensus tree grouped *S. bartramii* as sister species to *S. dodecandra* (prior probability [PP] = 100%)*,* which is unresolved in the *atpI-*

H MP consensus tree. In the *atpI-H* MP consensus tree, *S. gentianoides* and *S. brachiata* are sister species, but this is unresolved in the *atpI-H* Bayesian consensus tree.

The Bayesian consensus tree and the MP consensus tree for the combined dataset do not conflict with each other in terms of tree topology, but they have different resolution in two areas. The MP analysis for the combined dataset groups *S. angularis* as sister species to *S. gentianoides* + *S. capitata,* and *S. kennedyana* as sister species to *S. bartramii* + *S. dodecandra.* In the Bayesian consensus tree, *S. angularis* and *S. kennedyana* are unresolved at the bottom of the clade. Also, the MP combined data consensus tree successively nests *S. brevifolia, S. brachiata, S. quadrangula, S. macrophylla, S. difformis,* and the second accession of *S.quadrangula* in a single clade but the Bayesian consensus tree for the combined dataset does not include *S. brachiata* or *S. brevifolia* in that clade.

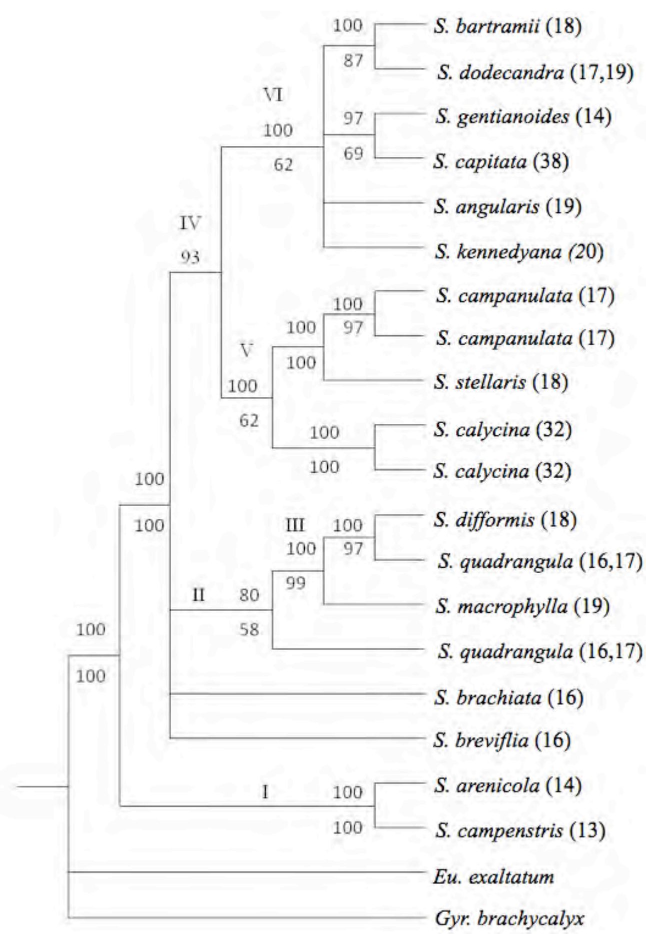

FIG. 4. Combined dataset Bayesian analysis consensus tree. Bootstrap values <50% are shown under the branches. Where no bootstrap values >50% were given, the space was left blank. Prior probabilities are shown above the branches, and the chromosome number (n=) for each species is shown in parentheses (Perry 1971).

DISCUSSION

In this study, increasing the amount of informative characters resulted in more resolved, better-supported tree depicting the phylogenetic relationships within *Sabatia.* The combined data analysis found only three most parsimonious trees, compared with the 37,545 parsimonious trees of the *atpI-H* data, showing that there is better resolving power in more data. Bayesian analysis showed high support for many of the resolved clades. Further, several of the clades in the *atpI-H* consensus tree are of those species with multiple accessions. While these clades do not resolve interspecific relationships, they do support the taxonomic status of these species.

Comparison of traditional systematic treatments with phylogenetic analyses results

Systematists have subdivided the genus *Sabatia* into two sections and five subsections (Table 2) on the basis of morphology and biosystematics (Grisebach 1845, Blake 1915, Wilbur 1955, Perry 1971). Biosystematic data conducted by Perry (1971) is based on artificial crossings. Much of the molecular data from this study and the earlier study of Mathews and Mansion (unpublished) support the traditional classification but there are discrepancies.

TABLE 2. Wilbur's (1955) treatment of *Sabatia*.

Section	Subsection	Species
I *Sabatia*.	A. Difformes	*difformis* *macrophylla*
	B. Angulares	*angularis* *quadrangula* *brachiata*
	C. Campestria	*arenicola* *campestris*
	D. Campanulatae	*campanulata* *stellaris* *brevifolia*
	E. Dodecandrae	*bartramii* *dodecandra* *kennedyana* *calycina*
II. *Pseudochironia*		*gentianoides* *capitata*

The *atpI-H* dataset, previous datasets, and the combined dataset strongly support the sister species classification of *S. difformis* and *S. macrophylla* in subsection (subsection). A; however, the MP and Bayesian strict consensus trees placed *S. quadrangula* in the same clade rather than grouping it with *S. angularis* and *S. brachiata*. Furthermore, *S. quadrangula* and *S. difformis* as sister species (BS = 97%, PP = 100%) for the combined data, suggesting that *S. quadrangula* should be reclassified to subsection A from subsection B, based on molecular data. Like *S. difformis* and *S. macrophylla, S. quadrangula* is pentamerous with white flowers and similar chromosome number (n = 18, n = 19, and n = 16, 17, respectively), providing morphological support for this reclassification (Table 3 or make an appendix) (Perry 1971). Perry (1971) found that members of subsection A crossed freely with *S. quadrangula* and *S. brevifolia;* however, he did not reclassify *S. quadrangula* because it had crossing and morphological affinities with other species as well (Perry 1971). Blake (1915), on the other hand, placed *S. quadrangula* in the same subsection as *S. difformis* and *S. macrophylla* (his subsection Angulares) based on morphology (Perry 1971).

Unfortunately, neither the *atpI-H* nor the combined dataset resolved the *S. angularis* + *S. brachiata* sister-species relationship in subsection B; however, Mathews and Mansion (unpublished) data support this classification. Perry (1971) found that *S. angularis* crossed with members of subsection D and with *S. dodecandra.* The consensus tree for the combined dataset placed *S. angularis* and *S. dodecandra* within the same clade.

Subsection C is strongly supported in both the *atpI-H* dataset and the combined dataset, with a bootstrap value of 100% in the combined dataset. Perry (1971) stated that *S. arenicola* and *S. campestris* appear to represent a well-differentiated line of evolution in *Sabatia* because they are genetically distinct (having the lowest chromosome numbers, n=14 and n=13, respectively) and geographically isolated. In the phylogenies generated in this study, *S. arenicola* and *S. campestris* are ancestral. If these two species are ancestral then their range today suggests that *Sabatia* once had a more widespread biogeographic distribution. *Sabatia. arenicola* is isolated on the Western Gulf coast and *S. campestris* is isolated in the midwest while today, most of the other species are limited to the Atlantic and Gulf coastal plain. If *S. arenicola* and *S. campestris* indicate a previously wider distribution of *Sabatia*, then they may represent the oldest *Sabatia* lineages (K. Mathews, Western Carolina University, pers. comm.), as indicated by our phylogenetic results.

Perry (1971) argued that species differentiation in *Sabatia* is correlated with changes in chromosome number which, in turn, prevent or reduce crossability. Speciation based on chromosome numbers within *Sabatia* is suggested by the *S. arenicola* + *S. campestris* clade. These two species have similar numbers of chromosomes (n=14 and n=13, respectively; Perry 1971), while the most derived species in the strict consensus trees have higher chromosome numbers. If *S. arenicola* and *S. campestris* are ancestral, then chromosome number appears to increase with speciation (K. Mathews, Western Carolina University, pers. comm.; Fig. 4).

The results in this study support the placement of *S. campanulata* and *S. stellaris* in the same subsection (D). Unfortunately, both datasets left *S. brevifolia* unresolved, perhaps because the dataset is missing *S. grandiflora,* a potentially close relative of *S. brevifolia.* The absence of these data may make it difficult to resolve the taxonomy of *S. brevifolia.* Perry's artificial crossing studies (1971) found that all members of subsection D are intercrossable except *S. brevifolia,* and that all the species are more closely related to each other than *S. brevifolia.* As mentioned earlier, there is evidence that *S. calycina* should also be placed in subsection D, rather than E. Blake (1915) placed *S. calycina* in subsection D, and Perry's (1971) hybridization evidence supported this placement. The MP analysis for both datasets placed *S. calycina* in the same clade as *S. campanulata* and *S. stellaris* (BS=100%).

Subsection E does not appear to be monophyletic. Both phylogenies support the placement of *S. bartramii, S. kennedyana, and S. dodecandra* in the same subsection (E); however, the combined dataset MP and Bayesian consensus trees also resolve *S. angularis, S. gentianoides,* and *S. capitata* in this clade (BS = 62%, PP = 100%) which indicates a s single origin of obligately polymerous flowers, a trait that is lost in *S. angularis.*

S. gentianoides, and *S. capitata* are sister species (BS = 69%; PP = 97%), which is considered low. However, in Perry's (1971) artificial crossings, *S. gentianoides* crossed with members of subsection E and *S. capitata* crossed with *S. dodecandra* and *S. bartramii,* which may explain why the phylogenies in this study resolved *S. gentianoides* and *S. capitata* in the same clade as several members of subsection E. Crossability is an ancestral character state that is related to recent divergence.

Conclusions

While morphological and biosystematic observations are valuable for understanding the systematics of the genus *Sabatia*, molecular data provide additional power in reconstructing phylogenetic relationships among taxa, especially when the molecular dataset combines several gene regions. For example, our data support a single common ancestor for those species of *Sabatia* that are polymerous, which morphological and biosystematic data could not determine alone. In light of the biogeographic distributions of species within the genus, the molecular data also indicate that the genus *Sabatia* once occupied a wider range. Today, most of the species are limited to the coastal plain of the Atlantic and Gulf coasts, with disjunct populations (Perry 1971).

Finally, the addition of the *atpI-H* dataset to previous datasets improved the resolution of the phylogenetic tree of *Sabatia.* However, there are still relationships that are unresolved, including the placement of *S. angularis, S. kennedyana, S. brachiata,* and *S. brevifolia,* as well as two species that were not included in this study, *S. grandiflora* and *S. tuberculata.* In order to fully resolve the phylogenetic relationships in the genus *Sabatia,* additional genetic regions should be sequenced. Also, it is unclear how an analysis of primarily nuclear DNA would compare to this study, where the majority of the data was chloroplast DNA.

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WATER QUALITY MONITORING OF THE UPPER CULLASAJA WATERSHED, HIGHLANDS, NORTH CAROLINA

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Abstract. The Upper Cullasaja River watershed is located in Highlands, North Carolina and is composed of four sub-watersheds: Cullasaja River, Big Creek, Mill Creek, and Monger Creek. In recent years, there have been documented water quality issues in the watershed, emphasizing the need for consistent monitoring. In order to provide an evaluation of the current state of the watershed we conducted a series of water quality assessments at six sites in the watershed. Physical and chemical monitoring was conducted through habitat assessment, Wolman pebble counts, and chemical analyses. Biological monitoring included a fish study to determine abundance and species diversity at each site and a study of aquatic invertebrates with calculations of an Index of Biotic Integrity (IBI) as an additional determination of stream health. The results of this study update the 2004 Upper Cullasaja Watershed Association (UCWA) Strategy and Action Plan. Additionally, the present study supports the development of a nine - element watershed restoration plan for the Upper Cullasaja that is to be completed in the next three years through funding from Section 319 of the NC Department of Environment and Natural Resources' (NCDENR) FY2010 Non Point Source Pollution Control Grant program.

Key words: biomonitoring; biotic index; Cullasaja River; EPT; habitat assessment; Highlands Plateau; stream chemistry; water quality, watershed plan; Wolman pebble count.

INTRODUCTION

Upper Cullasaja River Watershed

The Upper Cullasaja River watershed is located in the Blue Ridge Mountains of western North Carolina (Fig. 1). The Cullasaja River is a tributary to the Little Tennessee River located in southeastern Macon County. The watershed includes the Town of Highlands, a small mountain town with a population of approximately 1000, not including significant tourist and second-home communities. The residential and commercial development associated with these populations contributes to urbanization and associated problems, particularly with water quality. The Upper Cullasaja watershed can be divided into four sub-watersheds of the four main tributaries of the Highlands Plateau: Big Creek, Mill Creek, Monger Creek and the Cullasaja River which flow from their headwaters into Lake Sequoyah (Fig. 1). Land use varies throughout the Upper Cullasaja River watershed, resulting in varying conditions of the stream basins. For example, Mill Creek runs through downtown Highlands while Big Creek runs through relatively undeveloped private and public lands. The drainage area and the total miles of streams involved in each sub-watershed are listed in Table 1 (UCWA 2004a).

TABLE 1. Drainage area and total stream mileage of each sub-watershed.

Sub-Watershed	Drainage Area (mi^2)	Stream Mileage
Big Creek	5.3	10.0
Mill Creek	1.7	3.0
Monger Creek	2.0	3.7
Cullasaja River	5.4	10.3
Total	14.4	27.0

Various local and state organizations are involved in projects that monitor and address water quality issues in the Upper Cullasaja River watershed. The North Carolina Division of Water Quality (NCDWQ) is the principal coordinating agency for water quality studies, which include a basin-wide assessment report, Watershed Assessment and Restoration Projects (WARP), and the North Carolina Integrated Report. The Integrated Report categorizes stream segments on a scale of 1 to 5 based on data from water quality assessments. Category 1 streams attain the water quality standard and are not threatened, while impaired streams fall under Category 5. Section 303(d) of the Clean Water Act is a list of Category 5 impaired waters requiring the development of Total Maximum Daily Load (TMDL) to determine the maximum amount of a pollutant that each water body can receive and still attain water quality standards (NCDENR 2010). Both the Cullasaja River and Mill Creek, from their respective sources to Mirror Lake, are noted as impaired on North Carolina's 303(d) list.

In 2004, the Upper Cullasaja Watershed Association (UCWA) published a Strategy and Action Plan for the Upper Cullasaja watershed (UCWA 2004a). In section four of the 2004 plan (the strategy implementation section), the Highlands Biological Station (HBS) and other groups are called upon to implement chemical, physical and biological monitoring initiatives across the watershed. To this end, the current report provides monitoring data at six sites across the watershed including water chemistry, physical characterization of stream channels, measures of benthic invertebrate populations and fish surveys. These data will also be useful for a planned update to the watershed plan slated for 2011-2013.

The updated plan is funded by NC Department of Environment and Natural Resources (NCDENR) through their Section 319 Non Point Source Pollution Control Grant for FY2010, a program that administers federal Environmental Protection Agency (EPA) funds for watershed planning. The grant was awarded to the Little Tennessee Watershed Association (LTWA) in partnership with HBS to develop a nine-element watershed restoration plan for the Upper Cullasaja. Watersheds that have nine-element plans in place are eligible for EPA funding to implement practices addressing the water quality concerns identified in the plan. A nine-element plan addresses the nine key issues that EPA considers to be critical in the development of watershed planning efforts, such as identification of causes and sources of pollutants. Other elements of nine-element plans involve educational and monitoring components, with which HBS has agreed to provide assistance. In addition to the education and monitoring activities performed during the semester, the current study also provides updated maps, GIS analysis and background information to the 2004 plan that may be used in the nine-element plan.

TABLE 2. Site location and nomenclature used for the six study sites in the Upper Cullasaja watershed, Highlands, North Carolina.

Site Name	Road Name	Abbreviation	Latitude	Longitude
Monger Creek at Cyprus Restaurant	Highway 106	MoC1	35.04946°N	83.20747°W
Cullasaja River at Highway 64	Highway 64	CR1	35.06914°N	83.18779°W
Big Creek at Shortoff Road Bridge	Shortoff Rd.	BC1	35.09062°N	83.19395°W
Big Creek at Town Water Intake	Sequoyah Ridge Rd.	BC2	35.07183°N	83.21633°W
Mill Creek at old Sewage Treatment Plant	Un-named Rd. off Maple St.	MiC1	35.05689°N	83.20043°W
Mill Creek at Brookside Lane	Brookside Ln.	MiC1	35.05916°N	83.20429°W

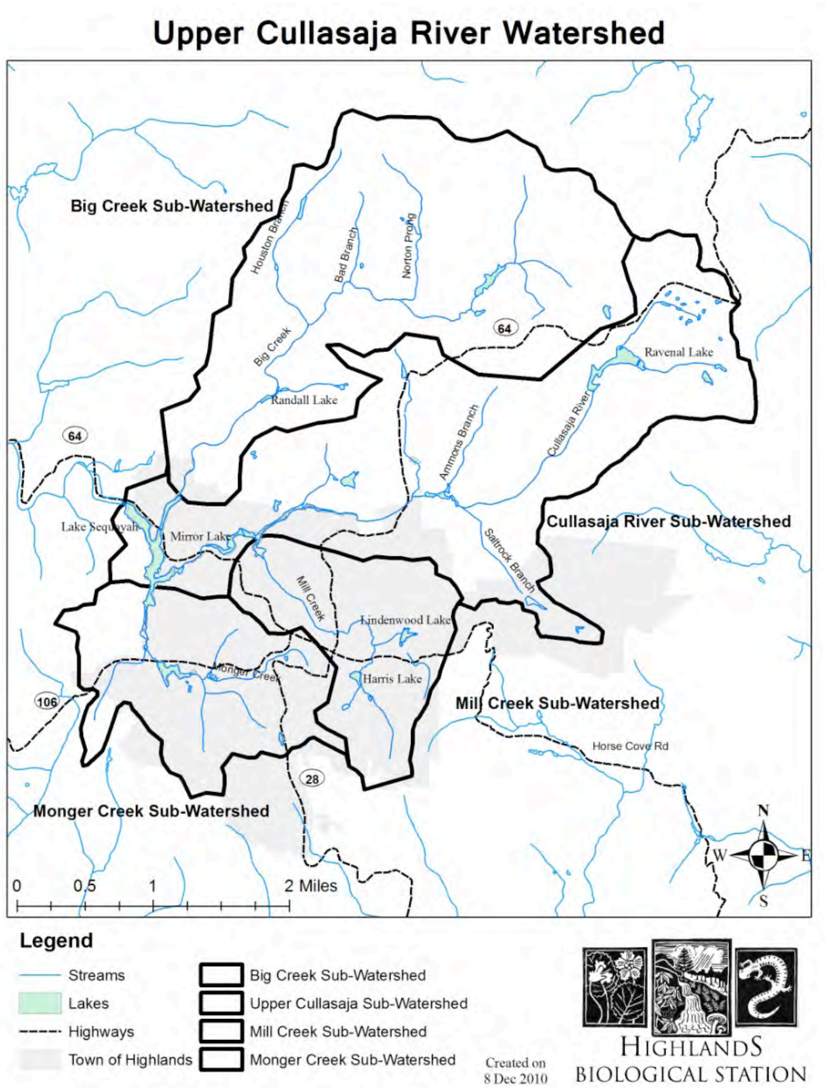

FIG. 1. Map of Upper Cullasaja River watershed with sub-watershed boundaries and labels included. Hydrology and road layers have been added for reference.

Hydrology

The Upper Cullasaja watershed includes an area of 14.3 mi^2 and contains the Town of Highlands, NC. Located on the Highlands Plateau and surrounded by the Blue Ridge Mountains, the watershed drains westward away from the eastern continental divide, which forms the watershed's southwestern, southern and eastern boundary. The Lake Sequoyah reservoir is the principal impoundment of the Upper Cullasaja River.

The United States Geological Survey (USGS) has denoted the watershed hydrologic unit No. 06010202 and the North Carolina Department of Water Quality (NCDWQ) Subbasin Code is 04-04-0. Mill Creek and the Cullasaja River flow into Mirror Lake, which, in turn, drain into Lake Sequoyah; Big Creek and Monger Creek flow directly into Lake Sequoyah. The mainstem of the Cullasaja river then discharges from Lake Sequoyah and flows northwest to its confluence with the Little Tennessee River in Franklin, NC.

USGS low flow estimates for this watershed, as referenced in a recent report by the Upper Cullasaja Watershed Association (UCWA 2004a), predict a 7Q10 (7 days lowest flow average in 10 years) of 2.2 cubic feet per second (cfs) for the upper Cullasaja River with approximately 3.9 mi^2 drainage at US 64. Values of 2.9 cfs and 5.4 mi^2 were recorded at Lake Sequoyah after the Cullasaja River confluence with Big Creek, Mill Creek and Monger Creek. 7Q10 for Big Creek was 2.8 cfs (5.2 mi^2) at US 64, while Mill Creek at Brookside Lane and Monger Creek at the Cullasaja confluence had 7Q10 values of 0.8 cfs (1.5 mi^2) and 1.1 cfs (2.0 mi^2), respectively. These estimates, though more accurate for size comparisons than width, provide a basis for comparison of flow based on size in order to examine effects of stresses from local development (UCWA 2004a).

Geography and soils

Highlands, North Carolina is located on a mountain plateau near the southern terminus of the Appalachian mountains. The U.S. Forest Service has identified the Highlands Plateau as "Highlands Upland," an area with unique combination of climate, geology, and geography (USFS 2010). It is classified as the only temperate, deciduous rainforest in the continental U.S. other than the Pacific Northwest. The forests are mainly oak-hickory and oak-heath complexes where heaths include species of *Rhododendron* and mountain laurel. Many rare plant species can be found in the rich understory of herbs and shrubs. Unique ecological habitats in the vicinity include southern Appalachian bogs, spray cliffs, old-growth forest patches, seeps, and Carolina hemlock bluffs. The watershed elevation ranges from 5,000 ft on Shortoff and Whiteside Mountains to 3,600 ft at Lake Sequoyah. The majority of the Highlands Plateau has a slope between 15 and 50 percent, with some areas exceeding a 60 percent grade (UCWA 2004a).

The Upper Cullasaja River watershed is underlain by gneiss bedrock covered with schist. The area includes prominent granite/gneiss rock outcrops and high elevation domed landscapes set above steep escarpments, such as Whiteside Mountain. The granite/gneiss intrusions make up 60% of the primary bedrock composition, greywacke-schist-amphibolite makes up 20%, and greywacke-schist makes up 19% (UCWA 2004a). The main soils in and around Highlands are stony and fine sandy loam.

Meteorology/Weather

The Upper Cullasaja River watershed is often characterized as a high elevation rain forest due to the characteristic heavy rainfall of the area (UCWA 2004a). The average annual rainfall over the past 30 years was 83.65 in, with a range between 58.79 in and 108.50 in. The average monthly rainfall is 6.99 in, with a minimum of 6.06 in October and a maximum of 8.11 in November (Fig. 2). Stream flows in this watershed are highly variable because the range of a single month's precipitation over the past 30 years is 0.04 in to 32.37 in. In the same time period, the average monthly temperatures in the watershed has ranged from 14.90°F to 84.20°F. The warmest month has usually been July with an average high of 78.39°F, and the coldest month has traditionally been January with an average low of 23.76°F from 1980 to 2010 (Fig. 2) (HBS 2010).

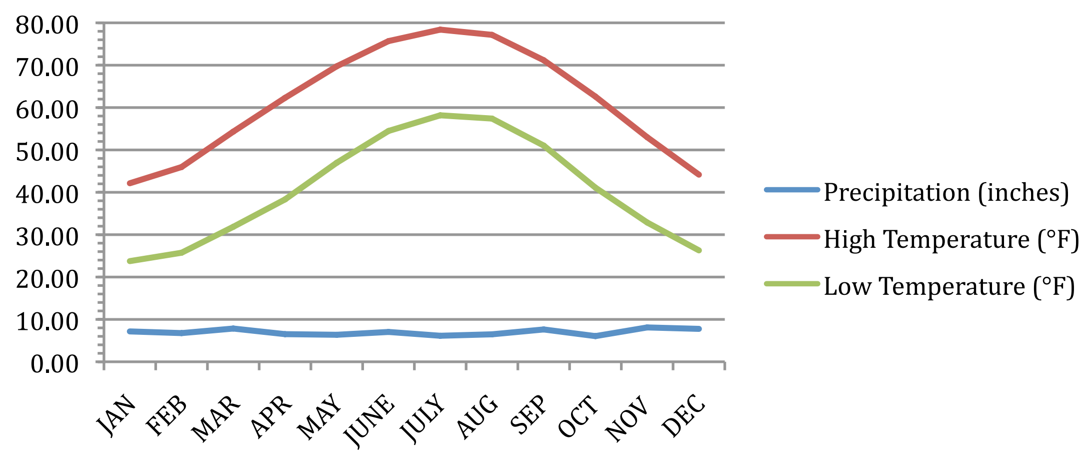

FIG. 2. Average monthly weather data for Highlands, NC from 1980-2010.

Land Use

The Highlands Plateau, along with much of western North Carolina, was extensively logged beginning in the late 1800's before being divided into private parcels and National Forest units. The historic Kelsey trail, at one time the only route to Whiteside Mountain that once ran through what Robert Zahner called the "primeval forest," fell victim to post-war logging operations and is now preserved only in written accounts (Zahner 1994). The Town of Highlands was incorporated in 1879 as a resort town, promoting itself and the surrounding area as more than just a 'passing attraction' but rather a pleasurable destination capable of restoring ones health (UCWA 2004a). Though development was initially slow due to a shortage of reliable roads, the construction of roadways in the early 20th century promoted economic growth and further development within the town; Lindenwood Lake, Ravenel Lake, Lake Sequoyah and the Lake Sequoyah hydroelectric dam and Highlands Country Club were all constructed during this era of development (UCWA 2004a). Champion Lumber cleared a large portion of the watershed in the 1940s and, by the 1980s, both the Wildcat Cliffs Country Club and Highlands Falls Country Club had been constructed on sites previously covered by old-growth forest. Residential and recreational development in the area coincided with a large number of stream modifications and impoundments over the course of the century (UCWA 2004a).

Based on GIS analysis of a 2006 land cover classification map (http://coweeta.uga.edu), approximately 60% of the watershed is currently forested or undeveloped, while close to 35% is developed to varying degrees of intensity. Land cover classifications for the 2006 land use layer were classified using the National Land Cover Database (NCLD) cover classes for 2001 (MRLC 2010). Further GIS analysis determined that approximately 30% of the watershed flows through the city limits of Highlands (http://gis.highlandsnc.org/), with discharge exposed to a variety of land uses, with various development classes (45.4%) and deciduous forest (41.5%) constituting the largest components.

By comparing the land cover layers in GIS for the years 1986 and 2006, it is possible to quantify the changes in land use in the Upper Cullasaja watershed between land use classes during this 20-year period in percentages (Fig. 3, Table 3; http://coweeta.uga.edu). The largest increases in proportion of land cover occurred within the developed/open space (+3.28%), deciduous forest (+3.40%) and mixed forest (+3.10%) classes. This is likely due to increased residential development and reductions in logging activity throughout the watershed in recent years (UCWA 2004a). Pasture/hay (-5.40%) and evergreen forest (-3.14%) categories experienced the largest reductions in land cover proportions, likely due to development forest cuts and conversion of old pasture to residential plots. A land use planning effort in 2002-2003 found that 800 parcels, 30% of all parcels within the city limits, remained undeveloped (UCWA 2004a).

TABLE 3. Change in land cover between 1986 and 2006 from Upper Cullasaja Watershed

Land Cover Class	1986 % Land Cover	2006 % Land Cover	% Change
Open Water	0.28	0.46	+ 0.18
Developed, Open Space	27.41	30.69	+ 3.28
Developed, Low Intensity	0.93	2.35	+1.42
Developed, Medium Intensity	0.35	0.65	+ 0.30
Developed, High Intensity	0.03	0.05	+ 0.02
Barren Land/Rock/Sand/Clay	0.10	0.20	+ 0.10
Deciduous Forest	42.40	45.80	+ 3.40
Evergreen Forest	10.70	6.14	-3.14
Mixed Forest	7.35	10.45	+ 3.10
Shrub/Scrub	1.45	1.41	- 0.04
Grassland/Herbaceous	0.00	0.50	+ 0.50
Pasture Hay	6.66	1.23	- 5.43
Cultivated Crops	1.60	0.02	- 1.58
Woody Wetlands	0.66	0.05	- 0.61
Emergent Herbaceous Wetlands	0.01	0.00	- 0.01

A large area of the Cullasaja sub-watershed upstream of Mirror Lake, more than half according to UCWA (2004a), is divided among three golf courses and their respective communities. A golf course and both high intensity commercial and residential development are located within the Monger Creek sub-watershed. The Mill Creek sub-watershed is heavily urbanized within downtown Highlands, and flows through mostly residential development above and below the town center (UCWA 2004a). The landowners and land managers in these three sub-watersheds have, over the years, cleared a large proportion of the riparian vegetation, altered stream channels, artificially stabilized banks, added impoundments and routed flow through culverts among other modifications, all of which have led to current water quality concerns (UCWA 2004a). Of all the sub-watersheds, Big Creek is the least developed and contains the largest area of protected/managed lands; 27.9% of the Big Creek sub-watershed is located within the Nantahala National Forest (UCWA 2004a).

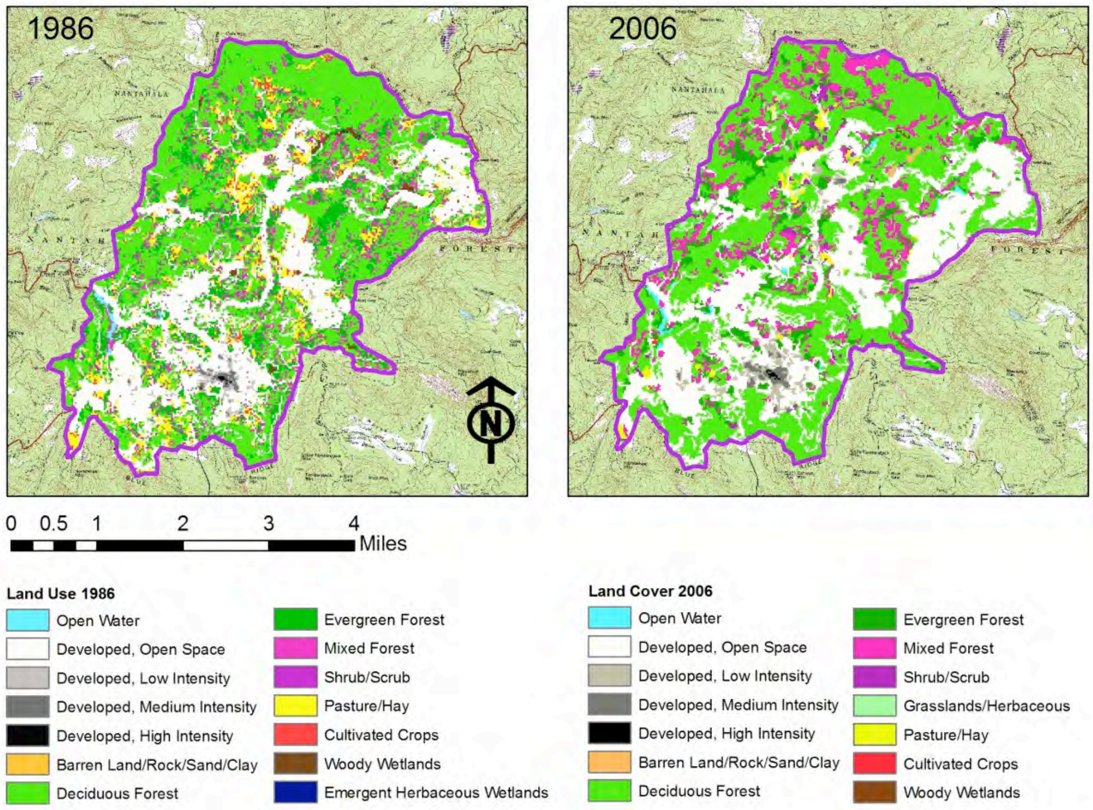

FIG. 3. Land use in the Upper Cullasaja watershed for 1986 and 2006.

Population

Highlands' population is difficult to estimate because the majority of houses serve as seasonal residences and vacation homes. The permanent population of Highlands is estimated to be 909 in the winter and increases to 4,000-5,000 residents in the summer (Census 2000). The local Chamber of Commerce estimates that up to 30,000 occupy the Upper Cullasaja River watershed in the summer; however, this number cannot be substantiated by hard data. Two-thirds of the property tax bills for Highlands are mailed to addresses outside of Macon County, and Macon County sends 50 percent of its county tax bills to owners outside the county (UCWA 2004a). The population data will be updated soon with the release of the 2010 census report. The current population count is out-of-date and should be used as a rough approximation until the 2010 census data become available. The large proportion of remote ownership of property due to seasonal residents adds to the complexity of working jointly with property owners on watershed issues.

Water Supply

Groundwater supplies the majority of private and community well systems throughout the Upper Cullasaja watershed, with the exception of the Town of Highlands, which uses the Big Creek arm of Lake Sequoyah as a source for drinking water in city limits (UCWA 2004a). Unlike coastal North Carolina, the watershed contains no underground aquifers (UCWA 2004a). Although water is provided throughout the Town from Big Creek, sewage service was only provided to 25% of houses as of 2003 estimates (UCWA 2004a); sewage services have subsequently been expanded. The restriction in sewer service was the result of multiple factors, including the high cost of constructing new infrastructure and the near maximum flow (80% of state permitted flow) the old wastewater plant was experiencing (UCWA 2004a). A new wastewater treatment plant with greater operating capacity than the old facility was recently finished, increasing system efficiency and the potential for sewer services throughout the Town, hopefully reducing leakage from septic systems into the groundwater.

Cullasaja River

The Cullasaja River sub-watershed begins on Whiteside Mountain and ends at the dam on Mirror Lake. The sub-watershed contains 5.4 mi^2 of drainage area and a total of 10.3 mi of stream, making it the largest sub-watershed on the Plateau. The Cullasaja River includes the longest length of stream (6.0 mi) in the Upper Cullasaja watershed, with the tributaries of Ammons Branch (0.9 mi), Salt Rock Branch (1.0 mi) and three unnamed tributaries (0.6, 0.6, and 1.2 mi) all contributing to total stream miles. The USGS topographic map for Highlands area (Highlands quadrangle) shows more than 14 ponds or small lakes within Wildcat Cliffs Country Club property and another nine ponds/ reservoirs downstream of Ravenel Lake. This count does not include the frequent low head dams on many of the tributaries in residents' backyards or along streams in commercial developments. The named lakes in this sub-watershed include Ravenel Lake (at Cullasaja Club), Highlands Falls Country Club Lake, Apple Lake, Mirror Lake, and Lake Sequoyah. The Cullasaja River has been monitored by NCDWQ every five years since 1990, with additional sampling occurring through watershed assessments and restoration projects. The Cullasaja River at US-64 is rated "fair" in bioclassification, which has resulted in listing the Cullasaja River as impaired on North Carolina's 303(d) list of impaired water bodies (NCDWQ 2010)

Mill Creek

The Mill Creek sub-watershed begins at Satulah Mountain, Sunset Rock, and the Bear Pen Mountains and flows into Mirror Lake below the Town of Highlands. This watershed includes over half of the drainage for downtown Highlands, with a total of 1.7 mi^2 of drainage. Most of the length of Mill Creek is in the main stem (2.0 mi) with the remaining stream length (1.0 mi) in Satulah Branch. The USGS topographic map for the area shows at least four impoundments in the watershed, including Lindenwood Lake and Harris Lake. Although preserved in land trusts or low-density residential development on the ridgelines, most of the Mill Creek sub-watershed is urbanized. Mill Creek has been monitored by NCDWQ every five years since 1990, with additional sampling occurring through watershed assessments and restoration projects. Mill Creek was not rated using the bioclassification index due to its small size, but has been placed on North Carolina's 303(d) list of impaired water bodies due to an earlier classification of "impacted" (NCDWQ 2010).

Monger Creek

The Monger Creek sub-watershed begins at Sassafras Knob and Little Yellow Mountain and ends at Lake Sequoyah. It contains 2.0 mi^2 of drainage area and 3.7 mi of stream. The main stem includes 1.7 mi of stream with the remainder included in three tributaries. The entire sub-watershed is within the Town of Highlands jurisdiction (UCWA 2004a). Unlike Big Creek and the Cullasaja River, Monger Creek has not been monitored on a regular basis, but the 2002 NCDWQ Assessment Report noted that Monger Creek has similar characteristics as Mill Creek, including stream bank erosion and effects from urban stormwater UCWA 2004b). Monger Creek is considered to be impacted (UCWA 2004a, 2004b).

Big Creek

The Big Creek sub-watershed begins at Cole and Shortoff Mountains and ends downstream at the US 64W bridge crossing on Lake Sequoyah. Many tributaries of Big Creek flow through the Nantahala National Forest and low-density residential areas. The sub-watershed includes Randall Lake and the Big Creek arm of Lake Sequoyah. Almost half of the stream length is included in the main stem of Big Creek, with Houston Branch, Bad Branch, and Big Norton Prong, plus three unnamed tributaries comprising the rest of the stream length. There are 10 impoundments found within the Big Creek sub-watershed, including Randall Lake, Highlands Reservoir, and Cold Springs Lake. The Big Creek sub-basin is the least developed of the four sub-watersheds (UCWA 2004a).

NCDWQ (2010) classifies Big Creek as "good" (Category 1). For this reason, sections of Big Creek have been used as reference sampling sites for water quality, storm water and benthic macroinvertebrate population comparisons with the Upper Cullasaja River. Still, Big Creek may be experiencing stresses due to the Randall Lake dam breach and other factors that could jeopardize future water quality (UCWA 2004a).

Fisheries

North Carolina Division of Water Quality (NCDWQ) classifies the waters in the Upper Cullasaja River watershed as trout waters. Despite this classification, there are few remaining populations of native trout in the watershed today (NCDWQ 2010). The Index of Biological Integrity (IBI) is a common method used to rate the quality of streams. Only the Big Creek and Cullasaja River sub-watersheds have IBI measures been calculated over the past 21 years. Data from Big Creek in 1999 and 2000 resulted in ratings of “good.” The Cullasaja River IBI rating varied between “good”, “fair”, and “poor” from 1991 to 2007. Three of the last four ratings were “fair” while most of the ratings over this 16-year span have been “good” or “fair” (McLarney 2008).

Stocked trout fisheries are common in the watershed for sport fishing communities, especially in the lakes and ponds of neighborhood communities. Due to high summer temperatures in these lakes, the stocked trout are generally only available during the cooler weather seasons of fall, winter, and spring. Artificially impounded water bodies in the watershed are not suitable for native trout populations and have traditionally been stocked with non-native species, including bass, bluegill, catfish, shiners, carp, and dace (UCWA 2004a).

MATERIALS AND METHODS

Physical and chemical characteristics

To determine the physical characteristics of the sites, a habitat assessment was performed at each of the six selected sites using the NCDENR’s Division of Water Quality’s Habitat Assessment Field Data Sheet (NCDWQ 2003). Assessments were performed on November 9, 2010 and November 23, 2010. The NCDWQ assessment required a survey of a 100-meter stream reach at each site. Assessments were performed beginning at the base of each reach, facing upstream, and surveying along the length of the reach. Eight criteria were assessed: Channel Modification, Instream Habitat, Bottom Substrate, Pool Variety, Riffle Habitats, Bank Stability and Vegetation, Light Penetration, and Riparian Vegetative Zone Width. These criteria were each scored on their own scale and then summed to determine a total score for each site. The total score is ranked on a 100-point scale with 0 as the minimum and 100 as the maximum. Additional information was obtained beyond the eight major criteria to provide information about site characteristics such as: Visible Land Use, Stream Width, Bank Height, Bank Angle, Flow Conditions, and Turbidity.

In addition to the habitat assessment, students conducted a Wolman pebble count to assess the substrate composition of the sites (Wolman 1954). One hundred particles were picked at each site by randomly selecting ten particles at even intervals in ten randomly placed bank-to-bank transects. Rulers were used to measure the intermediate axis (on the second largest dimension) of each particle, recording data as tallies in categories of values, ranging from silt to bedrock. The values of the median particle size category and the frequency of each particle size were compared between sites. Because data were recorded categorically, median particle size was represented as the middle range value of the median category.

To determine the chemical characteristics, we visited six sites with James Aaron of NCDENR’s Division of Water Quality on September 20, 2010. At each site we recorded water temperature, dissolved oxygen (DO), conductivity and pH using an YSI Pro Series meter, which is calibrated daily. We also collected water samples for laboratory analysis of volatile organic compounds, nutrients and heavy metals. In accordance with analytical protocols, water samples for volatiles were preserved with 0.5 mL of 1:1 HCl, while samples for nutrients were preserved with 2.0 mL of 1:3 H_2SO_4, and samples for metals contained 5.0 mL of 1:1 HNO_3 as a preservative. When collecting water for volatile samples, tubes were sealed under water so that exposure to air would not skew the natural conditions of the water. All samples were placed on ice for transport to the NCDWQ lab in Asheville, NC.

Fish study

On October 18, 2010, fish were collected at BC2, CR1, MiC2, and MoC1. Two weeks later, on November 2, 2010, fish were collected at BC2, BC1 and MiC1. Fish were sampled twice at BC2 because the fish collecting protocol was taught at that site. Fish were collected along a 50 m reach and beyond the 50 m reach to the nearest riffle or deep pool. Dip nets and a ¼ inch seine net were used to collect fish. Fish were collected for approximately 30 minutes at each site.

Fish were collected in groups with several people using the seine pointing upstream and two to three people disturbing the bottom of the stream by kicking and walking towards the seine net. The seine was then lifted and checked for fish. Other students collected fish using dip nets along the banks and shallows upstream and downstream. Captured fish were placed in a bucket for identification. After identifying the fish, some were released back into the water; a few individuals were placed into containers with 75% ethanol for reference. The fish from each site were identified and the number of fish of each species was recorded. We then calculated the Shannon Index of Diversity (SDI) for each site, as follows,

$$\textit{Shannon Index of Diversity} = H' = -\sum_{i=1}^{S} p_i \ln(p_i)$$

where S refers to species richness, p_i is the proportion of the total sample represented by species i, and $\ln(p_i)$ refers to the natural logarithm of p_i.

Aquatic insect study

Aquatic invertebrates were collected at each of the six selected sites by first establishing a sampling area by measuring a 50 m reach of stream habitat with transect tape. Our sampling team of 12-14 individuals was then divided into several groups that focused on sampling a specific habitat type along the reach for 15 minutes at each site. We sampled from all habitats present, including riffle habitat, bank habitat, and leaf packs. For sampling riffle habitat, two people held a kick net upright in the streambed while others shuffled their feet upstream, disturbing rocks and bed sediments to dislodge aquatic invertebrates so they would flow into the net. Along the banks, sweep nets were used to reach under roots and overhanging banks to dislodge aquatic invertebrates. Leaf packs were picked up by hand and deposited into a sieve bucket; sediments were strained out of the sample and the remaining leaf litter was elutriated in the field, searching all debris that remained in the bucket for aquatic invertebrates.

Specimens were gathered at each site and divided into bags by habitat type. These bags were brought back to the lab and the contents were further elutriated to remove leaf litter, sediments, and other debris. Aquatic invertebrates were separated into order were deposited into vials containing 95% ethanol. Classifications were performed using family keys (http://www.bsu.edu/web/mpyron/ 484info/Insects/List.html).

Analysis of samples was based solely on individuals that were in orders Ephemeroptera (Mayflies), Plecoptera (Stoneflies), or Trichoptera (Caddisflies). These orders are the most pollution intolerant and thus their abundance in a stream can serve as a good indicator of stream health. Accordingly, all Ephemeroptera, Plecoptera, and Trichoptera (EPT) individuals were subdivided into their families for assessment. The EPT data were compiled into a spreadsheet by site, listing the number of individuals found in each family within the order (Appendix A).

Using the EPT data, we were able to calculate the Biotic Index (BI) for each site. Each family of EPT insects is given a BI value that represents their tolerance of pollution in stream habitats, from 0-7, with a greater value indicating greater tolerance. To calculate the BI at each site, we used the equation:

$$BI = \frac{\sum abundance \times BI\ value}{total\ abundance}$$

We also used the EPT data to determine the feeding types present at each site by percentages. Each family has one general feeding type, which is described as scraper, collector, gatherer (subcategory of collector), filterer (subcategory of collector), predator, or shredder. Each family found at a site was assigned their corresponding feeding type, and the percentages of individuals at each site of each feeding type was calculated. We determined percentages of each feeding type at each site and compiled these into a table/graph. BI values and feeding type designations were provided by D. Penrose (pers. comm., Appendix B).

RESULTS

Physical and chemical characteristics

The maximum possible scores for each subcategory of the habitat assessment are presented in Table 4. In addition to individual scores for each of the eight subcategories, the assessment provided a total score for each site out of a maximum of 100. The subcategory and total scores for each site are presented in Fig. 4.

TABLE 4. Maximum possible score for each subcategory of the habitat assessment.

Subcategory	Channel Modi-fication	Habitat	Substrate	Pool Variety	Riffle Habitat	Bank Stability	Light Penetration	Riparian Zone Width
Maximum Score	5	20	15	10	15	15	10	10

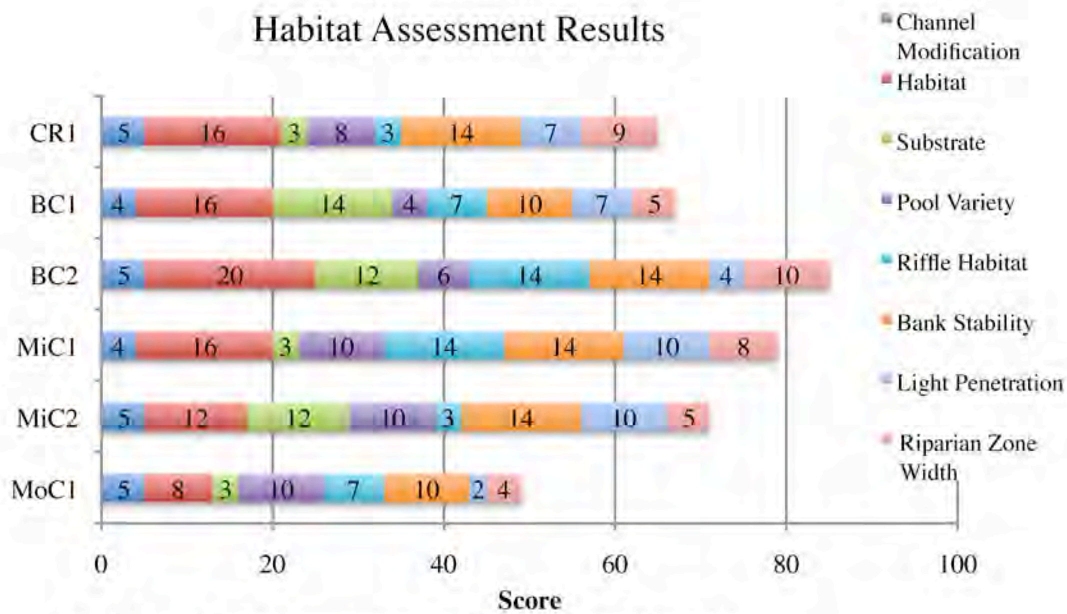

FIG. 4. Total habitat assessment scores for the six sampling sites.

Overall, the habitat assessment results revealed that the highest-ranking site was BC2 with a total score of 85, while the lowest-ranking site was MoC1 with a total score of 49. BC1, BC2, MiC1, and MiC2 all ranked higher than both CR1 and MoC1. In terms of the subcategories, the majority of sites received high (good) scores for Channel Modification, Habitat, Pool Variety, and Bank Stability. However, there was greater variation in results for the Substrate, Riffle Habitat, Light Penetration, and Riparian Zone Width subcategories. In the Substrate subcategory, BC1, BC2, and MiC2 all received scores greater than or equal to 12, while CR1, MiC1, and MoC1 all received scores of 3 (Fig. 5). In the Riffle Habitat subcategory BC1 and MiC1 received the highest scores of 14, BC2 and MoC1 received median scores of 7, and CR1 and MiC2 received the lowest scores of 3 (Fig. 6). In the Light Penetration subcategory, MiC1 and MiC2 received the maximum score of 10, Cr1 and BC2 received median scores of 7, and BC1 and MoC1 received low scores less than or equal to 4 (Fig. 7). In the Riparian Zone Width subcategory CR1, BC1, and MiC1 received the highest scores of greater than or equal to 8, while BC2, and MiC2, and MoC1 received lower scores of less than or equal to 7 (Fig. 8).

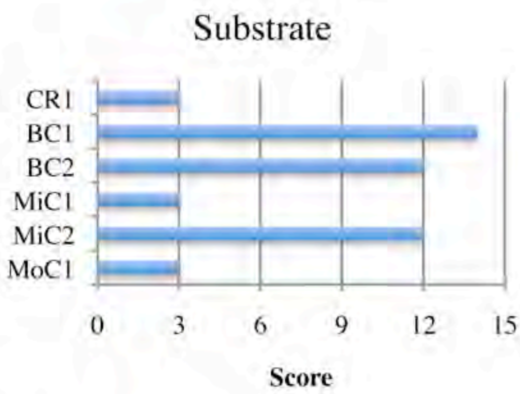

FIG. 5. Habitat assessment for all sites in the Substrate subcategory.

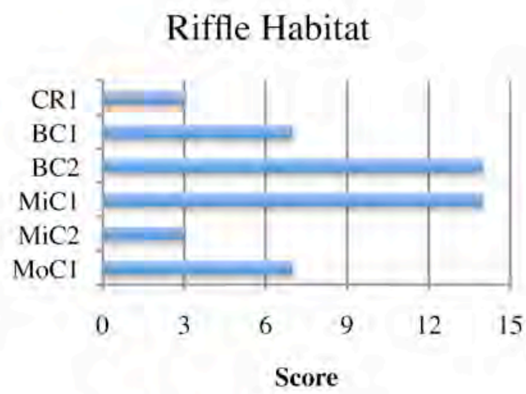

FIG. 6. Habitat assessment for all sites in the Riffle Habitat subcategory.

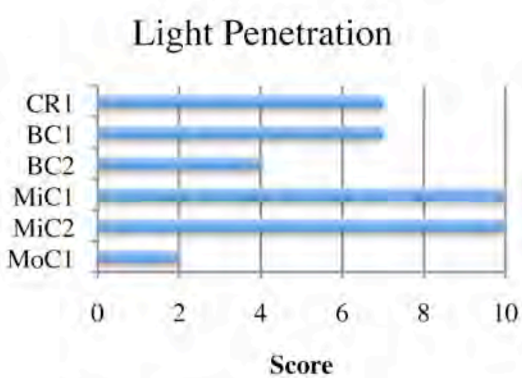

FIG. 7. Habitat assessment for six sites in the Light Penetration subcategory.

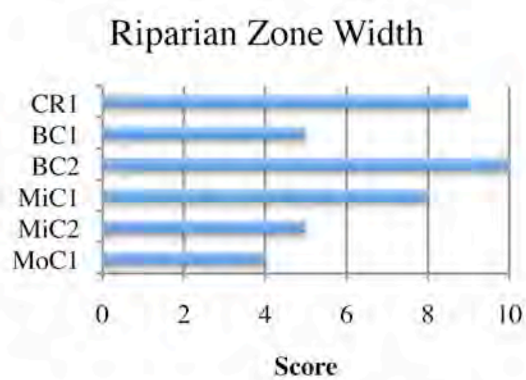

FIG. 8. Habitat assessment for six sites in the Riparian Zone Width subcategory.

A Wolman pebble count generated data on the distribution of substrate particles in each streambed. Generally, streambeds were found to contain greater proportions of sand and gravel than large particles, although many sites did exhibit a relatively high frequency of bedrock (Fig. 9). This trend excludes the MiC1 site, which exhibited a substrate size distribution skewed towards larger particles.

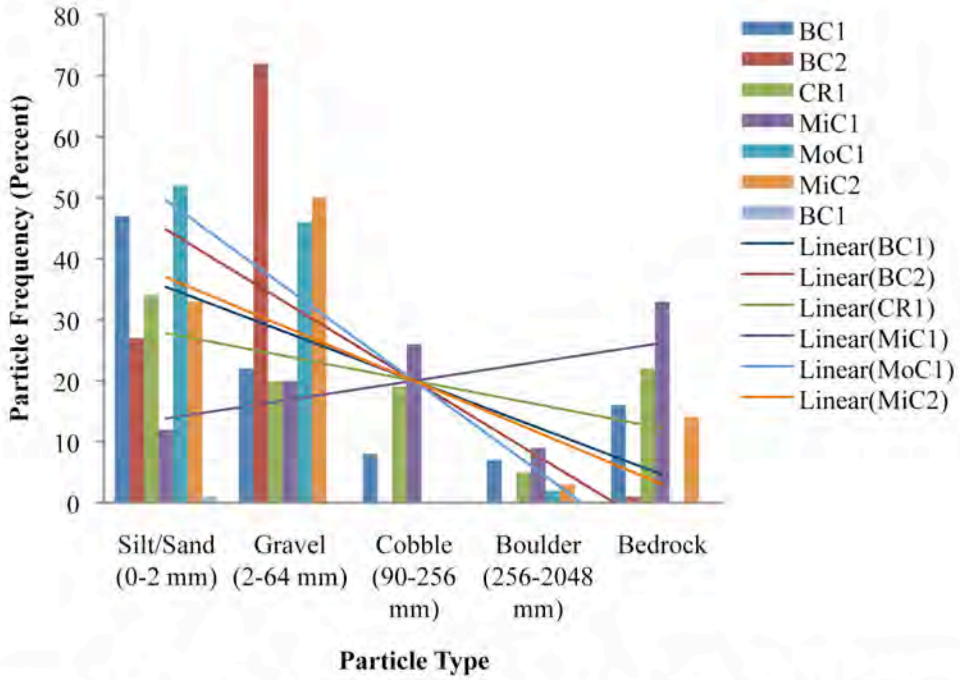

FIG. 9. Frequency of occurrence of each particle size at each site. The data are combined into broad categories for clarity.

Median particle sizes of less than eight mm were recorded at four of six sites (Fig. 10). At two of these, MoC1 and BC1, less than 2% of recorded substrate particles were larger than 32mm. The CR1 and MiC1 sites exhibited unusually high median values of 27.3 (very coarse gravel) and 154 mm (large cobble).

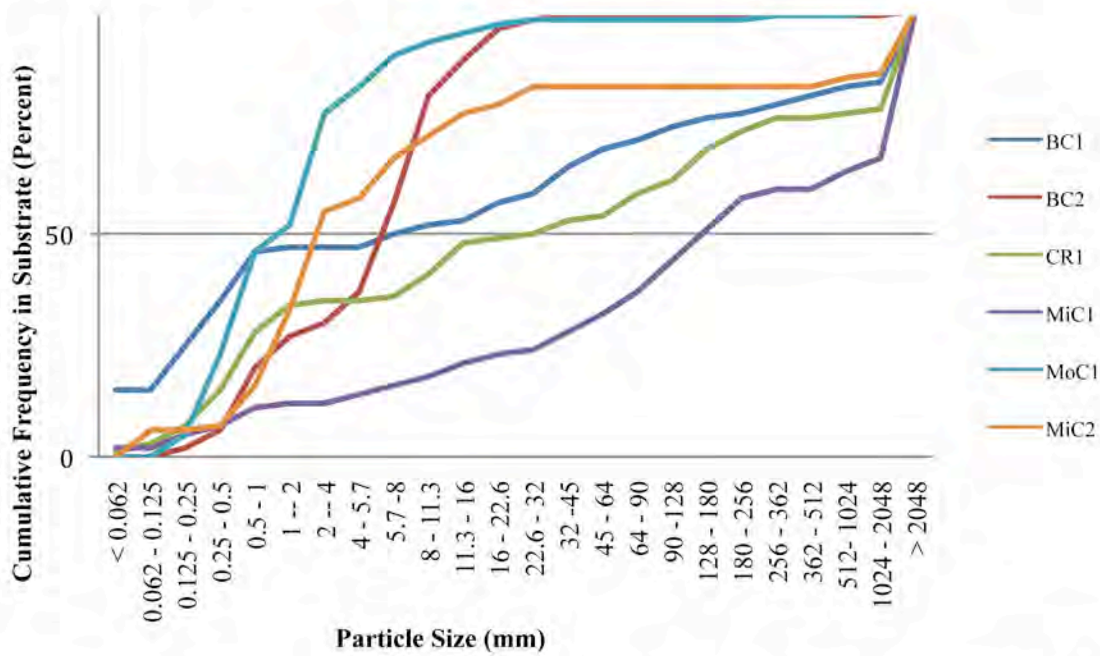

FIG. 10. Cumulative particle frequency in the substrate by site. The 50% line illustrates the median particle size of each site.

Results for most water quality parameters were consistent among sites, with the greatest variability noted in conductivity and fecal coliform levels (Tables 5-11, Figs. 11-15). Compared to other sites, conductivity in Monger Creek was highest at 103 micromhos/cm, while the lowest results were found in both sites on Big Creek at 27.2 micromhos/cm (BC1) and 24.9 micromhos/cm (BC2). Fecal coliform was highest at the upstream location on Mill Creek (MiC1) with 380 CFU/100mL, while sites at the Cullasaja River, Monger Creek, and the second site on Big Creek (BC2) were lowest, ranging from 29 to 35 CFU/100mL. Nitrogen concentrations represented by $NO_2 + NO_3$ were comparatively higher at both sites on Mill Creek and on Monger Creek at 0.35 mg/L (MiC1), 0.33 mg/L (MiC2), and 0.32 mg/L (MoC1), while being low at the first site on Big Creek at 0.05 mg/L (BC1) and 0.12 mg/L (BC2). Analytical results for NH_3 at all sites were the same at 0.02 mg/L (level of detection), except at the Cullasaja River, where a measurement of 0.04 mg/L was found. Total Kjeldahl Nitrogen (TKN) estimates were also the same at all sites at 0.2 mg/L (level of detection) with the exception of the Cullasaja River where an estimate of 0.4 mg/L was obtained. This is expected since NH_3 is a component of TKN. All pH and dissolved oxygen (DO) measurements were somewhat similar, being in the range of 6.5-7.1 SU for pH and 7.2-8.6 mg/L range for DO. Phosphorus concentrations at all sites were reported at the level of detection. Turbidity values were consistent, with the lowest being 1 NTU at both sites on Mill Creek and the highest being 3.0 NTU at the Cullasaja River, all well within established water quality standards. Temperatures were fairly consistent across sites with the exception of the Cullasaja River site, which was significantly warmer (by approximately 5°C) than other sites.

TABLE 5. Chemical analysis results for MC1 site.

Location	Date	Time	Units	Detection Level	Analysis	Results
MoC1	9/20/2010	15:30	mg/L as N	0.02	NH_3 as N in liquid	0.02
MoC1	9/20/2010	15:30	mg/L as N	0.02	$NO_2 + NO_3$ as N in liquid	0.32
MoC1	9/20/2010	15:30	mg/L as N	0.2	Total Kjeldahlas N in liquid	0.2
MoC1	9/20/2010	15:30	mg/L as P	0.02	Phosphorus total as P in liquid	0.02
MoC1	9/20/2010	15:30	CFU/100mL	1.0	Coliform, MF Fecal in liquid	33.0
MoC1	9/20/2010	15:30	NTU	1.0	Turbidity	2.7

TABLE 6. Chemical analysis results for CR1 site.

Location	Date	Time	Units	Detection Level	Analysis	Results
CR1	9/20/2010	15:35	Mg/L as N	0.02	NH_3 as N in liquid	0.04
CR1	9/20/2010	15:35	Mg/L as N	0.02	$NO_2 + NO_3$ as N in liquid	0.16
CR1	9/20/2010	15:35	Mg/L as N	0.2	Total Kjeldahlas N in liquid	0.41
CR1	9/20/2010	15:35	Mg/L as P	0.02	Phosphorus total as P in liquid	0.02
CR1	9/20/2010	15:35	CFU/100mL	1.0	Coliform, MF Fecal in liquid	29
CR1	9/20/2010	15:35	NTU	1.0	Turbidity	3.0

TABLE 7. Chemical analysis results for BC1 site.

Location	Date	Time	Units	Detection Level	Analysis	Results
BC1	9/20/2010	16:20	Mg/L as N	0.02	NH_3 as N in liquid	0.02
BC1	9/20/2010	16:20	Mg/L as N	0.02	$NO_2 + NO_3$ as N in liquid	0.05

BC1	9/20/2010	16:20	Mg/L as N	0.2	Total Kjeldahlas N in liquid	0.2
BC1	9/20/2010	16:20	Mg/L as P	0.02	Phosphorus total as P in liquid	0.02
BC1	9/20/2010	16:20	CFU/100mL	1.0	Coliform, MF Fecal in liquid	100.0
BC1	9/20/2010	16:20	NTU	1.0	Turbidity	2.3

TABLE 8. Chemical analysis results for BC2 site.

Location	Date	Time	Units	Detection Level	Analysis	Results
BC2	9/20/2010	15:00	mg/L as N	0.02	NH_3 as N in liquid	0.02
BC2	9/20/2010	15:00	mg/L as N	0.02	$NO_2 + NO_3$ as N in liquid	0.12
BC2	9/20/2010	15:00	mg/L as N	0.2	Total Kjeldahlas N in liquid	0.2
BC2	9/20/2010	15:00	mg/L as P	0.02	Phosphorus total as P in liquid	0.02
BC2	9/20/2010	15:00	CFU/100mL	1.0	Coliform, MF Fecal in liquid	35.0
BC2	9/20/2010	15:00	NTU	1.0	Turbidity	2.1

TABLE 9. Chemical analysis results MC1 site.

Location	Date	Time	Units	Detection Level	Analysis	Results
MiC1	9/20/2010	13:55	mg/L as N	0.02	NH_3 as N in liquid	0.02
MiC1	9/20/2010	13:55	mg/L as N	0.02	$NO_2 + NO_3$ as N in liquid	0.35
MiC1	9/20/2010	13:55	mg/L as N	0.2	Total Kjeldahlas N in liquid	0.2
MiC1	9/20/2010	13:55	mg/L as P	0.02	Phosphorus total as P in liquid	0.02
MiC1	9/20/2010	13:55	CFU/100mL	1.0	Coliform, MF Fecal in liquid	380.0
MiC1	9/20/2010	13:55	NTU	1.0	Turbidity	1.0

TABLE 10. Chemical analysis results for MC2 site.

Location	Date	Time	Units	Detection Level	Analysis	Results
MiC2	9/20/2010	14:35	mg/L as N	0.02	NH_3 as N in liquid	0.02
MiC2	9/20/2010	14:35	mg/L as N	0.02	$NO_2 + NO_3$ as N in liquid	0.33
MiC2	9/20/2010	14:35	mg/L as N	0.2	Total Kjeldahlas N in liquid	0.2
MiC2	9/20/2010	14:35	mg/L as P	0.02	Phosphorus total as P in liquid	0.02
MiC2	9/20/2010	14:35	CFU/100mL	1.0	Coliform, MF Fecal in liquid	150
MiC2	9/20/2010	14:35	NTU	1.0	Turbidity	1

TABLE 11. Field parameter results for all sites.

Site	Temperature (°C)	Dissolved Oxygen (mg/L)	Conductivity	pH
MiC2	16.4	8.4	75	7.0
MiC1	16.8	8.4	73	7.1
CR1	21.6	7.2	49	6.7
BC2	16.1	8.6	24.9	7.0
MoC1	16.2	8.1	103	6.8
BC1	16.8	7.6	27.2	6.5

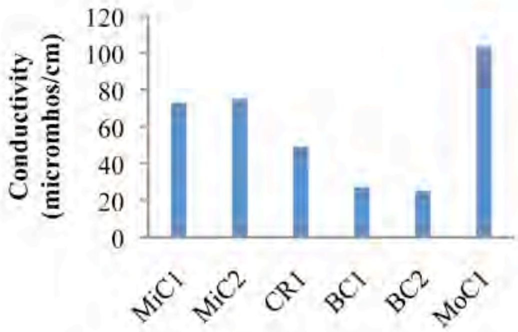

FIG. 11. Conductivity comparison by site.

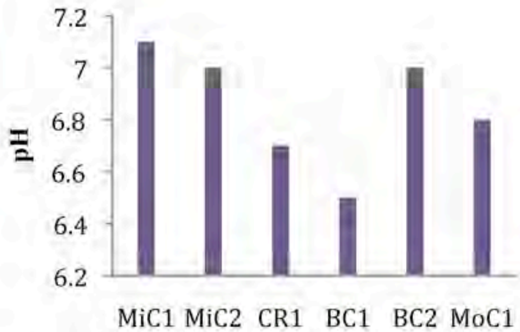

FIG 12. pH comparison by site.

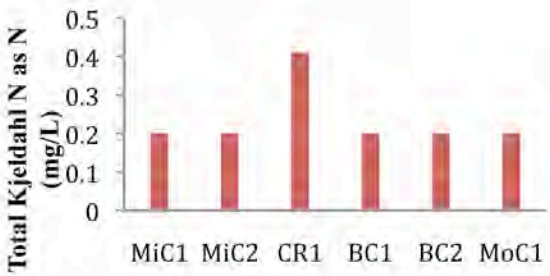

FIG. 13. Total Kjeldahl-N comparison by site.

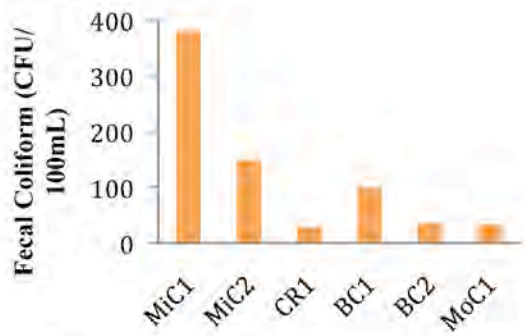

FIG. 14. Fecal coliform comparison by site.

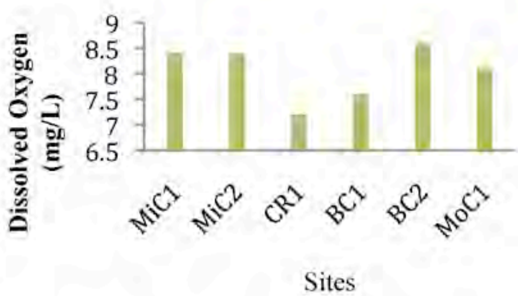

FIG. 15. Dissolved oxygen comparison by site.

Fish study

A total of 202 fish were collected, comprising 10 different species. The Shannon Index of Diversity was highest for BC2 with a value of 1.723 and was lowest at MoC1 with a value of 0.117. These results are summarized in Table 12. A graph comparing the Shannon Indices at each site is included in Fig. 16.

TABLE 12. Fish species found and Shannon Diversity Index (SDI) by site.

Site	Species Name	Common Name	Count	SDI
BC2	*Onchorhynchus mykiss*	Rainbow Trout	1	1.723
	Nocomis leptocephalus	Bluehead Chub	7	
	Rhinichthys obtusus	Blacknose Dace	7	
	Notropis leuciodus	Tennessee Shiner	2	
	Clinostomus funduloides	Rosyside Dace	2	
	Salmo trutta	Brown Trout	2	
BC1	*Rhinichthys obtusus*	Blacknose Dace	3	0.562
	Lepomis auritus	Redbreast Sunfish	9	
CR1	*Rhinichthys obtusus*	Blacknose Dace	3	0.478
	Notemigonus crysoleucas	Golden Shiner	33	
MiC2	*Lepomis auritus*	Red Breast Sunfish	2	0.064
	Nocomis leptocephalus	Bluehead Chub	1	
	Clinostomus funduloides	Rosyside Dace	84	
MiC1	*Clinostomus funduloides*	Rosyside Dace	4	0.637
	Cottus bairdii	Sculpin	2	
MoC1	*Rhinichthys obtusus*	Blacknose Dace	39	0.117
	Rhinichthys cataractae	Longnose Dace	1	

Note: Big Creek at town water intake was sampled twice.

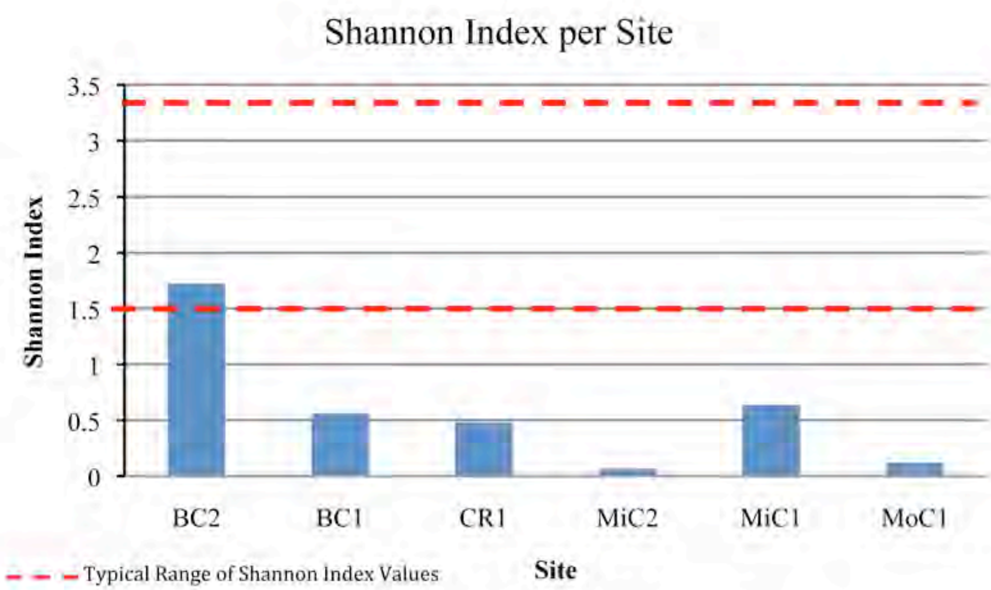

FIG. 16. Graph comparing Shannon Index values at each site.

Aquatic insect study

Total individuals present at each site, as well as functional feeding group and family diversity varied widely among the sites sampled. Mill Creek at the former wastewater treatment plant (MiC1), where only six organisms were found, had the lowest diversity and overall abundance of organisms. The greatest numbers of EPT organisms were found at the Cullasaja River site, although functional feeding group and family diversity were significantly greater at both Big Creek sites. When assessed for Biotic Index (BI), MoC1 had the greatest BI score (indicating poorest quality) at 4.00, and BC2 had the lowest BI (indicating highest quality), at 2.88 (Table 13, Fig. 17). Analyses of functional feeding group diversity indicated that 100% of organisms at MiC1 were of the same feeding type, while BC1 had the most diverse among feeding groups, with organisms from each feeding type represented (Fig. 18).

TABLE 13. Biotic Index values by site.

Site	Biotic Index Value
MoC1	4.0
CR1	3.92
BC1	3.42
BC2	2.88
MiC1	3.83
MiC2	3.75

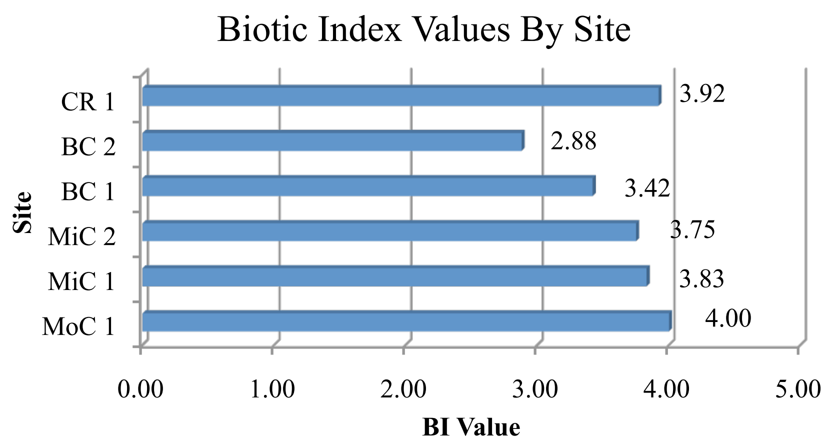

FIG. 17. Biotic Index values by site.

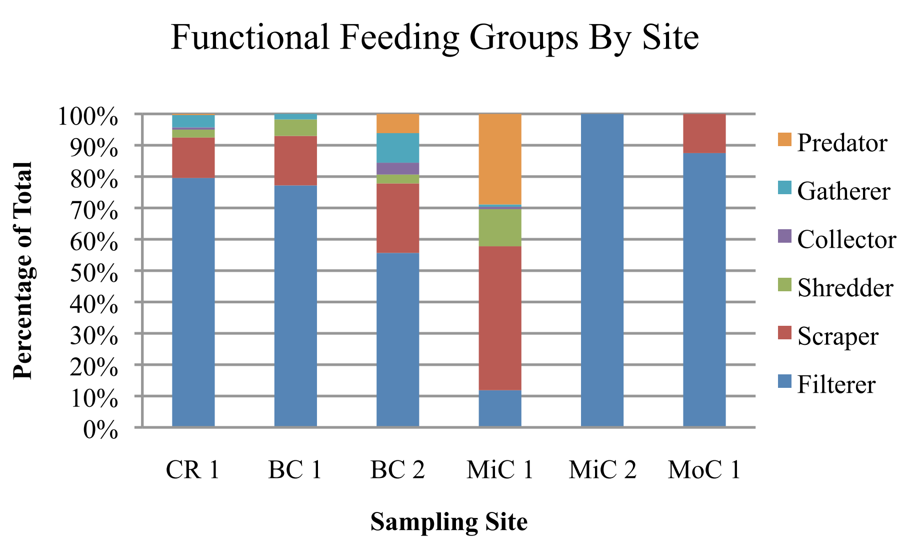

FIG. 18. Functional feeding group by percentage at each site.

DISCUSSION

The following discussion examines overall stream quality at each of the six sites in relation to the results of the studies on physical and chemical characteristics, fish, and aquatic insects. The limitations of the various methods used to evaluate stream quality are also discussed, and suggestions for future stream evaluations at these sites are provided.

Cullasaja River at Highway 64 (CR1)

The physical assessment performed at this site yielded a total score of 65, the second lowest total score of the six sites surveyed. In addition to a poor total score, the site received the lowest score in the Substrate and Riffle Habitat subcategories. The Substrate score resulted from low variety and a high concentration of bedrock in the substrate. The Wolman pebble count recorded a median particle size of "coarse gravel" between 22.6 - 32 mm, the second-highest value recorded. It is likely that smaller sediments are not more prevalent because of upstream impoundments, which may trap small substrate particles. The low score in Riffle Habitat resulted from infrequency and small size of riffle structure in the stream. The site received the median score in Habitat, Pool Variety, Light Penetration subcategories and scored highly in the Bank Stability and Riparian Zone Width categories.

The CR1 site is located downstream of a golf course and several water impoundments. This location is also exposed to direct sunlight. These factors likely account for the elevated temperature and may account for the higher levels of nitrogen measured as TKN in the stream due to fertilizer usage on the golf course. Dissolved oxygen (DO) and pH were lower compared to most measured streams, but were within established limits. Phosphorus levels were at the level of detection and are likely the limiting nutrient in this stream. The relatively low nutrient concentration may be a related to the time of year that the measurement was taken.

Fish sampling revealed that the Shannon Diversity Index value for CR1 was 0.478, which indicates low diversity of fish in the river. Only one possible native fish species was found, *Rhinichthys obtusus,* and only three species were found. The low fish diversity in the river suggests that there is low overall biotic integrity.

Low diversity was also reflected in the aquatic invertebrate sampling where CR1 had one of the highest BI values (indicating lowest water quality) of all sampled steams. Aquatic invertebrate sampling at CR1 also indicated that, although all functional feeding groups were represented, the system was heavily dominated by filter feeders in the trichopteran family Hydropsychidae. The relatively high BI value of 3.92 indicates that the system has fewer ecologically sensitive organisms than other sites with lower BI values. A lack of sensitive aquatic macroinvertebrate species indicates a significant perturbation of the system, likely due to an overabundance of fine particulate organic matter as evidenced by the large number of filter feeders.

Big Creek at Shortoff Road Bridge (BC1)

In the habitat assessment, the BC1 site received a relatively low total score in comparison with other sites. Low scores in the Pool Variety, Riffle Habitat, and Riparian Zone Width subcategories contributed to this low score. The low score in Pool Variety is due to a low frequency of pools and a low diversity in pool size. The low score in Riffle Habitat is due to short length of riffle zones in the stream. The low score in Riparian Zone Width is due to a narrow riparian zone on the right bank of the stream section. The Wolman pebble count recorded a mean particle size of very fine gravel, between 5.7 and 8 mm. Low substrate particle sizes suggest the presence of natural and anthropogenic sources of sedimentation, including bank erosion and a nearby wetland.

BC1 is located in a rural environment. While this stream is affected by runoff from roads in the area and other anthropogenic sources, it is less affected than other streams that were evaluated in the watershed. Conductivity, pH, fecal coliform, and dissolved oxygen (DO) results were comparatively low, likely due to the stream's location. However, DO and pH were still within designated standards. Nitrogen and phosphorus levels were at or below the level of detection.

A low diversity of fish is indicated in Fig. 16. *Rhinichthys obtusus,* likely a native species, was collected at this site, along with one other exotic species. The low Shannon Index value for this site (Fig. 16) indicates low diversity and low overall biotic integrity. This lack of diversity could be explained by the small substrate particle size as well as low pool and riffle habitat diversity.

BC1 had relatively high functional feeding group and family diversity scores for aquatic invertebrates. All feeding groups were represented at this site, although the number of filter feeders was still disproportionately high. BC1 also contained the second greatest number of stoneflies (plecopterans), an order that is generally intolerant of perturbation, indicating that BC1 is less perturbed than the other sites evaluated. This is further supported by the relatively high BI value of BC1.

Big Creek at Town Water Intake (BC2)

In the habitat assessment of BC2, high scores in all subcategories contributed to the highest habitat assessment score of the sites evaluated. The Pool Variety subcategory was slightly low and this was due to low frequency of pools in the stream. Pebble count data revealed a median particle size of fine gravel, between 5.7 mm and 8 mm. Possible increases in runoff levels from anthropogenic activity and the presence of a dam immediately downstream of the study area may account for increased sedimentation of the streambed.

BC2 and BC1 have similarly low conductivity measures. BC2 is located in a more pristine environment than BC1, which is located near several houses and a retirement complex. The dissolved oxygen (DO) concentration and pH in BC2 are comparatively higher than the other sites that were measured in the study. The levels of DO and pH can be explained by the relatively low disturbance and development pressure in the Big Creek sub-watershed, which also may account for the low fecal coliform levels in this stream. Nitrogen and phosphorus for this stream reach were at or below the level of detection.

The highest diversity of fish of all the sites was sampled at BC2. The Shannon Index value is relatively low when compared to the typical range of values of the index, but is relatively high when compared to other sites. Furthermore, one native species was collected, *Rhinichthys obtusus*, in addition to two species of non-native trout, *Onchorhynchus mykiss* and *Salmo trutta*. The lack of diversity and the abundance of exotic species may be negative indicators of overall biotic integrity.

Based on aquatic invertebrate family diversity and feeding group assessment, BC2 was the healthiest site evaluated. The health of this system is further evidenced by the presence of Helicopsychidae, a rare caddisfly, in BC2, and the greatest number of plecopterans. This site also had the lowest BI value (highest biological integrity) of the six sites sampled as a result of increased presence of sensitive species relative to other sites.

Mill Creek at old Sewage Treatment Plant (MiC1)

The habitat assessment of the MiC1 site resulted in a total score of 79, the second highest score of the six sites. The site received high scores in all subcategories except the Substrate subcategory. The low score in substrate was due to low diversity of substrate size and a high concentration of bedrock. Pebble count data show a median particle size between 128 and 180 mm (large cobble), the largest value recorded at any site. Bedrock comprised 33% of substrate particles recorded, the highest concentration of bedrock at any site. The singularly steep slope of the MiC1 site and correspondingly higher water velocity may prevent small particles from accumulating on the streambed.

MiC1 is immediately downstream of Highlands adjacent to the old wastewater treatment facility on Mill Creek, and is influenced by storm water from the Town that can carry organics and metals from paved areas and chemical enrichment and pollution from septic systems and any lawn chemicals that are used on yards. These factors are most likely the cause of the comparatively higher conductivity and fecal coliform values that were found in the stream. In fact, MiC1 is the only site where unacceptable levels of fecal coliform were found. Nitrogen, as expected, showed an increased concentration of NO_2+NO_3 at 0.35 mg/L. As with other sites, DO and pH were within established limits.

The low Shannon Index value for MiC1 indicates a lack of fish diversity found at this site. All species identified are exotic to the Highlands Plateau. The complete lack of native species could be a negative indicator of the quality of this stream. However, the small sample of fish taken here prevents us from drawing any conclusions from the fish data alone.

The lowest abundance and diversity of aquatic invertebrates was recorded at MiC1, with only six EPT individuals found in two families. All organisms were filter feeders and five of the six insects recovered were hydropsychid caddisflies, evidence of a degraded stream. A healthy stream should have organisms in each functional feeding group, and the dominance of one group means the stream has been perturbed. The fact that all of the organisms are hydropsychids also indicates that fine particulate organic matter is in the stream.

Mill Creek at Brookside Lane (MiC2)

The MiC2 site received a total score of 71 in the habitat assessment and received high scores in all subcategories except the Riffle Habitat and Riparian Zone Width subcategories. The low score in Riffle Habitat was due to low frequencies and the small size of riffle zones in the stream. The low score in Riparian Zone Width was due to a narrow, non-intact riparian zone on the right bank. The pebble count recorded a median particle size of very fine gravel, between 2 and 4 mm, and particles larger than coarse gravel comprised only 17% of particles recorded. The presence of several houses adjacent to the stream and the presence of small impoundments in the waterway may be anthropogenic sources of sedimentation of the streambed.

The second site on Mill Creek is also significantly affected by anthropogenic sources. Conductivity, DO and pH were about the same as results from the first site on Mill Creek. However, levels from fecal coliform were much lower. Levels of NO_2+NO_3 at this site were similar to those found at MiC1, which is probably caused by the presence of drainage pipes containing storm water and fertilizer discharging directly into the stream.

Although the greatest numbers of fish were collected at MiC2, this site has the lowest diversity of all the sites sampled. Both species collected are exotic to the Highlands Plateau. The extremely low diversity and complete absence of native species may be a negative indicator of the quality of this stream.

The data for aquatic invertebrates at MiC2 showed signs of degradation at this site. The majority of EPT individuals found at MiC2 were filter feeders, and a disproportionate number of filter feeders suggests an overabundance of fine particulate organic matter in the stream. The diversity of feeding types at MiC2 should be a sign of good health in the stream, but the dominance of filter feeders, specifically in the family Hydropsychidae, is evidence of perturbation. The abundance of EPT individuals was also lower than would be expected in a healthy stream. The BI value was in the mid-range, at 3.75.

All metrics examined at the MiC2 site show room for improvement. High levels of sedimentation are likely due to the absence of riffle habitat and impoundments in the stream, which may in turn lead to low levels of dissolved oxygen. High conductivity levels and discharge into the stream from private homes constitute additional threats to water quality. Very low diversity recorded among feeding groups present may also reflect low water quality in this stream.

Monger Creek at Cyprus Restaurant (MoC1)

The physical assessment performed at this site yielded the lowest total score of all sites sampled in this study. Reflecting this poor score, the site received the lowest scores in Habitat, Substrate, Light Penetration and Riparian Zone Width subcategories of physical assessment. The Habitat subcategory results indicate that the MoC1 site had few occurrences of habitat cover materials such as rocks, sticks, leaf packs, and snags. The Substrate score was based on the low variety of substrate material and high occurrence of sand. The Wolman Pebble Count confirmed this score, yielding a median particle size of "coarse sand" between 1-2 mm, the smallest mean value calculated at any site. Additionally, only 2% of particles recorded at MoC1 were larger than coarse gravel, showing that small particles occur almost to the exclusion of all else. This substrate composition suggests high levels of runoff and sedimentation, which may be accounted for in part by upstream commercial development. The score for light penetration is indicative of limited shading of the stream due to suboptimal canopy cover. A low score in Riparian Zone Width was the result of a non-intact, narrow vegetation zone on the left bank.

Chemical assessment of the MoC1 site indicated a high conductivity that is most likely due to urban runoff. Nitrogen concentrations, represented by the measurement of Kjeldahl-N, were consistent with other results except for those recorded at the Cullasaja River. Levels of dissolved oxygen and pH are also consistent with other measured streams and are within the designated standards. The result for fecal coliform in the stream appears low considering the location of the creek relative to the upstream urban environment. Phosphorus levels were at or below the level of detection.

Fish sampling at MoC1 resulted in the collection of only two *Rhinichthys* species, most of which were *R. obtusus*. Both *Rhinichthys* species collected here are native to the Highlands Plateau. The presence of native species may be a positive biotic indicator, but the Shannon Index score indicates very low diversity for this creek and possibly a lower biotic integrity. This is reflected in the aquatic invertebrate data for Monger Creek. The site had the highest BI, which suggests the worst overall health with the fewest environmentally sensitive organisms existing in the stream. The number of EPT organisms found here was low, and the majority were filter feeders, specifically Hydropsychidae, indicating that the stream is perturbed and that there is excessive fine particulate organic matter in the stream.

Aquatic invertebrate sampling conducted at MoC1 revealed that the creek had the highest BI value of all streams sampled, indicating that it has the fewest environmentally sensitive organisms of the six sites. This lack of sensitive invertebrate species and relatively low number of EPT organism found here indicates a poor overall stream health. The high proportion of filter feeders, specifically Hydropsychidae, again indicates that the stream system is perturbed and has an overabundance of fine particulate organic matter.

Limitations and suggestions for future evaluation

There were several limitations and sources of error associated with the physical and chemical assessments in the study. The primary source of error in the habitat assessment was subjectivity and inconsistency in the evaluation due to multiple observers. To correct for this source of error in future studies, we recommend uniformity and experience in the stream observer. Possible sources of error in pebble count data include small sample size (as only ten transects were run at each site), difficulty categorizing different varieties of sand, and inexperience of fieldworkers. Future studies may achieve more reliable data by increasing the number of transects until new data appears redundant, using sized screens to determine sand sizes, and repeating observations to determine whether there is a temporal component of substrate composition.

Because of the low abundance and diversity of fish species, it was not possible to conduct a formal biotic integrity assessment. Even in intact streams, headwaters are generally difficult to assess because of overall lower abundance and diversity in comparison to larger streams. However, the fact that all species collected were exotic except for *Rhinichthys obtusus* and *R. cataractae* indicates low biotic integrity of the Upper Cullasaja watershed (Little Tennessee Watershed Association and Barden 2003).

More efficient sampling methods such as electrofishing may allow for a more complete picture of fish abundance and diversity. Due to the inability to make a conclusive analysis from the fish sampling results, the assessment of stream quality is better inferred from macroinvertebrate data for the time being.

The results for aquatic invertebrates discussed here are subject to the sampling methodology and timing used in this study. As with many studies involving ecological sampling, results could likely have been improved with more time and sampling opportunities. Additional samples taken at each site could potentially have made the results more conclusive and illustrated trends that are not readily apparent in our data. The time constraints of this project proved to be the limiting factor in what we could accomplish. Sampling sites within streams were chosen for their accessibility rather than whether or not they appeared indicative of the habitat or health of the stream as a whole. Additionally, all non-EPT organisms collected could not be analyzed and included in our data due to a lack of time. A more conclusive study of aquatic macroinvertebrates in the Upper Cullasaja watershed would certainly include analyses for these species, and is likely bring to light additional information on the health of the systems sampled. Similarly, the timing of this project limited sampling dates to September 30 and October 6, 2010. Future studies within this watershed might benefit from sampling during the summer months before cold temperatures arrive and begin to limit insect activity.

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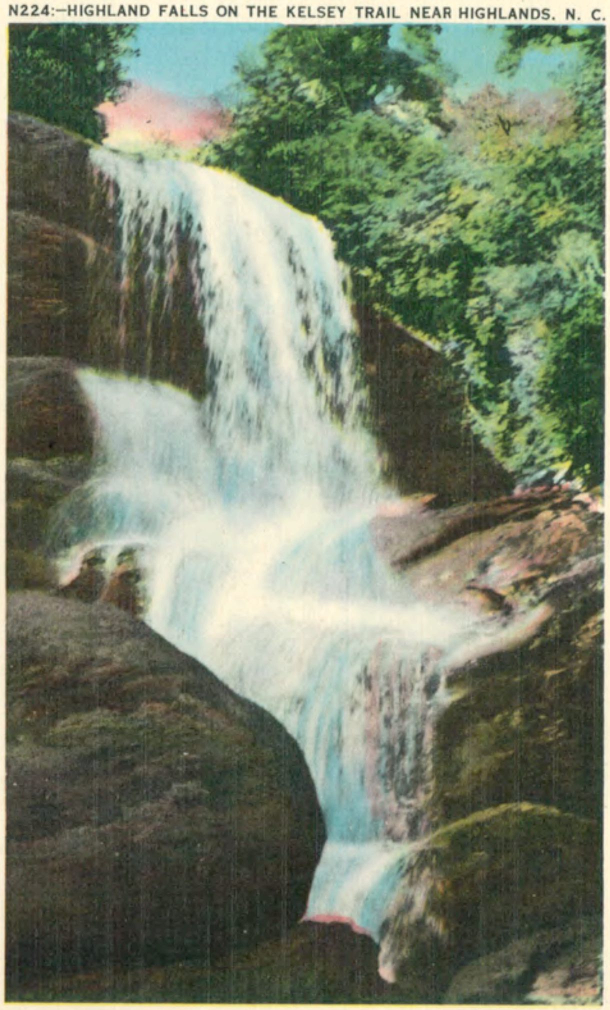
Appendix A

The number of EPT organisms and their respective functional feeding groups organized by family by site (digital archive on attached cd).

Appendix B

Biotic Index values and feeding type designations (digital archive on attached cd).

N224:—HIGHLAND FALLS ON THE KELSEY TRAIL NEAR HIGHLANDS, N. C.



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