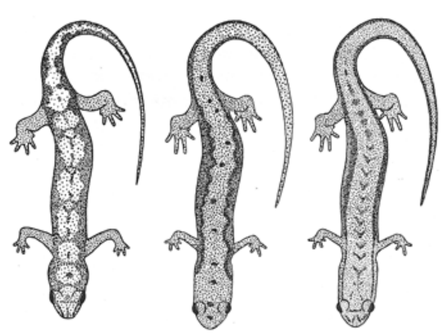
CAROLINA ENVIRONMENTAL PROGRAM
HIGHLANDS FIELD SITE
2006 INTERNSHIP RESEARCH REPORTS

HIGHLANDS BIOLOGICAL STATION
HIGHLANDS, NORTH CAROLINA

Illustrations
Front cover: John James Audubon, “Passenger Pigeon, *Ectopistes migratorius*.” Plate 15 in Irmscher, C. (1999)
John James Audubon: Writings and Drawings. Library of America, New York, NY, USA. Introduction page: Isabelle
Hunt Conant, “Mountain Dusky Salamander (*ochrophaeus*): Variations in dorsal patterns.” Plate 81 in Conant, R.
(1975) *A Field Guide to Reptiles and Amphibians of Eastern and Central North America*, 2nd edition. Houghton Mifflin
Company, Boston, MA, USA.

INTRODUCTION

This volume represents the culmination of the semester-long internship research component of the Carolina Environmental Program's Highlands Field Site during fall 2006. The Carolina Environmental Program (CEP) is an off-campus program for students of the University of North Carolina, Chapel Hill, and the Highlands Biological Station has served as one of its Field Sites since 2001. Located on the Blue Ridge Escarpment of the southern Appalachian mountains, the Highlands Biological Station affords CEP students abundant opportunities to study aspects of the ecology and evolution of the region's rich biota, its complex history of land use, and increasing threats to southern Appalachian natural systems. A centrally important feature of the CEP program at the Highlands Field Site is the internship, in which students identify areas of personal interest and are paired with mentors in matching fields. This year's mentors come from research institutions, government agencies, and non-profit organizations. The role of the mentor is to design and help students to implement hands-on projects in such diverse areas as ecology, conservation, land use planning, and policy. The students spend two days per week on their projects collecting and analyzing data, ultimately presenting their results as a scientific paper or in scientific paper format. This year's projects are as varied as the environmental problems facing the Highlands Plateau and environs; some students explored aquatic systems, others analyzed unique plant communities, and some took on the biology of particular organisms or organism groups. The fruits of their labors – from maps and data tables to policy recommendations and an annotated bibliography – are presented here as contributions toward an improved understanding of the complex nature of natural biological systems and the ways in which humans impact them.



ACKNOWLEDGEMENTS

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Jim Costa, Site Director
Anya Hinkle, Associate Site Director

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Annemarie Nagle worked with Brian Kloeppel, Coweeta Hydrologic Laboratory

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THE CORRELATION OF pH INDICATOR PLANT SPECIES WITH THE GEOLOGY OF A RICH MOUNTAIN COVE

LAURA M. BOGGESS

Abstract. A stream cove located in the Inner Piedmont of South Carolina contains high and low pH indicator plant species in close association. The project involves the analysis of ecological factors contributing to this unusual mixture of plant species. Thus far, our research has included mapping the geology of the cove and conducting intensive surveys of plant species in selected plots. The terrain contains bedrock consisting of the regionally dominant felsic Henderson gneiss interlayered locally with mafic hornblende-biotite gneiss. The preliminary results from the first three months of the study indicate that geological patterns directly influence the distribution of pH indicator species. Further study will include additional floristic surveys, analyses of soil chemistry, hydrology, slope, and aspect at the site, and graphic and statistical analysis of all ecological factors. These analyses will provide a baseline for future studies of mixed indicator coves as well as components for developing predictive models that can be employed in both geological mapping and floristic surveys.

Key words: geological patterns; pH indicator species; plant ecology connections; southern Appalachian mountains; soil chemistry

INTRODUCTION

A rich mountain cove forest is defined as a mesic forest of low to middle elevation (600 to 1400 m), generally occurring on concave lower slopes or flats, and containing a "rich montane herbaceous flora" (Schafle 2002). One such rich mountain cove in the Jocassee Gorges Recreation Area in northern South Carolina exhibits an interesting phenomenon with regard to plant distribution. In cove forests, certain plant species grow only in acidic soils, while others grow only in neutral soils. Generally, acid indicators such as *Rhododendron maximum* (rosebay rhododendron) or *Tsuga canadensis* (eastern hemlock) do not grow in close association with basic indicators like *Adiantum pedatum* (maidenhair fern) and *Asimina triloba* (paw paw). However, in the Jocassee Gorges cove, there are many instances of mixed pH indicator species in close association. For example, on one occasion we found *Adiantum pedatum,* a basic indicator, growing alongside *Galax urceolata* (galax), an acid indicator. In order to explore this anomaly, we investigated the potential biotic and abiotic factors that contribute to the plant species distribution at this site. Various factors can affect plant distribution: underlying geology; the distribution of other species in close association and at a distance; soil chemistry and profile patterns; microclimate; and drainage/hydrology patterns. This report examines the effects of one of the first of these factors: the correlation of the underlying geology with the plant distribution at the site.

The southern Appalachian mountains are generally composed of broad areas of felsic rock, a light-colored igneous rock low in iron and magnesium content but abundant in feldspar and quartz. Felsic rock is a foundation for acidic soils. Interspersed within the felsic areas are scattered bodies of mafic rock—a dark-colored mineral rich in iron and magnesium—supporting plant communities that thrive in mesic to neutral pH soils. The study area is underlain by a combination of these two rock types: felsic Henderson gneiss interlayered with mafic hornblende-biotite gneiss. The Henderson gneiss is the dominant substrate (see Photo 1 of Appendix B for mineral composition) and it supports acidic indicators. The hornblende-biotite gneiss (Photo 2 of Appendix B) supports circumneutral communities, with pH values near 7. As both substrates undergo secondary weathering, they release cations. Henderson gneiss releases aluminum and potassium which are acidic cations. The hornblende-biotite releases magnesium, sodium and calcium which are all basic cations. Thus Henderson gneiss produces acidic soil, and the hornblende-biotite produces circumneutral soil. In this study, we investigate whether the complex interlayering of the felsic Henderson gneiss and the mafic hornblende-biotite gneiss underlying the cove contributes to the presence of the mixed pH indicator species communities, and their transitions and boundaries.

METHODS AND MATERIALS

Our objectives were to survey plant species within the study site and identify their soil pH preference. We surveyed and mapped the geology of the site and examined correlations between the rock substrate and the plants that grow above it.

The study area is 280 by 280 m on South Carolina Department of Natural Resources (SCDNR) Timmerman Natural Resources Area on Jocassee Gorges land in northern Pickens County, South Carolina (Fig. 1.). The cove is forested with hardwoods and scattered conifers, and has a narrow stream floodplain.

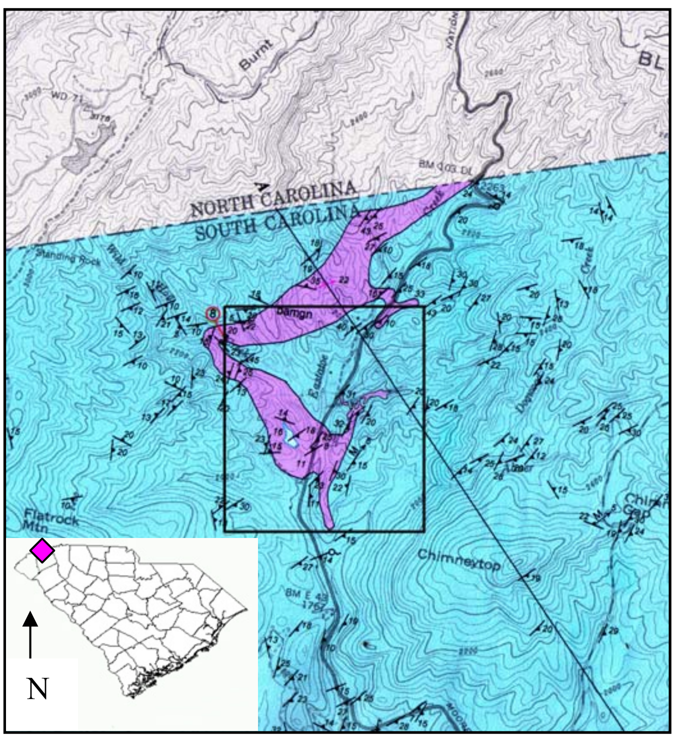


FIG. 1. Map of the study area in northern Pickens County. Henderson gneiss indicated in blue and hornblende-biotite indicated in pink.

The cove also exhibits abrupt changes in soil pH over short distances. Some areas of the cove support plant communities with clearly observable species boundaries while others have mixed pH indicator species in close proximity.

In the field, we established a grid system of 20 m by 20 m plots throughout the entire study area. We used an alidade and other surveying tools to sight lines along the SW/NE axis parallel to the general direction of the cove stream (approx. 66 ° NE). We checked the distance and position against tape measurements and GPS points and placed marked iron pipes (5” protrusion) at 20 m intervals within the study area. We also marked the center of the plot and at ten meters to aid in the vegetation survey. We then created a template of the study area using Adobe Illustrator. We used a Wacom Tablet® to enlarge and refine a section of the 7.5 minute USGS Eastatoe Gap Quadrangle and overlayed a grid map of the plots we surveyed (Fig. 2).

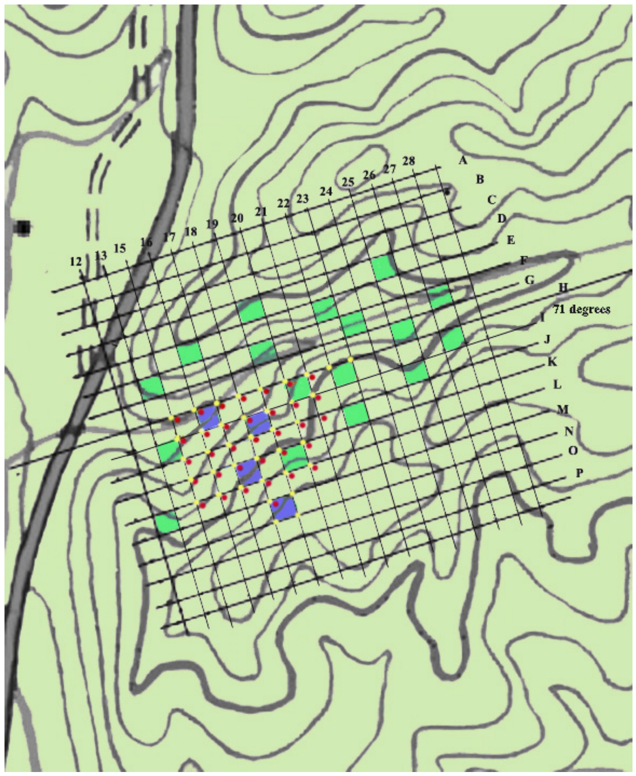


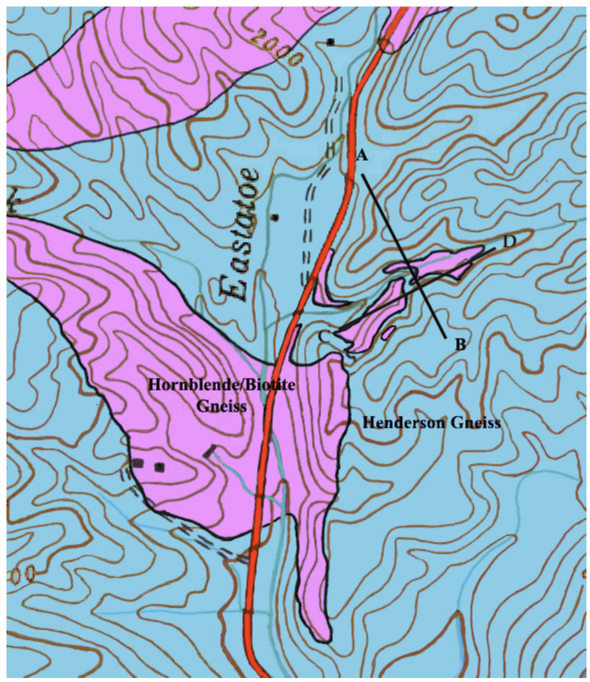
FIG. 2. Map of plots laid out (in green). Surveyed plots are shown in purple

Next, we surveyed and documented all the vegetation in select plots. We used the Carolina Vegetation Survey Pulse Protocol developed by Dr. Robert Peet (2006) and the Carolina Vegetation Survey. We chose to follow the most intensive protocol, which involves documenting all species within the 20 m by 20 m plot. We compiled a complete species list (Appendix A), notating acidic and neutral indicator species.

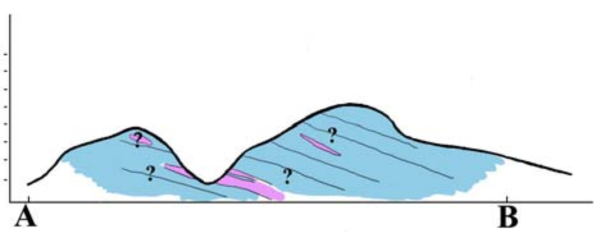
Finally, we mapped the geology of the study area. First we collected data at each rock outcrop within the site including: rock type (mafic or felsic), GPS coordinates, and strike and dip of the foliation. Samples were visually analyzed at 30X magnification. Then we plotted the GPS coordinates of the outcrops on the 7.5 minute USGS Eastatoe Gap Quadrangle using MAPTECH software. We then created maps of the surface (Fig. 3) and subsurface distribution (Figs. 4 and 5) of Henderson gneiss and the hornblende/biotite gneiss.

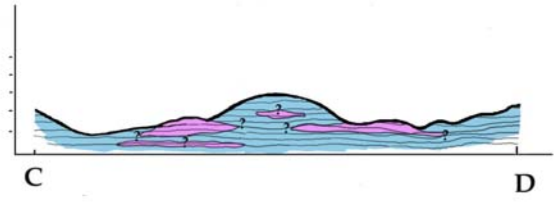
RESULTS AND DISCUSSION

Detailed geologic mapping of the cove shows that the hornblende-biotite gneiss is interlayered with the Henderson gneiss as discontinuous layers, blocks, and lenses with foliation that is parallel to regional foliation. Fig. 2 Fig. 3 illustrates the geological map from above. Figures 4 and 5 show a cross-section of the layering patterns based on our calculations of the strike and dip in of felsic outcrops. Table 1 illustrates the correlation of indicator species with the substrate. Table 2 presents a complete list of observed species and plot(s) in which they were found.



FIGS. 3, 4, 5. Detailed geologic maps of the study area showing outcrops of hornblende-biotite gneiss (pink) surrounded by Henderson gneiss (blue).





Plot I-18, pH 6.8 hornblende/biotite gneiss substrate	Plot H-16, pH 5.3 Henderson gneiss substrate
Actaea pachypoda, Doll's Eyes	*Athyrium asplenioides,* Southern Lady Fern
Adiantum pedatum, Northern Maidenhair Fern	*Calycanthus floridus,* Sweetshrub
Aesculus flava, Buckeye	*Galax urceolata,* Galax
Asimina triloba, Paw Paw	*Kalmia latifolia,* Mountain Laurel
Caulophyllum thalictroides, Blue Cohosh	*Magnolia fraseri*, Umbrella Tree
Deparia acrostichoides, Silvery Glade Fern	*Rhododendron maximum,* Rosebay Rhododendron
Diplazium pycnocarpon, Narrow Glade Fern	*Rhododendron minus,* Carolina Rhododendron
Lindera benzoin, Spice Bush	*Thelypteris noveboracensis,* New York Fern
Thalictrum thalictroides, Thalictrum	*Tsuga canadensis,* Canada Hemlock

TABLE 1. List of indicator species found in plots with hornblende-biotite substrate and Henderson gneiss substrate.

Geologic patterns appear to directly correlate with plant species patterns. In general, species that are known to prefer neutral to basic pH are found above substrates that are known to produce neutral soil, and species that are acid indicators are found above substrates that produce acidic soil. For example, Table 1 illustrates that known pH indicator species such as *Rhododendron maximum* are found growing on plots underlain by the Henderson gneiss substrate. Furthermore, *Adiantum pedatum*, a neutral soil indicator, is found growing on hornblende-biotite substrate. Field observations suggest that the variation in the size and distribution of the two rock types appears to contribute significantly to soil chemistry variations, which, in turn, may permit the close association of pH indicator species.

However, the correlation between rock types and indicator species is not perfect. Thirty percent of the acid indicators listed in Table 1 also grow in areas that are *not* underlain by Henderson gneiss, and as much as sixty-five percent of the basic indicators grow in areas that are not underlain by hornblende-biotite gneiss. For example, in plot K-17 we observed *Galax urceolata* (galax), a known acid indicator, growing on the hornblende-biotite substrate. It is possible that the plant itself has adapted to more neutral soil, or the root system may have found a more acidic microenvironment. The patch of acid soil could be caused by a drainage pattern which results in acidic cations flowing downhill and pooling near the *G. urceolata*. The micro-variation could also be due to interactions between surrounding plants and the soil. Perhaps their metabolism causes the release of acidic cations, allowing just enough acidic soil to permit the growth of *G. urceolata*. Like acid indicators, neutral indicators also grow on substrates that produce acid soils. *Actaea pachypoda* (doll's eyes), *Asimina triloba* (paw paw) were also found in plots underlain by Henderson gneiss. The existence of these anomalous associations requires further study to determine which factors, other than the underlying geology, are at work.

Further study could involve comparing pH indicators species distributions with a number of factors. Geology experiments need to be replicated to enlarge the sample size and eliminate bias caused by factors such as slope and aspect. Once the correlation between geology and indicator species is established, soil patterns need to be examined. Fine-scale soil analysis will allow the creation of study-area maps illustrating distribution of pH, base saturation, cation exchange coefficients, mineral composition and percent organic matter. Identifying and mapping microclimate types and drainage/hydrology patterns in and adjacent to the site would be helpful as well. Ultimately, developing predictive models for the occurrences of pH indicator species and plant communities outside the study area will allow this study to take on a broader usefulness.

There are benefits to further study of geology and plant community correlations. In the case of geological mapping, a basic knowledge of pH indicator species could aid geologists in choosing what areas to investigate when creating a map. Changes in plant communities can alert geologists to the possibility of a different underlying geological pattern, indicating where to take rock samples. The geological foundations of forest coves may also be important factors in determining conservation priorities. The diverse geological patterns in mixed indicator coves produce soils that can support a greater species richness than geologically homogenous sites. Not all coves can support the same diversity of species and an understanding of geological features of a site can give clues as to the long-term species richness that a cove can sustain.

ACKNOWLEDGEMENTS

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APPENDIX A. Complete species list and presence in three representative plots. Neutral indicators in blue and acid indicators in red.

Plot ID:	Plot H-16TG	Plot I-18TG	Plot K-17TG
Date surveyed:	September 8, 2006	October 3, 2006	October 23, 2006
Substrate:	Modules 1- 4: Henderson gneiss	Modules 1- 4: hornblende/biotite gneiss	Modules 1 and 4: hornblende/biotite gneiss; Modules 2 and 3: Henderson gneiss:
Topographic position:	Basin Floor	Low Slope	Mid-slope
Hydrologic Regime:	Occasionally flooded	Upland	Upland
Ophioglossaceae			
Botrychium virginianum	X	X	X
Botrychium biternatum	X		
Pteridacee			
Adiantum pedatum	X		X
Dryopteridacea			
Deparia acrostichoides	X	X	
Polystichum acrostichoides		X	X
Athyrium asplenioides			X
Diplazium pycnocarpon		X	
Thelypteridaceae			
Phegopteris hexagonoptera	X	X	X
Thelypteris noveboracensis			X
Aspleniaceae			
Asplenium platyneuron	X		
Pinaceae			
Tsuga canadensis	X		X
Cyperaceae			
Carex spp.	X	X	X
Liliaceae			
Disporum lanuginosum	X	X	
Smilax spp.		X	
Medeola virginiana		X	X
Orchidaceae			
Goodyera pubescens			X
Tipularia discolor		X	X
Juglandaceae			
Carya spp.	X	X	
Araceae			
Arisaema triphyllum		X	
Betulaceae			
Betula lutea	X		X
Carpinus caroliniana	X		
Fagus grandifolia		X	X
Fagaceae			
Quercus falcata	X	X	X
Aristolochiaceae			
Hexastylis shuttleworthii			X
Urticaceae			
Laportea canadensis	X	X	X
Calycanthaceae			
Calycanthus floridus		X	X
Polygonaceae			
Tovara virginiana	X		
Ranunculaceae			
Actaea pachypoda	X	X	X
Thalictrum thalictroides	X	X	X
Hepatica acutiloba	X	X	X
Berberidaceae			
Caulophyllum thalictroides		X	
Magnoliaceae			
Liriodendron tulipifera	X	X	X
Magnolia fraseri			X
Annonaceae			
Asimina triloba	X	X	

Lauraceae			
Lindera benzoin	X	X	X
Adoxaceae			
Viburnum acerifolium			X
Papaveraceae			
Sanguinaria canadensis	X		
Saxifragaceae			
Tiarella cordiflora	X	X	
Hydrangea arborescens			X
Rosaceae			
Agrimonia paviflora	X		
Agrimonia gryposepala	X		
Prunus serotina	X	X	
Hamamelidaceae			
Liquidambar styraciflua		X	
Hamamelis virginica		X	
Caprifoliaceae			
Lonicera japonica	X	X	
Fabaceae			
Desmodium nudiflorum	X	X	
Cercis canadensis		X	
Anacardiaceae			
Rhus radicans	X	X	X
Aquifoliaceae			
Ilex opaca	X		
Celastraceae			
Euonymus americana	X	X	
Diapensiaceae			
Galax urceolata			X
Aceraceae			
Acer rubra	X	X	X
Hippocastanaceae			
Aesculus flava	X	X	X
Vitaceae			
Vitis rotundifolia	X	X	
Parthenocissus quinquefolia	X		
Tiliaceae			
Tilia americana	X	X	X
Hypericaceae			
Hipericum spp.	X		
Violaceae			
Viola candensis	X	X	X
Cornaceae			
Cornus florida	X	X	X
Cornus alternafolia			X
Ericaceae			
Leuchothoe fontanesiana	X		X
Chimaphila maculata			X
Rhodendrum maximum	X		X
Kalmia latifolia	X		X
Rhododendron minus	X		X
Gentianaceae			
Obolaria virginica	X	X	
Oleaceae			
Fraxinus americana		X	
Rubiaceae			
Mitchella repens	X		
Galium circaezans	X	X	
Diapensiaceae			
Galax urceolata			X
Asteraceae			
Elephantopus carolinianus	X		
Eupatorium rugosum	X	X	
Rudbeckia lanciniata	X	X	
Aster cordifolia		X	X
Solidago curtisii		X	X

APPENDIX B. Images

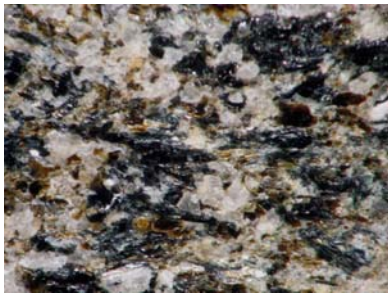

PHOTO 1. Henderson Gneiss
Quartz: SiO_2
Biotite Mica: $K(Mg, Fe)_3 (AlSi_3 O_{10})(OH)_2$
Microcline feldspar: $KAlSi_30_8$
Orthoclase feldspar: $KAlSi_30_8$

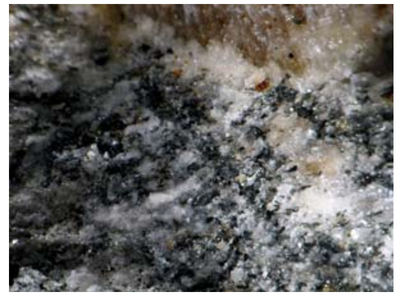

PHOTO 2. Hornblende/Biotite gneiss
Quartz: SiO_2
Hornblende: $(Ca, Na)_{2\text{-}3}(Mg, Fe, Al)_5 Si_6(Si, Al)_2O_{22}(OH)_2$
Biotite: $K(Mg, Fe)_3 (AlSi_3 O_{10})(OH)_2$
Plagioclase feldspar: $Ca_2Al_2Si_2O_8$

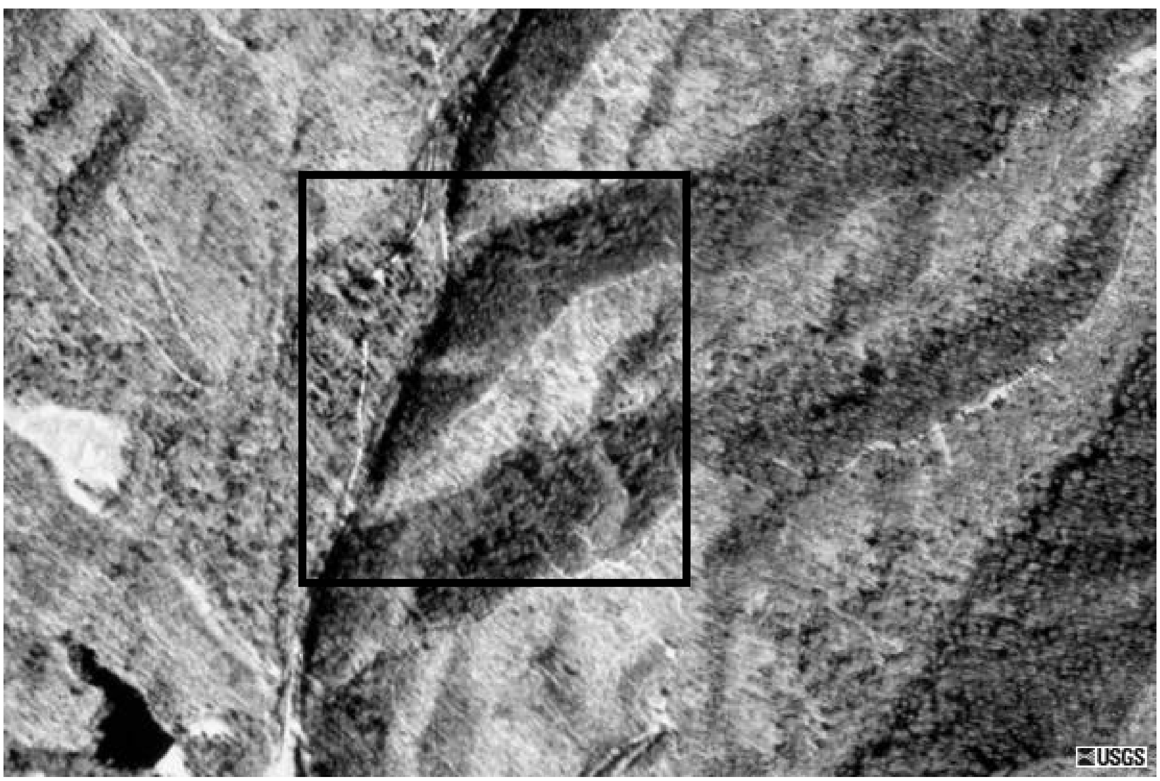

PHOTO 3. Aerial photo of the research site. (USGS aerial photo).

PHOTO 4. Side cove supporting two plant communities corresponding to the substrate: acidic on the left and circum-neutral on the right.

PHOTO 5. Typical circum-neutral plant community underlain by Hornblende/Biotite gneiss.

PHOTO 6. Author standing on hornblende gneiss with Henderson Gneiss boulders above.

PHOTO 7. One of the anomalous pH specialists at the site that we will study further. *Asplenium rhizophyllum*, a rare fern, typically grows on marble or limestone (higher pH) but here it grows on granite with thin soil of pH approx. 5.8.

DISTURBANCE IMPACTS ON HIGH-ELEVATION ROCK OUTCROP COMMUNITIES IN THE SOUTHERN APPALACHIANS

ELLEN BOLAS

Abstract. High-elevation granite rock outcrops in the southern Appalachians hold rare and fragile plant communities. Many outcrop plants are considered relictual alpine flora from the Pleistocene, and six taxa have disjunct populations in the Northern Appalachians. Flora on rock outcrops are uniquely suited to the alpine conditions of their habitat, but are very susceptible to impacts of disturbance such as trampling or rise in global temperatures. Line intercept transects were taken in 13 10 x 10 m plots on rock outcrops on the mountains surrounding Highlands, NC. Using PC-ORD, vegetation composition was correlated with the vegetation found on these plots 15 years ago to note how disturbance may have affected these plots. Additionally, vegetation composition between plots was compared against disturbance measurements to better understand how these impacts affect plant growth. Results indicate that disturbance affects species composition in rock outcrop communities.

Key words: disjunct; distribution; endemism; succession growth

INTRODUCTION

High elevation granite outcrops in southern Appalachian mountains are unique environments. The outcrops are usually granite gneiss domes created from igneous rock pushing through metamorphic rock (Quarterman et al. 1993). A rarity of bare rock in the southern Appalachians makes these areas virtual islands. Often, outcrops have steeper slopes, causing most rainfall to become run-off. This creates characteristics of shallow soils, limited nutrients, severe erosion, and near xeric conditions between summer rainfall events. Additionally, rock outcrops are on exposed mountain tops and experience high solar irradiance and extreme temperatures (Phillips 1982, Quarterman et al. 1993). Unless the plot is located on a seepage site, the combination of these factors creates variations in soil moisture availability, from saturated to near desert conditions.

Southern Appalachian high elevation rock outcrop communities are notable for their high percentage of endemic and disjunct taxa. During the Pleistocene, the southern Appalachians supported alpine flora. It is postulated that when the glaciers receded, many of these species remained on outcrops because of similarities with Pleistocene environmental conditions (Wiser et al. 1998). Some current outcrop species are considered glacial flora relicts, and have disjunct counterparts that have been documented in the White Mountains of New Hampshire (Wiser 1998). High levels of endemism are further indications that these communities have existed in the southern Appalachians for an extended time (Wyatt and Fowler 1977, Quarterman et al. 1993).

Actual creation of rock outcrop communities takes place over a long course of time. Pooling of rainwater makes depressions in the rock where the only available soil may be found (Phillips 1982). Successional plant growth begins with the formation of mat communities. In the Southern Appalachians, these mats are composed of *Selaginella tortipila*, an herbaceous plant that acts as a sponge. Eventually *Danthonia* and *Carex* species establish on the soils created by the presence of *Selaginella tortipila* (Quarterman 1993). On steeper slopes, rainwater can loosen mats, causing them to detach from the rock completely (Wyatt and Fowler 1977). Often, mats will stack up, creating even more available soil for further growth. Plants of rock outcrops grow slowly over extended time periods and have the ability to withstand long periods of desiccation (Quarterman et al. 1993). Additionally, because of the isolated nature of outcrops, plants must be able to disperse long distances (Wyatt and Fowler 1977).

The fragile nature of high elevation rock outcrop communities makes them susceptible to many outside threats. Outcrop species prefer alpine-like environments with limited moisture and cooler temperatures, and a rise in global temperatures could have significant impacts. Additionally, as many rock outcrops are in places regularly visited by hikers, the plant communities are threatened by human disturbance, and a mat that has been trampled can take several years to recover.

High-elevation rock outcrop plant communities are important for the rare and endemic species they harbor. However, little is know about these communities in response to disturbance mechanisms. In this study, my objective was to determine if physical disturbances, including trampling, are changing species composition or leading to loss of high elevation outcrop vegetation. I estimated disturbance and compared plant community composition and abundance among outcrops on the Highlands Plateau. In addition, I compared present vegetation composition with vegetation data collected in 1990 by S. Wiser (unpublished data).

MATERIALS AND METHODS

Study Sites

In the fall of 2006, thirteen rock outcrop sites around the Highlands Plateau were chosen for study. Study plots were selected from the plots used in a previous study by Susan K. Wiser in 1990, and the data set for Wiser plots was incorporated in this study. Appendix A contains all Wiser plot data. Appendix B provides the location and description of current plots, to be referred to as Bolas plots. These sites are characterized by being less than 1600 m in elevation and having more gradual slopes (Wiser et al. 1996). The Bolas plots, 10 x 10 m, were sampled for disturbance level, average soil depth, and vegetation cover. Disturbance level was estimated on a scale from 1-5 with 5 being most heavily disturbed. Average soil depth was calculated from measurements taken at 1 m intervals along two 10 m transects within the plots. Using the standard line intercept technique, two transects were placed at 3 and 7 m to measure vegetation (Chapman 1976). The distance of all vascular and non-vascular plant species and bare rock that intersected the transects was recorded to provide a total coverage index. Additionally, all plant species within each plot were documented; approximately 60 plant species were sampled. Table 1 provides additional details for each study site. For a complete list of plant species per plot, see Appendix C.

Plot Number	Plot Location	Elevation (m)	% Slope	Aspect (°)	Average soil depth (cm)	Disturbance Level (1-5)
51	Devil's Courthouse	1350	30	348	4.66	3
52	Devil's Courthouse	1366	14	248	6.41	3.5
53	Cold Mountain	1402	20	276	4.04	1
54	Scaly Mountain	1439	11	200	6.23	4.5
55	Cold Mountain	1402	28	284	6.04	1
60	Yellow Mountain	1556	16	344	0.88	1
67	Fodderstack Mt.	1280	5	256	4.91	3.7
68	Fodderstack Mt.	1274	15	285	4.43	4
70	Whiteside Mt.	1402	64	254	2.14	1
73	Shelton Pisgah Mt.	1256	24	204	13.95	4
74	Mt. Satulah	1366	28	270	6.76	2.5
75	Mt. Satulah	1366	34	290	2.95	3
76	Blackrock	1244	16	170	4.18	1

TABLE 1. Current 10 x 10 m plot descriptions.

Data Analyses

Data were analyzed by NMS ordination using PC-ORD v. 4 (McCune and Mefford 1997). This ordination scales plots by overlap in species composition; i.e., plots that are more similar in composition are closer together. Among Bolas plots, data were weighted by abundance using the Bray Curtis analysis. This ordination was then correlated with disturbance levels of each plot to asses the impacts of disturbance on vegetation composition. Two separate ordinations were run for plot responses to disturbance: one with rock, and one without rock included in abundance measurements. To assess changes in species composition between Bolas plots and Wiser plots, Jaccard's index of presence/absence ordination was used. These data were also correlated with disturbance levels for current plots.

RESULTS

Current Vegetation Composition

Results show trends in disturbance effects on plant composition in rock outcrop communities. For a compilation of raw data for each Bolas plot, see Appendix A. The ordination of Bolas plots as compared with disturbance is a 2-dimensional ordination and 11.11886 as the final stress (badness of fit). The ordination reveals a trend in species composition related to disturbance level, with less disturbed plots in the upper left quadrant and more disturbed plots in the lower right quadrant (Fig. 1).

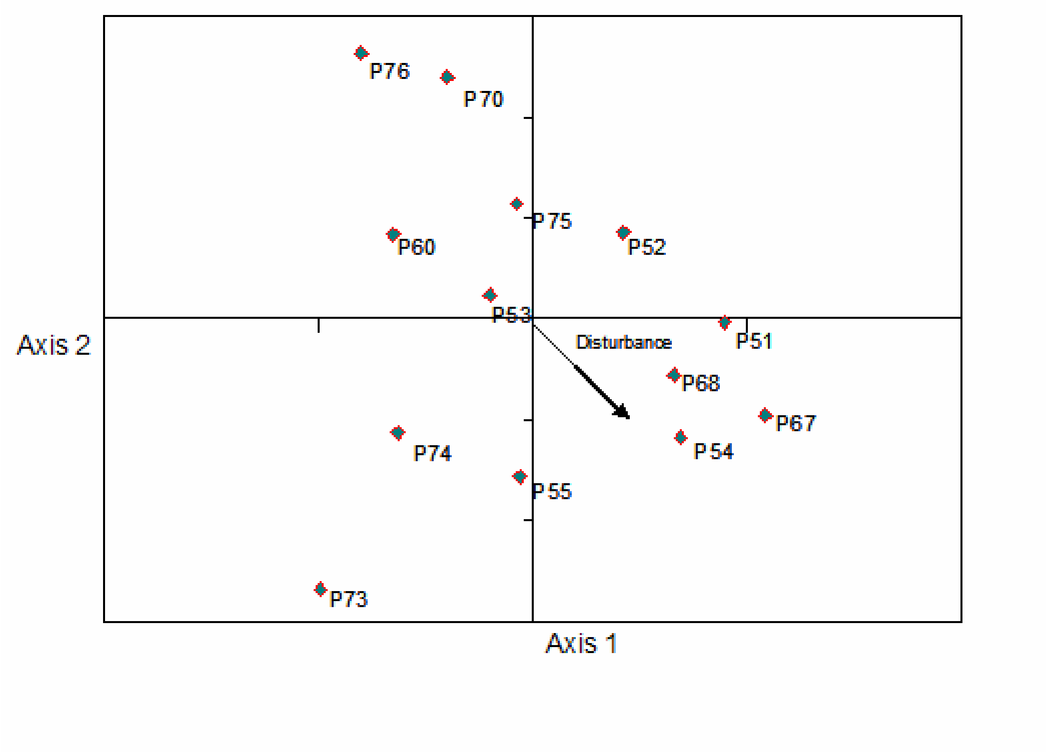

FIG. 1. Impacts of disturbance compared with species composition for Bolas plots with rock. Direction of arrow indicates increase in disturbance level.

A second ordination of Bolas plots with rock left out yielded a 2-dimensional ordination with 14.21608 as the final stress. This ordination also revealed a directional trend in species composition with disturbance, from less disturbed plots in the upper left quadrant to more disturbed plots in the lower right quadrant (Fig. 2).

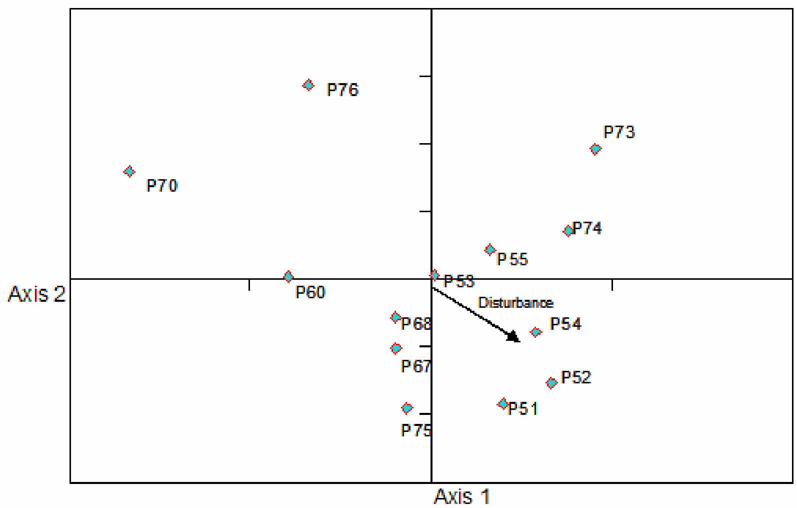

FIG. 2. Impacts of disturbance compared with species composition for Bolas plots with rock excluded. Direction of arrow indicates increase in disturbance level.

Two plant species, *Selaginella tortipila* and *Danthonia* sp., are related to plot disturbance level with rock included and excluded (Figs. 3 and 4). As indicated by the size of the triangles, *Selaginella* increase with disturbance when rock is included and *Danthonia* increases with rock excluded.

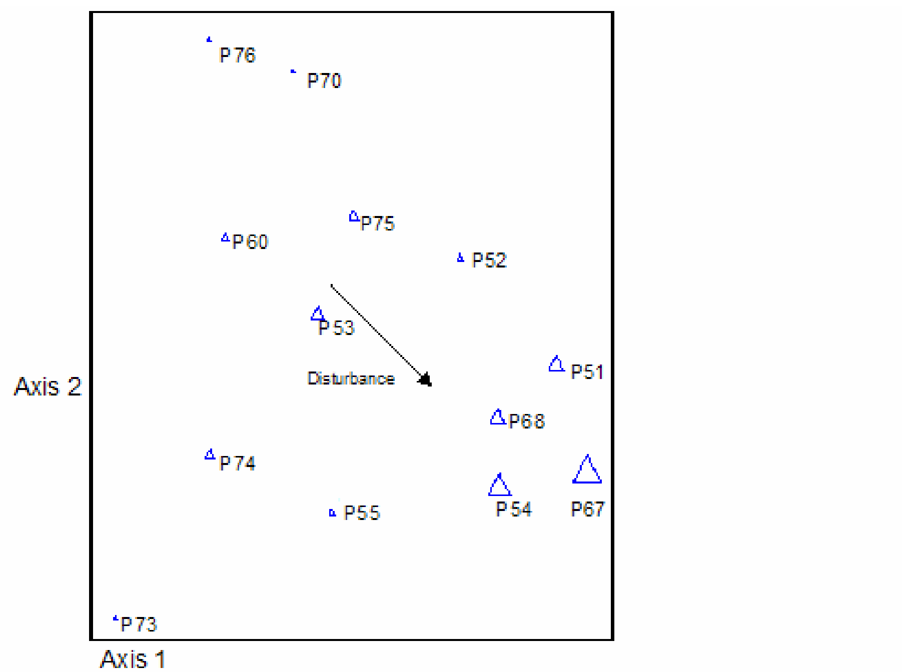

FIG. 3. Abundance of *Selaginella tortipila* among Bolas plots with rock. Direction of arrow indicates increase in level of disturbance.

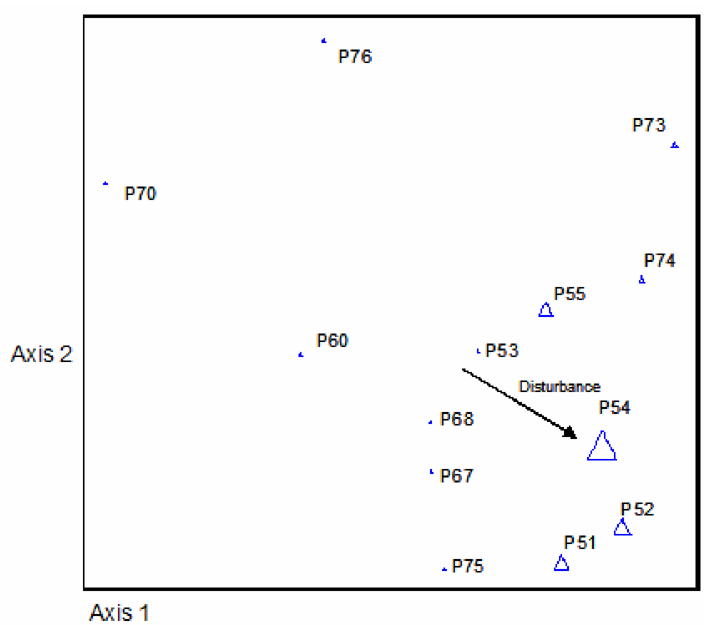

FIG. 4. Abundance of *Danthonia* in Bolas plots with rock excluded.

Direction of arrow indicates increase in level of disturbance.

Table 2 provides a list of the three most abundant species per Bolas plot in regard to level of disturbance.

Plot Number	Disturbance Level	*Agrostis perennans*	*Carex*	*Cladina mitis*	*Cladina rangiferinea*	*Danthonia*	*Dichanthelium acuminatum*	*Hypericum buckleii*	*Juniperus communis var. depressa*	*Kalmia latifolia*	*Leiophyllum buxifolium*	*Pinus rigida*	*Schizachyrium scoparium*	*Selaginella tortipila*	*Sphagnum Moss*	*Umbillicaria*	*Vaccinium corymbosum*	*Vaccinium pallidum*
54	4.5					x				x				x				
68	4		x								x			x				
73	4			x						x								x
67	3.7		x										x	x				
52	3.5					x	x						x					
51	3					x							x	x				
75	3	x											x	x				
74	2.5								x					x				x
53	1			x	x									x				
55	1		x	x														x
60	1			x												x	x	
70	1		x					x							x			
76	1										x	x			x			

TABLE 2. Three most abundant species per plot, plots arranged by decreasing disturbance level.

Change in Species Composition

Ordination of Bolas plots and Wiser plots shows a directional change in species composition with disturbance over the last 15 years (Fig. 5). This ordination has a 2-dimensional solution with a final stress of 22.4. Plots 52-54 showed relatively little change in composition, while plots 73 and 76 showed the greatest change.

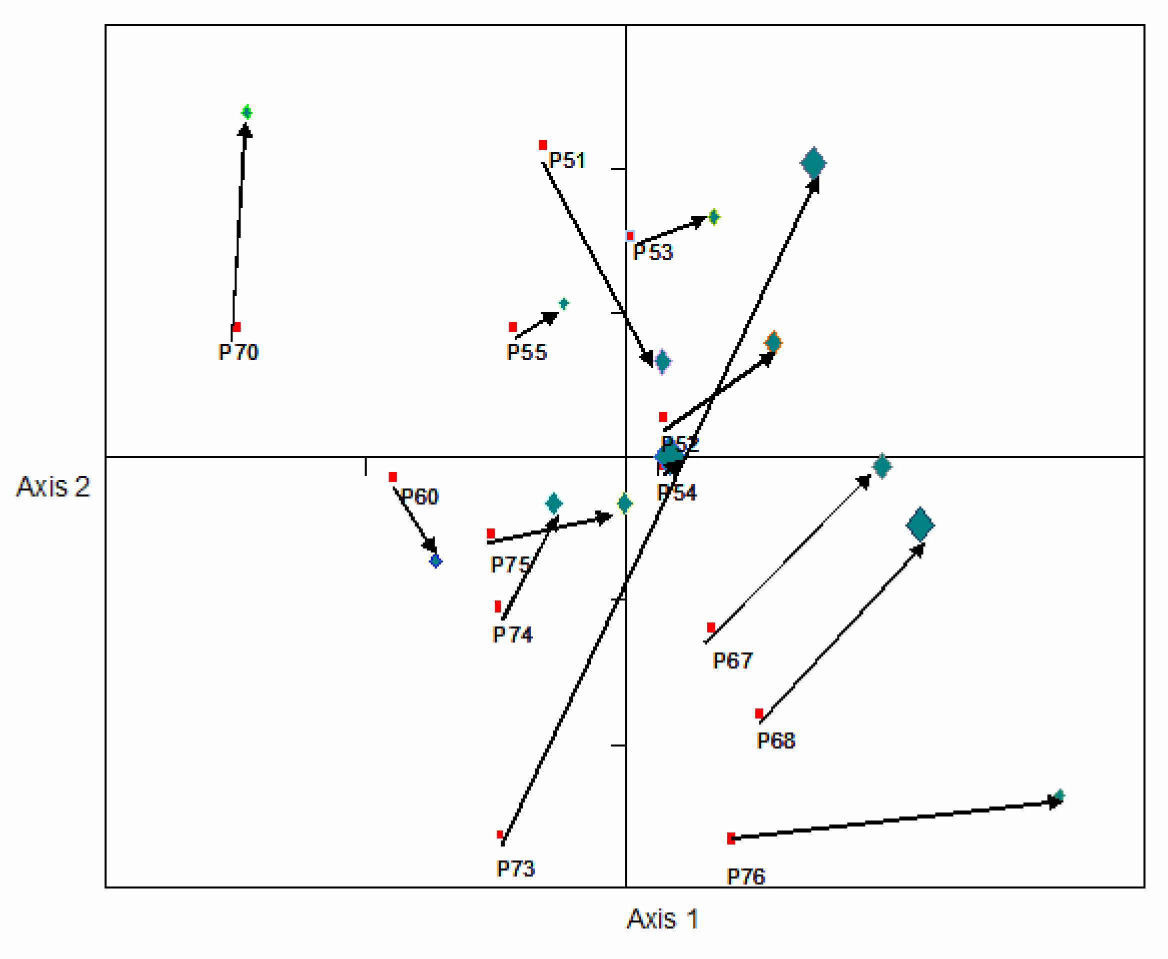

FIG. 5. Relationship between Wiser and Bolas plots compared with impacts of disturbance. Red squares denote Wiser plots, labeled with plots number. Blue diamonds denote corresponding Bolas plots, size of diamond indicates level of disturbance. Arrows show direction of change and amount of difference between Wiser and Bolas plots.

DISCUSSION

Vegetation patterns indicate disturbance does have an effect on current high elevation rock outcrop communities. Regardless of presence of rock, plots that experience increased disturbance have a higher abundance of the early succession species *Selaginella tortipila* and *Danthonia* sp. This could be because high amounts of trampling hinder a community's ability to progress beyond these early successional species.

However, the percentage of rock within each plot rock does have an impact on the overall community composition. Fig. 1, where rock is included in the abundance measure, demonstrates that plots with a higher composition of rock are arrayed on the least disturbed end of the spectrum. Plots with the most exposed rock experience the least amount of disturbance, as people can walk on the rock rather then on plant communities. The lack of trampling can allow later successional species to establish. The outliers in Fig. 1 are Plots 73, 74, and 55, all of which have high abundances of *Vaccinium pallidum* and other later successional species. In the 'no rock' ordination, Plots 60, 70 and 76. Each of these plots is overlaid on a seep, which may lead to different vegetation composition and successional trajectories.

Comparison between Wiser and Bolas plots indicate the direction of change in vegetation composition is related to disturbance. Among plots, 73 shows the most change in composition; however, the exact location of the previous plot could not be determined, which may account for the extreme difference. As previously mentioned, plots 70 and 76 are located on a seep, so they may be growing at different rates from other plots which may account for their "bigger" change. The four remaining plots that showed "big change," 51, 52, 67, and 68, also experienced some level of disturbance. These plots are also related by location. Plots 51 and 52 were both found on Devil's Courthouse, while plots 67 and 68 were located on Fodderstack Mountain. It is possible that these areas are experiencing more human traffic, thereby increasing disturbance levels and affecting the plant communities. It is difficult to determine if there are specific species present in new plots that can account for the congruent direction of change. One interesting note is that *Schizachyrium scoparium* appears only in Bolas Plots 52, 67, 68, and 75. Definitive results for other species affecting direction could not be determined.

My research, which included only thirteen plots, suggest that disturbance influences high elevation outcrop plant communities. Changes in plant composition over time were difficult to ascertain because of lack of information about exact locations of original plots. Further, Wiser plot data did not include a species coverage index, making it more difficult to determine how these plant communities have expanded. Future research that included more sample sites and a more in depth analysis of plant species available is needed. Additionally, it would be interesting to observe how disturbance impacts the successional growth of these communities and their plant composition. It is possible that less disturbed areas eventually develop a shrub community, while in disturbed areas, only grasses persist. Current information about coverage and disturbance does provide a baseline for future studies that could go into further detail about the impacts of trampling.

There are several other follow up studies that would provide important information about rock outcrop communities. It is clear that disturbance changes community composition. These communities grow in alpine-like conditions, and changes in temperature could affect plant growth. Future studies could overlay species composition and coverage information with temperature data for these sites. From this it could be determined if these communities are retreating or losing species richness.

Additionally, little is known about dispersal mechanisms among communities. More could be learned about propagation of species within communities. Even less is known about propagation of species among different communities, and it is possible that theories of island biogeography can be applied in understanding this dynamic.

There is still much that can be learned from the study of high elevation rock outcrop communities. They are ecologically significant for their high levels of endemism and disjunct flora, and their isolated nature. They serve as reminders of the Earth's physical history. Also, they can serve as indicators for global climate change. Their importance ecologically and scientifically compounded by their fragile nature makes rock outcrop plant communities a conservation concern. Often found in highly public areas and easily affected by trampling, people should be made aware of the rare and delicate nature of these communities.

ACKNOWLEDGEMENTS

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APPENDIX A (ELECTRONIC, SEE DISC). Raw data for Wiser and Bolas plots.

APPENDIX B. Plot location and descriptions.

Plot Number	Plot Name	Plot Location North	West	Plot Description
p51	Devil's Courthouse	35.08838	83.13414	Main outcrop area, southwest side
p52	Devil's Courthouse	35.08846	83.13407	Main outcrop area, flat top, 5 m east of previous
p53	Cold Mt.	35.16564	82.98949	In Panthertown Valley, west face, first outcrop down from stone alter at top, near to where trail opens onto outcrop
p54	Scaly Mt.	35.03598	83.28473	First outcrop down from top when approaching the mountain trails off Highway 106, wide area on southwest of outcrop
p55	Cold Mt.	35.16575	82.9859	In Panthertown valley, west face, go north from plot 53 past first vegetation barrier
p60	Yellow Mt.	35.1359	83.19141	20 m north of radio tower, small outcrop surrounded by forest, on a seep

p67	Fodderstack Mt.	35.03613	83.18327	Go south to the largest outcrop area on the mountain
p68	Fodderstack Mt.	35.03649	83.18336	North 10 m from previous plot in a seepage
p70	Whiteside Mt.	35.08015	83.14109	Take a right on the trail to the top from the old road trail (southwest side of loop. Plot is the seepage cliff to the left of the trail when it goes over the wooden bridge
p73	Shelton Pisgah	35.17485	82.99176	Plot is along trail that runs the top of the mountain.
p74	Mt. Satulah	35.08089	83.1777	First ridgeline down from the summit, to the east of the summit if facing the trail head, north end of outcrop.
p75	Mt. Satulah	35.03637	83.19254	5 m south of previous plot on same ridgeline.
p76	Blackrock	35.17082	83.02092	Panthertown Valley, From Salt Rock, follow main trail. At three way junction, take left (high) trail. Follow around mountain, past power lines. Once trail has "doubled back" take small grassy trail to left, opens to large outcrop with seep, plot is left of trail.

APPENDIX C. Plant species by plot number.

plot number	spp id	species name
p51	s337	*Acer rubrum*
p51	s883	*Amelanchier arborea*
p51	s13	*Carax*sp.
p51	s4636	*Danthonia* sp.
p51	s4873	*Dichanthelium acuminatum*
p51	s6751	*Hamamelis virginiana*
p51	s7178	*Houstonia longifolia*
p51	s7336	*Hypericum gentianoides*
p51	s7857	*Kalmia latifolia*
p51	s7932	*Krigia montana*
p51	s25	*Pinus pungens*
p51	s12224	*Rhododendron minus*
p51	s13370	*Schizachyrium scoparium*
p51	s13661	*Selaginella tortipila*
p51	s14233	*Sorbus americana*
p51	s15500	*Vaccinium pallidum*
p52	s631	*Agrostis perennans*
p52	s883	*Amelanchier arborea*

p52	s1771	*Aster* sp.
p52	s13	*Carax*sp.
p52	s4873	*Dichanthelium acuminatum*
p52	s7178	*Houstonia longifolia*
p52	s7336	*Hypericum gentianoides*
p52	s7857	*Kalmia latifolia*
p52	s8156	*Leiophyllum buxifolium*
p52	s22	Moss A
p52	s10987	*Pinus strobus*
p52	s12224	*Rhododendron minus*
p52	s13370	*Schizachyrium scoparium*
p52	s13661	*Selaginella tortipila*
p52	s14233	*Sorbus americana*
p52	s15500	*Vaccinium pallidum*
p52	s15917	*Viola sagittata*
p53	s337	*Acer rubrum*
p53	s2447	*Calamagrostis* sp.
p53	s13	*Carax*sp.
p53	s14	*Cladina mitis*
p53	s15	*Cladina rangiferina*
p53	s4873	*Dichanthelium acuminatum*
p53	s4992	*Diervilla sessilifolia*
p53	s5972	*Eurybia surculosa*
p53	s7178	*Houstonia longifolia*
p53	s7219	*Huperzia appalachiana*
p53	s7857	*Kalmia latifolia*
p53	s8836	*Lycopodium obscurum*
p53	s26	*Polytrichum juniperinum*
p53	s12224	*Rhododendron minus*
p53	s17306	*Rubus* sp.
p53	s13661	*Selaginella tortipila*
p53	s31	*Umbillicaria* sp.
p53	s32	Unknown 1
p53	s15500	*Vaccinium pallidum*
p54	s13	*Carax*sp.
p54	s14	*Cladina mitis*
p54	s15	*Cladina rangiferina*
p54	s4636	*Danthonia* sp.
p54	s4873	*Dichanthelium acuminatum*
p54	s7178	*Houstonia longifolia*
p54	s7336	*Hypericum gentianoides*
p54	s7857	*Kalmia latifolia*
p54	s7932	*Krigia montana*
p54	s22	Moss A
p54	s23	Moss B
p54	s26	*Polytrichum juniperinum*
p54	s27	*Quercus coccinea*
p54	s28	*Rhododendron calendulaceum*
p54	s13661	*Selaginella tortipila*
p54	s14157	*Solidago* sp.

p54	s31	*Umbillicaria* sp.
p54	s15500	*Vaccinium pallidum*
p55	s337	*Acer rubrum*
p55	s883	*Amelanchier arborea*
p55	s2447	*Calamagrostis* sp.
p55	s13	*Carex*sp.
p55	s14	*Cladina mitis*
p55	s18	*Cladonia fimbriata*
p55	s4636	*Danthonia* sp.
p55	s4873	*Dichanthelium acuminatum*
p55	s7316	*Hypericum buckleii*
p55	s7857	*Kalmia latifolia*
p55	s8836	*Lycopodium obscurum*
p55	s26	*Polytrichum juniperinum*
p55	s11999	*Quercus rubra*
p55	s12224	*Rhododendron minus*
p55	s13661	*Selaginella tortipila*
p55	s14157	*Solidago* sp.
p55	s15500	*Vaccinium pallidum*
p60	s631	*Agrostis perennans*
p60	s13	*Carex*sp.
p60	s14	*Cladina mitis*
p60	s4636	*Danthonia* sp.
p60	s7178	*Houstonia longifolia*
p60	s7316	*Hypericum buckleii*
p60	s7857	*Kalmia latifolia*
p60	s7932	*Krigia montana*
p60	s22	Moss A
p60	s11191	Poaceae sp.
p60	s11999	*Quercus rubra*
p60	s12223	*Rhododendron maximum*
p60	s17306	*Rubus* sp.
p60	s13344	*Saxifraga michauxii*
p60	s13661	*Selaginella tortipila*
p60	s31	*Umbillicaria* sp.
p60	s15481	*Vaccinium corymbosum*
p67	s13	*Carax*sp.
p67	s14	*Cladina mitis*
p67	s7178	*Houstonia longifolia*
p67	s7932	*Krigia montana*
p67	s10987	*Pinus strobus*
p67	s17306	*Rubus* sp.
p67	s13370	*Schizachyrium scoparium*
p67	s13661	*Selaginella tortipila*
p67	s15500	*Vaccinium pallidum*
p67	s15898	*Viola primulifolia*
p68	s883	*Amelanchier arborea*
p68	s13	*Carax*sp.
p68	s14	*Cladina mitis*
p68	s15	*Cladina rangiferina*

p68	s4319	*Croton willdenowii*
p68	s21	*Gaultheria procumbens*
p68	s7932	*Krigia montana*
p68	s8156	*Leiophyllum buxifolium*
p68	s23	Moss B
p68	s10983	*Pinus rigida*
p68	s13370	*Schizachyrium scoparium*
p68	s13661	*Selaginella tortipila*
p68	s31	*Umbillicaria* sp.
p68	s15500	*Vaccinium pallidum*
p70	s883	*Amelanchier arborea*
p70	s13	*Carax*sp.
p70	s6257	*Galax urceolata*
p70	s6751	*Hamamelis virginana*
p70	s7316	*Hypericum buckleii*
p70	s7857	*Kalmia latifolia*
p70	s24	Moss C
p70	s11999	*Quercus rubra*
p70	s12223	*Rhododendron maximum*
p70	s12224	*Rhododendron minus*
p70	s29	Sphagnum Moss
p70	s33	Unknown 2
p73	s337	*Acer rubrum*
p73	s1771	*Aster* sp.
p73	s11	*Betula allegheniansis*
p73	s2571	*Campanula divaricata*
p73	s14	*Cladina mitis*
p73	s15	*Cladina rangiferina*
p73	s4636	*Danthonia* sp.
p73	s4873	*Dichanthelium acuminatum*
p73	s20	*Epigaea repens*
p73	s7857	*Kalmia latifolia*
p73	s23	Moss B
p73	s11191	Poaceae sp.
p73	s26	*Polytrichum juniperinum*
p73	s11902	*Quercus alba*
p73	s27	*Quercus coccinea*
p73	s12224	*Rhododendron minus*
p73	s17306	*Rubus* sp.
p73	s13370	*Schizachyrium scoparium*
p73	s13661	*Selaginella tortipila*
p73	s31	*Umbillicaria* sp.
p73	s34	Unknown 3
p73	s15500	*Vaccinium pallidum*
p74	s631	*Agrostis perennans*
p74	s13	*Carax*sp.
p74	s14	*Cladina mitis*
p74	s15	*Cladina rangiferina*
p74	s17	*Cladonia cristatella*
p74	s18	*Cladonia fimbriata*

p74	s4636	*Danthonia* sp.
p74	s6257	*Galax urceolata*
p74	s7316	*Hypericum buckleii*
p74	s7812	*Juniperus communis var. depressa*
p74	s7857	*Kalmia latifolia*
p74	s7932	*Krigia montana*
p74	s8156	*Leiophyllum buxifolium*
p74	s22	Moss A
p74	s10987	*Pinus strobus*
p74	s26	*Polytrichum juniperinum*
p74	s11902	*Quercus alba*
p74	s13661	*Selaginella tortipila*
p74	s14157	*Solidago* sp.
p74	s31	*Umbillicaria* sp.
p74	s15481	*Vaccinium corymbosum*
p74	s15500	*Vaccinium pallidum*
p75	s631	*Agrostis perennans*
p75	s14	*Cladina mitis*
p75	s4636	*Danthonia* sp.
p75	s4873	*Dichanthelium acuminatum*
p75	s4992	*Diervilla sessilifolia*
p75	s6257	*Galax urceolata*
p75	s7316	*Hypericum buckleii*
p75	s7336	*Hypericum gentianoides*
p75	s7812	*Juniperus communis var. depressa*
p75	s7857	*Kalmia latifolia*
p75	s7932	*Krigia montana*
p75	s8156	*Leiopyllum buxifolium*
p75	s22	Moss A
p75	s26	*Polytrichum juniperinum*
p75	s17306	*Rubus* sp.
p75	s13370	*Schizachyrium scoparium*
p75	s13661	*Selaginella tortiplia*
p75	s14157	*Solidago* sp.
p75	s14233	*Sorbus americana*
p75	s31	*Umbillicaria* sp.
p75	s15500	*Vaccinium pallidum*
p75	s15898	*Viola primulifolia*
p76	s337	*Acer rubrum*
p76	s631	*Agrostis perennans*
p76	s1087	*Andropogon virginicus*
p76	s1771	*Aster* sp.
p76	s12	*Betula lenta*
p76	s13	*Carax*sp.
p76	s15	*Cladina rangiferina*
p76	s19	Cyperaceae sp.
p76	s5972	*Eurybia surculosa*
p76	s21	*Gaultheria procumbens*
p76	s7932	*Krigia montana*
p76	s8156	*Leiophyllum buxifolium*

p76	s9678	*Nyssa sylvatica*
p76	s10983	*Pinus rigida*
p76	s12306	*Rhynchospora capitellata*
p76	s17306	*Rubus* sp.
p76	s13549	*Scleria triglomerata*
p76	s29	Sphagnum Moss
p76	s30	*Tsuga canadensis*
p76	s35	Unknown 4

SATULAH SUMMIT BASELINE STUDY FOR THE HIGHLANDS-CASHIERS LAND TRUST OF HIGHLANDS, NORTH CAROLINA

LUCY PAGE CHESNUTT

Abstract. The Highlands-Cashiers Land Trust (HCLT) was established in 1883 as the Highlands Improvement Association (HIA). Since then the association has worked to acquire property around the Highlands-Cashiers area in order to protect, preserve, and promote the natural beauty of the Highlands area. This document utilized vegetation sampling, research, and analysis using ESRI Arc Map to synthesize the many different aspects of this product. This document is a compilation of information that is relevant to the study area including location, description, history, community composition, soil composition, influences, research opportunities, conservation and monitoring activities, and management suggestions. This information is to serve as a template for other studies and give suggestions for management of the area.

Key words: baseline; community; composition; conservation efforts; endemic species; preserve.

INTRODUCTION

The Highlands Improvement Association was established in 1883 only eight years after the founding of the town. The founding residents of Highlands realized quickly that in order to protect and preserve their community and the surrounding area from rampant development, proactive steps to conserve the beautiful vistas surrounding the town had to be taken. According to Randolph Schaffner, author of Heart of the Blue Ride: A History of Highlands, North Carolina (2004); the HIA worked to "protect, preserve, and promote the natural beauty of Highlands." In addition to its mission it also worked closely with the local garden club to build trails, promote green space, and work to provide public areas for recreation.

In the early 1900's the Ravenel Family made a move to sell some of the property they owned in and around the Highlands area. This included the summit of Satulah Mountain. The mountain, which had only one road to the summit and very few houses along its flanks, was a favorite spot of many residents. Its scenic views, prominent green space, and quiet areas for reflection offered a close and accessible area to observe the grandeur of the Highlands Plateau. The first bidders had the intention to build a grand hotel on the summit that would attract people from around the southeast. However, when this began to circulate through town many people were very opposed to the idea. The HIA began to raise money to purchase the summit to be preserved in perpetuity. Finally, in 1909 the summit of Satulah Mountain was acquired for a mere $500. Following the purchase, the new Highlands Land Trust, a name adopted by the HIA following the purchase, improved the road leading up to the summit, and opened and cleared trails for public use. The 4,543 foot granite dome summit overlooks the Nantahala Game Lands, part of the Nantahala National Forest, and the Chattooga River Watershed. The summit has nearly a 360° view with The Fodderstacks, Whiteside Mountain, and Black Rock

Mountain to the northeast, the wide expanse of the undulating southern Appalachians into South Carolina to the south, and the southwest face viewing Rabun Bald in Georgia.

Three distinctly different types of vegetation characterize the mountain. These can be characterized as deciduous forest, shrubby evergreen, and granite dome outcrop. This vegetation grows as a gradient up the north ridge to the summit which is a granite dome rock outcrop. The west, south, and east faces consists of granitic cliffs which drop steeply into the valley where forest vegetation again grows. The entire area provides habitat for highly sensitive endemic species as well as contiguous undisturbed forest.

Satulah Mountain contains a number of unique and sensitive communities making it important for organizations like the HCLT to catalog and conserve its components. This baseline document compiles information about vegetative community composition, soil composition, geologic history, and research opportunities. It also provides history and current issues facing the area, management priorities, and conservation and monitoring activities.

MATERIALS AND METHODS

The baseline data was collected during numerous trips to the mountain focusing on the vegetative cover which included sampling on the rock outcrops, mapping trails, and taking monitoring photos which are included in this report. The vegetative sampling was one part of a larger project that examined rock outcrop communities in the Highlands area (Bolas 2006). The vegetative sampling consisted of making two 10 m by 10 m plots and running two transects across them at intervals of 3 m and 7 m. Along these transects, the vegetation was identified each centimeter. This vegetation was recorded and additional coverage was taken of the surrounding vegetation not found within the plots. This data was synthesized into a spreadsheet denoting the species found on the mountain. (Bolas 2006). The data about soils coverage was compiled using the Macon County soils database (US Dept. of Agriculture). Each soil type is identified and described and a soils map was created using Arc Map by ESRI. The geologic information was taken from Steve Yurkovich, (professor, Western Carolina University, pers. comm.) and historical data from (Schaffner 2004). The land use history was researched using Schaffner's book as well. Current issues, research opportunities, and conservation efforts were researched by interviewing local residents, utilizing primary literature such as Hinkle (1993), Stevenson (1993) and Quarterman (1993), and using HCLT files.

The following sections in this document summarize the findings of these investigations. This information constitutes a baseline for the property owned by the Land Trust for future monitoring by the HCLT. It will also provide a comprehensive view of the available resources within the preserve and serve as a template for other baseline studies.

RESULTS

Study Area Location

Satulah summit is situated at 4,543 feet over looking the small town of Highlands, North Carolina. It is perched along the edge of the Highlands Plateau overlooking the bulk of Nantahala Game Lands in Nantahala National Forest and the Chattooga River watershed. Satulah Mountain is located in the USGS Highlands 7.5 minute Quadrangle topographic map and is home to a variety of unique plants and animals (Quarterman 1993; Bolas 2006). Satulah Summit Road provides the only access to the summit and US Highway 28, colloquially known as Walhalla Road, curves around the base of the mountain. This is important because these roads isolate the preserve from other contiguous tracts of land (i.e. Nantahala National Forest) which could impair mobility of species. Overall, the location of the mountain makes it easily accessible from town for research oriented, recreational, or personal pursuits.

Study Area Description

The entire preserve encompasses 70 acres of predominantly rock outcrop communities and fringe areas (the outer edge or periphery of a rock outcrop). The north ridge rises gently up from the town of Highlands, North Carolina, while the entire south face is characterized by steep, granite cliffs which plummet into the valley. From the summit there is a nearly 360° view of the surrounding area including views of Whiteside Mountain, Black Rock Mountain, and The Fodderstacks to the northeast, South Carolina to the south, and Rabun Bald in Georgia to the southwest. The vegetation in the preserve can be classified into three different categories deciduous forest coverage, shrubby evergreen coverage, and rock outcrop coverage. A map of this vegetation coverage can be seen in Appendix A.

The deciduous forest surrounding the preserve is characterized as an "Appalachian Oak and Mixed Mesophytic Forest Region" by Hinkle (1993) and Stephenson (1993). This type of forest community is one of the most biologically rich systems of the temperate regions of the world, certainly in the United States (Hinkle 1993). Along the summit rhododendron (*Rhododendron maximus; Rhododendron minus; Rhododendron catawbiense*), mountain laurel (*Kalmia latifolia*) and dwarf pine (*Pinus* spp.) dominate the understory and fringe areas of the rock outcrop encompassing the shrubby evergreen category. The rock outcrops are dominated by highly sensitive granite dome vegetation which will also be discussed at length later (Bolas 2006).

Part of what makes the vegetation on Satulah unique is the soil composition. The soil composition of the mountain includes highly xeric soil that is characterized by high acid content. The soil in the preserve is thin and has very few nutrients available. This indicates why the plants that grow in this area and others are so highly adapted to survive in such extreme environments. A soils map can be viewed in Appendix B.

Because of its proximity to town and easy accessibility the area is fairly impacted by humans. No road goes directly through the preserve however many trails criss-cross the mountain sometimes trampling sensitive vegetation and disturbing the ecosystem. Several homes have been built along Satulah Summit Road up to the perimeter of the preserve. Most of the homes are landscaped in an ecologically friendly way, using native vegetation so that there is a gradient from the highly developed areas into the forested area. This helps to ameliorate the impact of construction on habitat within the preserve and the mountain as a whole. An aerial photo of the preserve can be viewed in Appendix C.

This area represents a large contiguous tract of undeveloped land with highly sensitive vegetation communities. Relatively undisturbed by human influences, this allows a wide variety of organisms to maximize the available resources. This area is important because it can be utilized for scientific study of vegetation, habitat, and cover types. It also provides recreational opportunities, scenic views, prominent green space and quiet areas for reflection.

History of Study Area

I. Geology

Satulah Mountain, like the other mountains in the area, was formed by numerous orogenous events. According to Dr. Steven Yurkovich (pers. comm.), a series of three orogenous events took place over the course of 15 million years. The final event, known as the Appalachian Orogeny, created the mountains we know today as the Appalachians. These events, which pushed mountains against other mountains created huge mountains that eventually were eroded down creating the undulating ribbon that we see today. The rock is primarily granite with some mica and quartz deposits (Shaffner 2004). There are some indications of volcanic activity on Satulah. The Cherokee name has several translations including “Big Grumbler Mountain”, “puffer” and “snorter”. Satulah has been reported to emit sulphur fumes and rumble on several occasions but no official volcanic account has ever been recorded (Shaffner 2004).

II. Land Use

The area was acquired in 1909 when the HIA officially made its first purchase. The HIA was founded in 1883 with the intended purpose monitor the town’s growth, as well as protect, preserve and promote the natural beauty of Highlands (Shaffner 2004). In 1905, the association officially declared its intention:

> *“to promote the prosperity and progress of Highlands by systematic effort; to guard its natural beauties and as far as possible to restore those that have perished; to maintain its healthful climate; to initiate and aid public measures that tend directly or indirectly to further these aims; to create by word and deed an enlightened public opinion that shall cherish and safeguard its unique scenic and sanitary possessions”(Shaffner 2004).*

Satulah summit was purchased for $500 and “dedicated to public use in perpetuity” (Shaffner 2004). The HIA built a stone shelter house “for the benefit and protection of those who desire to spend the night on the summit for the purpose of beholding the beauties of the sunset, of the starlit heavens, and the glories of sunrise” (Shaffner 2004).

The walls and chimney of this structure are still standing on the summit (Appendix D). The HIA also improved the road originally built in 1890 by Captain Prioleau Ravenel, Sr., and opened, cleared, and marked the trails (Shaffner 2004). Today, the HCLT maintains the trails on Satulah Mountain and works to preserve the natural areas, scenic beauty, and green spaces of the Highlands Plateau for the enjoyment and benefit of the public (HCLT 2006).

Study Area Community Composition

Satulah summit is home to a wide variety of plants and animals. They can be divided into three main categories: deciduous forest, shrubby evergreen vegetation, and granite dome vegetation (Appendix A). The following section details the composition of the vegetation found on Satulah. It also comments on possible fauna that may reside in the specific microclimates of the different vegetative communities. Soil composition is also described.

I. Deciduous Forest Communities

The deciduous forest community, which composes approximately half of the preserve, can be described as primarily Appalachian Oak and Mixed Mesophytic Forest. This includes species such as white pine (*Pinus strobus*), white oak (*Quercus alba*), red oak (*Q. rubra*), hickory (*Carya* spp.), chestnut oak (*Q. prinus*), tulip poplar (*Liriodendron tulipifera*), cucumber magnolia (*Magnolia acuminata*), and, historically, American chestnut (*Castanea dentata*). A full list of the sampled vegetation is available in Appendix E. The vegetative coverage described in Stephenson (1993) and Hinkle (1993) is congruent with the sampled vegetation on all accounts. Impacts to the area have included logging of the forest surrounding the study area for building homes. The loss of the American chestnut also significantly impacted the ecosystem. Like many forests in the area, the deciduous forest community on Satulah is a prime example of a recovering forest community. The variety of species and early growth are indicative of previous disturbance, but the growth is healthy and vibrant.

II. Shrubby Evergreen Communities

The fringe areas of the granite dome outcrop on Satulah Mountain are dominated by shrubby evergreen vegetation. Based on recent vegetation sampling, these plants include mountain laurel (*Kalmia latifolia*), rosebay rhododendron (*Rhododendron maximum*), and Carolina rhododendron (*Rhododendron minus*). The understory is primarily composed of galax (*Galax rotundifolia*), and running cedar (*Lycopodium digitatum*). These communities are most visible on the hike up to the summit. The mountain laurel and rhododendron thickets part to create a pathway for people to venture to the top of the mountain. These communities are especially dense along the edge of the rock outcrop where they receive more sunlight and rain.

III. Granite Dome Communities

Granite dome communities are highly specialized and fragile environments. The summits where these communities occur are especially vulnerable to human trampling, particularly because they take so long to grow, sometimes hundreds of years. They experience temperature extremes, are exposed to large amounts of sunlight, wind, and rain, and have very thin soil. All of these elements combine to create particularly harsh living conditions. The granite dome on Satulah Summit is especially large and has had relatively little human impact. This makes it a good candidate for granite dome studies including ecosystem and vegetative cover analyses. There are six different microhabitats within the granite outcrop on Satulah. Each habitat is described below, listing sampled vegetation and possible flora and fauna. For a complete list of sampled vegetation please see Appendix E.

A. Exposed Rock Communities

The summit of Satulah is primarily composed of exposed rock communities. This habitat is underlain by bare rock that has been colonized by "low growing lichens and mosses" (Quarterman 1993). Our sampling showed species of rock tripe (*Lasallia pustulata*), foliose lichen (*Xanthparmelia conspersa*) and pioneer moss (*Grimmia laevigata*) (Bolas 2006). These communities are of particular importance because they provide the underlying support structure for the eventual accumulation of soil and organic matter. When soil and organic matter accumulates, other successional plants can grow. Quarterman (1993) also investigates the possible fauna that lives in this habitat, although this was not specifically investigated in our study, but could serve as an excellent project for a master's student. Possible species include several insects such as the endemic rock grasshopper (*Trimerotropis saxatilits*), lichen spider (*Pardos lapidicina*), caeculid mite (*Caeculus crossslei*), centipedes (*Lithobius* spp.), millipede (*Spirobolus marginatus*), walking stick (*Anisomorpha ferruginea*), and the *Collops georgianus* (Quarterman 1993). The main threat to these communities is human impact. When the summit of Satulah is first reached by foot, a large expanse of exposed rock stretches out before the viewer. Mosses and lichens grow abundantly except where this vegetation has been trampled. Loss of this habitat has a deleterious effect on the insect communities that use this type of vegetation. A good rule of thumb when visiting Satulah and other rock outcrops is to stay to the well beaten path and avoid creating social trails that may destroy the sensitive vegetation.

B. Shallow Pool Communities

This habitat occurs on flat to slightly slanted areas of the granite dome. They are characterized by circular or asymmetrical depressions that fill with water making ephemeral pools when it rains. Eventually, these pools may fill with soil from runoff leading to successional vegetation growth. The primary species that was found in these communities include the grasses *Agrostis perennans, Danothonia* spp. and *Cladonia* spp. On Satulah, these communities are around the main summit outcrop, and along the top edge of the cliffs on the southwest side of the mountain. These shallow pools are especially apparent after a good rain or in the winter time when they ice over. For pictures of these communities see Appendix D. The fauna of these communities is dependant on the amount of rain in a given season. Small aquatic invertebrates that could possibly inhabit this area include diving beetles (*Agabus* sp. and *Hydrovatus* sp.) and midge larvae (*Chironomus* sp.). Others include turbellarians such as, *Mesostoma georgianum*, *Phagocata busaperforata*, and *Geocentrophora marcusi*. These species occur often in wet seasons, but will suffer high mortality during dry seasons (Quarterman 1993).

C. Seepage Area Communities

Seepage areas moisture content is also highly dependant on precipitation. The reed *Isoetes piedmontana* is characteristic of such areas. Sampled vegetation included *Agrostis perennans*, *Danthonia* sp., *Carax* sp. and *Cladonia* spp. The primary seep on Satulah is found on the southwest face looking towards Rabun Bald in Georgia. Here, water seeps out of the denser fringe vegetation and through cracks in the rocks creating this specific type of community. Mosses and coverings such as *Selaginella* sp. grow extensively in this region as well. Most vegetation will grow well in these areas since water; the limiting agent for most rock outcrop communities is more abundant here. Seepage areas can also serve as a refuge for coastal plain species of grasses, reeds, and rushes (Quarterman 1993). No particular fauna are associated specifically with this community. For photographs of this type of community see Appendix D.

D. Marginal Communities

The marginal zone located between exposed rock and adjacent soil accumulation or forest provides habitat for a large number of species. According to Quarterman (1993), "the soil is similar in depth and composition to that of the deeper soil islands, but conditions are usually more mesic." Sampled species include *Selaginella* sp., *Cladonia* sp., *Danthonia* spp., *Carex* sp., *Agrostis perennans, Cladina mitis, Juniperus comunis,* white pine (*Pinus strobus*), and eastern hemlock (*Tsuga canadenisis*) (Bolas 2006). These marginal communites are characterized by drier and shallower soils. This community functions as a gradient between the exposed rock community and successional, mat, or forest communities. Possible fauna living here includes jumping spiders (Salticidae), wolf spiders (Lycosidae), rock grasshoppers (*Trimerotropis saxatilis*), ants (i.e. *Formica schaufussi*), and Honeybees (i.e. *Apis mellifera*) (Quarterman 1993).

E. Successional Plant Communities

Successional plant communities are characterized by shallow soil and are generally isolated from one another by exposed rock. This is by far the most abundant vegetation community on Satulah summit. The dominant flora found in the successional plant communities includes *Selaginella* sp., which is highly tolerant of low moisture, *Kregia montana, Cladonia* sp., *Danthonia* spp., *Carex* spp., *Agrostis perennans, Cladina mitis,* and *Juniperus communis* (Bolas 2006). These communities also contained mountain laurel (*Kalmia latifolia*), white pine (*Pinus strobus*), Allegheny sand myrtle (*Leiophyllum buxifolium* var. *prostratum*), and Catawba rhododendron (*Rhododendron catawbiense*) (Quarterman 1993: Bolas 2006). Trails across the summit cut through large thickets of Allegheny sand myrtle (*Leiophyllum buxifolium*), juniper (*Juniperus communis*), and mountain laurel (*Kalmia latifolia*). No specific fauna lives solely in this particular community. As the area of successional plant communities expands the larger and more intricate the food web becomes (Quarterman 1993).

F. Mat Communities

The formation of mats on rock outcrops is considered to be of "primary significance in early stages of plant succession" (Quarterman 1993). The succession of vegetation, eventually forming mat communities can take hundreds of years. Once lichens have attached themselves to bare rock, more organic material will begin to accumulate (Quarterman 1993). Eventually, communities of *Cladonia leporine* and *Selaginella* sp. will invade, displacing the lichen and allowing more organic material to accumulate. This will eventually be displaced by *Grimmia* sp., *Andropogon* sp., and *Danthonia* sp. Eventually, wood seedlings such as red maple (*Acer rubrum*) fringe tree (*Chionanthus virginica*), red cedar (*Juniperus virginiana)*, eastern hemlock (*Tsuga canadensis*), juniper (*Juniperus communis*), and white pine (*Pinus strobus*) will invade the mat (Quarterman 1993: Bolas 2006). Eventually these mats will get heavy and will not be able to attach themselves to the rock. When this happens they will slide off the rock leaving bare rock. The mats will pile up providing deeper soil for other plants to grow in. Mat communities on Satulah are especially vulnerable to human trampling, particularly because they take so long to grow, sometimes hundreds of years.

Vertebrates that might live in such communities include some amphibians such as tree frogs (*Hylidae*), Fowler's toad (*Bufo fowleri*), five-lined skink (*Eumeces fasciatus*), six-lined racerunner (*Cnemidophorus sexlineatus*), and ground skink (*Scincella lateralis*), copperhead (*Agkistrodon contortrix*), timber rattlesnake (*Crotalus horridus*), black racer (*Coluber constrictor*), and eastern coachwhip snake (*Masticophis flagellum*) (Quarterman 1993). Birds may include mockingbird (*Mimus polyglottos)*, raven (*Corvus corax*), crow (*Corvus brachyrhynchos*), and other songbirds which may forage in the shrubby herbaceous area. Mammals that may benefit from mat communities include some voles (*Microtus* spp.), shrews (*Soricidae* spp.), cottontail rabbit (*Sylvilagus floridanus*), gray squirrel (*Sciurus carolinensis*), white tailed deer (*Odocoileus virginianus*), gray fox (*Urocyon cinereoargenteus*), raccoon (*Procyon lotor*), coyote (*Canis latrans*), and black bear (*Ursus americanus*) (Quarterman 1993).

IV. Soil Composition

The soil on Satulah is composed of seventeen different soil types as defined by the US Department of Agriculture-Natural Resources Conservation Service (US Dept of Agriculture 1990: Appendix B). The majority of the summit is categorized as Rock-Outcrop Cleveland with the periphery consisting of Cleveland-Chestnut Rock Outcrop. There are three different types of this soil, the distinction is made based on the slope of the rock and is categorized into 15-30 percent slope, 30 to 50 percent slope, and 50 to 95 percent slope. The other soil includes Cashiers, a gravelly fine sandy loam with 50 to 95 percent slope. Two types of Chandler, a gravelly fine sandy loam, one with 15 to 30 percent slopes which occurs along the top ridge of the mountain and the other with 50 to 95 percent slopes which occurs along the east and westward cliffs. Three types of Chestnut Edneyville soil occur which are characterized as stony and windswept occur along the outer periphery of the property. Cullasaja, Cullasaja-Tuckaseegee, Edneyville-Chestnut, Plott, and Tuckaseegee-Whiteside encompass the remainder of the property. All of these soils are dominantly a sandy, gravel loam with low moisture retention and somewhat high acidity (US Dept. of Agriculture 1990).

DISCUSSION

Research Opportunities

Much more field work needs to be done in order to fully understand these unique ecosystems. A wide variety of research opportunities are available including basic inventory, monitoring projects, management, ecological comparisons among microhabitats and describing rare and endemic species. On Satulah specifically, a full investigation of the flora and fauna living there and their ecological interactions could be conducted. Also, a disturbance study where a specific outcrop is blocked off from human trampling and over time this area is compared to other areas that do suffer from human trampling might lead to interesting conclusions. A good resource for potential research opportunities in regard to granite dome outcrops is also available in Biodiversity of the Southeastern United States (Quarterman 1993).

Conservation and Monitoring Activities

The HCLT strives to preserve and protect this highly fragile environment. One important aspect in achieving these goals is to document the current vegetation and take photographic inventories at regular (i. e. annual) intervals. Such work is highly dependant on volunteers; if you would be interested in conducting such field work please contact the Highlands-Cashiers Land Trust executive director.

Suggestions for Management

Satulah Summit provides an easily accessible area for many people to appreciate its scenic views, green space, and unique vegetation. Management issues surrounding this area should be primarily concerned with trail maintenance and limiting trampling of granite outcrop communities. The main trail up to the summit is in extreme disrepair and would benefit from regrading. Additionally, a complete inventory of the trail system using GPS would increase knowledge about the summit. An effort to educate the public about the sensitive vegetation on the mountain would be beneficial and hopefully diminish trampling.

ACKNOWLEDGEMENTS

I thank Gary Wein, Executive Director of the Highlands-Cashiers Land Trust for serving as a mentor for this project. I also thank Glenda Zahner for assisting with identifying plants and becoming familiar with this area. Huge thanks to Ellie Bolas for assistance in compiling information, especially with regards to flora of granite dome outcrops. I also acknowledge the Dr. Jim Costa and Dr. Anya Hinkle for helping proofread and edit. Lastly, I thank Highlands Biological Station and Carolina Environmental Program for allowing me to conduct this internship.

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APPENDIX A

Vegetation Coverage Map of Satulah Summit. ESRI Arc Map. December 8,2006

APPENDIX B

Soils Map Coverage. ESRI Arc Map. US Dept. of Agriculture-Natural Resources Service. December 1, 2006.

APPENDIX C

Satulah Summit Aerial Photo Map. ESRI Arc Map. December 1, 2006.

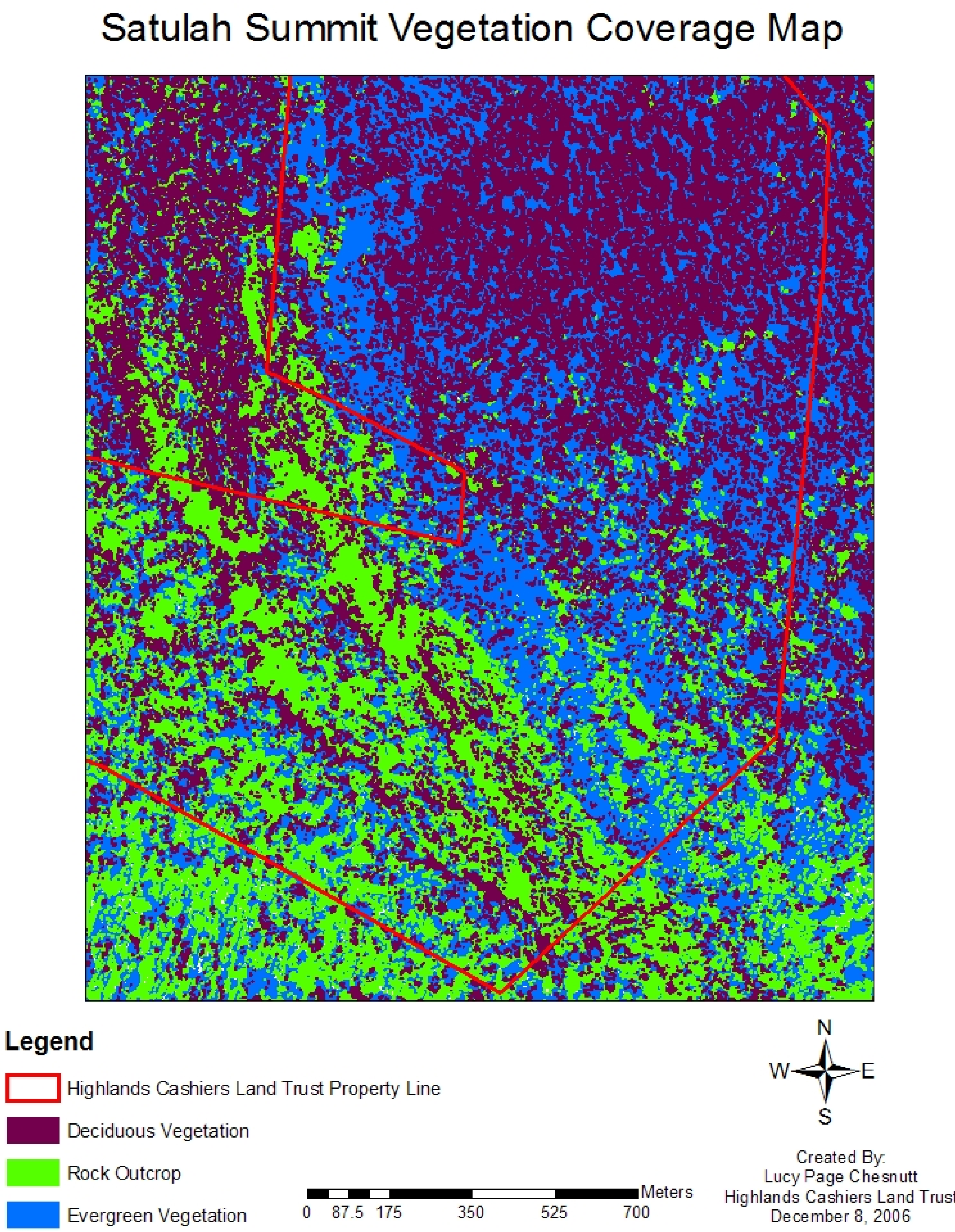
APPENDIX D

Photo Gallery. Photos taken on December 6, 2006.

APPENDIX E

Bolas, Ellen and Chesnutt, Lucy Page. Sample Vegetation Species List for Satulah Summit. Conducted on October 10, 2006.

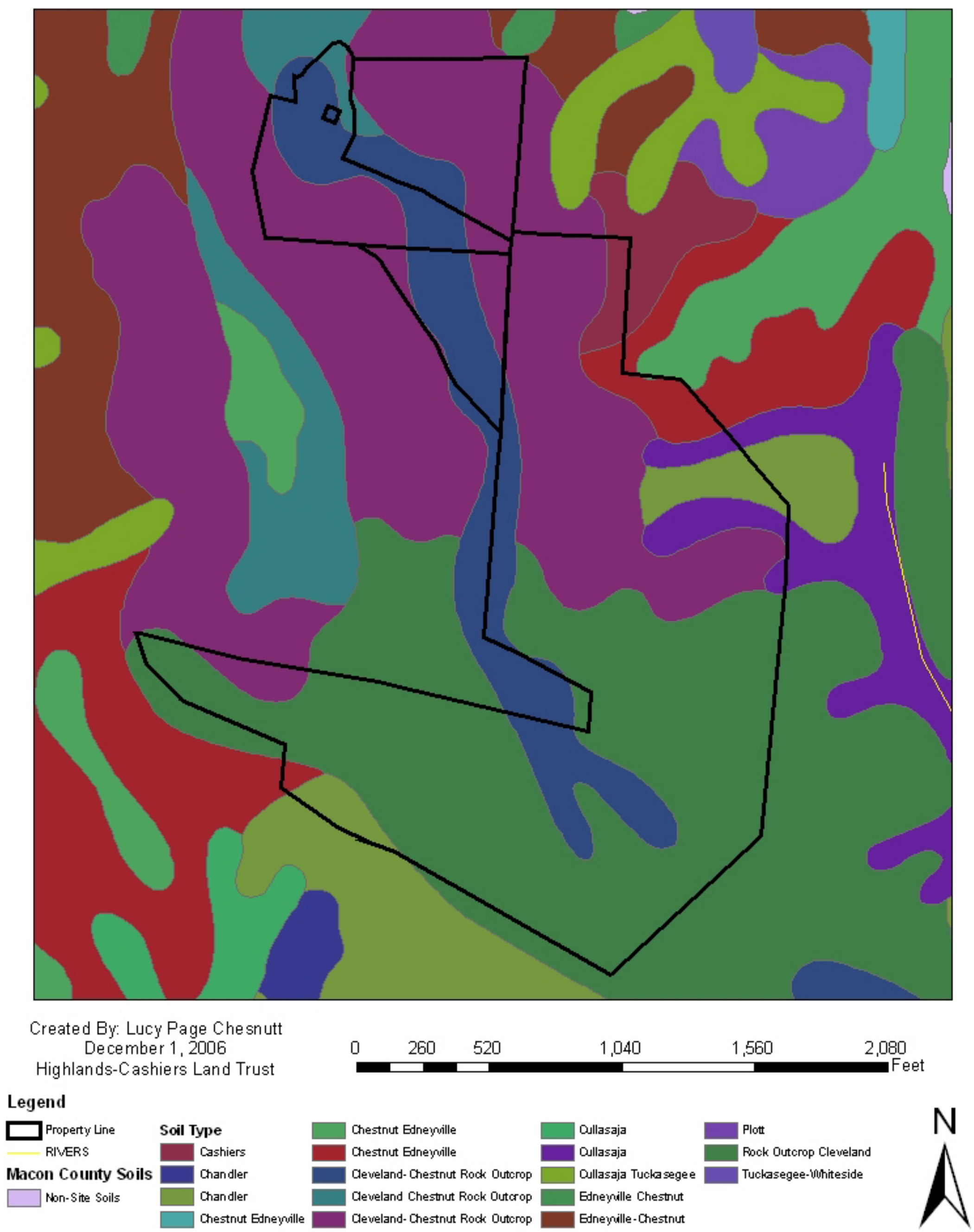
APPENDIX A



Satulah Summit Vegetation Coverage Map
Legend
Highlands Cashiers Land Trust Property Line
Deciduous Vegetation
Rock Outcrop
Evergreen Vegetation
0 87.5 175 350 525 700
Meters
N
W
E
S
Created By:
Lucy Page Chesnutt
Highlands Cashiers Land Trust
December 8, 2006

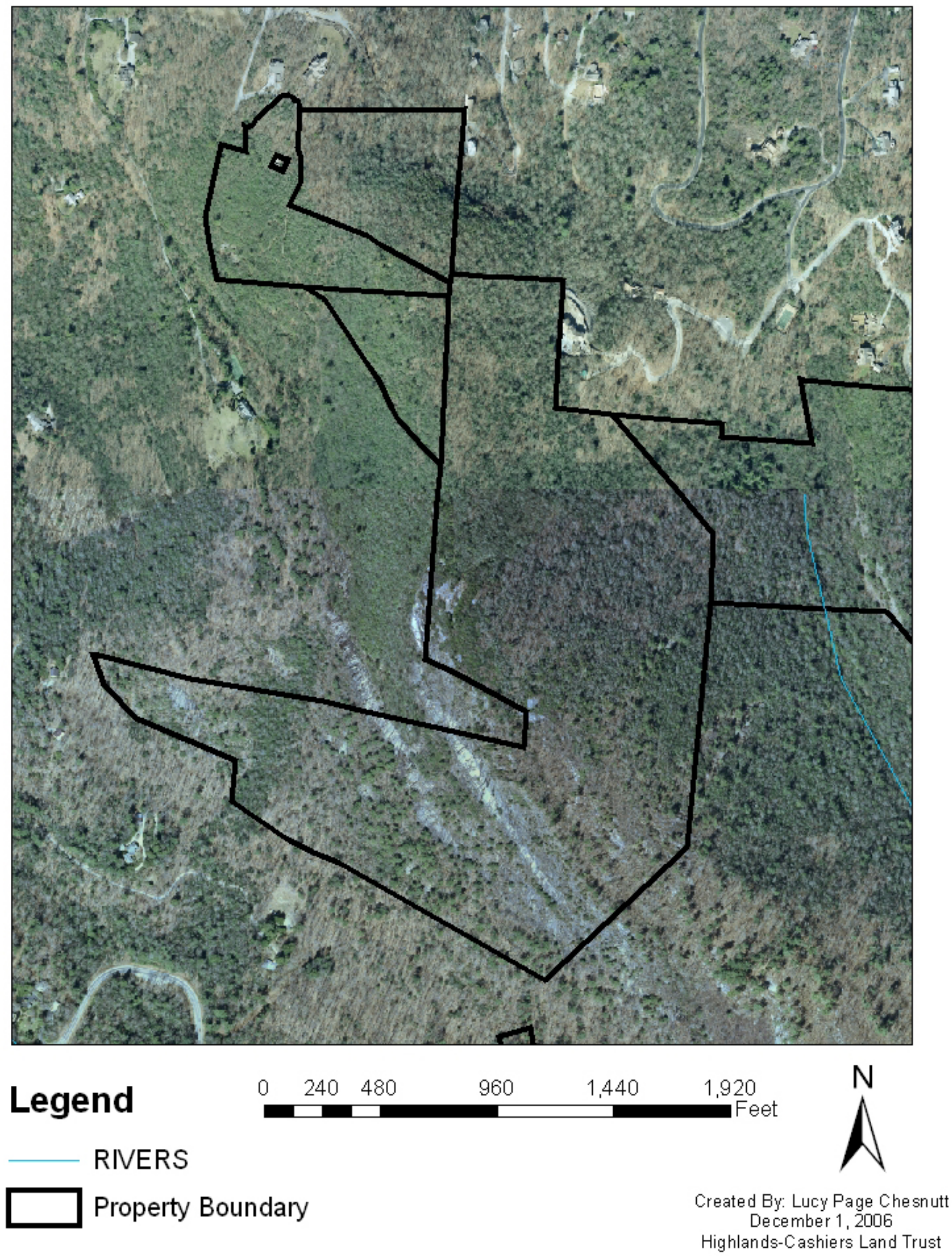
APPENDIX B

Satulah Summit Soils Map



APPENDIX C

Satulah Summit Aerial Photo



APPENDIX D

Photo Gallery

PHOTO 1: Satulah summit trailhead

PHOTO 2 (A & B): Shrubby evergreen coverage leading up to summit

PHOTO 3: Main rock outcrop on summit

PHOTO 4: Main rock outcrop on summit

PHOTO 5: HIA Rock House

PHOTO 6: USGS elevation marker

PHOTO 7: Entrance sign at summit

PHOTO 8: Sampling Plot #1 seepage areas

PHOTO 9: View of Black Rock and Whiteside Mountain from main outcrop

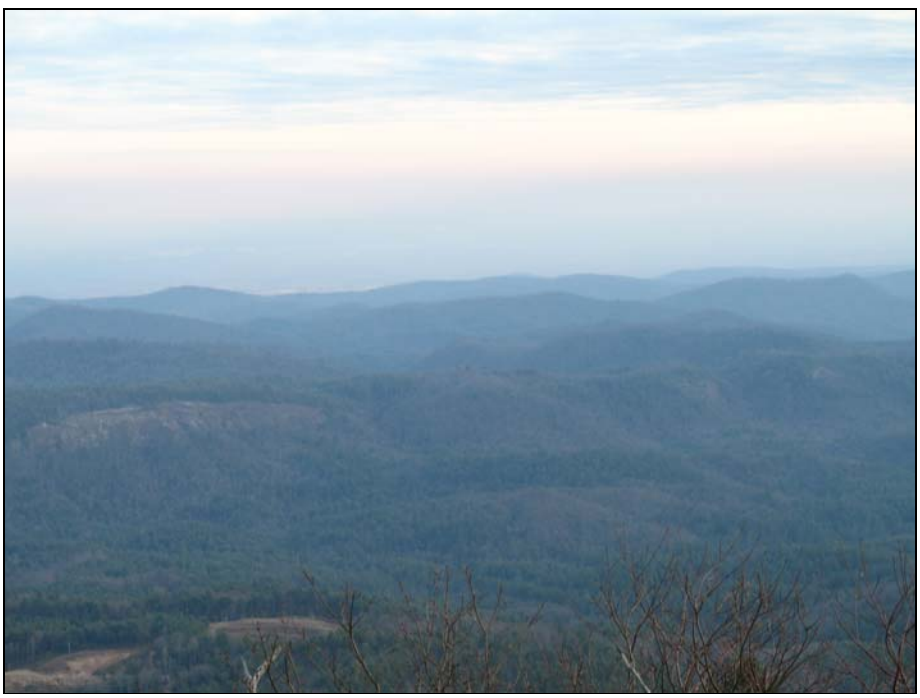


PHOTO 10: View towards South Carolina from summit

PHOTO 11: View of Rabun Bald in Georgia from summit

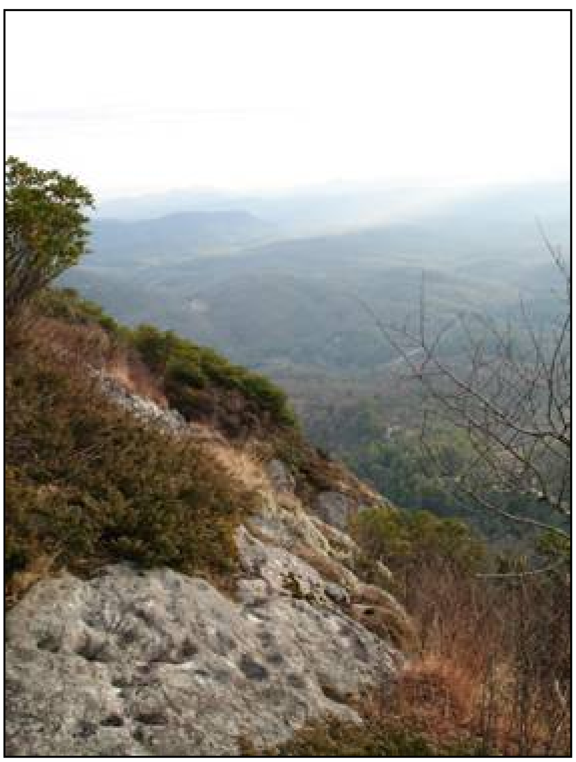


PHOTO 12: Southwest facing cliffs

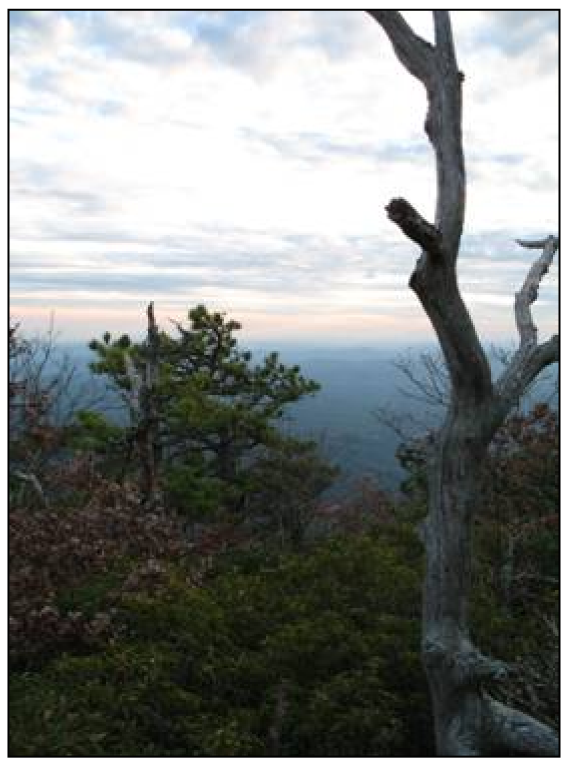


PHOTO 13: View from southwest outcrop

Appendix E

Sample Vegetation Species List

Acer rubrum
Agrostis perennans
Carax sp.
Cladina mitis
Cladina rangiferina
Cladonia cristatella
Cladonia fimbriata
Danthonia sp.
Galax urceolata
Hypericum buckleii
Juniperus communis var. *depressa*
Kalmia latifolia
Krigia Montana
Leiophyllum buxifolium
Moss A
Pinus strobus
Polytrichum juniperinum
Quercus alba
Rock/trampled
Selaginella tortipila
Solidago sp.
Umbillicaria sp.
Vaccinium corymbosum
Vaccinium pallidum
Agrostis perennans
Cladina mitis
Danthonia sp.
Dichanthelium acuminatum
Diervilla sessilifolia
Galax urceolata
Hypericum buckleii
Hypericum gentianoides

PANTHERTOWN BOG MAPPING PROJECT

DAVID A. EITELBERG

Abstract. Panthertown Valley has changed ownership many times throughout its history and has been logged, planted with Christmas trees and is now a part of the Nantahala National Forest. Panthertown contains a number of bogs that are under management consideration by the USFS. I conducted field research to find these bogs and map them with a GPS unit and assess their species composition. Three bogs were found through field work, with 30 additional potential bogs being found through the analysis of an infrared image with Feature Analyst® and ArcMap™ software. The information was then used to produce one map of the ground-truthed bogs and one map of the potential bogs.

Key words: bog; GIS; mapping; Nantahala National Forest; Panthertown.

INTRODUCTION

Panthertown Valley, which is part of the Nantahala National Forest and located near Glenville, NC, came under the supervision of the USDA Forest Service (USFS) in 1989 after being bought and sold many times. There has never been any evidence of permanent settlement in Panthertown Valley, although Native Americans had fished and hunted there for hundreds of years due to the rich and abundant biotic assemblages. The valley was originally called “town of painters,” “painters” being the local mountain word for panthers. This area is thought to have formerly been densely populated with panthers, though none exist in the area today. Around 1900, Panthertown was bought by R. G. Jennings, a wealthy businessman from Pittsburgh, PA. He used it as his personal fishing ground until the 1920’s when he sold it for logging. In the 1960’s the land was sold to Liberty Properties of N.C. which improved some of the old logging roads and build additional ones. They also planted white pine Christmas tree plantations, though these trees were never harvested. In 1987, Duke Power purchased the land and built a high voltage transmission line along the east side of the valley. Once construction was completed on the power line in 1989 they sold the land, with the exception of the right-of-way along the power lines, to the Nature Conservancy. The Nature Conservancy immediately handed it over to the USFS, which currently has jurisdiction over the valley and surrounding peaks under the Highlands Ranger District Office management. Today, Panthertown is a popular place for many forms of recreation including hiking, horseback riding, mountain biking and fishing. It serves as a black bear sanctuary as well as supporting many species of snake, deer and birds (Kornegay 2003).

Mountain bogs like the ones found in Panthertown, are rare, yet they are among the most important ecosystems around. N. A. Murdock (1994) states that “at least one-third of the threatened and endangered species of the United States live in wetlands. Southern Appalachian bogs and fens, in particular, support a wealth of rare and unique life forms, many of which are found in no other habitat type.” This is one of the reasons that the USFS is looking to improve and manage these wetland ecosystems. Species such as *Clemmys muhlenbergii* and the *Sarracenia rubra* are among some of the almost 90 endangered species that complete all or part of their life cycle in bogs (Murdock 1994). One of the reasons that bogs contain such a high number of endangered species is that many of them are relic species that are remnant of the last glaciation period. Pitillo (2004) concludes that "long-established southern Appalachian bogs have provided continuously suitable habitats for relict northern species since the peak of the glacial ice advance 18,000 years ago." These relic species are now becoming endangered due to, human development and agriculture to name a few reasons. Bogs are important and should be maintained and managed for a number of reasons such as "flood control, pollution filtration, nutrient recycling, sediment accretion, groundwater recharge and water supply, erosion control, and plant and wildlife preservation" (Hartig 1997).

The USFS is mapping and blazing the trails in Panthertown as part of their Panthertown Trail Project. They are interested in where the bogs are and where potential bogs may be because they may create more bogs or enlarge certain ones as part of the Trail Project. Panthertown contains a few rare mountain bogs that have never been formally mapped. In this paper, I will present the data that was collected and the figures and tables that were produced.

MATERIALS AND METHODS

Data Collection and Analysis

In order to map bogs in Panthertown, I was given the Big Ridge, NC USGS 7.5 minute topographical quadrangle as the map for the site. The map contained reliably-mapped river and valley locations and so I went to these areas and began searching for bogs. Since the main trail into the valley has a few trails leading into smaller valleys to the south, I walked up these smaller valleys along the trails and then backtracked by walking in the major stream or creek associated with each valley. If I observed typical bog flora, like sphagnum moss, I searched the banks to determine if there was a bog nearby or not. If there was a bog, I marked a waypoint with the USFS supplied GPS unit, a Garmin GPS 12, so that I could return later with a higher quality GPS unit and map an outline of the bog. I did this over all areas that I deemed "bog-prone" due to their proximity to the valley floor and water availability.

While in the field, I recorded my estimated percentages of sphagnum moss, herbaceous ground cover, shrubby vegetation, tree species and water cover for the bogs that I mapped (see Appendix B). After receiving the higher end Garmin GPS 76S GPS unit, I returned to the bogs and mapped to the best of my ability the outlines of the bogs. I walked with the Garmin in front of my body held out at about a half arms length to get a good signal.

Once data collection was completed, the data were then uploaded to ArcMap™ (Ornsby 2004) to produce a map of the bogs. An extension for ArcMap™, Feature Analyst® was then used to recognize the reflectance signature of bogs and identify other potential boggy areas on a 1-meter resolution infrared image, obtained from USGS orthoimagry. It was the Big Ridge 4, 3.75 minute quad image, which was taken in the winter of 1998. I then produced two maps, one of the ground-truthed bogs and the other of the potential bogs. Another extension for ArcMap™, Data East's XTools, was used to calculate area, perimeter, acres and hectares for both the known bogs and potential bogs data sets (Appendix B and D).

RESULTS AND DISCUSSION

Using ArcMap™, I constructed a map of bogs in Panthertown (Appendix A). A table (Appendix B) represents the known data about these bogs. The areas where bogs have the potential to exist, but have not been ground-truthed, are represented in Appendix C. A table representing the area, perimeter, acres and hectares of these potential bogs was produced (Appendix D).

Of the three bogs that were ground-truthed, only Panthertown Creek Bog #1 was largely clear of canopy species. This was also the only bog that was able to be completely mapped by walking the perimeter with a GPS unit. It appeared that this bog was maintained by a beaver dam along Panthertown Creek because there is a large clearing in which the bog is located, but only the area up-stream of the dam exhibits qualities specific to a bog. There are two more creeks supplying water to this bog; one is Boggy Creek and there is another unnamed stream.

Panthertown Creek Bog #2 is located along Panthertown Creek between Big Green Mountain and Goldspring Ridge. This bog was thoroughly vegetated with rhododendron and mountain laurel and thus was not able to be mapped via perimeter walking. It had only one identifiable source of water, which was Panthertown Creek.

Frolictown Creek Bog was the smallest of the bogs and, like Panthertown Creek Bog #2, it was heavily vegetated with shrubs and trees such that it was not possible to walk the perimeter with a GPS unit. This bog had a heavily braided stream going through it with very slow moving water.

In conclusion, three bogs were found, and thirty additional potential bog locations were identified. The large amount of tree cover in Panthertown Bog #2 may make it an ideal bog for restoration through tree and shrub removal. Panthertown Bog #1 has the potential to be expanded via the building of an artificial beaver dam along Panthertown Creek. Open space, in addition to the area already classified as a bog, exists at the east end of the bog and would likely be easily converted to a bog given an adequate supply of water. Frolictown Creek Bog is relatively small and will likely grow smaller as ecological succession continues. The locations identified as potentially containing bogs have undergone the very first stage of identification and will need to be ground-truthed and assessed prior to making management decisions regarding their areas.

ACKNOWLEDGEMENTS

I thank Duke Rankin, a USFS employee and my mentor throughout the process. He provided me with the background knowledge needed to properly identify bogs. He also helped me to obtain the proper equipment needed to go off-trail and map bogs. I also thank Gary Wein, who was an essential part of this project in that he provided the knowledge, training and software needed to produce the supplied figures and tables.

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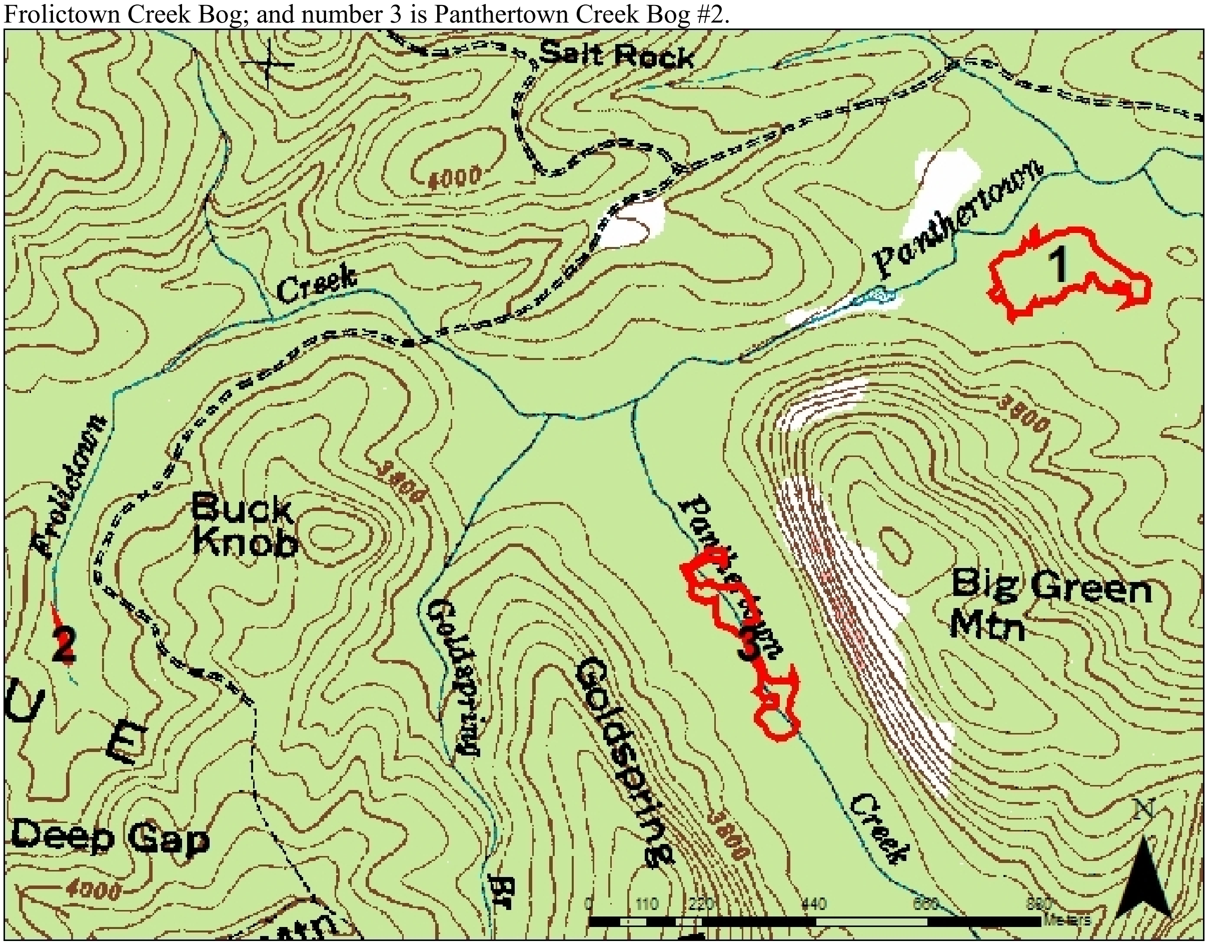
Murdock, N. A. 1994. Rare and endangered plants and animals of southern Appalachian wetlands . Water, Air & Soil Pollution **77**:385-405.

Ormsby, T., E. Napolean, R. Burke, C. Groessl, and L. Feaster. 2004. Getting to know ArcGIS desktop. ESRI Press: Redlands, CA.

Pittillo, J. D. 2004. Vegetation of three high elevation Southern Appalachian bogs and implications of their vegetational history. Water, Air & Soil Pollution **77**:333-348.

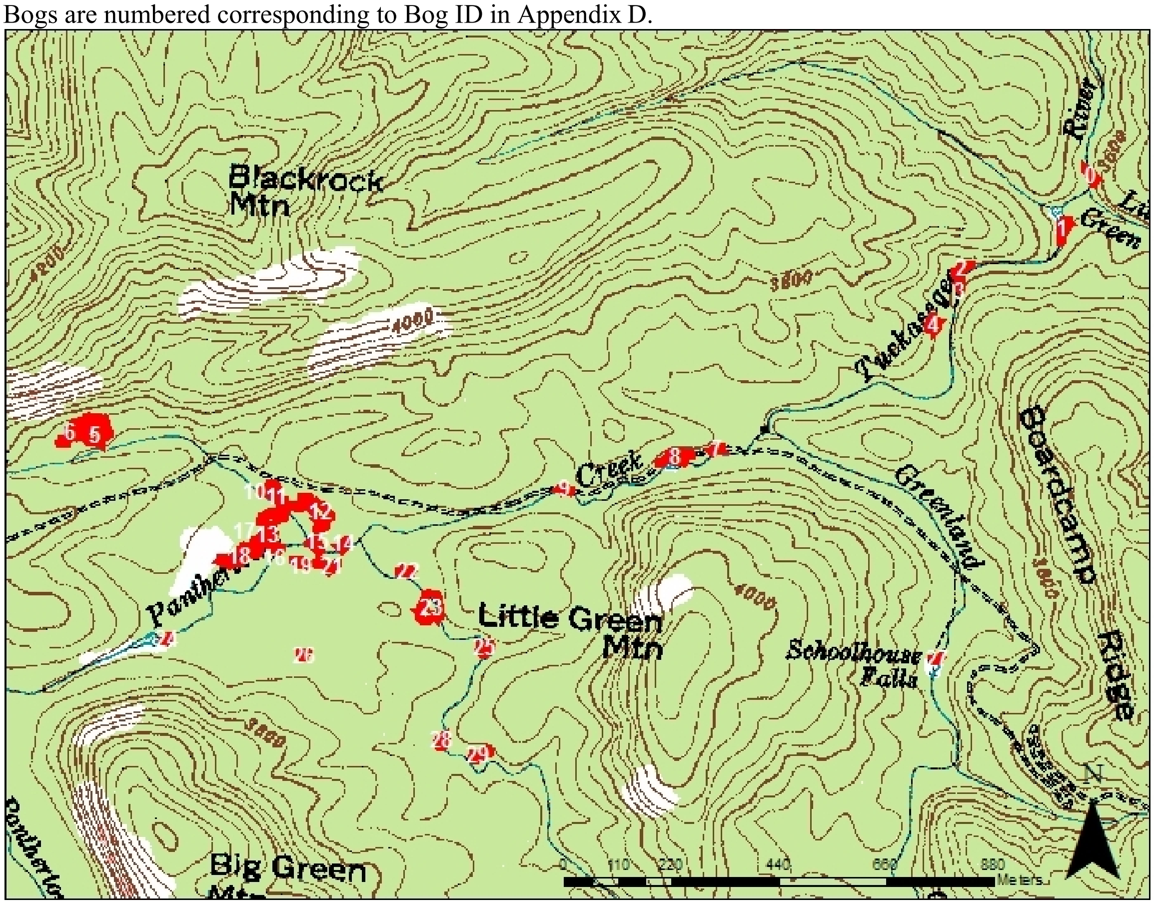
APPENDIX A: Map of known bogs in Panthertown. number 1 is Panthertown Creek Bog #1; number 2 is Frolictown Creek Bog; and number 3 is Panthertown Creek Bog #2.



APPENDIX B: Known Panthertown bog data

Info	Panthertown Creek Bog #1	Frolictown Creek Bog	Panthertown Creek Bog #2
Perimeter (m)	3360.429885	553.0112158	4214.459597
Area (m^2)	296094.1183	6742.623668	164760.2578
Acres	6.797385635	0.15478934	3.782375064
Hectares	2.750804371	0.062641024	1.530672882
NAD83 Easting	243192.7053	241151.0677	242460.4572
NAD83 Northing	164228.6744	163514.4619	163572.176
Percent Sphagnum	80	50	40
Percent Herbacious	80	40	50
Percent Shrub	20	70	80
Percent Tree	2	10	15
Percent Water	1	10	5

APPENDIX C: Potential bogs in Panthertown identified with Visual Learning Systems Inc. Feature Analyst® software extension for ESRI ArcMap™ and 1 meter pixel resolution infrared aerial photography. Bogs are numbered corresponding to Bog ID in Appendix D.



APPENDIX D: Potential Panthertown bog data

Bog ID	Perimeter (m)	Area (m^2)	Acres	Hectares
0	391.1963089	4512.769442	0.103598931	0.041925
1	486.9309273	7845.545205	0.180108935	0.0728875
2	419.9330669	3896.535571	0.089452148	0.0362
3	344.2477406	3604.564501	0.082749415	0.0334875
4	371.9440409	7178.182759	0.164788401	0.0666875
5	1500.188384	26834.42867	0.616033716	0.2493
6	851.2540588	11436.65482	0.262549468	0.10625
7	259.3127708	3335.46674	0.07657178	0.0309875
8	893.8993286	12097.28982	0.277715561	0.1123875
9	284.8231482	2160.855016	0.049606405	0.020075
10	319.0810097	3465.979154	0.079567933	0.0322
11	1581.918783	28615.85584	0.656929657	0.26585
12	1319.251916	27994.24002	0.642659321	0.260075
13	359.5544596	5320.062723	0.122131835	0.049425
14	271.2189666	2744.797156	0.063011872	0.0255
15	482.4904963	4049.921294	0.0929734	0.037625
16	342.7647762	4017.629563	0.092232084	0.037325
17	445.7125022	3570.927281	0.08197721	0.033175
18	881.8990194	15267.26144	0.350488095	0.1418375
19	333.172545	3500.961863	0.080371025	0.032525
20	191.086214	2104.344486	0.048309102	0.01955
21	312.0174266	2914.328745	0.066903782	0.027075
22	345.6808774	3371.794938	0.077405761	0.031325
23	1019.416471	29502.53296	0.677284962	0.2740875
24	213.8928381	2195.837725	0.050409498	0.0204
25	392.2567536	7357.13277	0.168896528	0.06835
26	252.0539099	2179.691859	0.05003884	0.02025
27	262.1645479	2810.726108	0.064525393	0.0261125
28	379.1760979	6381.653388	0.146502603	0.0592875
29	478.1797707	5114.202937	0.117405944	0.0475125

AN ANNOTATED BIBLIOGRAPHY OF CURRENT RESEARCH ON THE HEMLOCK WOOLLY ADELGID (*ADELGES TSUGAE*) AND ITS IMPACT ON EASTERN AND CAROLINA HEMLOCKS (*TSUGA CANADENSIS* AND *T. CAROLINIANA*)

KELLY M. HINES

Abstract. The hemlock woolly adelgid (HWA, *Adelges tsugae*) is an invasive pest that is threatening the health of eastern and Canadian hemlock trees (*Tsuga canadensis* and *T. caroliniana*) in eastern United States forests. The decline of hemlocks will cause major ecological impacts in hemlock forest ecosystems. This annotated bibliography summarizes recent studies about HWA and its impacts that can serve as a resource for non-profit organizations, students, and the general public.

Key words: Adelges tsugae; *annotated bibliography; hemlock decline; hemlock woolly adelgid*; *Imidacloprid; predator beetle;* Sasajiscymnus tsugae.

INTRODUCTION

The hemlock woolly adelgid (HWA) is an aphid-like insect introduced to the United States in 1924 from Asia. First found in the northeastern U.S., the adelgid has found its way into most forests along the eastern seaboard. White cottony sacs at the base of hemlock needles are indicators of adelgid infestations. This invasive species uses its mouthparts to suck sap from the base of hemlock needles; their saliva is believed to contain a toxic chemical that prevents new needle growth (McClure et al. 2001). The hemlock needles drop permanently, defoliating the tree and thus preventing or stunting tree growth. Tree death can occur within several years. Death of hemlocks will have major ecological impacts on many components of forest ecosystems.

The eastern hemlock (*Tsuga canadensis*) and the Carolina hemlock (*T. caroliniana*) have been severely impacted by HWA. These tree species play a large role in forest ecosystems; they provide unique and diverse habitats for many different plant and animal species. The eastern Hemlock is more of a generalist species ranging from southern Ontario to Georgia and westward to Minnesota. The Carolina hemlock's range is limited to the Blue Ridge Mountains of the Southern Appalachian Mountains and is usually found in ravines or on rocky outcrops. These two hemlocks like moist, acidic soils with good drainage (Little 1980).

Currently there are several methods that are utilized to combat HWA. Imidacloprid is the best known chemical control. The chemical is commercially sold by Bayer Corporation as Merit® and is the same chemical used in flea medicines for cats and dogs. It is a systemic, chloro-nicotinyl insecticide; it moves through plants from the place where it was applied and kills insects when they feed (Cox 2001). Application methods for adelgid control include soil injections, stem injections, and foliar sprays on hemlock trees. A biological control approach uses predator beetles, such as Asian Ladybird beetles (*Sasajiscymnus tsugae*, Coccinellidae), which prey on the adelgid (Skinner et al. 2003). Initially imported from Japan in 1992, the Ladybird beetle was released at the Connecticut Agricultural Research Station in 1995 for the first biological control study on the adelgid. Millions of these beetles have been released in infested sites from Georgia to Maine (McClure et al. 2001).

Other adelgid controls include an organic approach that utilizes compost tea material combined with a fungal component. This method is not widely known and there are no scientific studies published that prove or disprove its effectiveness. Additional to the *S. tsugae*, other predator beetles that eat the adelgid are *Laricobius nigrinus*: Derodontidae and *Harmonia axyridis*: Coccinellidae. These are not as commonly used, but are considered predators of HWA as well (Flowers et al. 2006).

Success of the control measures depends on various environmental and climatic factors. For example, if heavy rains are expected, then it is advised to withhold soil and foliar Imidacloprid treatments (Cowles et al. 2005). The Ladybird beetle has to be released in sites where there are numerous infested hemlock trees for them to populate. Success of the biological control depends on previous infestation of adelgids; the beetle feeds on the pest and if there are none, beetle populations die (McClure et al. 2001). At this time, there is no consensus as to how to treat for the adelgid with complete success.

The purpose of this compilation of summaries is to provide arborists, landscapers, and homeowners with scientific information about the current and future problems that our forests are experiencing. This annotated bibliography is a brief overview of various studies that deal with the HWA and its devastating effects on hemlock trees of the eastern United States.

MATERIALS AND METHODS

The papers summarized in the annotated bibliography were identified using the ISI Biological Abstracts online database performed by selecting papers published between 1990 and 2006. Keywords used as search terms were: "*Adelges tsugae,*" "hemlock woolly adelgid," "biology of hemlock woolly adelgid," "hemlock decline," "Imidacloprid," "survival of hemlock woolly adelgid," "*Sasajiscymnus tsugae*" and "Ladybird predator beetle." Papers were selected according to their relevance to the thematic subheadings within the annotated bibliography and abstracts of relevant papers were summarized.

ANNOTATED BIBLIOGRAPHY

Adelgid Biology

McClure, M. S. 1991. Density-dependent feedback and population cycles in *Adelges tsugae* (Homoptera: Adelgidae) on *Tsuga canadensis*. Environmental Entomology **20**:258-264.

In one experimental hemlock plantation and in four hemlock stands, they found that the HWA reduced the survival of hemlocks. The presence of adelgids inhibited new growth on hemlocks the following year. Over a four year period, adelgid populations were found to have rapid growth and peak densities during the initial year of adelgid infestation in hemlocks. Adelgid populations declined rapidly during the second year when little growth was produced. During the third year the HWA populations increased with stunted hemlock growth and crashed again in the fourth year. This study suggests that adelgids prefer to feed on new hemlock growth and once a hemlock starts to deteriorate, they move on to other trees.

Skinner, M., B. L. Parker, S. Gouli, and T. Ashikaga. 2003. Regional responses of hemlock woolly adelgid (Homoptera: Adelgidae) to low temperatures. Environmental Entomology **32**:523-528.

The authors, researchers at the University of Vermont, used field and control populations of the HWA (*Adelges tsugae*) to test for their resistance to cold. The study evaluated the effect of low temperatures on *A. tsugae* collected from different plant hardiness zones. Along a geological gradient, differential cold resistance among adelgid populations suggest that the adelgid is able to develop greater tolerances to cold. The tested field populations were taken from northern, central, and southern sites with one site in Massachusetts and two in Connecticut. In the control populations in the lab, the adelgid showed 100% mortality at -25°C while approximately 10% of adelgids from the field sites survived exposure to that temperature. The study concludes that cold temperatures during the winter are likely to reduce field populations, mostly in the northern range of this insect. At lower latitudes warmer temperatures may allow the adelgid to have higher survival rates during the colder months.

Treatment Strategies

Costa, S. D., M. Skinner, S. Gouli, M. Brownbridge, V. Gouli, W. Reid, and B. L. Parker. 2004. Development of insect-killing fungi for management of hemlock woolly adelgid. *In* Gottschalk, Kurt, W., editors. *Proceedings, XV U.S. Department of Agriculture interagency research forum on gypsy moth and other invasive species* Northeastern Agricultural Research Station: 18-19.

In a laboratory setting, fungal isolates that showed activity against the HWA were evaluated on forest trails during the spring and fall of 2001-2003. The most potent fungal isolates were selected to determine and find the best timing and concentration for fungal applications. The study concluded that fall applications were the most favorable for targeting HWA and resulted in obvious reductions in HWA survival. The HWA populations reduced by fungi and fungal isolate applications demonstrate the promise of fungi as a component in biological management of HWA. Future research is needed to discern dosages, optimal time for applications, and long-term effects for adelgid reductions in hemlocks.

Cowles, R. S., M. E. Montgomery, and C. S. S.-J. Cheah. 2006. Activity and residues of Imidacloprid applied to soil and tree trunks to control hemlock woolly adelgid (Hemiptera: Adeldidae) in forests. Journal of Economic Entomology **99**:1258-1267.

Through the Department of Entomology at the Connecticut Agricultural Experiment Station, the authors tested three Imidacloprid application methods. Applications were made in the fall and the following spring, and the adelgid populations were assessed in the fall of two successive years after treatment. The study concluded that the adelgid populations were dramatically reduced on the hemlocks treated with soil applications, for up to two years; on hemlocks receiving trunk injections, there were no differences to the populations on untreated hemlocks. Tree assessment occurred in November of 2003 which could vary the results if assessment were made in another year as cold temperatures could have affected adelgid populations.

Cowles, R. S., C. S.-J. Cheah, and M. E. Montgomery. 2005. Comparing systemic Imidacloprid application methods for controlling hemlock woolly adelgid. Connecticut Agricultural Experiment Station 169-172.

Among the many methods used to apply Imidacloprid to hemlocks suffering from adelgid attacks, this study concluded that soil applications resulted in 80% mortality of adelgids, and trunk injections resulted in 64% mortality. The soil injections had long-term "moderate" concentrations of Imidacloprid in the sap which may be responsible for the effective suppression of adelgids. The trunk injections have to be timed so the Imidacloprid is carried through the sap during feeding seasons of the adelgid. They also note that chemical control of the adelgid should be a "stop-gap" measure until biological control (Coccinellidae) is established.

Flowers, R. W., S. M. Salom, and L. T. Kok. 2006. Competitive interactions among two specialist predators and a generalist predator of hemlock woolly adelgid, *Adelges tsugae* (Hemiptera: Adelgidae) in south-western Virginia. Agricultural and Forest Entomology **8**:253-262.

Two specialist predators, *Laricobius nigrinus* and *Sasajiscymnus (Pseudoscymnus) tsugae*, and a generalist predator, *Harmonia axyridis*, of the HWA, *Adelges tsugae*, were evaluated to see if competition among them decreased their effectiveness in killing the HWA. The authors found that predator survival was not affected by the addition of other predators. Additionally, their results found that the predator beetles' feeding of the adelgid increased when together suggesting that their interactions do not interfere with adelgid control. They also suggest that it would be beneficial to group predator beetles together when released for adelgid control.

Ecological Impacts

Brannon, M. P., and S. R. Rogers. 2005. Effects of canopy thinning by hemlock woolly adelgids on the local abundance of terrestrial salamanders. Journal of the North Carolina Academy of Science **121**:151-156.

This study conducted on the Highlands Plateau of western North Carolina tested for the changing effects in riparian zones where the HWA was killing the hemlocks. Since canopy openings allow more sunlight to penetrate to the forest floor, there were increased temperatures and drying of leaf litter where there was hemlock canopy loss. If leaf litter becomes too dry, salamanders cannot survive, thus resulting in decreased populations. Brannon and Rogers found that although the hemlocks were dying, the salamander populations were not being reduced. Other canopy tree species have grown in the hemlock canopy gaps, keeping the leaf litter and forest floor moist, sustaining adequate conditions for salamanders to thrive.

Eschtruth, A. K., N. L. Cleavitt, J. J. Battles, R. A. Evans, and T. J. Fahey. 2006. Vegetation dynamics in declining eastern hemlock stands: 9 years of forest response to hemlock woolly adelgid infestation. Canadian Journal of Forest Research **36**:1435-1450.

In the Delaware Water Gap National Recreation Area, this was the first study conducted using a pre-adelgid infestation hemlock stand. From 1994 to 2003 annual monitoring to determine hemlock decline in correlation with HWA infestation was assessed by changes in light variability and vegetation type. In 1994 the average percent total transmitted light was 5.0% and in 2003 was almost doubled at 11.7%. The study found that overall species richness increased with 59 species gained and 19 lost. An interesting factor in this study was that the hemlock stand was free of invasive species in 1994 and in 2003 found invasive species in 35% of the hemlock stand. This study concluded that the decline of the hemlocks in response to adelgid infestation allowed for vegetation changes and invasive species to establish themselves.

Orwig, D. A., and D. R. Foster. 1998. Forest response to the introduced hemlock woolly adelgid in southern New England, USA. Journal of the Torrey Botanical Society **125**:60-73.

The authors, working at Harvard University, assessed the imminent damage to forests with the increased mortality of eastern hemlocks (*Tsuga canadensis*). *T. canadensis* damage varied broadly across the study area ranging from near zero to greater than 95% mortality. The results of this study show that in dozens of stands throughout the state of Connecticut, forests are being severely impacted by the adelgid. The rate and intensity of infestation in not attributable to any site factor or stand characteristic; varying degrees of adelgid infestation at the stand level resulted in high *T. canadensis* mortality rates and dramatic changes in microenvironment characteristics. This study also concludes that changes in cover type go from domination by *T. canadensis* to *Betula* (birch), *Quercus* (oak), and *Acer* (maple) species.

Ross, R., R. M. Bennett, C. D. Snyder, J. A. Young, D. R. Smith, and D. P. Lemarie. 2003. Influence of eastern hemlock (*Tsuga canadensis* L.) on fish community structure and function in headwater streams of the Delaware River basin. Ecology of Freshwater Fish **12**:60–65.

The authors assessed the ecological impacts on aquatic biodiversity in response to the death of hemlocks. They collected over 1400 fish of 15 species from 7 families. Streams within hemlock stands harbored only one to four species. They found that brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*) were two to three times more prevalent in streams within hemlock stands than in hardwood stands. Their results also show that functional diversity of fishes in hemlock and second-order streams was numerically greater than that of hardwood and first-order streams. The data suggests that the infestation of the adelgid in hemlock stands threatens fish biodiversity in the aquatic environment.

Small, M., C. J. Small, and G. D. Dreyer. 2005. Changes in a hemlock-dominated forest following woolly adelgid infestation in southern New England. Journal of the Torrey Botanical Society **132**:458-470.

The first appearance of HWA in the Connecticut College Arboretum in 1987 spurred a study lasting from 1987 to 2002. Basal area of *T. canadensis* documented before, during, and after adelgid infestation, decreased by 70% from 1982 to 2002. Forest communities responded to hemlock decline by filling canopy gaps with species such as oaks (*Quercus*) which increased from 28% basal canopy area in 1982 to 41% in 2002. Trends associated with the decline of hemlocks consist of a shift in canopy dominance and other vegetative changes. The study concludes that there is considerable understory development including increased herbaceous species and invasive species abundance.

Pontius, J. A., R. A. Hallett, and J. C. Jenkins. 2006. Foliar chemistry linked to infestation and susceptibility to hemlock woolly adelgid (Homoptera: Adelgidae). Environmental Entomology **35**:112-120.

This study examines the role that foliar chemistry of hemlocks may play in the success of HWA. In more resistant hemlock species, higher concentrations of phosphorous and lower concentrations of nitrogen were found relative to more susceptible hemlocks. Higher concentrations of calcium, potassium, nitrogen, and phosphorous were strongly associated with higher HWA densities. The study concluded that higher concentrations of nitrogen and potassium enhance hemlock susceptibility, therefore increasing HWA populations. Higher concentrations of calcium and phosphorus may discourage overwhelmingly dense populations of HWA to occur. The results indicate that relative amounts of these elements in commercial fertilizers can play a role in HWA infestations in hemlocks.

Raupp, M. J., R. E. Webb, A. Szczepaniec, D. Booth, and R. Ahern. 2004. Incidence, abundance, and severity of mites on hemlocks following applications of Imidacloprid. Journal of Arboriculture **30**:108-113.

The University of Maryland and the Beltsville Agricultural Research Center collaborated on a study that found that hemlocks treated with Imidacloprid are more likely to be infested with spruce spider mites and hemlock rust mites. The frequency with which rust mites infested treated and untreated hemlocks were 79% and 80%, respectively. The study revealed a greater level of mite injury to hemlocks treated with Imidacloprid. This goes to show that the pesticide Imidacloprid weakens the health of hemlocks allowing for infestations of other pests to occur.

Stradler, B., T. Muller, and D. Orwig. 2006. The ecology of energy and nutrient fluxes in hemlock forests invaded by hemlock woolly adelgid. Ecology **87**:1792-1804.

The effects of HWA infestation on the vertical energy and nutrient fluxes from the canopy to the forest floor were analyzed in south-central Massachusetts. The authors found that adelgids caused higher dissolved organic carbon (+24.6%), dissolved organic nitrogen (+28.5%), and potassium (+39.3%) fluxes in throughfall collected from infested trees. Additionally, lower inorganic nitrogen (-39.8%) fluxes were recorded from throughfall in adjacent litter solutions collected beneath infested trees compared to uninfested trees. They found that needle litter from unifestated trees had lower concentrations of nitrogen than those that were infested. The study concludes that HWA-affected throughfall leads to differences in nitrogen export from the litter layer. They also conclude that nitrogen fluxes decrease initially, but as infestation continues nitrogen fluxes rise with hemlock decline.

Webb, R. E., J. R. Frank, and M. J. Raupp. 2003. Eastern hemlock recovery from hemlock woolly adelgid damage following Imidacloprid therapy. Journal of Arboriculture **29**:298-302.

The objective of the authors was to determine if the initial health conditions of the hemlocks affected their responses to Imidacloprid treatment. Healthy sap flow is important in transporting Imidacloprid from the soil throughout the trees, and severe damage by the adelgid hindered the tree's ability to transport the pesticide. The study found that in all of the Imidacloprid treated hemlocks, the abundance of adelgids largely decreased. Also, the trees in the healthy category with the highest levels of adelgids experienced the greatest reduction in adelgid abundance. The authors stressed two conclusions: first, that after adelgid populations are suppressed, new growth occurs on the hemlocks; and second, a single administration of Imidacloprid affords long-lasting control for suppressing the adelgids. They suggest that when using Imidacloprid, the healthier a tree is pre-treatment, the better the tree will do post-treatment.

ACKNOWLEDGEMENTS

I would like to thank Dr. James T. Costa and Dr. Anya Hinkle of the Highlands Biological Station and the Jackson-Macon Conservation Alliance of Highlands, NC for their continued support and invaluable input.

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MAPPING AND ANALYZING UNDOCUMENTED STREAMS IN A MUNICIPAL WATERSHED

GRANT KIMMEL AND BYNUM HOEKSTRA

Abstract. In 2005, the Town Council of Highlands, NC, created an extraterritorial jurisdiction zone (ETJ). The purpose of an ETJ is to reduce the costs, both economic and ecological, from unregulated development in the peripheral areas of the Highlands watershed. Within the ETJ, one significant part of the Highlands watershed, Big Creek, contains tributary streams that were previously unmapped for the Town of Highlands Zoning Department. In this study, these streams were mapped using GPS for the Zoning Department, and analyzed for stream health for the Upper Cullasaja Watershed Association (UCWA) with the Bank Erosion Hazard Index (BEHI) and Habitat Assessment Index. The resulting map will enable the Highlands Zoning Department to enforce a 25-foot buffer around 10 newly-mapped perennial streams within the Big Creek watershed. The most ecologically damaged sites along the Big Creek watershed were noted to UCWA for stream restoration projects. The site of greatest need of stream restoration is Tributary #1. This tributary receives a large volume of storm water runoff from a gravel road and also exhibits severe mass wasting along its banks; we hypothesize that this tributary contributes the most significant amounts of sediment to Big Creek.

Key words: Extraterritorial jurisdiction; GPS mapping; stream health; stream buffer; watershed management.

INTRODUCTION

Management of watersheds is of great importance and concern for municipalities, especially for those whose realms of control contain the headwaters of streams and rivers. Pollution of watersheds has always been a major management priority because it is important for a municipality to supply residents with clean water. Equally important is whether or not to permit polluted water to flow to its downstream neighbors. For a community located in the mountains, such as Highlands, North Carolina, the greatest watershed pollution concern comes from the deposition of soil and sediment into streams as a result of poorly managed development in riparian zones.

Deposition of sediment into a creek or stream can be devastating not only to the biodiversity of the stream (Bond and Downes 2003), but also to the municipality that uses that stream for its water supply. For example, the Town of Highlands will have to dredge the excess sediment from the intake area by its water treatment facility because excess sedimentation has occurred along Big Creek (Wisdom 2006). The excess sediment deposited into the creek has caused a water pump to stop working after only 5 years of a 20-year projected operating life (L. Gantenbein, Town of Highlands Town Planner/Zoning Administrator, pers. comm.). Thus, protection of watersheds is not only important to town planners, but also to an organization such as the Upper Cullasaja

Watershed Association (UCWA) whose mission is to protect the trophic structure of riparian ecosystems.

Studies have shown that the creation of buffers, defined as vegetated areas with minimal disturbance, around riparian zones greatly improves stream health of the riparian ecosystem (Weller et al. 1998) by decreasing the influx of sediment. The town of Highlands enforces a 25-foot buffer around creeks and streams for any new development (Town of Highlands 2001).

For a municipality that desires to control watershed pollution outside of its city limits, an expedient zoning tactic is to claim an extraterritorial jurisdiction (ETJ) zone around the entire watershed that contributes to its water supply. Within an ETJ, a municipality enforces its zoning ordinances, often to curb development outside of its town limits. Regarding watershed protection, an ETJ can be used to prevent development that would disrupt or pollute a riparian ecosystem by the enforcement of a buffer.

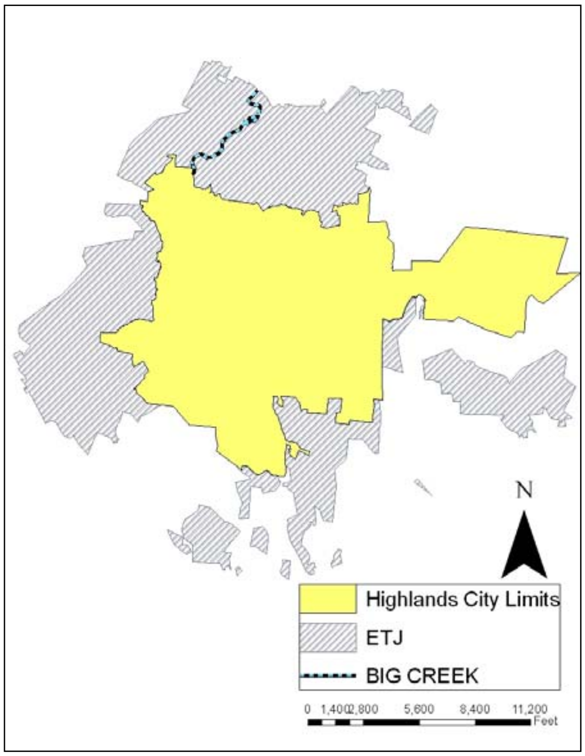

FIG. 1. Map showing Highlands city limits and the area now in its control in the extraterritorial jurisdiction zone.

In November 2005 (Kucharski 2006), the town council of Highlands voted in favor of creating an ETJ that ideally would, among other things, prevent further sediment from being deposited into the Big Creek Watershed. However, because Big Creek was not formerly within the town limits of Highlands its watershed was not mapped. It was known that there were tributary streams within the Big Creek watershed portion of the ETJ, but none were on record in the Highlands Zoning Map (Fig. 1).

Having these previously unrecorded tributaries mapped and analyzed for their health serves the agendas of both the Highlands Zoning Department and UCWA. With the tributaries on record, the Highlands Zoning Department can enforce the 25-foot buffer around the entire Big Creek Watershed, helping to assure that its water pumps will last their projected operating lifetimes and its reservoirs will not become filled in. UCWA, which serves as a watchdog for stream health, will use the information provided about these formerly unmapped tributaries to hold the town of Highlands accountable for any stream restoration projects that it may have to undertake in the future.

In this report we present information on the tributaries of Big Creek that will be used by both UCWA and the Highlands Zoning Department. We created a map of the tributaries which we surveyed along an approximately 1-mile reach of Big Creek within the Highlands ETJ. We also created a map to show the impact of a 25-foot buffer encompassing these newly documented streams. Stream health analyses were only reported where severe health impacts such as stream channelization, bank erosion, and sediment deposition were taking place, and these health assessments were compared to a control site on Big Creek that showed no adverse health effects.

MATERIALS AND METHODS

Data Collection

Before we could map Big Creek and identify points of interest, we were provided with necessary equipment and trained in data collection techniques. The Town of Highlands provided us with a Trimble® Model XM Global Positioning System (GPS) receiver, training on how to use the GPS receiver, Town of Highlands code enforcement badges, a camera, waders, helmets, and wading shoes. UCWA provided us with clip boards, training with a watershed specialist, bank erosion hazard index (BEHI) forms (Appendix A and B), and habitat assessment forms (Appendix C).

We used the Trimble® GPS receiver which enabled us to make waypoints and polylines on the map of the Big Creek watershed (Fig. 2), indicating where the unmapped perennial tributaries were located; the polylines were used to indicate the perennial tributaries, and the waypoints would indicate a location where a habitat assessment and BEHI form was used, point source sediment deposition was occurring, or point source pollution was located.

The identification of a perennial tributary from an intermittent or ephemeral tributary was very important to our mapping procedures. Perennial streams have macro-invertebrates that require a long time period to metamorphose from larvae to adult form which intermittent or ephemeral tributaries cannot provide. We looked at the characteristics of the streams in order to determine why bank erosion or sediment deposition occurred; we wanted to see if sediment deposition was caused from impervious surface runoff or from bank erosion.

The BEHI and habitat assessment were used for areas of concern that we felt needed to be addressed to UCWA and The Town of Highlands Planning/Zoning Administrator. The BEHI "provides an indication of bank stability utilizing indicators including bank height ratio, rooting depth of vegetation, root density, bank angle and surface protection" (Rosgen 1993). The BEHI also allows the user to assign values to each of the five categories which are added together to get a total index value (Foster 2004). The total index values allow the user to compare the total BEHI values to other studied sites but do not allow the user to determine the main contributor to the index value. The habitat assessment was done using a form developed by the North Carolina Division of Water Quality (NCDWQ 2003; Appendix C). The habitat assessment allows the user to describe the physical characteristics of a stream, (i.e. width, depth, bank angle, channel modification), while also giving numerical values to other aspects of stream quality, (i.e. channel modification, instream habitat, bottom substrate, pool variety, riffle habitats, bank stability and vegetation, light penetration, and riparian zone width).

After we gathered our waypoints, polylines, BEHI, and habitat assessments, we entered the waypoints and polylines from the GPS receiver into an ArcGIS® 9.1 geodatabase (Ormsby et al. 2004). ArcGIS® 9.1 is a software program designed to enable the production of digital maps. After inputting the waypoints and polylines into

ArcGIS®, a map of Big Creek with its perennial tributaries was created so that the Town of Highlands' Planning/Zoning Administrator, Larry Gantenbein, can enforce ETJ regulations on the newly mapped tributaries.

Mapping

The first step in mapping Big Creek was to identify all the possible perennial tributaries flowing into the creek. We started at the dam downstream from Randall Lake, adjacent to the water treatment plant, and moved upstream. One of us walked along the left side of the creek while the other walked on the right side to visually identify tributaries flowing into the creek. Once a tributary was identified, we tied flagging tape on nearby vegetation and also made a waypoint in the GPS receiver to mark where we found the possible perennial tributary.

After marking all the possible perennial tributaries on Big Creek, we started at the dam and worked our way upstream. When we reached the first tributary, we created a polyline at the mouth of the tributary. While walking along the tributary we were looking for signs that the stream was perennial; macro-invertebrates under cobblestones and boulders were key signs. We also looked for points of interest concerning bank erosion, abnormal sediment deposition, and point source pollution. When points of interest were found, we photographically documented the site and referenced it to a waypoint to supplement the BEHI and habitat assessment forms. Sources of sediment deposition concerning construction sites and point source pollution sites were immediately reported to Larry Gantenbein for enforcement of city regulations concerning the ETJ and watershed regulations.

The information collected in the Trimble® was implemented with preexisting Big Creek data in Arc GIS® 9.1 and a final map was created. The final map will be used by The Town of Highlands Planning/Zoning Administrator and UCWA to enforce ETJ regulations and to regulate future construction sites along the Big Creek watershed.

RESULTS

In our assessment of the Big Creek watershed we found 10 tributaries between Randall Lake and Lake Sequoyah as shown in Fig. 2.

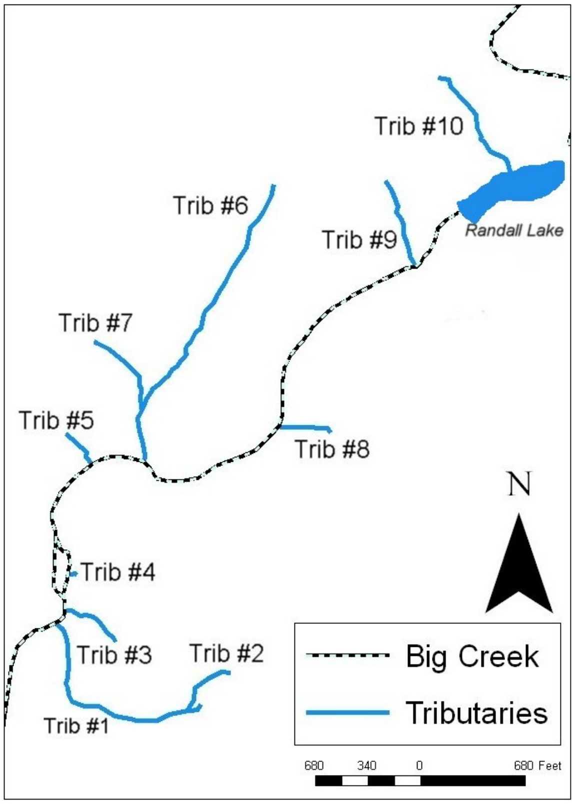

FIG. 2. Reach of Big Creek examined for unmapped tributaries within the Town of Highlands extraterritorial jurisdiction zone.

Of these tributaries, four were deemed to be of sufficient concern to perform health assessments. These tributaries (#1, #5, #6, #9, and #10) were chosen for health assessments because of their exhibiting stream bank erosion, severe sediment deposition, or human-induced effects that reduced stream habitat heterogeneity. The results of the BEHI and Habitat Assessment analyses are shown in Tables 1-3.

These tables show that by both health analysis matrices, Tributary #3 is the least impacted development or pollution. Tributaries #9 and #1 were both the most impacted by development according to the BEHI and Habitat Assessment scores. These scores have concordance with our observations of these tributaries. Tributary #1 has experienced mass wasting of one of its banks, and is affected by a storm water drain that channels sediment into it. Tributary #9 is affected in that one of its banks is completely unvegetated because of a house built virtually on top of the tributary, and is also piped into a corrugated steel pipe.

Tributary #	Channel Modification	In-stream Habitat	Bottom Substrate	Pool Variety	Riffle Habitats
1	5	10	4	4	16
3	5	20	15	10	16
5	4	20	12	10	10
6	4	20	8	10	14
9	4	10	3	10	16
10	5	11	3	10	7

TABLE 1. Part 1 of Habitat Assessment scores of Tributaries #1, #5, #6, #9, and #10. Higher scores indicate better stream health.

Tributary #	Bank Stability (Left)	Bank Stability (Right)	Light Penetration	Riparian Zone Width (Left)	Riparian Zone Width (Right)	Total Score
1	7	5	7	5	1	64
3	7	7	10	5	5	100
5	5	0	7	5	3	76
6	3	3	7	5	3	77
9	5	0	7	4	3	62
10	10	8	8	5	3	70

TABLE 2. Part 2 of Habitat Assessment scores of Tributaries #1, #5, #6, #9, and #10. Higher scores indicate better stream health.

Tributary #	Bank Height Ratio (ft/ft)	Root Depth Ratio (%)	Root Density (%)	Bank Angle (degrees)	Surface Protection (%)	Total Index
1	8	4	5	3	5	35
3	3	2	2	3	2	12
5	2	7	7	8	6	30
6	1	6	2	8	2	19
9	10	7	5	3	5	40
10	3	3	3	3	6	28

TABLE 3. Bank Erosion Hazard Index (BEHI) scores for Tributaries #1, #3, #5, #6, #9, and #10. Lower scores indicate better stream health.

When a 25-foot buffer is created to overlay all of the newly mapped tributaries, the resulting map shows the effect that these streams will have on property owners in the Big Creek watershed (Figs. 3-6). Our results and observations would indicate that the majority of the sediment that is entering Big Creek is coming from natural in-stream processes and from Tributary #1 (Figs. 7 and 8).

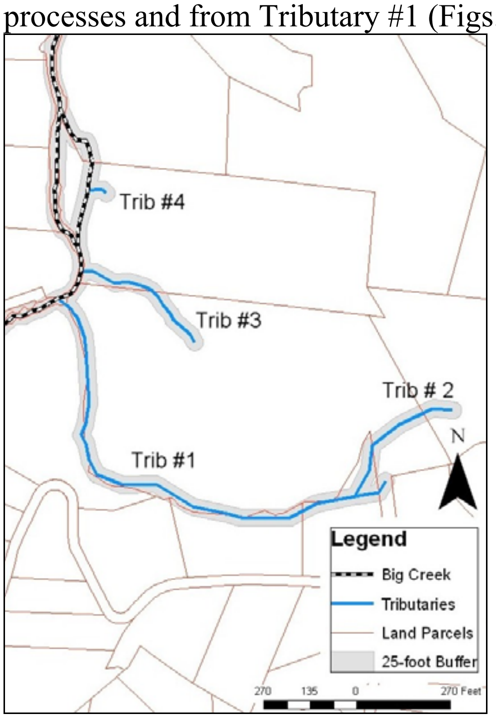

FIG. 3. Tributaries #1-4 at the southernmost reach of Big Creek, with a 25-foot buffer.

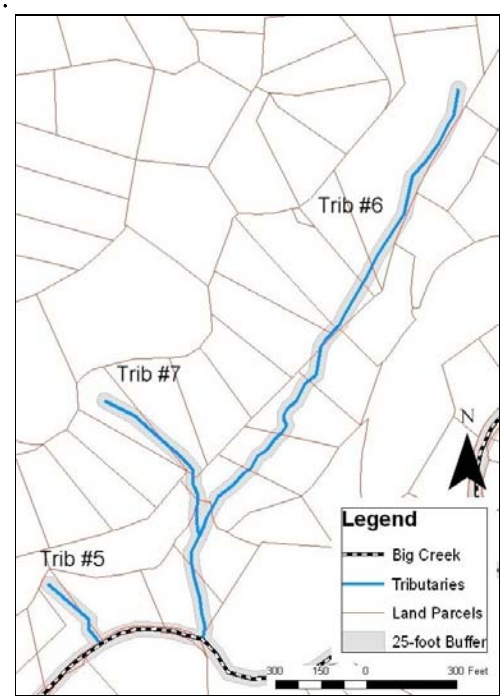

FIG. 4. Tributaries #5-7 in the middle reach of Big Creek, with a 25-foot buffer.

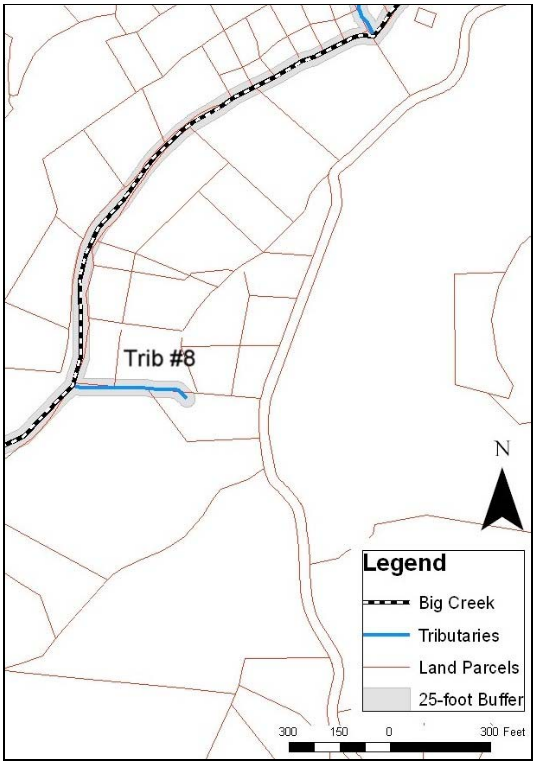

FIG. 5. Tributary #8 toward the upper reach of Big Creek, with a 25-foot buffer.

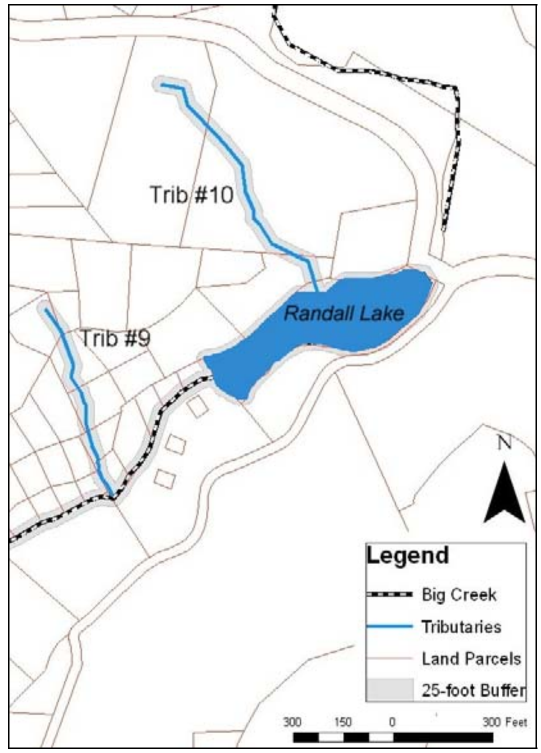

FIG. 6. Tributaries #9-10 at the northernmost reach of Big Creek by Randall Lake, with a 25-foot buffer.


FIG. 7. View from the confluence of Tributary #1 and Big Creek showing the sediment and gravel that have been transported by this tributary.

Tributary #1 is located immediately upstream from the Highlands water treatment facility. This stream has likely contributed a significant amount of sediment in Big Creek for two reasons. First, this tributary is located very close to an unpaved gravel road (Fig. 8) which funnels sediment and fast-running water through the tributary every time that it rains.

FIG. 8. Road adjacent from Tributary #1 which transports runoff sediment into the tributary.

This process has likely caused a steep stream bank to experience mass wasting and break through a silt fence (Fig. 9) and further contributing to the sediment that this tributary has deposited into Big Creek. We recommend that UCWA focus its stream restoration efforts on this tributary and on the storm water drainage system that contributes to its sediment transport.

On Tributary #10 we found several uprooted eastern hemlocks (*Tsuga canadensis).* These hemlocks were growing adjacent to the bank before they fell over which released a significant amount of sediment into the tributary. Immediately downstream from the hemlocks we found embedded cobblestones and boulders in one or two inches of sediment deposits (Fig. 10).

FIG. 9. Silt fence along stream bank of Tributary #1 which has been knocked over after the bank experienced mass wasting.

Between Tributaries #8 and #9 we found construction sites where silt fencing had been installed. The silt fencing was toppled over from heavy build-up of sediment behind the fences which eventually knocked most of the fencing completely over. We found signs of ephemeral, runoff streams coming from the sediment buildup near the silt fencing; the sediment runoff ran directly into Big Creek (Fig. 11).

FIG. 10. Felled eastern hemlock which has contributed to sediment deposition along Tributary #10.

FIG. 11. Sediment (foreground) from a construction site entering Big Creek (background) after a breach in silt fencing.

Discussion

The tributaries that were mapped provided to the Town of Highlands planning/zoning official an expanded area to enforce ETJ regulations to protect the Big Creek watershed. Without the mapping of the perennial tributaries, areas of the Big Creek watershed will be more susceptible to human disturbance because the ETJ regulations cannot be enforced on unmapped tributaries. With the increased building of residential areas along the watershed, protection of the riparian zone along the Big Creek watershed is an essential issue that needs more monitoring by both The Town of Highlands planning/zoning official and UCWA.

Out of the ten tributaries that we mapped, we found 5 tributaries that had areas of concern: Tributaries 1, 5, 6, 9, and 10 (Fig. 2). Tributary #1 (Fig. 3) had massive bank erosion due to the runoff of water from the impervious gravel road on Hickory Hill Road. The recommended solution to this problem would be to divert the running water from the road to a collection point that treats storm water during rainfall; in addition, by decreasing the velocity of the water from the road, the competency, ability to transport sediment, of the water will decrease. Tributary #5 (Fig. 4) had sediment deposition from a gravel road that was made for access to an open lot in Laurel Falls at Skyline Lodge, a restaurant and resort area north of Highlands. The recommended solution to this problem would be to build a sediment fence that prevents the deposition of gravel into the tributary during heavy rainfall; in addition, increasing vegetation on the bank of the tributary will prevent erosion. Tributary #6 (Fig. 4) had point-source pollution from a PVC pipe at Skyline Lodge that smelled of laundry detergent and also had areas along the riparian zone where trees were recently cut down. The recommended solution to stopping the pollution would be to have the property owner stop the discharge of the water or administer fines until the discharge is stopped. The loss of the vegetative zone will need to be replanted with vegetation that previously existed in that area. Tributary #9 (Fig. 6) had a bank that had no vegetation to keep the bank from eroding into the tributary; during heavy rainfall, the sediment will wash downstream into Big Creek. The recommended solution would be to have the property owner create a vegetative cover on the bank. Tributary #10 (Fig. 6) experienced sediment deposition from the falling of hemlock trees along the riparian zone. There is no solution to this problem except to be prepared to treat the affected areas after sediment deposition occurs.

As mentioned, some of the tributaries that we documented as having areas of concern were not impacted by human disturbance. The hemlock woolly adelgid is decreasing the health of the hemlocks in Highlands, NC which makes them more prone to falling over during heavy rainfall and high windstorms. The monitoring of these sites are of even greater importance because the habitats that are located downstream from the hemlocks will lose the potential for being a suitable environment for macro-invertebrates; moreover, embeddedness from sediment deposition prevents the macro-invertebrates from being able to live under cobblestones and boulders. The loss of macro-invertebrates in the tributaries will reduce the amount of food sources for the fish that live in Big Creek which will impact the organisms that feed on the fish. By restoring the habitats of the organisms at the lower echelons of the food chain, we can ensure that organisms that rely on macro-invertebrates will be less impacted.

The maps of the Big Creek watershed also allow the Town of Highlands Planning/Zoning Administrator and UCWA to document the areas that are affecting the town's drinking water supply. Without knowing where the sources of sediment deposition are coming from or why the deposition is occurring, the town can only treat the symptoms of bank erosion into the tributaries and Big Creek. With our information of where bank erosion is occurring, the Town of Highlands can restore the banks of concern and will save money by not having to replace clogged water pumps or dredge the bottom of Big Creek near the water pumps.

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Appendix A. Bank Erosion Hazard Index (BEHI)

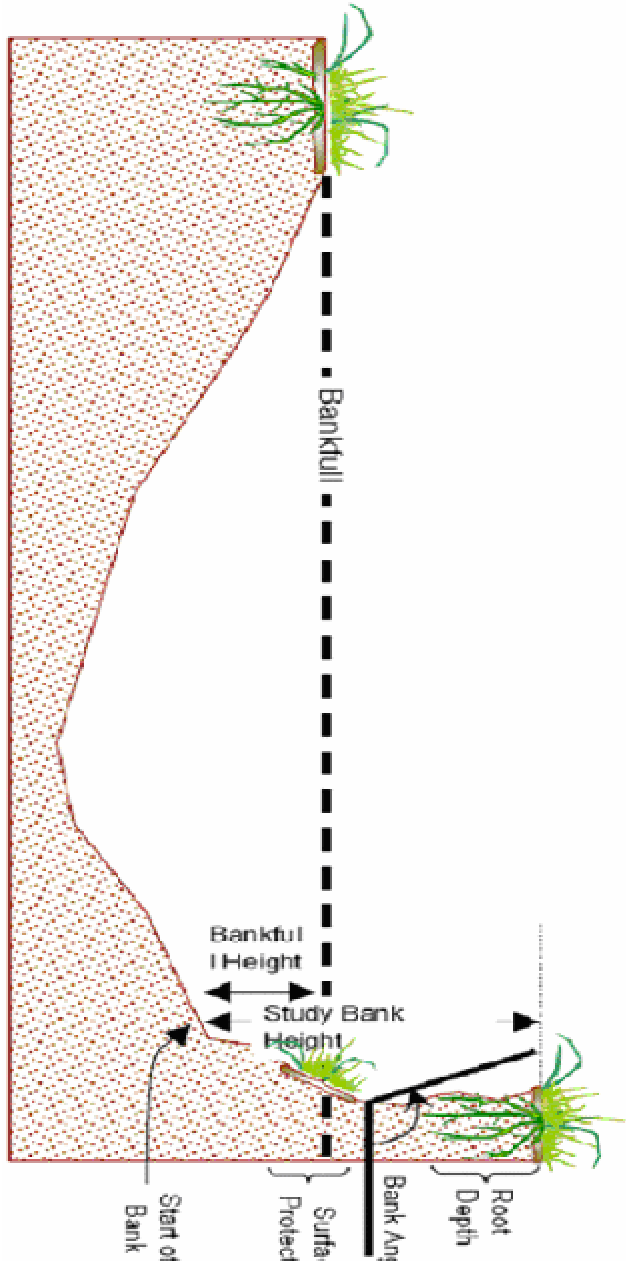
Category		Bank Ht Ratio (ft/ft)	Root Depth Ratio (ft/ft)	Root Density (%)	Bank Angle (degrees)	Surface Protection (%)	Total Index
Very Low	Value	1.0 - 1.1	100 - 80	100 - 80	0 - 20	1.0 - 0.9	
	Index	1 - 2	1 - 2	1 - 2	1 - 2	1 - 2	< 10
Low	Value	1.1 - 1.2	80 - 55	80 - 55	20 - 60	0.9 - 0.5	
	Index	2 - 4	2 - 4	2 - 4	2 - 4	2 - 4	10 - 20
Moderate	Value	1.2 - 1.5	55 - 30	55 - 30	60 - 80	0.5 - 0.3	
	Index	4 - 6	4 - 6	4 - 6	4 - 6	4 -6	20 - 30
High	Value	1.5 - 2.0	30 - 15	30 - 15	80 - 90	0.3 - 0.15	
	Index	6 - 8	6 - 8	6 - 8	6 - 8	6 - 8	30 - 40
Very High	Value	2.0 - 2.8	15 - 5	15 - 5	90 - 120	0.15 - 0.05	
	Index	8 -9	8 - 9	8 - 9	8 - 9	8 - 9	40 - 45
Extreme	Value	> 2.8	< 5	< 5	> 120	< 0.05	
	Index	10	10	10	10	10	> 45
Field Measure	Value						
	Index						

Total Field Index _______

Numerical Adjustments _______

Bedrock: BEHI Very Low
Boulders: BEHI Low
Cobble: Decrease by one category if gravel/sand less than 50%
Gravel: Adjust Index up 5 - 10 points depending on sand %
Sand: Adjust Index up 10 points
Silt/Clay: No Adjustment
Stratification: Adjust Index up 5 - 10 points depending on position of unstable layers in
Relation to bankfull stage

Adjusted BEHI _______



APPENDIX B. Bank Erosion Hazard Index Variable

APPENDIX C

Habitat Assessment Field Data Sheet
Mountain/Piedmont Streams

Biological Assessment Unit, DWQ
Directions for use: The observer is to survey a **minimum of 100 meters** of stream, preferably in an **upstream** direction starting above the bridge pool and road right-of-way. The segment which is assessed should represent average stream conditions. To perform a proper habitat evaluation the observer needs to get into the stream. To complete the form, select the description which best fits the observed habitats and then circle the score. If the observed habitat falls in between two descriptions, select an intermediate score. A final habitat score is determined by adding the results from the different metrics.

Stream__________________ Location/Road:___________(Road Name____________)Country________

Date_____________**CC#**___________Basin__________________Subbasin________________________

Observer(s)_______Type of Study: □ Fish □Benthos □Basinwide □Special Study(Describe)_________

Latitude_______ Longitude_______ Ecoregion: □MT □P □Slate Belt □Triassic Basin

Water Quality: Temperature_____°C DO_____mg/l Conductivity (corr.)_____µmhos/cm pH_______

Physical Characterization: Visible land use refers to immediate area that you can see from sampling location- include what you see driving thru the watershed in watershed land use.

Visible Land Use: ______%Forest ______%Residential ______%Active Pasture ______%Active Crops
______%Fallow Fields ______%Commercial ______%Industrial ______%Other – Describe__________

Watershed land Use: □Forest □Agriculture □Urban □Animal operations upstream

Width: (meters) Stream_______ Channel (at top of bank)______ Stream **Depth**: (m) Avg____ Max_____
□Width variable □Large river >25m wide
Bank Height (from deepest part of channel (in riffle or run) to top of bank): (m)______

Bank Angle: ________° or □NA (Vertical is 90°, horizontal is 0°. Angles >90° indicate slope is towards mid-channel, <90° indicate slope is away from channel. NA if bank is too low for bank angle to matter.)

□Deeply incised-steep, straight banks □Both banks undercut at bend □Channel filled in with sediment
□Recent overbank deposits □Bar development □Buried structures □Exposed bedrock
□Excessive periphyton growth □Heavy filamentous algae growth □Green tinge □Sewage smell
Manmade Stabilization: □N □Y: □Rip-rap, cement, gabions □Sediment/grade control structure □Berm/levee
Flow Conditions: □High □Normal □Low
Turbidity: □Clear □Slightly Turbid □Turbid □Tannic □Milky □Colored (from dyes)

Weather Conditions:_____________________ **Photos:** □N □Y □Digital □35mm

Remarks:____

I. Channel Modification Score

	Score
A. channel natural, frequent..	5
B. channel natural, infrequent bends (channelization could be old)............	4
C. some channelization present...	3
D. more extensive channelization, >40% of stream disrupted.....................	2
E. no bends, completely channelized or rip rapped or gabioned, etc...........	0

□Evidence of dredging □Evidence of desnagging=no large woody debris in stream
□Banks of uniform/shape height
Remarks____ Subtotal______

II. Instream Habitat: Consider the percentage of the reach that is favorable for benthos conlonization or fish cover. If >70% of the reach is rocks, 1 type is present, circle the score of 17. Definition: leafpacks consist of older leaves that are packed together and have begun to decay (not piles of leaves in pool areas). Mark as **R**are, **C**ommon, or **A**bundant.

____Rocks ____Macrophytes ____Sticks and leafpacks ____Snags and logs ____Undercut banks

AMOUNT OF REACH FAVORABLE FOR COLONIZATION OR COVER

	>70% Score	40-70% Score	20-40% Score	<20% Score
4 or 5 types present.........	20	16	12	8
3 types present................	19	15	11	7
2 types present................	18	14	10	6
1 type present.................	17	13	9	5
No types present.............	0			

□No woody vegetation in riparian zone Remarks____________________________ Subtotal_____

III. Bottom Substrate (silt, sand, detritus, gravel, cobble, boulder) look at entire reach for substrate scoring, but only look at riffle for embeddedness.

	Score
A. substrate with good mix of gravel, cobble, and bounders	
1. embeddedness <20% (very little sand, usually only behind large boulders).....	15
2. embeddedness 20-40%..	12
3. embeddedness 40-80%..	8
4. embeddedness >80%..	3
B. substrate gravel and cobble	
1. embeddedness <20%	14
2. embeddedness 20-40%..	11
3. embeddedness 40-80%..	6
4. embeddedness >80%..	2
C. substrate mostly gravel	
1. embeddedness <50%..	8
2. embeddedness >50%..	4
D. substrate homogenous	
1. substrate nearly all bedrock...	3
2. substrate nearly all sand...	3
3. substrate nearly all detritus..	2
4. substrate nearly all silt/clay..	1

Remarks____Subtotal_______

IV. Pool Variety Pools are areas of deeper than average maximum depths with little or no surface turbulence. Water velocities associated with pools are always slow. Pools may take the form of "pocket water," small pools behind boulders or obstructions, in large high gradient streams.

	Score
A. Pools present	
1. Pools frequent (>30% of 100m area surveyed)	
a. variety of pool sizes...	10
b. pools same size (indicates pools filling in)..............................	8
2. Pools Infrequent (<30% of the 100m area surveyed)	
a. variety of pool sizes...	6
b. pools same size...	4
B. Pools absent...	0

Subtotal_________

□Pool bottom boulder-cobble=hard □Bottom sandy-sink as you walk □Silt bottom
□Some pools over wader depth

V. Riffle Habitats

Definition: Riffle is area of reaeration- can be debris dam, or narrow channel area.

	Riffles **Frequent** Score	Riffles **Infrequent** Score
A. well-defined riffle and run, riffle as wide as stream and extends 2X width of stream..	16	12
B. riffle as wide as stream but riffle length is not 2X stream width....................................	14	7
C. riffle not as wide as stream and riffle length is not 2X stream width.............................	10	3
D. riffles absent...	0	

Channel Slope: □Typical for area □Steep=fast flow □Low=like a coastal stream Subtotal_________

VI. Bank Stability and Vegetation

FACE UPSTREAM

	Left Bank Score	Right Bank Score
A. Banks stable		
1. no evidence of erosion or bank failure, little potential for erosion...	7	7
B. Erosion areas present		
1. diverse **trees**, shrubs, grass; plants healthy with good root systems..	6	6
2. few trees or small trees and **shrubs**; vegetation generally healthy....	5	5
3. sparse **mixed** vegetation; plants suggest poor soil binding................	3	3
4. mostly **grasses**, high erosion and failure potential at high flow........	2	2
5. no bank vegetation, mass erosion and bank failure evident..............	0	0

Total_________

Remarks____

VII. Light Penetration (Canopy is defined as tree or vegetative cover directly above the stream's surface. Canopy would block out sunlight when the sun is directly overhead).

	Score
A. Stream with **good** shading with some breaks for light penetration..................................	10
B. Stream with **full canopy**- breaks for light penetration absent..	8
C. Stream with **partial** shading- sunlight and shading are essentially equal.........................	7
D. Stream with **minimal** shading- full sun in all but a few areas..	2
E. **No shading**..	0

Subtotal_______

Remarks____

VIII. Riparian Vegetative Zone Width

Definition: Riparian zone for this form is area of natural vegetation adjacent to stream (can go beyond floodplain). Definition: A break in the riparian zone is any place on the stream banks which allows sediment or pollutants to directly enter the stream, such as paths down to stream, storm drains, uprooted trees, otter slides, etc.

Dominant vegetation: □Trees □Shrubs □Grasses □Weeds/old field □Exotics (kudzu, etc.)

FACE UPSTREAM

	Left Bank Score	Right Bank Score
A. Riparian zone **intact** (no breaks)		
1. width >18 meters..........	5	5
2. width 12-18 meters..........	4	4
3. width 6-12 meters..........	3	3
4. width < 6 meters..........	2	2
B. Riparian zone **not intact** (breaks)		
1. breaks rare		
a. width >18 meters..........	4	4
b. width 12-18 meters..........	3	3
c. width 6-12 meters..........	2	2
d. width < 6 meters..........	1	1
2. breaks common		
a. width >18 meters..........	3	3
b. width 12-18 meters..........	2	2
c. width 6-12 meters..........	1	1
d. width < 6 meters..........	0	0
		Total_________

Remarks____

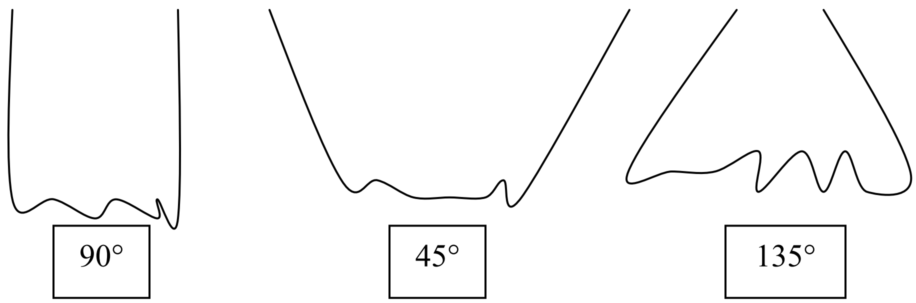
Supplement for Habitat Assessment Field Data Sheet

Channel Flow Status

Useful especially under abnormal or low flow conditions

A. Water reaches base of lower banks, minimal channel substrate exposed.................. ☐
B. Water fills >75% of available channel, or <25% of channel substrate exposed......... ☐
C. Water fills 25-75% of available channel, many logs/snags exposed.......................... ☐
D. Root mats out of water.. ☐
E. Very little water in channel, mostly present as standing pools.................................. ☐

Diagram to determine bank angle:



Site Sketch:

Other Comments: ____

____

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ANALYSIS OF THREE HIGHLANDS RESERVIORS

KARLY R. MCLEOD

Abstract. National Forest land is divided up into different management areas. Approximately every ten years the management plans are evaluated. Three reservoirs near the town of Highlands, NC were evaluated based on abiotic water variables, a visual analysis, and GPS map analysis. The three reservoirs that were evaluated include Cliffside Lake, Houston Lake, and Upper Wilson Lake. The results included a photograph of each reservoir, an aerial photograph with an outline made using a shapefile in ArcMap, and a table listing the water variables. Two management alternatives were discussed for each reservoir.

Key words: Highlands; management plans; reservoirs

INTRODUCTION

The Nantahala National Forest is located in western North Carolina near the southern border of North Carolina and is divided up into different management areas. Management areas are "zoned to achieve different desired conditions, emphasize different activities, permit different uses of the forest, emphasize differing wildlife species and landscape features" (Land and Resource Management Plan Amendment 5 1994). Three areas that are included in the study that are in the Management area book include management areas 2A, 4C, and 13. Three old reservoirs for the town of Highlands, NC were examined.

The first area, Cliffside Lake, is classified in management area 13. Land that is included in management area 13 "are special interest areas that are managed to protect, and where appropriate foster public use and enjoyment of unique scenic, geological, botanical or zoological attributes." The land that surrounds Cliffside can not be classified as "selected for timber production." "These areas include significant examples of the diverse natural communities of the Southern Appalachians which may also include unique scenic, botanical, zoological or geological features" (Land and Resource Management Plan Amendment 5).

The land surrounding Houston Lake is classified under the management area 4C. The management objectives of land in this area include emphasizing visually pleasing scenery and nonmotorized recreation use. Limitations in this area include no roads for motorized vehicles. This land is classified as suitable for timber production in order to meet visual quality objectives and wildlife habitat needs, or lands not cost efficient for timber management over the planning horizon. Older forests in the 4C management areas are also managed "primarily for bear, and animals requiring a similar environment" (Land and Resource Management Plan Amendment 5).

Wilson Lake is classified under the management area 2A. The primary goal of land in the 2A classification is to emphasize visually pleasing scenery through motorized recreation use. Secondary to the scenery is timber production. On this land timber production may occur but it must be modified to meet visual quality objectives. Road construction is permitted in this area. Another management goal of land in the 2A categorization is to manage the habitat of small animals including squirrels, piliated woodpeckers, and animals requiring a similar habitat. The abiotic data, visual analysis, and GPS maps were used to evaluate and support future management options.

Materials and Methods

The measurements taken were general baseline measurements that were used to evaluate management plans. The three areas were examined to analyze the current management plans and evaluate future options. After the data was collected, two options were offered for each reservoir.

Depth measurements were taken using a tape measure and a weight. Biotic data was collected using a LaMonte water testing kit. Water sampling was done on September 17, 2006 for Cliffside and Houston Lake and on September 22, 2006 for Wilson Lake. The water sampling kit measured temperature, pH, dissolved oxygen, phosphorus, nitrogen, and alkalinity. The water samples were taken in the middle of each lake at a depth 0.3 meters using a row boat. The water samples were taken following the directions described in the kit. One water sample was taken for each variable. Then the water was tested using the chemicals provided in the kit.

The GPS maps were created using 2004 USGS aerial photographs. The aerial photographs were imported into Arc GIS 9.1. Then the editor tool was used to create an outline of the lake. Each outline was saved as a shapefile. The shapefiles were then exported and saved as images.

In addition to the quantitative measurements, visual observations were recorded at each site. Visual observations were used to help analyze possible management options in the future. Included in the visual observations was trail condition, condition of facilities, and use by the public. A visual observation was made once at each site and a photograph was taken at each site during the month of December.

Results and Discussion

GPS Maps

Figs. 1, 2, and 3 present the outlines of the three reservoirs. The area, perimeter, and acreage were calculated from the outlines (Table 1).

FIG. 1. Cliffside Lake Reservoir

FIG. 2. Houston Lake Reservoir

FIG. 3. Upper Wilson Lake Reservoir

	Cliffside	Houston	Wilson
Perimeter (m)	1,105	595	766
Area (m)	30,439	8,298	11,128
Acres	7.5	2.1	2.7

TABLE 1. GPS map statistics of Highlands reservoirs

Abiotic lake characteristics

The abiotic variables are listed in Table 2.

	Cliffside	Houston	Wilson
Temperature (°C)	16.5	14	18
pH	6.5	6	5.5
Nitrate	close to zero	close to zero	close to zero
Phosphorus	close to zero	close to zero	close to zero
Dissolved Oxygen (ppm)	9	9	8.4
Alkalinity	8	30	22

TABLE 2. Water variables of the three reservoirs

Visual analysis

A visual observation about the status of the trails and facilities and the use by the public was recorded. Since Cliffside is a public attraction, the trails and restrooms were maintained well. There were also a number of picnic tables and a swimming area. Cliffside is clearly maintained to meet the needs of the public. Fig. 4 is a picture of Cliffside in December.

FIG. 4. Cliffside Lake in December

Houston Lake is not open to the general public. Therefore, there are no trails or buildings. The dam is well maintained, but the equipment that regulates the water level is in poor condition. The equipment is rusting and falling apart and the wooden dock is in very poor condition. The rusting equipment is pictured in Fig. 5.

FIG. 5. Rusting dock and equipment at Houston Lake

Upper Wilson Lake is not currently advertised as a tourist attraction, but there are still visitors to the area. The people that were encountered included local people that considered the area an unknown treasure. There is a trail to the Lake but it is not marked. It was moved a couple of times during the fall. There is a rope swing on the southeast side of the lake. Figure 6 was taken will standing on the dam and facing northeast.

FIG. 6. Upper Wilson Lake

Cliffside Lake

Cliffside is classified under management area 13. This land is managed to foster enjoyment by the public. As the present time, there is an area to swim and many areas to picnic. An option that would expand the use of Cliffside is to designate a camping area. This is not an option that could be quickly decided upon. More research would be required to determine the demand. This research would include surveys and estimates of cost. Additional costs for a campground include the cost to maintain additional facilities and the cost to employ someone to watch over the camping area. Another option is to keep the area as it is. Currently, the area is used by many people, so there is little reason to make drastic changes. Cliffside Lake will continue to require regular maintenance including more sand for the beach area and trail maintenance.

Houston Lake

Houston Lake is part of the 4C management plan. After reviewing the results there are two possible management plans for Houston Lake. The first option is to let sedimentation fill in the reservoir and let the area turn into a wetland This option requires minimal maintenance and will help maintain biodiversity in the area by providing a wetland habitat. The second option is to dredge the reservoir. This option is not practical and would cost the Forest Service more money than the first option.

Upper Wilson Lake

The Wilson Lake area is categorized under management area 2A. This area is meant to be enjoyed by visitors especially those that are enjoying the area by car or boat. Currently Upper Wilson Lake is not a well advertised area. One management option for the area is to improve the area and promote tourism. There are many possibilities for the area including trails and fishing. It is possible to use small boats in the reservoir but there is little access to the area and there are many fallen trees in the reservoir. The other option is to leave Upper Wilson Lake as it is. Local people currently enjoy many of the previously mentioned activities. The second option to keep the reservoir as it is would require less funding. Some local people said they would prefer if the area is left as is.

Conclusion

The recommended management plans are only suggestions. In most cases, drastic changes will require more research and the expertise of the Forest Service as well as input from the community. The baseline study could be improved by using better equipment. The study could also be improved by used a high resolution GPS unit. For a baseline project like this it makes sense to use a GPS unit with one meter resolution. In general, the three areas that were studied do not require drastic changes at this time.

LITERATURE CITED

U.S. Department of Agriculture. 1994. Land and Resource Management Plan Amendment 5. Asheville, NC: Federal Courthouse.

MICROHABITAT SELECTION AND USE BY THE EASTERN BOX TURTLE (*TERRAPENE C. CAROLINA*) AT PURCHASE KNOB, GREAT SMOKY MOUNTAINS NATIONAL PARK

EMILY K. MEINEKE

Abstract. Turtle longevity, development, and population growth may be compromised by human development. The purpose of this study was to contribute to current knowledge regarding habitat use and population dynamics of the eastern box turtle (*Terrapene carolina carolina*). Tracking data were collected for five individual turtles from June 2006 through October 2006 to assess habitat preference regarding vegetation cover type and soil type. Two turtles appeared to exhibit preferences in cover type. One was considerably associated with successional field habitat, while the other preferred understory forest habitat. Four out of five turtles were found associated with a subset of Wayah Sandy Loam soil. Results are based on one year of data collection; more precise conclusions can be drawn about eastern box turtle habitat selection with data collected over multiple years.

INTRODUCTION

Purpose

Recent evidence suggests that turtle longevity, development, and population density may be compromised by urbanization (Budischak et al. 2006). The eastern box turtle once had a fairly ubiquitous distribution throughout the eastern United States, but populations are declining because of human development (Thorbjarnarson et al. 2000). Because habitat loss is often directly followed by increased human activity and, subsequently, further habitat fragmentation, box turtles face secondary threats to population density such as highway mortality and overcollection by the pet trade (Klemens 2000). Temple (1987) found that habitat fragmentation also causes increased ecological edge and, therefore, a higher incidence of predation on turtle nests. Turtles in deforested areas may also experience retarded developmental rates that prevent them from reaching the safety of adult size early in life. Slow maturation could also delay mating ability (Dodd 2001, Budischak et al. 2006). These factors further diminish population densities.

Declining turtle populations are an immediate biological concern, as is evident in a 1990 study by Doroff and Keith, who found that the current ornate box turtle (*Terrapene ornata*) population in south-central Wisconsin cannot endure losing one adult per year. Eastern box turtles are a popular pet species in eastern North America, and they are exposed to significant urbanization throughout their range. Therefore, this species is of particular interest regarding the way it uses its habitat when relatively undisturbed by human activity. This study aims to contribute to a better understanding of the habitat use of eastern box turtles located in a high-elevation, protected area that includes several habitat types. Improved awareness of turtle movements may aid in better protection and management of this species both within and outside such protected areas as national parks.

MATERIALS AND METHODS

Study Area

This study was conducted in 2006 at the Appalachian Highlands Science Learning Center, located at Purchase Knob on the eastern edge of the Great Smoky Mountains National Park (GSMNP; Appendix A). Purchase Knob is mixed forest and managed open field site. The study site is characterized by four distinct vegetation cover types, the most disturbed of which is an open herbaceous field. This area is mowed every three years, once during the study period in Mid-August of 2006. Vegetation is predominantly timothy and fescue grass (*Festuca* spp.), with woody saplings and blackberry (*Rubus* spp.) in small abundance.

Old growth forest cover dominates the area directly below Purchase Knob. It is characterized by a relatively open understory and by typical northern hardwood canopy cover, the most dominant species being red oak (*Quercus rubra*) and red maple (*Acer rubrum*). Some open canopy areas are present due to loss of the American chestnut (*Castenea dentata*). There is limited and selective cutting in this area. Disturbance in forested areas is limited to removal of individual forest emergent tree species, while still saplings. The last removal was in winter of 2005/2006. Subcanopy species include eastern hemlock (*Tsuga canadensis*), mountain laurel (*Kalmia latifolia*), and *Rhododendron* spp. The forest edge is characterized by a significant amount of early successional species such as goldenrod (*Solidago* spp.), blackberry (*Rubus* spp.), and grasses.

On the east and west sides of the road leading up to the Learning Center at Purchase Knob, Fraser fir (*Abies fraseri*) has been planted for genetic conservation. These trees are sprayed and kept as two separate monocultures. For the purpose of this study, these areas were identified as managed field habitats. Several areas of commercial firs are also located within the study area, the largest of which is situated at the southernmost edge of the protected property. The commercial tree areas harbor a significant amount of undergrowth and are referred to in this study as successional fields.

Data Collection

Interns and groups led by GSMNP rangers Paul Super and Shelly Buranek located five eastern box turtles within the Purchase Knob area and tracked their movements for various durations from June 2006 until hibernation in late October 2006. After capture, each turtle was marked by attaching a transmitter with Devon 5-minute Epoxy on the front end of its shell, then released in the same area it was collected.

FIG. 1. *Terrapene c. carolina* showing attached radio transmitters; Christina, left; Rufus, right.

A radio frequency unique to each receiver allowed for individual identification of turtles after capture. National Park employees and interns tracked individuals twice weekly when possible, using a TRX-485 receiver. Six-digit codes unique to each transmitter were used to confirm the identification of turtles. Researchers limited interactions with the animals as much as possible, approaching them momentarily for identification.

Measurements

Descriptive data were recorded upon recovery of turtles, including activity (if turtle was stationary, moving, copulating, eating), relative humidity (measured with a sling psychrometer), soil temperature, ground temperature, and cover type. Turtle location was marked on a Garmin Etrex 12-channel GPS unit. Either directly before or directly after recovery, weather was documented from the National Weather Service's Climate Station at Purchase Knob. Barometric pressure and dew point were recorded from the NOAA National Weather Service site at Asheville Regional Airport, as this was the closest location from which to record this information.

Analysis

As soil type and vegetation cover type describe microhabitat, these factors were chosen for analysis. Four cover types were identified within turtles' ranges: managed field, understory forest, forest with sparse understory, and successional field. Nine soil types were classified by the USDA Natural Resources Conservation Service within turtle home ranges (Table 1).

Soil classification	Soil composition	Slope (%)
AwB	Wesser complex	0 - 8
WaC	Wayah sandy loam	5 - 15
WaD	Wayah sandy loam	15 - 30
WaF	Wayah sandy loam	30 - 95
WeF	Wayah sandy loam	30 - 95
OwF	Oconaluftee-Guyot-Cataloochee complex	50 - 95
PwE	Leatherwood clay	30 - 50
TaC	Tanasee-Balsam complex	5 - 15
TaD	Tanasee-Balsam complex	15 - 30

TABLE 1. Soil types found in the study site at Purchase Knob, Great Smoky Mountains National Park.

In order to make predictions regarding what types of soil and vegetation turtles might prefer, position, soil type, and vegetation cover type maps were made using ArcMap software (Appendix B). Based on these maps, home ranges were identified. Stickel (1989) predicted average home range size of box turtles in Maryland, but the results were inapplicable to this study, as average home range size calculated was significantly smaller than the area utilized by turtles at Purchase Knob. In the present study, operational home ranges were determined by first identifying the two furthest location points for each turtle. This distance was used as the diameter of a circular area centered on the midpoint. This circular area was identified as the operational home range for each turtle. Fig. 2 and Appendices C and D provide vegetation cover and soil maps, respectively, with operational home ranges indicated.

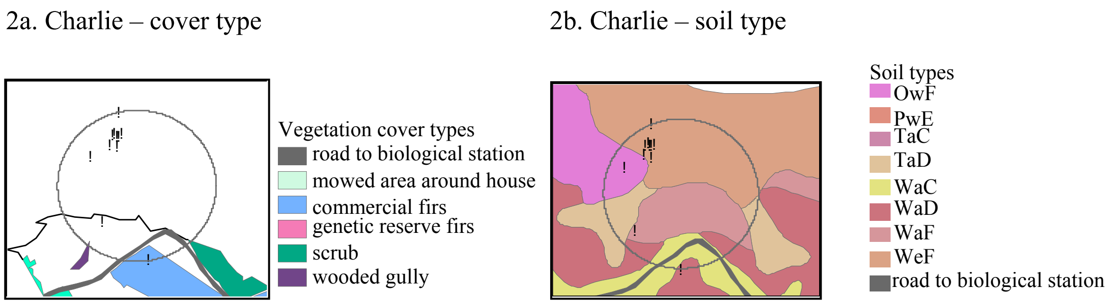

FIG. 2. Examples of operational home range maps

Using these circles, estimated areas of operational home ranges were calculated, as shown in Table 2.

Name	Operational home range area (m^2)
Charlie	126,901
Christina	420,978
Lucy	25,415
Peggy Sue	128,871
Rufus	182,657

TABLE 2. Operational home range sizes for five eastern box turtles studied at Purchase Knob, Great Smoky Mountains National Park.

Soil types and cover types within home ranges were then recorded. Cover types or soil types that measured less than 10 by 10 m were not counted. This value was chosen by researchers as an arbitrary area for which soil and cover types were too insignificant to expect turtle discovery and selection. Chi square tests were then used to test association with vegetation cover types and soil types available to each turtle within its home range (Zar 1999). In using this approach, the assumption was made that turtles had equal access to soil and vegetation types located in their operational home ranges (i. e. turtles had the ability to select for any habitat in the time interval between successive observations).

RESULTS

Location data are summarized for the five study turtles in Table 3. Complete data and a sample data sheet are located in Appendices E and F, respectively.

Turtle	Sex	Dates tracked (2006)	No. of observations*
Charlie	M	8/25 – 10/27	12
Christina	F	6/16 – 10/27	21
Lucy	F	6/23 – 7/11	4
Peggy Sue	F	6/27 – 8/30	8
Rufus	M	6/10 – 9/8	6

*Observations were only included if precise location of turtle was recorded.

TABLE 3. Summary data for *Terrapene c. carolina* studied at Purchase Knob, Great Smoky Mountains National Park.

Percent association with vegetation cover for each turtle is summarized in Fig. 3.

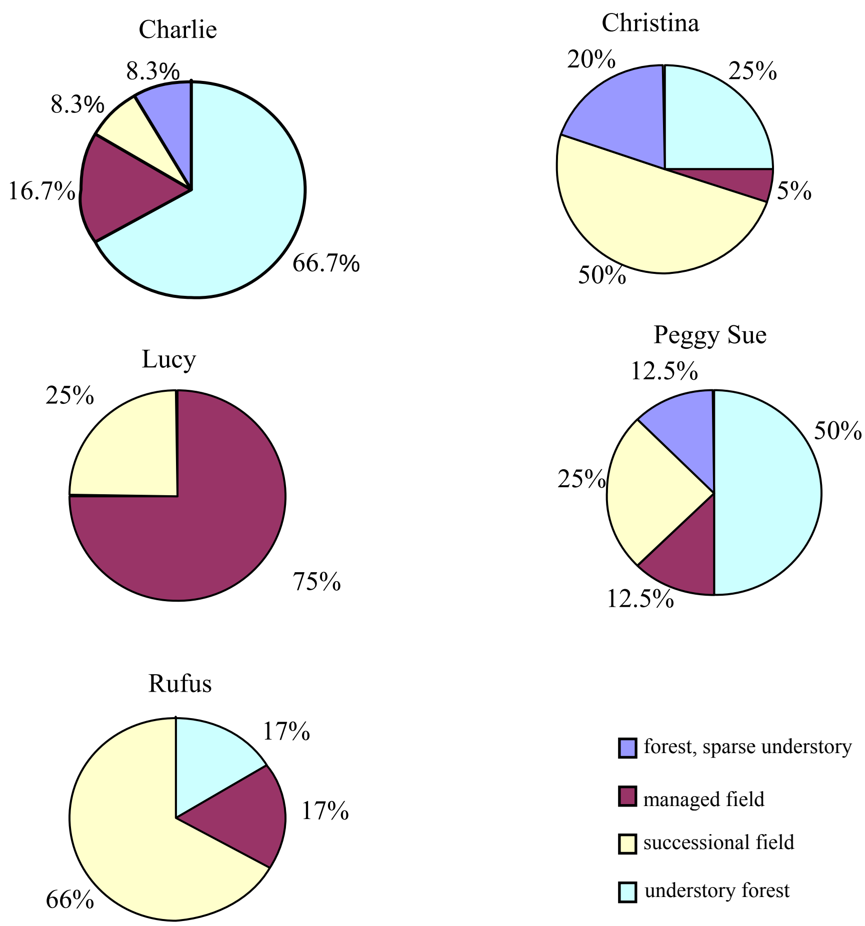

FIG. 3. Turtle incidence among vegetation cover types within operational home ranges.

Turtle home ranges included all cover types, except in the case of Lucy, who had only two cover types in range. Two turtles exhibited significant cover preferences. Statistical values associated with chi square analysis are listed in Table 4.

	Vegetation Cover					
Turtle Name	UF	SF	FSU	MF	χ^2	P
Charlie	8	1	1	2	11.3	0.01
Christina	7	10	*	4	18.16	0.05 > P > 0.025
Lucy	–	1	-	3	1.00	0.50 > P > 0.25
Peggy Sue	4	2	1	1	3.00	0.50 > P > 0.25
Rufus	1	4	0	1	5.98	0.25 > P > 0.10

*One data point under SF was not used in soil analysis or in Table 2, because there was no visual conformation of turtle. However, the turtle was triangulated in a successional field area, so the data point was counted as cover information.

TABLE 4. Association of turtles with vegetation cover at Purchase Knob, Great Smoky Mountains National Park; Vegetation cover types are abbreviated as follows: UF – understory forest; SF – successional field; FSU – forest, sparse understory; MF – managed field. A dash indicates that the habitat type is not present within a turtle's operational home range.

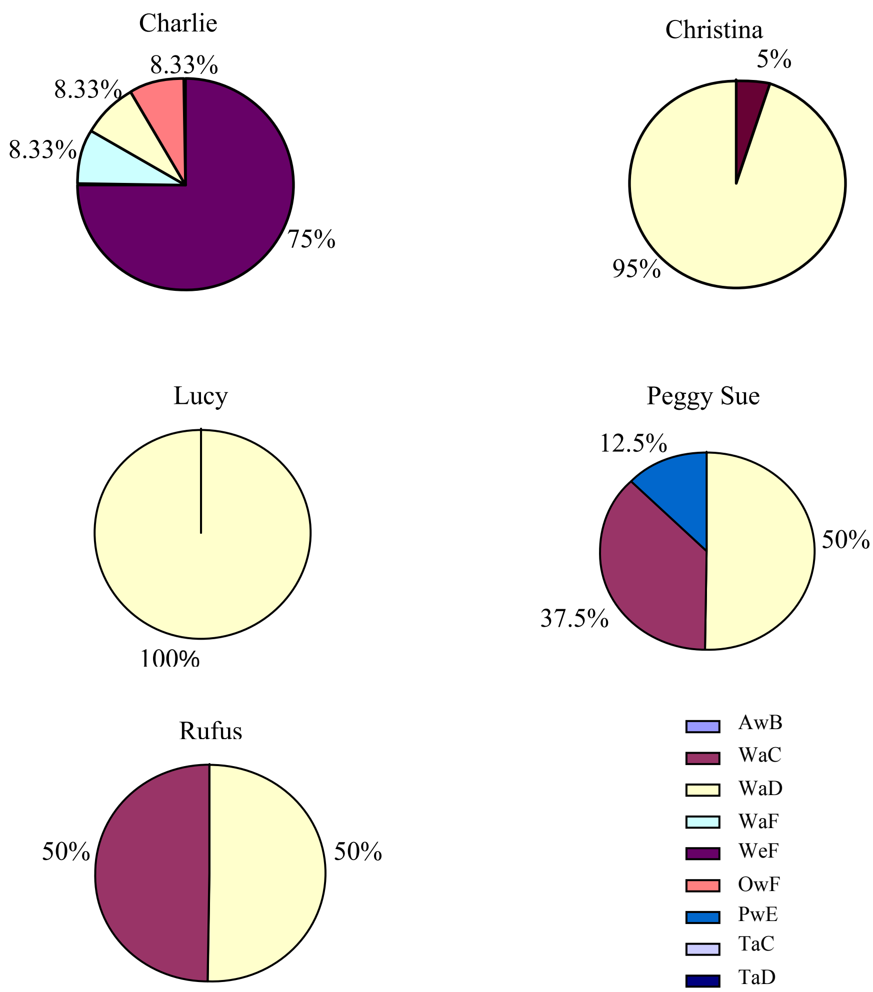

FIG. 4. Turtle incidence among soil types within operational home ranges.

Percent association with soil type for each turtle is presented in Fig. 4.

The combination of soil types was different in each operational home range. Table 5 indicates significance values for chi square analysis based on turtle association with home range soil types.

	Soil types*									χ^2	P
Turtle	AwB	WaC	WaD	WaF	WeF	OwF	PwE	TaC	TaD		
Charlie	0	0	1	1	9	1	-	-	0	29.5	$P < 0.001$
Christina	0	1	20	0	0	0	-	-	-	8.16	$P < 0.001$
Lucy	-	0	4	-	-	-	-	0	-	8.20	$0.025 < P < 0.01$
Peggy Sue	0	3	4	0	-	-	1	0	-	11.7	0.05
Rufus	-	3	3	-	-	-	-	0	0	6.00	$0.25 < P < 0.10$

* See Table 1 for explanation of soil classifications.

TABLE 5. Association of turtles with soil types at Purchase Knob, Great Smoky Mountains National Park; A dash indicates that the soil type is not present within a turtle's operational home range.

Summary vegetation cover and soil data for all turtles are presented in Fig. 5. Overall, turtles were predominantly associated with understory forest and successional field habitats and Wayah sandy loam (WaD) soil, although chi square analysis was not performed for compiled turtle data.

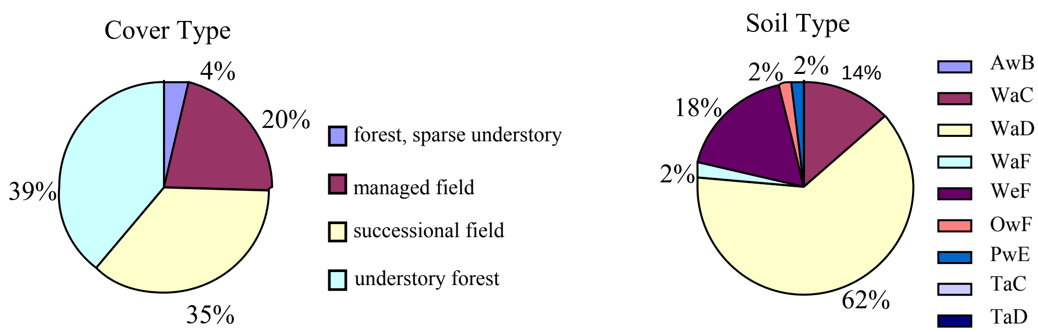

FIG. 5. Compiled data of turtle association with vegetation cover types and soil types.

DISCUSSION

Of the five turtles tracked during the 2006 season at Purchase Knob, only two yielded enough data for robust analysis. During the study period, Lucy and Peggy Sue lost their transmitters, and researchers lost signal from Rufus. Perhaps another type of epoxy, for example PC-7 epoxy cited in Morrow's 2001 study of the bog turtle (*Clemmys muhlenbergii*), would aid in reducing the effects of lost transmitters. Additionally, Charlie was not found and fitted with a transmitter until late August. Therefore, the amount of data available for each turtle was limited by early cessation or late onset of data collection. Researchers were occasionally unable to visualize turtles, finally, because of brambles or dense vegetation. This further limited the amount of data available for statistical analysis.

No notable difference was found between male and female habitat selection. Additionally, no significant correlation was found between the habitat selection of male and female turtles. Christina was the only turtle for which data was collected throughout the entire study period, and she had the largest operational home range. It is probable that other turtles would have had larger home ranges had data been available over a larger time frame. Therefore, no conclusions can be drawn about possible differences in home range size between males and females.

However, groups, interns, or National Park employees involved in subsequent years of data collection should consider some trends found within this first year study. It is noteworthy that Charlie and Christina, the turtles for which the most data points were collected, were those with identifiable cover preferences, understory forest and successional field, respectively. With further data, other individuals may have also shown patterns for incidence in certain vegetation cover. Furthermore, as Christina was found in the understory forest area in the fall, it is reasonable to consider that Charlie was associated with forest habitat because he was collected later, i.e., Charlie might have been associated with successional field habitat earlier in the study period.

Both Christina and Charlie, the only turtles for which data on hibernation site was available, chose hibernation areas within understory forests. This is especially significant in Christina's case, because before this point she was found mostly in successional field habitat. This is consistent with other studies that have indicated that box turtles often hibernate in forested areas, perhaps for protection and moderated climate (Claussen et al. 1991).

All turtles exhibiting a soil type preference – Lucy, Charlie, Christina, and Peggy Sue – were found associated with some subset of Wayah sandy loam soil (Table 1). This is not surprising, as these are the predominant soils in the Purchase Knob area. It is possible, however, that physical attributes of this soil or the vegetation it supports are attractive to the turtles. Wayah sandy loam soils are often associated with high-elevation areas and, therefore, high-elevation vegetation, such as Fraser firs (National Cooperative Soil Survey). Data indicates that turtles are selecting areas in which fir and, more importantly, associated cover is prevalent. Analysis from this study indicates that turtles were found in managed field and successional field habitats for 74% of the turtle recovery observations made over the course of this study. Qualitative data regarding cover directly surrounding turtles upon location showed that turtles appear to be associated with herbaceous cover within the Fraser fir dominated areas, such as blackberry and goldenrod.

Rossell et al. (2006) found that turtles prevent desiccation by selecting for soil types that retain moisture and allow for high humidity. No soil humidity data was collected in this study. However, turtles were mostly associated with the WaD subset soil, which is of relatively gentle slope. Therefore, it may be reasonable to assume that turtles remained in areas with minimal runoff and maximal soil moisture. Additionally, turtle association with blackberry and goldenrod may indicate that turtles prevent desiccation by remaining in microhabitat areas in which vegetation cover allows for humid microclimates.

As mobility constraints are a factor in turtle habitat selection, a more thorough future approach may involve using ArcMap software to create polygons around each vegetation and soil type, in order to estimate the area of each polygon and assign a relative importance value to each vegetation and soil type based on area. As this is a preliminary study, the polygon-based approach may be implemented when further data are collected.

Supplemented with further data, this study will supply a better understanding of how eastern box turtles utilize habitat when relatively undisturbed. Identification of trends in selection of certain soil and cover areas may significantly contribute to better management and protection of this species.

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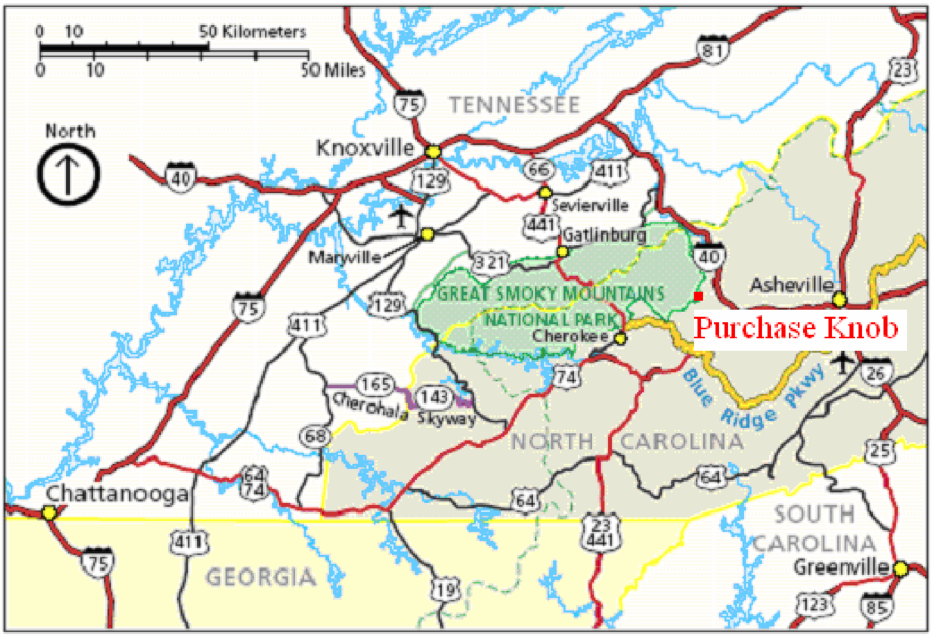
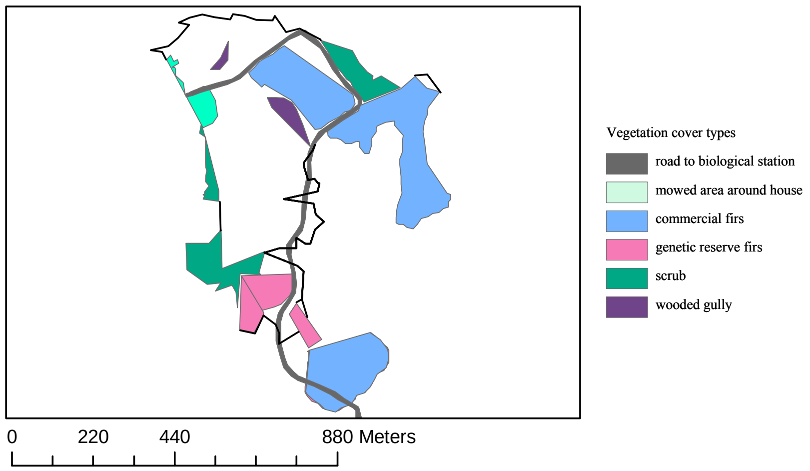
APPENDIX A. Map of Great Smoky Mountains National Park with Purchase Knob indicated.

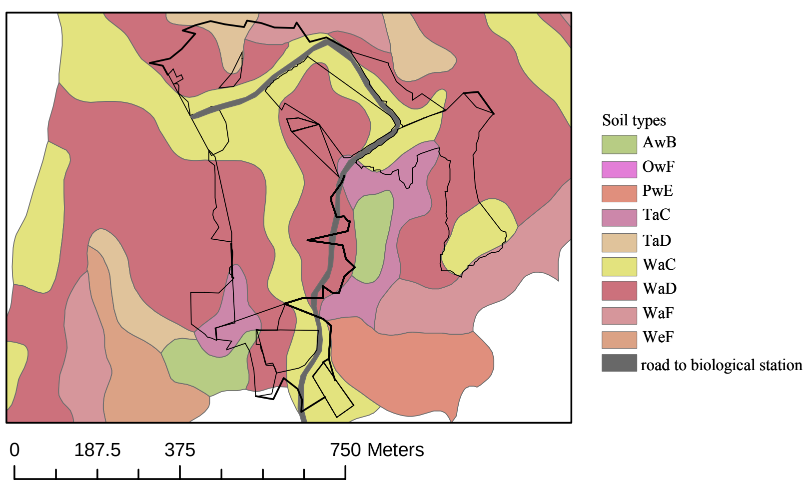


APPENDIX B. Vegetation cover type and soil type maps of Purchase Knob, Great Smoky Mountains National Park.

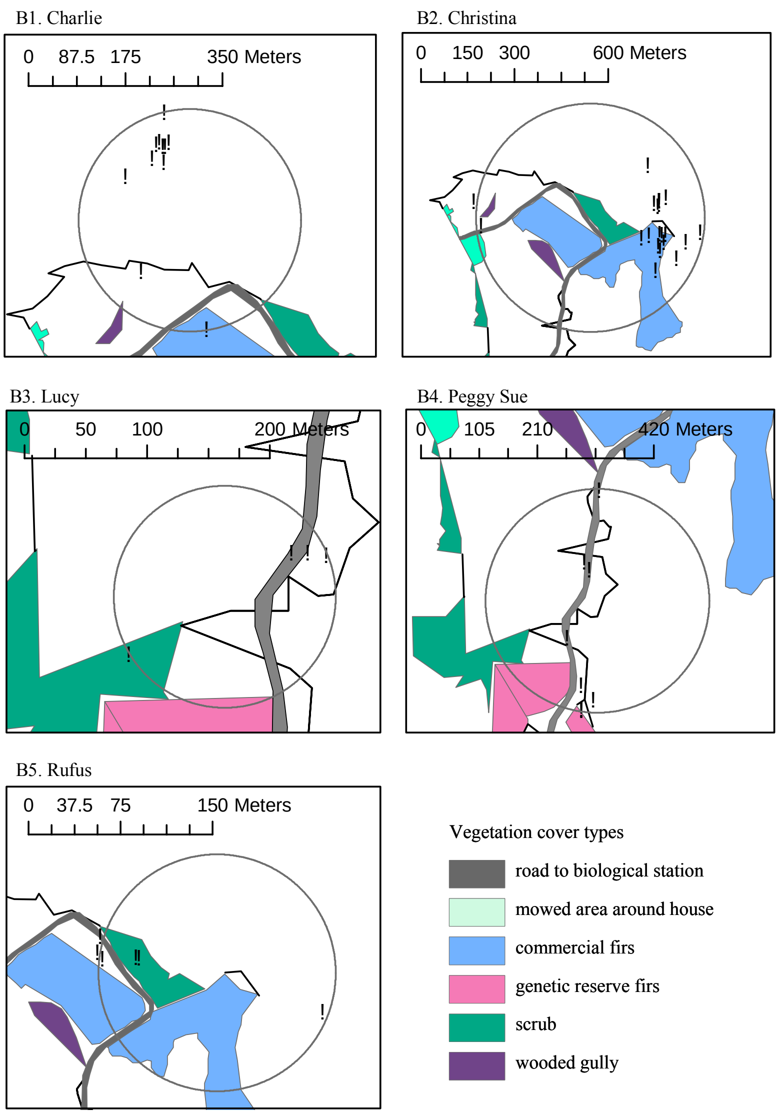
B1. Cover Type



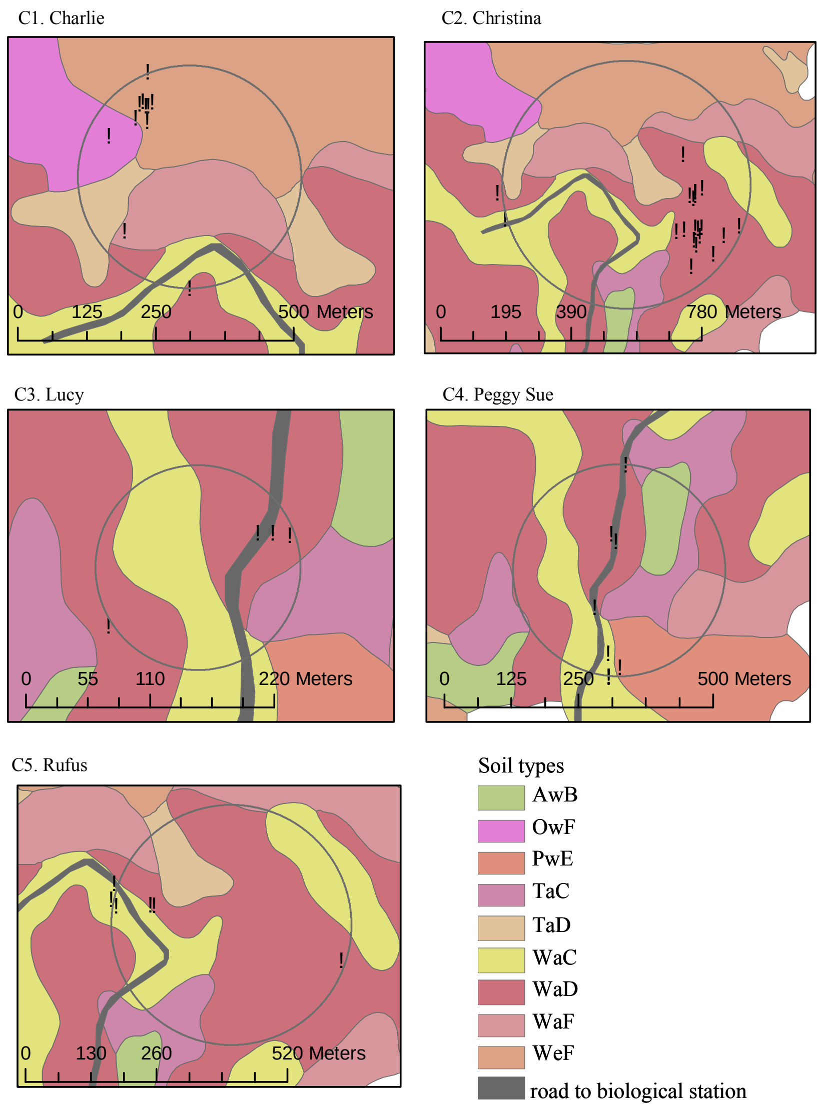
B2. Soil Type



APPENDIX C. Vegetation cover types within operational home ranges of five eastern box turtles studied at Purchase Knob, Great Smoky Mountains National Park.



APPENDIX D. Soil types within operational home ranges of five eastern box turtles studied at Purchase Knob, Great Smoky Mountains National Park.



APPENDIX E. Compiled data for five eastern box turtles studied at Purchase Knob, Great Smoky Mountains National Park during the 2006 field season.

Name	Date	Time found	Air temp. (°C)	Rain (mm)	Wind direction	Wind speed (mph)	Barometric pressure (Hg)	Dew point (°C)	Humidity (%)	Cloud cover	Easting
Charlie	8/25/2006	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	312282
	8/30/2006	n/a	20.5	6	N	2	29.91	19.4	87	partly cloudy	312234
	9/8/2006	1:30	18	4.9	n/a	n/a	30.19	14.4	58	overcast	312262
	9/20/2006	n/a	13.5	0	NE	3	n/a	n/a	71	Clear	312303
	9/22/2006	3:30	166	0.254	NW	3	30.1	13.8	92	overcast	312295
	9/27/2006	2:40	n/a	0	N	2	29.99	10.5	49	partly cloudy	312312
	9/29/2006	10:46	12.2	0	N	2	30.04	5.5	68	partly cloudy	312289
	9/30/2006	11:25	n/a	n/a	n/a	n/a	n/a	n/a	n/a	clear	312380
	10/6/2006	10:35	10	0.254	N	7	30.14	12.7	81	overcast/foggy	312304
	10/11/2006	10:00	15.5	0.254	NE	4	29.83	13.3	63	overcast	312305
	10/13/2006	12:13	16.1	0	NW	13	29.98	-6.1	63	clear	312301
	10/27/2006	9:36	6.6	0.254	SW	5	30.03	-6.1	86	overcast	312301
Christina	6/16/2006	7:55	15	0	SW	1	30.27	10.5	63	clear	312190
	6/27/2006	9:40	18.5	6	NE	2	30.05	16.6	90	overcast	312781
	6/28/2006	10:03	18.3	0	NE	2	30.21	15.5	78	partly cloudy	312764
	6/30/2006	n/a	20	0	N	4	30.21	15.5	78	clear	n/a
	7/5/2006	n/a	20	0	N	9	30.21	15.5	78	n/a	n/a
	7/11/2006	12:10	19.4	0	NW	2	30.27	18.8	81	vercast	312770
	7/18/2006	11:07	22.7	2	N	3	30.17	16.1	82	clear	312816
	7/20/2006	9:10	26.5	0	n/a	n/a	30.24	18.8	74	overcast	312758
	7/22/2006	n/a	n/a	n/a	n/a	n/a	29.93	19	n/a	overcast	312893
	8/1/2006	9:35	22.7	0	NW	3	30.12	20	72	clear	312847
	8/5/2006	11:20	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	312775
	8/15/2006	2:20	21.1	trace	NE	4	30.07	18.8	87	overcast / rainy	312704
	8/17/2006	n/a	19.4	trace	NE	5	30.25	17.7	71	n/a	312725
	9/8/2006	12:06	18	4.9	n/a	n/a	30.19	14.4	n/a	overcast	312727
	9/13/2006	7:42	17.7	0	N	6	29.93	11.1	69	partly cloudy	312762
	9/22/2006	6:19	12.7	0.254	SW	3	30.17	13.8	92	overcast	312749
	9/26/2006	12:45	14.4	0.4	SE	3	n/a	n/a	88	partly cloudy	312745
	9/29/2006	2:00	12.2	0	N	2	30.04	5.5	68	partly cloudy	312756
	9/30/2006	1:40	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	312761
	10/3/2006	3:30	n/a	n/a	n/a	n/a	n/a	n/a	n/a	clear	312167

Name	Date	Time found	Air temp. (°C)	Rain (mm)	Wind direction	Wind speed (mph)	Barometric pressure (Hg)	Dew point (°C)	Humidity (%)	Cloud cover	Easting
	10/13/2006	11:28	16.1	0	NW	13	29.98	-6.1	63	clear	312761
	10/27/2006	9:56	6.6	0.254	SW	5	30.03	-6.1	86	overcast	312761
Lucy	6/23/2006	n/a	20.5	3	NE	5	30.2	18.3	81	overcast	312279
	6/27/2006	10:20	18.5	6	NE	2	30.05	16.6	90	overcast	312411
	6/28/2006	8:40	18.3	0	NE	2	30.21	15.5	78	partly cloudy	312424
	7/5/2006	n/a	18.3	0	NE	2	30.4	15.5	78	n/a	n/a
	7/11/2006	13:20	19.4	0	NW	2	30.27	18.8	81	overcast	312439
Peggy Sue	6/27/2006	n/a	27	0	NW	2	29.99	16	86	partly cloudy	312426
	6/28/2006	8:50	18.3	0	NE	2	30.21	15.5	78	partly cloudy	312435
	7/5/2006	n/a	18.3	0	NE	2	30.21	15.5	78	overcast	312421
	7/11/2006	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	7/14/2006	8:40	17.7	1.016	SE	2	30.16	18.8	95	overcast	312420
	7/18/2006	10:23	22.7	2	N	3	30.17	16.1	82	clear	312421
	7/20/2006	9:50	26.5	0	n/a	n/a	30.24	18.8	74	partly cloudy	312442
	7/22/2006	n/a	n/a	n/a	n/a	n/a	29.93	19	n/a	overcast	312395
	8/1/2006	n/a	22.7	0	NW	3	30.12	20	72	clear	n/a
	8/30/2006	n/a	20.5	6	NE	na	29.91	19.4	87	partly cloudy	312453
Rufus	6/10/2006	n/a	17.2	0	NW	3	n/a	13.3	81	partly cloudy	312480
	6/13/2006	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	6/15/2006	n/a	18.5	0	NE	7	n/a	n/a	75	partly cloudy	312484
	6/21/2006	3:20	22.2	0	NE	5	30.18	13.3	57	partly cloudy	312474
	6/27/2006	11:25	18.5	6	NE	2	30.05	16.6	90	overcast	312559
	6/28/2006	9:30	18.3	0	NE	2	30.21	15.5	78	partly cloudy	312552
	6/30/2006	n/a	20	0	N	4	30.21	15.5	78	clear	n/a
	7/5/2006	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	7/18/2006	11:35	22.7	2	N	3	30.17	16.1	82	clear	312932
	8/1/2006	n/a	22.7	0	NW	3	30.12	20	72	clear	n/a
	8/12/2006	n/a	14.5	16.002	E	9	n/a	16	100	overcast	312427

APPENDIX E (CONT.). Compiled data for five eastern box turtles studied at Purchase Knob, Great Smoky Mountains National Park during the 2006 field season.

Name	Date	Northing	Elevation (m)	GPS Precision (m)	Activity	Ground temp. (°C)	Soil temp. (°C)	Relative humidity (%)	Vegetation/Habitat
Charlie	8/25/2006	3940231	1463.3	n/a	moving	n/a	n/a	n/a	managed field
	8/30/2006	3940198	1468.5	6	stationary	n/a	18	n/a	managed field
	9/8/2006	3940027	1468.2	6	stationary	23.5	12.5	81	successional field
	9/20/2006	3940224	1467.3	5	burrowing	n/a	n/a	n/a	u-story forest
	9/22/2006	3940261	1467.9	6	burrowing	13	19.5	95	forest, sparce u-story
	9/27/2006	3940260	1467.6	6	burrowing	18	13.5	n/a	u-story forest
	9/29/2006	3940256	1467	15	burrowing	11	11	n/a	u-story forest
	9/30/2006	3939922	1471.3	15	burrowing	19.5	11.5	n/a	u-story forest
	10/6/2006	3940314	1471.6	26	burrowing	14.4	14.9	n/a	u-story forest
	10/11/2006	3940253	1472.5	8	burrowing	14	12	n/a	u-story forest
	10/13/2006	3940253	1473.1	8	burrowing	7	11.1	n/a	u-story forest
	10/27/2006	3940253	1473.7	8	burrowing	9.5	9.8	n/a	u-story forest
Christina	6/16/2006	3939867	1496	n/a	moving	20.3	60.2	90	managed field
	6/27/2006	3939841	1436	6	stationary	16.85	13	90	u-story forest
	6/28/2006	3939789	1460	6	stationary	17.5	11	n/a	u-story forest
	6/30/2006	n/a	1463.9	n/a	n/a	n/a	n/a	n/a	n/a
	7/5/2006	n/a	1463.6	n/a	n/a	n/a	n/a	n/a	successional field
	7/11/2006	3939839	1463	5	stationary	24.5	14	n/a	successional field
	7/18/2006	3939763	1487	6	stationary	22	12	66	forest, sparse u-story
	7/20/2006	3939804	1459	21	stationary	18.5	12.5	82	successional field
	7/22/2006	3939847	n/a	28	feeding	19	12	91	forest, sparce u-story
	8/1/2006	3939817	1492	6	feeding	22	13	91	forest, sparce u-story
	8/5/2006	3939815	n/a	5	moving	n/a	n/a	n/a	n/a
	8/15/2006	3939830	1454	5	stationary	20.5	13.5	100	successional field
	8/17/2006	3940061	1470	7	stationary	23	15.5	75	successional field
	9/8/2006	3939836	1470.3	5	stationary	21.5	16	90	successional field
	9/13/2006	3939842	1469.4	6	stationary	11.5	16.5	n/a	successional field
	9/22/2006	3939725	1469.1	7	moving	13.9	12.1	n/a	u-story forest
	9/26/2006	3939939	1469.7	7	stationary	22	12	53	successional field
	9/29/2006	3939930	1468.8	7	burrowing	8.9	11	n/a	successional field
	9/30/2006	3939937	1470.7	n/a	moving/stationary	15	12	n/a	successional field
	10/3/2006	3939946	1471.9	12	stationary	14	14	57	u-story forest
	10/6/2006	3939960	1470.96	8	burrowing	10.2	12.1	n/a	u-story forest
	10/11/2006	3939948	1472.2	8	burrowing	13.5	13	n/a	forest, sparse u-story

Name	Date	Northing	Elevation(m)	GPS Precision (m)	Activity	Ground temp. (°C)	Soil temp. (°C)	Relative humidity(%)	Vegetation/Habitat
	10/13/2006	3939948	1472.8	8	burrowing	9.9	10.3	n/a	u-story forest
	10/27/2006	3939948	1473.4	8	burrowing	8.9	9.9	n/a	u-story forest
Lucy	6/23/2006	3939379	1413	10	stationary	23	20.5	83	managed field
	6/27/2006	3939461	1432	5	moving	22	14	n/a	managed field
	6/28/2006	3939461	1428	24	stationary	22	13	n/a	managed feild
	7/5/2006	n/a	1465.5	n/a	n/a	n/a	n/a	n/a	n/a
	7/11/2006	3939459	1424	5	stationary	32.5	14	n/a	succession
Peggy Sue	6/27/2006	3939527	n/a	n/a	stationary	18	n/a	n/a	managed field
	6/28/2006	3939512	1436	8	stationary	21.5	13.5	n/a	successional field
	7/5/2006	3939260	1417	5	stationary	25.2	16.1	60	successional field
	7/11/2006	n/a	1465.1	n/a	n/a	n/a	n/a	n/a	n/a
	7/14/2006	3939303	1427	15	stationary	21	12	n/a	u-story forest
	7/18/2006	3939258	1424	7	moving	19	12	66	u-story forest
	7/20/2006	3939277	1430	6	burrowing	19.5	12	83	forest, sparse u-story
	7/22/2006	3939389	n/a	11	stationary	22	12	100	u-story forest
	8/1/2006	n/a	1466.4	n/a	n/a	n/a	n/a	n/a	n/a
	8/30/2006	3939656	1415	5	stationary	n/a	20	n/a	u-story forest/successional field
Rufus	6/10/2006	3939954	1463	n/a	moving	22	26	n/a	managed field
	6/13/2006	n/a	1464.3	n/a	n/a	n/a	n/a	n/a	n/a
	6/15/2006	3939909	1460	n/a	stationary	21.5	n/a	85	successional field
	6/21/2006	3939922	1457	7	moving	21.2	16.5	76	successional field
	6/27/2006	3939911	1463	5	stationary	24.5	12.5	n/a	successional field
	6/28/2006	3939912	1442	6	stationary	21.5	12.5	n/a	successional field
	6/30/2006	n/a	1464.5	n/a	n/a	n/a	n/a	n/a	n/a
	7/5/2006	n/a	1464.9	n/a	n/a	n/a	n/a	n/a	n/a
	7/18/2006	3939801	1506	8	stationary	23.75	11	67	successional field/u-story forest
	8/1/2006	n/a	1465.8	n/a	n/a	n/a	n/a	n/a	n/a
	8/12/2006	3939364	1426	7	moving	15.5	12	100	forest, sparse u-story

APPENDIX E.

APPENDIX F. Sample data sheet for tracking eastern box turtles in 2006 at Purchase Knob, Great Smoky Mountains National Park.

Turtle Tracking Data Sheet **North Carolina, Haywood County, Great Smoky Mtn NP, Purchase Knob**					
Date ________		Data recorder________	**Name**______________		
Tracking team members _____________			Scan # or Freq #______		
Time found ____________					
Weather Data from Purchase Knob & NOAA					
Waynesville, NC weather station					
Temperature (°F)	______	Barometric Pressure (Hg)	______		
Precipitation (since 12 a.m.)	______	Dew Point (°F)	______		
Wind Direction	______	Humidity (%)	______		
Wind Speed	______	Cloud Cover	Clear	Partly Cloudy	Overcast
Current Location			**Turtle Activity**		
GPS waypoint #	______		Moving	Copulating	
Lat & Long N ______ W______			Stationary	Burrowing	
UTM coordinates 17S______ ______			Feeding (*if feeding note food items below*)		
			Food_____________		
Data at Site			**Vegetation (*circle one*)**		
Physical Characteristics			Managed field	Successional Field	
Ground Temp. (°C)	________		Riparian Area	Understory Forest	
Soil Temp (°C)	________		Water	Forest, sparse u-story	
Relative Humidity (%)	________				
Notes: Where found, typical plants in area, unusual behavior, or condition of transmitter. Anything that is recurring between specimens or in stark contrast; these are the observations that will lead to future projects Plant Species:					

COMPARISON OF SOIL CO_2 EFFLUX IN DECIDUOUS AND CONIFEROUS (WHITE PINE) WATERSHEDS IN THE COWEETA BASIN AT DIFFERENT TEMPORAL AND SPATIAL SCALES

ANNEMARIE M. NAGLE

Abstract. Soil CO_2 efflux is an essential component of the global carbon cycle. Because respiration-derived CO_2 escaping from the forest floor is such a huge component of total annual carbon emissions to the atmosphere, understanding factors controlling efflux and quantifying their effects is essential in formulating projections under global climate change. Soil temperature and soil moisture are well-established environmental predictors for soil respiration rates. In this study we compare trends in soil CO_2 efflux, soil temperature, and soil moisture at diurnal and annual temporal scales between paired watersheds differing in cover type (white pine monoculture vs. mixed hardwoods). Findings showed that the majority of the variation seen in soil temperature and moisture occurs at the annual scale, and that the two watersheds do not vary markedly in annual patterns for these two drivers. Yet, significant differences in summer and fall efflux rates between the two watersheds point to other, possibly biotic differences in drivers.

Key words: carbon cycle; global climate change; net ecosystem exchange; soil CO_2 efflux; soil moisture; soil temperature; respiration.

INTRODUCTION

The study of nutrient dynamics in forested ecosystems has contributed a great deal to our understanding of essential ecological processes such as succession, biomass accumulation, forest productivity, soil development, and decomposition. The carbon cycle is an important subset of these nutrient dynamics. Atmospheric carbon in the form of CO_2 is sequestered by photosynthesizing organisms and forms the building blocks for their structural and functional components. Plant death and litterfall contribute organic material to the forest floor to form detritus, which is broken down by soil microbes and fungi during decomposition. These soil organisms utilize the organic carbon in construction of their own tissues, and release the remainder of the detrital carbon to the atmosphere as metabolic waste, in the form of respiration-derived CO_2. Respiration in the highly active, rapidly growing, fine roots of plants also releases CO_2 to the atmosphere (Waring and Schlesinger 1985). The combined release of CO_2 from heterotrophic soil microbes, decomposing and mycorrhizal fungi, and plant roots is termed soil CO_2 efflux, and is the primary focus of this study (Law 2001).

The net difference between the amount of carbon released from soil CO_2 efflux and aboveground respiration, and carbon sequestered by autotrophs is termed Net Ecosystem Exchange (NEE). NEE determines if a system is a carbon source or sink, depending on the ecosystem in question, season, time of day, or environmental variables such as moisture, temperature, nutrients, and disturbances (Law 2001). The NEE of an ecosystem plays a role in the level of organic matter storage and buildup in the system. A general latitudinal gradient in efflux rates exists globally, with carbon turnover being extremely high in hot tropical forests, resulting in little carbon storage in the soil, and low in cold boreal forests, which experience large-scale accumulation of soil organic material (Valentini 2000, Khomik 2006). The effects of global climate change on ecosystem NEEs has become an important research topic in recent years. Soil CO_2 efflux, which constitutes 60-90% of net CO_2 released to the atmosphere in temperate forests (Valentini 2000, Law 2001), is likely more responsive to temperature increases than primary production, so increases in global temperatures are most likely to result in conversion of current carbon sinks to sources of atmospheric carbon (Fierer 2006). Because of the important implications that CO_2 efflux has in global climate change, quantifying efflux rate for a variety of Earth's ecosystems and understanding the factors influencing it is extremely important (Liu 2006).

Two very important environmental predictors of soil CO_2 efflux, soil temperature and soil moisture, have been well established (Wen 2006). Previous studies have shown that soil temperature is the driver most highly correlated with measured CO_2 efflux rates (Lloyd and Taylor 1994, Kirschbaum 1995, Fierer 2006, Liu 2006). Temperature and efflux are generally positively correlated. This is due to the fact that microbial, fungal, and autotrophic metabolic rates are highly dependent upon the temperature of the surrounding soil. Higher temperatures increase metabolic activity resulting in more respirative CO_2 release, whereas low temperatures inhibit it (Lloyd and Taylor 1994, Kirschbaum 1995). Soil moisture is another recognized driver of efflux rates, but has not been shown to be as highly correlated as soil temperature. Overall, the relationship between soil moisture and efflux tends to be parabolic. Very high soil moistures tend to result in anaerobic conditions, in which there is very little respiration. Low soil moistures also inhibit both heterotrophic and autotrophic activity levels, so the highest effluxes are generally seen at intermediate moisture levels (Howard and Howard 1993, Khomik 2006). Biotic factors, such as vegetation cover, also play important roles in determining efflux rates, and each biome type tends to possess characteristic efflux values (Meyer 2006).

In this project, we used a paired watershed study to examine the effect of converting a mixed hardwood forest to a white pine (*Pinus strobus*) monoculture on carbon cycling within the system and on soil CO_2 efflux in particular. We used two different data collection systems to monitor diurnal, seasonal, and topographic patterns in efflux, as well as two of its important drivers, soil moisture and soil temperature, in each watershed. We compared patterns in efflux rates and in the two drivers on diurnal and annual scales for the two watersheds. We also quantified soil moisture and soil temperature as predictors for efflux in each watershed. Finally, continuing periodic litter collection and pending analysis for C and N concentrations will provide a comparison of litter productivity for the two watersheds.

MATERIALS AND METHODS

Study site

Our study site is located in the Coweeta basin, near the town of Otto in western North Carolina. Watershed 17 (WS 17) was used as our treatment watershed, and adjacent watershed 18 (WS 18) was used as the reference. Both watersheds have a northwest aspect, and are close in size. Watershed 18 is a native mixed hardwood stand that has remained undisturbed for about 80 years. (Coweeta 2006). The mixed hardwood forest originally covering WS 17 was clearcut in 1942, and suckers were cut almost annually until 1955. White pine seedlings were planted over the entirety of the watershed in 1956, and released from hardwood competition with herbicides and cutting (Swank and Douglass 1974).

Data Collection

Automated and manual systems were used to collect data on soil CO_2 efflux and soil moisture and temperature. The automated systems, installed in 2004 in WS18 and in 2005 in WS17, consist of a series of 8 to 10 soil collars arranged in a random array at mid-slope elevations in each watershed. Compressed air drives the opening and closing of soil collar lids for data acquisition. Soil efflux is measured on a continuous basis with this system, with sampling occurring at 5 second intervals during a collar measurement and each collar being measured 15 to 16 times per day. Soil moisture and temperature data were collected at 9 to 10 minute intervals. Information collected using this system allowed us to examine temporal patterns (diurnal and seasonal) in efflux and drivers. We began collecting data with this system beginning in 2004 and 2005, but data from the year 2006 was more complete and was therefore used in modeling annual trends in soil temperature and moisture. After examining diurnal data across a series of days, Julian day 204 (23 July) in the year 2005 was chosen as a representative day for modeling typical diurnal patterns at both sites.

The manual data collection system consists of a portable infrared gas analyzer unit that is attached to permanently affixed PVC soil collars during measurements, and an attached probe that measures soil temperature near the collar. Three topographical zones (ridge, mid-slope, and cove) were designated in each watershed. In each of these zones, three $900m^2$ plots were marked, and five soil collars were randomly placed within each plot. Measurements are taken monthly, and data from the two watersheds are collected on two consecutive days as nearly as possible. The average distance from the lip of the collar to the leaf litter within it is measured for each collar, and entered into the gas analyzer unit to calculate the volume of gas the collar holds. Air within the collar is scrubbed of CO_2 to a pre-set lower boundary below ambient concentration, and CO_2 concentration is then measured in the chamber at 2 second intervals for a 60 second period. This number is then divided by the calculated collar volume for a volumetric efflux rate given in $\mu mol\ m^{-2}\ s^{-1}$. Soil moisture is also measured at 10cm depth in close proximity to each collar. Data collected using this system allows a view of topographical (spatial) patterning in efflux and drivers.

Leaf litter traps were used to collect litterfall in each of the nine plots in both watersheds. Litter was then sorted according to whether it was leaf material or other debris in WS 17, and according to species for WS 18. Sorted litter is slated to be weighed, ground, and chemically analyzed for C and N concentrations.

Data Analysis

SAS version 9.1 (SAS Institute, 2004) was used to process flux and drivers data and to analyze the relationships between them. SigmaPlot® version 9.0 was used for graph creation, and linear regression was used to evaluate relationships between drivers and efflux rates. ANOVA was used to determine relative contributions of soil temperature and soil moisture to variation seen in both watersheds.

RESULTS

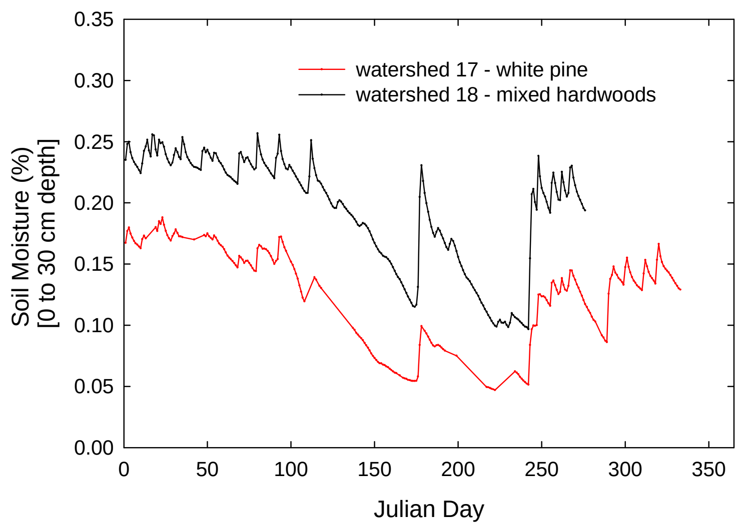


FIG. 1. Annual patterns in percent soil moisture content at 0 to 30cm soil depth for WS 17 and 18 at the autochamber (mid-slope) locations in 2006.

Annual soil temperature patterns track one another closely within the two watersheds, but WS 18 shows consistently higher moisture levels (Fig. 1).

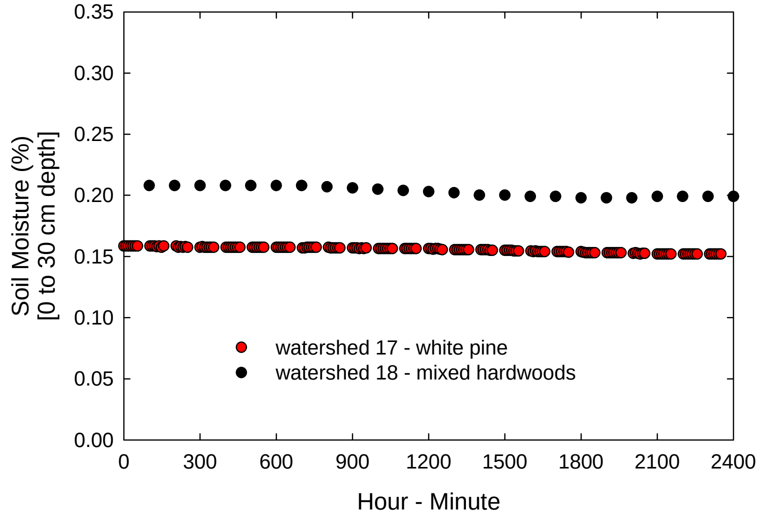


FIG. 2. Diurnal patterns in percent soil moisture content at 0 to 30cm soil depth for WS 17 and 18 at the autochamber (mid-slope) locations on Julian Day 204 (23 July), 2005.

There is very little variation in soil moisture on the diurnal scale, and the majority of the variation we see in this predictor is on an annual basis (Fig. 2).

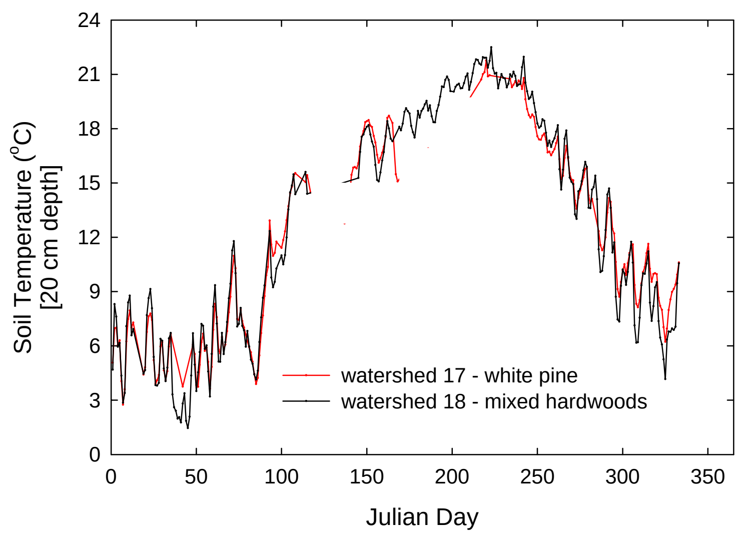


FIG. 3. Annual patterns in soil temperature at 20cm soil depth for WS 17 and 18 at the autochamber (mid-slope) locations in 2006.

Similar to the overall patterning seen in soil moisture, annual soil temperatures within the two watersheds track one another closely. Peak temperatures are seen between Julian Days 200-250 (August and September) and minimum annual temperatures are seen between Julian Days 0-50 (January and February; Fig. 3). This annual pattern is fairly typical for this region (Hursch 1949).

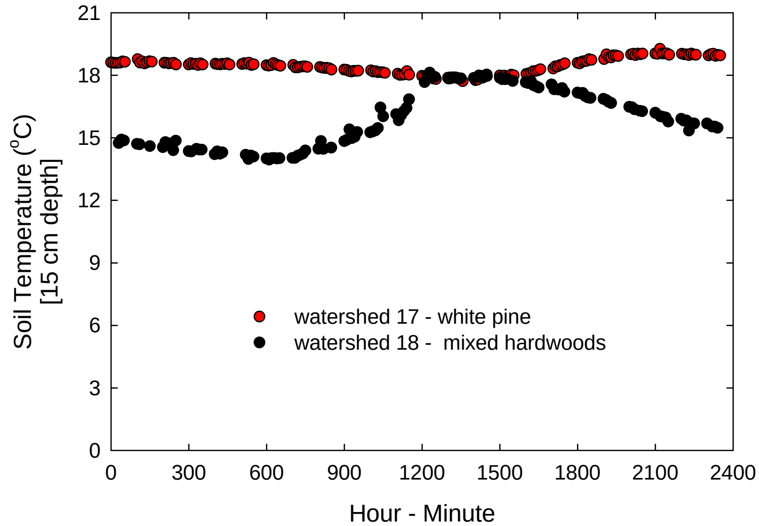


FIG. 4. Diurnal patterns in soil temperature at 15cm soil depth for watersheds 17 and 18 at the autochamber (mid-slope) locations on Julian Day 204 (23 July), 2005.

More variation is seen on the diurnal scale in WS 18 than in WS 17. Soil temperatures in WS 18 rise and peak around midday, and then gradually drop. Little variation is seen throughout the day in WS 17 (Fig. 4). Though some changes are seen on the diurnal scale, again, the majority of the variation seen in this predictor happens at an annual temporal scale.

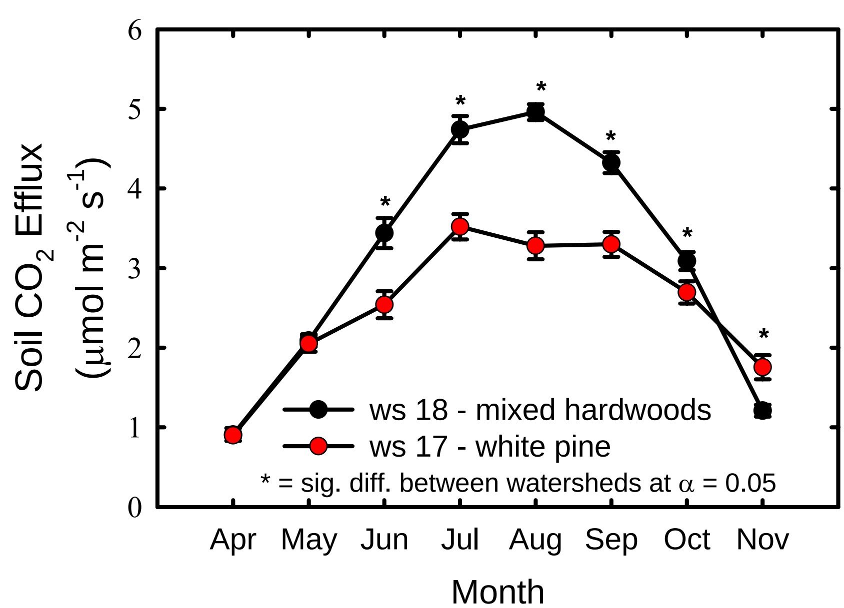


FIG. 5. Monthly (seasonal) patterns in soil CO_2 efflux for watersheds 17 and 18 for 2006. Data points represent the mean of the nine manual plot averages in each watershed. Standard errors are shown for each plot mean with error bars and an asterisk denotes significant differences at α=0.05. These data were collected using the manual system.

Soil CO_2 efflux values for watersheds 17 and 18 collected with the portable infrared gas analyzer unit were essentially the same for the months of April and May. Divergence occurred in the month of June, with WS 18 showing consistently significantly higher efflux rates throughout the summer months. Values for the two watersheds again begin to converge in the fall months. A switch in the relative magnitude of efflux occurred in the month of November, with efflux values seen in WS 18 falling below those seen in WS 17, likely due to a significant rainfall event between measurements of WS 17 and WS 18 (Fig. 5).

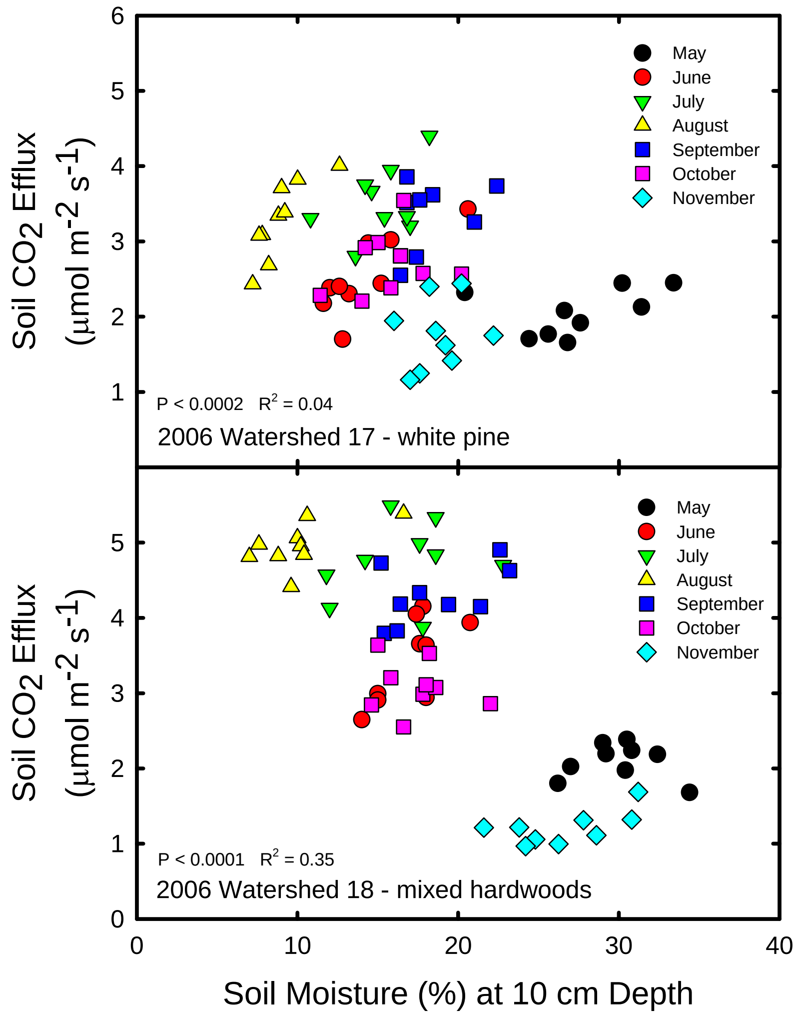


FIG. 6. Soil moisture content at 10cm soil depth as a predictor for soil CO_2 efflux rates for the months May-November, 2006. Significant P-values for both watersheds indicate a relationship, but low R^2 values indicate moisture does not explain much of the variation in efflux.

A statistically significant relationship between soil moisture and soil CO_2 efflux is seen for both watersheds (WS 17, $P<0.0002$; WS 18, $P<0.0001$). Soil moisture does not explain a great deal of the variation seen in efflux however (WS 17, $R^2=0.04$; WS 18, $R^2=0.35$). The difference in soil moisture content between the two watersheds due to a rainfall event between measurement days in the month of November is nearly 10% (Fig. 6).

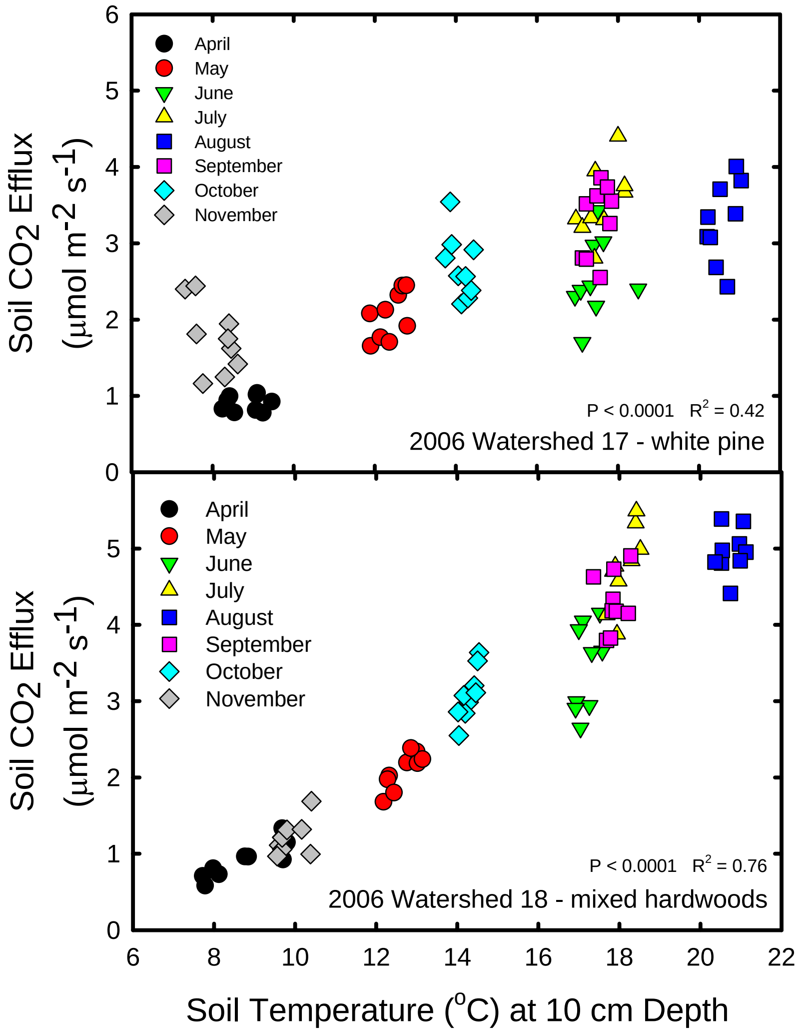


FIG. 7. Soil temperature at 10cm soil depth as a predictor for soil CO_2 efflux rates for the months April-November, 2006. Significant P-values for both watersheds indicate a relationship, and much higher R^2 values indicate temperature explains much more of the variation seen in efflux, especially for WS 18.

A statistically significant relationship between soil temperature and soil CO_2 efflux is seen for both watersheds (WS 17, $P<0.0001$; WS 18, $P<0.0001$). Soil temperature explains a great deal more of the variation seen in efflux values than soil moisture, which was expected (WS 17, $R^2=0.42$; WS 18, $R^2=0.76$). A general seasonal trend can be seen tracking the relatively straight line regression (Fig. 7).

DISCUSSION

Figure Interpretation

Soil moisture trends for watersheds 17 and 18 on both annual (Fig. 1) and diurnal (Fig. 2) scales track one another relatively closely in overall pattern. Yet, we see that soil moisture content in WS 18 is consistently higher at both temporal scales. There are several possible explanations for this pattern. First, the autochamber location in WS 18 is situated in a flat cove region, which forms a sort of basin that collects runoff on its way down the watershed. The autochamber location in WS 17, on the other hand, is situated on a steep slope that is likely very well-drained throughout the year. This topographical difference in the two autochamber sites may explain the consistently higher soil moistures seen on both temporal scales. Second, it is possible that vegetative factors may contribute to differences in soil moisture content in the watersheds as well. Canopy interception of precipitation by the densely packed white pines in WS 17 is higher than that seen in WS 18, reducing the total throughfall of moisture (Waring and Schlesinger 1985). The reduction in rainfall reaching the forest floor in WS 17 could account, at least partially, for the differences in soil moisture contents seen between the watersheds.

Overall, soil moistures vary little over the course of a day (Fig. 2), in the absence of a rainfall event. The fact that the majority of variation seen in moisture occurs at an annual scale, and the fact that soil moisture is known to explain a small part of variation in respiration that we see between watersheds, we would expect that the majority of soil moisture's effects on efflux will be seen at annual time scales.

Soil temperatures in the two watersheds track one another closely on an annual basis. However, we see more variation in diurnal soil temperatures in WS 18 than WS 17 (Fig. 4). Differences in diurnal soil temperature patterning may again be explained by differences in vegetative cover. The closed, dense canopy seen in the white pine stand allows very little light penetration to the forest floor, reducing heating via insolation. The canopy of WS 18 on the other hand is more open, allowing more light penetration, and presumably more warming of the forest floor throughout the day. This explanation would be consistent with the observed diurnal pattern in soil temperature for WS 18, as it peaks during peak hours of solar radiation, at hour 12:00.

Figs. 6 and 7 show the relative contributions of soil moisture and soil temperature to patterns seen in soil CO_2 efflux in both watersheds. Overall, relationships were as expected, with soil temperature the primary driver for measured efflux, and soil moisture a secondary driver. Soil moisture and soil temperature both predicted more of the variation seen in WS 18 (Soil moisture, R^2=0.35; Soil temp, R^2=0.76) than in WS 17 (Soil moisture, R^2=0.04; Soil temp, R^2=0.42). The lower predictive abilities of the two drivers we examined for WS 17 could be a result of more significant biotic controls over respiration rates in this watershed, details of which will be discussed later.

Finally, Fig. 5 shows a very interesting diverging pattern in CO_2 efflux values beginning in June and continuing throughout the summer months and into the fall. WS 18 has consistently higher effluxes after June, but the differences decrease in the fall. It is clear that there are different processes occurring in the two watersheds, especially in the summer months, but our data do not provide much insight as to the cause of these differences. It is not evident from annual temperature and moisture patterns examined for the two watersheds that these drivers are the origin of differences, due to the fact that both overall patterns track one another closely (Figs. 1 and 3).

Possible Interpretations for Efflux Differences

Differences in monthly efflux rates between the two watersheds apparently occur independently of soil moisture and temperature, and are therefore potentially biotic in origin. The influences of several speculative biotic factors may cumulatively explain the variation we see. The first of these potential factors could be the developmental stage of the trees on WS 17. At approximately 50 years old, these white pines have presumably passed their peak growth periods, and growth rates may be declining. A decrease in growth rates would likely result in a decrease in fine root growth and activity, causing the autotrophic respiration component in WS 17 to be reduced.

Secondly, litterfall composed almost exclusively of pine needles in WS 17 could cause differences in soil chemistry, which may affect microbial activity and responsiveness to temperature and moisture change. Pine litter typically represents poorer quality organic substrate than deciduous litter, which poses barriers to decomposition (Waring and Schlesinger 1985). Decomposition may therefore proceed at a slower rate in WS 17, causing the measured efflux to be lower. Future litter quality analysis will provide information concerning C and N concentrations and ratios in pine and deciduous litter, which will give us an idea of nutrient sources available for decomposer use.

Lastly, the presence of different types of microbial communities or variations in microbial diversity in the two watersheds could also contribute to differences in efflux. Soil chemistry differences or differences in biotic assemblages in WS 17 could support different types or quantities of soil microbes (Soe and Buchmann 2005, Meyer 2006).

Significance

The most significant corollaries of this study are in global climate change. The greater sensitivity of rates of soil microbial respiration to temperature increase relative to net primary productivity has already been discussed. Increases in global temperatures by even a few degrees could potentially cause a net transfer of carbon currently sequestered in soils to the atmosphere. The fact that average temperatures are expected to increase most markedly in boreal regions, where massive quantities of undecomposed organic material are stored in very thick organic soils, is particularly disturbing (Fierer 2006). Understanding and quantifying the effects of predictors for efflux rates in different types of ecosystems is therefore very important to quantifying effects of global climate change. Current climate models poorly describe effects of climate change on efflux rates, partially due to a limited understanding of factors controlling sensitivity and response of soils to temperature increases (Khomik 2006).

Implications of soil CO_2 efflux rates in soil formation and characteristics are also important to note. Changes in decomposition rates and therefore in accumulation rates of soil organic material and nutrient mineralization rates can greatly influence the availability of nutrients to plant communities. Decomposition and its implications for plant communities could have resounding effects on the processes of sedimentation and erosion. Decreases in depth of soil surface organic material could adversely affect soil moisture retention and reduce insulation of the forest floor from temperature fluctuations (Waring and Schlesinger 1985). Increases in stream sedimentation and decreases in soil moisture retention could have grave implications for sensitive animal species as well, such as stream invertebrates and terrestrial salamanders.

Further Study

The two years of data discussed in this paper are part of a long term study, and similar data will be collected in years to come. Continuation of litter collection and completion of C and N concentration analysis will allow for comparisons of litter productivity between the two watersheds for 2006. Also, because litter productivity is variable and often differs on a year to year basis, comparison of multiple years of litter quality and efflux data will be valuable (Waring and Schlesinger 1985). In a similar light, continuation of respiration measurements with both the manual and automated data collection systems will allow us to see if the patterns in efflux rates observed for 2006 were anomalous, or if they are repeated over time. Finally, a closer examination of the components of efflux (autotrophic, microbial, and fungal inputs) and quantification of their individual contributions could provide us with a better picture of why and how the watersheds differ.

ACKNOWLEDGEMENTS

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URBANIZATION OF A HEADWATER STREAM AND ITS IMPACT ON THE ABUNDANCE OF AQUATIC SALAMANDERS

BETH ANNE PURVIS

Abstract. Salamanders are indicator species of stream health because of their low tolerance for environmental variance. I assessed salamander abundance in three study sites of Mill Creek that flows through the town of Highlands, NC and the effects of sedimentation on associated microhabitats. Area-constrained searches of rocks demonstrated a significant reduction in salamander diversity in Mill Creek due to heavy urbanization, inadequate riparian buffer strips, and severe sedimentation.

Key words: Desmognathus*; salamanders; sedimentation, stream impairment; Southern Appalachians; urbanization.*

INTRODUCTION

The southern Appalachians are renowned for their diversity and abundance of salamanders (Hairston 1949). Streams and riparian areas are important habitats for a variety of aquatic and semi-aquatic species (Krzysik 1979). Salamander density and biomass in streamside habitats are extremely high in this region (Petranka and Murray 2001). Salamanders have been found to be good indicator species of stream and riparian zone health (Welsh and Ollivier 1998) because of their low mobility, strong site fidelity, lengthy larval period, ability to populate beyond obstacles of movement, and limited environmental tolerance (Bisson et al. 2002, Raphael et al. 2002).

Mill Creek is a 1.4 mile length stream that runs through the center of the town of Highlands, NC and forms the headwaters of the Cullasaja River. It begins at Lindenwood Lake (formerly Ravenel Lake) at the Highlands Biological Station and empties into Mirror Lake, and is responsible for draining the entire town of Highlands. Urbanization of the headwaters has caused a severe reduction in riparian buffer, which has consequently resulted in heavy sedimentation within Mill Creek. In addition, artificial dams that have been constructed in order to make artificial pools for aesthetic purposes have changed the flow of the stream and have altered microhabitats.

In 2002, the Water Assessment and Restoration Project was created by the North Carolina Department of Environmental and Natural Resources Division of Water Quality (NCDWQ) to assess the health of the creek, and to determine causes of any impairment based on surveys of benthic macroinvertebrates and chemical analyses of the water. This report categorized the creek as "impaired" in its entirety, and listed the greatest causes of impairment as stormflow scour of benthic microinvertebrates and organic microhabitats downstream due to a combination of gradient force and the high proportion of impervious surfaces in town, lack of upstream colonization sources for the benthic community after storms, toxicants and in-stream impoundments in tributaries, and lack of organic microhabitat such as leafpacks and sticks (NCDWQ 2002). A similar study performed by the Little Tennessee Watershed Association (2003) from 1990-2002 on water quality and habitat trends for macroinvertebrates and fish in the Upper Little Tennessee Watershed classified Mill Creek as "poor."

Many factors that impair aquatic insect and fish environments can also impact salamander habitats. Salamanders are very sensitive to toxins because they respire through their skin (Feder 1983). Riparian buffer zones help to prevent runoff and erosion into the stream that can alter stream microhabitats important for many species (Semlitch and Bodie 2003). Not only does the buffer zone maintain stream microclimates (Brosofske et al. 1997) and filter runoff pollutants (Semlitsch and Bodie 2003), it is core habitat for foraging and breeding by salamanders (Petranka and Smith 2005, Crawford and Semlitsch 2006).

In addition, aquatic salamander diversity is strongly correlated with density of rocks in a stream (Davic and Orr 1987). Streams with varying depths and rocks sizes show the largest amount of diversity (Kleeberger 1985). Salamander abundance is reduced by sedimentation of streams and substrate embeddedness (Orser and Shure 1972, Welsh and Ollivier 1998, Lowe and Bolger 2002, Lowe et al. 2004). The purpose of this study is to examine how the loss of microhabitats due to sedimentation has affected population density and diversity of salamanders in Mill Creek.

MATERIALS AND METHODS

Description of Study Sites

Three Mill Creek sites were selected based upon locations that had been previously assessed for benthic macroinvertebrates (NCDWQ 2002) and fish (LTWA 2003). At each location, a 25 m transect was established within the creek. Buffer widths were measured at 12.5 m intervals along both sides of the transect, from the streambanks to the far edge of the riparian forested strip. The first site is located above the town center along Laurel Street (35^{o}03'/83^{o}11', Fig. 1). This site has an average terrestrial buffer width of 2.85 m, and there are very few exposed rocks in the stream because the bottom is covered in sediment. In addition, there is little organic microhabitat such as leafpacks and woody substrates. Using established habitat assessment guidelines (Barbour and Stribling 1994), this section of Mill Creek was characterized was "poor."

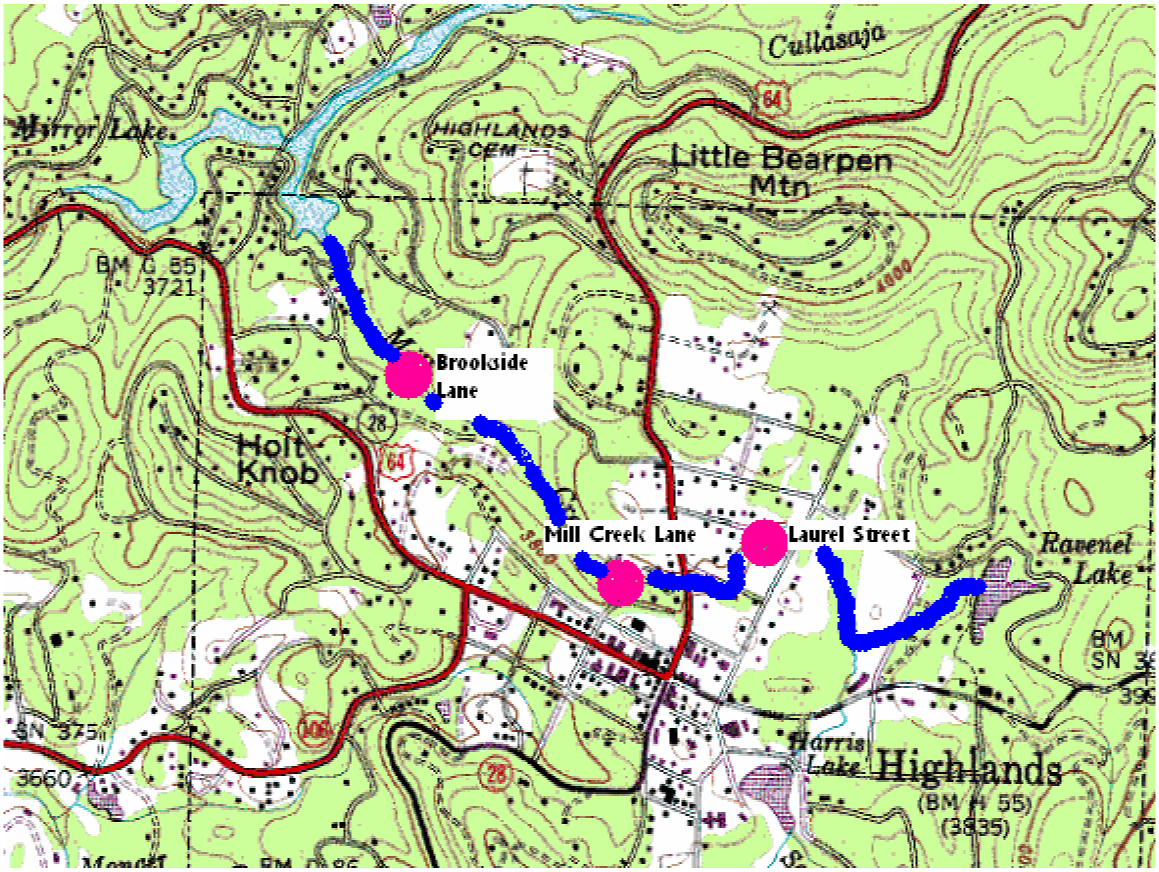

FIG. 1: Location of study sites along Mill Creek.

The second site is located near the center of town downstream from the Laurel Street site, just below the end of Mill Creek Lane (35°03’/83 °12’, Fig. 1). The buffer zone at this site averages 27.3 m, and there are many rocks and little sediment in this part of the creek. Water flow is swift and there is a lot of riffling. The habitat of this section of Mill Creek was assessed as “good.”

The third site is located furthest downstream in a residential area near Brookside Lane (35°04’/83 °12, Fig. 1). The buffer zone on one side averages 8.85 m, but on the other side there is none. There are many rocks but most are covered with sediment. The water flow here is reduced due mostly to artificial dams built to create pools. The habitat of this section of Mill Creek was also assessed as “poor.”

A reference site (NCDWQ 2002) was also established along a section of Skitty Creek outside of Highlands within the Nantahala National Forest at Cliffside Recreational Area (35°05’/83 °13, Fig. 2) for comparative purposes. The site has a buffer zone greater than 50 m on either side of the stream. The site was assessed as “excellent” habitat with lots of rocks, frequent riffles, and pools.

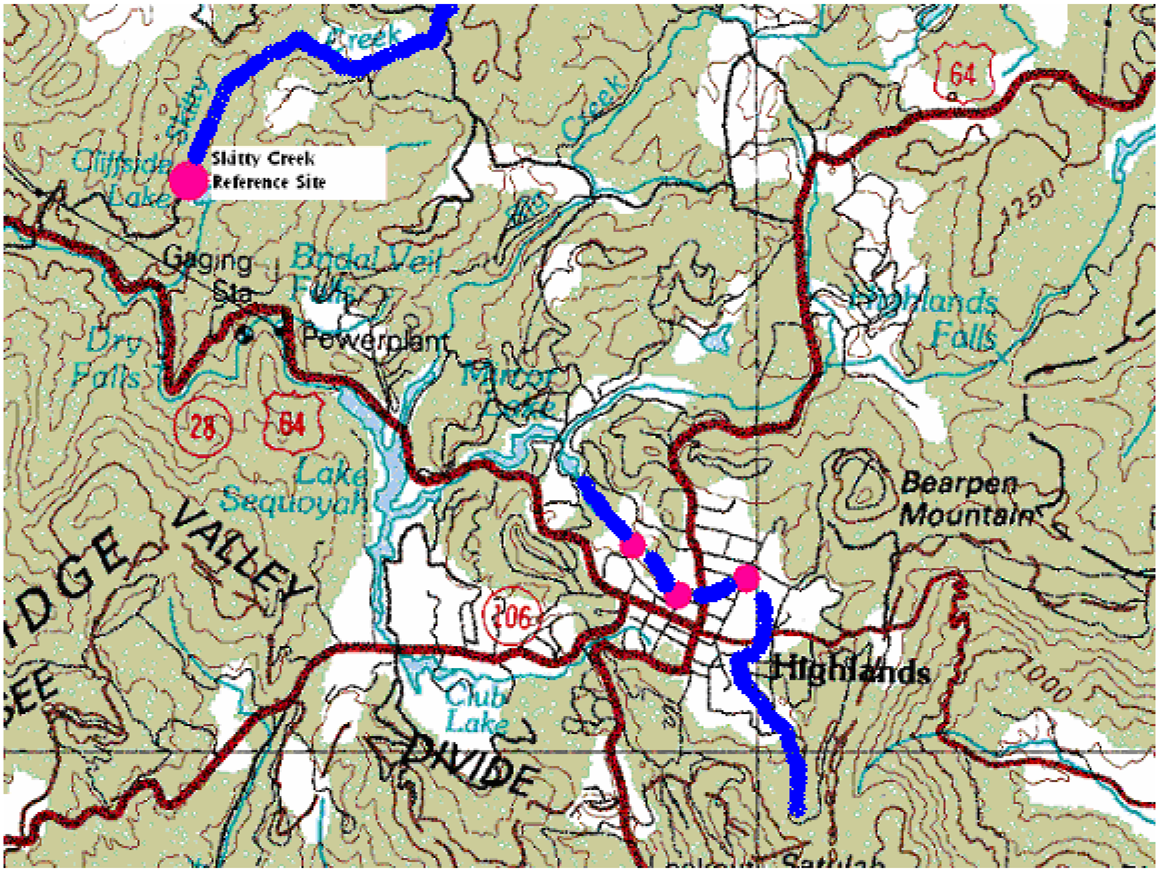

FIG. 2: Location of reference site along Skitty Creek in the Nantahala National Forest.

Salamander Surveys

Eleven surveys of aquatic salamanders were conducted at each site from September to November 2006 using daytime area-constrained searches of cover objects (Petranka and Smith 2005). All rocks greater than 10 cm in diameter that were movable and not embedded in sediment were turned over, tallied, and replaced. Each salamander found was identified to species, noting larvae, and its snout to vent length (SVL) was also measured. A minimum of two days elapsed between each survey in order to minimize disturbance.

Water Quality Assessment

Several other environmental variables were measured during each survey. Average water depths were obtained by measuring the depth with a meter stick at three randomly selected points along each transect. Aquatic salamanders are sensitive to water temperature and chemistry (Feder 1983), so I also measured the dissolved oxygen (DO) with an YSI 85 Oxygen, Conductivity, Salinity and Temperature meter, acidity with a Hanna Instruments electric pH probe, and temperature with a submersible outdoor thermometer.

Analysis of Data

Because stream sample sites varied in width, captures of salamanders were converted to captures per m^2. Comparisons of salamander density and environmental variables at each study site with those at the reference site were performed using Student's *t*-tests. In addition, correlation analysis was used was used to examine relationships of captures with each environmental variable measured.

RESULTS

The water at all three Mill Creek sites was significantly deeper and warmer than that of the reference site (Table 1). However, dissolved oxygen (DO) was similar at all sites (Table 1). Water was significantly more acidic at Laurel Street, but was similar to the reference site at Mill Creek Lane and at Brookside Lane (Table 1). Cover objects (rocks) were significantly more numerous at the reference site than any of the three Mill Creek sites (Table 1).

Variable	Skitty Creek (Reference)	Laurel Street			Mill Creek Lane			Brookside		
	Mean	mean	*t*	*p*	mean	*t*	*p*	mean	*t*	*p*
Water depth	12.71	18.74	-6.05	**<.001**	25.50	-16.72	**<.001**	29.13	-19.20	**<.001**
Water temperature	12.00	14.00	-5.93	**<.001**	13.89	-6.60	**<.001**	13.15	-6.00	**<.001**
DO	10.46	10.10	1.60	0.14	10.53	-0.33	0.75	10.75	-1.62	0.14
pH	6.88	6.38	5.94	**<.001**	6.93	-0.49	0.63	6.93	-0.71	0.49
Number of rocks	690.81	209.00	24.07	**<.001**	318.73	15.37	**<.001**	505.36	5.11	**<.001**
Salamanders per m^2	0.24	0.06	7.78	**<.001**	0.06	6.43	**<.001**	0.07	6.29	**<.001**
Number of salamander species	3.36	1.64	5.19	**<.001**	2.36	3.03	**<.05**	2.09	5.37	**<.001**
Average SVL	3.29	3.16	0.21	0.83	4.01	-1.21	0.25	1.40	6.57	**<.001**

TABLE 1: Results of *t*-test between Mill Creek study sites and the reference site. Significant values are in bold.

Salamander captures at each site are summarized in Table 2. Salamander density was significantly greater at the reference site as compared to all Mill Creek study sites, as was the total number of species (Table 1). Significantly smaller salamanders were found furthest downstream at Brookside Lane (Table 1). Captures of salamanders were significantly positively correlated with number of rocks (r = 0.727, p < 0.001), and there was a significant negative relationship with stream depth (r = -0.627, p < 0.001). There was no significant correlation of captures with any other habitat variable.

Species	Common Name	Skitty Creek (Reference)	Laurel Street	Mill Creek Lane	Brookside Lane
Desmognathus monticola	Seal Salamander	71	22	31	28
D. ocoee	Ocoee Salamander	89	2	22	8
D. quadramaculatus	Blackbelly Salamander	84	10	35	39
Eurycea cirrigera	Two-lined Salamander	8	7	2	0
Gyrinophilus porphyriticus	Spring Salamander	1	0	0	0
Unidentified *Desmognathus* Larvae		31	17	7	32
Totals		**284**	**58**	**97**	**107**

TABLE 2: Captures of aquatic and semiaquatic salamanders (n) at each site.

DISCUSSION

Diversity of salamanders in Mill Creek has been greatly reduced in terms of both species richness and evenness, and is likely a result of inadequate riparian buffer strips. Recent studies recommend a buffer zone of 92.6 m to maintain healthy abundances of streamside salamanders (Crawford and Semlitsch 2006). Heavy urbanization upstream has also created high stormflows that can carry away organic microhabitat such as leafpacks, and deplete upstream colonization sources (NCDWQ 2002). Most mature aquatic salamanders reproduce in headwater stream areas and dispersal of larvae occurs via downstream drift (Bruce 1985), which may explain why greater numbers of small salamanders were found at the Brookside Lane site.

Although sedimentation was not found to negatively affect benthic invertebrates in Mill Creek (NCDWQ 2002), this study indicates that it is a major source of impairment for salamander populations. As spaces between rocks are filled with silt, the amount of protective surface cover from predators such as fish and larger salamanders is reduced (Lowe and Bolger 2002, Lowe et al. 2004). Rocks and streambanks also serve as nesting areas (Hom 1987). As these retreats are depleted, competition between species may increase and shift community structure (Southerland 1986, Roudebush and Taylor 1987).

Reduced salamander diversity at the Mill Creek sites may also be a result of stream contamination from runoff from the extensive paved areas in the center of town (NCDWQ 2002, LTWA 2003). Sediment from Mill Creek has previously been found to contain high levels of the metals cadmium, lead, and zinc, the chlorinated pesticides dieldrin and DDE (a breakdown product of DDT), and some semi-volatile organic compounds (NCDWQ 2002). Adult salamanders are highly sensitive to environmental toxins because they are lungless and have cutaneous respiration (Feder 1983). Pollutants such as insecticides, herbicides, fertilizers and de-icing salts can negatively impact populations of aquatic salamanders in streams that are contaminated (Turtle 2000, Boone and James 1997). Streams with a low pH can also negatively impact salamander abundance (Kucken et al. 1994, Mushinky 1975).

The Upper Cullasaja watershed is atypical because its headwater area is significantly urbanized. Whereas headwater tributaries generally represent the cleanest sections, water quality in the Cullasaja River gradually improves downstream (LTWA 2003). As little as 10-15% urbanization has been shown to significantly decrease species diversity of aquatic invertebrates, and may also enhance invasion of exotics (Riley et al. 2005). Artificial dams such as those at Brookside Lane alter the habitat by creating deep pools, and can lead to a reduction in salamander abundance due to increased predation by fish such as trout (Lowe and Bolger 2001, Lowe et al. 2004).

Studies have found that stream amphibians are often more greatly influenced by riparian and watershed features than in-stream conditions (Bisson et al. 2002). Response of species to perturbation depends on spatial context and scale, and that response may persist longer than the perturbation itself (Grover and Wilbur 2002). Long-term conservation efforts should therefore consider land use throughout entire watershed, not just within narrow riparian zones (Wilson and Dorcas 2002). A strategy that includes the preservation of wide strips of native vegetation along stream banks, minimal construction along steep slopes, responsible use of chemical and organic contaminants and a reduction of stormwater runoff volume, and the elimination of in-stream dams (NCDWQ 2002) may help to mediate many of the factors impacting salamander diversity in Mill Creek.

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