TRACKING STREAM CONDITIONS ON PRIVATE LANDS IN THE SOUTHERN APPALACHIAN MOUNTAINS: BOTTOM UP AND TOP DOWN APPROACHES TO STREAM MONITORING IN A RAPIDLY EXURBANIZING REGION

by

JEREMY CHARLES SULLIVAN

(Under the Direction of Catherine Pringle)

ABSTRACT

Monitoring the impacts of exurbanization on streams poses several challenges to researchers that include accurately predicting where residential development is likely to occur, and obtaining landowner permission to access streams on private lands. Here, we implemented two complimentary strategies for detecting changes to streams on private lands undergoing the early phases of urbanization. The first phase of this study was a "top-down", long-term monitoring project that utilized a predictive land use/land cover model to accurately forecast residential development in selected sub-watersheds. We detected differences in water chemistries and fish communities between *forested* and *suburban* sub-watersheds that fall in line with the "urban stream syndrome" and suggest the early phases of biotic homogenization. Next, we developed and tested the Southern Appalachian Stream Visual Assessment Protocol: a "bottom-up", landowner-centered, habitat survey, modified for wadable streams of the Southern Blue Ridge eco-region. Field testing of the protocol demonstrated that individual scoring elements correlate strongly with paired habitat metrics, while overall scores correlate with fish index of biotic integrity scores. We also showed the protocol can reliably be used by both novice and expert users to determine overall stream habitat ratings. Lastly, in an interdisciplinary investigation of the relationship between landowner perceptions of stream health and stream habitat condition, we found most of photo-survey respondents generally prefer streams with forested riparian zones, and that these preferences change depending on whether streams are used for recreation vs. aesthetic enjoyment. To our knowledge this is the first study to incorporate a "top-down", scientist-led, long-term ecological monitoring project; and a "bottom-up" landowner-centered stream habitat assessment, in an investigation of stream responses in watersheds undergoing different degrees of residential and commercial development. Our work demonstrates the importance of including private lands in studies of ecological change in regions undergoing rapid development, and the benefits of engaging landowners in stream stewardship. Our hope is to provide a model for future collaborative and interdisciplinary projects that seek to bridge the gaps between academic research, conservation practice, and public perception.

INDEX WORDS: exurbanization, land use/land cover, private lands, long-term monitoring, SVAP, citizen science, biotic-homogenization, urban stream syndrome Southern Appalachian Mountains, Southern Blue Ridge eco-region, bio-monitoring, habitat assessment, wadable streams, outreach, conservation, interdisciplinary research, collaboration, fish, macroinvertebrates, predictive modeling

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DEDICATION

To my wife, Lena Völklein, for supporting me and having patience during my pursuit of this degree.

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CHAPTER 1

INTRODUCTION

Consistent responses of streams to watershed urbanization are well documented, and include flashier hydrographs, increased channel incision, excessive bank erosion, increased nutrient and contaminant loading, reduction in habitat quality and quantity, decreased species richness, and a reduction in overall biotic integrity (Walsh et al. 2005; Roy et al. 2009; Hale et al. 2016; Parr et al. 2016). Still, characterizing the impacts of low-density residential development, or exurbanization, on streams has proven challenging for several reasons (Lohse and Merenlender 2009). Exurbanization is defined as the migration of urban residents into rural communities on the urban fringe and is the most rapidly growing land use throughout the United States (Theobald 2005). Unlike the large-scale habitat loss associated with high-density urbanization, the effects of exurbanization tend to be more indirect. For instance, exurban development tends to fragment habitat patches (Fahrig 2003); and introduce resources that increase populations of certain *synanthropic* species (that benefit from human dominated landscapes) and reduce populations of other, less tolerant, species (Marzluff 2008).

Although moderate levels of development can, in some instances, increase species richness by altering or increasing the types of habitats available (Mckinney 2006; Marzluff 2008), conventional land development typically displaces sensitive native species and introduces non-native and invasive species (Theobald 2001; Radeloff et al. 2005; Lohse and Merenlender 2009; Midler 2007; Groffman et al. 2014). Furthermore, by its very nature, exurban development is usually located near highly biodiverse and protected regions (Theobald 2005; Gagne and Fahrig

2010). If left unchecked, sprawling exurban development will not only continue to degrade habitats on private lands, but can also reduce the long-term viability of protected areas (Hansen et al. 2005; Ewing et al. 2005; Milder 2007).

The subdivision of privately owned land parcels associated with exurbanization also tends to intensify the impact of private riparian land management decisions on waterways, as impacts to streams aggregate across watersheds (Evans 2013; Chambers et al. 2017). For example, the removal of large woody debris (LWD) from streams and removal of riparian vegetation from stream banks can negatively impact local stream ecosystems and downstream regions (Parker and Hart 2014; Sweeney and Newbold 2014; Wohl et al. 2016). Still, most private property owners and land managers are unaware of the ways exurban development impacts local ecosystems (Thompson 2004). Furthermore, more owners, on smaller parcels of lands, and changes to land ownership, can further complicate the possibilities of research on private lands, especially when long-term access to study sites is required.

The risks to headwater streams posed by low-density residential development, as well as the general lack of studies conducted on private riparian lands undergoing the early phases urbanization, motivated the following work that seeks to further our understanding of how streams respond to land cover changes associated with exurban and suburban development. Our study is set in the southern Appalachian Mountains of Georgia and North Carolina; a highly biodiverse region, known for its scenic views and federally protected national parks and forests. Nearly 70% of forested lands throughout the southeastern U.S. are privately owned, and many of these landowners have streams on their properties (Wear and Greis 2002). This region has also experienced among the most dramatic rates of exurban development throughout the country in recent decades (Culbertson et al. 2008; McDonald et al. 2010; Vercoe et al. 2014). For these reasons, here we focus on private riparian lands containing streams draining watersheds in various stages of urban development throughout the southern Appalachian Mountain region.

In the following study, we use and examine two complimentary strategies for detecting changes to streams in watersheds undergoing the early phases of urbanization; advancing a "top-down", researcher-led, long-term, ecological monitoring program designed to track conditions in streams draining sub-watersheds undergoing different levels of development; and creating a "bottom-up", citizen-centered, user-friendly, habitat assessment for southern Appalachian riparian landowners. We also explore the relationship between landowner perceptions of stream health and actual stream conditions to gauge the ability of riparian landowners to accurately judge relative stream habitat quality and gain insight regarding the motivations behind the management of privately owned riparian lands.

Our work is presented in the following three chapters:

- Chapter 2: The Coweeta-LTER *Hazard Site* Project (CHSP): evidence for biotic homogenization in streams draining suburban landscapes in the southern Appalachian Mountains.

- Chapter 3: Development and testing of the Southern Appalachian Stream Visual Assessment Protocol (saSVAP): a tool for the independent assessment of wadable streams by riparian landowners.

- Chapter 4: Perceived value vs. habitat condition of wadable streams: a comparison of ecological assessment scores and riparian landowner preferences for streams habitats in Western North Carolina.

In Chapter 2, we present and discuss findings from the first three-time points (2000, 2005, and 2010) of The Coweeta Hazard Site Project (CHSP); a monitoring protocol designed to track the chemical, biological, and geomorphological responses of low-order streams draining sub-watersheds predicted to undergo substantial residential development in the next decades. The CHSP was designed and carried out by a multi-disciplinary, multi-institution, collaborative research team through the Coweeta Long-term Ecological Research (LTER) project and was funded by the National Science Foundation (NSF). We conclude the chapter with a discussion of the implications of our findings regarding stream responses to low-density residential development; the potential benefits of long-term ecological studies on developing landscapes; and suggestions for future iterations of the CHSP and similar studies.

While preparing for the field research presented in chapter 2, we were tasked with obtaining updated landowner permission to access our study sites. When meeting with landowners, many would ask us about the relative condition, or “health”, of streams on their properties. These questions from curious landowners, general lack of citizen-centered stream assessment protocols, and the possibility of increasing data collection from private lands, motivated us to develop the Southern Appalachian Stream Visual Assessment Protocol (saSVAP); a user-friendly tool designed for landowners who wish to independently determine local stream habitat conditions. This work was conducted by an interdisciplinary team of scientists, with input from residents, landowners, and conservation groups; and was based on previous versions of the Stream Visual Assessment Protocol (SVAP) developed by the University of Georgia and the United States Department of Agriculture-Natural Resource Conservation Service (USDA-NRCS) (Bjorkland et al. 2001; USDA-NRCS 2009). In Chapter 3, we present the development and testing of saSVAP, and discuss the tools strengths, limitations, current uses, and possible future applications.

In Chapter 4, we present an interdisciplinary study of how riparian landowner perceptions of streams desirability, health, cleanliness, and aesthetic value align with findings from saSVAP, and several macroinvertebrate-based metrics of stream condition. This study used anthropological survey-based methods, and ecological habitat assessments, to compare landowner's subjective preferences for streams to more objective measurements of habitat quality. In this chapter, we discuss the current necessity for collaborations between the social and natural sciences when designing research into socio-ecological systems; and explain the implications of our findings for local private conservation opportunities and environmental outreach.

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CHAPTER 2

THE COWEETA-LTER *HAZARD SITE* PROJECT (CHSP): EVIDENCE FOR BIOTIC HOMOGENIZATION IN STREAMS DRAINING SUBURBAN LANDSCAPES IN THE SOUTHERN APPALACHIAN MOUNTAINS[1]

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ABSTRACT

The Coweeta Hazard Site Project (CHSP) was initiated in 2000 to proactively detect potential responses of headwater streams to urbanization in eight sub-watersheds within the Little Tennessee (LT) and French Broad (FB) watersheds of the southern Appalachian Mountains. Sites within focal sub-watersheds were sampled in 2000, 2005 and 2010 for specific abiotic (stream solute chemistry, bed particle size) and biotic (algae, fish) parameters. Here, we expand on the initial *snapshot* descriptions of these sites collected in 2000 (and published in 2009), by examining the studies initial findings in the context of subsequent data *snapshots* in 2005 and 2010. Land use/land cover (LULC) findings from focal sub-watersheds from 2005 and 2010 validate LULC model predictions of development made in 2000. *Suburban* watersheds (n=4) experienced the greatest increases in building density and developed cover, and the largest decreases in forested cover. Conversely, *forested* watersheds (n=4) experienced little to no building construction and remained more than 97% forested from 2000 to 2010. Water chemistry data demonstrate consistently higher concentrations of NO_3, NH_4, K, Na, Ca, Mg, PO_4, SO_4, and Mg in *suburban* vs *forested* streams. Cumulative fish community data showed *suburban* streams to consistently contain more species-rich, cosmopolitan, and homogeneous fish communities relative to *forested* streams. Findings also suggest that *suburban* focal streams contain fish communities that have undergone prior biotic homogenization but have not yet reached the damaging level of urbanization that would extirpate highland endemics. Nonmetric multi-dimensional scaling (NMDS) ordination axes of fish community data were strongly correlated (r-value $\geq$ 0.70) with percent agricultural, developed, and forested land cover and building density. *Forested-reference* streams exhibited greater temporal variability (between 2000, 20005, and 2010) in diatom and fish communities, relative to streams draining developed areas, which underscores the potential inaccuracies of defining biotic

reference conditions at only one point in time. We recommend continued study of these rapidly changing landscapes to further uncover the ecological impacts of both low- and high-density development, and to tease apart the influence of land use legacies and contemporary development on southern Appalachian stream ecosystems.

INTRODUCTION

The rapid growth of cities is pervasive across the globe and is accelerating in response to an increasing human population and migration to urban areas (Chen et al. 2014, Scheuer et al. 2016). Urbanization tends to homogenize the physical conditions of terrestrial and aquatic environments, as cities are built to meet human societal needs (Mckinney 2006). In recent decades, multiple studies have shown that **habitat** homogenization, resulting from urbanization, can drive **biotic** homogenization, a process characterized by the gradual replacement of regionally distinct, native communities by cosmopolitan, non-native communities (Marzluff 2001; DeCandido et al. 2004; Tait et al. 2005; Scott 2005; Olden 2006; Bertin 2013; Groffman et al. 2014, Knop 2016, Palma et al. 2016). As urbanization accelerates, management questions arise as to how best detect, quantify, and mitigate the effects of biotic homogenization before native species are lost.

The consistent responses of stream ecosystems to watershed urbanization are collectively known as the “urban stream syndrome” and include flashier hydrographs, increased channel incision and bank erosion, increased nutrient and contaminant loading, reduction in habitat quality and quantity, decreased species richness, and a reduction in overall biotic integrity (Walsh et al. 2005, Roy et al. 2009). Recent studies have highlighted differences in the expression of the urban stream syndrome in cities around the world due to regional differences in climate (Hale et al. 2016), urban infrastructure, historical landcover, and timing of development (Parr et al. 2016). For these reasons, efforts to characterize the interaction of urban development and urban streams have proven more successful when applied to specific case studies rather than global generalizations (Booth et al. 2016). Also, monitoring the effects of urbanization on biotic communities through time may offer a more nuanced understanding of local responses to urbanization.

Characterizing biota through time in urbanizing areas has proven challenging since: (1) spatial and temporal scales of data collection are usually not designed to detect long-term trajectories of community change in urbanizing areas (Gido et al. 2010); (2) differentiating between natural and anthropogenically imposed community shifts is difficult due to a lack of pre-disturbance data on community variability in urban landscapes; and (3) in many cases, long-term studies have not used standardized sampling methods (Geheber and Piller 2011). Studies that have demonstrated biotic homogenization have either compared historical to present-day assemblages (e.g., study by Marchetti et al. 2006) or compared community assemblages along a gradient of land uses (see Walters et al. 2003; Scott 2005). These latter studies have often relied on space-for-time (SFT) substitution, where data from watersheds in different stages of urbanization are used to infer temporal trends (Godwin et al. 2009; O'Brien and Wehr 2010). The SFT substitution method has widely recognized limitations in stream systems due to the high spatio-temporal variability of biotic assemblages (Sundermann et al. 2008; Kappes et al. 2010). Few studies have attempted to track local community composition through time, as previously forested watersheds gradually become more urbanized. Such studies can provide a rare, yet needed, complementary approach to the more commonly used SFT substitution technique (Carter et al. 2009; Wenger et al. 2009) and can shed light on the importance of place-specific analyses and management strategies.

The Coweeta Hazard Site Project (CHSP) was developed by Gardiner et al (2009) to detect potential responses of headwater streams to urbanization in eight selected sub-watersheds located in the French Broad (FB) and Little Tennessee (LT) River drainages in the southern Appalachian

Mountains. The CHSP was part of the larger Coweeta Long-term Ecological Research Program (CWT-LTER), funded by the National Science Foundation. Gardiner et al. (2009) used a predictive land use/land cover (LULC) model (Wear and Bolstad 1998) to select focal sub-watersheds where residential development was likely to occur over the next two decades within the LT and FB watersheds of Georgia and North Carolina. In the first iteration of the CHSP, Gardiner et al. (2009) indicated key physical, chemical, and biological differences among study sub-watersheds across a gradient of urban development at one point in time (2000). In the present study we coordinated the 2010 sampling events at all focal study sub-watersheds, and aggregated data sets from 2000, 2005, and 2010. Here, we analyze this long-term, yet temporally course-grained data set to test predictions of stream impacts associated with low-density residential and suburban development and assess the effectiveness of Wear and Bolstad's (1998) predictive model of LULC.

In this study, we test the hypothesis that biotic homogenization is occurring in aquatic communities within urbanizing sub-watersheds due to changes in geomorphological and chemical characteristics of stream habitats. To do this, we examine the cumulative effects of landscape development on abiotic and biotic stream attributes at three points in time (2000, 2005, and 2010) across streams draining sub-watersheds undergoing different degrees of urban development. We build on Gardiner's (2009) initial predictions for the year 2000 and propose several new predictions based on our analysis of cumulative LULC datasets from 2000, 2005 and 2010. We also acknowledge challenges and inaccuracies made during the collection of macroinvertebrate community datasets in 2005 and 2010 (which were collected in different seasons in 2000, 2005, and 2010), that preclude our ability to evaluate predictions regarding macroinvertebrate communities.

Over five-year incremental snapshots (i.e. between 2000, 2005, and 2010) we predict that:

1) *forested* sub-watersheds will exhibit little-to-no building construction, little-to-no differences in land covers, and relatively small shifts in biological (fish and diatom) communities and environmental conditions (water chemistry and bed particle sizes)

2) *suburbanizing agricultural* sub-watersheds will have more building construction and developed land covers, less agricultural and forested land covers, greater diatom and fish species richness, more cosmopolitan biological communities, and environmental conditions that become more like *suburban* sub-watersheds;

3) *suburban* sub-watersheds will show cumulative increases in building densities and developed land covers, decreasing agricultural and forested land covers, increasingly homogenous biotic communities, and shifts in environmental conditions in line with the "urban stream syndrome" (i.e., increasing ionic concentrations in water chemistries and decreasing bed particle sizes);

4) *suburban* and *suburbanizing agricultural* sub-watersheds will have less species-rich biotic communities with lower proportions of endemic species, higher proportions of cosmopolitan taxa, and more homogenous biotic communities compared to *forested* sub-watersheds; and

5) fish and diatom community composition will strongly correlate with environmental variables related to urbanization (e.g. increasing building density, increasing developed cover, decreasing forest cover, decreasing bed particle size, increasing ionic concentration).

METHODS

The study area is in the Blue Ridge ecoregion of western North Carolina and northeastern Georgia. Cold-water streams that drain the southern Appalachian Mountains are inhabited by a highly diverse freshwater fauna and an abundance of endemic forms (Stein et al. 2000). Although this region is rapidly developing, many of its watersheds are predominantly forested and are just beginning to experience substantial urbanization (Taylor 2005). These factors make the Blue Ridge region an ideal study location for research on the impact of ongoing watershed urbanization on stream ecosystems.

The eight-focal study sub-watersheds are in the Little Tennessee (LT) and French Broad (FB) watersheds (Figure 2.1). Wear and Bolstad (1998) used land cover maps and building densities from 1950 and 1990 to determine land use change over time and found that the LT and FB watersheds were characterized by different land use histories. In the LT, the most common land cover change between 1950 and 1990 was the conversion of non-forested to forested land cover. The LT also underwent substantial increases in low density residential development, particularly in the form of vacation homes being built on previously forested hill slopes. The FB had higher proportions of agricultural land uses in both 1950 and 1990, as well as higher housing densities than the LT. At the onset of this study in summer 2000, rural second home development was evident in the LT, and agricultural lands were being converted to residential and commercial land uses in the FB (Gardiner et al. 2009). The Coweeta Hydrologic Lab is located near Franklin, N.C. in the LT watershed. Franklin is a small urban center, with a population of 3,896 (US Census Bureau, 2012). Asheville is the largest city in the study area, with a population of 85,712 (US Census Bureau, 2012), and is in the north-central portion of the FB watershed.

<u>Site selection</u>

The LULC model developed and validated by Wear and Bolstad (1998) combined a negative binomial regression model of building density (as a proxy for land use) with a logit model of land cover to conduct a spatial analysis of landscape change in the southern Appalachians. Both the LT and FB watersheds were predicted to undergo substantial development over subsequent decades.

Two metrics were used to identify eight focal study sub-watersheds within the larger LT and FB with high likelihoods of increased building densities over the projected three-decade span of the study (2000-2030). The first metric, the difference between building density projected for 1990 and the actual building density observed in 1990, provided a measure of the un-capitalized value of desirable land parcels in 1990. The second metric, the difference between building density projected for 2030 and observed building density in 1990, provided a measure of expected trends in future land use. Gardiner et al. (2009) inferred a high likelihood of building construction by 2030 in sub-watersheds where both indices exceeded three buildings per nine-hectare land parcel. Six sub-watersheds that fit these criteria and did not show evidence of construction at the time, along with two reference sub-watersheds, were chosen for long-term study.

Gardiner et al. (2009) used a decision tree to categorize sub-watersheds based on land cover percentage of forest, agriculture, and development in 1993. One group, deemed *forested,* was comprised of two reference sub-watersheds located on protected national forest lands (Coweeta and Avery), and two predominantly forested sub-watersheds (Darnell and Wayah), all of which had greater or equal to 98% forested and less than or equal to 1% developed land covers. The Coweeta Hydrologic Lab is in the LT watershed and contains the USFS Coweeta Hydrologic Laboratory, while Avery is in the FB watershed at Pisgah National Forest near Brevard, NC (Figure 2.1). Darnell and Wayah are in the LT. Another group, categorized as *suburbanizing agricultural*, was comprised of three sub-watersheds (Watauga, Hooper's and Gap) that had less than 85% forested and less than 10% developed covers. Watauga is in the LT, while Hooper's and Gap are in the FB. Lastly, one sub-watershed located in the FB (Robinson) had less than 85% forested and greater than 10% developed land cover and was categorized as *suburban*.

All sub-watersheds were restricted to sizes between 10 and 40 km^2 in area, and 550 and 720 m a.s.l. in elevation, to avoid differences in fish assemblage structure due to elevation, and sub-watershed size (Gardiner et al. 2009). Long-term sampling reaches, named "hazard" sites, were established at the outlet of each sub-watershed, and a permanent benchmark was embedded in concrete on the left bank to mark each sampling reach.

Three sub-watersheds originally categorized as *suburbanizing agriculture* (Watauga, Hooper's, and Gap) exceeded 10% developed land covers by 2010 and were re-classified as *suburban* in the current study using the project's original decision tree (Gardiner et al. 2009). All four watersheds in the *forested* group (Coweeta, Avery, Darnell, and Wayah) remained more than 97% forested and less than or equal to 1% developed throughout the study. For all subsequent analysis of biotic and abiotic data, we examined temporal changes between study years at sub-watersheds using the both the original LULC categories developed in 2000 (*forested*, *suburbanizing agricultural*, and *suburban*), and the more recent LULC categories developed in 2010 (*forested* and s*uburban*).

Physical Assessments

Land Use and Land Cover

Land cover data from 1993 to 1994 were previously collected and compiled from aerial photographs (Wear and Bolstad 1998). Land use (buildings/km^2) and land cover (km^2) data for 2000, 2005, and 2010 were collected from 30-meter resolution ortho photo images downloaded from the U.S. Geological Survey (http://www.usgs.gov/pubprod/). All sub-watersheds were analyzed using ArcGIS software (ESRI, Inc.), in a projected coordinate system (UTM Zone 17 N, NAD 1983), to estimate building densities and the total watershed area in forested, agricultural, and developed land covers. All LULC data were categorized and analyzed using methods from Gardiner et al. (2009) and Wear and Bolstad (1998).

Water Chemistry

Three 125ml water samples were collected once every five years between June and August in 2000, 2005, and 2010 at each "hazard" site. Water samples were collected from the thalweg of run habitat at base flow following methods from Gardiner et al. (2009). Water samples were filtered in the field, stored on ice, and transported to the UGA Analytical Chemistry Laboratory in 2000, and Coweeta Hydrological Laboratory in 2005 and 2010, for chemical analysis. Water samples were analyzed for NH_4, Cl, NO_3, PO_4, K, Na, Ca, and Mg using methods from Deal (2001). We included several non-standard cations (Cl, Ca, and Mg) in the analysis due to their associations with exurban development (Webster et al. 2012).

Pebble Counts

Pebble counts were conducted once every five years between June and July in 2000, 2005, and 2010 at each "hazard" site. One hundred bed-particles from representative riffle habitats were measured along their medial axis (mm) as in a "Wolman" pebble count (Wolman, 1954). These lengths were then converted to phi size (i.e. the negative base two logarithm). Mean phi-size and mean 90^{th} percentile for medial axis length (D_{90}) were then calculated and used to compare bed particle sizes across sites.

<u>Biological Assessments</u>

Fishes

Fishes were collected once every five years between April and early November in 2000, 2005, and 2010 at each of the eight "hazard" sites with backpack electro-shockers, seines, and dip nets following the methods described in Gardiner et al. (2009). At each site, a quantitative sample was taken during one thorough pass within a representative 50-meter reach. To ensure comparable catch per unit effort, an attempt was made to equalize electroshocking time per area sampled. Fish were identified to species, enumerated in the field, and returned to the stream. One voucher specimen of each species was preserved and accessioned at the Georgia Museum of Natural History for future reference. Fish species were then categorized as either cosmopolitan or endemic following procedures described by Scott (2005). Four species were not categorized as endemic nor cosmopolitan: Rainbow Trout (*Oncorhynchus mykiss*) and Brown Trout (*Salmo trutta*), two introduced game species were both categorized as non-native and widely distributed; and Long-nose Dace (*Rhinichthys cataractae*) and Telescope Shiner (*Notropis telescopus*), were both categorized as native to the southern Appalachian Mountains but found elsewhere. These species were included in total abundances but were not included in abundances of endemic or cosmopolitan species when calculating relative abundances. Mottled Sculpin (*Cottus bairdi* ssp.) were classified as highland endemics based on designations made by Scott and Helfman (2001), Scott and Bettinger (2005) and Kirsch et al. (2014); and because they share benthic habitat and prey requirements with many highland endemic darter species (Walters et al 2005). Species were also categorized by feeding guild (i.e., trophic generalist, benthic insectivore, herbivore, insectivore, generalist carnivore, and insectivorous cyprinid), habitat preference (i.e., pool, pool-run, habitat generalist, benthic, and riffle-run) and spawning guild (i.e., benthic nest builders, benthic nest associates, benthic nest excavators, benthic crevice spawners, cavity spawners, gravel spawners, general broadcasters, live bearers, rock attachers, and unknown) using Virginia Tech's FishTraits Database (Frimpong and Angermeier, 2009). Relative abundances were calculated for each group and compared across sub-watersheds, on the assumption that capture efficiencies for different species and groups did not vary among stream sites

Diatoms

Benthic periphyton was quantitatively sampled once every five years between July and August at each of the eight "hazard" sites in 2000, 2005, and 2010 following procedures from Gardiner et al. (2009). Samples were taken with a modified Loeb sampler (Loeb 1981) at base flow (no less than ten days after a high discharge event). Three replicate samples were taken and composited from submerged wood or rock substrates at 10m intervals along a 100m reach. Samples were preserved in 10% formalin and returned to UGA for analysis. Subsamples from each composite sample along the reach were combined, processed using standard methods (Stevenson and Bahls 1999), and made into permanent microscope slides. Diatoms were enumerated in each subsample and identified to the lowest taxonomic level possible using algal floras from the southeastern USA (Camburn and Lowe 1978, Kociolek and Kingston 1999). Cell densities (cells/ml) were quantitatively calculated from diatom counts. Diatoms were also categorized based on local distribution (i.e. endemic, cosmopolitan, or intermediate) and growth form (upright, prostrate and attached, prostrate and mobile, and planktonic). We used cell densities, in lieu of diatom count data, because the diatom data set from stuy year 2000 only included cell densities and not sample volumes (leaving us unable to determine diatom count data for that study year).

Statistical Analyses

Fish and diatom communities were analyzed using hierarchical cluster analysis (HCA), Wishart's objective function, non-metric multidimensional scaling (NMDS), and indicator species analysis (ISA) in PC-ORD 6 (McCune and Mefford 2011). HCA and NMDS both require a measure of compositional dissimilarity between sites. Since fish and diatom matrices were both zero-rich, a Bray-Curtis distance measure was chosen to reduce the influence of joint zeroes between pairs of sites. We quarter-root transformed fish abundances (#/sample) and diatom densities (cells/ml), to allow a clearer examination of the influence of less common species (Peck 2010). In each dataset we also removed any species present in only one site in a single sample year to reduce noise (McCune and Grace 2002, Peck 2010).

The dendrograms produced from HCA were used to assess the similarity of assemblages across sites and study years. In HCA, the Wishart's objective function is a measure of how much of the total sum of squared distances between assemblages is captured by different groups of sites or samples. The larger the proportion of the objective distance function spanned by a group of sites or samples, the more heterogeneous the assemblages found in those groups. The percent information remaining statistic indicates the relative distance between sites and groups of sites. The higher the percent information remaining, indicated by branching points in the dendrogram, the more homogenous the assemblages linked by that node.

NMDS is an ordination method used to view the relationships among sites through time by reducing the dimensionality of the data space (McCune and Grace 2002). We used the NMDS autopilot option in PC-ORD with the "slow and thorough" setting, including 250 runs with real data and 250 runs with randomized data. PC-ORD then suggested an optimal number of dimensions, two in our case for both fish and diatom ordinations. We then graphed the two dimensions using varimax rotation. We examined the linear Pearson correlations between environmental variables (sub-watershed characteristics, LULC variables, and water chemistry variables) and ordination axes to determine which of these variables explained the most variation in ordination space. We chose r-values greater than 0.70 as evidence of strong association between variables. A value of 0.70 was used because a correlation of this magnitude accounts for nearly half of the variance (McCune and Grace 2002, Brown et al. 2009). Convex hulls and centroids from the NMDS scaling analysis were used to analyze the taxonomic dissimilarity of fish and diatom communities of each LULC group over the study period.

Indicator species analysis (ISA) (Dufrene and Legendre 1997) was used to highlight diatom and fish taxa associated with either *forested* or *suburban* sites. ISA combines the relative abundance of a species in a group with the relative frequency of a species in each group (i.e. two LULC groups: *forested* and *suburban*). Indicator values (IV) can range from 0 (no indication) to 100 (perfect indicator). Monte Carlo tests based on 5000 randomizations of the original species matrices were used to determine the significance of observed maximum indicator values. We determined which diatom and fish species had strong associations with either *forested* or *suburban* sites by selecting all species with IV values greater than or equal to 0.50 and p values less than 0.05.

The Wilcoxon rank sum statistic was used to compare substrate particle sizes and water chemistries, as well as several diatom and fish community parameters (e.g. species richness, relative abundances of cosmopolitan and endemic taxa, etc.), between *forested* and *suburban* sites. These analyses were performed in JMP IN v. 5.1 (SAS Institute, Cary, NC, USA). The non-parametric Wilcoxon rank sum test was chosen because all continuous variables were non-normally distributed. In JMP, the nonparametric Wilcoxon rank sum test is equivalent to the Mann-Whitney test.

RESULTS

Land Use (bldgs./km^2) and Land Cover Change

As predicted by the Wear and Bolstad (1998) LULC model, from 2000 to 2010, *forested- reference* sub-watersheds (Coweeta and Avery) exhibited no new building construction (Avery, 0 buildings in 2000 and 2010; Coweeta, 15 buildings in 2000, and 14 buildings in 2010). Coweeta and Avery experienced no changes in *forested*, agricultural, and developed land cover percentages and exhibited over 99% *forested* land cover for the duration of the study. Darnell, which was originally classified by Gardiner et al. (2009) as *forested* with low density development, also had a small decrease in buildings (21 buildings in 2000 to 18 buildings in 2010). Darnell remained 98% forest cover for the duration of the study. Wayah, which was also originally classified as *forested* with low-density development, experienced construction (100 to 152 buildings), and remained 97.5% forested between 2000 and 2010. New building construction was apparent in sub-watersheds that were originally classified as *suburbanizing-agricultural* (Watauga, Gap, Hooper's). From 2000 to 2010 the number of building at Watauga increased from 611 to 739; at Gap, from 729 to 1029; and at Hooper's, from 738 to 1870 (Figure 2.2). Watauga, Hooper's and Gap also had decreasing agricultural and increasing developed land covers (Figure 2.3). Watauga and Gap exceeded 10% developed cover between 2000 and 2005, whereas Hooper's exceeded 10% developed land cover between 2005 and 2010 (Figure 2.3). New building construction occurred at Robinson (890 to 1565 buildings), which was originally classified as *suburban*. Robinson had among the most rapid increases in building densities (Figure 2.2), developed land covers, and most rapid declines of forested land cover (Figure 2.3). Due to stable land covers (which remained over 97% forested), and lack of new building construction at *forested* sub-watersheds originally predicted to undergo low density residential development (Wayah and Darnell), we re-classified Avery, Coweeta, Wayah, and Darnell as *forested* in 2010. Conversely, due to the rapid development detected at Watauga, and the fact that Watauga, Hooper's, and Gap exceeded the 10% developed cover threshold established by Gardiner et al. (2009), we re-classified Watauga, Hooper´s, and Gap, and Robinson as *suburban* in 2010.

Water Chemistry

As expected, *forested* sites (Avery, Coweeta, Darnell, and Wayah) exhibited ionic concentrations that were generally lower than the other more developed sites. Ion concentrations at *forested* sites also changed little and remained similar from site to site within the same study year relative to the more developed sites (Figure 2.4). Sites originally characterized as *suburbanizing agricultural* (Watauga, Hooper´s, and Gap) exhibited higher levels than *forested* sites for nearly all measured ions, except for PO_4. *Suburbanizing agricultural* sites also exhibited greater temporal fluctuations in ion concentrations and greater differences between sites within years than forested sites. Concentrations of several ions (Na, Ca, Mg, SO_4) from *suburbanizing agricultural* sites were found at their highest levels in 2010 and have become more like that of Robinson, the most developed *suburban* site. Concentrations of NO_3 exhibited a consistent decrease at Watauga and Hooper's between study years. As we expected, Robinson exhibited the highest recorded concentrations of several ions associated with urban development (NO_3, Ca, Mg) and experienced consistent increases in NO_3 from study year to study year (Figure 2.4).

Using the 2010 LULC categories, the four *forested* streams (Avery, Coweeta, Darnell, and Wayah) exhibited lower concentrations for all examined ions (NO_3, NH_4, K, Na, Ca, Mg, PO_4, SO_4) in nearly all study years, than the four *suburban* streams (Watauga, Robinson, Hooper's, and Gap) (Figure 2.4). In 2000, 2005, and 2010 *forested* sites had mean NO_3 concentrations ranging from 0.04 ±0.003 to 0.06 ±0.009 mg L^{-1}, while *suburban* sites ranged from 0.30 ±0.03 to 0.37 ±0.05 mg L^{-1}. Throughout the study *forested* sites had mean NH_4 concentrations ranging from 0.01 ±0.00058 to 0.02 ±0.001 mg L^{-1}, while *suburban* sites ranged from 0.02 ±0.001 to 0.03 ±0.005 mg L^{-1}. Through all study years, *forested* sites had mean K concentrations ranging from 0.47 ±0.02 to 0.63 ±0.02 mg L^{-1}, while *suburban* sites ranged from 1.54 ±0.04 to 1.87 ±0.05 mg L^{-1}. *Forested* sites had mean Na concentrations ranging from 1.14 ±0.08 to 3.88 ±0.14 mg L^{-1}, while *suburban* sites ranged from 3.7 ±0.16 to 7.08 ±0.21 mg L^{-1} throughout the study. In 2000, 2005, and 2010 *forested* sites mean Ca concentrations ranging from 0.85 to 1.62 ±0.06 mg L^{-1}, while *suburban* sites ranged from 4.44 ±0.37 to 5.50 ±0.36 mg L^{-1}. *Forested* sites had mean Mg concentrations ranging from 0.42 ±0.04 to 0.57 ±0.05 mg L^{-1}, while *suburban* sites ranged from 1.65 ±0.12 to 1.90 ±0.12 mg L^{-1} throughout the study. Through all study years *forested* sites had mean $P0_4$ concentrations ranging from 0.005 ±0.001 to 0.02 ±0.003 mg L^{-1}, while *suburban* sites ranged from 0.01 ±0.003 to 0.04 ±0.0002 mg L^{-1}. *Forested* sites had mean SO_4 concentrations ranging from 0.79 ±0.08 to 2.25 ±0.08 mg L^{-1}, while *suburban* sites ranged from 2.26 ±0.09 to 3.52 ±0.14 mg L^{-1} (Figure 2.5) throughout the study.

Forested sites were found to have consistently lower concentrations of NO_3 in 2000 (Wilcoxon rank-sum test: χ^2=17.3, d.f.=1, p<0.0001), 2005 (Wilcoxon rank-sum test: χ^2=17.295, d.f.=1, p<0.0001), and 2010 (Wilcoxon rank-sum test: χ^2=17.295, d.f.=1, p<0.0001). *Forested* sites also exhibited lower concentrations of K in 2000 (Wilcoxon rank-sum test: χ^2=17.280, d.f. =1, p<0.0001), 2005 (Wilcoxon rank-sum test: χ^2=17.288, d.f. =1, p<0.0001), and 2010 (Wilcoxon rank-sum test: χ^2=17.280, d.f. =1, p<0.0001). *Forested* sites had lower concentrations of Ca in 2000 (Wilcoxon rank-sum test: χ^2=17.280, d.f. =1, p<0.0001), 2005 (Wilcoxon rank-sum test: χ^2=17.2800, d.f. =1, p<0.0001), and 2010 (Wilcoxon rank-sum test: χ^2=17.280, d.f. =1, p<0.0001). *Forested* sites had lower concentrations of Na in 2000 (Wilcoxon rank-sum test: χ^2=17.280, d.f. =1, p<0.0001), 2005 (Wilcoxon rank-sum test: χ^2=17.2800, d.f. =1, p<0.0001), and 2010 (Wilcoxon rank-sum test: χ^2=17.280, d.f. =1, p<0.0001). *Forested* sites had lower concentrations of Mg in 2000 (Wilcoxon rank-sum test: χ^2=17.280, d.f. =1, p<0.0001), 2005 (Wilcoxon rank-sum test: χ^2=17.2800, d.f. =1, p<0.0001), and 2010 (Wilcoxon rank-sum test: χ^2=17.288, d.f. =1, *p*<0.0001). There were no clear differences between sites in terms of PO_4 concentrations in 2000 but *forested* sites exhibited lower PO_4 concentrations than *suburban* sites in 2005 (Wilcoxon rank-sum test: χ^2=12.7242, d.f.=1, *p*=0.0004) and 2010 (Wilcoxon rank-sum test: χ^2=5.901, d.f.=1, *p*=0.0151). *Forested* sites demonstrated consistently lower NH_4 concentrations than *suburban* sites in 2000 (Wilcoxon rank-sum test: χ^2=6.3102, d.f. =1, *p*=0.0120), 2005 (Wilcoxon rank-sum test: χ^2=16.8915, d.f. =1, *p*<0.0001), and 2010 (Wilcoxon rank-sum test: χ^2=13.072, d.f. =1, *p*=0.0003). *Forested* sites exhibited lower SO4 concentrations than *suburban* sites in 2000 (Wilcoxon rank-sum test: χ^2=17.280, d.f. =1, *p*<0.0001), 2005 (Wilcoxon rank-sum test: χ^2=17.280, d.f. =1, *p*<0.0001), and 2010 (Wilcoxon rank-sum test: χ^2=16.8033, d.f. =1, *p*<0.0001) (Figure 2.5).

Bed Particle Sizes

Mean D_{90} bed particle sizes at *forested* sites fluctuated from study year to study year, but not in any consistent direction. Mean phi-size was less in 2000, than in 2005 or 2010 at all four *forested* sites. There was no consistent direction of change in D_{90} found among sites originally characterized as *suburbanizing agricultural*. Mean phi-size consistently increased at Watauga and Hooper's, but not at Gap. Overall, Hooper's exhibited the smallest D_{90} sizes of the study. At Robinson both D_{90} particle size and phi size exhibited consistent increases from study year to study year.

Using the 2010 LULC classifications (i.e. *forested* and *suburban)*, we found no significant differences in phi sizes between *forested* and *suburban* sites. Mean D_{90} particle sizes were consistently smaller at *suburban* relative to *forested* sites. Mean D_{90} particle sizes were smaller at *suburban* sites in 2000 (Wilcoxon rank-sum test: χ^2=1.3, d.f. =1, *p*=0.2482) 2005 (χ^2=4.0833, d.f. =1, *p*=0.0433), and 2010 (χ^2=5.33, d.f. =1, *p*=0.0209)(Figure 2.6). *Forested* streams had mean D_{90} sizes of 201.75 ±23.914 mm in 2000, 245.7 ±16.476 mm in 2005, and 241.45±16.2666 mm in

2010. *Suburban* streams had mean D_{90} sizes of 151 ±85.0307 mm in 2000, 116.825 ± 42.0245 mm in 2005, and 108.25 ±31.1083 mm in 2010.

Fishes

Our combined fish data set included 6093 individuals representing 32 species and 7 families. Several developing sites exhibited directional change in the relative abundances of cosmopolitan and endemic species. Fish species richness was higher in 2010 than in 2000 at Avery, Darnell, Wayah, Gap, and Hooper's, with consistent increases at Darnell. We also found a consistent decrease in species richness found at Robinson between study years. The relative abundances of cosmopolitan fish species at *forested* sites were similar in 2000 and 2005, but increased in 2010, becoming more like that of *suburban* sites. At Robinson, we found a consistent increase in the relative abundance of cosmopolitan fish throughout the study. At Hooper's the relative abundance of endemic species consistently decreased with increasing study year.

In our analyses of fish communities using the *suburban* and *forested* LULC groupings, we found several clear differences between the four *forested* and the four *suburban* sites. At *forested* sites, *Cottus bairdi* ssp. and cyprinids comprised 63 percent and 29 percent of total fish abundance, respectively. In contrast, at the *suburban* sites, *C. bairdi* ssp. and cyprinids comprised 28 percent and 58 percent of total fish abundance, respectively. Over the course of the study *C. bairdi* ssp. and cyprinids were the numerically dominant fish at both *forested* and *suburban* sites. *Oncorhynchus mykiss* and *Salmo trutta* were found at *forested* sites, but not found at three of four *suburban* sites. The one exception to this was Hooper's, where individuals of *O.mykiss* and *S. trutta* were collected only in 2010. *Rhinichthys cataractae* were also found at *forested* sites and not *suburban* sites. *Erimonax monacha,* a federally protected species, and *Phenacobius crassilabrum* were only collected at Watauga. Two cosmopolitan, native, centrarchid species, *Lepomis auritus* and *Lepomis cyanellus*, were found exclusively at *suburban* sites. Two highland endemic darter species, *Etheostoma swannanoa* and *Etheostoma flabellare*, although present at both *forested* and *suburban* sites, were found at higher abundances at *suburban* sites.

NMDS ordination and HCA showed that fish communities at *forested* and *suburban* sites were distinct from one another in terms of composition, inter-site similarity, and community variability over time. The positions of fish communities on ordination axes indicated differences in composition among *forested* sites, which appear on the upper left side of the ordination, and *suburban* sites, which appear on the lower right side (Figure 2.7). *Suburban* sites were closely grouped in ordination space, in contrast to the more dispersed positioning of the four *forested* sites. The fish community at Hooper's (originally classified as *suburbanizing agriculture*) did move closer to the fish community composition observed at Robinson (classified as *suburban*) in ordination space, as predicted. Contrary to our predictions, fish communities at the Watauga and Gap (both originally classified as *suburbanizing agricultural*) did not move closer to fish community composition at Robinson in ordination space. In most cases, NMDS ordination revealed successional vectors of fish community change that switched direction between study years. Successional vector analysis also showed greater distances between study years at each *forested* site vs. lesser distances between study years at each *suburban* site (Figure 2.7). In other words, *suburban* fish communities shifted less between 2005 and 2010 than *forested* fish communities, and the greatest shifts between study years were found at Coweeta, a protected *forested* site. These findings suggest that community composition was more variable between study years at *forested* sites compared to *suburban* sites. Over the course of the study fish communities from *suburban* sites had more overlapping convex hulls and closer group centroids than *forested* sites (Figure 2.8). These findings suggest fish communities at the three most developed sites (Hooper's, Robinson, and Gap) were more like each other than fish communities inhabiting *forested* sites, and that this pattern was consistent through time. Although separately positioned on the NMDS ordination, Hierarchical Cluster Analysis (HCA) of fish communities showed the fish community at Watauga to be more like those of other *suburban* sites than to *forested* sites. The three most developed sites (Gap, Robinson, and Hooper's) formed a distinct cluster with an information remaining value near 60%. *Forested* sites formed a more heterogenous grouping with an information remaining value slightly greater than 25%. The three time-points from Watauga formed a relatively homogenous cluster near 75% information remaining, and a heterogenous cluster with the other *suburban* sites at an information remaining value less than 25% (Figure 2.9).

Indicator species analysis (ISA) showed that 11 fish species had significant IV's greater than or equal to 50. Three species had strong associations with *forested sites*, while eight species had strong associations with *suburban* sites (Table 2.1).

Suburban sites had consistently higher mean fish species richness than *forested* sites in 2000 (χ^2=5.4, d.f. =1, p=0.0202), 2005 (χ^2=5.33, d.f. =1, p=0.0209), and 2010 (χ^2=3.6, d.f. =1, p=0.0575) (Figure 2.10a). *Suburban* sites also had greater mean relative abundances of cosmopolitan fish species than f*orested* sites in 2000 (χ^2=4.08, d.f. =1, p=0.0433), 2005 (χ^2=5.33, d.f. =1, p=0.0209), and 2010 (χ^2=1.33, d.f. =1, p=0.2482) (Figure 2.10b). There were no significant differences found between *forested* and *suburban* sites in terms of mean relative abundances of endemic fish species in 2000 (χ^2=1.33, d.f. =1, p=0.2482), 2005 (χ^2=0.75, d.f. =1, p=0.3865), and 2010 (χ^2=0.08, d.f. =1, p=0.7728) (Figure 2.10c). Throughout the study, fish communities at *suburban* sites had consistently higher proportions of trophic generalist fish species in 2000 (χ^2=5.33, d.f. =1, p=0.0209), 2005 (χ^2=5.4, d.f. =1, p=0.0202), and 2010 (χ^2=3.0, d.f. =1, p=0.0833)(Figure 2.10d), lower proportions of generalist carnivore fish species in 2000 (χ^2=5.33, d.f. =1, p=0.0209), 2005 (χ^2=5.33, d.f. =1, p=0.0209), and 2010(χ^2=4.08, d.f. =1, p=0.0433) (Figure 2.10e), and lower proportions of riffle-run habitat specialists than *forested* sites in 2000 (χ^2=4.08, d.f. =1, p=0.0433), 2005 (χ^2=0.75, d.f. =1, p=0.3865), and 2010 (χ^2=3.0, d.f. =1, p=0.0833) (Figure 2.10f).

Diatoms

Our combined diatom data set included 186 species, 3 of which were endemic to the region (*Meridion alansmithii*, *Gomphonema mehleri*, *Achnanthidium lapidosa var. appalachiana*) (. NMDS ordination of diatom community data demonstrated some overlap between communities in the two groups, with the four *forested s*ites plotted in the center and upper left side, and the four *suburban* sites plotted in the center and lower right side of the ordination (Figure 2.11). In both *forested* and *suburban* sites NMDS ordinations revealed small inter-site differences within each study year, compared to the large shifts between study years within each site (Figure 2.11). Convex hulls and group centroids of diatom communities indicated changes in dissimilarity over the study period, yet there were no clear differences between LULC groups (Figure 2.12). In other words, diatoms assemblages collected on the same date were more similar, irrespective of sub-watershed identity or LULC classification. Hierarchical Cluster Analysis (HCA) of diatom community data show no clear distinction of sites based on *forested* or *suburban* LULC groupings, with sites switching clusters between study years near the 50% information remaining level (Figure 2.13).

Indicator Species Analysis (ISA) showed that 25 diatom species had significant IV's greater than 50. Four species had strong associations with *forested* sites while 21 species had strong associations with *suburban* sites (Table 2.2).

Correlations with Environmental Variables

Pearson correlations of environmental variables contributing to axis one and axis 2 of NMDS of fish community data revealed strong correlations (greater than 0.7) with one sub-watershed variable (elevation), four LULC variables (building density, agricultural land cover, developed land cover, and forested land cover), and four water chemistry variables (NO_3, Ca, K, Na), whereas Pearson correlations between environmental variables and diatom community data indicated strong correlations with one LULC variable (agricultural land cover), one geomorphic variable (mean phi size), and one water chemistry variable (K concentration) (Table 2.3).

DISCUSSION

In the current study, consistent chemical, physical and biological differences were found between *forested* and *suburban* sites that suggest *suburban* stream ecosystems have been altered by past land uses, currently contain more homogenous fish communities than *forested* sites, and that *forested* sites may be similarly altered as they develop over the next few decades. Furthermore, GIS findings from 2005 and 2010 validated LULC model predictions of sub-watershed development made in 2000, which has several implications for improving the design of long-term ecological studies of urbanization effects moving forward.

In the CHSP study conducted in 2000, Gardiner et al (2009) made two sets of predictions of how stream communities and abiotic factors were likely to change in sub-watersheds based on two alternative landscape trajectories: low-density residential development in largely forested sub-watersheds found in the LT watershed; and suburban and urban development in largely agricultural sub-watersheds found in the FB watershed. The fact that sub-watersheds originally classified as *suburbanizing agricultural* shifted to the *suburban* LULC category during this project, provides strong evidence of the ability of the LULC model to accurately predict when and where urban development is likely to occur. The model also correctly predicted little-to-no building construction and no changes in land cover at *forested* sub-watersheds of the LT. As expected, no development occurred in the two, *forested-reference* sub-watersheds (Coweeta and Avery), that are located on federally protected lands. The lack of development at Darnell and Wayah, however, was unexpected, as both sub-watersheds were originally predicted to experience low-density development at the onset of the study (Gardiner et al 2009). This may have been partially due to the housing market crash in 2008 that slowed in-migration and home construction in non-metropolitan regions nationally (Frey 2009; Rickman and Guetabbi 2015). As of 2010, the U.S. housing market has largely recovered, and we currently expect Darnell and Wayah to experience substantial development in subsequent decades. Landscape scenarios like those found in the LT and FB (where sub-watersheds undergoing the early stages of urbanization, and protected reference sub-watersheds, are nested within a single larger basin) present unique opportunities to examine how adjacent development impacts the ecology of nearby protected areas, as contiguous forested habitats are increasingly fragmented across the landscape.

Several lines of evidence from the current study point to sub-watershed development, and not the geographic distance between sub-watersheds, as a possible driver of the differences in water chemistries and fish communities between *forested* and *suburban* sub-watersheds. Avery, although located in the FB, exhibited similar water chemistries to *forested* streams in the LT. Watauga, conversely, is in the LT, and exhibited similar water chemistries and fish communities to the other rapidly developing sub-watersheds located in the FB. Consistent differences in environmental conditions between *forested* and *suburban* sub-watersheds conform to the "urban stream syndrome" (Walsh et al. 2005), although no directional trends in water chemistry or stream bed particles sizes were apparent through time. *Suburban* sites were found to have greater concentrations of most measured ions than *forested* sites. Webster et al. (2012) found relatively high conductivity values and nitrate concentrations associated with urban and agricultural development in southern Appalachian Mountain streams. Watersheds dominated by agricultural land use experience high inputs of chemical fertilizers to streams from runoff. Watersheds experiencing suburbanization often have point source inputs, as well as fertilization of home lawns, that can enter streams and may lead to water chemistries with higher ion concentrations than more forested watersheds. We also found smaller bed particles in *suburban* sites compared to *forested* sites. Increased input of fine sediment from watershed development and increased frequency of erosive flow in urban areas are both well documented aspects of the urban stream syndrome (Walsh et al. 2005; Brown et al. 2009). Gardiner et al. (2009) reported similar chemical and physical differences between forested and developed "hazard" sites in 2000.

Comparisons of community composition across three points in time (2000, 2005, 2010), allow us to characterize and compare community change at sites that span a gradient of urbanization. Our findings in this area have several interesting implications for alternative methodologies and hypothesis development in future studies of biotic homogenization associated with urbanization. The relatively large degree of temporal variability in both diatom and fish communities, especially at *forested-reference* sites (that had stable sub-watershed land uses and water chemistries), underscore the potential inaccuracies in defining biotic reference conditions at only one point in time. This suggests that the substitution of space for time (SFT) method, alone, may not be effective in characterizing the impact of landscape development on biota, due its inability to account for temporal variability in biotic communities. Also, urbanization, which is commonly thought of as affecting community composition through species replacement (McKinney, 2006), may also homogenize fish communities by reducing overall temporal variability. Furthermore, we can speculate that environmental factors not directly addressed in the current study, such as a rapidly warming regional climate, may differentially affect community variability of fish at *forested* and *suburban* sites. Using a linear regression model that estimated stream temperature from atmospheric temperature, Caldwell et al. (2014) predicted increasing mean stream temperatures in streams of the Appalachian forest ecoregion through 2060. Streams of the Appalachian forest ecoregion contain many temperature-sensitive fish species. Therefore, increasing summertime stream temperatures may have profound effects on cold-water fish communities in the region (Booth et al. 2014). Climate has also been shown to affect the expression of stream responses to urbanization by increasing losses of sensitive species and changing the magnitude and direction of stream flashiness (Hale et al. 2016). These findings highlight the need for the continuation and implementation of long-term studies, like the CHSP, which directly measure community change through time as an ecological feature that may be impacted by long-term processes such watershed urbanization and climate change.

In the original study, Gardiner et al. (2009) predicted fish communities in forested sub-watersheds undergoing low-density development to become more like those in rural sub-watersheds. Gardiner also predicted more homogeneous fish communities and higher fish diversity in forested sub-watersheds expected to undergo low-density development, as cosmopolitan fish species usually found in warmer streams at lower elevations invade cooler headwater streams without displacing highland endemics; a mechanism proposed by Scott and Helfman (2001). In sub-watersheds transitioning from agricultural to suburban land covers, Gardiner predicted that fish populations in agricultural streams would become more like that of suburban streams. Although few directional trends of community change became apparent during this phase of the CHSP, we found consistent differences in fish community composition between *forested* and *suburban* sites, that suggest biotic homogenization resulting from watershed urbanization. Previously, Gido et al. (2009) compared the similarity of fish communities in streams and reservoirs using ordination. They found that reservoir points were more closely clustered, and stream points were more dispersed, indicating a more homogenous community with less variability in reservoirs. Also, Marchetti et al. (2006) used NMDS ordination to show that historical fish communities were more homogenous than present day communities in Californian streams. Similarly, we suggest the closely clustered group of fish communities from the three most developed sites (Hooper's, Robinson, and Gap) may reflect more biotic homogenization associated with prior land use and urban development.

Our findings suggest that suburban regions of the southern Appalachian highlands currently contain fish communities that have undergone prior biotic homogenization but have not yet reached a level of urbanization that would extirpate highland endemics. Those fish species that we identified as strongly associated with either *forested* (*R. cataractae* and *O. mykiss*) or *suburban* (*N. rubricroceus*, *R. atratulus*, *H. nigricans*, *E. flabellare*, and *S. atromaculatus*) sub-watersheds in 2005 and 2010 are the same land use/habitat associations reported by Gardiner et al. (2009) for the year 2000. In a previous study of urbanization, also in the southern Appalachian highlands, Scott and Helfman (2001) suggested that the early stages of urban development can alter stream conditions in ways that facilitate the establishment of cosmopolitan fish species normally associated with lower elevations, while remaining hospitable to highland endemics. Several other studies have shown that biotic homogenization is initially driven by increases in cosmopolitan fish abundances, as opposed to decreases in endemic abundances (Rahel 2000; Walters et al. 2003; Taylor 2004). In a meta-analysis of urbanization-induced biotic homogenization, Mckinney (2006) notes that suburban areas are often more species- rich than more forested regions due the influx of cosmopolitan and invasive species. Similarly, our study found that fish communities at *suburban* sites were more species-rich and had greater proportions of cosmopolitan and trophic generalist fish species than *forested* sites.

As recently explored in Utz et al. (2016), certain biological, hydrological, and physiochemical conditions of streams may provide a degree of ecological resistance to urbanization. The authors hypothesized that a high degree of meta-population connectivity may buffer urbanizing streams against species loss. In the current study, we found that all sub-watersheds, including those undergoing the most development, remained predominantly forested, that may have provided a buffer to reduced species richness throughout the region. It is also possible that proximity to the mainstem of the French Broad River allowed species to persist in the three *suburban* sub-watersheds. Also, due to time lags in species extirpations due to urbanization, species richness can initially increase as cosmopolitan species are introduced and endemic species remain (Sax and Gaines 2003). Eventually, the negative impacts of urbanization will likely result in the decline or loss of native species (Ruesink 2003). Consequently, a pattern of comparatively high species richness associated with suburban landscapes relative to nearby forested landscapes (like the pattern found in fish communities in the present study) may provide an early warning sign of biotic homogenization and impending species extirpations as urbanization continues and meta-population connectivity is reduced. In future iterations of the CHSP we expect fish communities at *forested* sites to become more homogeneous from site to site, species-rich, and less variable over time as development progresses. As *suburban* sub-watersheds become increasingly developed, and habitat disturbances become increasingly frequent and intense, we predict a reduction in species richness as highland endemic species are extirpated and wide-spread species become more dominant.

Gardiner et al. (2009) predicted increases in diatom diversity due to higher irradiance and nutrient inputs to streams associated with riparian deforestation. Diatom assemblages in forested streams were also predicted to be characterized by endemic and shade tolerant species, with more cosmopolitan taxa occurring if riparian vegetation was removed due to building construction. Our analyses of the combined diatom data set, that included 186 species, 3 of which were endemic to the region (*Meridion alansmithii*, *Gomphonema mehleri*, *Achnanthidium lapidosa var. appalachiana*), did not support the initial predictions of community change or trends in diatom species richness thought to be associated with watershed urbanization. Unlike the consistency of associations between stream habitats and fish species, only one (*E. incisa*) of six diatom species remained a strong indicator of *forested* sites, and two (*C. affinis, M. varians*) of six remained strong indicators of developed sites in both the current and former CHSP studies (Gardiner et al. 2009). *E. incisa* has been characterized as indicative of forested, oligotrophic, headwater streams (Greenwood and Rosemond 2005; Potopova and Charles 2007), while *M. varians* has been characterized as somewhat shade intolerant and indicative of mesotrophic streams (Gardiner et al. 2009). The strong associations between these diatom species and *forested* or *suburban* sub-watersheds suggests an impact of land use on diatom community composition. Still, the inconsistency of indicator species identity throughout both "hazard" site studies, and the similarity of diatom communities collected in the same study year (regardless of LULC grouping), suggest that there may be a large degree of temporal variability in diatom communities that should be accounted for when using diatoms in studies of watershed urbanization (Thackery et al. 2008). We did not find increases in diatom species richness at *suburban* sites. Furthermore, diatom communities at the two *forested* sites (Coweeta and Avery) were not less species-rich than developing sites throughout the study. These findings are inconsistent with the expectation that streams in forested regions contain communities with lower algal diversity than more developed regions due to lower light and nutrient input (Lowe et al. 1996; Gardiner et al. 2009). At the onset of the CHSP, *suburban* sites had less riparian forest cover than forested sites, but canopy cover and light levels were not directly measured at diatom sampling locations through time (Gardiner et al. 2009). The riparian conditions of headwater streams can change drastically from year to year due to rapid removal or regrowth of stream side vegetation (Landis and Leopold 2014). Such changes could affect diatom community structure and diversity in ways not detected in our study, which collected data every five years.

As predicted, we found a high degree of correlation between the NMDS ordination axes of biota and several environmental variables related to watershed urbanization. Other studies that have used correlations of NMDS axes and environmental attributes have also found that variables related to urbanization strongly correlated with biotic assemblage structure (Kennen et al. 2005, Brown et al. 2009). These strong correlations, although not direct evidence of causal dependencies between watershed urbanization and biotic responses, can indicate potential drivers of ecological change, provide insight for future hypothesis development, and be used in the design of effective stream conservation plans for rapidly urbanizing regions.

SUMMARY

Our cumulative findings from 2000, 2005 and 2010, demonstrate how a predictive land use/land cover model can be used to accurately forecast urbanization in space and time. Furthermore, our findings show how ecological monitoring at a broad temporal scale (every five years) can be effective in characterizing differences in biological, physical, and chemical conditions between streams in different phases of watershed urbanization. The continuation of the CSHP from 2000 to 2010 also shows that a long-term study can characterize temporal variability of biotic assemblages and, thereby, provide a complementary approach to the more commonly used space for time substitution technique. Accordingly, prior publications have also indicated that the ecological impacts of urbanization could benefit from accurate, spatially-explicit, predictions of landscape development (Veldkamp and Lambin 2001, Sohl et al. 2012, Pellissier et al. 2013, Rosa et al. 2014). Such predictions can be used to design proactive monitoring strategies that capture changes in urbanizing ecosystems as they occur (Pavri et al. 2013).

We suggest that more species-rich, cosmopolitan, and homogeneous fish communities that we observed in *suburban*, relative to *forested* sites. may be due to the early stages of biotic homogenization. We realize the limitations of suggesting trends or characterizing community dynamics from only three data points, taken five years apart. Still, the consistency of observed differences between *forested* and *suburban* sites, despite the CHSP's broad temporal sampling schedule, suggest an extensive impact of past land use. Continued study of these rapidly changing landscapes over the next few decades will be necessary to tease apart the influence of land use legacies and contemporary development on stream ecosystems.

Moving forward we suggest some changes that may improve the CHSP and the generalizability of its findings. We recommend the addition of canopy cover surveys; large woody debris (LWD) counts; and monthly stream temperature that could allow future researchers to test more mechanistic hypotheses regarding how urbanization and climate change affect stream habitats and biota. We also suggest including measurements of stream gradients in future sampling events. Furthermore, we also recommend that fish surveys be conducted bi-annually to capture the degree of community variability at a finer temporal resolution. Lastly, we suggest the next iterations of CHSP sampling be conducted in 2020, 2025 and 2030, in order to add "temporally-relevant" snapshots to the long-term "hazard-site" dataset. By building on the findings presented here, the continued long-term monitoring of these “hazard” sites, and their sub-watersheds, could reveal key insights regarding the complex interrelationship between low-density development and stream ecosystems in an ancient mountain system on the edge of urbanization.

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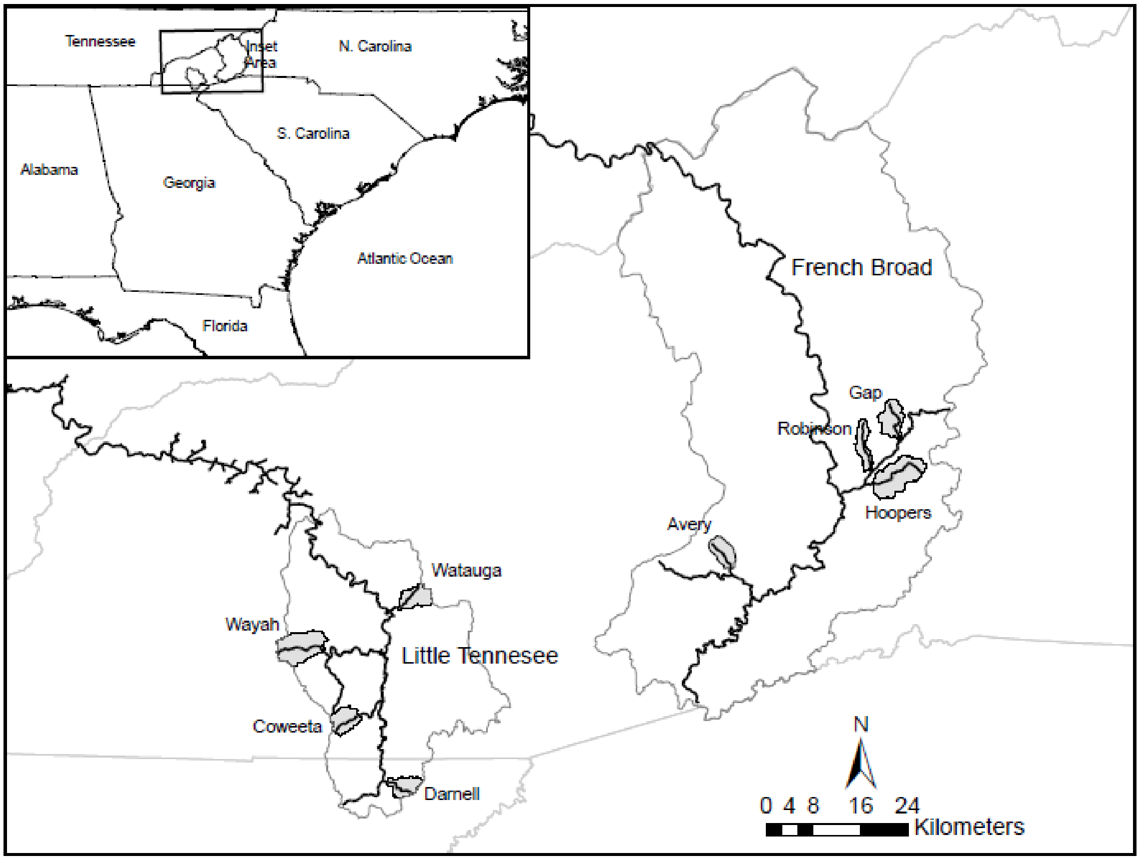

FIGURE 2.1. Map depicting the eight study sub-watersheds, each containing a "hazard" site where reach-scale sampling was conducted in the years 2000, 2005, and 2010. All sub-watersheds are in the Little Tennessee (Coweeta, Darnell, Wayah, and Watauga) and French Broad (Avery, Robinson, Gap, and Hooper´s) watersheds of the Blue Ridge ecoregion. Inset (upper left) depicts location of the two main watersheds (Little Tennessee and French Broad) in relation to state borders.

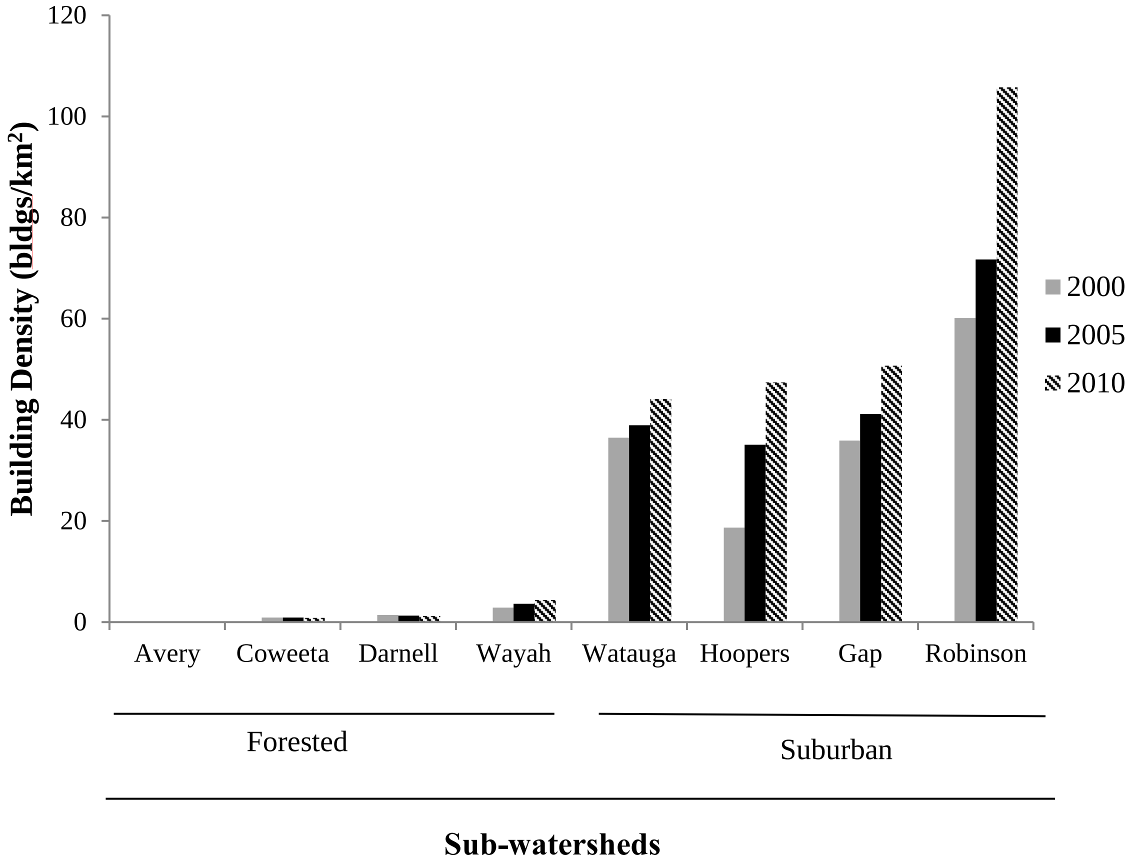

FIGURE 2.2. Building density (bldgs/km^2) for each of the eight study sub-watersheds, grouped by 2010 LULC classifications (*forested* and *suburban*), in years 2000, 2005, and 2010.

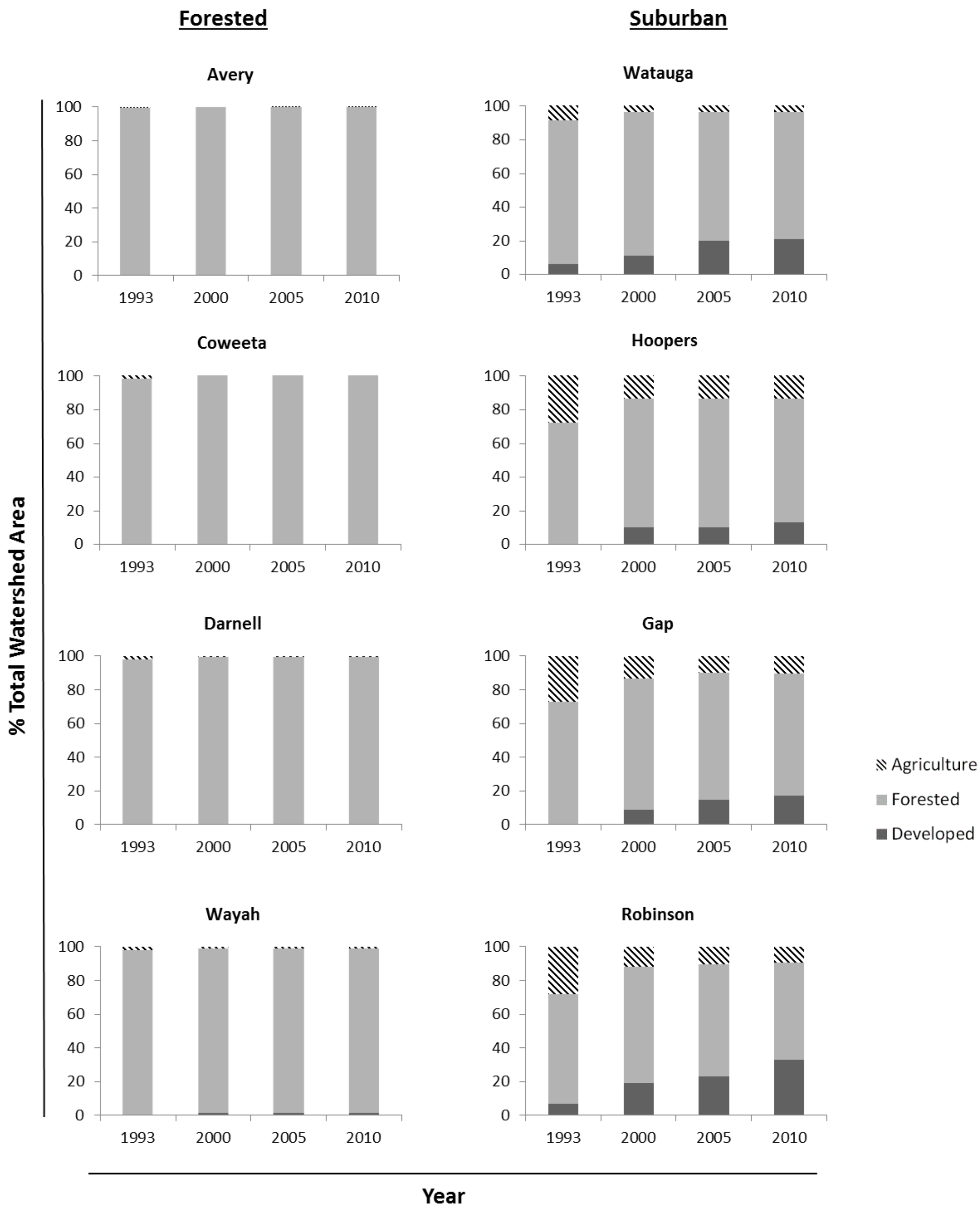

FIGURE 2.3. Relative changes through time in land cover (forested, agriculture, and developed). Sub-watersheds are grouped by 2010 LULC classification (*forested* and *suburban*).

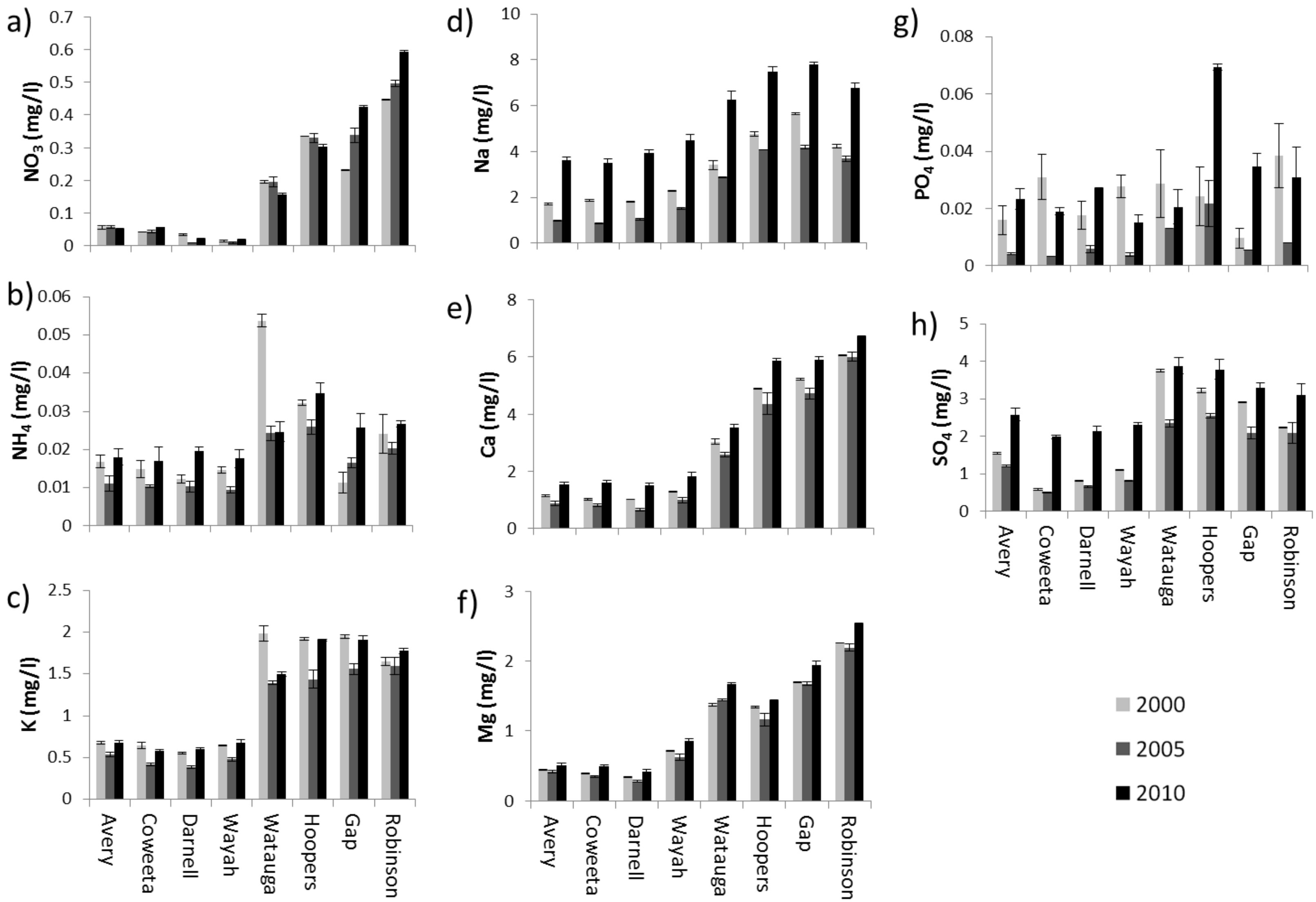

FIGURE 2.4. Concentrations of (a) NO_3, (b) NH_4, (c) K, (d) Na, (e) Ca, (f) Mg, (g) PO_4, and (h) SO_4 ($\bar{x} \pm$ 1SE) for each hazard site (N=3) in the years 2000, 2005, and 2010.

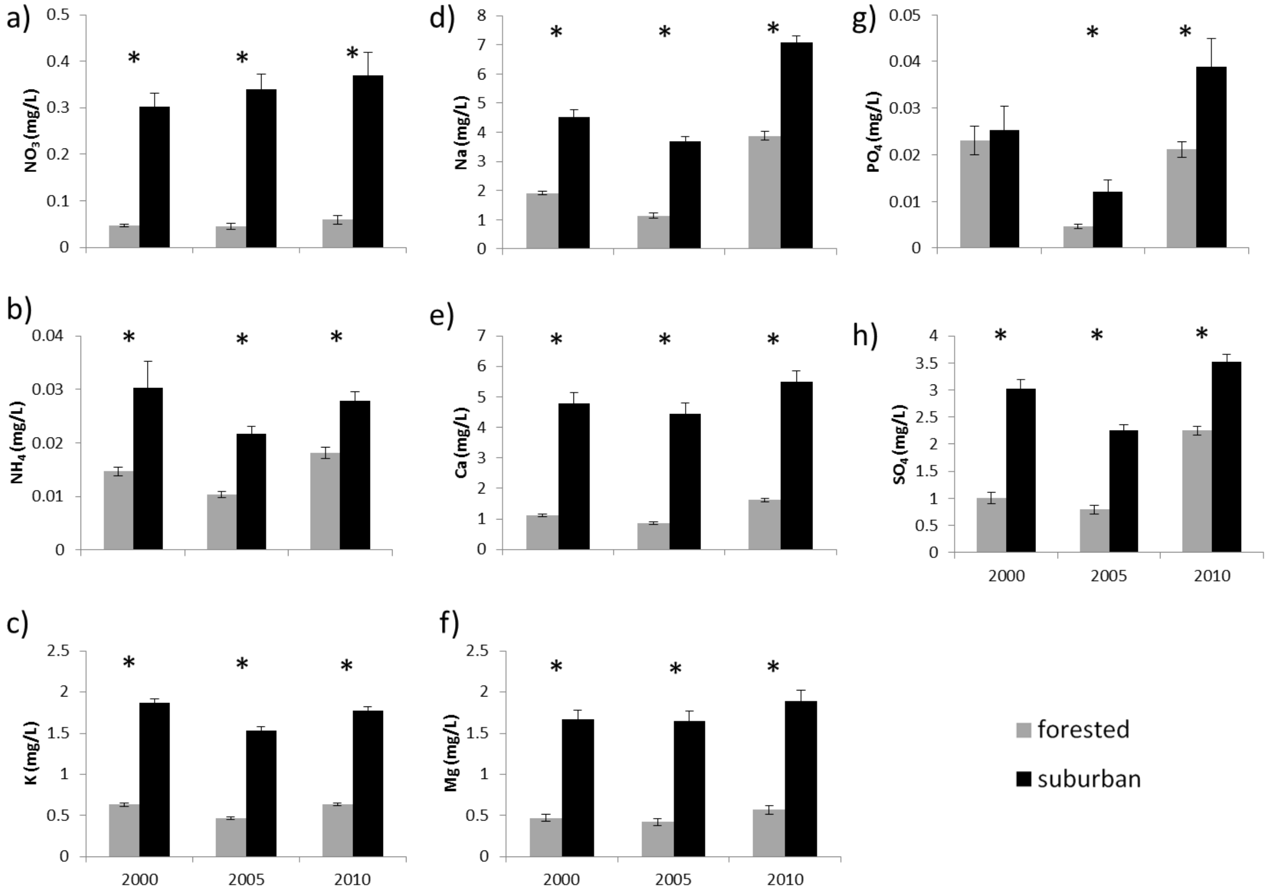

FIGURE 2.5. Concentrations of (a) NO_3, (b) NH_4, (c) K, (d) Na, (e) Ca, (f) Mg, (g) PO_4, and (g) SO_4 ($\bar{x} \pm$ 1SE) for *forested* (N=4) and *suburban* sub-watersheds (N=4) in the years 2000, 2005, and 2010. Asterisks above years indicate significant differences ($p<0.05$) between *forested* and *suburban* sites as determined by Wilcoxon rank sum tests.

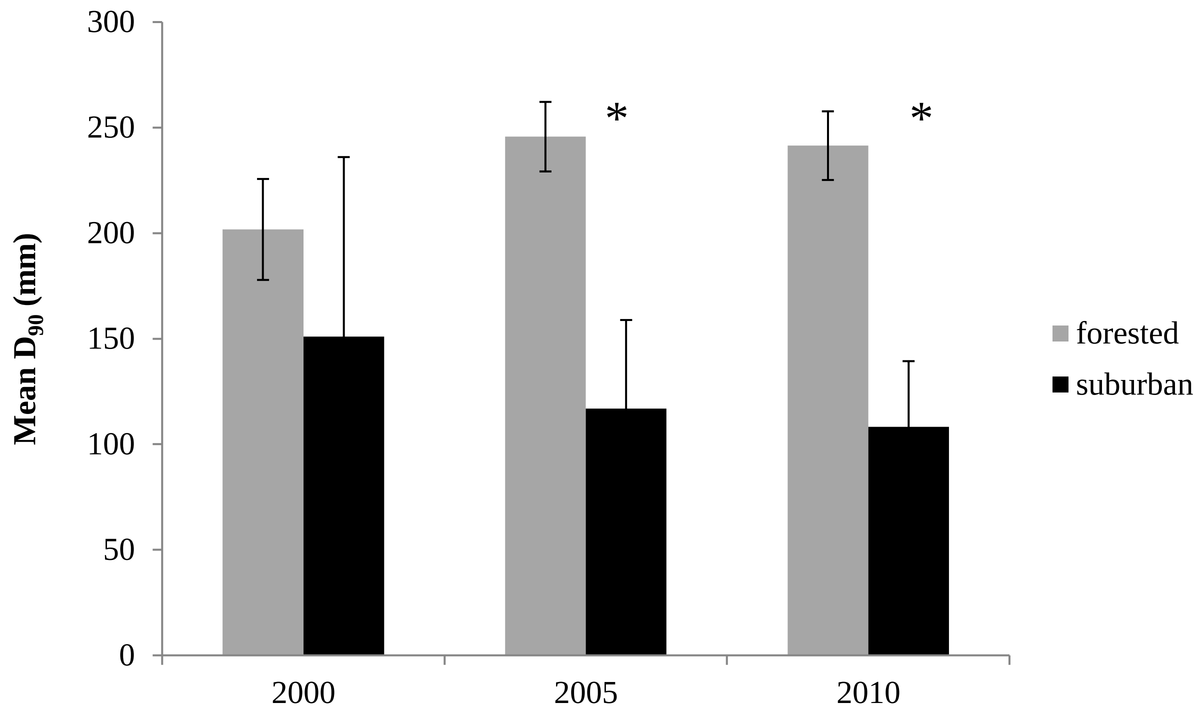

FIGURE 2.6. Bed D_{90} particle sizes ($\bar{x} \pm$ 1SE) for *forested* (N=4) and *suburban* (N=4) sub-watersheds in the years 2000, 2005, and 2010. Asterisks above years indicate significant differences ($p<0.05$) between *forested* and *suburban* sub-watersheds as determined by Wilcoxon rank sum tests.

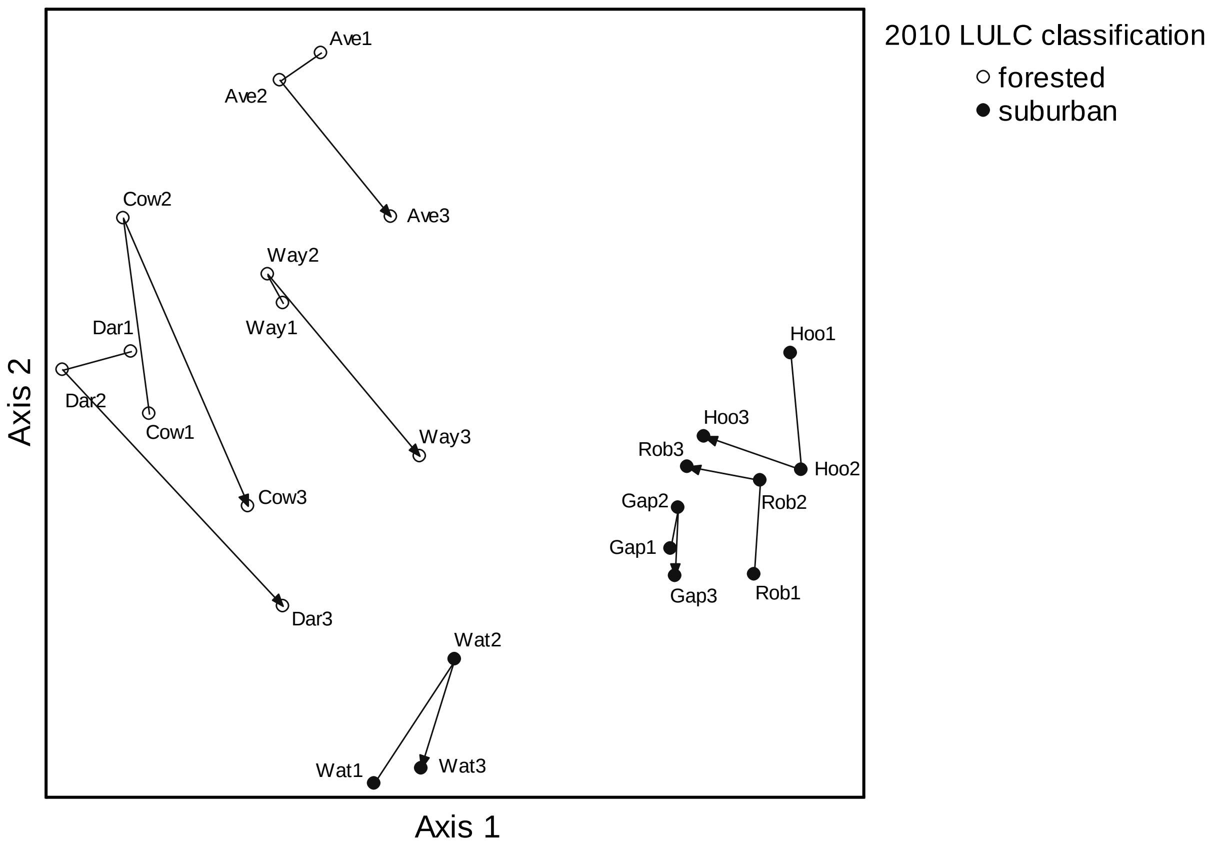

FIGURE 2.7. Nonmetric multidimensional scaling (NMDS) ordination of fish species abundance at each hazard site displaying hazard sites (where Ave = Avery, Cow = Coweeta, Dar = Darnell, Way = Wayah, Wat = Watauga, Hoo = Hooper´s, Gap = Gap, Rob = Robinson) with sample years (where 1 = 2000, 2 = 2005, 3 = 2010), and successional vectors. Successional vectors link community trajectories at sites through time, with arrowheads indicating the direction of time. The most suitable ordination was a 2-dimensional solution, with a final stress of 10.565 and an instability of <0.00001. The r^2 of axis 1 and 2 were 0.58 and 0.33, respectively.

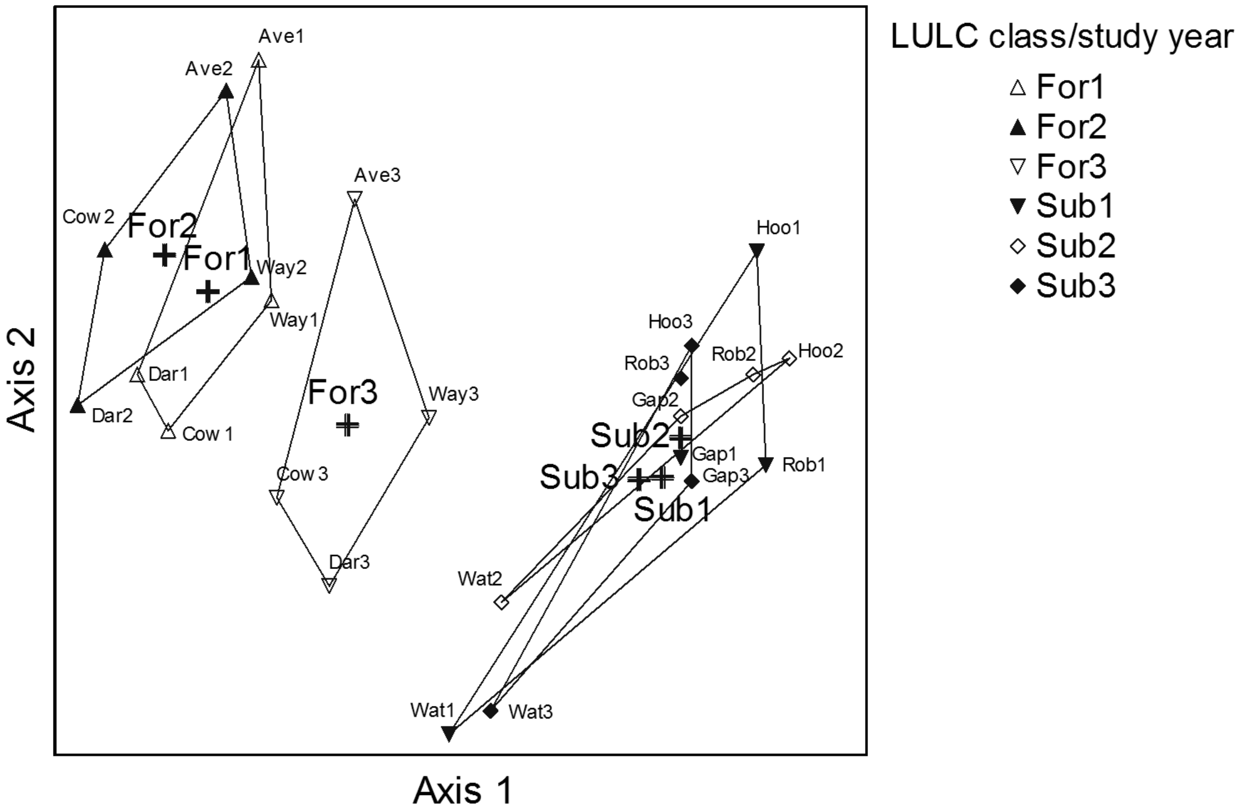

FIGURE 2.8. Output of NMDS analysis used to test for changes in the taxonomic composition and dissimilarity of fish communities among the eight hazard sites (where Ave = Avery, Cow = Coweeta, Dar = Darnell, Way = Wayah, Wat = Watauga, Hoo = Hooper´s, Gap = Gap, Rob = Robinson) over 3 study years (where 1 = 2000, 2 = 2005, 3 = 2010). Results are summarized by convex hulls whose centroids (indicated by + symbol; where For = forested, Sub = suburban) represent the mean taxonomic dissimilarity among fish communities in each study year (with closer centroids indicating more similar communities over the study period), and areas represent the overall taxonomic composition in each study year (with more overlapping areas indicating more similar communities over the study period).

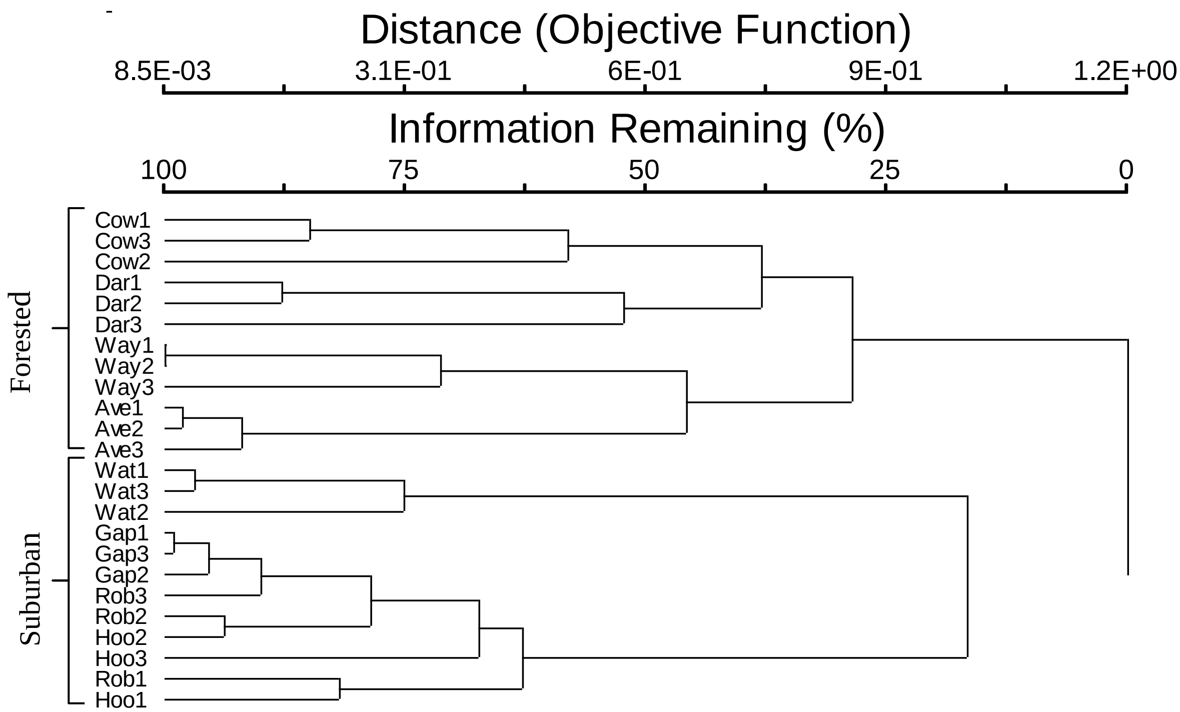

FIGURE 2.9. Hierarchical Cluster Analysis (HCA) dendrograms of fish assemblages at each hazard site, displaying hazard sites (where Ave = Avery, Cow = Coweeta, Dar = Darnell, Way = Wayah, Wat = Watauga, Hoo = Hooper´s, Gap = Gap, Rob = Robinson) with sample years (where 1 = 2000, 2 = 2005, 3 = 2010).

TABLE 2.1. Fish taxa strongly associated (≥0.50), via indicator species analysis and Monte Carlo permutation tests, with *forested* and *suburban* sites. Geographic distribution, indicator values, and p-values for each taxon are shown. Highland endemic distribution refers to species only found in Southern Appalachian mountain streams.

Taxon	Distribution	Indicator Value	p-value
Fish associated with *forested* sites			
Rhinichthys cataractae	cosmopolitan	91.7	0.0002
Oncorhynchus mykiss	cosmopolitan/non-native	90.9	0.0002
Clinostomus funduloides	highland endemic	58.3	0.0046
Fish associated with *suburban* sites			
Semotilus atromaculatus	cosmopolitan	91.2	0.0002
Hypentelium nigricans	cosmopolitan	91.1	0.0002
Rhinichthys atratulus	cosmopolitan	84.4	0.0002
Luxilus coccogenis	highland endemic	77.7	0.0016
Notropis rubicroceus	highland endemic	74.6	0.0006
Etheostoma flabellare	highland endemic	72.6	0.0006
Etheostoma swannanoa	highland endemic	66.1	0.0022
Lepomis auritus	cosmopolitan	50.0	0.0108

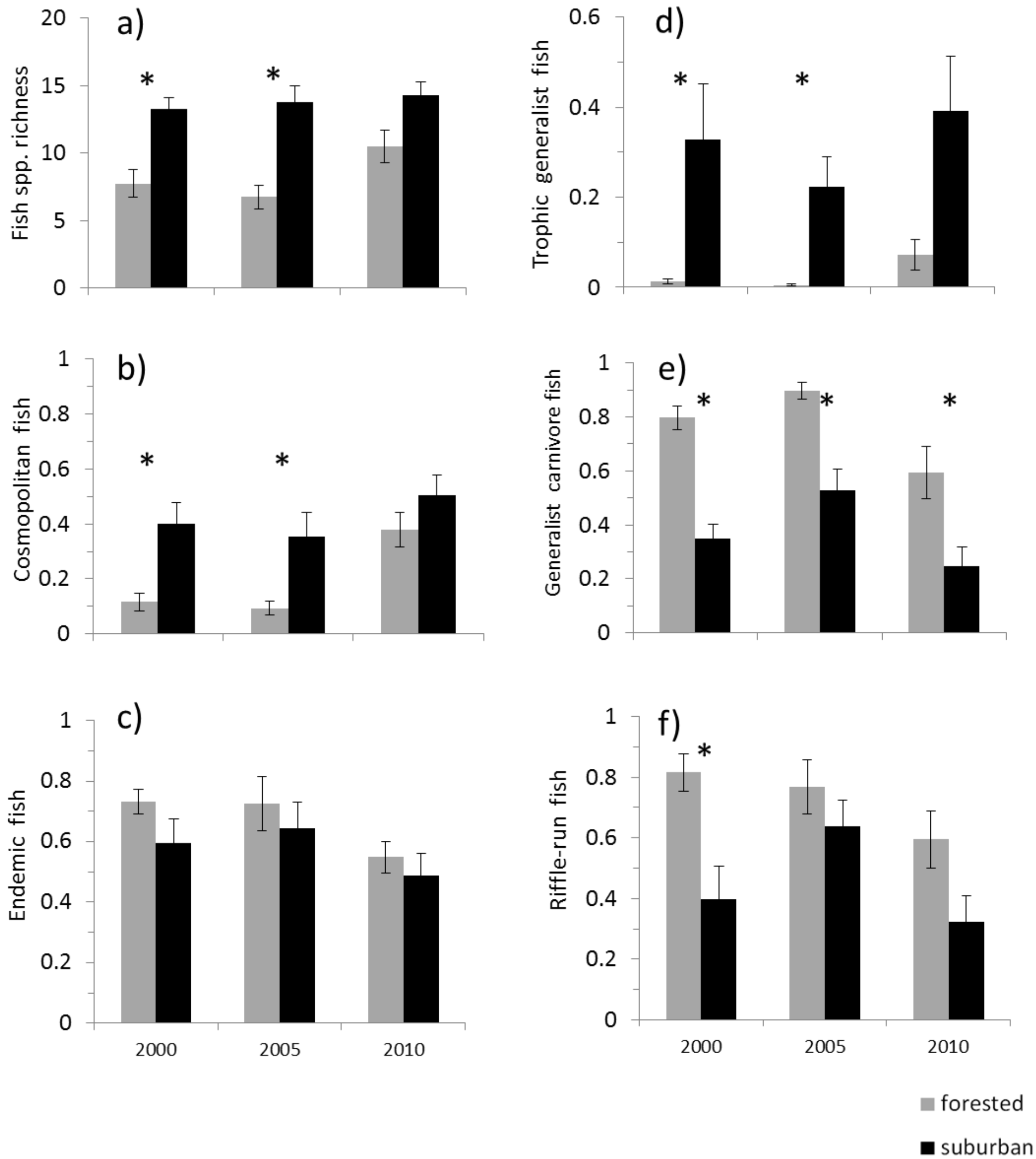

FIGURE 2.10. (a) Fish species richness ($\bar{x} \pm$ 1SE), (b) relative abundance of cosmopolitan fish species ($\bar{x} \pm$ 1SE), (c) relative abundance of endemic fish species ($\bar{x} \pm$ 1SE), (d) relative abundance of trophic generalist fish species ($\bar{x} \pm$ 1SE), (e) relative abundance of generalist carnivore species ($\bar{x} \pm$ 1SE), and (f) relative abundance of riffle-run specialist fish species ($\bar{x} \pm$ 1SE) for *forested* (N=4) and *suburban* sub-watersheds (N=4) in the years 2000, 2005, and 2010. Asterisks above years indicate significant differences ($p<0.05$) between *forested* and *suburban* sites as determined by Wilcoxon rank sum tests.

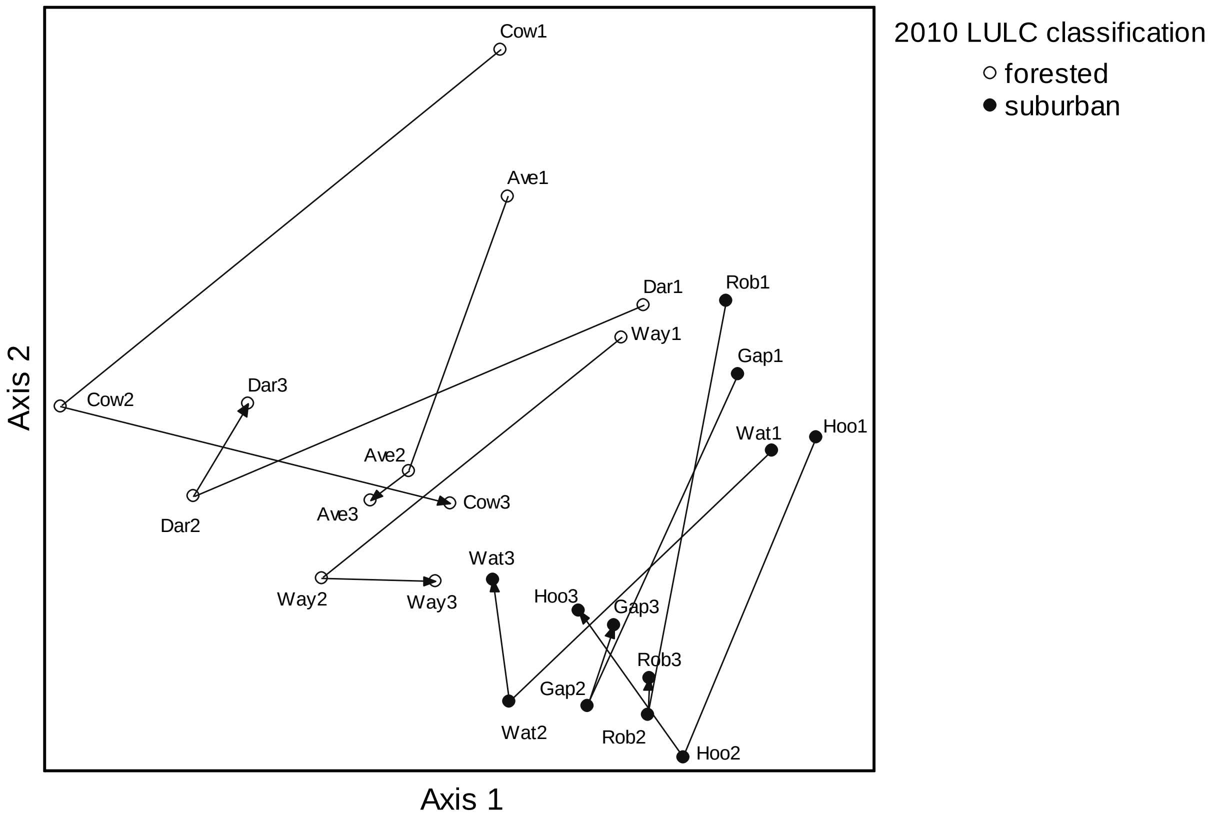

FIGURE 2.11. Nonmetric multidimensional scaling (NMDS) ordination of diatom cell densities at each hazard site, displaying hazard sites (where Ave = Avery, Cow = Coweeta, Dar = Darnell, Way = Wayah, Wat = Watauga, Hoo = Hooper´s, Gap = Gap, Rob = Robinson) with sample years (where 1 = 2000, 2 = 2005, 3 = 2010), and successional vectors. The most suitable ordination was a 2-dimensional solution, with a final stress of 10.974 and an instability of <0.00001. The r^2 of axis 1 and 2 were 0.38 and 0.52, respectively.

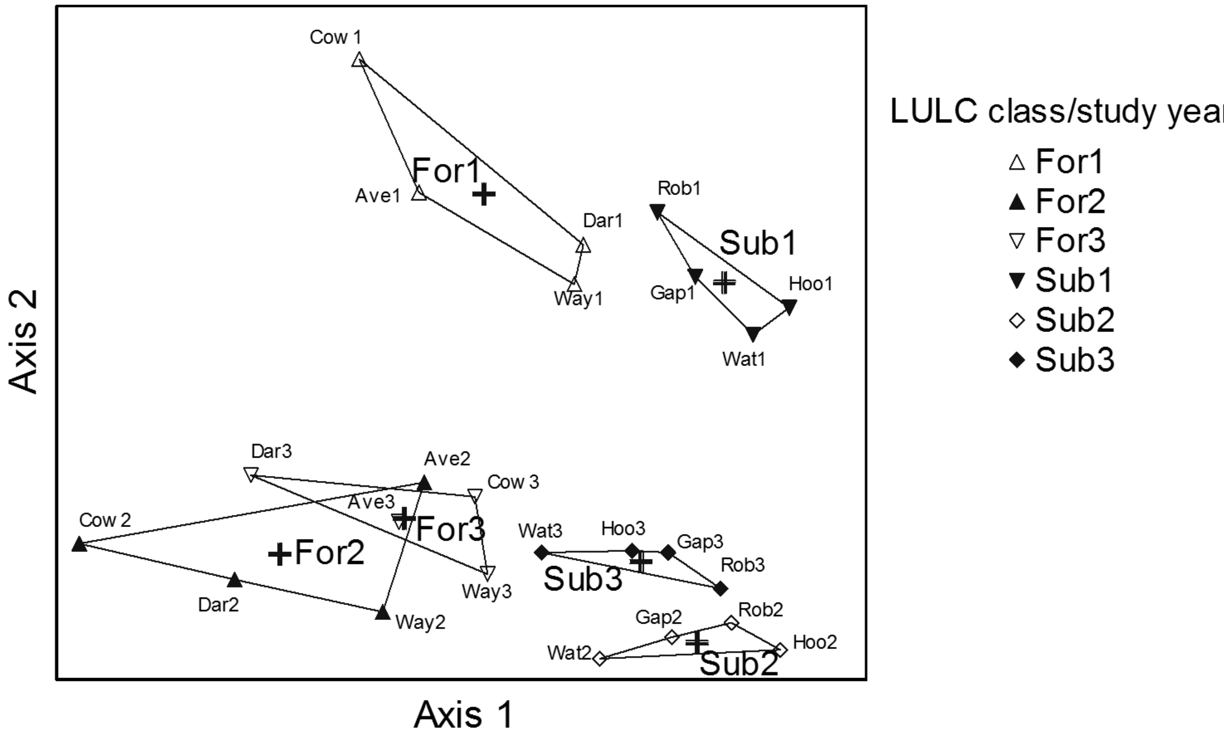

FIGURE 2.12. Output of NMDS analysis used to test for changes in the taxonomic composition and dissimilarity of diatom communities among the eight hazard sites (where Ave = Avery, Cow = Coweeta, Dar = Darnell, Way = Wayah, Wat = Watauga, Hoo = Hooper´s, Gap = Gap, Rob = Robinson) over 3 study years (where 1 = 2000, 2 = 2005, 3 = 2010). Results are summarized by convex hulls whose centroids (indicated by + symbol; where For = *forested*, Sub = *suburban*) represent the mean taxonomic dissimilarity among diatom communities in each study year (with closer centroids indicating more similar communities over the study period), and areas represent the overall taxonomic composition in each study year (with more overlapping areas indicating more similar communities over the study period).

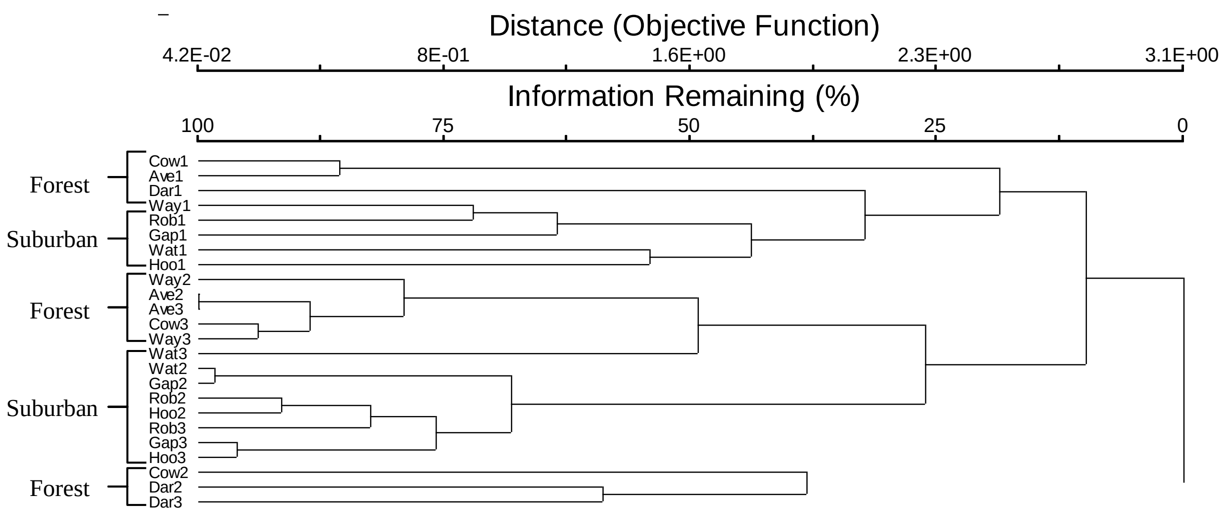

FIGURE 2.13. Hierarchical Cluster Analysis (HCA) dendrograms of diatom assemblages from each hazard site, displaying hazard sites (where Ave = Avery, Cow = Coweeta, Dar = Darnell, Way = Wayah, Wat = Watauga, Hoo = Hooper´s, Gap = Gap, Rob = Robinson) with sample years (where 1 = 2000, 2 = 2005, 3 = 2010).

TABLE 2.2. Diatom taxa strongly associated ($\geq$0.50), via indicator species analysis and Monte Carlo permutation tests, with *forested* and *suburban* sites. Geographic distribution, indicator values, and p-values for each taxon are shown.

Taxon	Distribution	Indicator Value	p-value
Diatoms associated with *forested* sites			
Eunotia incisa	cosmopolitan	72.6	0.0010
Synedra rumpens var. fragilaroides	cosmopolitan	67.3	0.0052
Frustulia rhomboids var. amphipleuroides	cosmopolitan	59.6	0.0236
Navicula angusta	cosmopolitan	56.1	0.0466
Diatoms associated with *suburban* sites			
Geissleria decussis	cosmopolitan	99.5	0.0002
Achnanthdium subhudsonis	intermediate	96.1	0.0020
Gomphonema parvulum	cosmopolitan	91.1	0.0054
Encyonema minutum	cosmopolitan	88.0	0.0148
Cymbella tumida	cosmopolitan	87.1	0.0008
Navicula cryptotenella	cosmopolitan	86.9	0.0008
Planothidium lanceolatum	cosmopolitan	83.1	0.0020
Nitzschia palea	cosmopolitan	81.1	0.0012
Cymbella affinis	cosmopolitan	78.0	0.0012
Fragilaria vaucheriae	cosmopolitan	78.0	0.0150
Nitzschia linearis	cosmopolitan	75.0	0.0002
Reimeria sinuate	cosmopolitan	75.0	0.0006
Synedra ulna	cosmopolitan	73.1	0.0128
Navicula cryptocephala	cosmopolitan	72.6	0.0252
Psammothidium subatomoides	cosmopolitan	68.9	0.0330
Navicula rostellata	cosmopolitan	66.7	0.0024
Melosira varians	cosmopolitan	65.8	0.0042
Navicula schroeteri	cosmopolitan	58.3	0.0054
Navicula germainii	cosmopolitan	58.0	0.0050
Gomphonema pumilum	cosmopolitan	57.6	0.0100
Aulacoseira italic	cosmopolitan	50.0	0.0112

TABLE 2.3. Pearson correlations of environmental variables contributing to axes 1 and 2 of a nonmetric multidimensional scaling of fish and diatom communities sampled at the eight hazard sites in 2000, 2005, and 2010. Bolded values indicate Pearson correlations with r-values > 0.70.

Environmental variable	Fish ordination		Diatom ordination	
	Axis 1	Axis 2	Axis 1	Axis 2
Sub-watershed variables				
Drainage area (km^2)	0.344	0.112	0.239	-0.247
Elevation (m)	-0.390	**0.827**	-0.430	0.423
LULC variables				
Agricultural land cover (%)	**0.907**	-0.471	**0.701**	-0.415
Developed land cover (%)	**0.706**	-0.531	0.493	-0.559
Forested land cover (%)	**-0.864**	0.542	-0.635	0.546
Building density (buildings/km^2)	**0.752**	-0.511	0.543	-0.520
Geomorphic data				
Mean D_{90}	-0.512	0.284	-0.505	0.285
Mean Phi-size	0.603	-0.389	**0.799**	0.009
Water chemistry variables				
NO_3 concentration (mg/l)	**0.874**	-0.378	0.630	-0.479
Ca concentration (mg/l)	**0.926**	-0.465	0.670	-0.460
K concentration (mg/l)	**0.850**	-0.592	**0.762**	-0.387
Na concentration (mg/l)	**0.730**	-0.551	0.489	-0.437
NH_4 concentration (mg/l)	0.461	-0.565	0.556	-0.235
PO_4 concentration (mg/l)	0.205	-0.092	-0.046	-0.017
Mg concentration (mg/l)	-0.019	-0.227	-0.409	-0.451
SO_4 concentration (mg/l)	0.108	-0.172	-0.392	-0.603

CHAPTER 3

DEVELOPMENT AND TESTING OF THE SOUTHERN APPALACHIAN STREAM VISUAL ASSESSMENT PROTOCOL (saSVAP): A TOOL FOR THE INDEPENDENT ASSESSMENT OF WADABLE STREAMS BY RIPARIAN LANDOWNERS[2]

[2] Jeremy C. Sullivan, S.R. Evans, E. Nixon, M.P. Dudley, J.F. Chamblee, C.R. Jackson, T.L. Gragson, C.M. Pringle

To be submitted to *Citizen Science: Theory and Practice*

ABSTRACT

In response to the lack of citizen-centered visual stream assessments and difficulties associated with conducting long-term ecological research on private lands, we developed and tested the Southern Appalachian Stream Visual Assessment Protocol (saSVAP). This tool is a user-friendly habitat survey, designed for independent use by riparian landowners to assess the ecological conditions of small, low-order, streams draining their properties. Using previous SVAP versions as guides, we modified saSVAP for wadable streams of the Southern Blue Ridge ecoregion, a highly biodiverse and scenic region facing rapid exurban development. The Southern Appalachian SVAP includes an illustrated element scoring guide; a site mapping procedure; a photo-point monitoring guide; and an illustrated riparian plant guide. Field testing of saSVAP demonstrated that the visual scoring elements on saSVAP correlate strongly with paired habitat metrics, overall habitat scores from saSVAP strongly correlate with fish IBI scores, and that the tool can reliably be used by both novice and expert users to determine overall stream habitat ratings. We recommend the development of habitat assessment tools modified for local stream conditions and designed for independent use by landowners, to detect habitat impairment, increase public awareness of local resource concerns, and allow researchers to gain information about streams found on privately-owned lands. Moving forward, the incorporation of saSVAP into a regional land trust's stream bio-monitoring effort will allow researchers and citizens to characterize how stream habitats change over time in a rapidly developing region.

INTRODUCTION

The general purpose of visual stream habitat assessment is to evaluate the physical characteristics of streams and determine an overall rating, or score, for the ecological condition of a stream or stream reach (Somerville 2010). Visual habitat assessments are often included in environmental monitoring programs by natural resource managers and conservation agencies throughout the United States and abroad due their speed and ease of use with minimally trained volunteers (Ward et al. 2003; Dias et al. 2015; Kiourtziadis et al. 2016). Variations of visual habitat assessments have been used to inform decisions in fisheries management and land-use planning; to characterize streams for resource utilization; to monitor streams for compliance to federal and state permits; and to track changes in stream conditions over time (USDA-NRCS 2009; Somerville 2010; Doll et al. 2016). Although many visual habitat assessments can be used by volunteers, most require some training and the assistance of conservation groups or stream science professionals. Considering the absence of citizen-centered stream assessment protocols, questions remain on if, and to what degree, untrained citizens can reliably visually assess the ecological condition of streams. The development of a locally-modified, visual stream assessment tool, geared towards independent use by local landowners, may shed light on these questions. Such a tool could also empower citizens to take part in stream monitoring, improve public understanding of the links between land use practices and stream conditions, and increase the scope of stream conservation efforts by allowing landowners to assess the condition of streams found on their own lands.

Community participation in freshwater monitoring has increased globally over the last 20 years (Bonney et al. 2014; Huddart et al. 2016). Involving residents and landowners in environmental monitoring has many potential benefits that include: increasing the amount and coverage of spatially detailed data (Dickenson et al. 2012); increasing scientific literacy and awareness of local resource concerns among participants (Stepenuck and Green 2015); and improving the relationship between the public and the government agencies enforced with protecting their natural resources (Storey et al. 2016). Several versions of stream monitoring protocols have been designed for use by trained volunteers. The USEPA's Save our Streams (SOS) and Adopt-a-Stream (AASF) are well established programs that lead volunteer groups in stream bio-monitoring, water quality assessment, visual habitat assessment, and restoration efforts. Volunteers for these, and similar, programs usually require several hours of in-door and out-door training and are ideally conducted in teams supervised by a technical advisor. These programs, due to their reliance on training sessions and technical supervision, usually require months of preparation by volunteer-based steering committees that lead, organize, and coordinate stream surveys. Utilizing untrained citizens for stream assessments, if feasible, can create opportunities to increase the number of stream miles monitored by giving landowners the ability to assess streams on their lands without the logistical and budgetary constraints that can hamper larger volunteer stream monitoring efforts. To further explore these possibilities, the following project set out to design, and test, a citizen-centered, visual habitat assessment tool, regionally modified for small streams of Southern Blue Ridge (SBR) ecoregion.

Despite the important role that low-order streams play in determining the overall ecological condition of watersheds (EPA 2015), assessing wadable streams found on privately-owned lands remains difficult (Dodds and Oates 2008). This is largely due to the need for researchers to acquire landowner permission to access stream sites (Olsen and Peck 2008). Furthermore, streams found on private lands are primarily managed by local landowner decisions, which largely depend upon the knowledge base of the landowner. These decisions can lead to the conservation, restoration, degradation, and in some cases, destruction of unique stream ecosystems. Although the Clean Water Rule (2015) has included headwater streams under Clean Water Act protection since 2015, the current U.S. administration has ordered the USEPA to eliminate or curtail this federal protection (Executive Order No. 13778, 2017). These events could leave headwater streams at risk of unchecked degradation and pollution (Owen 2017). For these reasons, public-outreach that communicates to stakeholders the value of resource conservation is vital to strengthening relationships between scientists, stakeholders, and policymakers. Giving landowners and residents a tool to determine the quality of streams on their lands may help to introduce landowners to environmental stewardship and bridge the gap between the public and the federal agencies enforced with protecting their natural resources.

Stream habitat assessment methods fall into two general categories: primarily quantitative, comprehensive, rigorous, methods that incorporate standardized sampling and require specialists or professionals with access to technical equipment; or primarily qualitative, rapid, visually-based methods, which can be conducted by trained staff and volunteers. Examples of more quantitative assessments include The U.S. Geological Survey's (USGS) National Water-Quality Assessment (NAWQA) Program (Fitzpatrick et al. 1998) and the U.S. Environmental Protection Agency's (USEPA) Environmental Monitoring and Assessment Program (EMAP) (Lazorchack et al. 1998). These assessments usually require several hours to days to complete and can only be conducted by users with relatively high levels of expertise in aquatic conservation or field techniques. Habitat and multidisciplinary assessments that are primarily qualitative include the USEPA's Rapid Bio-assessment Protocol (RBP) (Plafkin et al. 1989), the Ohio EPA's Qualitative Habitat Evaluation Index (QHEI) (Rankin 1989), the Riparian Channel and Environmental Inventory (RCE) (Peterson et al. 2001), the Bureau of Land Management's (BLM) Proper Functioning and Conditioning

(PFC) method (Prichard et al. 1994), the Natural Resource Conservation Service's (NRCS) Stream Visual Assessment Protocol (SVAP) (NRCS 1998), and the updated SVAP2 (NRCS 2009). Visual assessment tools can take a narrative approach, where a survey or questionnaire is used to document visual observations and determine a qualitative rating or numerical score, or a photographic approach, where photo-monitoring is used to document stream conditions. Visually-based stream assessments are often included, along with biological and chemical parameters, in volunteer stream monitoring efforts throughout the country. These more qualitative assessments usually take less than several hours to complete and can be conducted by users with a low to moderate level of training (Frothingham and Bartlett 2012).

The original Stream Visual Assessment Protocol (SVAP) was developed in a partnership between the U.S. Department of Agriculture (USDA) – Natural Resources Conservation Service (NRCS) and the University of Georgia's Odum School of Ecology and Department of Geography (Bjorkland et al. 1999). SVAP was designed as a nation-wide introductory screening-level assessment method and educational tool for landowners working alongside NRCS personnel. The SVAP tool measures a maximum of fifteen elements, all based on visual inspection of the biological and physical characteristics of in-stream and riparian environments of wadable streams. Each scoring element is meant to correspond to an important stream feature (i.e. channel condition, degree of bank stability, riparian zone condition, degree of nutrient enrichment, appearance of stream water, presence of absence and extent of barriers to fish movement, presence or absence of instream fish cover, presence or absence and condition of stream pools, and the presence or absence and extent of forest canopy cover over a stream) and is based on a choice among several text-based descriptions of possible stream states. From those choices a numerical score from one to ten is assigned for each element and averaged to determine an overall qualitative rating ("poor", “fair”, “good”, or “excellent”) of the stream reach. The USDA-NRCS Stream Visual Assessment Protocol Version 2 (SVAP2) is a revised national (U.S.) protocol designed for use by conservation planners and field office personnel, with the assistance of private landowners (USDA-NRCS, 2009). Like the original SVAP, SVAP2 provides a basic level of ecological assessment based on qualitative descriptions of physical and biological features of stream habitats. SVAP2 provides more detail regarding the importance of each element and more comprehensive descriptions of several scoring elements (i.e. channel condition, hydrological alteration, riparian condition, and fish habitat complexity) than the original SVAP. Since their original publication, SVAP and SVAP2 have been used as tools to: (1) establish the eligibility of Farm Bill programs; (2) assess quality criteria for conservation planning (Bjorkland et al. 2001); (3) identify potential environmental resource concerns (USDA-NRCS, 2009); (4) evaluate changes in riparian conditions (Teels et al. 2006) and stream corridors (Frothingham and Bartlett 2012) over time; (5) examine how invasive species recruitment (Warren et al. 2015) and stream biodiversity (Santos et al. 2016) are affected by riparian buffer conditions; and finally (6) to evaluate stream restoration projects (Doll et al. 2016). SVAP has also been locally modified for streams in Belize (Esselman 2001) Hawaii (HSVAP) (NRCS, 2001b), Costa Rica (Mafla-Herrera 2005), Greece (Kiourtziadis et al. 2014), New Zealand (Clapcott 2015), and Portugal (Dias et al. 2015).

Here, in partnership with the Coweeta Hydrological Laboratory (CHL), the Mainspring Conservation Trust (MCT) (formally known as the Land Trust for the Little Tennessee) and the Odum School of Ecology (OSE), we present the Southern Appalachian Stream Visual Assessment Protocol (saSVAP), a preliminary assessment protocol tailored to the wadable streams of the Southern Blue Ridge (SBR) eco-region. Throughout the development and testing of saSVAP, we sought to create a tool that could be independently used by untrained landowners to assess wadable streams of the primarily forested, highly biodiverse, watersheds of the southern Appalachian Mountain region. Using the original SVAP and SVAP2 as models, an interdisciplinary team of scientists, conservationists, and local landowners, made modifications and additions to improve the tools accessibility to laypersons and it's regional focus. These revisions included the development of an illustrated element scoring guide, modified textual prompts of the scoring elements and background descriptions, a site mapping procedure, a photo-point monitoring guide, and an illustrated riparian plant guide. Our goal in making a modular stream assessment, with optional sections, was to create a flexible tool that could be adapted to the user's needs, interests, motivations, and time constraints.

This paper presents the development and testing of saSVAP. More specifically, we explain the modifications and additions in saSVAP and present the findings of validity (how well saSVAP scores correspond to quantitative habitat metrics), and inter-respondent reliability (how consistently saSVAP users score stream sites) testing of the document. We predicted that saSVAP element scores would accurately reflect the relative habitat condition of streams throughout the SBR ecoregion. In line with this prediction, we expected individual saSVAP element scores to strongly correlate with paired quantitative habitat metrics, and overall saSVAP scores to strongly correlate with fish Index of Biotic Integrity (IBI) scores. We also predicted that saSVAP users would reliably rate stream habitat conditions regardless of prior experience in stream assessment or stream ecology. Accordingly, we expected saSVAP scores from both "novice" (those with little-to-no experience with stream ecology and assessment) and "expert" users (those with prior experience in stream ecology or assessment) to exhibit similar levels of agreement when rating the same stream reaches.

METHODS

Study Area

The saSVAP tool was modified for wadable streams of the SBR ecoregion and tested in streams of the Upper Little Tennessee River Basin (Figure 3.1). The SBR spans approximately 159,300 square kilometers from southern Virginia, across western North Carolina, to northern Georgia. Streams of the SBR are usually cold, clear, and typically contain a range of stream habitats including riffles, runs, plunge-pools, cascades, and waterfalls. Due to its diverse habitat features and unique history, the Blue Ridge region is a major center of aquatic biodiversity and endemism in the temperate world.

The rapid pace of land development in the region currently threatens this unique ecoregion and its diverse animal and plant inhabitants. Forested and agricultural lands throughout the Southern Appalachian Mountains are rapidly shifting to residential and commercial uses (Gragson and Bolstad 2006). Predictions expect 75% of new development in the area to be *suburban* in nature (Kirk et al. 2012). By 2030, 67% of this suburban development is expected to occur on previously forested lands (Kirk et al. 2012). Also, residential development that has historically occurred in the valleys is shifting to more forested slopes, which can have profound impacts on nearby stream ecosystems that integrate changes throughout their watersheds (Gragson and Bolstad 2006; Williamson et al. 2008). Rapid land development may have local effects on streams, such as loss of riparian vegetation, more disturbed soils, more flashy stream flows caused by expansion of impervious surfaces (i.e. roads, roofs, parking lots), and local extinctions of sensitive species; as well as more regional consequences, such as increased sedimentation, increased nutrient loading, and an overall reduction in aquatic biodiversity (Walsh et al. 2005). The threats posed by rapid land use change, and the uniqueness of the Blue Ridge region in terms of topography and species richness, provided the impetus to develop and test saSVAP.

saSVAP Modification

Beginning in 2010, a partnership between the CHL, the MCT, and the OSE, set out to modify the SVAP for headwater streams of the SBR ecoregion. Both the original SVAP, and SVAP2, include general instructions for the customization and calibration of the tool's scoring elements to attain greater sensitivity to resource conditions at a regional level. These instructions suggest a simple approach to modify the nation-wide SVAP to better reflect local conditions that relies on the professional judgement of an interdisciplinary team in the development, testing, and evaluation of revisions to the tool. We used this simple approach to modify SVAP for the SBR, using the prior versions of SVAP as models. The saSVAP working group was formed in fall 2011 and consisted of doctoral students in ecology and anthropology; and a panel of experts in stream ecology, geomorphology, hydrology, anthropology, and watershed conservation.

From fall 2011 through summer 2012, the saSVAP working group produced textual descriptions for each scoring element based on previous versions of SVAP and local stream conditions. Unlike SVAP and SVAP2, which primarily used text-based descriptions on the scoring element sections, saSVAP uses simple line drawings with captions to provide visual examples of stream conditions and corresponding scores. Several studies from the field of education and health communication suggest simple drawings with captions are more effective in facilitating reading comprehension and conceptual understanding when compared to text or photographs (Moll 1986; Readance and Moore 1981; Carney and Levin 2002; Houts et al 2006). A scientific illustrator was recruited to the saSVAP working group in fall 2012. Adobe Illustrator CS6 (Version 16.0.2, Adobe, 2012) was used to produce illustrations of local stream conditions. These illustrations were informed by visits and photo-surveys of the 58 sampling sites established in 2009 by the Coweeta LTER Synoptic Sampling Program to encompass the range of land uses and stream conditions found throughout the southwestern Appalachian region (Gragson 2008).

During the academic years of 2013-2014 monthly meetings were held at UGA to discuss modifying the text and illustrations of each scoring element. Drawing from the saSVAP working group's cumulative expertise, the instruction, scoring element, and background information sections were revised to more effectively communicate the protocol to novice users, and new sections were added to improve data quality and procedural reproducibility. During these meetings, the decision was made to use a 1 - 4-point scale, with half scores (e.g. 1.5, 2.5, etc.) allowed, on the element scoring portion of saSVAP. Using SVAP2 as a model, the working group added condensed background information and scoring tips for each element. The working group also removed or combined certain scoring elements from previous versions of SVAP to produce a more stream-lined, and user-friendly, assessment catered to streams of the southern Appalachian region (Table 3.1). To further simplify saSVAP and create a "snap-shot" assessment tool, we removed elements that require prior knowledge of stream conditions. For instance, "hydrologic alteration", an element on SVAP2, was removed from saSVAP due to its reliance on landowner knowledge of flow conditions up to a decade in the past. The "salinity" element from previous SVAP versions was also removed due to a lack of saline streams in the SBR. Instead, an optional measurement of conductivity for situations where salinity or ion concentration may be affecting stream habitat quality was added. In saSVAP, we added the scoring element "algal growth". This element combined two elements from SVAP2: "water appearance" and "nutrient enrichment". An optional turbidity measurement was included in saSVAP for situations where water appearance may be affecting habitat quality. Instead of including a "manure or human waste element" as in

SVAP2, the element “livestock access” is present on saSVAP (Table 3.1). This element describes manure presence as evidence of livestock in the stream. Questions dealing with the presence of human and animal waste, as well as litter, and strange smells such as gasoline odors, are included in the preliminary stream assessment portion of saSVAP. Rather than include a separate scoring element to assess riffle embeddedness, as in SVAP2, saSVAP instead includes a characterization of the dominant substrate on the stream bottom and an optional pebble count on the preliminary stream assessment. Visually estimating riffle embeddedness has been criticized for problems with replicability among users (Sylte and Fishenich 2007; Descloux et al. 2010).

saSVAP layout

The saSVAP tool is divided into two sections. The first section includes user instructions, the preliminary stream assessment, the scoring elements, and the scoring worksheet. The second section includes site mapping and photo-point monitoring procedures, a site map worksheet, a site map data sheet, and common riparian plant identification chart (Appendix 3.1).

saSVAP Section One

The preliminary stream assessment includes prompts for general information, surrounding land- use, riparian cover type, slope, dominant substrate, and an optional pebble count procedure (Appendix 3.1). This portion of saSVAP is meant to be completed before the scoring element portion.

The scoring element portion of saSVAP consists of ten scoring elements, which are accompanied by illustrations and corresponding textual descriptions, and reflect the range of local stream conditions (Table 3.1). Scoring elements are divided into four scoring classes, from one (poor condition) to four (excellent condition), with half scores (i.e. 1.5, 3.5) allowed for reaches that fall between scoring classes. Scored elements are then averaged to determine an overall score for the reach. Overall reach quality is then assigned based on the following categories:

- Poor - overall score less than 2
- Fair – overall score between 2 and 2.5
- Good – overall score between 2.6 and 3
- Excellent – overall score greater than 3.

Section one of the saSVAP document also includes a reference to the modified Virginia Save Our Streams (SOS) protocol for rocky bottom streams (http://www.vasos.org/monitors-page/data-sheet-downloads/). This protocol should be conducted by trained volunteers and requires macroinvertebrate sampling equipment (e.g. 3×3-foot Kick-seine with 1/16-inch mesh kick-net, forceps, hand magnifier, etc.). We encourage users to conduct this macroinvertebrate-based assessment and compare their findings with stream ratings from saSVAP, when possible.

The first section of saSVAP can be completed independently of the second section. If collecting more site information is appropriate (e.g. assessing the same stream reach before and after stream restoration), the second section should be conducted.

saSVAP Section Two

The second section of saSVAP includes the mapping and photo-point monitoring procedures and corresponding worksheets. The mapping and photo-monitoring procedure for saSVAP is a modified "pace and compass" mapping technique that allows saSVAP users to produce quantitative site maps and photos to accurately track changes to stream features over time (Appendix 3.1). This section can be completed independent of section one. An illustrated common riparian plant identification key is included to assist users with native and non-native plant identification. Certain optional measurements (e.g. canopy cover, turbidity, conductance, and water temperature) that require stream sampling equipment (e.g. spherical densiometer, portable turbidity meter, conductivity meter) are also included in this section. These optional measurements should be conducted by users with some experience in stream ecology and assessment.

<u>Testing of saSVAP Scoring Elements</u>

After designing and modifying saSVAP, we tested the validity and reliability of the illustrated element scoring portion of the tool. To test the validity of the scoring system, we examined the correlation between individual saSVAP element scores and paired habitat metrics; and overall saSVAP scores and fish IBI scores from a subset of test sites. To test the reliability of the document, we evaluated how similarly saSVAP users rated streams, in terms of each scoring element, as well as overall stream scores. We also compared the level of agreement between "novice" users, to the level of agreement between "expert" users when rating streams with saSVAP to evaluate the accessibility of the tool for untrained volunteers.

<u>Testing saSVAP for Validity</u>

Validity testing of the saSVAP scoring elements was conducted in May 2013 by a three-person team composed of ecology graduate students and ecology laboratory technicians at 39 sites throughout the Upper Little Tennessee River Basin. Thirty-one of these 39 sites were previously established by the Coweeta LTER Synoptic Sampling Program in 2009 to encompass the range of land uses and stream conditions throughout the southern Appalachian region (Gragson 2008). The eight additional sites (Ammon's Branch, Betty's Creek, Hemlock Hills, Porter Creek, Sky Valley, Ulco Creek, Upper Mica, and Willis Cove) were selected based on their surrounding land use and being permitted access to the stream by landowners. Permissions to access test sites were obtained by contacting the land owner by phone or home visit, and subsequently obtaining the land owners signature on a letter that described the saSVAP project (Appendix 3.2).

Upon reaching the stream site, the team walked the stream length to identify a representative stream reach that generally characterized the stream conditions found on the property. The team then defined a starting point and calculated the average wetted width from three measurements taken at representative points along the reach. This mean wetted width was then multiplied by 15 to calculate the total reach length to be assessed. Start and end points of the assessed reach were identified, and the reach was divided into 15 equidistant transects that were marked with flagging tape.

One team member then walked the stream reach and conducted the scoring element portion of saSVAP. To eliminate variation in scoring, the same team member conducted the scoring element portion at all test sites. Final scores were recorded on the saSVAP worksheet. Concurrently, two team members conducted the pool count, fish barrier count, built structure count, and in stream large woody debris count. Pool counts were conducted by tallying pools with depths of 0.2 to 0.5 meters and greater than 0.5 meters within the reach. Fish barrier counts were conducted by tallying fish barriers (e.g. dams, culverts, diversions, weirs, etc.) found within the stream reach or in the stream channel within eyesight from the assessed reach. Built structure counts were conducted by tallying any manmade structures (e.g. sheds, barns, fences, etc.) within 20 meters inland of each stream bank. Large woody debris counts were conducted by tallying woody debris with diameters between 0.1 and 0.8 meters and greater and lengths between 1.5 and 15 meters and greater (Appendix 3.3).

Two team members then conducted the substrate and cross section surveys, bank measurements, riparian measurements, and canopy cover estimates (Appendix 3.3). Substrate and cross section surveys, bank measurements, and canopy cover estimates were modified from procedures outlined in EMAP-SW-Streams Field Operations Manual (1998). Substrate and cross section surveys were conducted at all 15 transects by taking depth measurement at five equidistant points starting from the left stream bank and ending at the right stream bank. At each of the five points the dominant substrate size class and percent embeddedness was noted (Appendix 3.3).

Measurements of stream bank angle (0-360 degrees) for the left and right stream banks were taken at the 15 transects using the "Clinometer HD" mobile application (Breitling 2012) for Apple's iPhone 4s © running iOS© version 6.1.3. Undercut distance of each bank was also measured at all 15 transects along the reach (Appendix 3.3).

Canopy cover measurements were taken with a spherical densitometer by one team member at all test sites. Densiometer readings were taken at five equidistant transects along the study reach by taking three measurements at each transect. Two densitometer readings were made while standing in the stream along the right and left bank, and one while standing in the center of the stream. These measurements were than averaged to obtain mean percent canopy cover for the reach.

Riparian vegetation measurements were taken at the left and right banks of five equidistant transects along the reach. Riparian heights were taken with a 25-foot fiberglass surveying rod at each bank. The surveying rod was placed vertically alongside the stream bank. Wherever vegetation touched the surveying rod, the height was recorded. Riparian widths were measured with the surveying rod by placing the rod along the ground perpendicular to the stream reach. Riparian buffer widths estimated to be over 30 meters were not measured and marked as greater than 30 meters on the field data sheet. The presence or absence of exotic/invasive plant species and vegetation type (bare ground, grass, shrub, mid-canopy vegetation, and upper canopy vegetation) were also noted at each of the five transects (Appendix 3.3). The livestock access saSVAP element was not assessed for validity due to lack of variability among the 39 test sites. Lastly, two researchers conducted a standard Wolman pebble count procedure at a representative riffle within the reach.

Validity Testing of Overall saSVAP Scores Using Fish Index of Biotic Integrity (IBI) Scores

Fish IBI and overall saSVAP scores were compared at a subset of 16 sites where MCT biomonitoring surveys were conducted by local volunteers between 2000 and 2016 (Figure 3.1). Fish communities were surveyed using standard fish IBI protocols (EPA). Biomonitoring data was accessed through Coweeta Hydrological Laboratory's data portal (The Little Tennessee Watershed Association 2017) and annual MCT biomonitoring reports available on the MCT website (Mclarney 2017). Gaps existed in the biomonitoring data because the same sites were not sampled each year. For this reason, when selecting IBI data to include in the comparison with saSVAP scores, priority was given to geographic proximity to saSVAP test sites first, and then to temporal proximity to the summer 2013 field season when saSVAP was conducted. The oldest fish biomonitoring data included in the comparison was from Iotla Creek (2000) and Ball Creek (2001). Although we concede that fish populations may well have changed since then at these streams, the degraded state of Iotla Creek's stream habitat due to its proximity to a small airport, and the pristine and protected state of Ball Creek due to its location inside protected forest service lands, motivated us to use these datasets despite their age because of the habitat condition endpoints these sites represent. We used fish biomonitoring data from 2009 (Frogtown, Lower Jerry, and South Skeenah), 2010 (Cowee Creek), 2011(Lower Darnell), 2013 (Upper Skeenah, Watauga Hazard, Lower Wayah, Caler Fork, Betty's Creek, and Upper Jones) and 2014 (Upper

Wayah, Jaycee Park). The most recent fish data included was from Bates Upstream in 2016, a newly added site to the biomonitoring effort.

<u>Testing saSVAP for Inter-respondent Reliability (IRR)</u>

We then tested the element scoring portion of saSVAP for inter-respondent reliability (IRR). IRR is a measure of agreement among raters of unstructured phenomena (Krippendorff 2011). Reliability testing was conducted from late summer to early fall 2012 at three wadable streams in the Upper Little Tennessee Watershed. These three test sites were Ball Creek (surrounded by forested land cover and forested riparian zone greater than 10-meter width), Watauga Hazard (surrounded by agricultural and residential land uses with a single tree riparian zone less than 3-meter width), and Crawford Branch (surrounded by urban land use with no forested riparian zone). These sites were chosen because they represented gradients of stream condition and surrounding land use common throughout the region.

A total of 40 saSVAP testers visited the three sites after an orientation consisting of group introductions, and a short question and answer session. The saSVAP tester group consisted of first year undergraduate students from Elon University and Davidson College, residents of Franklin, NC, and ecology and forestry graduate students from the University of Georgia. During data analysis, saSVAP testers were divided into two groups based on previous experience in stream research or habitat assessment. One group of 30 volunteers, deemed "novice" users, had no prior experience with habitat assessment and little background in stream ecology, geomorphology, or hydrology. The other group of 10 volunteers, deemed "expert" users, had either prior experience conducting stream visual assessment (such as with SOS stream biomonitoring group or university level laboratory exercise) or some graduate level training in stream ecology, geomorphology, or hydrology. Before conducting saSVAP, users were instructed to work independently and not to discuss their choices of element scores with other users. Testers then conducted the element scoring portion of saSVAP at the three stream sites.

<u>Statistical Analyses</u>

The data collected during the validity testing of saSVAP were analyzed in JMP v.12.1 (SAS Institute, Cary, NC, USA). Pearson and Spearman correlations were calculated between saSVAP element scores and paired quantitative habitat metrics. Pearson and Spearman correlations between overall saSVAP reach scores and fish IBI scores were also calculated. All correlations with p-values less than 0.05 were considered significant. Correlations equal to or greater than 0.7 were considered strong.

Analysis of the scoring data from IRR tests were performed in R 3.2.1 (R core team 2013) using the irr package (Gamer et al. 2012) function for Krippendorf's alpha. Krippendorf's alpha is a coefficient of reliability originally developed for content analysis to assess how much agreement is achieved from different raters who evaluate a given set of objects using a survey or questionnaire (i.e. likert scale surveys). Krippendorf's alpha is a versatile statistic that can accept any number of observers, can be corrected for small sample sizes, can handle missing data and is applicable to nominal, ordinal, interval, and ratio data. Because saSVAP scoring elements qualitatively ranked stream features, and because the distance between qualitative categories was unknown, saSVAP elements scores were treated as ordinal variables when calculating Krippendorff's alpha.

RESULTS

<u>saSVAP Scores and Overall Rating Break Points</u>

Overall saSVAP scores from the 39 validity test-sites ranged from 1.6 to 4.0 (Table 3.2). The livestock access element demonstrated little variation in scores with 35 out of 39 sites receiving a score of 4, suggesting an absence of livestock access at most test sites.

Higher overall saSVAP scores were associated with forested land uses and forested riparian zones greater than 10 meters wide (Table 3.3). Of the 16 sites with saSVAP scores greater than three, 14 had forested riparian zones, and 12 were surrounded by forested land uses. Of the six sites with scores less than two, four were surrounded by urban land uses, and five had either single tree riparian zone less than three meters wide or no vegetated riparian zone. A similar pattern was found between overall saSVAP scores and fish IBI scores, with lower IBI scores generally associated with lower overall saSVAP scores. For instance, the three lowest saSVAP scores also had the three lowest IBI scores; while the sites with the highest saSVAP scores had relatively high IBI scores (Table 3.4).

Comparisons between saSVAP scores, land uses, riparian classes, and fish IBI scores, as well as informal impressions of habitat conditions at the test sites among team members, informed the decision to set breakpoints for saSVAP scores associated with "poor", "moderate", "good", and "excellent" ratings for overall stream condition. These ratings corresponded well to ratings determined from fish IBI scores (Table 3.4). All streams rated "excellent" by saSVAP were rated "good" in term of IBI scores, while all streams rated "poor" by saSVAP were also rated "poor" in terms of IBI scores. Of the nine streams that were rated as "moderate" or "poor" by saSVAP, six were rated fair, two were rated good, and one was rated poor in terms of IBI scores.

Validity Testing Results

The results from validity tests of saSVAP demonstrate differing degrees of correlation between individual element saSVAP scores and paired quantitative habitat metrics; and strong correlations between overall saSVAP scores and fish IBI scores (Table 3.5). Several saSVAP elements (channel condition, riparian area quantity, canopy cover, barriers to fish movement, and habitat cover) exhibited relatively strong correlations (Spearman Rho $\geq$ 0.70) with paired quantitative habitat metrics, while others (bank condition, riparian area quality) exhibited weaker relationships. The strongest correlations were between saSVAP scores for riparian area quantity and average riparian buffer width; scores for canopy cover and densitometer measurements of average canopy cover; and overall saSVAP scores and Fish IBI scores. The weakest correlations were found between riparian area quality saSVAP scores and total number of reaches with invasive plant species present; and barriers to fish movement scores and total number of fish barriers (Table 3.5).

IRR Testing Results

We found a high degree of reliability (Krippendorfs alpha $\geq$ 0.80) among novice and expert users in terms of overall stream ratings and differing degrees of reliability among users in terms of individual element scores (Table 3.6). More specifically, expert users were found to be more reliable than novice users for majority of the individual scoring elements. IRR results from riparian quantity and quality elements for both novice and expert users were found to be somewhat reliable (Krippendorfs alpha $\geq$ 0.667), although only expert users were found to have somewhat reliable ratings in terms of channel condition, pools, and available habitat/cover elements.

DISCUSSION

The development and testing of saSVAP has provided a tool for the visual assessment of wadable streams throughout the SBR that can be conducted in a relatively short amount of time by inexperienced volunteers and landowners. Validity testing has demonstrated the tools ability to provide scores for stream habitat features that strongly correlate with quantifiable habitat metrics, as well as overall scores that strongly correlate with fish IBI scores. Reliability testing of saSVAP has demonstrated a high degree of agreement among both novice and expert users in terms overall stream ratings, but higher levels of agreement among expert users, than among novice users, for most individual scoring elements. Together, these results support our initial predictions that saSVAP ratings would reflect the relative habitat condition of southern Appalachian streams; and that saSVAP users, regardless of prior experience in stream ecology or habitat assessment, would reliably rate overall stream conditions.

Strong correlations between overall saSVAP scores and fish IBI scores suggest that the element scoring system used in saSVAP is corresponding to local stream habitat quality. Previous studies have investigated the relationship between visually-based stream assessment scores and biotic community metrics. Hughes et al (2010) compared findings from QHEI, RBP, and SVAP assessments and USEPA quantitative rapid bio-assessments from 51 agricultural streams in 10 states. They found significant correlations between results from the four habitat assessments but only low to moderate correlations between SVAP scores and macroinvertebrate and fish indices of biotic integrity. Similarly, McQuaid and Norfleet (1999) found weak correlations between visual habitat assessments and fish IBI scores. Both these studies compared the results of nation-wide stream visual assessment protocols to locally modified indexes of biotic integrity, which may explain the lack of strong relationships between the habitat and biotic assessments. In a study Puerto Rican streams, de-Jesus-Crespo and Ramirez (2011) found significant relationships between macroinvertebrate diversity and scores from the modified Hawaii Stream Visual Assessment Protocol (HSVAP). Unlike SVAP and SVAP2, which are nation-wide protocols, HSVAP and saSVAP were both modified to better represent streams in a particular location or ecoregion. We suggest these modifications may have improved the ability of these assessments to reflect local habitat quality, and more strongly correlate with biotic community metrics. Although modifying SVAP to a locality reduces the tools ability to compare streams across regions, the potential benefits of this process, including greater sensitivity to local resource concerns and unique habitat conditions, may prove useful to watershed-based stream monitoring programs that involve local volunteers.

Here we suggest that stream features that are more difficult to visually assess, such as sediment deposition, are more likely to be reliably assessed by experts who may draw from some knowledge of fluvial geomorphology and stream ecology. Other stream characteristics, such as the width of riparian vegetation, may be easier for novices to visually estimate, and exhibit a high level of agreement among both novice and expert volunteers. Furthermore, our validity testing results show that certain elements (i.e. riparian area quantity and canopy cover) that may have been simple to visually quantify strongly correlated with paired habitat metrics that directly quantify that habitat feature, such as riparian area quantity and riparian width. Conversely, elements that may have been difficult to visually quantify (i.e. riparian area quality and bank condition) exhibited weaker correlations with paired quantitative metrics. Although these findings underscore the potential benefits of multiple experiences using saSVAP and the presence of more experienced users, the finding of similar levels of agreement among novice and expert users saSVAP in terms of overall stream rating demonstrates the tools accessibility to users with no background in stream assessment.

Previous studies have also compared stream assessment results from volunteers to those from professionals in stream ecology and environmental monitoring. Storey et al. (2016) found high levels of agreement between volunteers from the local community and more experienced government officials when conducting biological, chemical, and physical habitat assessments. In terms of physical habitat assessment, the strongest correlations were found between volunteers and officials when visually assessing riparian zones and channel alteration; while the weakest correlations were found when assessing aquatic animal habitat, bank stability and sediment deposition. Together, these studies have demonstrated that volunteers with little background in environmental monitoring, can produce valid, although course, qualitative ratings of stream habitat characteristics.

By simplifying the text of certain elements, the authors understand there is trade-off between the danger of overlooking the complexity of certain stream features and making the tool more user-friendly. In this project we chose to err on the side of ease of use and speed due to the tool being designed for independent use by the public. Validity and reliability testing has demonstrated that saSVAP, despite being geared toward those unfamiliar with stream science and habitat assessment, can effectively and consistently evaluate the condition of stream habitats in the SBR. Also, the addition of saSVAP's site mapping, photo-point monitoring, and optional quantitative measurements may prove useful for science professionals and conservationists who require a more detailed assessment of stream habitat conditions.

In 2014, a partnership between MCT, CHL, OSE, and the University of Georgia's Integrative Conservation (ICON) PhD program, developed saSVAP into the "Grade Your Stream" protocol, which retains the visual scoring system of saSVAP with some modifications and less background information. Grade your stream furthers saSVAP's overall goal to provide landowners and residents with a tool for independent stream assessment. Preliminary versions of saSVAP and the "Grade Your Stream" protocol have been implemented by the MCT and local volunteers during their annual biomonitoring survey. During the 2016 sampling season, the bio-monitoring team implemented saSVAP at 24 of their 30 monitoring sites and found that saSVAP results corresponded very well to fish IBI ratings. The Mainspring team also found that saSVAP scores generated independently by volunteers were virtually indistinguishable from those generated by the more experienced staff members (Mclarney 2017). These findings further support the claim that saSVAP can be successfully used by laypeople to effectively, and reliably assess stream habitat quality.

The Mainspring Conservation Trust is continuing to include saSVAP in future volunteer stream biomonitoring efforts. This partnership will not only allow further testing and improvement of the saSVAP tool but will also provide opportunities to investigate how well saSVAP can capture changes in stream habitats over time. When combined with local MCT stream restoration and land conservation projects, saSVAP can be used to qualitatively compare pre- and post-restoration stream habitat conditions and can provide local landowners a tool to tract the condition of streams on private lands placed in MCT conservation easements. The current study did not address the relationship between saSVAP scores and several other more quantitative habitat metrics such as macroinvertebrate community data and water quality data. Nonetheless, future iterations of MCT's biomonitoring program that include saSVAP or "Grade Your Stream" assessments, can further investigate the relationships between saSVAP scores, and more quantitative stream metrics such as biological community indexes and water chemistry data.

CONCLUSIONS

Visual habitat assessments are generally small components of larger environmental monitoring projects that require detailed planning, technical expertise, and expensive equipment. As we have demonstrated, the saSVAP tool presented here provides a logical framework and essential background information to residents who have no training or background in stream assessment. In saSVAP, we have created a stand-alone visual habitat assessment protocol modified for use by untrained stakeholders that can act as an entry-point into environmental stewardship for those who are aware of the importance of stream health and curious about stream ecology but may not be able to make the time commitment required for larger, more group-based, volunteer environmental monitoring projects. Taking the scientist out of the proverbial driver's seat of environmental monitoring has well-recognized potential downsides, such as poor data quality and procedural inconsistencies (Riesch and Potter 2014). Still, the responsibilities of today's scientists and science-educators must include the creation of opportunities and tools accessible to the public. Despite its potential drawbacks, giving residents the ability to independently assess local ecosystems can play an important role in cultivating a scientifically literate citizenry capable of understanding and responding to the rapidly developing, and hereto unforeseen, consequences of life in the Anthropocene.

We suggest the model presented here for developing and testing a regionally sensitive and landowner-centered version of SVAP be applied to other regions. In highly biodiverse regions that are being rapidly urbanized, tools adapted for local conditions and designed for independent use by landowners, can act as "*bell-weathers*" of impending stream impairment, increase public awareness of local resource concerns, and allow researchers to gain information about streams found on privately-owned lands. We recommend the development of habitat assessment tools modified for local stream conditions and designed for independent use by landowners that can detect habitat impairment, increase public awareness of local resource concerns, and allow researchers to gain information about streams found on privately-owned lands. Moving forward, the incorporation of saSVAP into the MCT´s stream bio-monitoring efforts will allow researchers and citizens to characterize how stream habitats change over time in a rapidly developing region. Giving citizens an opportunity to independently monitor their own natural resources can also open the door for further exploration of important ecological issues and create opportunities for dialogue between stakeholders, land managers, and local government officials.

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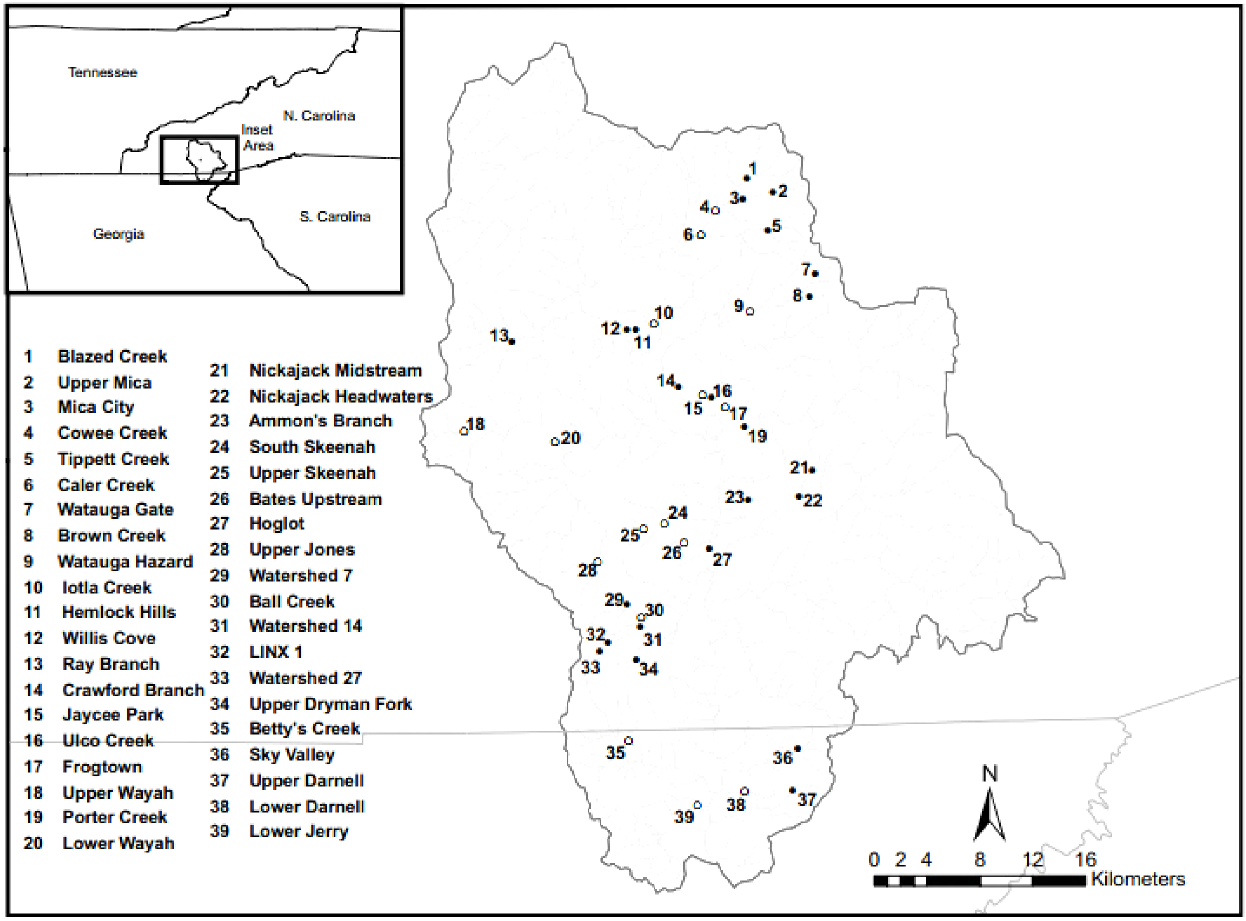

FIGURE 3.1. Map depicting the 39 saSVAP validity testing sites. All sites are in the Upper Little Tennessee River Basin of the Southern Blue Ridge ecoregion. Open circles represent test sites where fish Index of Biotic Integrity scores are available. Inset depicts location of the Upper Little Tennessee River Basin in relation to state borders.

TABLE 3.1. Stream habitat scoring elements from SVAP, SVAP2, and saSVAP.

SVAP scoring elements	SVAP2 scoring elements	saSVAP scoring elements
Channel condition	Channel condition	Channel condition
Hydrologic alteration	Hydrologic alteration	Bank condition
Riparian zone	Bank condition	Riparian area quantity
Bank stability	Riparian area quantity	Riparian area quality
Water appearance	Riparian area quality	Canopy cover
Nutrient enrichment	Canopy cover	Algal growth
Barriers to fish movement	Water appearance	Livestock access
Instream fish cover	Nutrient enrichment	Pools
Pools	Manure or human waste	Barriers to fish movement
Invertebrate habitat	Pools	Available habitat/cover
Canopy cover	Barriers to fish movement	
Manure presence	Fish habitat complexity	
Salinity	Aquatic invertebrate habitat	
Riffle embeddedness	Aquatic invertebrate community	
Macroinvertebrates observed	Riffle embeddedness	
	Salinity	

TABLE 3.2. Overall saSVAP scores per validity testing site and individual element scores that make up that average value: 1. Channel Condition, 2. Bank Condition, 3. Riparian Area Quantity, 4. Riparian Area Quality, 5. Canopy Cover, 6. Algal Growth, 7. Livestock Access, 8. Pools, 9. Barriers to Fish Movement, and 10. Available Habitat/Cover.

Site	Overall score	1	2	3	4	5	6	7	8	9	10
1	3.6	3.5	3.25	3.75	3.75	4	4	4	4	3	3
2	3.6	3.5	3.75	3.75	4	4	4	4	3.5	1	4
3	1.6	2.5	1.25	1.25	1.25	1	2.5	1	2	2	1.5
4	2.4	2.5	2.25	1.25	1.25	2	3	4	3	2	2.5
5	3.5	3.5	4	4	4	4	3.5	4	3	1	3.5
6	2.9	3	2.5	1.75	2.25	2.5	3	4	3	4	2.5
7	2.3	2.5	2.5	1.25	1.25	1.5	3	4	1	4	1.5
8	3.6	3	3	4	4	4	3.5	4	3	3.5	4
9	2.4	2.5	2.75	1.75	1.75	2	2	4	1.5	4	1.5
10	1.6	1	1.25	1.5	2	1	1.5	3	1	2	1.5
11	2.8	2	2.25	2.75	2.5	4	3.5	4	1.5	3	2.5
12	3.4	3.5	4	4	4	4	3.5	4	2	1.5	3.5
13	3.8	4	4	3.75	4	3	3	4	4	4	4
14	1.7	1	1.5	1	1	2	2	4	1	2	1
15	1.7	1.5	1.25	1	1	1	2.5	4	1	2.5	1
16	2.3	1.5	1.5	3.25	2	3	3.5	4	1	1	2.5
17	1.7	1.5	1.25	1.5	1.5	1	2.5	4	1	2	1
18	3.8	4	4	3.75	4	3	3.5	4	4	4	4
19	1.9	1	1.25	2.5	2	2	2.5	4	1	1.5	1.5
20	2.6	3	2.5	1.5	3	2.5	2.5	2.5	2	4	2
21	2.8	3	3.25	2.75	3.25	2.5	2.5	4	1.5	3	2.5
22	2.8	3.5	3.25	1.75	2.25	2.5	3.5	4	3.5	1	3
23	2.8	3	3.5	3.25	1	3.5	3	4	2	2.5	2.5
24	2.8	2.5	1.75	2	1.5	3	3	4	4	4	2.5
25	2.1	3	3.25	1	2	1	2.5	4	2	1.5	1
26	2.6	2	2.5	1.75	1.75	2.5	3	4	2	4	2.5
27	2.2	1.5	2.25	2	1.75	3.5	3	1.5	1	3.5	2
28	4.0	4	4	4	4	4	4	4	3.5	4	4
29	3.5	3.5	3.75	4	4	4	3.5	4	3.5	1	4
30	3.4	3.5	3.25	3.5	3.5	3.5	3.5	4	4	1	4
31	3.4	4	3.75	4	4	3	3	4	3	1	4
32	3.9	4	4	4	4	3	3.5	4	4	4	4
33	3.9	4	4	4	4	4	4	4	3	3.5	4
34	4.0	4	4	4	4	4	3.5	4	4	4	4
35	3.4	3	3.75	3	3.25	4	3.5	4	2	3.5	3.5
36	2.1	1.5	2	1.25	1.25	1	3.5	4	3	2.5	1
37	3.4	3	3.5	4	4	4	4	4	2.5	1	4
38	2.4	3	2.25	1.75	1.25	2	2.5	4	3.5	1	2.5
39	2.3	2	1.25	2.25	2.5	1.5	2.5	4	1	3.5	2

TABLE 3.3. Validity testing sites arranged by increasing overall saSVAP score with corresponding land use classes (F = basin and riparian zone are nearly fully forested, CV = agricultural/residential valley with forested hillslopes, MV = streams in agricultural/residential valleys with significant residential development on forested hillslopes, M = headwater streams in areas of significant residential development on forested hillslopes, U = streams in urban areas, FRV = streams in forested basins with residences among the trees in the valley) and riparian codes (0 = no forested riparian zone, 1 = “single tree” riparian zone less than 3m wide, 2 = narrow forested riparian zone 3-10m wide, 3 = forested riparian zone greater than 10m wide).

Site	**Overall score**	**Land use**	**Riparian code**
3	1.6	CV	1
10	1.6	MV	0
14	1.7	U	0
15	1.7	U	0
17	1.7	U	1
19	1.9	U	2
25	2.1	CV	1
36	2.1	U	2
27	2.2	MV	0
7	2.3	M	0
16	2.3	U	2
39	2.3	CV	0
4	2.4	CV	0
9	2.4	MV	1
38	2.4	CV	2
20	2.6	CV	2
26	2.6	MV	1
11	2.8	MV	1
21	2.8	MV	1
22	2.8	M	3
23	2.8	CV	2
24	2.8	CV	1
6	2.9	MV	0
12	3.4	MV	1
30	3.4	F	3
31	3.4	F	3
35	3.4	CV	3
37	3.4	F	3
5	3.5	M	2
29	3.5	F	3
1	3.6	F	3
2	3.6	CV	3
8	3.6	F	3
13	3.8	F	3
18	3.8	FRV	3

32	3.9	F	3
33	3.9	F	3
28	4.0	F	3
34	4.0	F	3

TABLE 3.4. Subset of validity testing sites arranged by increasing overall saSVAP score, with corresponding overall qualitative saSVAP condition ratings, fish IBI scores, and overall qualitative IBI condition ratings.

Site	**Overall score**	**saSVAP condition**	**IBI score**	**IBI condition**
10	1.6	Poor	28	Poor
15	1.7	Poor	35	Poor
17	1.7	Poor	25	Poor
25	2.1	Moderate	33	Poor
39	2.3	Moderate	41	Fair
38	2.4	Moderate	39	Fair
4	2.4	Moderate	47	Good
9	2.4	Moderate	44	Fair
20	2.6	Good	52	Good
26	2.6	Good	39	Fair
24	2.8	Good	42	Fair
6	2.9	Good	42	Fair
35	3.4	Excellent	51	Good
30	3.4	Excellent	55	Good
18	3.8	Excellent	47	Good
28	4.0	Excellent	48	Good

TABLE 3.5. Correlations between qualitative saSVAP scoring elements and selected quantitative metrics (modified from EMAP metrics) with p-values less than 0.05 (n=39).

saSVAP scoring element	**Quantitative metric***	**Pearson correlation**	**Spearman correlation**
Channel Condition	PCT_SAFN	-0.69	-0.73
Bank Condition (Left/Right)	XBA	-0.44/-0.44	-0.33/-0.49
Riparian Area Quantity (Left/Right)	XRBW	0.89/0.87	0.88/0.83
Riparian Area Quality (Left/Right)	RVL	0.35/0.23	0.33/0.26
	RINV	-0.47/-0.46	-0.52/-0.52
Canopy Cover	XCDEN	0.89	0.88
Algal Growth	XCDEN	0.61	0.66
Livestock Access**	NA	NA	NA
Pools	PGT50	0.65	0.67
Barriers to Fish Movement	FB	-0.43	-0.42
Habitat/Cover	SBC	0.65	0.72
	SWA	0.66	0.70
Overall saSVAP score***	Fish IBI	0.78	0.80

*PCT_SAFN = % substrate in size classes smaller than sand (2mm)
XBA = average bank angle
XRBW = average riparian buffer width
RVL = number of riparian vegetation heights
RINV = number of assessed reaches with invasive/exotic plant species present
XCDEN = mean % canopy
PGT50 = number of pools >50cm deep
FB = number of fish barriers
SBC = number of small boulder clusters
SWA = number of small wood accumulations

**Livestock access was not assessed due to lack of variability among the 39 test sites.

***Overall saSVAP scores were assessed at 16 of the 39 validity testing sites where fish biomonitoring was conducted by Bill McClarney and MCT volunteers between years 2000-2013.

TABLE 3.6. Krippendorf's alpha values of inter-respondent reliability (IRR) for saSVAP scoring elements. IRR tests were conducted by "novice" * (N=30) and "expert" ** saSVAP users (N=10) at Ball Creek (forested) Watauga Creek (agricultural/hillside development) and Crawford Creek (urban development).

saSVAP scoring element	**α ("novice" users)**	**α ("expert" users)**
Channel Condition	0.64	0.75
Bank Condition (Left/Right)	0.46/0.46	0.61/0.60
Riparian Area Quantity (Left/Right)	0.66/0.67	0.64/0.69
Riparian Area Quality (Left/Right)	0.69/0.70	0.85/0.75
Canopy Cover	0.54	0.65
Algal Growth	0.46	0.62
Livestock Access	0.47	0.04
Pools	0.57	0.74
Barriers to Fish Movement	0.44	0.36
Available Habitat/Cover	0.45	0.79
Overall saSVAP score	**0.83**	**0.87**

*"novice" saSVAP users were undergraduate students or local landowners who had little to no experience in stream assessment and little prior knowledge of basic stream ecology (as determined through personal communication).

** "expert" saSVAP users were science professionals or local landowners who had past experiences with stream assessment (such as the S.O.S. protocol) and some knowledge of basic stream ecology (as determined through personal communication).

CHAPTER 4

PERCEIVED VALUE VS. HABITAT CONDITION OF WADABLE STREAMS: A COMPARISON OF ECOLOGICAL ASSESSMENT SCORES AND RIPARIAN LANDOWNER PREFERENCES FOR STREAM HABITATS IN WESTERN NORTH CAROLINA[3]

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To be submitted to *Citizen Science: Theory and Practice*

ABSTRACT

Here, we examine how responses from a photo-survey of riparian landowners regarding the relative “desirability”, “cleanliness”, and “health” of streams, align with findings from the Southern Appalachian Stream Visual Assessment Protocol and several macroinvertebrate-based metrics of stream condition. Our results indicate that most surveyed riparian landowners have some ability to visually perceive stream habitat quality, and that streams with forested riparian zones are preferred over streams lacking riparian vegetation. Our findings also suggest surveyed landowners may prefer different stream settings for recreational uses vs. aesthetic enjoyment. Discrepancies between survey results and habitat assessments, especially at stream sites that were intermediate between the high and low end of landowner preferences, may have been due to surrounding land uses not visible in stream photos from the survey. In future studies that use photo-choice surveys, we recommend including descriptions of surrounding land uses that may improve the level of agreement between landowner perceptions and habitat conditions. Considering these findings, we advise local conservation agencies throughout southern Appalachia region to focus on streams that currently have forested riparian buffers, restore riparian vegetation when possible, and to continue educating landowners on the risks posed by riparian deforestation to stream health. Moving forward, we recommend the development of interdisciplinary socio-ecological studies that investigate the influence of direct-use experiences on landowner perceptions of habitat integrity, and the influence of landowner perceptions of habitat condition on private land management decision-making.

INTRODUCTION

Perceptions of ecosystem integrity influence the ways humans utilize, impact, and value ecosystems (Fielding et al. 2005; Nassauer et al. 2009). Here, we define *perception* as “the way an individual observes, understands, interprets, and evaluates a referent object, action, experience, individual, policy, or outcome" (Munhall 2008; Bennett 2016). The scale at which humans, as organisms, perceive landscapes has been referred to as the *perceptible realm*. At this scale, which can range from small privately owned back-yards near the city center, to large conservation areas on the urban-fringe, humans directly connect with ecological processes and alter landscapes (Nassauer 2012). Private land management decisions; voluntary conservation plans (Farmer et al. 2017); support for the restoration of urban woodlands (Gobster et al. 2016); the valuation of forests and grasslands (Henderson et al. 2016); and the public's acceptance of stream restoration projects (Metcalf et al. 2015) are strongly influenced by residents' perceptions at this localized scale.

Studies into the public's perceptions of landscapes can reveal motivations behind landowner behavior on private lands, and help determine the feasibility of land management decisions, conservation plans, ecological restoration strategies, and educational outreach efforts (Chambers et al. 2016). Despite this, few studies of landowner perception have been conducted at the scale of individual riparian parcels, where a resident's behaviors and land use decisions affect both local and downstream ecological conditions. Here, we investigate how well riparian landowner perceptions of small streams align with the ecological conditions of stream habitats in a rapidly developing exurban landscape. Our hope is that this study can shed light on the perceptions that drive riparian landowner decisions and can inform riparian land managers and aquatic conservation agencies on the most effective ways to engage the public in rural areas facing rapid exurbanization.

Disparities between residents' aesthetic preferences for habitats and actual habitat conditions can lead to two potential problems. First, land management decisions that do not align with residents' perceptions may lead to local opposition to restoration and conservation programs and a general breakdown of trust between the public and natural resource agencies (Bright et al. 2006; Piwowarczyk and Wróbel 2016). Moreover, positive local perceptions are integral to public support for local conservation programs (Bennett 2016), as well as community acceptance for ecologically-sound landscape design (Nassauer et al. 2009). Second, a disparity between perception and habitat condition can lead to uninformed decisions on land management being made by policy makers and the public (Slagle et al. 2015). For instance, landowners may make well-intentioned land management decisions that degrade stream habitat, such as removing large woody debris and deforesting riparian buffers (Dutcher et al 2004; Evans 2013; Jackson et al. 2015).

These potential problems underscore the need for studies into landowner perceptions of ecosystems and how those perceptions align with ecosystem conditions (Lewis and Popp 2013; Cockerill and Anderson 2014). Several studies have shown varying levels of agreement between perception of ecosystem integrity and ecosystem condition. Pendleton et al. (2001) investigated the perception of stakeholders in southern California and found that most survey respondents misperceived water quality on beaches. They concluded that public education efforts were not successfully informing the public of regional water quality. Nassauer et al. (2004) used digitally simulated images to compare public perceptions of attractiveness for several alternative future designs for exurban residential subdivision development and found that landscapes associated with improved water quality were perceived as the most attractive by residents of the upper mid-west. Piegay et al. (2005) and Chin et al. (2007) used photo-surveys to investigate university students' perceptions of large woody debris in rivers and found that most student participants throughout Europe and the United States considered rivers with large woody debris to be less aesthetic, more dangerous and needing more improvement than rivers without large woody debris. These studies highlight the wide range in level of agreement between the public's perceptions of a "healthy" ecosystem and preferences for features of habitats that have been shown to contribute to ecological integrity and function. Investigations into how well the perceived value of an ecosystem relates to ecological conditions can provide valuable insight into the cultures, motivations, beliefs, and knowledge gaps of local communities who wish to become more effective stewards of their local natural resources.

Here, in collaboration with University of Georgia's Odum School of Ecology and Department of Anthropology, we examine how well photo-survey responses from riparian landowners regarding the relative "desirability", "cleanliness", and "health" of streams, align with findings from a visual stream habitat assessment and several macroinvertebrate-based metrics of stream condition. We conducted the newly developed Southern Appalachian Stream Visual Assessment Protocol (saSVAP), tailored to streams of the Southern Blue Ridge (SBR) ecoregion; and three common macroinvertebrate bio-assessment metrics: Hilsenhoff's Family Biotic Index (HBI), the percentage of taxa belonging to the orders Ephemeroptera, Plecoptera, or Tricoptera (%EPT), and the percentage of total organisms belonging to the family Chironomidae (%Chironomids) at the streams depicted on the photo-survey. Our study is uniquely poised to examine how landowner perception of streams relates to the ecological condition of streams and can provide valuable information regarding the motivations behind riparian land owner decision making.

The overall goal of this research is to test the hypothesis that riparian landowner preferences for stream habitats align with stream habitat quality due to the high degree of direct-use experience riparian landowners have in streams. In line with this hypothesis, we predict the following:

1. Stream sites that are chosen by photo-survey respondents to be the healthiest, cleanest, and most desirable will exhibit higher saSVAP scores, higher proportions of EPT taxa, lower proportions of Chironomids, and lower HBI scores (indicating better habitat conditions)
2. Streams sites that are chosen by photo-survey respondents to be the least attractive, and least natural will exhibit lower saSVAP scores, lower proportions of EPT taxa, higher proportions of Chironomids, and higher HBI scores (indicating worse habitat conditions).

METHODS

Study Area

This study was conducted in Macon County, North Carolina, in the Blue Ridge ecoregion and southern Appalachian Mountains (Olsen et al. 2001). The southern Appalachian region is a center for North American biodiversity and endemism and is known as the "water tower" to the southeast, given its' predominantly forested mountain terrain and proximity to major metropolitan areas (Viviroli et al. 2007). Macon County has a population of approximately 33,000 as of 2012 and has experienced a 68% increase in population from 1980 to 2010 (http://www.census.gov/). The county is comprised of 45% public lands, much of which lies in Nantahala National Forest (Kirk et al. 2012). Largely due to this federally protected area, 75% of Macon County's total land cover is currently forested (Kirk et al. 2012).

As with many counties throughout southern Appalachia, the demographic composition and predominant land uses in Macon County have shifted dramatically over the last century. In the early 1900's the majority of southern Appalachia was clear cut for timber extraction and small-scale agriculture comprised 22% of the landscape. During the 1950' till 70's, a pattern of outmigration to metropolitan areas led to a reduction of agricultural land uses, which eventually declined to 4% of the landscape by 2010 (Kirk et al. 2012). Beginning in the 1970's, in-migration by second home owners, retirees, and others, spurred increases in populations and residential development throughout the region.

Approximately 70% of forested lands throughout the southern Appalachian region are privately owned and many of these lands have direct access to streams (Wear and Greis 2002, Evans 2013). Residential development that has historically occurred in the valleys is shifting to more forested slopes that can have profound impacts on nearby stream ecosystems which integrate changes throughout their watersheds (Gragson and Bolstad 2006; Williamson et al. 2008). By 2030, 67% of new residential development is expected to occur on previously forested lands (Kirk et al. 2012). For these reasons, this region provides an ideal setting for studies into riparian landowner preferences for stream appearance, and how these preferences relate to stream habitat conditions.

Photo-choice Survey

This study draws from anthropological dissertation research conducted in Macon County in 2013 that included a survey to investigate the perceptions of stream integrity amongst Macon county riparian landowners (Evans 2013). The first section of this survey was designed to determine riparian landowner's preferences for stream appearance and posed eight questions that asked survey respondents to choose among six photographs of streams depicting different types of riparian vegetation (Figure 4.1). For this study, six out of the original eight questions on the survey were chosen due to their relevance in determining landowner perceptions of stream "health", "desirability", and "cleanliness" (Figure 4.1). The two questions that were omitted from this analysis were the following: "Which stream photo looks most similar to the stream on your property?" and "In your opinion, in which stream photo would you be most likely to find snakes?" These questions were not included in this study because they did not directly relate to landowner perceptions of stream integrity, and because the authors lacked data from streams found on survey respondents land. All photos were of streams of similar size and gradient, and represented a range of riparian conditions including: grass mowed to stream edge (Photo E); agricultural field with bushy vegetation along stream with no trees (Photo D) and few trees (Photo C); active pasture with riparian buffer of grass and few trees (Photo A); residential area with riparian buffer of trees, bushes, and grasses (Photo F); and densely forested riparian buffer of rhododendron understory (Photo B). Here, we build on the results of this photo-survey, and assess the stream habitats depicted in the photos, to compare landowner preferences with stream habitat conditions.

This survey coincided with the development of saSVAP, a locally adapted stream visual assessment protocol for wadable streams of the southern Blue Ridge ecoregion. The authors formed an interdisciplinary partnership at the onset of their dissertation research. After a year of working side by side to explore the socio-ecological features of Macon County and Western North Carolina, the authors planned the following study, which set out to compare riparian landowner perceptions of streams with the ecological conditions of streams as measured with saSVAP and several common macroinvertebrate indices of habitat condition. In summer 2013, the authors returned to each of the stream sites depicted in the six photos from the photo-choice survey and conducted saSVAP and macroinvertebrate sampling.

saSVAP

saSVAP was conducted at each of the six stream sites by the same team member to reduce inter-respondent variability. The assessed reach was determined by referencing the photos in the photo-experiment, with each reach starting as close to the vantage point of the photographer as possible. From this point, the saSVAP field element scoring procedure was followed as stated in the saSVAP document.

Macroinvertebrate Sampling

Macroinvertebrate sampling was conducted by a three-person team, at each of the six stream sites, following the Standard Qualitative Method for the North Carolina Department of Water Quality (NCDWQ). Within the assessed reach established when conducting saSVAP, the research team performed two kick net samples, three sweep net samples, one leaf pack sample, two fine mesh rock/log wash samples, one sand sample, and a visual collection. For the kick net samples, samples were taken with a standard 500-micron kick net from the least embedded cobble riffle areas when possible. Sweep net samples were taken with a 500-micron D-net by vigorously disrupting undercut banks, root masses, and macrophyte beds and sweeping through the disturbed area with the net. The leaf pack sample was taken by washing leaf packs, sticks, and small logs in a sieve bucket with a U.S. Standard No. 30 sieve (0.600 mm mesh) bottom. Four leaf packs were collected from rocks or snags in fast current areas when possible. Fine mesh samples were taken using a “Chironomid-getter” that consisted of a 300-micron mesh placed inside PVC pipe fittings. Rocks and logs, preferably with moss, were washed with a scrub brush in a bucket partially filled with water. Each fine mesh sample consisted washing 15 logs or rocks, of similar size, to create a composite sample. The material in the bucket was then poured through the fine mesh sampler. The residue in the sampler was then preserved by placing the mesh into a food container half filled with 95% ethanol solution. The sand sample was conducted by disturbing depositional areas consisting of silt, sand, and fine gravel, and sweeping through the area with a U.S. No. 10 Sieve (2mm mesh) to find large invertebrates. Visual inspection was conducted for 10 minutes by all team members by walking slowly down the reach and looking on and underneath streambanks, the streambed, large rocks, and logs when possible.

Samples were picked from each sample in the field using forceps and shallow white trays and preserved in 95% ethanol in glass vials. Each vial was labeled with site, date, and sample type. Organisms were then transported back to University of Georgia's Limnology lab and stored. The primary author and two undergraduate volunteers then identified the organisms in these macroinvertebrate samples to family.

Using these macroinvertebrate abundance data, Hilsenhoff's Family Level Biotic Index scores (Hilsenhoff 1988), percent Ephemeroptera, Plecoptera, and Trichoptera taxa (%EPT), and percent Chironomidae (% Chironomids), were calculated (Hauer and Lamberti 2007).

RESULTS

Survey Results

The mail-in survey had a response rate of 16%, with a total of 326 completed and returned surveys from riparian landowners throughout Macon County. When asked question 1: "If you were to choose one of these streams to have on your property, which one would you choose?", Photo B received the largest proportion of responses (54.7%), followed by Photo F (19.8%), photo A (17.9%), photo E (5.7%), photo C (1.6%), and photo D (0.3%). For question 2: "In your opinion, which stream photo looks like the cleanest stream?", photo B received the highest proportion of responses (66.7%), followed by photo F (13.7%), photos A and E (7.3%), photo C (5.1%), and photo D, which received no responses. For question 3: "In your opinion, which stream photo looks like the healthiest stream?" photo B received the highest proportion (64.2%) of responses, followed by photo F (24.3%), photo A (5.3%), photo E (3.7%), photo C (2.2%), and lastly photo D (0.3%). When asked question 4: "Which stream would you prefer for recreation (playing, swimming, tubing, etc.)?" Photo B received the highest proportion of responses (41.2%), followed by Photo E (20.3%), photo F (15%), photo A (13.1%), photo C (8.1%), and photo D (1.6%). Question 5 asked “which stream photo do you think is the least attractive (beautiful, aesthetic)? Photo E received the most responses (58.9%) followed by photo D (21.8%), photo C (8.7%), photo B (5.3%), photo F (3.1%), and photo A (2.2%). Question 6 asked “in your opinion, which stream photo looks like the least natural stream?”. Photo E received the most responses (84.2%), followed by photo D (7.9%), photo C (3.2), photo A (2.2), photo B (1.6), and photo F (0.9%) (fig 2).

Alignment of Survey and Habitat Assessment Results

Results from the survey on landowner stream preferences somewhat aligned with habitat ratings from saSVAP and macroinvertebrate metrics, especially at the high and low ends of landowner preferences. Ball Creek (photo B), which received the most responses for most desirable (Q1), cleanest (Q2), healthiest (Q3), and most preferred for recreation (Q4); and the fewest responses for the least attractive (Q5) and least natural (Q6) stream; also received the highest saSVAP overall score (Table 4.2), and the lowest HBI index (Table 4.1), indicating high quality habitat and water quality ratings. Furthermore, Ball Creek received the second highest proportion of EPT taxa, and second lowest % chironomids, behind Mica City (photo A) which also indicates relatively high-quality stream habitat (Table 4.1).

Jaycee Park (photo E), received the most responses for least attractive and least natural stream and among the fewest responses for most desirable, cleanest, and healthiest stream. Jaycee park also received among the lowest overall saSVAP scores (Table 4.2), and among the highest % chironomids (Table 4.1), indicating relatively poor habitat and water quality. Interestingly, for the question regarding preference for recreation (Q4), Jaycee Park received the second most responses after Ball Creek.

Jaycee Park (photo E), received among the lowest saSVAP overall scores, and tied with Mica City (photo A). This was primarily due to the low livestock access score on saSVAP received by

Mica City, where cattle were observed entering the stream. Jaycee Park lacked livestock and received a high livestock access score on saSVAP.

Lower Rocky Branch (photo D) received the highest HBI score, among the highest % chironomids (Table 4.1), and the second lowest overall saSVAP score (Table 4.2), indicating relatively poor habitat and water quality. Lower Rocky Branch also received the fewest responses for most desirable (Q1), cleanest (Q2), healthiest, and most preferred for recreation (Q4); and the second most responses for least attractive (Q5) and least natural stream (Q6). Quality ratings from HBI and saSVAP did not align with each other, with only one stream, Ball Creek, receiving and "excellent" rating on both assessments (Table 4.3). All streams were rated very good to excellent by HBI ratings and poor to excellent according to saSVAP overall scores.

DISCUSSION

Here, we compared landowner photo-survey responses to findings from saSVAP and macroinvertebrate indexes of stream habitat integrity. Our results generally support the hypothesis that riparian landowner preferences align with habitat condition, especially at the high and low end of landowner perceptions of relative "desirability", "cleanliness", and "health". Ball Creek (photo B), located within the federally protected area of Coweeta Hydrological Laboratory, received a large majority of survey responses for questions 1 through 4 regarding a positive perception of stream habitats, and among the fewest survey response for the questions 5 and 6 regarding a less positive perception of stream habitats. Ball Creek also earned the highest rating from saSVAP of all the stream sites. Conversely, Jaycee Park (photo E), located downtown in the city of Franklin, N.C. (the most urbanized setting of all the stream sites), was both the only stream with a riparian zone of mowed grass and visible "rip-rap" along streambanks for erosion control. This stream received the fewest survey responses on positive questions, the most survey responses on negative questions, among the lowest saSVAP overall scores, and the second highest proportion of chironomids. These results suggest that survey respondents used the presence and condition of a streams riparian buffer as visual cues that provided information about the desirability, health, and ideal aesthetic of wadable streams. These results also support riparian landowners' ability to visually perceive relative stream conditions in ways that closely align with more objective stream habitats assessments.

There were several discrepancies between survey results and habitat assessments that did not align with our initial predictions, especially at stream sites that were intermediate between the high and low end of landowner preferences. For instance, Mica City (Photo A) received the highest %EPT taxa, indicating relatively good water quality, and among the lowest saSVAP overall scores, indicating poor habitat quality. Furthermore, Mica City received few responses when landowners were asked to choose the "most desirable", "cleanest," and "healthiest" stream site. Mica City had few trees in its riparian zone and open access to livestock, which lowered the saSVAP score. Despite the poor local habitat conditions characterized by saSVAP and the photo-survey results, this stream had fully forested riparian zone only a few hundred meters upstream from the photo location. This forested section of the stream, and the input of LWD it provided, may have resulted in the high %EPT taxa compared to the other test sites. Alternative explanations include the fact that the visual assessment score from saSVAP may be inaccurate about actual biological capacity of macroinvertebrates and that %EPT is an inaccurate measure of stream health.

Conversely, Upper Iotla (Photo F) received the lowest %EPT taxa, and a relatively high saSVAP score. This site was perceived positively by survey respondents and received the second most responses for the most desirable, cleanest, and healthiest stream, following Ball Creek (Photo B). Upper Iotla also exhibited the highest proportion of chironomids in the study, indicating a relatively poor stream habitat. We suggest this mismatch between the survey responses, saSVAP, and bio-assessment findings may have been due to the hillslope residential development surrounding this stream. Although Photo F depicts a forested riparian zone, houses and roads were located approximately 100 meters adjacent to the photo location and may have impacted the local macroinvertebrate community. We also observed a high level of riffle embeddedness due to fine sediments at this site, which lends more support to the idea that surrounding land uses may have impacted the local macroinvertebrate community.

Water quality ratings at all streams ranged from good to excellent according to HBI metrics, despite habitat ratings of poor to excellent on saSVAP. This suggests macroinvertebrates may have not been negatively impacted by visual habitat features rated by saSVAP and depicted by survey photos. Also, since family level metrics were used to calculate HBI, and not species level community data, such as those used in the locally adapted North Carolina Index of Biotic Integrity (NCBI), our water quality ratings may not accurately reflect regional water quality conditions. Still, on-going monitoring by the North Carolina Division of Water Quality Bio-assessment Branch, has rated most streams throughout Macon County as having good to excellent water quality using locally modified fish and macroinvertebrate species based biotic indexes (NCDEQ, 2017). These results suggest that the predominantly forested uplands present in Macon County may currently provide benthic macroinvertebrates a buffer against the impacts of increased local development.

These discrepancies between visual habitat assessment and bio-assessment scores highlight a shortcoming of this study. Namely, when answering questions on the photo-survey, riparian landowners were only provided stream photo’s, which lacked details on surrounding land cover and land uses. For this study, we were primarily interested in the visual cues provided by the stream photos alone and did not control for the surrounding land uses. In future studies that include photo-surveys, we advise researchers to provide a description or map of the landscape adjacent to and surrounding the stream of interest, or control for surrounding land uses during site selection. We also suggest the inclusion of contextual descriptions of streams may improve the level of agreement between landowner perceptions and habitat conditions.

Analysis of survey responses to question 4, which asked about the desirability of streams for recreational purposes, suggested that landowner preferences for streams based on recreational activities (swimming and fishing) are somewhat distinct from their perceptions of stream health, cleanliness, and desirability. Photo B was still chosen by most respondents, but with less of a majority than the other positive questions and more of an even split between photo's A, E, and F. The fact that Jaycee Park (photo E) received the second most responses after Ball Creek (photo B) suggests that residents evaluate streams differently for recreational uses vs. aesthetic enjoyment. Jaycee Park lacked riparian vegetation and had little to no LWD, which may have been interpreted by landowners as a more desirable setting for swimming and wading because of increased safety and ease of use.

The overall response rate for the photo-survey was 16%, which is considered low for most anthropological surveys. This low response rate may have been due to aspects of residents' local culture in Southern Appalachia, which has been characterized as private, insular, with a strong belief in private property rights (Evans 2013). It is likely that some Macon County residents viewed the mail survey as a form of outside interference and chose not to participate. Several researchers have identified a strong resistance to environmental regulations and a lack trust in local and national government in rural communities of Southern Appalachia (Chambers et al. 2016; Burke et al. 2015, Vercoe et al. 2014). Other researchers have highlighted a disconnect between "bottom up” household level land use decisions that are largely driven by aesthetics, tradition, culture, and societal norms, and “top-down” institutional land management decisions that are driven largely by economic valuation and measured ecological variables (Weber 2003, Koontz and Newig 2014). Studies into the public’s perceptions of local landscapes are needed to reconcile these “top-down” and “bottom-up” decision-making strategies that may improve the public’s acceptance of institutional management decisions as well as inform individual behavior on private lands. Given the lack of zoning regulations throughout Macon County (Kirk et al. 2012), and the general disdain for command-and-control regulations that can limit private land-owner decision making (Gragson 2008, Gustafson et al. 2014), studies into the attitudes, perceptions, and preferences of landowners can be especially useful in designing alternatives to “top-down” land management plans that may not be feasible in rural areas throughout the United States.

It is generally accepted that humans cannot directly sense ecological quality, and that a disjuncture between perceived aesthetic experiences and ecological functions follows from this. Despite this understanding, some have theorized that there may be a tendency, based on cultural expectations and evolutionary processes, to associate good aesthetic quality to good ecological quality (Gobster 2007, Rosley et al. 2014). Still, a positive aesthetic perception is not always associated with ecological integrity (Jefferson et al. 2014). Recent studies show varying levels of agreement between landowners’ perceptions of streams and actual habitat conditions. Silvano et al. (2005) compared riparian farmer’s perceptions of stream ecological integrity to findings from the nation-wide Stream Visual Assessment Protocol (SVAP) in Brazil and found that the farmers tended to overestimate the ecological integrity of stream reaches located inside their properties. Similarly, Lewis and Popp (2013) compared the public’s perception of ecosystem integrity to macroinvertebrate bio-assessment scores (Hilsenhoff Biotic Index) and visual habitat assessment results (Rapid Bio-assessment Protocol) and found that residents significantly overestimated or underestimated ecosystem integrity. Lewis and Popp (2013) found that residents with lifestyles that tended to connect them to watershed ecosystem processes were more likely to rank ecosystem condition similarly to bio-assessment scores. Other studies provide further support for a positive relationship between direct-use experiences in ecosystems and accurate public perceptions of ecosystem integrity (Racevkis et al 2006; Rochet et al. 2007; Chambers et al. 2016).

Riparian landowners often have complex, and conflicting views towards stream conservation. Chambers et al. (2016) demonstrated that riparian land owners are influenced by aquatic areas and wildlife but are generally disinterested in freshwater conservation issues. Others have shown that riparian landowners are typically accepting of wetland conservation, but often lack access to reliable information regarding conservation (Johnson 1996) and may fail to appreciate their own contributions to stream degradation (Dutcher et al. 2004; Shandas 2007; Evans 2013). Here, we have found that most survey respondents´ choices of “best” and “worst” streams in terms of “desirability”, “heath”, and “cleanliness” largely align with habitat assessment metrics. Although the present study did not assess survey respondents’ degree of direct-use experience in streams, the authors assume that riparian landowners may have more direct-use experiences in streams than non-riparian landowners due to their proximity to and use of streams. We suggest most survey respondents had a basic understanding of the importance of riparian vegetation to stream health which led them to choose Photo B, as the “healthiest”, “cleanest”, and “most desirable” stream. But, when responding to questions regarding the desirability of a stream for recreation, many respondents chose the stream with no riparian buffer, suggesting that stream management decisions may be influenced by whether they plan to primarily use the stream for swimming or aesthetic enjoyment. Considering these findings, we suggest future socio-ecological investigations consider two additional survey metrics when designing studies into landowner perceptions of local stream ecosystems. First, we suggest measuring the degree of direct-use experience in streams among riparian landowners. Second, we suggest asking landowners to characterize the primary use of streams located on their property.

Our results indicate that surveyed riparian landowners have some ability to visually perceive stream habitat quality and prefer streams with forested riparian zones on their lands. These findings present opportunities to focus outreach efforts towards building on the accurate perceptions of landowners towards streams, while dispelling myths regarding the benefits of riparian deforestation and LWD removal, and motivating landowners to make ecologically sound landscape management decisions in the future. Moving forward, we advise local conservation agencies throughout southern Appalachian region to focus on streams that currently have forested riparian buffers, and to continue educating landowners on the risks posed by riparian deforestation to stream health. Also, we suggest voluntary conservation easements like those offered by Macon County's Mainspring Conservation Trust may be an effective stewardship option for southern Appalachian landowners interested in stream conservation but wary of more "top-down" regulations that can infringe of private property rights. Furthermore, tools like saSVAP, and programs like the Mainspring Conservations Trust's annual bio-monitoring efforts, provide opportunities for local landowners and residents to learn more about stream ecology and conservation, while increasing direct-use experiences in streams.

CONCLUSIONS

Ecologists and biologists are rarely formally trained to conduct anthropological research into human perception or attitudes toward ecosystems. Likewise, anthropologists are rarely formally trained in the design and implementation of ecological studies. This separation of skill-sets means researchers must closely collaborate to produce effective research into the processes and character of complex social-ecological systems where the lines that separate academic disciplines do not strictly apply. Studies that investigate the relationship between inter-dependent social and ecological factors are needed to understand our past, present, and possible futures, in the Anthropocene.

The research presented here, from its initial planning stages and design, through to its execution, analysis, and presentation, have exemplified a truly inter-disciplinary collaboration. We utilized anthropological techniques to characterize human perceptions of streams, and concurrent ecological monitoring to assess local habitat conditions, to determine how landowner perceptions align with ecosystem condition in a rapidly developing landscape. We have demonstrated that most survey respondents have some ability to visually perceive stream habitat quality and prefer streams with forested riparian zones. Due to the interdisciplinary character of this study, our findings are accessible and relevant to academics, land managers, private landowners, and government officials alike. Our findings regarding landowner preferences for streams and riparian zones provide opportunities for the development of locally adapted riparian conservation strategies, as well as a framework for facilitating change in private landscape management on a regional scale.

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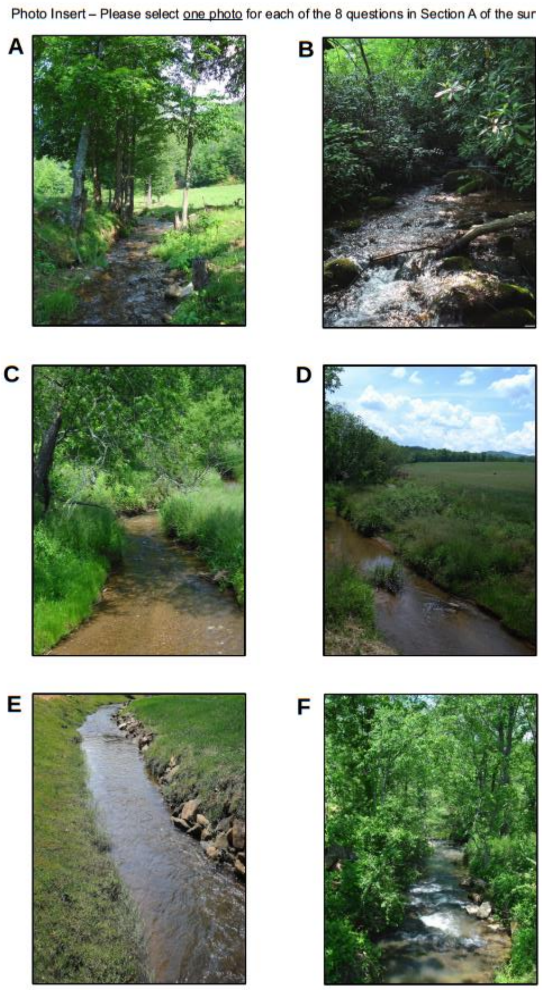

Questions about your stream preference: For these questions, please refer to the photos on the insert included with this survey. These photos feature six different streams in Macon County and are intended to represent the diversity of streams in Macon County.

<u>For each of the following questions, please circle one letter</u> for the stream that best represents your preference or opinion.

If you were to choose one of these streams to have on your property, which would you choose?	A B C D E F
In your opinion, which stream photo looks like the cleanest stream?	A B C D E F
In your opinion, which stream photo looks like the healthiest stream?	A B C D E F
Which stream would you prefer for recreation (playing, swimming, tubing, etc.)?	A B C D E F
Which stream photo do you think is the least attractive (beautiful, aesthetic)?	A B C D E F
In your opinion, which stream photo looks like the least natural stream?	A B C D E F

FIGURE 4.1. Photo insert from survey and selected questions on preference for stream appearance from mail in survey (from Evans 2013).

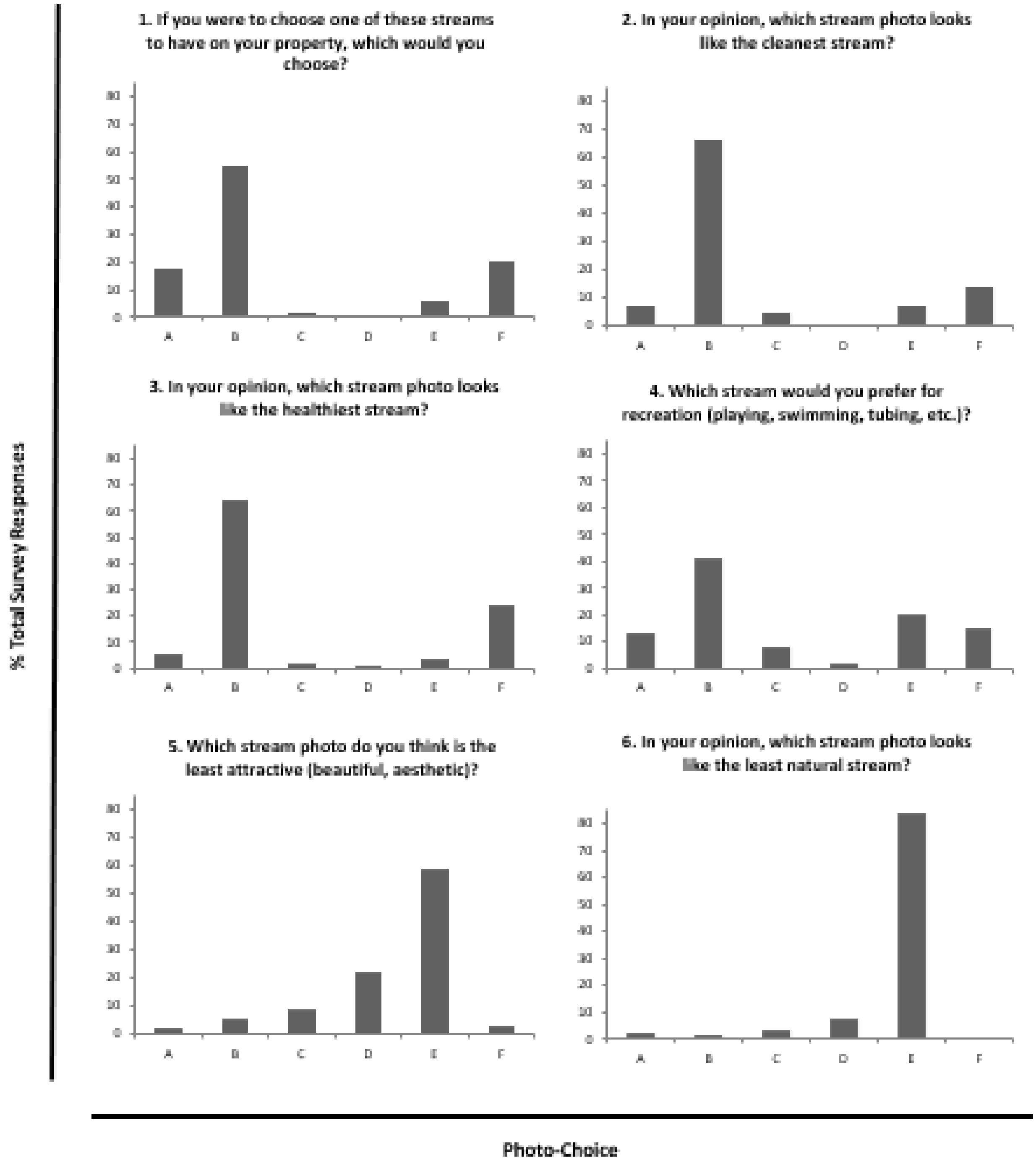

FIGURE 4.2. Proportion of responses to questions on photo-choice experiment.

TABLE 4.1. Photo-experiment sites, photo ID's, and locations, with macroinvertebrate metrics (%EPT, % Chironomids, HBI) by site.

Site	PhotoID	Location (Lat, Long)	%EPT	% Chironomids	HBI
Mica City	A	35°17'34.28"N, 83°20'35.44"W	73.9	0.99	2.6
Ball Creek	B	35° 3'25.14"N, 83°25'50.04"W	72.7	2.61	2.0
Upper Rocky Branch	C	35°13'28.27"N, 83°23'16.96"W	68.0	7.93	3.9
Lower Rocky Branch	D	35°13'29.91"N, 83°23'16.07"W	61.1	7.77	4.0
Jaycee Park	E	35°10'48.32"N, 83°23'21.49"W	63.6	7.87	2.7
Upper Iotla	F	35°14'7.72"N, 83°23'59.82"W	57.9	9.58	3.0

TABLE 4.2. Overall saSVAP scores and individual saSVAP element scores (E1= channel condition, E2= bank condition, E3= riparian area quantity, E4= riparian area quality, E5= canopy cover, E6= algal growth, E7= livestock access, E8= Pools, E9= barriers to fish movement, E10= available habitat/cover) for photo-experiment sites by photoID.

PhotoID	Overall score	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
A	1.7	2.5	1.3	1.3	1.3	1.0	2.5	1.0	2.0	2.0	1.5
B	3.4	3.5	3.3	3.5	3.5	3.5	3.5	4.0	4.0	1.0	4.0
C	1.9	2.0	2.0	1.3	1.5	1.0	3.0	2.0	1.5	3.0	2.0
D	1.8	2.0	1.5	1.0	1.0	1.0	3.0	2.0	2.0	3.0	1.0
E	1.7	1.5	1.3	1.0	1.0	1.0	2.5	4.0	1.0	2.5	1.0
F	3.1	3.0	2.5	3.0	3.0	3.0	3.0	4.0	3.0	3.5	3.0

TABLE 4.3. saSVAP and HBI Qualitative ratings of stream sites depicted in stream photos.

Site	PhotoID	HBI rating	saSVAP rating
Mica City	A	Excellent	Poor
Ball Creek	B	Excellent	Excellent
Upper Rocky Branch	C	Very good	Poor
Lower Rocky Branch	D	Very good	Poor
Jaycee Park	E	Excellent	Poor
Upper Iotla	F	Excellent	Good

CHAPTER 5

SUMMARY AND RECOMMENDATIONS

Here we have presented the findings of both “top-down” and “bottom-up” approaches to monitoring streams in rapidly developing watersheds. The previous chapters discuss these findings, as well as the strengths and weaknesses of these approaches in capturing potential stream responses to rapid exurban and suburban development on a parcel to watershed-level scale. First, in a multi-institution, multi-disciplinary, collaboration, led by the Coweeta Long-term Ecological Research Project (LTER) and funded by the National Science Foundation (NSF), we summarized and advanced the Coweeta Hazard Site Protocol (CHSP); a long-term project to monitor streams in rapidly developing watersheds. Second, in a partnership between The Coweeta LTER, UGA’s Odum School of Ecology, UGA’s Department of Anthropology, and the Mainspring Conservation Trust (MCT), we designed and tested a land-owner centered visual habitat assessment tool for wadable streams of the Southern Appalachian Mountains. Lastly, we conducted an interdisciplinary, socio-ecological, investigation of how riparian landowner stream preferences compare to local stream habitat conditions. To our knowledge this is the first study to incorporate a “top-down”, scientist-led, long-term ecological monitoring project; and a “bottom-up” landowner-centered stream habitat assessment, in an investigation of stream responses in watersheds undergoing different degrees of residential and commercial development. We propose that this model can be used in other rapidly urbanizing regions to improve our understanding of the potential impacts of land development on watersheds and streams, foster the exchange of knowledge between scientists and the public, and encourage landowner stewardship of local streams.

In Chapter 2 we used a LULC model to predict the direction of LULC change at all study sub-watersheds. We suggest the continued use of predictive LULC models in future long-term ecological studies that seek to track the impacts of urbanization through time. Analysis of data from our long-term monitoring protocol, the CHSP, detected differences in fish community variability between streams in *forested* vs. *suburban* sub-watersheds that suggest the early stages of biotic homogenization in a rapidly developing landscape. Furthermore, we found differences in water chemistry between *forested* and *suburban* streams in line with the "urban stream syndrome" that suggest an impact of exurban and suburban sub-watershed development. Interestingly, we found "*suburban*" streams to have more species-rich, cosmopolitan, and homogeneous fish communities, compared to *forested* streams. We propose that the moderate levels of development observed in this study may be altering stream habitats in ways that support more cosmopolitan species, while still not reaching a threshold of degradation that would extirpate sensitive native populations. As urbanization continues, we expect increased extirpation of sensitive native species and lowered species richness at the more developed sub-watersheds. These results highlight the need for continued study of the impacts of land use change on watersheds throughout the southern Appalachian region, which remains a biodiversity hotspot while undergoing rapid exurbanization. We also found that *forested* reference streams, with stable land covers, exhibited greater temporal variability in both diatom and fish communities, than developing streams. This finding highlights another potential impact of urbanization; the reduction of biotic community variation over time. This potential for "temporal biotic-homogenization" underscores the importance of long-term studies, like the CHSP, which track stream conditions through time and can complement the Space for Time (SFT) substitution technique commonly used ecological studies of urbanization. We suggest continued study of these rapidly changing landscapes over the next few decades to further uncover the ecological impacts of low-density development.

In chapter 3, we developed and tested the Southern Appalachian Stream Visual Assessment Protocol (saSVAP), a user-friendly habitat survey, designed for independent use by southern Appalachian riparian landowners. The motivation for this study was a response to the lack of citizen-centered visual stream assessments and difficulties associated with conducting long-term ecological research on private lands. Validity and Inter-respondent reliability (IRR) testing demonstrated that most of the visual scoring elements on saSVAP correlate strongly with paired habitat metrics, and that the tool can reliably be used by both novice and expert users to determine overall stream habitat ratings. In rural and suburban areas, where most of land is privately owned and managed, landowners, armed with tools like saSVAP, may be the most effective sentinels of headwater stream condition, due to their proximity to and management of streams on their properties. Experience using saSVAP can inform landowners about stream features that determine stream habitat quality, improve landowners understanding and acceptance of local research programs, and may increase the likelihood of landowners granting researchers permission to access streams on private lands. We propose that tools like saSVAP can also serve to identify "*streams at risk*" of degradation due to local land use change,. Researcher-led, monitoring strategies like the CHSP, could then focus in-depth on these "*at risk*" streams. In the future, the incorporation of saSVAP into the ongoing MCT stream bio-monitoring efforts will allow both researchers and citizens to characterize how stream habitats change over time in rapidly developing regions; as well as detect the potential impacts of local land use change to fish communities as they occur.

In Chapter 4, we investigated the relationship between riparian landowner perceptions of small streams and the ecological "condition" of stream habitats in a rapidly developing exurban landscape. Landowner perceptions of, and preferences for, certain features of natural landscapes have been shown to influence private land management decisions, which subsequently impact the connectivity and quality of local habitat. We conducted this study by comparing landowner photo-survey responses to findings from saSVAP and macroinvertebrate indices of stream habitat integrity. Our results suggest that Macon County riparian landowners can be effective in visually perceiving overall stream habitat quality and that landowners prefer streams with forested riparian zones on their lands. Our findings also suggest that riparian landowners may prefer different stream settings for recreational uses vs. aesthetic enjoyment. Considering these findings, we advise local conservation agencies throughout southern Appalachia region to focus on streams that currently have forested riparian buffers, restore riparian vegetation when possible, and to continue educating landowners on the risks posed by riparian deforestation to stream health. Moving forward, we recommend the development of interdisciplinary socio-ecological studies that investigate the influence of direct-use experiences on landowner perceptions of habitat integrity, and the influence of landowner perceptions of habitat condition on private land management decision-making.

By furthering a long-term monitoring project of streams in watersheds undergoing a range of development pressure, creating and testing a stream habitat assessment tool for private landowners in a region undergoing rapid exurban development, and conducting an inter-disciplinary investigation of how landowner perceptions of streams align with stream habitat quality, this work provides strategies and tools for conducting research on private lands, and engaging landowners in local stream stewardship. We hope our work here can provide a model for future collaborative and interdisciplinary projects that seek to bridge the gaps between academic research, conservation practice, and public perception.

Appendix 2.1. Abundances of fish species collected in 2000, 2005, and 2010 from the 4 *forested* study sites.

		Avery			Coweeta			Darnell			Wayah		
Species name	Common name	2000	2005	2010	2000	2005	2010	2000	2005	2010	2000	2005	2010
Ichthyomyzon greeleyi	Lamprey	0	0	0	0	0	0	0	11	1	0	0	0
Campostoma anomalum	Central Stoneroller	0	0	27	1	4	4	62	48	179	11	2	64
Clinostomus funduloides ssp.	Smokey Dace	0	0	0	14	0	1	0	6	1	14	2	4
Cyprinella galactura	Whitetail shiner	0	0	0	0	0	0	0	0	1	0	0	0
Hybopsis amblops	Bigeye chub	0	0	0	0	0	0	0	0	0	0	0	0
Luxilus coccogenis	Warpaint shiner	0	0	0	0	0	0	0	0	16	0	0	9
Nocomis micropogon	River chub	0	0	0	2	0	9	2	0	7	3	1	16
Notropis leuciodus	Tennessee shiner	0	0	0	0	0	0	0	0	19	0	0	2
Notropis lutipinnis	Yellowfin shiner	0	0	0	1	0	0	1	5	6	0	0	0
Notropis rubicroceus	Saffron shiner	0	0	0	0	0	0	0	0	0	0	0	3
Notropis spectrunculus	mirror shiner	0	0	0	0	0	0	0	0	0	1	0	0
Notropis telescopus	Telescope shiner	0	0	0	0	0	0	0	0	0	0	0	0
Phenacobius crassilabrum	Fatlips minnow	0	0	0	0	0	0	0	0	0	0	0	0
Rhinichthys atratulus	Blacknose dace	8	8	6	0	0	0	0	0	0	8	8	12
Rhinichthys cataractae	Longnose dace	5	4	3	17	6	0	4	1	3	21	9	13
Semotilus atromaculatus	Creek chub	0	0	0	0	0	1	0	0	1	0	0	0
Catostomus commersoni	White sucker	0	0	0	0	0	0	0	0	0	0	0	0
Hypentelium nigricans	Northern hog	0	1	2	1	0	1	0	0	1	2	1	2
Oncorhynchus mykiss	Rainbow trout	15	33	17	3	7	1	15	21	1	2	1	0
Salmo trutta	Brown trout	5	10	6	0	0	0	0	0	0	1	6	3
Cottus bairdi ssp.	Mottled Sculpin	51	49	64	77	65	47	223	298	126	205	208	109
Ambloplites rupestris	Rock Bass	0	0	0	4	2	5	0	0	0	0	0	4
Lepomis auritus	Redbreast	0	0	0	0	0	0	0	0	0	0	0	0
Lepomis macrochirus	Bluegill	0	0	0	0	0	0	0	0	0	0	0	0
Lepomis cyanellus	Green sunfish	0	0	0	0	0	0	0	0	0	0	0	0
Hybrid Lepomis sp.	Hybrid	0	0	0	0	0	0	0	0	0	0	0	0
Micropterus salmoides	Largemouth Bass	0	0	0	0	0	0	0	0	0	0	0	0
Etheostoma blennioides	Greenside darter	0	0	0	0	0	0	0	0	0	0	0	0
Etheostoma flabellare	Fantail darter	3	0	2	0	0	0	0	0	0	0	0	0
Etheostoma swannanoa	Swanannoah darter	0	0	1	0	0	0	0	0	0	0	0	0
Percina evides	gilt darter	0	0	0	0	0	0	0	0	0	0	0	0
Erimonax monacha	Spotfin chub	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 2.2. Abundances of fish species collected in 2000, 2005, and 2010 from the 4 *suburban* study sites.

		Watauga			Hoopers			Gap			Robinson		
Species name	Common name	2000	2005	2010	2000	2005	2010	2000	2005	2010	2000	2005	2010
Ichthyomyzon greeleyi	Lamprey	0	0	0	0	3	4	0	3	1	5	5	0
Campostoma anomalum	Central Stoneroller	15	4	39	2	14	43	116	63	167	3	39	40
Clinostomus funduloides ssp.	Smokey Dace	0	0	0	0	0	0	0	0	0	0	0	0
Cyprinella galactura	Whitetail shiner	9	0	5	0	0	2	0	0	0	0	0	0
Hybopsis amblops	Bigeye chub	0	0	0	0	0	47	0	0	0	0	0	2
Luxilus coccogenis	Warpaint shiner	12	12	19	0	4	3	6	12	52	13	4	2
Nocomis micropogon	River chub	4	16	7	0	0	8	21	4	25	10	0	3
Notropis leuciodus	Tennessee shiner	19	0	19	0	0	0	0	0	0	0	0	0
Notropis lutipinnis	Yellowfin shiner	4	2	14	0	0	0	0	0	0	0	0	0
Notropis rubicroceus	Saffron shiner	0	0	0	49	7	74	77	25	203	50	2	67
Notropis spectrunculus	mirror shiner	0	0	0	0	0	0	0	0	0	0	0	0
Notropis telescopus	Telescope shiner	0	0	3	1	0	0	0	0	0	2	0	0
Phenacobius crassilabrum	Fatlips minnow	1	5	1	0	0	0	0	0	0	0	0	0
Rhinichthys atratulus	Blacknose dace	1	6	7	46	10	11	61	21	34	23	34	16
Rhinichthys cataractae	Longnose dace	0	0	0	0	0	0	0	0	0	0	0	0
Semotilus atromaculatus	Creek chub	0	4	2	11	25	120	16	24	39	28	50	51
Catostomus commersoni	White sucker	0	0	0	2	5	0	0	1	0	3	0	0
Hypentelium nigricans	Northern hog	1	4	2	3	15	15	7	7	29	6	10	14
Oncorhynchus mykiss	Rainbow trout	0	0	0	0	0	1	0	0	0	0	0	0
Salmo trutta	Brown trout	0	0	0	0	0	1	0	0	0	0	0	0
Cottus bairdi ssp.	Mottled Sculpin	95	134	72	13	32	8	80	255	118	13	135	84
Ambloplites rupestris	Rock Bass	1	1	0	3	1	1	2	0	3	3	0	0
Lepomis auritus	Redbreast	1	0	0	0	5	5	0	0	0	4	4	1
Lepomis macrochirus	Bluegill	0	0	0	0	1	0	0	0	0	5	2	0
Lepomis cyanellus	Green sunfish	0	0	0	0	2	0	1	2	0	0	1	0
Hybrid Lepomis sp.	Hybrid	0	0	0	0	0	0	0	0	0	0	2	0
Micropterus salmoides	Largemouth Bass	0	0	0	0	1	0	0	0	0	0	0	0
Etheostoma blennioides	Greenside darter	0	0	0	0	1	0	0	0	1	0	0	0
Etheostoma flabellare	Fantail darter	0	0	0	13	14	3	36	37	12	7	14	16
Etheostoma swannanoa	Swanannoah darter	0	0	0	13	5	1	38	21	20	0	14	6
Percina evides	gilt darter	14	17	4	0	0	0	1	0	1	0	0	0
Erimonax monacha	Spotfin chub	31	0	14	0	0	0	0	0	0	0	0	0

Appendix 2.3. Cell densities (cells/ml) of diatom species collected in 2000, 2005, and 2010 from the 4 *forested* study sites.

Species name	Avery			Coweeta			Darnell			Wayah		
	2000	2005	2010	2000	2005	2010	2000	2005	2010	2000	2005	2010
Achnanthdium subhudsonis	0.00	832.24	483.31	0.00	99.02	1926.25	0.00	54.23	103.74	77.07	902.97	1833.08
Achnanthidium deflexum	413.27	0.00	0.00	128.42	0.00	0.00	1059.19	0.00	0.00	651.24	0.00	37.63
Achnanthidium GV	223.86	99.02	47.15	98.36	9.43	161.12	371.64	0.00	47.15	69.36	0.00	0.00
Achnanthidium lapidosa var. appalachiana	0.00	374.86	669.56	0.00	132.03	0.00	0.00	37.72	179.18	0.00	0.00	6230.32
Achnanthidium minutissimum	159.28	0.00	0.00	185.80	0.00	0.00	1300.75	0.00	0.00	84.78	0.00	0.00
Achnanthidium sp. 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.41	0.00	0.00
Achnanthidium sp. 10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Achnanthidium sp. 12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.86	0.00
Achnanthidium sp. 14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.85	0.00	0.00
Achnanthidium sp. 15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.85	0.00	0.00
Achnanthidium sp. 17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.56	9.43	0.00
Achnanthidium sp. 3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	43.00
Achnanthidium sp. 4	0.00	0.00	0.00	0.00	0.00	0.00	37.16	0.00	0.00	0.00	0.00	0.00
Achnanthidium sp. 5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Achnanthidium sp. 6	12.91	0.00	0.00	2.73	0.00	0.00	0.00	0.00	0.00	23.12	0.00	0.00
Achnanthidium sp. 7	6.46	0.00	0.00	16.39	0.00	14.32	0.00	0.00	0.00	3.85	0.00	0.00
Achnanthidium sp. 8	2.15	0.00	0.00	0.00	0.00	0.00	18.58	0.00	0.00	3.85	0.00	0.00
Achnanthidium sp. 9	0.00	0.00	0.00	0.00	0.00	28.64	0.00	0.00	0.00	0.00	0.00	43.00
Amphora libyca	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amphora sp. 1	0.00	0.00	0.00	10.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Asterionella formosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aulacoseira granulata var. angustissima	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aulacoseira italica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Caloneis bacillum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cocconeis placentula	12.91	91.95	14.15	2.73	0.00	7.16	222.99	0.00	0.00	26.97	4.72	0.00
Craticula cuspidata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Craticula halophila	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cymbella affinis	0.00	9.43	0.00	0.00	0.00	64.45	0.00	0.00	0.00	3.85	0.00	59.13
Cymbella cf. cistula	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.79	0.00
Cymbella GV	0.00	0.00	0.00	5.46	0.00	0.00	204.40	0.00	0.00	0.00	0.00	0.00
Cymbella naviculiformis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cymbella tumida	6.46	9.43	18.86	0.00	0.00	50.13	18.58	0.00	0.00	84.78	0.00	21.50
Diadesmis contenta	0.00	28.29	0.00	0.00	0.00	14.32	18.58	0.00	18.86	0.00	0.00	0.00
Diatoma mesodon	2.15	0.00	0.00	2.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Encyonema minutum	19.37	75.44	0.00	2.73	0.00	42.96	111.49	9.43	0.00	53.95	18.86	107.51

Encyonema minutum var. pseudogracilis	0.00	0.00	0.00	0.00	0.00	21.48	18.58	0.00	0.00	0.00	9.43	0.00
Encyonema silesiacum	8.61	240.48	9.43	10.93	0.00	146.80	743.29	0.00	0.00	19.27	0.00	21.50
Eolimna minima	0.00	66.01	47.15	0.00	37.72	14.32	18.58	18.86	0.00	0.00	0.00	0.00
Eunotia exigua	0.00	9.43	9.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eunotia G.V.	4.30	0.00	0.00	27.32	0.00	0.00	37.16	0.00	0.00	30.83	0.00	0.00
Eunotia incisa	2.15	58.94	56.58	2.73	16.50	42.96	55.75	0.00	0.00	0.00	51.87	21.50
Eunotia minor	10.76	47.15	28.29	13.66	28.29	186.18	0.00	77.80	9.43	0.00	30.65	64.51
Eunotia pectinalis	4.30	0.00	30.65	0.00	0.00	57.29	0.00	0.00	0.00	0.00	37.72	5.38
Fragilaria capucina	10.76	0.00	0.00	5.46	0.00	0.00	483.14	0.00	0.00	7.71	0.00	0.00
Fragilaria crotonensis	0.00	0.00	0.00	0.00	0.00	0.00	315.90	0.00	2.36	26.97	0.00	32.25
Fragilaria delicatissima var. angustissima	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fragilaria vaucheriae	2.15	0.00	18.86	0.00	0.00	186.18	130.08	9.43	0.00	7.71	47.15	86.01
Frustulia rhomboides	2.15	0.00	0.00	0.00	0.00	0.00	18.58	0.00	0.00	0.00	0.00	0.00
Frustulia rhomboides var. amphipleuroides	12.91	7.07	7.07	2.73	0.00	121.73	55.75	0.00	11.79	7.71	0.00	26.88
Frustulia saxonica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Frustulia vulgaris	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Geissleria decussis	0.00	0.00	0.00	0.00	0.00	0.00	18.58	0.00	0.00	15.41	0.00	0.00
Geissleria punctifera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gomphonema angustatum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.93	0.00
Gomphonema cf. subclavatum	0.00	0.00	0.00	0.00	0.00	14.32	0.00	0.00	0.00	0.00	9.43	0.00
Gomphonema clavatum	6.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.85	0.00	0.00
Gomphonema freesei	0.00	0.00	37.72	0.00	28.29	3.58	0.00	0.00	73.09	0.00	0.00	102.14
Gomphonema gracile	0.00	7.07	18.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.50
Gomphonema GV	43.05	0.00	0.00	0.00	0.00	0.00	315.90	0.00	0.00	61.66	0.00	0.00
Gomphonema lagenula	0.00	49.51	16.50	0.00	0.00	17.90	0.00	9.43	9.43	0.00	51.87	107.51
Gomphonema mehleri	0.00	0.00	0.00	0.00	0.00	14.32	0.00	0.00	28.29	0.00	0.00	0.00
Gomphonema minutum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	61.66	0.00	0.00
Gomphonema parvulum	10.76	30.65	0.00	8.20	0.00	214.82	148.66	37.72	37.72	19.27	70.73	177.39
Gomphonema pumilum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.43	16.13
Gomphonema rhombicum	0.00	0.00	0.00	0.00	0.00	71.61	0.00	0.00	0.00	0.00	0.00	37.63
Gomphosphaenia grovei	0.00	0.00	0.00	2.73	0.00	0.00	18.58	0.00	0.00	0.00	0.00	0.00
Gyrosigma attenuatum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hannaea arcus	4.30	9.43	7.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Leminola hungaricum	2.15	0.00	0.00	2.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Luticola goeppertiana	0.00	56.58	54.23	0.00	0.00	89.51	0.00	7.07	0.00	0.00	75.44	53.76
Melosira varians	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.97	0.00	0.00
Meridion alansmithii	4.30	56.58	0.00	5.46	0.00	32.22	148.66	56.58	0.00	0.00	0.00	43.00
Navicula angusta	6.46	96.66	33.01	5.46	28.29	132.47	260.15	0.00	0.00	0.00	66.01	48.38
Navicula cf. cryptotenella	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	38.53	0.00	0.00

Navicula cf. meniculus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.71	9.43	0.00
Navicula cf. salinarum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Navicula cf. schroeteri	10.76	0.00	0.00	0.00	0.00	0.00	315.90	0.00	0.00	7.71	0.00	0.00
Navicula cryptocephala	6.46	28.29	61.30	0.00	0.00	114.57	0.00	25.93	42.44	50.10	141.46	155.89
Navicula cryptotenella	19.37	9.43	63.66	0.00	0.00	57.29	222.99	0.00	9.43	38.53	9.43	0.00
Navicula difficultissima	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.43	0.00	0.00	18.86	0.00
Navicula germainii	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.50
Navicula meniculus	0.00	37.72	18.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Navicula radiosa	2.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Navicula rhynchocephala	0.00	0.00	0.00	0.00	0.00	71.61	0.00	0.00	0.00	3.85	9.43	0.00
Navicula rostellata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Navicula salinarum	0.00	0.00	0.00	0.00	0.00	0.00	18.58	0.00	0.00	0.00	0.00	0.00
Navicula schroeteri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Navicula seminulum	0.00	0.00	9.43	0.00	0.00	114.57	0.00	0.00	0.00	0.00	18.86	0.00
Navicula viridula	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitzschia acicularis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitzschia amphibia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitzschia dissipata	0.00	58.94	28.29	0.00	0.00	71.61	55.75	0.00	0.00	3.85	0.00	21.50
Nitzschia gracilis	0.00	0.00	28.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitzschia inconspicua	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitzschia linearis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitzschia palea	0.00	0.00	18.86	0.00	0.00	0.00	92.91	0.00	18.86	34.68	0.00	0.00
Nitzschia recta	0.00	0.00	0.00	2.73	0.00	28.64	18.58	0.00	0.00	3.85	9.43	0.00
Pinnularia mesogonglya	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.43	0.00	0.00	0.00
Pinnularia obscura	0.00	0.00	0.00	0.00	0.00	28.64	0.00	0.00	0.00	0.00	0.00	0.00
Pinnularia sp. 1	2.15	0.00	0.00	0.00	0.00	28.64	0.00	0.00	0.00	0.00	0.00	0.00
Pinnularia subcapitata	2.15	0.00	33.01	0.00	0.00	0.00	130.08	9.43	0.00	3.85	0.00	0.00
Pinnularia viridis	0.00	0.00	0.00	0.00	0.00	3.58	0.00	0.00	0.00	0.00	18.86	43.00
Planothidium lanceolatum	0.00	14.15	0.00	2.73	0.00	0.00	18.58	0.00	0.00	30.83	0.00	0.00
Platessa lutheri	0.00	0.00	0.00	0.00	0.00	0.00	18.58	0.00	0.00	0.00	0.00	0.00
Platessa stewartiii	10.76	49.51	66.01	0.00	0.00	0.00	92.91	0.00	9.43	7.71	0.00	0.00
Psammothidium subatomoides	6.46	9.43	0.00	0.00	0.00	0.00	55.75	0.00	18.86	15.41	9.43	0.00
Reimeria sinuata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rhoicosphenia abbreviata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rossithidium anastasiae	0.00	0.00	0.00	0.00	0.00	0.00	1765.31	0.00	0.00	0.00	103.74	80.63
Sellaphora pupula	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.85	0.00	0.00
Stephanodiscus pseudostelligera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Surirella angusta	0.00	0.00	0.00	0.00	0.00	0.00	18.58	0.00	0.00	0.00	0.00	0.00
Surirella minuta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Surirella sp. 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Surirella tenera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Synedra acus	4.30	0.00	0.00	19.13	0.00	0.00	278.73	0.00	0.00	0.00	0.00	0.00
Synedra rumpens	0.00	84.87	30.65	0.00	0.00	501.25	18.58	0.00	0.00	0.00	134.38	204.27
Synedra rumpens var. familiaris	2.15	261.70	37.72	0.00	25.93	293.59	0.00	44.79	28.29	7.71	80.16	881.60
Synedra rumpens var. fragilaroides	6.46	101.38	129.67	0.00	0.00	483.35	0.00	226.33	56.58	15.41	117.88	112.89
Synedra ulna	2.15	63.66	42.44	0.00	0.00	32.22	92.91	4.72	0.00	53.95	14.15	48.38
Synedra ulna var. ramsei	4.30	0.00	47.15	0.00	0.00	46.55	0.00	0.00	0.00	107.90	0.00	32.25

Appendix 2.4. Cell densities (cells/ml) of diatom species collected in 2000, 2005, and 2010 from the 4 *suburban* study sites.

	Watauga			Hoopers			Gap			Robinson		
Species name	2000	2005	2010	2000	2005	2010	2000	2005	2010	2000	2005	2010
Achnanthdium subhudsonis	409.02	5144.99	1754.07	96.52	57859.59	5144.80	18.66	13705.76	6789.74	13.54	42739.66	23151.22
Achnanthidium deflexum	9816.39	0.00	0.00	77.22	0.00	0.00	4665.46	0.00	0.00	124.54	0.00	0.00
Achnanthidium GV	681.69	0.00	23.58	19.30	0.00	40.27	223.94	0.00	0.00	18.95	0.00	90.43
Achnanthidium lapidosa	0.00	2063.94	768.58	0.00	13182.20	523.54	0.00	2022.99	1794.43	0.00	6484.16	3346.08
Achnanthidium	2635.88	0.00	0.00	270.26	0.00	0.00	1604.92	0.00	0.00	40.61	0.00	0.00
Achnanthidium sp. 1	45.45	0.00	0.00	38.61	0.00	0.00	0.00	0.00	0.00	2.71	0.00	0.00
Achnanthidium sp. 10	272.68	0.00	0.00	0.00	0.00	0.00	93.31	0.00	0.00	0.00	0.00	0.00
Achnanthidium sp. 12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.71	0.00	0.00
Achnanthidium sp. 14	45.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Achnanthidium sp. 15	181.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Achnanthidium sp. 17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Achnanthidium sp. 3	0.00	0.00	0.00	164.09	7577.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Achnanthidium sp. 4	363.57	0.00	0.00	77.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Achnanthidium sp. 5	0.00	0.00	0.00	57.91	0.00	0.00	0.00	0.00	0.00	13.54	0.00	0.00
Achnanthidium sp. 6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Achnanthidium sp. 7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.71	0.00	0.00
Achnanthidium sp. 8	45.45	0.00	0.00	0.00	0.00	0.00	205.28	0.00	0.00	0.00	0.00	0.00
Achnanthidium sp. 9	0.00	0.00	0.00	0.00	5288.67	1933.07	18.66	151.72	0.00	0.00	1115.55	0.00
Amphora libyca	0.00	0.00	0.00	48.26	0.00	201.36	0.00	0.00	55.43	0.00	0.00	0.00
Amphora sp. 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.71	0.00	0.00
Asterionella formosa	0.00	0.00	0.00	0.00	0.00	90.61	0.00	0.00	90.07	5.41	0.00	0.00
Aulacoseira granulata var.	0.00	0.00	0.00	0.00	0.00	0.00	18.66	101.15	6.93	0.00	0.00	271.30
Aulacoseira italica	0.00	47.58	0.00	0.00	0.00	0.00	55.99	1390.81	27.71	10.83	0.00	271.30
Caloneis bacillum	0.00	0.00	0.00	9.65	0.00	0.00	0.00	0.00	0.00	0.00	557.78	0.00
Cocconeis placentula	45.45	136.80	0.00	77.22	315.74	322.18	0.00	0.00	512.70	64.98	766.94	1243.47
Craticula cuspidata	0.00	0.00	0.00	19.30	0.00	20.14	0.00	0.00	0.00	0.00	0.00	0.00
Craticula halophila	0.00	0.00	0.00	19.30	947.22	40.27	0.00	0.00	27.71	0.00	0.00	0.00
Cymbella affinis	727.14	95.17	0.00	250.95	0.00	80.54	149.29	202.30	69.28	32.49	209.17	180.87
Cymbella cf. cistula	0.00	0.00	0.00	28.96	0.00	0.00	55.99	0.00	0.00	0.00	0.00	0.00
Cymbella GV	181.79	0.00	0.00	115.82	0.00	0.00	18.66	0.00	0.00	8.12	0.00	0.00
Cymbella naviculiformis	45.45	0.00	0.00	28.96	157.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cymbella tumida	636.25	23.79	0.00	231.65	1499.77	291.97	298.59	379.31	48.50	10.83	209.17	339.13
Diadesmis contenta	0.00	0.00	9.43	19.30	0.00	60.41	18.66	0.00	0.00	5.41	0.00	67.83
Diatoma mesodon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Encyonema minutum	454.46	344.98	4.72	0.00	5683.34	241.63	37.32	303.45	221.71	10.83	1917.36	1356.52

Encyonema minutum var.	0.00	0.00	0.00	0.00	0.00	60.41	0.00	0.00	83.14	0.00	0.00	0.00
Encyonema silesiacum	545.36	118.96	37.72	96.52	315.74	40.27	55.99	75.86	110.85	18.95	139.44	180.87
Eolimna minima	0.00	95.17	0.00	0.00	1262.97	201.36	0.00	151.72	110.85	2.71	557.78	0.00
Eunotia exigua	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eunotia G.V.	0.00	0.00	0.00	19.30	0.00	0.00	0.00	0.00	0.00	10.83	0.00	0.00
Eunotia incisa	0.00	0.00	0.00	0.00	0.00	10.07	0.00	0.00	0.00	0.00	0.00	0.00
Eunotia minor	0.00	0.00	0.00	0.00	631.48	40.27	0.00	0.00	0.00	0.00	0.00	0.00
Eunotia pectinalis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fragilaria capucina	0.00	0.00	0.00	0.00	0.00	0.00	37.32	0.00	0.00	8.12	0.00	0.00
Fragilaria crotonensis	0.00	0.00	0.00	0.00	78.94	0.00	18.66	0.00	27.71	2.71	0.00	271.30
Fragilaria delicatissima	0.00	0.00	0.00	9.65	0.00	0.00	18.66	0.00	0.00	0.00	0.00	678.26
Fragilaria vaucheriae	227.23	731.60	61.30	0.00	947.22	201.36	55.99	252.87	69.28	2.71	139.44	90.42
Frustulia rhomboides	90.89	23.79	0.00	0.00	0.00	0.00	0.00	0.00	13.86	0.00	0.00	0.00
Frustulia rhomboides var.	45.45	0.00	0.00	0.00	0.00	20.14	0.00	0.00	0.00	0.00	0.00	0.00
Frustulia saxonica	0.00	23.79	11.79	0.00	0.00	40.27	0.00	0.00	0.00	0.00	0.00	90.43
Frustulia vulgaris	45.45	0.00	0.00	38.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Geissleria decussis	90.89	23.79	18.86	415.04	4104.64	1188.04	18.66	50.57	221.71	8.12	139.44	271.30
Geissleria punctifera	0.00	0.00	0.00	0.00	0.00	80.54	0.00	0.00	0.00	2.71	0.00	0.00
Gomphonema angustatum	0.00	0.00	18.86	28.96	315.74	0.00	0.00	0.00	0.00	0.00	139.44	90.43
Gomphonema cf.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gomphonema clavatum	636.25	0.00	0.00	28.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gomphonema freesei	0.00	1933.09	0.00	0.00	5999.08	80.54	0.00	4905.75	450.34	0.00	2614.58	1446.95
Gomphonema gracile	0.00	23.79	0.00	0.00	0.00	0.00	0.00	50.57	0.00	0.00	139.44	90.43
Gomphonema GV	1090.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.41	0.00	0.00
Gomphonema lagenula	0.00	237.92	0.00	0.00	1262.97	120.82	0.00	101.15	0.00	0.00	383.47	972.17
Gomphonema mehleri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	139.44	0.00
Gomphonema minutum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.66	0.00	0.00
Gomphonema parvulum	181.79	642.38	113.17	19.30	3788.90	362.45	55.99	1226.44	110.85	8.12	1150.41	90.43
Gomphonema pumilum	45.45	47.58	18.86	0.00	1105.09	110.75	0.00	0.00	145.49	0.00	0.00	452.17
Gomphonema rhombicum	0.00	142.75	9.43	0.00	0.00	30.20	0.00	265.52	13.86	0.00	0.00	0.00
Gomphosphaenia grovei	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gyrosigma attenuatum	0.00	0.00	9.43	0.00	315.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hannaea arcus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Leminola hungaricum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Luticola goeppertiana	0.00	0.00	18.86	0.00	0.00	40.27	0.00	0.00	0.00	0.00	0.00	0.00
Melosira varians	0.00	0.00	9.43	28.96	0.00	241.63	223.94	0.00	69.28	2.71	557.78	813.91
Meridion alansmithii	45.45	0.00	37.72	0.00	0.00	161.09	0.00	0.00	0.00	0.00	0.00	90.43
Navicula angusta	0.00	0.00	9.43	0.00	0.00	0.00	37.32	0.00	0.00	0.00	0.00	180.87
Navicula cf. cryptotenella	0.00	0.00	0.00	67.56	0.00	0.00	149.29	0.00	0.00	5.41	0.00	0.00

Navicula cf. meniculus	0.00	0.00	18.86	0.00	0.00	402.72	0.00	0.00	228.63	0.00	0.00	2283.47
Navicula cf. salinarum	45.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Navicula cf. schroeteri	0.00	0.00	0.00	9.65	0.00	0.00	18.66	0.00	0.00	0.00	0.00	0.00
Navicula cryptocephala	318.12	0.00	28.29	57.91	631.48	432.93	149.29	50.57	207.85	2.71	139.44	361.74
Navicula cryptotenella	454.46	47.58	108.45	86.87	1262.97	201.36	55.99	177.01	69.28	24.37	278.89	90.43
Navicula difficultissima	0.00	0.00	0.00	0.00	315.74	0.00	0.00	0.00	27.71	0.00	0.00	90.43
Navicula germainii	0.00	23.79	0.00	0.00	1894.45	352.38	0.00	101.15	55.43	0.00	697.22	452.17
Navicula meniculus	0.00	35.69	0.00	0.00	6472.70	40.27	0.00	189.66	0.00	0.00	1394.44	90.43
Navicula radiosa	90.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Navicula rhynchocephala	0.00	0.00	0.00	0.00	315.74	30.20	0.00	0.00	0.00	2.71	139.44	361.74
Navicula rostellata	0.00	47.58	28.29	0.00	5051.86	765.18	0.00	303.45	117.78	0.00	557.78	1514.78
Navicula salinarum	0.00	0.00	0.00	9.65	0.00	0.00	0.00	0.00	0.00	29.78	0.00	0.00
Navicula schroeteri	45.45	249.81	311.21	0.00	0.00	40.27	0.00	50.57	0.00	0.00	139.44	271.30
Navicula seminulum	0.00	23.79	18.86	0.00	4104.64	523.54	0.00	50.57	83.14	0.00	697.22	0.00
Navicula viridula	0.00	0.00	0.00	0.00	0.00	60.41	0.00	0.00	0.00	0.00	0.00	271.30
Nitzschia acicularis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.57	0.00	0.00	0.00	180.87
Nitzschia amphibia	0.00	0.00	9.43	0.00	0.00	0.00	0.00	0.00	55.43	2.71	0.00	0.00
Nitzschia dissipata	499.91	0.00	18.86	67.56	1894.45	130.89	0.00	0.00	159.35	46.03	244.03	0.00
Nitzschia gracilis	0.00	0.00	9.43	9.65	315.74	0.00	0.00	0.00	0.00	2.71	0.00	180.87
Nitzschia inconspicua	0.00	0.00	0.00	38.61	0.00	161.09	0.00	0.00	0.00	0.00	0.00	0.00
Nitzschia linearis	45.45	0.00	0.00	1187.20	789.35	432.93	111.97	0.00	62.35	8.12	418.33	90.43
Nitzschia palea	90.89	0.00	311.21	28.96	1420.84	926.26	149.29	25.29	277.13	0.00	2021.94	633.04
Nitzschia recta	318.12	0.00	21.22	0.00	631.48	40.27	0.00	0.00	27.71	0.00	0.00	723.48
Pinnularia mesogonglya	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	27.71	0.00	0.00	0.00
Pinnularia obscura	0.00	0.00	9.43	9.65	473.61	80.54	0.00	0.00	0.00	0.00	0.00	0.00
Pinnularia sp. 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pinnularia subcapitata	0.00	0.00	0.00	0.00	0.00	302.04	0.00	0.00	0.00	2.71	0.00	226.09
Pinnularia viridis	0.00	0.00	18.86	9.65	0.00	261.77	0.00	0.00	41.57	5.41	0.00	0.00
Planothidium lanceolatum	90.89	0.00	0.00	415.04	16971.10	1228.31	37.32	139.08	367.20	13.54	1568.75	768.69
Platessa lutheri	45.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Platessa stewartiii	0.00	0.00	0.00	0.00	0.00	40.27	0.00	101.15	0.00	0.00	278.89	0.00
Psammothidium	136.34	0.00	18.86	48.26	631.48	241.63	0.00	50.57	27.71	2.71	139.44	0.00
Reimeria sinuata	136.34	47.58	0.00	77.22	631.48	0.00	18.66	151.72	0.00	18.95	139.44	90.43
Rhoicosphenia abbreviata	0.00	0.00	0.00	86.87	157.87	120.82	0.00	0.00	180.14	16.24	0.00	0.00
Rossithidium anastasiae	0.00	202.23	47.15	0.00	0.00	0.00	0.00	0.00	277.13	0.00	0.00	271.30
Sellaphora pupula	0.00	0.00	0.00	9.65	0.00	0.00	0.00	0.00	20.78	2.71	139.44	0.00
Stephanodiscus	0.00	0.00	0.00	0.00	315.74	0.00	0.00	0.00	193.99	2.71	0.00	0.00
Surirella angusta	0.00	0.00	0.00	9.65	631.48	30.20	0.00	0.00	0.00	0.00	0.00	0.00
Surirella minuta	0.00	0.00	0.00	0.00	0.00	0.00	18.66	0.00	0.00	2.71	0.00	0.00

Surirella sp. 2	0.00	0.00	0.00	0.00	0.00	20.14	0.00	0.00	6.93	0.00	0.00	0.00
Surirella tenera	45.45	0.00	0.00	48.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Synedra acus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Synedra rumpens	0.00	95.17	0.00	0.00	631.48	120.82	0.00	0.00	180.14	2.71	976.11	180.87
Synedra rumpens var.	0.00	0.00	9.43	0.00	947.22	120.82	0.00	0.00	55.43	0.00	0.00	0.00
Synedra rumpens var.	0.00	53.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	90.43
Synedra ulna	272.68	23.79	0.00	144.78	157.87	40.27	18.66	151.72	124.71	5.41	139.44	316.52
Synedra ulna var. ramsei	772.59	0.00	23.58	48.26	631.48	120.82	18.66	0.00	90.07	2.71	0.00	0.00

APPENDIX 3.1. The Southern Appalachian Stream Visual Assessment (saSVAP) document.

The Southern Appalachian Stream Visual Assessment Protocol (saSVAP)

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University of Georgia
Coweeta Long-Term Ecological Research Program

saSVAP Southern Appalachian Stream Visual Assessment Protocol Version 1

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Introduction

The Southern Appalachian Stream Visual Assessment Protocol (saSVAP) is a user-friendly, visually-based, method for monitoring and accessing the condition of small, wadable, streams. The process of customizing saSVAP has involved a panel of experts in stream ecology, geomorphology, hydrology, and anthropology. Each panel member offered their input on how saSVAP could better reflect the characteristics of Southern Appalachian stream ecosystems and improve the tools accessibility to those new to stream assessment. Using their cumulative expertise as a guide, each element was modified or condensed, and new sections were added to improve data quality and procedural reproducibility. The saSVAP can be used by stakeholders who are curious about the ecological condition of local streams, biology instructors during field trips, or natural resource managers in need of a fast, reliable, measure of stream habitat quality. The saSVAP tool has been developed with support from the NSF's Coweeta Long Term Ecological Research Program.

saSVAP is divided into two sections:

> **Section 1** consists of a preliminary stream assessment and an illustrated element scoring portion. The scoring portion consists of ten scoring elements, which are accompanied by illustrations and textual descriptions that reflect the range of local stream conditions.
>
> **Section 2** consists of a a site mapping procedure, a photo-point monitoring method, and a survey of common native and non-native streamside plant species with an illustrated plant identification key.

Both sections of saSVAP can be used seperately depending on the needs of the user. Users can conduct the mapping procedure one day and return to the same stream at a later date to score the visual elements, or a team of four can split the procedure with two users scoring the stream reach, while the other two conduct the mapping prodedure. If time is limited users can choose either section of saSVAP to conduct in the field.

The saSVAP tool is designed to be used by local residents and members of the general public for assessing local streams. The motivation behind creating saSVAP is to give interested citizens a way to learn more about stream ecology and determine the ecological condition of streams in thier own communities.

The Southern Blue Ridge Eco-region (SBR)

The Southern Blue Ridge Ecoregion (SBR) spans approximately 9.4 million acres (38,000 km^2) across portions of Virginia, Tennessee, North Carolina, South Carolina, and Georgia (Fig. 1). Due to it's unique geological history and diverse habitat features, the SBR is a major center of biodiversity and endemism in the temperate world. The Appalachian mountain range was formed by a variety of geological processes including uplift of the earths crust and volcanic intrusions, but has largely remained geologically stable for over the last 245 million years. Over these hundreds of millions of years, erosion has worn the once high, jagged mountain peaks down to a series of ridges and valleys. This process has resulted in the watersheds and freshwater ecosystems of the SBR, like lakes, rivers, and streams, which provide a wide variety of habitats for plants and animals. Streams of the SBR usually contain cold, clear water, and are comprised of a range of stream habitat types including riffles, runs, plunge-pools, cascades, and waterfalls. These diverse features make streams in the SBR ideal habitat for many freshwater fish, insects, and other aquatic organisms. Infact, 66 at-risk aquatic species are found throughout the SBR, 20 of which are currenlty listed as nationally threatened or endangered. The SBR is also cooler and wetter than surrounding regions and managed to largely escape the expansion of glaciers during the last ice age approximately 2.5 million years ago. This made the SBR an important area where ancient plant and animal species took refuge. As a result of this history, topography, and location the SBR currently contains the highest number of salamander species in the world, the most diverse terrestrial snail communities in the United States, nearly 400 rare plant species, and over 250 edemic plant species. These characteristics make the SBR one of the most biologically significant ecoregions in both the U.S. and the world.

Although the SBR is one of the more ecologically functional and intact ecoregions in the U.S., the rapid pace of land development in the region currently poses threats to this region and its diverse animal and plant inhabitants. Forested and agricultural lands throughout the SBR are rapidly shifting to residential and commercial uses. Also, development that has historically occurred in the valleys is shifting to more forested slopes, which can have profound impacts on nearby stream ecosystems which integrate changes throughout their watersheds (Williamson et al. 2008). Rapid land development may have local effects on streams, such as loss of riparian vegetation, more disturbed soils, more flashy stream flows caused by expansion of impervious surfaces (i.e. roads, roofs, parking lots), and local extinctions of sensitive species; as well as more regional consequences, such as increased sedimentation, increased nutrient loading, and an overall reduction in aquatic biodiversity (Walsch et al. 2005). The threats posed by rapid land use change, and the uniqueness of the Blue Ridge region, in terms of topography and species richness, provided the impetus to create saSVAP, a tool specifically designed for southern Appalachian stream ecosystems.

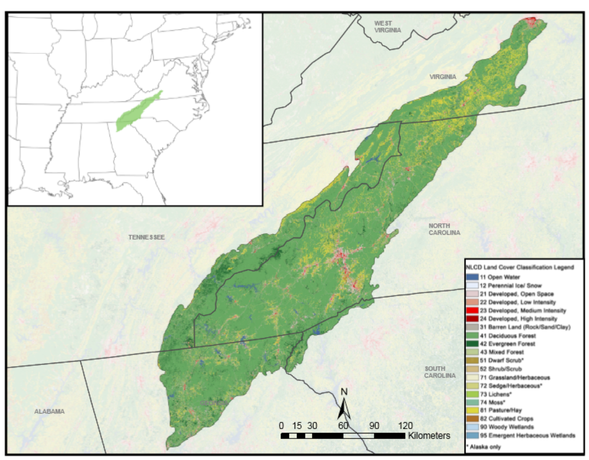


Figure 1. The Southern Blue Ridge Ecoregion (SBR). Underlying landcover is from the 2011 National Land Cover Database (NLCD) (Homer et al 2015).

saSVAP Section 1

includes:

- -Safety Concerns
- -Using saSVAP
- -Preliminary stream assessment
- -Scoring elements
- -Scoring sheet

Safety Concerns

Safety is of critical importance while conducting saSVAP. **All saSVAP users should read and follow these safety precautions before conducting saSVAP!**

- Always conduct saSVAP with at least one partner. Always let another person know where you are conducting saSVAP, when you intend to come back, and what to do if you do not come back on time.
- Have a safety plan. Always have a charged cell phone with you. Know the location and fastest route of the nearest medical center. Have each member of the group write down emergency contact information and important health information such as allergies, epilepsy, diabetes, etc.
- Always honor private property rights. Landowners are encouraged to conduct saSVAP on their own lands. Never cross or enter a landowners property without permission. Many times riparian landowners own only one stream bank. Keep this in mind when entering streams and do not trespass on stream banks of privately owned lands.
- Always check local weather reports. Do not conduct saSVAP if severe weather is predicted and stop saSVAP if a storm occurs while at the site.
- Never wade in high or fast-moving water. Do not enter the stream at flood stage. Never wade if the stream is more than knee-deep.
- Beware streams that appear severly polluted. Do not enter if a stream is posted as unsafe for body contact.
- Never drink stream water.
- Wash hands with soap if they have been in contact with stream water.
- Be careful when walking in the stream. Rocky-bottom streams can be extremely slippery and may contain deep pools. Muddy or silty-bottom streams can be dangerous in areas where mud, silt, or sand has accumulated in sink holes. Use a long stick and probe the stream bottom for deep water, obstacles, and muck.
- Do not walk on unstable stream banks. Disturbing stream banks can accelerate erosion and might be dangerous if a bank collapse is imminent. Avoid disturbing stream side vegetation.
- Beware of animals and plants. Be cautious of dogs, farm animals, wildlife, and insects such as ticks, hornets, and wasps. Watch for poison ivy, poison oak, sumac and other vegetation that may cause rash or irritation.

- Have a first aid kit. It is recommended that at least on team member has first aid/CPR training. Be aware of any pertinent medical conditions of the team members (e.g. allergies to bee stings, heart conditions). The first aid kit should contain at least the following items:
    - Telephone numbers of emergency service personnel such as police and ambulance services
    - Bandages for minor cuts
    - Antibacterial soap or alcohol wipes
    - Gauze pads 3-4" square for deep wounds with excessive bleeding
    - Acetaminophen or aspirin for pain relief and fever reduction
    - Needle and tweezers for removing splinters
    - First aid manual which outlines diagnosis and treatment procedures
    - Single edge razor blade for minor surgery and cutting tape to size
    - A 2"-wide roll of gauze
    - A triangular bandage for large wounds
    - A large compress bandage to hold dressings in place
    - A 3"-wide elastic bandage for sprains and applying pressure to bleeding wounds
    - If a participant is allergic to bee sings, include their doctor-prescriped antihistamine
- **Remember safety first! If you feel uncomfortable about the condition of the stream or your surroundings, stop saSVAP and leave the site immediately.**

Equipment List

- Waders or Rubber Boots
- Metric Ruler
- 100-meter measuring tape
- Pens and Pencils

References

Volunteer Stream Monitoring: A Methods Manual. USEPA Office of water. EPA 841-B-97-003. November 1997.

A Citizen's Guide to Basic Watershed, Habitat, and Geomorphology Surveys in Stream and River Watersheds - Volume 1. Maine Stream Team Program. Main Deparment of Environmental Protection. February 2009.

Hoosier Riverwatch Volunteer Stream Monitoring Training Manual. Indiana Department of Environmental Management. 2015

Using saSVAP

The saSVAP is designed for members of the public who have little experience with stream ecology, or environmental assessment. Certain optional measurements in section 2 of saSVAP should only be conducted by those trained in how to use the necessary equipment. Ideally, the protocol should be conducted by the landowner or tenant to promote opportunities to learn about their local streams, discuss local natural resource concerns, and promote land use practices that contribute to restoring or maintaining healthy streams. Although saSVAP can be conducted any time of year, and allows for partial completion if certain environmental or seasonal conditions restrict the completion of certain elements, saSVAP was designed for use during the spring and summer seasons, before the leaves fall from the trees in autumn and after the leaves fully emerge in the spring.

The Preliminary Stream Assessment

When possible, the preliminary stream assessment should be completed before visually assessing streams. Some sections of the preliminary stream assessment require knowledge on surrounding land uses, which may be difficult to determine in the field. Users can gather information about land use in the watershed of your assessment site using online resources such as Google Maps©, Google Earth,© and The U.S. Environmental Protection Agency's (EPA) Surf Your Watershed Website (http://www.epa.gov/surf). Users can also ask community members about surrounding land use, human alterations to the stream, or suspected causes of stream impairment. An optional pebble count is also included in the preliminary stream assessment which can be conducted by users interested in a more detailed evaluation of the stream bed.

Determining Sample Reach Length

Before beginning the field portion (scoring elements) of saSVAP users should walk along the stream banks for as much of the streams length as possible. The goal here is to obtain an initial impression of the stream. Remember to observe the conditions on both sides of the stream. Always indicate left and right banks (while facing downstream, in the direction of water flow)on the site map. Try to choose a sample reach with relatively consistent gradient (slope).

The minimum sample reach length for saSVAP is fifteen times the wetted width of the stream. The wetted width of a stream is the width of the current flow in the stream or simply the width of the water in the stream from one streambank to the other. The minimum wetted width to consider using saSVAP at a stream site is 1 meter (app. 3 feet). The recommended maximum wetted width to consider using saSVAP is 6m (app. 20 feet). To determine the sample reach length measure three wetted widths that are representative of the stream, determine the average of these measurements, and multiply this average by fifteen. Mark the endpoints of reach with a stick or stone and record the reach length on the data sheet. Consecutive runs of saSVAP can be conducted on multiple reaches if a detailed characterization of longer sections of the stream if desired.

The saSVAP requires users to score four elements based upon the entire length of the stream that is within a single landowner's property. These are: riparian area quantity, riparian area quality, canopy cover, and barriers to aquatic species movement.

How to Score saSVAP Elements

To score the saSVAP elements choose an appropriate visual and textual prompt that best matches what you see at the stream site. Base the score you choose for each element on your observations, the descriptions in the element scoring instructions, and the illustrations provided. If there is a situation where a stream reach falls between two scores, the user can record a ½ point (e.g., between a 1 and 2, score a 1.5).

Preliminary Stream Assessment

A. General Information

Reach location (Lat.,Long.): ____________________ Stream name/Site code: _______________

Date of assessment: _________ Weather: ______________ (temp.\% cloud cover)

User name/email address: _____________________ Start time: _____ End time: _____

B. Surrounding Land Use: Estimate the percent contribution of the following land uses on the property where the stream is found. Percentages should add to 100%.

Forested ___% Agricultural/Pasture ___% Agricultural/Crops ___% Urban ___% Suburban ___%

C. Riparian cover type(s): Estimate the percent contribution of each growth type along the left and right stream banks (while facing downstream, in the direction of water flow).

Left stream bank: Tree___% Shrub___% Herbaceous ___% Lawn ___% Bare ___%

Right stream bank: Tree___% Shrub___% Herbaceous ___% Lawn ___% Bare ___%

D. Gradient/slope (check one): Low (0-2%) ___ Moderate (>2<4%) ___ High (>4%) ___

E. Dominant Substrate (%): Estimate the percent composition of each size substrate to the stream bottom (for a clear explanation of substrate size classifications refer to the glossary).

boulder(>250 mm)___ cobble(60-250mm)___ gravel (2-60mm)___ sand (2-.06mm)___ fine sediments(< .06mm)___

F. Pebble Count (optional):

1. Choose a representative riffle within the sample reach. If a riffle is not present in sample reach, choose a representative run to conduct the pebble count.
2. Take one step into the water, perpendicular to flow, and while looking away, bend down and pick up the first pebble you feel with your index finger next to your big toe.
3. Take another step and repeat step 2 until you reach the other side or measure 100 pebbles. If you do not reach 100 pebbles, walk back across the channel and repeat the previous steps until you do. Remember not to look at the particle until after you have selected it.
4. Measure the width (intermediate axis, see figure 11) of the particle to the nearest millimeter (mm) using a metric ruler. Record these data on the sheet provided. For pebbles with widths smaller than 2mm, enter a "<2mm" entry on the pebble count data sheet provided. For pebbles with widths larger than 60mm, enter a ">60mm" entry on the pebble count data sheet.

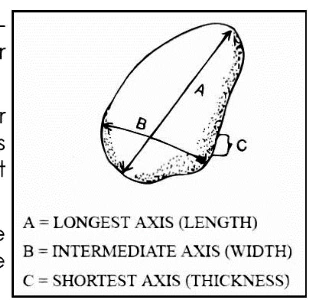


Figure 11. Pebble lengths.

Pebble #	Width (mm)
1	____
2	____
3	____
4	____
5	____
6	____
7	____
8	____
9	____
10	____
11	____
12	____
13	____
14	____
15	____
16	____
17	____
18	____
19	____
20	____
21	____
22	____
23	____
24	____
25	____
26	____
27	____
28	____
29	____
30	____
31	____
32	____
33	____
34	____
35	____
36	____
37	____
38	____
39	____
40	____
41	____
42	____
43	____
44	____
45	____
46	____
47	____
48	____
49	____
50	____

Pebble #	Width (mm)
51	____
52	____
53	____
54	____
55	____
56	____
57	____
58	____
59	____
60	____
61	____
62	____
63	____
64	____
65	____
66	____
67	____
68	____
69	____
70	____
71	____
72	____
73	____
74	____
75	____
76	____
77	____
78	____
79	____
80	____
81	____
82	____
83	____
84	____
85	____
86	____
87	____
88	____
89	____
90	____
91	____
92	____
93	____
94	____
95	____
96	____
97	____
98	____
99	____
100	____

Preliminary Stream Assessment Prompts and Questions

1. Describe any major human alterations to the stream, stream banks or riparian zone (e.g. culverts, riprap, human waste, animal waste, water withdrawals, litter, smell of gasoline, etc.):

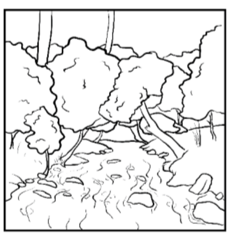
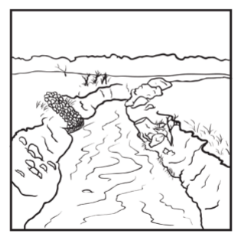
2. List all suspected causes of stream impairment (e.g. dams, upstream garden or trout ponds, condominiums, shopping centers, etc). If you are unfamiliar with the stream site, we reccommend that you use online mapping resources such as google maps ©:

3. List any recommendations for further assessments or actions:

Scoring Elements

Element 1: Channel Condition

The channel of a stream is the path that contains moving water. Channel condition refers to how the channel's shape and bed material change over time. This element visually assesses the stability of the channel by determining if the bed material in the channel is being washed downstream, making the stream deeper (incision); or settling in the channel, making the stream more shallow (aggradation). Human activities such as land development, road construction, and agricultural activities can cause increased erosion of the channel or add fine sediments like sand to the stream. These changes to the channel can have substantial impacts on stream organisms by changing the habitat in which they thrive and reproduce. Human-induced (anthropogenic) changes to channel condition may also affect adjacent streamside areas. For example: a stream that is rapidly incising due to increased runoff from roads can lower the water table and stress bank vegetation and trees alongside the stream (Walsch et al 2005). Conversely, if a channel is aggrading due to sediment input from nearby construction and becoming shallower, water temperature can increase and streamside areas can flood more frequently.

			
No signs of incision (e.g. vertical banks) or aggradation (e.g. shallow, braided channels) Low stream banks/few bank failures present	Some bank erosion evident; stream banks appear to be steepening **or** Sediment deposits form shallow areas in the reach Fewer than 3 point bars	Channel is incising. Stream bank plants are stressed and falling into the stream channel Banks are steep and bank failures are visible Point bars are adjacent to stream banks **or** Stream channel is very shallow in many areas due to deposition of sediment 3-4 point bars in channel	Channel is incising; vegetation is sparse; surface cracks present on banks Stream banks are steep; multiple bank failures present Severe bank erosion **or** Stream channel is very shallow throughout the reach due to deposition of sediment 5 or more point bars present; braided channels present

4 3.5 **3** 2.5 **2** 1.5 **1**

Scoring Tips

- If there are no signs of incision or aggradation in the channel, a score of 4 is appropriate. The channel should have low banks that show little signs of erosion. If a flood plain is present, the active channel is connected to it. These streams will usually have substantial meanders or curves. Riparian vegetation is not stressed. Bank failures are not present.
- If some bank erosion is evident (incision) and/or the stream banks appear to be steepening; a score of 3 is appropriate. If a floodplain is present, look for point bars to be present below the flood plain.
- If sediment deposits are present (aggradation) in shallow areas, a score of 3 is appropriate. Also look for point bars. If there are up to three point bars visible, select a score of 3.
- If vegetation along the stream bank appears stressed or is falling into the stream channel and the channel is incising, a score of 2 is appropriate. Look for steep stream banks and bank failures (collapsed section of bank).
- If the channel is aggrading there will be many shallow areas due to the deposition of sediment. A score of 2 is appropriate in this scenario. Also look for three to four point bars.
- If the channel is severely incised, vegetation along the stream bank is sparse, and/or there are visible surface cracks on stream banks, a score of 1 is appropriate. Look for steep stream banks and multiple bank failures. Look for signs of man-made bank stabilization such as rip-rap.
- If severe bank erosion is evident, and the channel is very shallow due to deposition of sediment, a score of 1 is appropriate. Look for braided channels and/or five or more point bars.

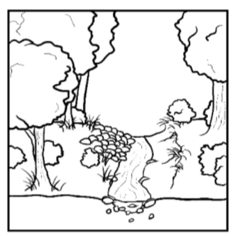
Element 2: Bank Condition

The stream bank is the terrain found along each side of a stream. Unstable banks erode easily and wash excess sediments into the stream channel, which can negatively impact many aquatic species. An excess of fine sediments (sand) in a stream can cause problems for fish by blocking thier gills, and filling in the spaces in between larger stones which some insects use for breeding and feeding. Excessive fine sediments in streams also can interfere with human uses of streams such as fishing, bathing, and drinking.

It is important to note that bank erosion is a naturally occurring process that does not necessarily indicate stream impairment. Excessive erosion, on the other hand, can be due to human land use practices.

Bank failure is when a bank collapses due to the interaction of gravity and/or water. Bank failures can occur on high, steep banks, where the base of the slope is undercut due to erosion. A well-developed, vegetated riparian zone, adds to bank stability. The roots of grasses, sedges, and trees stabilize the soil on stream banks and protect the bank from erosion during high flows.

Element 1 (channel condition) and 2 (bank condition) are related, but should be scored separately. Channel condition refers to the amount of aggradation or incision in the stream channel, which is influenced by sediments. When scoring the bank condition element the user should try to assess the current condition of the bank, and also infer how that bank will erode and affect the channel condition in the future. Observe the banks on each side of the sample reach. Record the score of each bank and the average score for both banks on the scoring sheet.

			
Stable banks protected by roots, wood, and rock No man-made structures on banks Little erosion or bank failures No livestock or recreational access	Moderately stable banks, protected by roots, wood, rock Few man-made structures on banks Erosion and bank failures present with some re-growth of vegetation Recreational and livestock access do not harm bank condition (e.g. low impact grazing)	Moderately unstable banks with little protection by roots, vegetation or rock Man-made structures cover more than half the reach or the entire bank Livestock or recreational access are impacting bank stability	Unstable banks not protected by roots, wood, rocks, or vegetation Man-made structures (e.g. Riprap) dominate banks Multiple bank failures and erosion are evident Livestock or recreational access are severly impacting bank stability

Right Bank	**4**	3.5	**3**	2.5	**2**	1.5	**1**
Left Bank	**4**	3.5	**3**	2.5	**2**	1.5	**1**

Scoring Tips

- Determine right and left bank scores while facing downstream.
- Score each bank separately and record the average score on the summary sheet.
- Along the assessment reach, there may be a range of bank conditions from stable to unstable. If a particular bank condition is predominant, use that bank type to score. Otherwise score the bank according to the worst bank condition present.
- Look for signs of erosion, such as exposed roots, un-vegetated banks, and crumbling banks.
- If there are stable banks with little erosion evident, no bank failures, and no man-made or stabilizing structures present on the banks a score of 4 is appropriate.
- If bank failures are present but not extensive and have some regrowth of vegetation a score of 3 is appropriate.
- Steep banks, which are more prone to collapse and erosion due to the action of gravity, should be scored lower (1 or 2) than less steep banks with gentle slopes.
- Look for tension cracks along the bank (parallel to stream flow), evidence of construction, and adjacent sections of collapsed stream bank lying in the stream as tell-tale signs of an unstable stream bank. Score unstable banks a 1 or 2.
- Look for animal paths, or evidence of livestock access, that can trample and erode banks. Assign a score of 1 or 2 if there is evidence of livestock reducing bank stability, such as trampled banks or grazed vegetation.
- Look for foot trails, tire tracks, and recreational access to the water's edge along the banks. Trails that are close to the bank can also cause banks to become unstable. If there is evidence of recreational access that had reduced bank stability, such as trails or paved surfaces on the bank, score a 1 or 2.

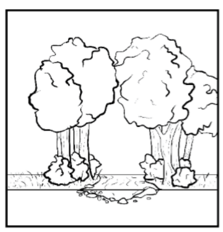
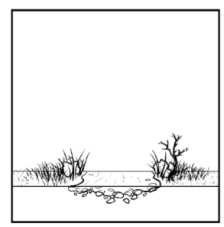
Element 3 & 4: Riparian Area Quantity and Quality

The terms “riparian zone”, “riparian area”, and “riparian buffer”, all refer to the areas of land running along sides of a stream or river. These riparian zones are important regions of ecological function due to their location at the interface between land and water in the stream. Well-vegetated riparian buffers function to trap sediment (Lee et al. 2000), reduce erosion, reduce flooding, filter excess nutrients, provide shade, and provide habitat for birds, mammals, amphibians, insects, and plants. Riparian zones also are sources of leaves, wood, and organic matter that fall into the stream and support many aquatic organisms by providing them shelter and food.

Due to rapid rates of land use change many of the riparian zones of local streams have been altered by construction and associated deforestation. For this reason, it is important that saSVAP be used to track riparian conditions over time, and relate these findings to other changes in local stream ecosystems such as water chemistry and species distributions. For element 3 and element 4, visually assess the entire stream within the property if possible. Score each bank separately and record the average score on the summary sheet.

Element 3: Riparian Area Quantity

Riparian area quantity refers to the area (width and length) of the vegetation in the riparian zone. Use the illustrations and text provided to judge how much vegetation is found from the edge of the channel to the where the vegetation ends and new land use/cover begins. Watch for any gaps in riparian vegetation, especially when those gaps comprise 1/3 (30%) or more of the entire riparian buffer. Visually assess riparian area quantity for the entire stream within the property if possible.

			
Riparian buffer of vegetation extends at least two active channel widths	Riparian buffer of vegetation extends one active channel width	Riparian buffer of vegetation extends half of the active channel width or Gaps in vegetation make up no more than 30% of the riparian buffer along the entire stream in the property	Riparian buffer extends a third or less of the active channel width or Gaps in vegetation exceed 30% of the riparian buffer along the entire stream on the property

Right Bank	**4**	3.5	**3**	2.5	**2**	1.5	**1**
Left Bank	**4**	3.5	**3**	2.5	**2**	1.5	**1**

Scoring Tips

- Determine right and left bank scores while facing downstream.
- Score the right and left bank riparian areas separately and record the average score on the summary sheet.
- Gaps in vegetation are stretches of land the riparian area with little to no vegetation. Estimate the percentage of gaps by dividing the total length of gaps by the total length of the stream on the property and multiplying by 100.

Element 4: Riparian Area Quality

Riparian area quality refers to the species composition, density, and age structure of the riparian vegetation. For this element use the riparian plant key to distinguish between native and non-native species in the riparian zone. Also note the age structure of riparian vegetation. Ideally, streamside vegetation consists of multiple structural layers (grasses, shrubs, and trees). More forested sites tend to contain a mix of shrubs and understory trees (such as Rhododendron). Disturbed sites (from land clearing, fire, grazing, etc.), which have had some time to recover, tend to contain herbaceous and woody vegetation, and tree seedlings. Sites that are continuously disturbed tend to have fewer species, which often include non-native and/or weedy plants. As a disturbed site recovers and vegetation matures, a multi-layered canopy eventually forms, which provides shade, falling wood, leaves, and bank-stabilizing roots, to the stream channel. Visually assess riparian area quality for the entire stream within the property if possible.

Riparian vegetation forms a multi-layered structure (shrubs and trees of different heights) Riparian buffer contains no invasive species (See attached riparian plant guide on common native and invasive plants in the area)	Riparian vegetation forms a multi-layered structure (shrubs and trees of different heights) Invasive species present but in low numbers (<20% of riparian vegeation)	Vegetation is sparse in the riparian area or Invasive species common (>20% of riparian vegetation)	Little to no vegetation present in riparian zone or Invasive species pervasive (>50% of riparian vegetation)

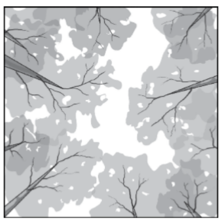
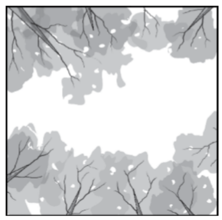
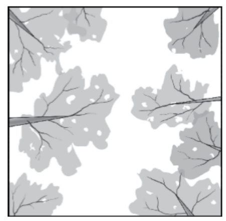
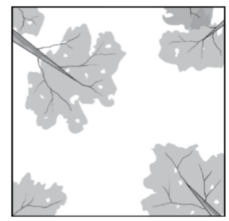
Right Bank	**4**	3.5	**3**	2.5	**2**	1.5	**1**
Left Bank	**4**	3.5	**3**	2.5	**2**	1.5	**1**

Scoring Tips

- Determine right and left bank scores while facing downstream.
- Score the right and left bank riparian areas separately and record the average score on the summary sheet.
- If introduced species have naturalized and form a well-developed multi-layer structure, score with a 3 or 4. Note the introduced species on the riparian buffer survey if possible. Some naturalized species can function similarly to native species if given time to mature.
- Note areas in the riparian zone (50-100 feet inland from banks on either side) with roads, structures, buildings, agricultural activities, excessive animal use, or bare soil on the riparian buffer survey. If there are any structures or land uses present in the riparian zone lower the score by 0.5.

Element 5: Canopy Cover

Canopy cover refers to the vegetation (usually trees) growing alongside and over the stream. The shade provided by canopy cover can keep in stream temperatures stable and limit algal growth in the channel. Without canopy cover, the stream may warm and negatively impact temperature-sensitive organisms. Canopy cover also provides falling leaves, twigs, and branches, to the stream, which are important food and habitat resources for insects and fish. Visually assess the canopy cover for the entire stream within the property if possible.

			
>65% of water surface shaded along the entire stream within the property	65-45% of water surface shaded along the entire stream within the property	45-25% of water surface shaded along the entire stream within the property	<25% of water surface shaded along the entire stream within the property

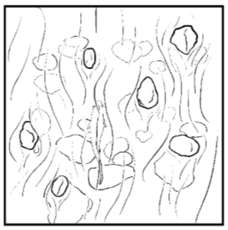
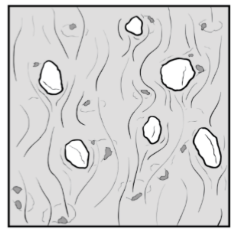
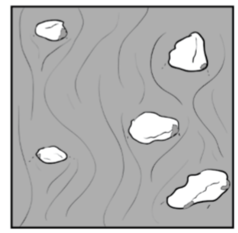
4 3.5 **3** 2.5 **2** 1.5 **1**

Scoring Tips

- For this element, visually assess the canopy cover for the entire stream within the property if possible. This may require estimates of canopy cover at several points along the stream within and outside of the assessment reach.
- When estimating canopy cover look straight up and try to estimate what percentage of the sky is blocked by vegetation.
- To help estimate the percent of the stream area shaded by canopy cover, use the photos from the photo point monitoring taken during the riparian buffer survey.
- This element should only be scored before the leaves have fallen off the trees in autumn and after the leaves have grown fully in the spring.

Element 6: Algal Growth

An excess of sunlight and/or nutrients can lead to excessive algal and aquatic plant growth that can damage stream ecosystems. As plant and algal growth increases, they respire and eventually die. Both the increased respiration from the plants themselves, and the increased activity of oxygen-dependent bacteria (which decompose the dead plant matter), can result in severe decreases in oxygen levels in streams. Algae usually forms a slimy, greenish, film on rocks or wood in the stream, which can make rocks slippery when wading. Visually assess the sample reach, unless there is a noticeable area of greenish water on the property outside the sample reach.

			
Water is clear along entire reach No algal growth on substrates (rocks, wood)	Water is clear along entire reach Little algal growth on substrates	Fairly clear or slightly greenish water Moderate algal growth on substrates	Greenish water in slow sections Abundant algal growth on substrates

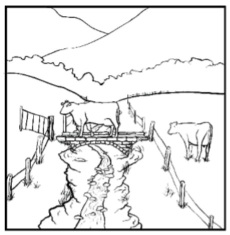
4 3.5 **3** 2.5 **2** 1.5 **1**

Scoring Tips

- Nutrient enrichment in high gradient mountain streams rarely results in algal blooms (thick mats of algae), so look for algal growth on woody debris and rocks.
- Substrates are any surface on which algae or water plants (macrophytes) can grow (e.g. rocks and wood).
- Sometimes it is difficult to distinguish and color in the water from the color of the streambed. Use a clear jar to collect a water sample and hold it against a white background in direct sunlight to determine the actual shade of the water.
- If the water in the stream is clear, and there is little to no algal growth present on substrates, a score of 3 or 4 is appropriate.
- If the water in the stream has a greenish tint, and there is little algal growth on substrates, a score of 2 is appropriate.
- If the water in slow moving sections of the stream (e.g. side-channels or pools) is green, and there is abundant algal growth on substrates, a score of 1 is appropriate.
- This element should be scored during the spring or summer when algal growth is at its peak.
- If the stream is well shaded look for algal growth on rocks that are exposed to light when scoring.

Element 7: Livestock Access

Many streams in the region are located on pastures with livestock. Livestock are attracted to riparian areas due to feeding opportunities, water, and shade (Clary 2004). Livestock can trample on the stream banks and graze riparian vegetation, which can lead to increased erosion of the stream banks. Also, manure and animal waste can contaminate stream waters if livestock have access to the stream. The presence of animal waste in streams can increase the proportion of fecal coliform bacteria in the water, which can have negative consequences for stream organisms and water quality. Visually assess the sample reach, unless there is a noticeable area of livestock access to the stream on the property outside the sample reach.

			
Livestock do not have access to stream	Livestock access to stream is controlled and/or limited to small watering or crossing areas	Livestock have unlimited access to stream during some portion of the year (e.g. closeable fenced in area) or Manure is noticeable in stream	Livestock appear to have unlimited access to stream during entire year (e.g. no fences or gate present or Manure is prevalent in stream

4 3.5 **3** 2.5 **2** 1.5 **1**

Scoring Tips

- Ask the landowner or tenant if there are livestock on the property.
- Look for features that can limit livestock access to the stream such as fences, water gaps, bridges, and hardened crossings. Hardened crossings are designated crossing areas that have hard bottoms (usually gravel or rock) that discourage livestock from congregating in the stream.
- If livestock do not have access to the stream, a score of 4 is appropriate.
- If livestock have access to the stream, but that access is limited to small watering or crossing areas, a score of 3 is appropriate.
- Look for livestock droppings in the channel or adjacent to the stream channel. If present, a score of 1 or 2 is appropriate.
- If livestock have unlimited access to the stream and/or manure is prevalent in the stream, a score of 1 is appropriate.
- Also, look for pipes that may be dumping animal waste into the stream channel. If pipes are present, note this on the summary sheet in the question/comments section. Also make note of the pipe on the riparian buffer survey map in the appropriate location.

Element 8: Pools

Pools are important areas where aquatic organisms can rest, hide from predators, and feed. Fish are especially dependent on pools for feeding and a diversity of pools allows for a variety of species to co-exist.
In this protocol we distinguish between moderate gradient and high gradient streams when assessing pools. Moderate gradient streams have a relatively gentle slope (2-4%) with few large cascades or waterfalls. In contrast, higher gradient streams have a steeper slopes (>4%), numerous cascades and waterfalls, and faster flowing water. Pools in higher gradient streams tend to be deeper (due to scouring by water falls) and more numerous than pools in streams with a more moderate gradient.

We also distinguish deep pools from shallow pools. For saSVAP, deep pools are defined as pools that have a depth of 0.5 meters (approximately 1.5 feet) or greater. Shallow pools are defined as pools that are less than 0.5 meters deep (Barbour et al 1999). Continuous pools, or pools not interrupted by riffles, runs, wood jams, or rock steps, are indicative of poor or possibly altered stream structure, and does not provide the habitat needed for a diverse aquatic community.

Moderate Gradient Streams	Stream reach contains more than two deep pools (depth is greater than or equal to 0.5m) Shallow pools (depth is less than 0.5m) present	One or two deep pools present At least one shallow pool present	Stream reach contains only shallow pools	Pools absent or Slow water habitat is present, but made up of shallow continuous pools
High Gradient Streams	Stream contains more than three deep pools (depth is greater than or equal to 0.5m)	Stream contains two to three deep pools At least one shallow pool present	Stream contains only shallow pools	Pools absent

4 3.5 3 2.5 2 1.5 1

Scoring Tips

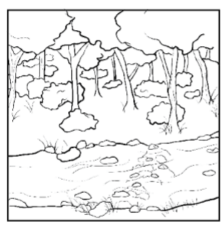
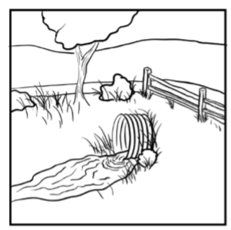
- First select whether the stream reach is of moderate or high gradient.
- If continuous pools dominate the reach, a score of 1 is appropriate.
- In order to assess pools for the stream reach, walk the stream and probe pools with a pole or large stick.
- Deep pools are often found on the outside of stream bends. Pools are also found near obstructions in the stream channel such as wood accumulations, fallen trees, boulders, beaver dams, and rock outcrops.
- Riffles, runs, or shallow water habitat usually separate pools.
- In higher gradient streams scour pools and plunge pools are common. Scour pools are usually formed by swiftly flowing water flowing around an obstruction (e.g. wood, rock). Lateral scour pools are usually formed at the bend in the channel as water is blocked by wood or rock. Plunge pools; commonly found in streams with a gradient of 4% or higher, are formed by water dropping vertically (e.g. cascade, waterfall) over large channel obstructions (e.g. large woody debris, boulders) (Dunster et al 1996).

Element 9: Barriers to Fish Movement

Fish species require movement through the stream channel in order to feed, escape predators, rest, and breed. Often, dams, pollution, or construction can result in barriers that effectively block or limit the passage of fish. These barriers can prevent migration, deny access to important habitats, and isolate populations of fish species; all of which can negatively impact the stream ecosystem.

Barriers can be physical (e.g., dams, culverts), chemical (e.g., poor water quality or point-source pollution), or biological (e.g., competition with non-native species). Physical barriers can be fabricated by humans or can naturally occur (e.g., waterfalls, large rapids, tree falls, land slides). For this element pay particular attention to fabricated physical barriers such as dams, culverts, diversions, weirs, etc. because they are easily detected and can be removed or modified during stream restoration to allow the passage of fish throughout the stream.

Physical barriers can be partial, temporary, or complete. Partial barriers block the movement of some species or certain age classes. Temporary barriers block all or most species and/or age classes sometimes (e.g. low flow conditions). Complete barriers block all fish all the time. Visually assess the entire stream for physical barriers within the property if possible.

			
No artificial barriers that restrict movement of fish	Physical structures and/or water withdrawals minimally restrict movement of fish species	Physical structures and/or water withdrawals restrict movement of fish species	Physical structures and/or water withdrawals severely restrict movement of fish species

4 3.5 3 2.5 2 1.5 1

Scoring Tips

- Ask the landowner or tenant about dams or other barriers within 5 miles of the assessed reach (both upstream and downstream).
- Culverts are common in streams of the S. Appalachians, and can pose a serious problem for fish movement. Some culverts are specifically designed to allow fish passage, but most are partial or complete barriers to fish species. Culverts can also be complete barriers, especially when:
  - >The culvert is not aligned with the stream channel.
  - >The width of the culvert is less than the width of the channel.
  - >The slope of the culvert is steeper than the channel slope.
  - >The culvert is located above an outlet pool.
  - >The culvert inlet or outlet does not lie flush with the streambed (especially in shallow regions of the reach).
  - >The culvert is blocked by debris.
- Inlet or outlet shows signs of erosion and/or instability.
- Low-head dam (dams usually used to back up water in a reservoir) can be temporary or complete barriers to fish. Look for dams with concrete aprons on the downstream side. Often, fish cannot get around these.
- Look for stream crossings for vehicles and livestock. If a stream crossing forms shallow areas that are narrower that the normal stream channel, this can pose a temporary barriers to fish.
- Keep track of the locations and sizes of physical barriers to fish passage in the reach and mark them on the riparian buffer survey map.

Element 10: Available Habitat/Cover (Barbour 1999)

This element assesses the relative quantity and variety of stream habitat features such as fallen trees, logs and branches, undercut banks, large rocks, or cobble riffles that may provide organisms a place to hide from predators, nest, or feed. As the diversity and abundace of these important stream features decrease, habitats becomes more uniform, and fewer species can persist.

Human-induced changes to the landscape have altered the aquatic habitat of many fishes. Cool, fast-flowing, headwater streams, such as those assessed by this protocol, normally support different species of fish than larger streams and rivers. Some fish species cannot tolerate the increases in temperature and sediment input associated with removal of riparian vegetation and road construction.

Aquatic macroinvertebrates (e.g., insects) in streams, many of which are the larval stages of flying insects like dragonflies and mayflies, require a diverse and complex habitat to co-exist and persist. These insects require a complex and diverse stream bottom (substrate) for habitat. In forested regions with intact soils and moderate erosion, streams contain a variety of substrate conditions from cobble to sand, which stay intact long enough for insect colonization. The increased sediment input and high flow events associated with urbanization can alter the diverse habitat features aquatic insects need to feed and reproduce. Insects may not have adequate time to recolonize when disturbances occur frequently.

Visually assess the entire assessment reach for the abundance and variety of habitat features. Use the scoring tips and chart below to identify stable habitat features.

Greater than 70% of stream reach contains stable habitat suitable for insects and fish; mix of logs, uncercut banks, cobble riffles, boulders, or other stable habitat (see scoring tips for other suggestions). Do not count new woody debris or debris that may easily move downstream.	40-70% of stream reach contains stable habitat well-suited for insect and/or fish habitat. There is adequate stable habitat (e.g. large logs, cobble riffle, boulders). There is also newly developed potential habitat for insects or fish (e.g. leaf packs, recently fallen woody debris).	20-40% of stream reach contains stable habitat; habitat availaibility is limited, substrate frequently disturbed or removed; cobble riffle may be covered in fine sediment (embedded). There is a lack of woody debris, stable undercut banks, or cover from riparian vegetation	Less than 20% of stream reach contains stable habitat; lack of habitat is clear, substrate is unstable. There is a clear lack of woody debris or riparian vegetation.
4 3.5	**3** 2.5	**2** 1.5	**1**

Scoring Tips

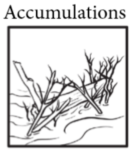
Look for the following habitat features:

- **Large woody debris, logs** – look for fallen trees or large parts of trees that are submerged or partially submerged. The wood should be large enough that it is relatively permanent and cannot be easily moved downstream by normal flows.
- **Small wood accumulations** – look for groups of branches, twigs, leaves, and roots. These small wood accumulations are often temporary, but they still add complexity to the habitat as they group and eventually break apart.
- **Deep pools** – Look for areas of slow moving water that are deep enough to provide cover for local fish species. These pools are usually 1m (approximately 3ft) deep or greater, but include pools that are slightly less deep if local fish can utilize them for cover.
- **Secondary Pools** – (scour pools, plunge pools) – Look for pools formed by wood or boulders that divert water. These are usually found in higher gradient streams.

- **Overhanging vegetation** – Look for branches or herbaceous vegetation growing out over the stream channel. This overhanging vegetation can provide shade and cover for fish species.
- **Large boulders** – look for submerged or partially submerged large rocks (>20 inch diameter). Many times these boulders form small wood accumulations.
- **Small boulder clusters** – Look for groups of 2 or more small rocks (>10 and <20 inch diameter) lying close together in the channel.
- **Cobble riffles** – Look for fast moving, turbulent water that flows over cobble (>2 and <10 inch diameter). This habitat can provide macroinvertebrate prey for many species of predatory fish.
- **Undercut banks** – Look for areas that have been scoured that extend horizontally beneath the surface of the stream bank. These form valuable underwater pockets where fish species can hide, feed, reproduce, and cool off.
- **Macrophyte beds/root mats** – Look for groups of aquatic plants (e.g. floating leaf plants like water lily) and roots from trees or shrubs that are partially submerged and dense enough to provide fish habitat.
- **Off-channel habitats** – Look for side channels, alcoves, and backwaters where fish can find cover.

Large Woody Debris

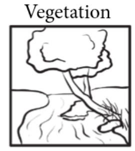
Small Wood Accumulations



Deep Pools

Secondary Pools

Overhanging Vegetation



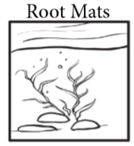
Large Boulders

Small Boulder Clusters

Cobble Riffles

Undercut Banks

Macrophyte beds/ Root Mats



Off-Channel Habitats

Optional Macroinvertebrate Community Survey

A truly thorough investigation of the organisms that comprise a streams aquatic community is a time-consuming endeavor. For this reason, the macroinvertebrate survey is optional and may require a return trip to a site for completion. We have adopted the Virginia Save our Streams protocol for saSVAP due to its history with citizen scientists, repeatability, strong correlation with professional indices, and previous use in the Southern Appalachian region(Engel and Voshell 2002). Equipment needed for this element include a standard SOS kick-net, a white sheet, and the Va. SOS modified method instructions (http://www.vasos.org/data-sheet-downloads.html).

Scoring Sheet

Stream Name: ___________ Date:________ User Name:________________ Email:_____________

Average wetted channel width (average of 3 widths) ________ meters or feet (circle)

Assessment Reach Length (multiply above width by 15) ________

IMPORTANT!!! For elements 2-4, determine left and right bank scores while facing downstream. The average score is the sum of the left and right bank scores divided by two.

ELEMENT	Left Bank	Right Bank	SCORE / Average
Element 1: Channel Condition			________
Element 2: Bank Condition	_________	_________	________
Element 3: Riparian Area Quantity	_________	_________	________
Element 4: Riparian Area Quality	_________	_________	________
Element 5: Canopy Cover			________
Element 6: Algal Growth			________
Element 7: Livestock Access			________
Element 8: Pools			________
Element 9: Barriers to Fish Movement			________
Element 10: Available Habitat/Cover			________
A. Sum of all elements scored (use avg for elements 2-4)			________
B. Number of elements scored			________

Overall score (A/B) _______

Overall Stream Rating __________________

Overall Score-Stream Rating:

Poor - overall score less than 2

Fair - overall score between 2 and 2.5

Good - overall score between 2.6 and 3

Excellent - overall score greater than 3

saSVAP Section 2

includes:

Site mapping instructions:

A. Scale bar instructions
B. Drawing the site map
C. Photo-point monitoring instructions

Site map graph paper
Site map key
Site map data sheet
Streamside plant identification chart

Site Map Instructions:

The site map is an important part of saSVAP that allows users to track changes to the stream and it's surroundings over time. It is therefore important that each survey is conducted in the same way. Please read through these instructions carefully before you begin your site map. These instructions describe how to:

A. Construct a scale bar
B. Draw the site mapl[
C. Conduct photo-point monitoring

A. Scale Bar Instructions:

The scale bar is used during photo-point monitoring to correctly estimate the size of objects in the photographs of the stream site.

Materials: one 20 inch piece of steel rebar (#3 bar size), one hack saw, approximately 10 feet of ½ inch (diameter) PVC piping, one ½ inch PVC slip-tee, black electrical tape, and a metric ruler (meter stick),

Cut three pieces of the PVC piping: one 4 foot (1.2m) piece, and two 2 foot (0.6m) pieces. Next, assemble the three pieces into a T-shape using the PVC slip-tee. The 4 foot piece forms the vertical leg of the scale bar. The two 2 foot pieces form the horizontal arms of the scale bar. Next, size the vertical leg and two horizontal arms using the metric ruler. Trim the vertical leg of the T such that it's total length is 100cm. Likewise, trim each horizontal arm to 50cm. Starting from the midpoint of the slip-tee, mark off five 10cm increments with a pencil on the horzontal arms. Do the same on the vertical leg of the T and remember to include the slip T in the first 10cm increment. Next, tape-off the first 10cm section of the right end of the horizontal arm. Progress down the arm, alternating tape, and then no tape; every 10cm. Repeat this pattern on the vertical leg starting with tape on the first bottom10 cm section (see fig. 1).

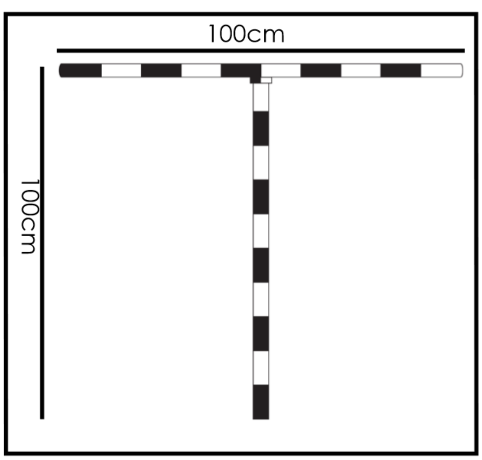


Figure 1. Diagram of scale bar.

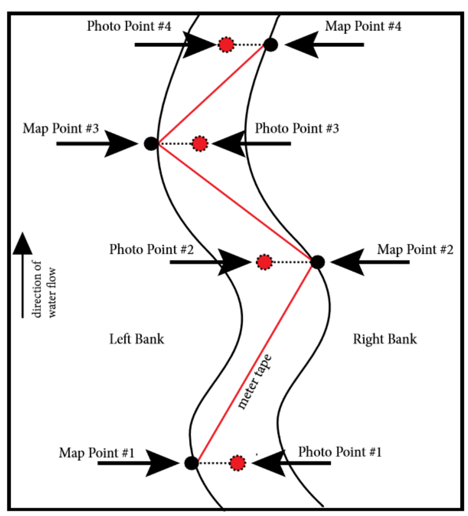


Figure 2. Diagram of site map with map points (black points) and photo points (red points)

B. Drawing the Site Map:

Materials: Pens, pencils, clipboard, riparian buffer survey sheet, 50-100 meter tape, compass (w/ sighting), colored pencils (optional), Smart phone with mapping application or GPS unit, graph paper, and scale bar.

- Hold the clipboard and graph paper directly in front of you (as if reading a letter) while facing in the direction of stream flow (downstream).

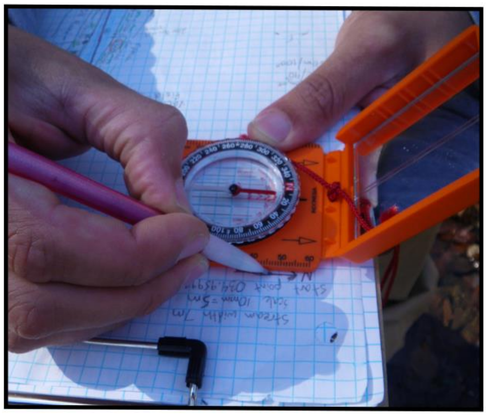


Figure 3a. Determining and noting north on the site map.

Figure 3b. Correct position of compass for marking north.

- Place the compass on the clipboard and align the direction of travel arrow (black arrow on compass baseplate) with the magnetic needle/north (solid red arrow) . Next, rotate the compass housing until the orientation arrow (arrow outlined in red) is also aligned with north. Using the baseplate of the compass as a guide, draw an arrow on your graph paper that indicates north (see fig. 3a and 3b).

Reach Length(meters)	Suggested Scale
150	5 meters/box
100	4 meters/box
50	2 meters/box

Table 1. Suggested scales for reach lengths.

- Determine an appropriate scale for each box on the graph paper (each grid box is approximately 5mm x 5mm on the included site map graph paper, although this grid box size may differ on other graph paper). For scale suggestions based on approximate sample reach lengths see table1. Write the scale you use on the upper right hand corner of your site map.

- Define the start point/map point #1. This point should be on either bank, just outside the wetted width of the stream (see fig. 2). If you cannot stand on the bank of the stream due to vegetation or risk of erosion, stand in the stream as close to the bank as possible. Mark the GPS coordinates of this point on the site map data sheet.

- Measure a straight line from the start point, along the waterway using the meter tape. Cross the stream to the opposite bank (see fig. 2 and fig. 4). Record this distance under "Distance to next map point" on the site map data sheet.

- While keeping the meter tape as straight as possible, allign the direction of travel arrow with the meter tape, make sure the orienting arrow on the compass housing is aligned with north, and note the degrees from north reading on compass housing (see fig. 5). Record this angle under the "angle from north/heading" column of the site map data sheet.

Figure 4. Running meter tape across channel.

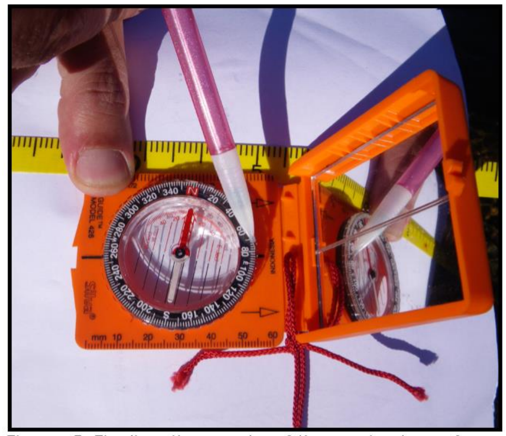


Figure 5. Finding the angle of the meter tape from north (81 degrees in photo).

- Using the north arrow on the site map (see step 4), draw a line on your map that represents the length of meter tape using the appropriate scale and angle from north (see fig. 7).
- Using the meter tape as a reference, estimate the distance to both banks and sketch both banks of the stream on your site map. Observe the land use within 50 meters (164ft) of each bank, perpendicular to the stream. Use the land cover classification number and color codes found on the back of the site map to note the surrounding land cover on the site map.
- As you walk downstream along side the meter tape, record what you see along each bank on the site map. Use the extended meter tape as a guide to determine relative distances between stream features. You may encounter man-made structures or unnatural objects such as houses, buildings, roads, garages, bridges, culverts, drainage pipes, riprap, concrete slabs, etc. Estimate the size of the objects and sketch them on the site map in the appropriate location. Carefully observe the stream side vegetation and draw in any trees or shrubs found in the riparian zone. Also, note the bank height on both sides of the stream and any other significant habitat features like large logs, cobble riffles, and large boulders (see fig. 8).

Figure 7. Drawing the first transect line.

- The point where the straight line measurement of the meter tape ends is map point # 2 and acts as the starting point for the next straight line measurement with the meter tape (see fig. 2). If the stream has curves or meanders, 3-5 map points may be required to capture the entire reach. Each distance measure must be a straight line between 2 points, so more distance measurements are required for more curved streams. The final map point/end point will not have a distance or heading because there is no next point.

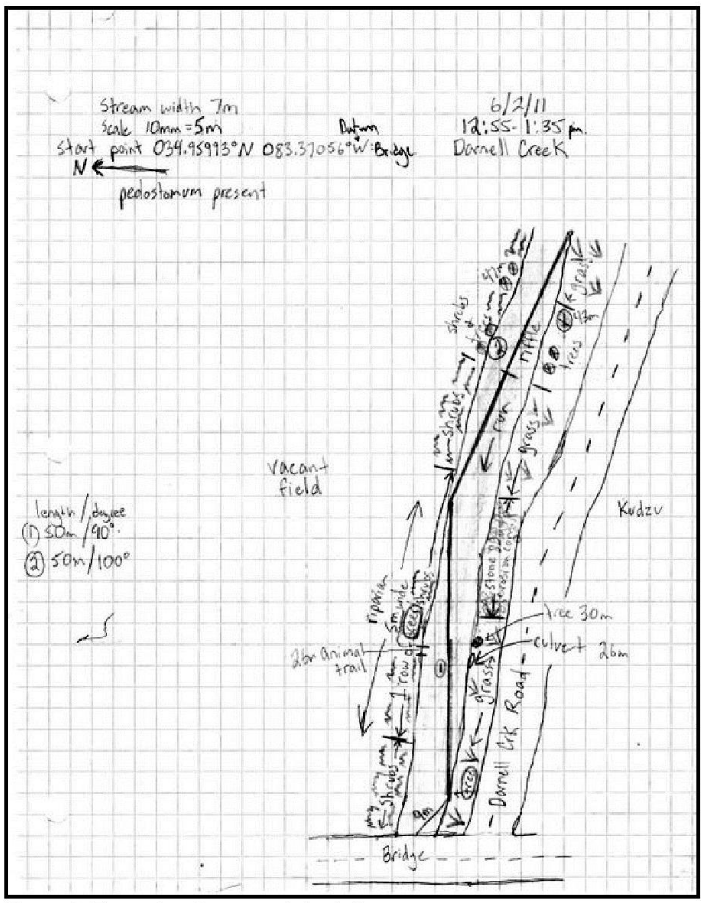


Figure 8. Example of a completed site map.

C. Photo Point Monitoring Instructions:

Photo-point monitoring is included in saS-VAP to record the visual state of the stream at the time of assessment. Each photo-point is associated with a map point on the site map so that users can take photo's from the same vantage points during repeat visits to stream sites.

Materials: Smart phone with camera or digital camera, rebar, and scale bar (see instructions above).

Photo point monitoring should be completed at each map point while drawing the site map. Each photo-point is located in line with the map point, in the stream channel, half way to the opposite bank (see fig. 2).

Firmly secure the piece of rebar in vertical position at the photo-point (if the stream bed is too hard to plant the rebar, use small boulders to secure it). Place the scale bar over the rebar so the scale bar stands in an upright position. Place the scale bar as close to the middle of the waterway as possible while keeping the horizontal bar level. When taking photos, try to keep camera level and the scale bar centered in the photograph.

Take three photos at each point : one upstream photo, one downstream photo, and one vertical photo. For the upstream and downstream photos (see fig. 9-10), stand approximately 3 meters (10 feet) away from the scale bar/photo-point.

Take the vertical photo of tree cover by pointing the camera straight up toward the sky above the scale bar (see fig. 11). Make sure the camera is not zoomed in at all. You want to capture as much of the tree cover as possible in the photo.

Repeat the photo-monitoring procedure at each map point.

Figure 9. Upstream photo.

Figure 10. Downstream photo.

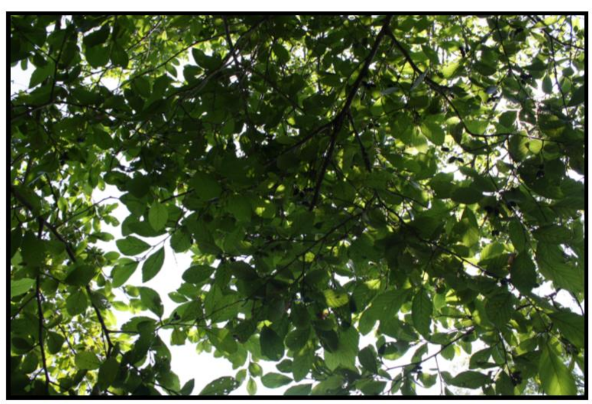


Figure 11. Canopy photo.

Site Map Grid

Date: _________ User's name: ________________

Stream name: ___________________ Tributary to: ___________________

Starting point/map point #1 location: Lat. __________ Long.__________ email:_______________

Notes:

Site Map Key (for more detailed descriptions see glossary)

Land Cover Class	Number Code	Symbol/Color (optional)
Lakes	111	Blue
Ponds/Reservoirs	112	Blue
Rivers	131	Blue
Streams	132	Blue
Single Family Residence	211	Orange
Lawn	213	Green
Golf Course	214	Light Green
Residential Developments	231	Red
Commerical/Industrial areas	230	Purple
Paved Roads	241	Light Grey
Unpaved Roads	242	Tan
Barren Land (rock, sand, or clay)	310	Yellow
Rock Outcrop	311	Grey
Construction Site	312	Pink
Deciduous Forest	410	Dark Green
Evergreen Forest	420	Green
Mixed Forest	430	Green
Shrubland	520	Green
Grassland/Herbaceous Vegetation	710	Green
Pasture/Hay	810	Light Brown
Cultivated Crops	820	Violet
Emergent Herbaceous Wetland	950	Green
Quarries/Strip Mines/ Gravel Pits	320	Dark Grey
Transitional Lands	330	White

KEY:

Site Map Data Sheet

Date: _________ Evaluator's name: ________________

Stream name: ___________________ Tributary to: ___________________

Starting point/map point #1 location: Lat. __________ Long.__________ email:_______________

map point #	Distance to next map point (m)	Angle from North/Heading	Notes
1			
2			
3			
4			
5			

Location of photos/photo data files: ____

Optional Measurements*

If possible, record these measurements from the thalweg at three equidistant points along the sample stream reach.

Parameter	Measurement 1	Measurement 2	Measurement 3	Average of 3 measurements
Canopy Cover (% cover)				
Turbidity (NTU)				
Conductance (μmhos/cm)				
Water Temp. (°C)				

Equipment Checklist for Optional Measurements:
Spherical densitometer, portable turbidity meter, conductivity meter

*These measurements should be taken by users who have some experience in stream ecology or field research; such as field technicians, stream scientists, etc.

Streamside (Riparian) Plant Identification Chart

Use this chart along with the stream-side plant key to identify common native and non-native plants along the stream bank. Also use this chart to assist in scoring element 4: Riparian Area Quality; and to add detailed locations of each identified plant to the site map. If it is difficult to count individual plants, report an abundance estimate as rare, common, or dominant (where rare is when a plant species makes up under app. 20% of the total plant species, common is when a plant species makes up from app. 20-50% of total plant species, and dominant is when a plant species makes up over app. 50% of total plant species, along the sample reach). Use the "map symbol" column find the correct symbol to represent that species on the site map. Use the "notes" column to record any other details you find interesting or important (e.g. disease, leaf damage). If you find a plant species at the stream site that is not on this chart create a symbol (the first letters of the name is reccommended).

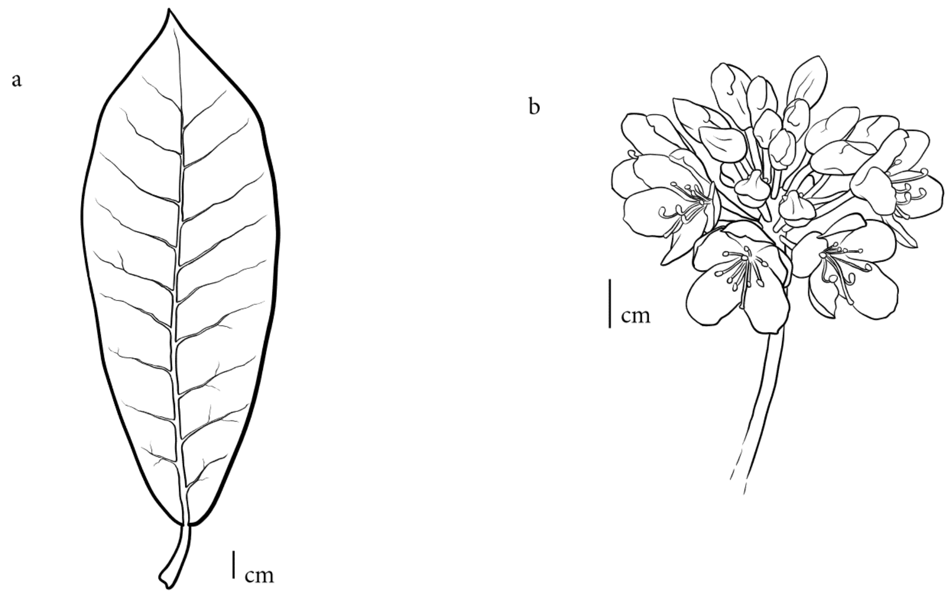
Native Streamside Plants	**Number**	**Abundance Estimate (rare, common, or dominant)**	**Map Symbol**	**Notes**
Rhododendron maximum (Rosebay Rhododendron, Great Laurel)			Rh	
Acer rubrum (Red Maple)			Ar	
Betula lenta (Black Birch)			Bl	
Cormus amomum (Silky Dogwood)			Ca	
Salix sericia (Silky Willow)			Sa	

Non-native Streamside Plants	**Number**	**Abundance Estimate (rare, common, or dominant)**	**Map Symbol**	**Notes**
Pueraria montana (Kudzu)			Pm	
Lonicera japonica (Japanese Honeysuckle)			Lj	
Ligustrum sinense (Chinese Privet)			Ls	
Microstegium vimineum (Japanese Stiltgrass)			Mv	
Celastrus orbiculatus (Oriental Bittersweet)			Co	
Berberis thunbergii (Japanese Barberry)			Bt	

Other Streamside Plants	**Number**	**Abundance Estimate (rare, common, or dominant)**	**Map Symbol**	**Notes**

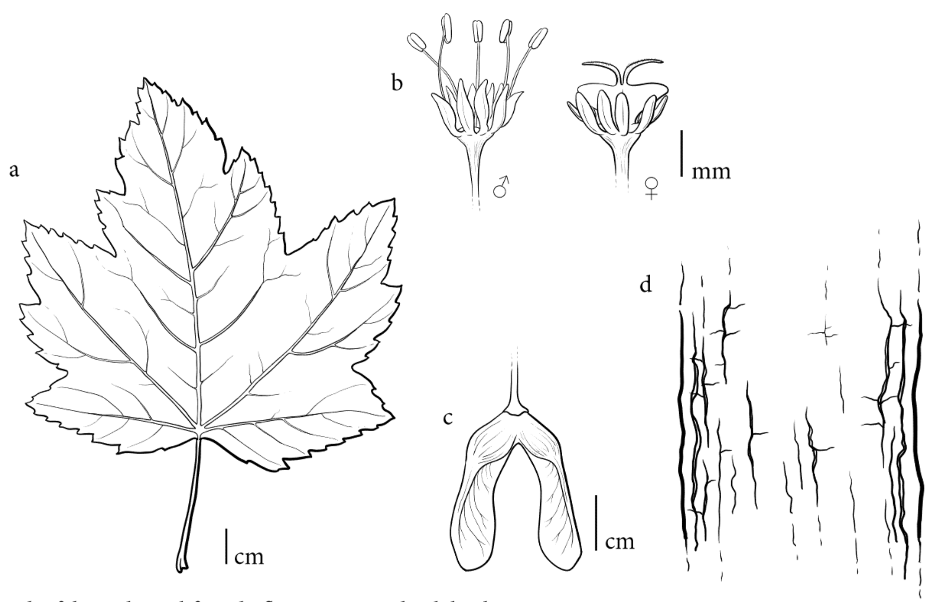
Native Streamside Plants

Rhododendron maximum **Great Laurel**



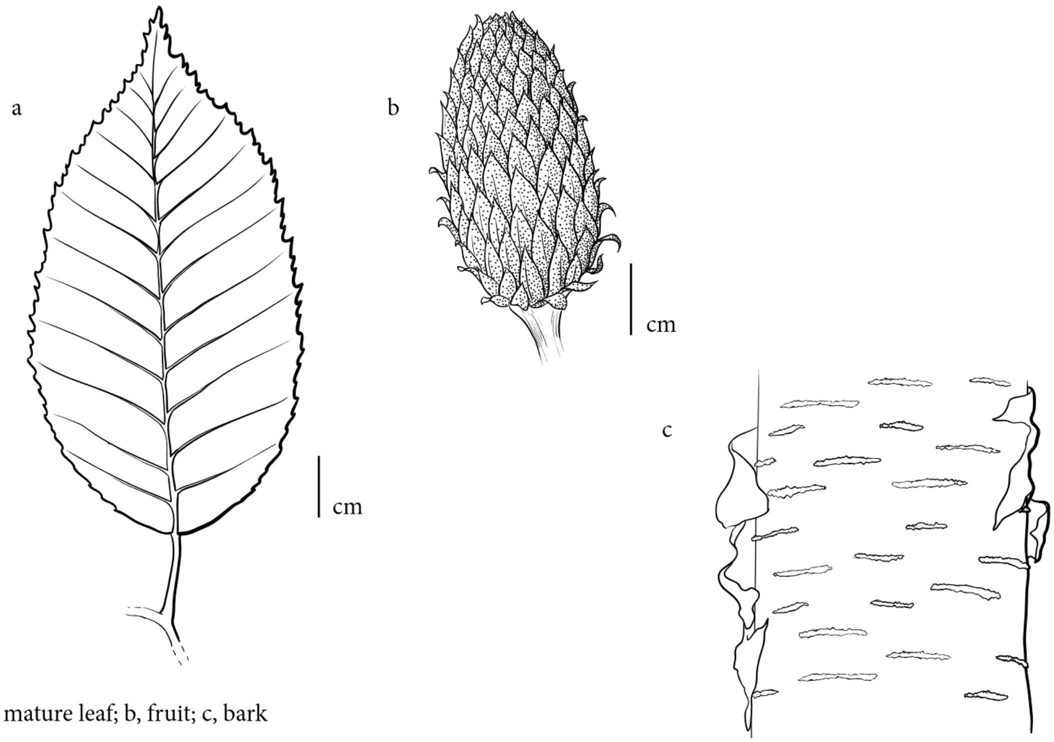
a, mature leaf; b, flower cluster

Acer rubrum **Red Maple**



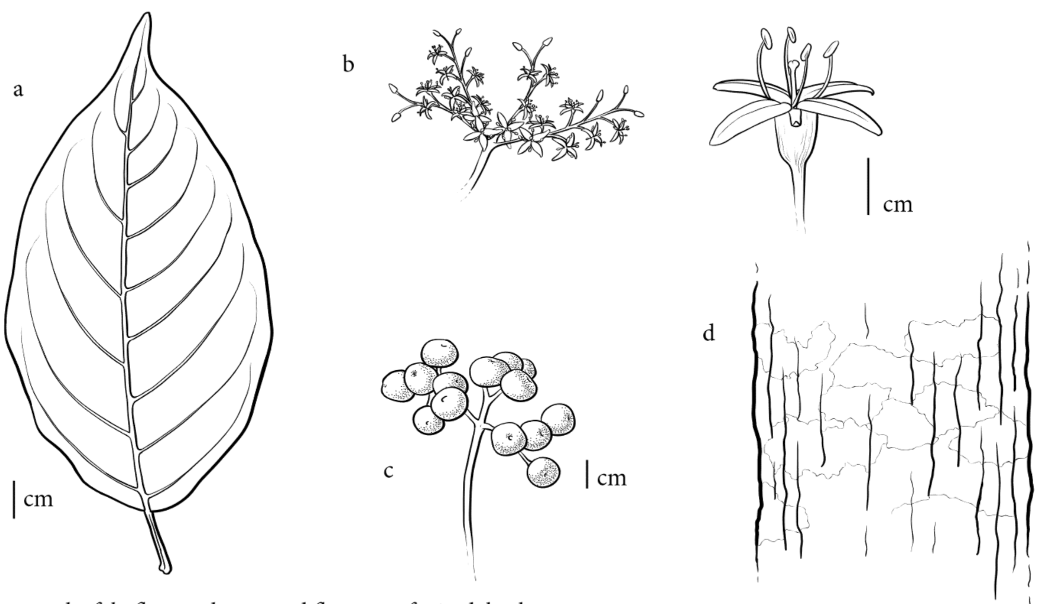
a, mature leaf; b, male and female flowers; c, seeds; d, bark

Betula lenta **Sweet Birch**



a, mature leaf; b, fruit; c, bark

Cornus amomum Silky Dogwood



a, mature leaf; b, flower cluster and flower; c, fruit; d, bark

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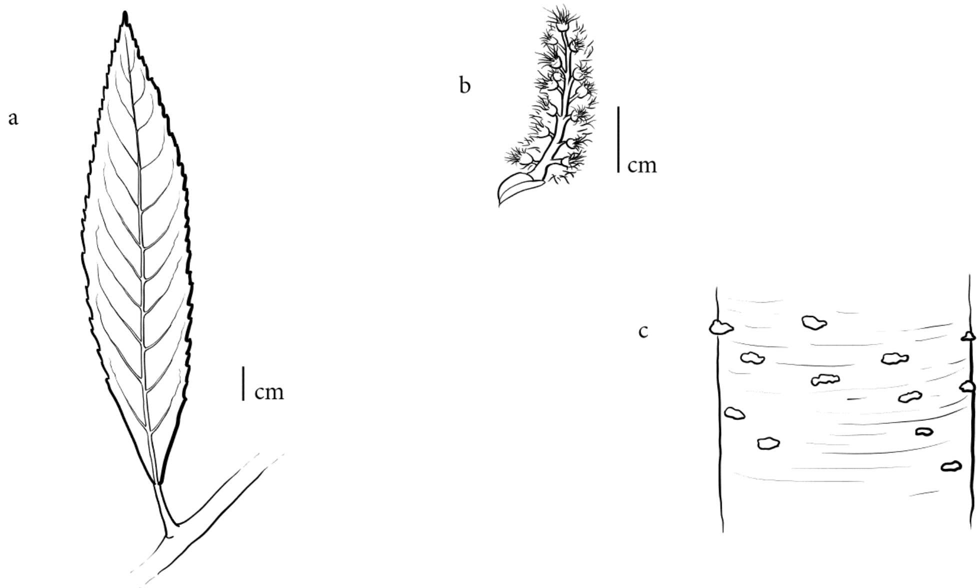
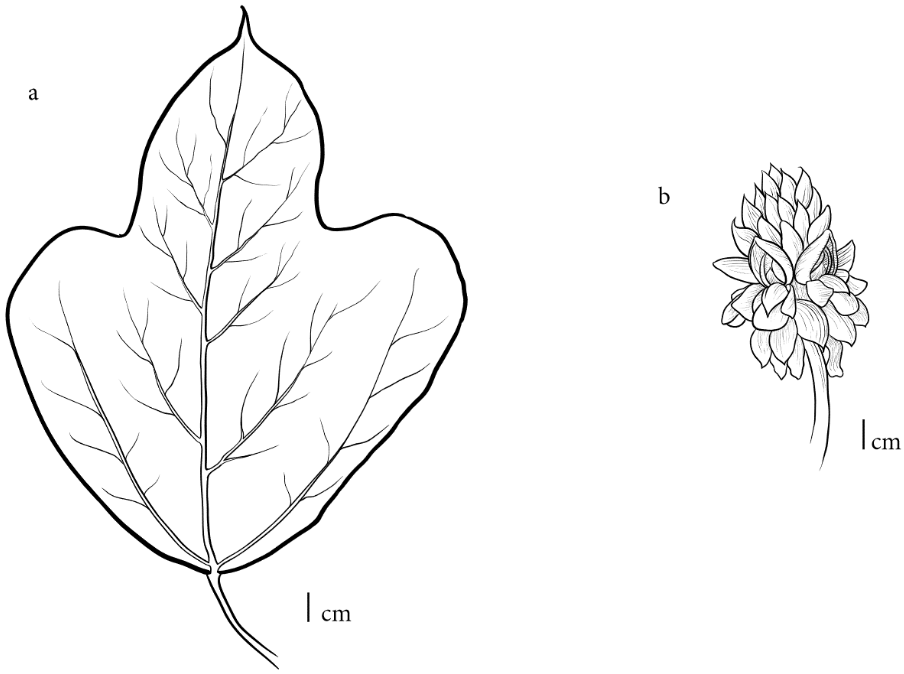
Salix sericea **Silky Willow**



a, mature leaf; b, fruiting body; c, bark

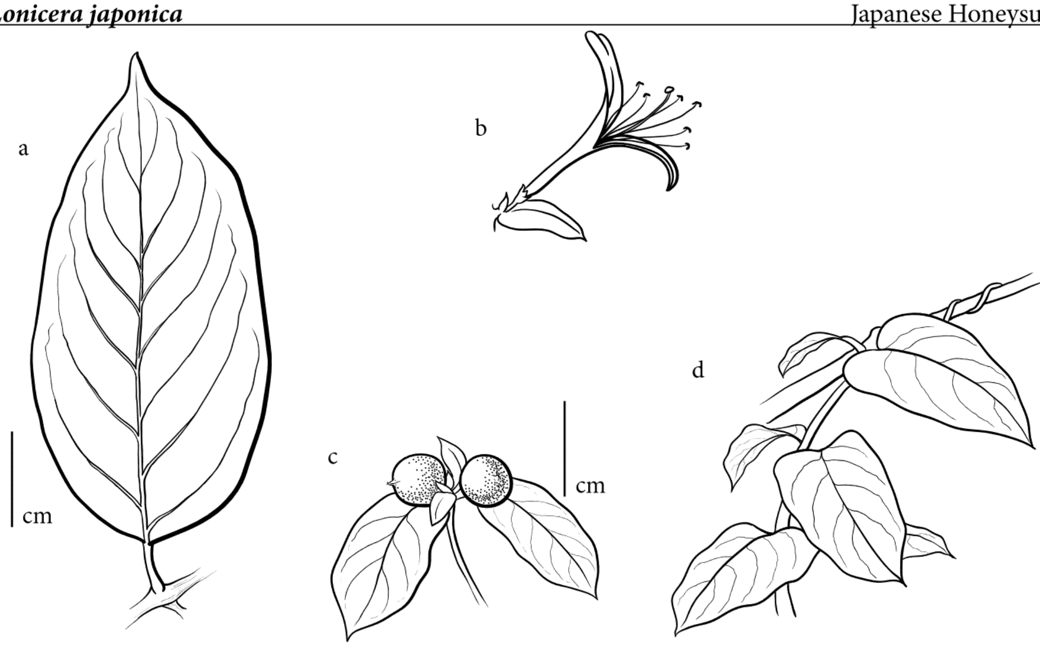
Non-Native Streamside Plants

Pueraria montana **Kudzu**



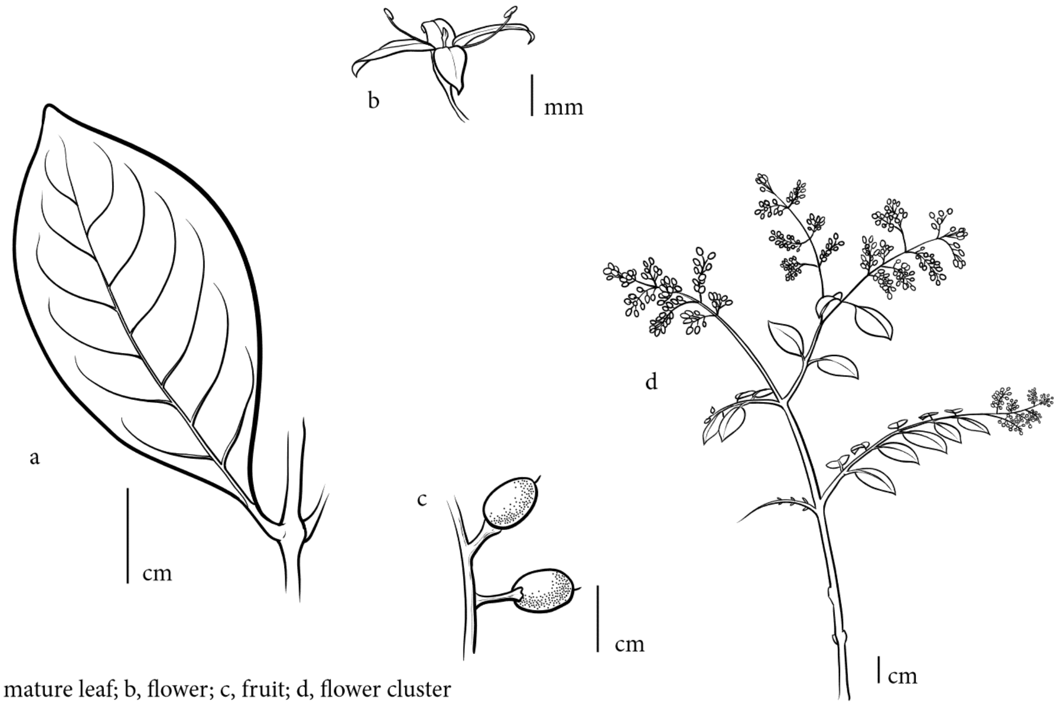
a, mature leaf; b, flower cluster

Lonicera japonica Japanese Honeysuckle



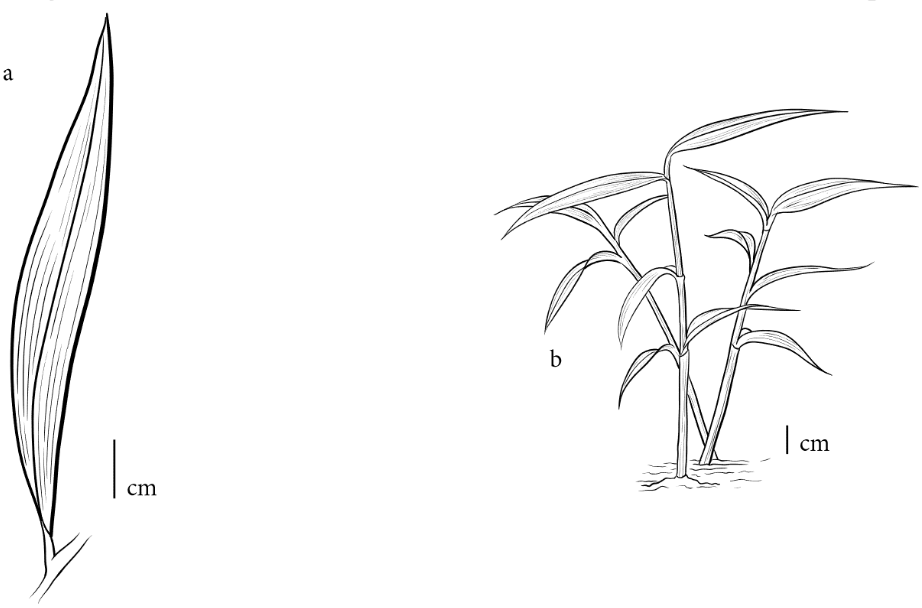
a, mature leaf; b, flower; c, fruit; d, vine

Ligustrum sinense Chinese Privet



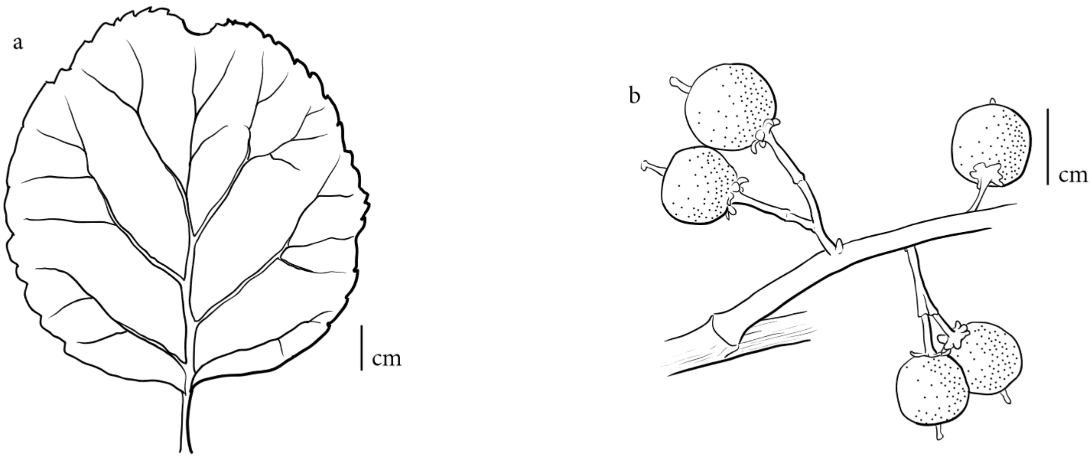
a, mature leaf; b, flower; c, fruit; d, flower cluster

Microstegium vimineum **Japanese Stiltgrass**



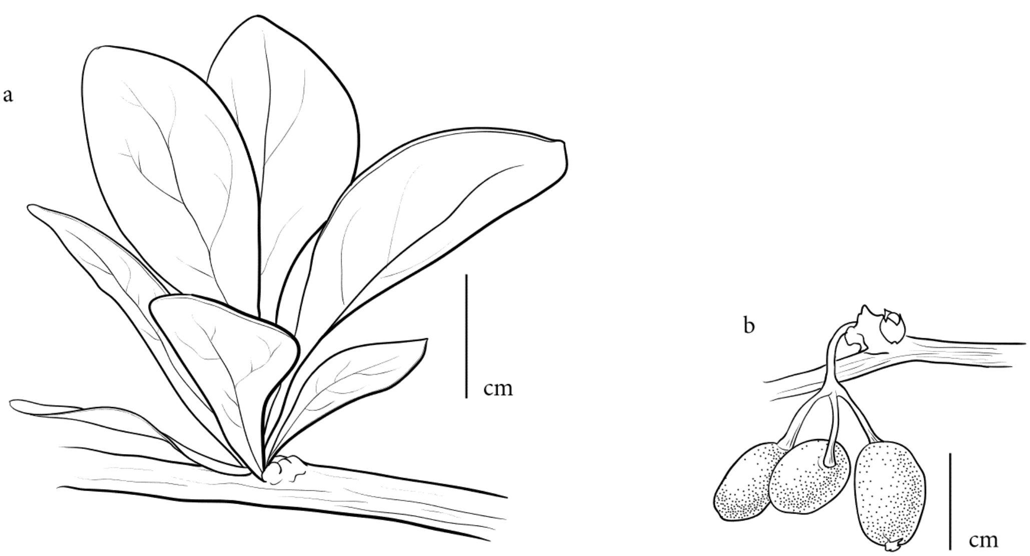
a, mature leaf; b, stand of plants

Celastrus orbiculatus Oriental Bittersweet



a, mature leaf; b, fruit

Berberis thunbergii Japanese Barberry



a, mature leaf; b, fruit

saSVAP glossary

Active channel width – The width from the edge of vegetation on one bank to the edge of vegetation on the opposite bank. Permanent vegetation generally does not become established in the active channel.

Active flood plain – The part of a flood plain that is occasionally inundated with water.

Aggradation – Geomorphic process by which a stream bottom or floodplain is raised in elevation by the deposition of material. Occurs when sediment supply rate exceeds transport rate.

Aquatic vegetation – Plants that have adapted to living on the aquatic environments. These plants, also called macrophytes, have special adaptations to live submerged in water or at the water's surface. These plants provide food and habitat to aquatic animals, and contribute to nutrient cycling and organic matter in streams.

Bank depth- The height of the riverbank from the riverbed.

Bank stabilization – The process of supporting or building stream banks in order to control bank erosion. Includes processes such as placing stones (riprap) and concrete blocks (e.g. ajacks, interlocking pavers, concrete mattresses) along stream banks, soil terracing, and restoration of riparian vegetation.

Bankfull channel width – The width of the stream at bankfull discharge. It is often difficult to determine in mountain streams or disturbed streams. Considered a highly repeatable measure of aquatic habitat area.

Bankfull discharge – The stream discharge (flow rate such as cubic feet per sec) that forms and controls the shape and size of the active channel and creates the floodplain. This discharge generally occurs once every 1.5 years on average.

Bankfull stage – The stage at which the water starts to flow over the floodplain; the elevation of the water surface at bankfull discharge.

Baseflow – The portion of stream flow derived from groundwater. This water discharges into the stream from natural underground storage (aquifers) between storms.

Bedrock step (BRS) – small waterfall over bedrock.

Benthos – The stream bottom.

Benthic organims – Bottom dwelling or substrate-oriented organisms.

Boulder Step (BS) – step is created by a group of boulders.

Boulders – Large rocks which a greater than 256mm across (basketball size and larger)

Cascade - Very high gradient with high velocity flow moving over boulders or bedrock. A hydraulic jump usually occurs at the base of the feature.

Channel (watercourse) - An open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of water.

channel Form- The morphology of the channel is typically described by thread (single or multiple channels in valley floor), sinuosity (the amount of curvature in the channel), variation in water depth and velocity, shape of banks, etc.

Channel roughness – Physical elements of a stream channel upon which flow energy is expended including coarseness and texture of bed material, the curvature of the channel, and variation in the longitudinal profile (e.g. large woody debris).

Channelization- Straightening of a stream channel to make water move faster and to facilitate human uses of adjacent land.

Cobble – Medium-sized rocks which measure 64-258 mm across (larger than a baseball and smaller than a basketball).

Cobble step (CS) – Step flows over and through a cobble jam.

Confined Channel – A channel that has limited access to a floodplain.

Connectivity – The amount of transfer of abiotic and biotic matter and energy between two or more habitat types. For example, streams have connectivity to the surrounding terrestrial habitat and to groundwater sources.

Culvert – A device used to channel water. Culverts are commonly used to allow water to pass underneath a railway, road or embankment. Culverts can be made of many materials with steel, PVC piping, and concrete being he most common. Culverts are also common barriers to fish movement in streams.

Dam – A barrier that impounds surface water or underground streams. Dams generally serve the purpose of retaining water for storage and electricity generation. In streams and rivers dams reduce discharge variability, trap sediments and reduce their transport to downstream reaches, and act as barriers to the movement of aquatic organisms.

Degradation/Downcutting – Geologic process by which a stream bottom is lowered in elevation due to the net loss of substrate material. Degradation occurs when sediment transport exceeds sediment supply.

Detritus – Materials such as leaves, twigs and branches that enter the stream from the upland or riparian area.

Discharge – The volume of water passing through a channel per unit time.

Eco-region – A geographic area defined by similarity of climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables.

Embeddedness – The degree to which an object is buried in stream sediment.

Emergent plants – Aquatic plants with structures that break the waters surface in order to photosynthesize more efficiently (e.g. Phragmites, Typha, Purple Loosestrife).

Ephemeral stream – A stream with a channel that is above the water table at all times and carries water only during and immediately after a rain event.

Falls – When water falls vertically to a lower elevation (i.e. waterfall).
Fine woody debris – Smaller pieces of vegetation (less than 10 cm diameter) such as twigs and leaves that fall into a river or stream. In forested headwater streams woody debris provides the primary source of energy (food) for many aquatic organisms.

Flood plain – The flat area of land adjacent to a stream that is formed by current flood processes. This area plays important roles in ecological functions such as nutrient input and sediment storage. It is also habitat for a diverse range a species including birds and invertebrates.

Flooding – When water overflows from a source, like a river or pipe, and moves to previously dry land. In rivers the flood regime, or regular pattern of flooding, is important for ecosystem functions in streams such as flow regulation, sediment storage, and nutrient mobilization and species that utilize active floodplains.

Flow augmentation – Artificially adding water to a stream channel with timing and magnitude that disrupts the natural flow regime. Examples include irrigation deliveries, trans-basin diversions, or wastewater from irrigated lands, treatment plants, or commercial facilities

Fluvial – A feature of or pertaining to the action of moving water.

Gabions – A wire basket filled with rocks. Used to stabilize streambanks and to control erosion.

Geomorphology – The study of the evolution and configuration of landforms.

Glides - Essentially a long pool with low but observable velocities and little variation in depth, velocity, or flow direction.

Gradient/slope – Slope calculated as the amount of vertical rise over horizontal run expressed as ft/ft or as percent (ft/100ft).

Gravel – Small rocks measuring 0.25 -2.5 inches across (larger than a pencil eraser and smaller than a baseball).

Habitat – The area or environment in which an organism lives.

Herbaceous – Plants with non-woody stems.

Hydrology – The study of the properties, distribution, and effects of water on Earth's surface, soil, and atmosphere.

Impervious surface – Often man-made structures, such roads, sidewalks, driveways, parking lots and rooftops that are covered with materials (pavement, asphalt, concrete, brick, stone, etc) that water cannot penetrate or seep through. Impervious surfaces reduce infiltration and increase runoff which has severe impacts on stream hydrology, geomorphology and ecology.

Intermittent stream – A stream in contact with the ground water table that flows only a certain times of the year, such as when the ground water table is high or when it receives water from surface sources (runoff).

Large woody debris (LWD) – Logs, branches, or other wood that falls into streams and rivers. LWD is typically defined as any piece of wood with a diameter of 4 inches or more and a length of at least 6 feet, which protrude or lay within the stream channel.

Lateral erosion – Erosion along the stream banks.

Leaf pack – A group of many leaves that collect around structures and objects in the stream or along the stream bed. These leaves are gradually processed or decomposed by bacteria, fungi, and insects in the stream.

Log jam (LJ) – The step is created by large woody debris.

Macroinvertebrates - A spineless animal visible to the naked eye or no larger than 0.5 mm.

Macrophyte bed – A section of stream covered by a dense mat of aquatic plants.

Meander – A winding section of stream with many bends that is at least 1.2 times longer, following the channel, than its straight-line distance. A single meander generally comprises two complete opposing bends, starting from the relatively straight section of the channel just before the first bend to the relatively straight section just after the second bend.

Mixed jam (MJ) – The step is a mix of organic and inorganic materials).

Natural flow regime – The full range of daily, monthly, or annual streamflows critical to sustaining native biodiversity and integrity in a freshwater ecosystem (see Poff et al. 1997 for detailed description).

Nickpoint – The point where a stream is actively eroding (downcutting) to a new base elevation. Nickpoints migrate upstream (through a process called headcutting).

Nutrient loading/enrichment – Anthropogenic input of nutrients (e.g.Nitrogen and Phosphorus) into streams via runoff from agricultural (e.g. fertilizer) and urban land (e.g. lawn fertilizer and sewage input) uses. Nutrient loading can lead to harmful algal blooms and oxygen depleted dead zones in rivers and lakes.

Oligotrophic – Having little or no nutrients and, thus, low primary production (vegetation).

Off-Channel habitat – Suitable habitat that is found outside the main channel of a stream.

Organic jam (OJ) – The step is created by a matrix of small organic material.

Overhanging vegetation – Trees, shrubs, vines, or other perennial herbaceous vegetation that hangs immediately over the stream surface, providing shade and cover.

Particle size distribution – A measurement of the size (diameter) and abundance of sediment particles on the streambed. This is normally measured with a pebble count.

Perennial stream – A stream that flows continuously through the year.

Pocket water - Areas with complex hydraulics created by large substrate (boulders or cobble aggregations) such that eddies are formed with small pool-like features created behind obstructions.

Point bar – A gravel or sand deposit on the inside of a meander; an actively mobile river feature.

Pool – Deeper area of a stream with slow-moving water.

Rapid - Fast flow with standing waves moving over and through cobbles and boulders with gravel and sand in the slower patches.

Reach – A section of stream (defined in a variety of ways, such as the section between tributaries or a section with consistent characteristics).

Riffle – A shallow section in a stream where water is breaking over rocks, wood, or other partly submerged debris and producing surface agitation.

Riparian buffer – The plant species composition of the riparian zone. These species differentially contribute to flood regulation and nutrient uptake, two important ecosystem functions.

Riparian zone – The zone adjacent to a stream or any other waterbody (from the latin word ripa, pertaining to the bank of a river, pond, or lake.

Riprap – Rock material of varying size used to stabilize streambanks and other slopes.

Root Mat - A complex tangle of roots that can provide habitat for insects and/or cover for fish.

Runs - Runs are not as fast or as steep as a riffle and have relatively uniformly flowing (moving in the same direction without acceleration or deceleration) with intermediate depths and velocities.

Sand- granular material ranging from 0.2 mm to 2.0 mm inches in diameter.

Scouring – The erosive removal of material from the stream bottom and banks.

Sedge - A grasslike, fibrous-rooted herb with a triangular to round stem, and leaves that are mostly three-ranked and with close sheaths; flowers are in spikes or spikelets, axillary to single bracts.

Silt – very fine granular material ranging from 0.002 mm and 0.063 mm in diameter. Silt particles are larger than clay particles and smaller than sand grains.

Soil Erosion – When soil is removed by the action of wind, water, or gravity. Agricultural practices such as tilling and overgrazing by cattle has drastically increased the rates of soil erosion and is a leading cause of soil degrada tion.

Step - Any location with a sudden drop in water surface elevation caused by either boulders, cobble jams, LWD, mixed jams, organic debris jams, etc. Will feature sediment accumulation above the step and a plunge feature below.

Stormwater runoff – Overland runoff from a precipitation event not absorbed by soil, vegetation, or other natural means.

Stream incision – Down cutting, or downward erosion in a stream. Incision often deepens and steepens the stream channel, which often prevents a stream from reaching the floodplain during flooding. Building roads and other impervious surfaces, such a parking lots can increase runoff and lead to more stream incision.

Stream order/ size - a stream characterization method, most commonly refers to the Strahler classification system, where smallest (i.e. headwater streams) streams are assigned first order. Stream order only increases when two streams of the same order join. Some difficulties with this method include determination of the smallest permanent streams and that stream order does not always correlate closely with important abiotic factors such as discharge and water chemistry.

Substrate – The mineral or organic material that forms the bed of the stream; the surface on which aquatic organisms live.

Surface fines – That portion of the streambed surface consisting of sand/silt (less than 2mm).

Thalweg – The line followed by the majority of the streamflow. The line connecting the lowest or deepest points along the streambed.

Turbidity – Murkiness or cloudiness of water caused by particles, such as fine sediments (silts, clays) and algae.

Undercut banks – Eroded areas extending horizontally beneath the surface of the bank forming underwater pockets used by fish for hiding and protection.

Water control structures – Any physical feature located in or adjacent to a stream used to control the direction, magnitude, timing, and frequency of water for instream or out-of-stream uses. Examples include dams, pumps, water treatment or power plant outfalls, gated culverts, standpipes, subsurface drains and ring wells.

Water depth – Measurement of depth of a water body from water's surface to the top of the bottom sediments.

Water flow- A general term for movement that can mean discharge, water velocity or both.

Water velocity/current – the speed of water in any small region of the channel.

Watershed/catchment – A ridge of high land dividing two areas that are drained by different river systems. The land area draining a waterbody or point in a river system; catchment area, drainage basin, drainage area.

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www.epa.gov/surf

www.ncwildlife.org

www.vasos.org/data-sheet-downloads.html

www.worldwildlife.org

APPENDIX 3.2. Landowner permission letter to access stream sites on privately-owned lands

The Coweeta Hydrolgic Lab

5/1/2013

Dear Macon County Resident,

I am writing to ask your permission to conduct research at the stream on your property. My name is Jeremy Sullivan. I am a PhD student working with the Coweeta Hydrologic lab and the Land Trust of the Little Tennessee (LTLT), and I would like to test a Stream Visual Assessment Protocol I have developed for citizen scientists, land owners, and outdoor enthusiasts on a stream located on your property. The stream work would consist of no more than 2, 2-hour visits to your stream, and would involve measuring the physical characteristics of the stream, and conducting a stream visual survey.

Thank you for taking the time to read this. Please initial below if you agree to give permission for us to work in the stream on your property. Please contact me at 914-621-xxxx or sullyjc@uga.edu if you have any concerns or questions.

Sincerely,

Jeremy C. Sullivan
Graduate Research Assistant
Odum School of Ecology
University of Georgia
Athens, GA 30602-2202

I hereby grant permission for graduate student researchers to sample the stream located on my property.

Sign here: x______________________________ Date: __________

Name: __________________________________

APPENDIX 3.3. Validity testing field data sheet and instructions**.**

1a. Substrate and Cross Section

Appendix 3. Validity testing field data sheet and instructions

Reach #	Loc.	DistLB (m)	Depth (cm)	Size class code (see key)	Embed. 0-100%
1	Lft	0.00			
	LCtr				
	Ctr				
	RCtr				
	Rgt				
2	Lft				
	LCtr				
	Ctr				
	RCtr				
	Rgt				
3	Lft	0.00			
	LCtr				
	Ctr				
	RCtr				
	Rgt				
4	Lft				
	LCtr				
	Ctr				
	RCtr				
	Rgt				
5	Lft	0.00			
	LCtr				
	Ctr				
	RCtr				
	Rgt				
6	Lft	0.00			
	LCtr				
	Ctr				
	RCtr				
	Rgt				
7	Lft	0.00			
	LCtr				
	Ctr				
	RCtr				
	Rgt				
8	Lft	0.00			
	LCtr				
	Ctr				
	RCtr				
	Rgt				
9	Lft	0.00			
	LCtr				
	Ctr				
	RCtr				
	Rgt				
10	Lft	0.00			
	LCtr				
	Ctr				
	RCtr				
	Rgt				
11	Lft	0.00			
	LCtr				
	Ctr				
	RCtr				
	Rgt				
12	Lft	0.00			
	LCtr				
	Ctr				
	RCtr				
	Rgt				
13	Lft	0.00			
	LCtr				
	Ctr				
	RCtr				
	Rgt				
14	Lft	0.00			
	LCtr				
	Ctr				
	RCtr				
	Rgt				
15	Lft	0.00			
	LCtr				
	Ctr				
	RCtr				
	Rgt				

saSVAP Validation Field Procedure (Overview)

Site:____________ Date:_____ User:______

SUBSTRATE SIZE CLASS CODES

RS = BEDROCK (SMOOTH) ● (LARGER THAN A CAR)
RR = BEDROCK (ROUGH) ● (LARGER THAN A CAR)
BL = BOULDER (250 TO 4000 MM) ● (BASKETBALL TO CAR)
CB = COBBLE (64 TO 250 MM) ● (TENNIS BALL TO BASKETBALL)
GC = COARSE GRAVEL (16 TO 64 MM) ● (MARBLE TO TENNIS BALL)
GF = FINE GRAVEL (2 TO 16 MM) ● (LADYBUG TO MARBLE)
SA = SAND (0.06 TO 2 MM) ● (GRITTY - UP TO LADYBUG SIZE)
FN = SILT/CLAY/MUCK ● (NOT GRITTY)
HP = HARDPAN ● (FIRM, CONSOLIDATED FINE SUBSTRATE)
WD = WOOD ● (ANY SIZE)
OT = OTHER ◎ (COMMENT)

1b. Bank Measurements

Reach #	Location	Bank Angle 0-360°	Undercut dist. (m)
1	Left		
	Right		
2	Left		
	Right		
3	Left		
	Right		
4	Left		
	Right		
5	Left		
	Right		
6	Left		
	Right		
7	Left		
	Right		
8	Left		
	Right		
9	Left		
	Right		
10	Left		
	Right		
11	Left		
	Right		
12	Left		
	Right		
13	Left		
	Right		
14	Left		
	Right		
15	Left		
	Right		

2a. Canopy Cover

Reach #	Location	Denisometer (0-96)
1	CenUp	
	CenL	
	CenR	
4	CenUp	
	CenL	
	CenR	
7	CenUp	
	CenL	
	CenR	
10	CenUp	
	CenL	
	CenR	
13	CenUp	
	CenL	
	CenR	

3. Pool Count

Pool Depth	Pool Count	notes
> 0.5m		
0.2- 0.5m		

4. Fish Barrier Count

Fish Barrier	Count	Notes/location

6. Large Woody Debris

Diameter of large end	Length 1.5-5m	5-15m	>15m
0.1 – 0.3m			
0.3 -0.6m			
0.6-0.8m			
>0.8m			

5. Built Structure Count

Man-made structure	Reach #'s	R/L bank

2b. Riparian Measurements

Reach #	Location	Riparian height (m)	Riparian width (m)	exotics	Veg Type (see key)
1	L				
	R				
4	L				
	R				
7	L				
	R				
10	L				
	R				
13	L				
	R				

Veg Type Key
Bg = bare ground
Gr = grass
Sh = shrub (1-4m)
MCV=mid canopy veg (4-10m)
UC = upper canopy veg (>10m)

1. Upon reaching the site, measure three representative wetted stream widths. Multiply this by 15 to calculate total reach length, and record on saSVAP.

2. Using meter tape and tacks/flagging to mark start and end points. Mark 15 equidistant reaches with tacks/flagging (whose lengths will be equal to the wetted width).

3a. One team member scores saSVAP elements for the reach and records scores.

3b. One team member conducts "pool count" (3), "fish barrier count" (4), "built structure count" (5), and "LWD count" (6).

4. Two team members conduct "substrate and cross section" (1a), "bank measurements" (1b), and "riparian measurements" (2b).

5. Two team members conduct "canopy cover" (2a) estimates. One person measures while the other records.

5b. Two team members conduct a pebble count of the "best" (least embedded) cobble riffle found in the reach. One team member measures while the other records.

6. Two team members conduct "habitat count" (6) while taking photos of stream banks, riparian zones, man-made structures, barriers to fish movement, LWD, and the canopy.

1a. Substrate/cross section

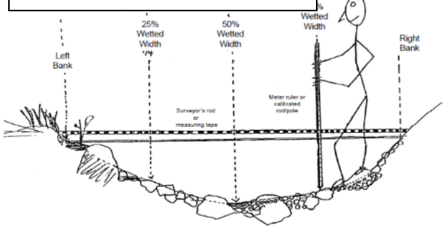


Figure 7-6. Substrate sampling cross-section.

Summary of Procedure 2a. Canopy Cover

Determine and record canopy closure for each of the six transects.

Transect 1, Upstream

Stand mid-channel at the transect and face upstream. Hold the densiometer at elbow height above the water level. (Recognize that use of this procedure may result in different readings due to different heights of operators.)

Hold the densiometer at a distance away from your body so that your forehead is visible in the mirror, but not within the grid area (see Figure 2).

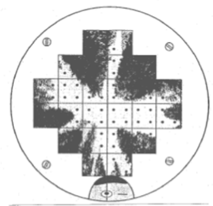


Figure 2. View of densiometer mirror showing placement of operator's head and with the 96 imaginary dots represented. (Pleus & Shuett-Hames, 1998)

Using the bubble in the lower right corner of the instrument as a guide, hold the densiometer level.

The spherical densiometer consists of 24 ¼" squares engraved onto a concave mirror. Each square of the grid must be subdivided mentally into 4 smaller squares and represented by an imaginary dot in the center of each of the smaller squares (See Figure 2). A total of 96 dots can be counted within the grid. Densiometer readings can range from 0 (no canopy cover) to 96 (maximum canopy cover).

Using only the dominant eye (keeping the other eye closed), count the number of dots in each engraved square that is blocked by canopy cover. Enter the total number of dots blocked into the appropriate cell on the datasheet (see Appendix A). Conversely, count the number of dots that are not occupied by canopy and subtract this total from 96.

Pebble Count Procedure:

F. Pebble Count (optional):

1. Choose a representative riffle within the sample reach. If a riffle is not present in sample reach, choose a representative run to conduct the pebble count.
2. Take one step into the water, perpendicular to flow, and while looking away, pick up the first pebble touching your index finger next to your big toe.
3. Take another step and repeat step 2 until you reach the other side or measure 100 pebbles. If you do not reach 100 pebbles, walk back across the channel and repeat the previous steps until you do. Remember not to look at the particle until after you have selected it.
4. Measure the width (intermediate axis, see figure 11) of the particle to the nearest millimeter (mm) using a metric ruler. Record these data on the sheet provided. For any particles that are less than 2mm, enter a "<2mm" entry on the data sheet provided

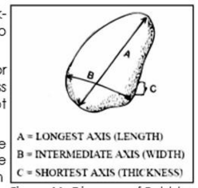
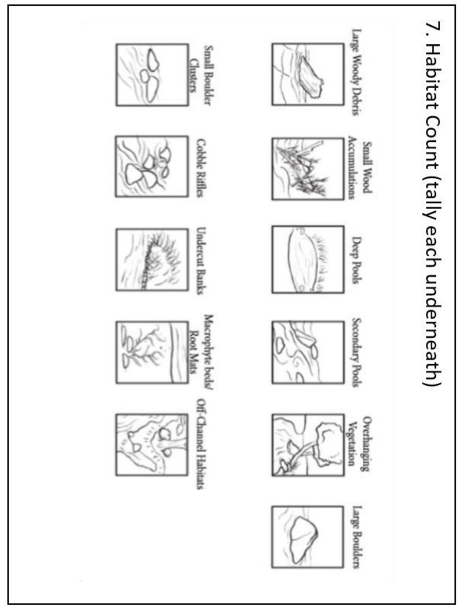


Figure 11. Diagram of Pebble.



Pebble #	Width (mm)
1	___
2	___
3	___
4	___
5	___
6	___
7	___
8	___
9	___
10	___
11	___
12	___
13	___
14	___
15	___
16	___
17	___
18	___
19	___
20	___
21	___
22	___
23	___
24	___
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27	___
28	___
29	___
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38	___
39	___
40	___
41	___
42	___
43	___
44	___
45	___
46	___
47	___
48	___
49	___
50	___

Pebble #	Width (mm)
51	___
52	___
53	___
54	___
55	___
56	___
57	___
58	___
59	___
60	___
61	___
62	___
63	___
64	___
65	___
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81	___
82	___
83	___
84	___
85	___
86	___
87	___
88	___
89	___
90	___
91	___
92	___
93	___
94	___
95	___
96	___
97	___
98	___
99	___
100	___

Habitat Type	**Count**
Small Wood Acc.	
Overhanging Veg.	
Large Boulders	
Small Boulder Clusters	
Cobble Riffles	
Undercut Banks	
Root Mats	
Off-Channel Habitat	
Other ( )	