National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Vital Signs Monitoring in Great Smoky Mountains National Park—Freshwater Communities

2014 Annual Report

Natural Resource Report NPS/GRSM/NRR—2015/1024

ON THE COVER
Porters Creek at Greenbrier, Great Smoky Mountains National Park
Photograph courtesy of the National Park Service

Vital Signs Monitoring in Great Smoky Mountains National Park—Freshwater Communities

2014 Annual Report

Natural Resource Report NPS/GRSM/NRR—2015/1024

Becky Nichols
Matt Kulp

National Park Service
Great Smoky Mountains National Park
1316 Cherokee Orchard Road
Gatlinburg, TN 37738

September 2015

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

This report is available in digital format from the Appalachian Highlands Network website http://science.nature.nps.gov/im/units/aphn/publications.cfm, and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

Nichols, B. and M. Kulp. 2015. Vital Signs monitoring in Great Smoky Mountains National Park—freshwater communities: 2014 annual report. Natural Resource Report NPS/GRSM/NRR—2015/1024. National Park Service, Fort Collins, Colorado.

NPS 133/129677, September 2015

Contents

Figures

Tables

Appendices

Abstract

Great Smoky Mountains National Park (GRSM) has had a long-term ecological monitoring program since the early 1990's, and it has recently been re-focused into the new NPS Vital Signs monitoring program. This service-wide program is designed to provide site-specific information so that ecosystem changes can be detected, to determine whether observed variability is within natural levels, and to guide management decisions. In GRSM, six primary Vital Signs, or indicators, were selected: acid deposition, climate changes, freshwater communities, soil quality, vegetation communities, and water chemistry. The goal of freshwater community monitoring is to determine the status and trends of aquatic macroinvertebrates and fish, and to provide an early warning of abnormal conditions.

The overall sampling design utilized for Vital Signs monitoring in GRSM included the selection of primary and secondary watersheds. Sampling for all components will be conducted, at least in part, within these watersheds. For freshwater communities, sampling sites for aquatic macroinvertebrates and fish were selected within 305 m (1,000 ft) elevation bands within each watershed, and co-located whenever possible.

In 2014, aquatic macroinvertebrates were sampled from 10 sites in 3 of the primary watersheds. Samples were collected following a rapid bioassessment protocol, which includes the use of kick nets, sieve buckets, d-nets, rock washing, and visual searching. Each site is sampled once per season, extending from June through September. Specimen identifications were conducted in-house to calculate the EPT index for each site.

Aquatic macroinvertebrate diversity levels in the streams sampled in 2014 generally were high, with values ranging from a low of 20 to a high of 36 EPT taxa. The stream condition rating was in the "good" category for all streams, with the exception of one stream (Abrams Creek) which rated in the "excellent" category, and another stream (Anthony Creek), which rated in the "good-fair" category. Further sampling will be conducted in Anthony Creek to determine whether the relatively low rating was an anomaly or reflects the general condition of the site.

Seven large-stream fish sites were sampled from within the six Vital Signs primary watersheds in 2014. In general, fish communities were found to be healthy, and representative of typical low- to mid-elevation stream communities in the Blue Ridge ecoregion. IBI scores ranged from "poor" to "good." The lower ratings can be attributed to the fact that these sites are at the uppermost applicable elevation range for IBI metrics; species diversity declines sharply above 700 m (2,300 ft).

In addition to the IBI sampling for fish, the 3-pass depletion method was also used at 11 sites on 8 Vital Signs streams. The total carrying capacity for salmonids in most GRSM streams was found to range from 10 – 44 kg/ha, with a higher carrying capacity occurring in streams with a relatively higher pH.

Introduction

At least 4301 km (2672 mi) of permanent streams, including the headwaters for local rivers, run through Great Smoky Mountains National Park (GRSM); the majority of these are small, first-order streams (Table 1). Five streams in the park have been designated as Outstanding Natural Resource Waters by the states of Tennessee and North Carolina: Abrams Creek (TN), Little River (TN), West Prong Little Pigeon River (TN), Middle Prong Little Pigeon River (TN), and Cataloochee Creek (NC).

Table 1. Stream lengths per stream order in GRSM.

Stream Order	Total stream lengths (km)
1	2823
2	859
3	381
4	228
5	10

In addition to streams, other aquatic resources within the park include small wetlands, ponds, springs, seeps, cave pools, and two large reservoirs along the southern and western park boundary. Aquatic communities within these habitats are diverse, and include fish, insects, algae, mollusks, crustaceans, and amphibians. While many wetlands in the park are too small and obscured by vegetation to be discovered by remote sensing, park staff recently have begun to inventory some of these wetlands. There also are several natural ponds in the park, most of which are related to limestone solution or cut-off meanders of the few low-gradient stream sections.

Tennessee boasts the richest freshwater fish fauna (over 300 native species) anywhere in the US (Etnier and Starnes 1993) and roughly 25% of these species are found within the streams of GRSM (i.e., 77 species of fish represented by 15 families). The lack of impacts from glaciation, coupled with the geologic, elevational, and hydrographic diversity represented in an array of cold, cool, and warm-water streams provide a wide variety of habitat for these freshwater organisms (Etnier and Starnes 1993). Four species of fish in the park are listed by the USFWS as Federally Threatened or Endangered. Efforts to restore these native species to their former ranges have been successful for three of the four species to date. Although brook trout (*Salvelinus fontinalis)* are the only salmonid native to GRSM, rainbow trout (*Oncorhynchus mykiss)* were well established in nearly every watershed of GRSM by 1934 and are the most frequently encountered species due to widespread stocking since the turn of the century (Burrows 1935, King 1937, 1938). Stocking continued throughout GRSM until 1975 when it was discontinued to comply with NPS policies.

Aquatic macroinvertebrates play a central role in most aquatic habitats and act as integrators of environmental conditions (Ward 1984). They are abundant in all types of aquatic systems in GRSM and are intricately involved in ecological processes, such as the breakdown and cycling of organic matter and nutrients (e.g., algae, detritus) (Voshell 2002), while also providing food for a number of other organisms, such as fish and amphibians. Aquatic macroinvertebrates are subjected directly to

changes in the physical and chemical conditions of the water and exhibit responses to a wide array of stressors; they have been routinely used as biological indicators (Bonada et al. 2006). Certain species, primarily in the EPT [Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies)] insect orders, are very sensitive to stressors, such as low pH, high concentrations of toxic metals, increased temperature, and high turbidity. All of these are stressors that exist in some park streams. Aquatic macroinvertebrates have been sampled in GRSM from over 150 sites over the years, with 27 sites receiving nearly 10 years of annual sampling. Over 900 species of macroinvertebrates, including insects, crustaceans, and mollusks, currently are known.

Impacts on Freshwater Communities

Many factors, including climatic and hydrologic conditions, atmospheric inputs, vegetation community type and condition, and soil chemistry impact freshwater communities in each of the park's aquatic systems. More specific potential impacts include: changes in flow regime, stream temperature, and input due to riparian zone disturbance; community structure changes due to invasive species; and severe habitat alteration/acid deposition and/or other pollutant inputs.

Acid Deposition

Due to the poor buffering capacity of underlying geology and some of the greatest atmospheric acid deposition in North America (Powers 1929, Silsbee and Larson 1983, Nodvin et al. 1995, Smoot et al. 2000), GRSM streams range in pH from <5.0 to 6.5, and stream conductivities generally are <30 μS/cm (Robinson et al. 2001). Park waters are therefore considered sensitive or very sensitive to anthropogenic acidification, although some streams are naturally acidic.

Compared to some units in the national park system, GRSM is fortunate that its streams almost entirely originate within the boundaries of the park; however, the deposition of atmospheric pollutants in the park is ubiquitous and deposition rates increase with elevation. High-elevation soils, which are porous and on steep slopes, are losing their ability over time to buffer the acidity of the water that percolates through them to springs, seeps, and smaller streams. The resulting influx of anthropogenic chemicals, and those being leached out of the soil, has led to an elevated acidity in high-elevation streams, and more recently in mid-elevation streams. These stream systems are complex, and the acidity observed depends on various factors, including differing parent material chemistry among watersheds, recent geologic landslides, and organic acids released by vegetation. The Clean Water Act of 1977 requires that streams have a mean baseflow pH of at least 6.0, and if ≥10% of the recorded values are below 6.0, the stream must be listed as impaired and placed on the state's 303(d) list. In 2006, the state of Tennessee listed 65.6 km of 12 streams in the park as impaired (Fig. 1).

Invasive Organisms

Anthropogenic impacts and non-native species have the potential to impact the park's aquatic ecosystems and adversely affect native fish, plant, and invertebrate species by depriving them of habitat, competing for limited resources, and altering the ecosystem and life histories of other park

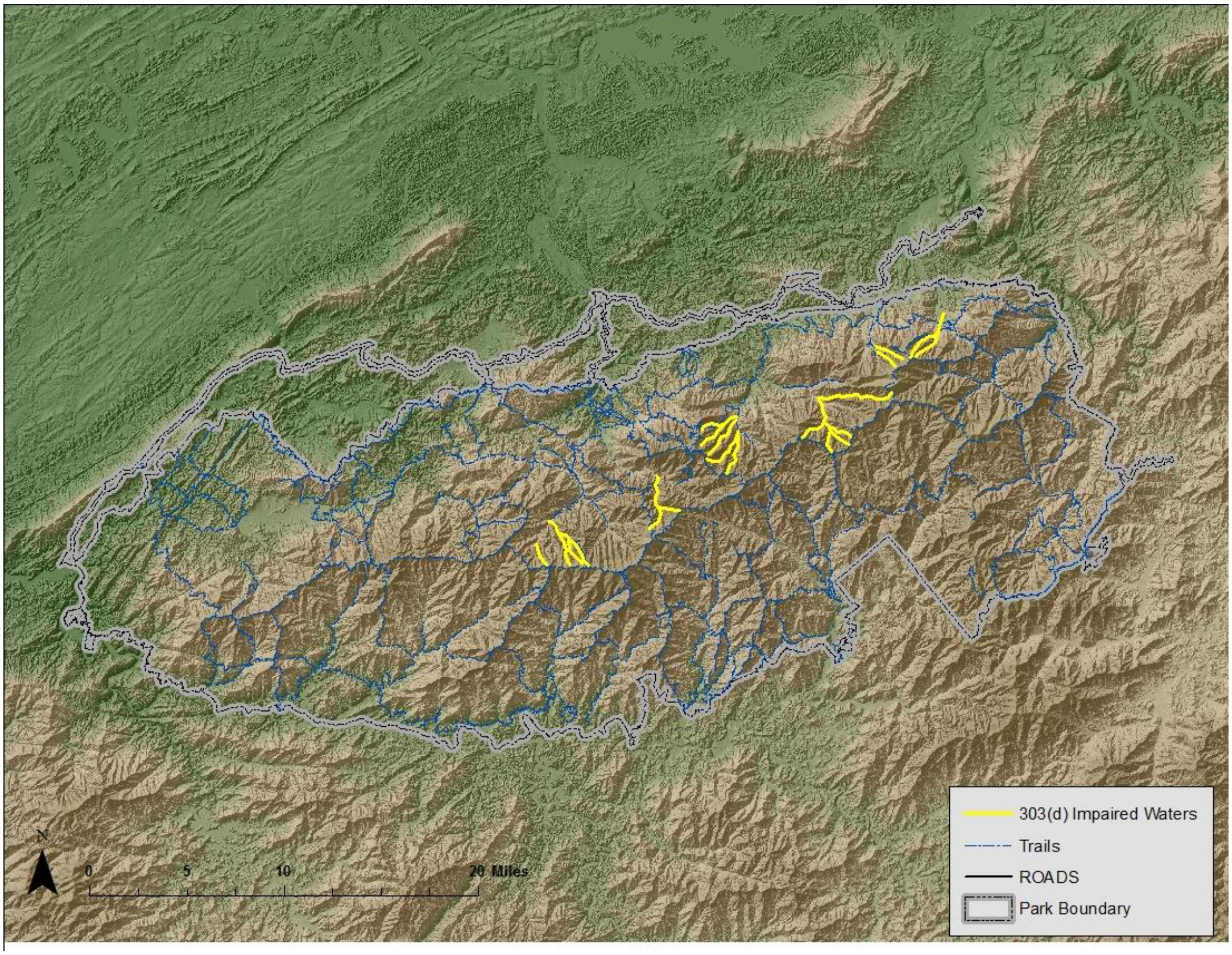

Figure 1. Map of twelve 303(d) streams listed as impaired (pH <6.0) in Great Smoky Mountains National Park.

species. For example, the introduction of non-native rainbow trout in the park displaced native brook trout from roughly 70% of its former range (S. Moore, pers. comm.). Given the amount of recreational fishing use in the park, and the close proximity to many vectors of infestation (e.g., reservoirs, tailwater fisheries, boundary water fish stocking), there is great potential for future invasion by other non-native aquatic species into GRSM. The following are examples of some of these species.

- Didymo *(Didymosphenia geminata*) is an invasive freshwater diatom, probably originally from Canada and the northwestern US, that can form massive blooms. This species is able to dominate stream surfaces by covering up to 100% of the substrate with thicknesses of greater than 20 cm, greatly altering physical, biological, and ecological properties of the stream (e.g., species diversity, population sizes, nutrient pools) (Larned et al. 2006). Invertebrate, fish, and native algal species diversity and population sizes may be altered. In addition, high growth rates and extensive mats of didymo may impact ecological processes such as ecosystem metabolism and nutrient cycling. This is a very adaptive diatom, and it has been documented in many locations worldwide that did not appear to have ideal conditions for growth and

establishment. It has been found in the tailwater of rivers and streams close to the boundary of the park, but not in the park.

- Bd (*Batrachochytrium dendrobatidis*) is a chytrid fungus (Division Chytridiomycota) that often causes a fatal disease in amphibians referred to as chytridiomycosis. This fungus has been identified in association with amphibian population declines on every amphibian-inhabited continent (Speare and Berger 2000) and is thought to have originated in South Africa (Weldon et al. 2004). Bd has been found within the park at various locations but has not been implicated in amphibian die-offs (Rothermel et al. 2008).
- *Ranavirus* (Family Iridoviridae) infections can cause catastrophic mortality of pond-breeding amphibians. This virus has been determined to be the cause of episodic amphibian mass die-offs in the park, including red-spotted newts (*Notophthalmus v. viridescens*), spotted salamanders (*Ambystoma maculatum*), marbled salamanders (*Ambystoma opacum*), and wood frogs (*Lithobates sylvaticus*) (Rothermel et al. 2008).
- Other aquatic invasive non-native species expected in the park area, with the potential for long-term impact, include the zebra mussel (*Dreissena polymorpha*), the New Zealand mud snail (*Potamopyrgus antipodarum*), and whirling disease (*Myxobolus cerebralis*), which affects salmonid fish.

Methods

Sampling Design and Monitoring Approaches

The original intent of the Inventory and Monitoring program developed in 1993 was to co-locate water quality, aquatic macroinvertebrate, and fish community monitoring sites along streams or within a watershed to observe the impacts of acid deposition, climate change, and other factors on all of these systems. Although this was achieved in some cases, it was felt that more integration was necessary. GRSM has now implemented the Vital Signs approach to the monitoring program, and has selected six components that will be monitored in the new program: acid deposition, climate changes, freshwater communities, soil quality, vegetation communities, and water chemistry.

To achieve an integrated sampling design for the six Vital Signs, a GRTS (Generalized Random Tessellation Stratified) sampling design procedure was used to select sampling areas. This procedure identified six primary and six secondary watersheds from which to integrate sampling whenever possible (Fig. 2). The primary watersheds will allow us to meet the park priorities of being able to say something about the park trends as a unit, and to understand the ecological processes that are driving change. The primary watersheds are the areas where all Vital Signs will be active and co-located to the maximum extent appropriate.

The freshwater communities Vital Sign was originally envisioned as including aquatic macroinvertebrates and fish, as with the previous monitoring program, but also including algae (especially diatoms), and amphibians (NPS 2014). In 2014, data was collected for aquatic macroinvertebrates and fish, and will be the focus of this report. As pertinent, data from the water chemistry component will be addressed.

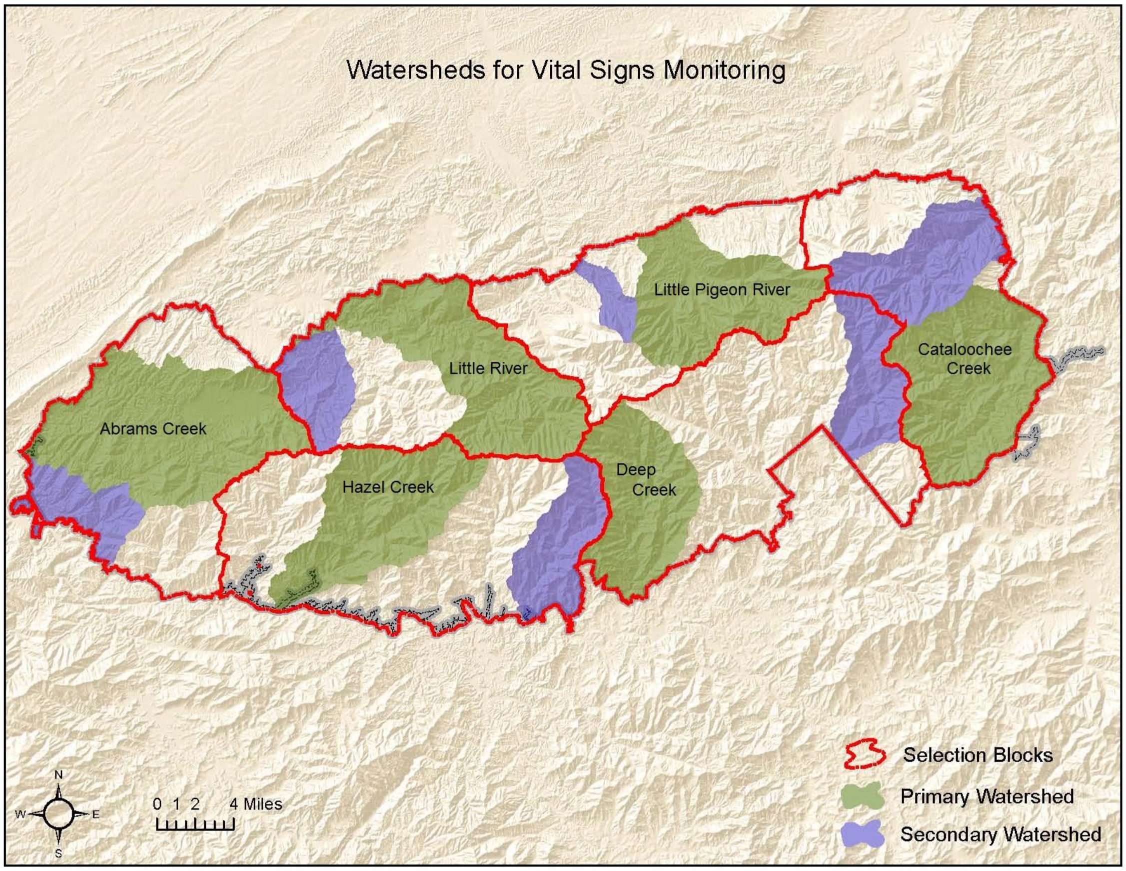

Figure 2. GRSM watersheds selected for Vital Signs monitoring.

The basic monitoring questions that the freshwater communities Vital Sign aims to answer are:

- What are the park-wide status and trends of macroinvertebrates and fish?
    - Species richness and calculated indices for macroinvertebrates
    - Species richness, condition, distribution, and relative abundance for fish
- To what extent do changes in other Vital Signs, such as acid deposition, vegetation communities, soil quality, water chemistry, and climate changes, affect freshwater communities?

2014 Site Selection and Sampling Plan: Macroinvertebrates

A site is defined as a section of river or stream approximately 100 to 200 m long. Sections 200 m long are established on streams greater than 9 m in width. Within a watershed, one site was chosen within each 305 m (1000 ft) elevation band; in some cases the higher elevation sites were not sampleable (i.e., stream not $\geq$ 1 m wide). Every effort was made to select sites at least 100 m downstream of any confluence so as to allow the two (or more) streams to sufficiently mix. Water chemistry can be highly variable at the point of confluence, depending upon the geology of each streams' drainage area. Some of the macroinvertebrate monitoring sites have been chosen to coincide

with fish monitoring sites; therefore, site length is dependent on stream size and the location of suitable natural impediments to fish movements at the lower and upper ends. Not all macroinvertebrate and fish sites are co-located, primarily due to differences in objectives for each of these programs. Also, in some cases macroinvertebrate sites are at elevations above where fish occur.

In 2014, three of the six primary watersheds were sampled (Abrams Creek, Hazel Creek, Cataloochee Creek) (Table 2). Benthic macroinvertebrates were collected from monitoring sites following a rapid bioassessment protocol, adapted from the Standard Operating Procedures developed and used by the North Carolina Department of Environment and Natural Resources, Division of Water Quality, Environmental Sciences Section, Bioassessment Unit (NCDENR 2011). The North Carolina state protocols have been used in GRSM in the past, with modifications for use in the generally higher elevation areas of western North Carolina and east Tennessee.

Before sampling for macroinvertebrates began, various site characteristics were recorded, including stream width, gradient, depth, dominant substrate size, and habitat classification. The standard qualitative method for sampling macroinvertebrates was followed at each collection site which consists of three kick-net samples, one composite D-net sample (composite samples are comprised of several collections in each distinct habitat type throughout the site; the quantity varies considerably among streams), one composite leaf-pack sample using a sieve bucket, one composite fine-mesh rock and/or log wash sample, one composite sand sample, and one composite visual search. Macroinvertebrates were separated from the rest of the sample in the field, and were picked roughly in proportion to their abundance; no attempt was made to remove all organisms. If an organism could be reliably identified as a single taxon in the field (i.e., *Tallaperla* sp.), no more than 10 individuals were collected. Specimens are preserved in plastic vials containing 95% ethanol.

Each site is sampled once per season, with the season extending from June through September. This time frame ensures that all samples can be analyzed without the need to compensate for seasonal population fluctuations. The number of watersheds and sampling sites completed each year depend on the size of the watersheds selected; selection is made in consultation with other park program managers in order to coordinate sampling whenever possible.

After field work was completed, samples were sorted to the orders Ephemeroptera, Plecoptera, and Trichoptera. All remaining orders were preserved for further analysis if necessary. In order to calculate the EPT Index, the number of taxa within each of the three orders was then determined.

2014 Site Selection and Sampling Plan: Fish

Fish sampling sites were identified in four of the six primary watersheds: Abrams Creek, Little River, Cataloochee Creek, and Hazel Creek (Table 2). The decision to initiate data collection in four of the six primary watersheds in 2014 was based upon staffing and volunteer support for that year. GRSM and University of Tennessee staff, as well as volunteers, surveyed potential survey sites on perennial streams that met the criteria of being along a single main stem corridor, were within each 305 m band, and were at access points where collections could feasibly be made. In potential sampling areas

Table 2. Sample site locations for aquatic macroinvertebrates and fish in 2014. Water chemistry sites are included only if they match up with the other two components (see Appendix C for a full listing)

Watershed	Stream	Site Codes			Elevation (ft)	Samples			
		Macros	Fish	Water		Macros	IBI (fish)	3-pass (fish)	water
Abrams Creek	Abrams Creek	AB1	ABC_1	156	1095	x	x		x
	Abrams Creek	AB2			1699	x			
	Anthony Creek	ANTH1	ABC_2	423	2096	x		x	x
	Anthony Creek	ANTH2	ABC_3	200	3307	x		x	x
Little River	East Prong Little River		EPLR_1	14	1147		x		
	East Prong Little River		EPLR_2	40	2307		x		x
	East Prong Little River		EPLR_3	213	3316			x	x
	East Prong Little River		EPLR_4		4158			x	
Hazel Creek	Hazel Creek	HZ1	HAZ_1	479	1738	x	x		x
	Hazel Creek	HZ2			2448	x			
	Bone Valley Creek		HAZ_2	310	2287			x	x
	Hazel Creek	HZ3			3040	x			
	Hazel Creek		HAZ_3	222	3622			x	x
	Hazel Creek	HZ4	HAZ_4		4200	x		x	
Cataloochee Creek	Cataloochee Creek	CC1	CAT_2	147	2454	x	x		x
	Bear Branch		CAT_3	286	3068			x	x
	Onion Bed Branch		CAT_4	130	4157			x	x
Deep Creek	Deep Creek		DPC_1		1802		x		
Middle Prong Little Pigeon River	Middle Prong Little Pigeon River		MPL_1		1373		x		

that included historic sampling sites, retaining old sites with long-term data sets were given preference over creating new Vital Sign sites with no data; they were also paired with established water quality monitoring sites where possible. In some cases, alternate sites were selected that were not on the main stem corridor, but met the elevation criteria and had good access. Additionally, preliminary sampling was conducted in Deep Creek and Middle Prong Little Pigeon River to establish a baseline in preparation for 2015 sampling. A different set of sites will be visited each year, resulting in a visit to each stream approximately once every three years.

Once a site was established, fish communities were sampled according to standard methods using the most appropriate sampling technique for the site (IBI or 3-pass depletion). The Index of Biotic Integrity (IBI) methodology (Karr 1981) involves depleting the number of species using electro-shockers within representative habitat types (i.e., riffles, runs, pools, and shoreline). Stunned fish were identified and enumerated before being released back into the stream. Young-of-year (YOY) fish were not counted in the IBI survey. All fish >20 mm total length were then identified to species;

those that weren't able to be identified in the field were preserved in alcohol and returned to the laboratory. Specimens were examined for external anomalies (i.e., deformities, eroded fins, lesions, and tumors), and weighed and measured. In some cases, sites were not conducive to IBI sampling due to low species diversity; therefore, 3-pass depletion surveys were conducted in these areas.

The 3-pass depletion method was used to estimate the population size of fish in small streams using backpack electro-shocking equipment. The principle behind this method is that if a section of stream is sampled repeatedly and the fish captured are removed, then each sampling pass should remove fewer fish. By extrapolating the decreasing number to 0, the total population can be estimated. Species composition and assemblage changes can then be evaluated in relation to historic data, and long-term trends can be detected. Captured fish were identified, weighed, and measured. One backpack unit was used for each 3 m (10 ft) of stream width, with block nets placed at the lower end and a barrier or another block net placed at the upper end to prevent immigration and/or emigration.

Seven large-stream IBI sites were sampled for fish in 2014 from within the six primary Vital Signs watersheds (Table 1). Most sampling was conducted by GRSM fisheries staff and volunteers; however, Tennessee Valley Authority (TVA) staff assisted with two sites (CAT_2 and EPLR_2), as these sites are part of the larger Southeast Monitoring Network (SEMN) sampling design. All results were recorded on GRSM datasheets (and some data recorded on TVA field data loggers at CAT_2) and QA/QC checked once back in the office. Once data was checked, pdf copies of all IBI data sheets were sent to Dave Matthews (TVA) for entry into the TVA IBI software, scoring, and uploading to the TVA Oracle database. The Oracle database stores IBI data from the entire Tennessee valley from the surrounding 10 states. Results of the analyses were then sent back to GRSM for use in reporting. Data were processed by site and scored according to the metrics developed for the upper Blue Ridge stream ecoregion. The IBI methodology uses a series of metrics to score the health of the aquatic ecosystem based upon abundance, diversity, and condition of species collected from various habitat types.

Temperature and Water Quality

Stream water temperature loggers were placed in four of the six primary watersheds (Abrams Creek, Middle Prong Little Pigeon River, Deep Creek, Hazel Creek) and set to collect temperature data at one hour intervals. Temperature loggers were not placed in Cataloochee Creek and East Prong Little River because each has a USGS stream gage which also logs real-time temperature data (see Appendix A for Little River data). Stream temperature data will capture seasonal variation as well as annual mean temperatures, both of which can be analyzed for climate change effects over time.

Annual water quality surveys were collected bi-monthly on the third weekend of each sampling month starting in January 2014 through November 2014. Water quality data were collected at each of the 43 historical collection sites during January, March, and May of 2014. Starting in July 2014, water quality data collection switched to four of the six new Vital Sign site collections and continued bi-monthly through November 2014. Water quality results are summarized annually and published in the NPS Natural Resource Report Series. Annual water quality reports can be downloaded from the IRMA website (https://irma.nps.gov/App/Portal/Home), and are therefore not covered in this report.

Results and Discussion

Macroinvertebrate Indices

Species richness, or number of species, is the simplest measure of diversity, and the association of good water quality with high species richness has been thoroughly documented (see Rosenberg et al. 2008). The EPT Index (Ephemeroptera, Plecoptera, Trichoptera), which is considered by some to be the most efficient of the macroinvertebrate indices at determining impairment (Barbour et al. 1992, Wallace 1996), is based on the premise that high-quality streams usually have the greatest species richness for these three orders, which are considered sensitive taxa as a whole. Increasing levels of ecosystem stress gradually eliminate the more sensitive species, leading to progressively lower species richness. Stream condition ratings using EPT taxa richness values for several major ecoregions have been developed for the standard qualitative sampling method (NCDENR 2011; Table 3).

Table 3. EPT taxa richness values and corresponding stream ratings.

Number of EPT taxa	Stream Condition Rating
>35	Excellent
28-35	Good
19-27	Good-Fair
11-18	Fair
0-10	Poor

Diversity levels in the streams sampled in 2014 generally were high, with values ranging from a low of 20 to a high of 36 EPT taxa (Fig. 3). The stream condition rating was in the "good" category for all streams, with the exception of Abrams 1, which rated in the "excellent" category, and Anthony 2, with a "good-fair" rating.

Anthony Creek is a tributary to Abrams Creek, and site 2 is at an elevation of 1000 m (3280 ft). It is a second order stream, and has a very high gradient; it was sampled on a rainy day in mid-June, 2014. In general, streams are still able to be sampled while it's raining; however, if the rain has persisted for a long period to the point where stream flow has risen above normal, benthic macroinvertebrates often will drift downstream and will be displaced from their typical habitats. The "good-fair" stream condition rating for this site could be due to a high volume of rain during that period, especially upstream of the sample site, and also due to the high gradient. This is a newly established site, so a baseline diversity level is not yet established. Future sampling will help determine whether the "good-fair" rating is an anomaly or the general condition of this site.

Abrams Creek, especially at the lower elevations, is the most biologically diverse stream in the park. It is also the largest stream in the park, and larger streams tend to have more available habitats, so it is not surprising that site 1 rated in the "excellent" category. This site has been sampled many times, and has always had a very high diversity score.

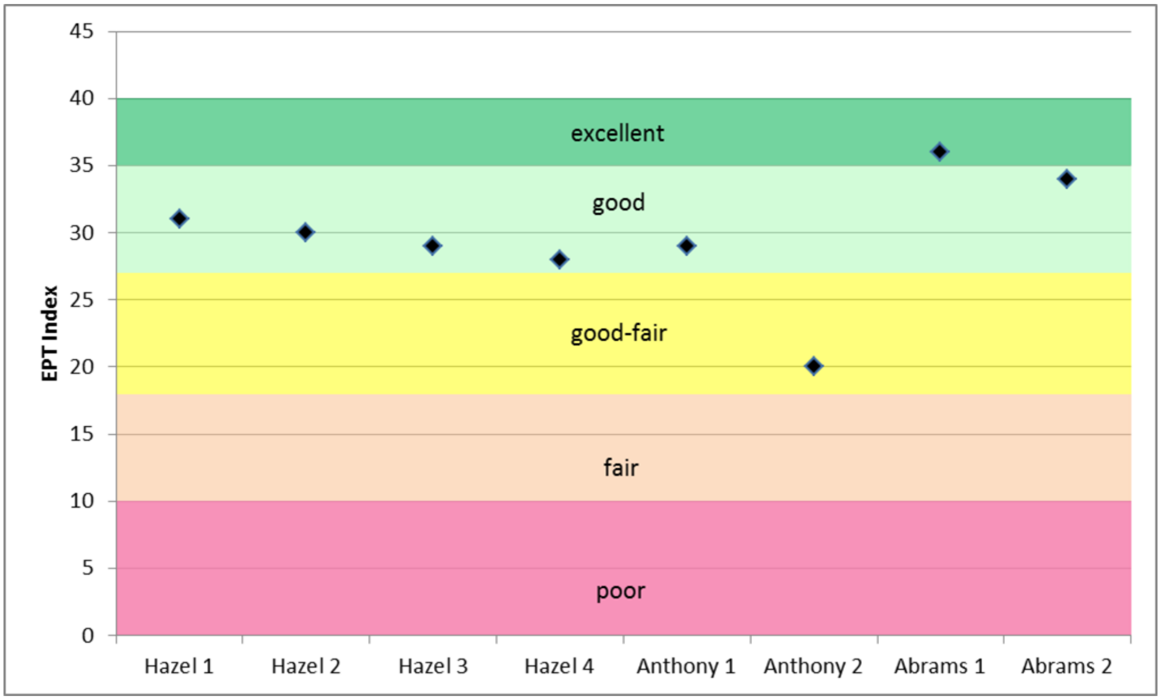

Figure 3. EPT Index scores for benthic macroinvertebrate samples from GRSM streams in 2014.

Fish Communities (IBI)

In general, fish communities in the six primary watersheds appear to be healthy and representative of typical low- to mid-elevation stream communities in the Blue Ridge ecoregion. There were no obvious signs of stress or disease in the species collected, other than ubiquitous and benign commensal parasites like black spot (black grub) and the occasional leech. East Prong Little River just upstream of the Townsend Wye was the most speciose site with 17 species of fish collected. The Middle Prong Little Pigeon River just upstream of the park boundary was the second most speciose site with 16 species of fish collected. The Little River just upstream of Elkmont had the lowest species diversity with only 4 species present.

IBI scores from the six primary streams ranged from “poor” to “good” (Table 4, Fig. 4) and included 4 to 17 species per site (Appendix B). Abrams Creek (ABC_1) scored the highest (52) and the Little River site at Elkmont (EPLR_2) scored the lowest (28) (Fig. 4). Although the scores for the six primary watershed sites are lower than anticipated, much of the lower scoring can be attributed to the fact that these sites are in the upper range of IBI applicability in terms of elevation. GRSM sites EPLR_2 and CAT_2 represent the uppermost applicable range of Blue Ridge stream IBI metrics because species diversity declines sharply above 700 m (2300 ft). Although sites such as EPLR_2 located just above Elkmont campground represent excellent cold water habitat, the lack of species diversity results in a low IBI score (28). Fish at the EPLR_2 site are healthy and typical of streams at that elevation; therefore the low score is accurate and not necessarily indicative of poor stream quality, but rather a higher elevation cold water habitat that is less speciose. In fact, across the primary watershed sites,

Table 4. IBI fish community ratings (Karr et al. 1986).

IBI Range	Rating
58-60	Excellent
48-52	Good
40-44	Fair
28-34	Poor
12-22	Very Poor

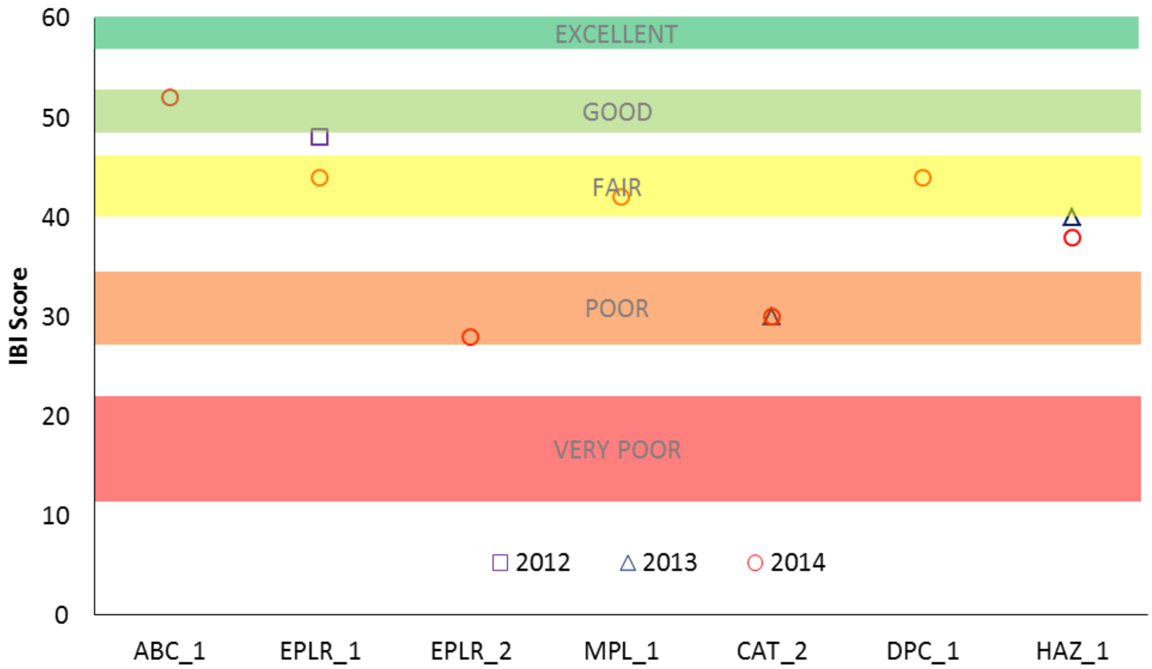

Figure 4. Index of Biotic Integrity (IBI) scores for six streams in Great Smoky Mountains National Park. Site codes refer to Abrams Creek (ABC), East Prong Little River (EPLR), Middle Prong Little Pigeon River (MPLP), Cataloochee Creek (CAT), Deep Creek (DPC) and Hazel Creek (HAZ). The Blue Ridge Stream metric was used as the scoring metric for all IBI scoring (Table 4).

elevation was inversely related to IBI score and explained 82% of the variation in scores in each watershed ($p<0.05$, $R^2=0.82$). These scores provide a good baseline for each site and indicate the scores should change very little from year to year unless major species assemblage changes occur.

The low variability of IBI scores within sites (0-4 points) and the minimal anthropogenic impacts to these sites will allow for less frequent revisit intervals than at 3-pass sites in the upper watershed, where changes occur more rapidly. The influence of acid deposition, drought, and flood events in the upper elevations of the watershed are more severe and create greater fluctuations in year-class strength than at lower elevations. These attributes support the decision to revisit the lower elevation IBI sites on a 3-year rotation versus the mid- to high-elevation 3-pass sites on an annual basis.

Fish Communities (3-Pass Depletion)

Three-pass depletion monitoring was conducted at 11 sites on 8 Vital Sign streams in 2014. In three of the 11 sites, 10 years of monitoring data were available, which afforded the opportunity to present the trend data using control charts. Control charts, developed for industrial applications, indicate when a system is going “out of control,” by plotting through time some measure of a stochastic process with reference to its expected value (Beauregard et al. 1992, Gyrna 2001, Montgomery 2001). Control charts may be univariate or multivariate, and can represent many different types of variables. Control charts have been applied to ecological data (McBean and Rovers 1998, Manly 2001) including fish communities (Pettersson 1998, Anderson and Thompson 2004) and natural resources within the Inventory and Monitoring program (Atkinson et al. 2003). Control charts contain upper and lower control limits specifying thresholds beyond which variability in the indicator reveals a biologically important change is occurring, and warns that management may need to act. Control charts present the annual abundance values (density or biomass), mean of population abundance and lower (LCL) and upper (UCL) confidence limits. Control limits can be set to any desired level; for our data, limits were calculated as ±3 times the standard error (SE) of the mean. For the remaining eight sites, biomass by species will be reported annually until 10 years of data are available to generate control charts.

Quantitative field surveys indicated that adult brook trout biomass ranged from 2.8-14.3 kg/ha (9.4-44.0 kg/ha total sympatric trout biomass) across sympatric populations and 12.3-37.7 kg/ha in allopatric populations. Total carrying capacity for salmonids in most GRSM streams ranges from 10-44 kg/ha. Streams such as Cosby Creek (COS_2) with average pH of 6.30 (SD=0.22) have higher carrying capacities than streams such as Rock Creek (site 137) that have mean pH of 5.86 (SD=0.24). The biomass of age-0 or YOY brook trout was slightly below average in Cosby Creek, Rock Creek (Figs. 5,6), and in most GRSM streams due to high flows between January and May 2014 that impacted fall spawning success. Species abundance patterns were similar in the eight sympatric sites as well where cumulative biomass was reported (Figs. 7, 8). Note that where found, brown trout typically represent ≤15% of the overall population (Figs. 7, 8). Also note that timing of major flood events (>1,000 ft^3/second) timed either during or in the three months following spawning, typically result in poor year class production in GRSM streams. These rainfall and high flow patterns do not always impact all species in sympatric areas equally due to differential spawning seasons (brook trout in the fall, rainbow trout in the spring). For example, poor brook trout year classes were observed in 2009 and 2013, whereas poor rainbow trout year classes were observed in 2008, 2009 and 2014 (Fig. 8).

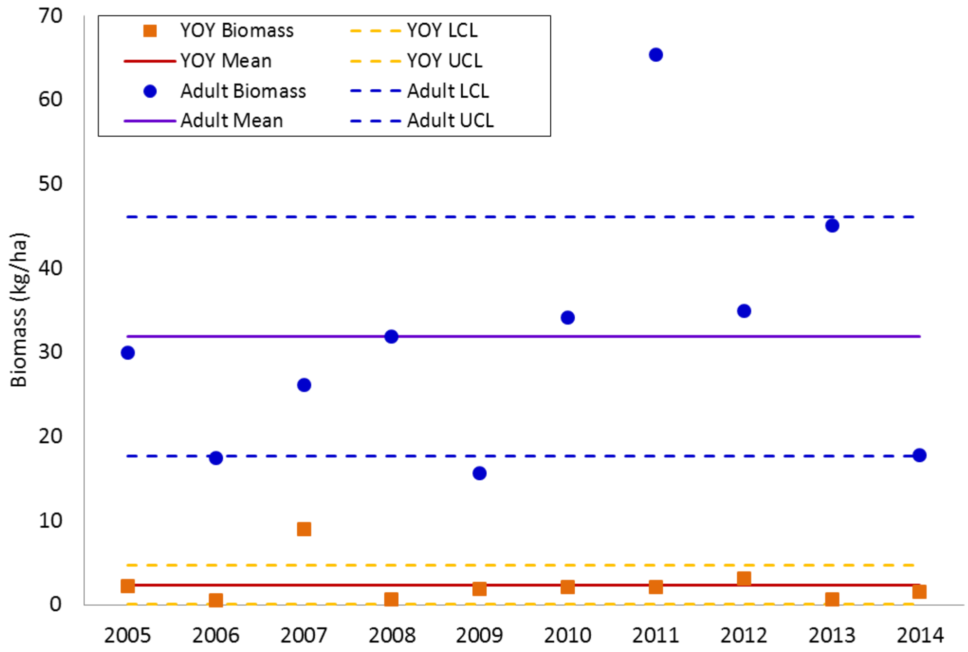

Figure 5. Control chart of young-of-year (YOY) and adult brook trout biomass in Cosby Creek between 2005 and 2014. Note mean represents 10 years of data during collection period. Lower confidence limit (LCL) and upper confidence limit (UCL) are 3 standard errors below and above the mean. Values outside of the LCL (and UCL) are considered outliers and should be examined more carefully.

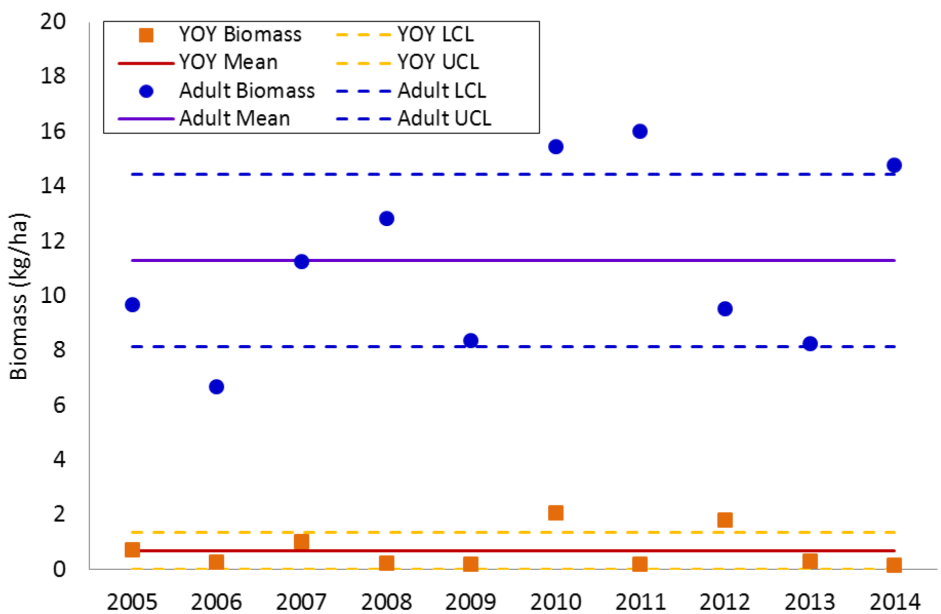

Figure 6. Control chart of young-of-year (YOY) and adult brook trout biomass in Rock Creek between 2005 and 2014. Note mean represents 10 years of data during collection period. Lower confidence limit (LCL) and upper confidence limit (UCL) are 3 standard errors below and above the mean. Values outside of the LCL (and UCL) are considered outliers and should be examined more carefully.

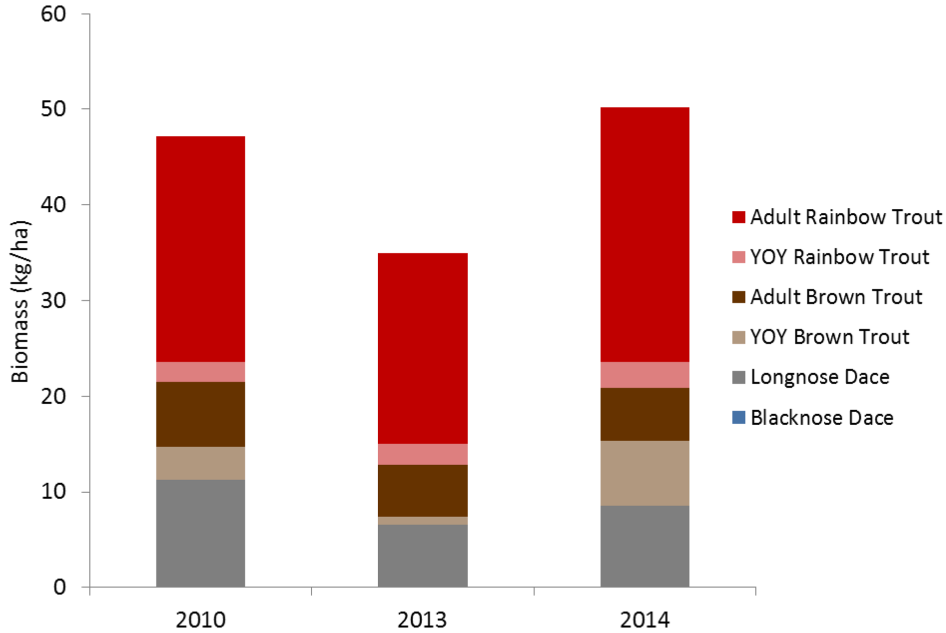

Figure 7. Annual biomass of four fish species sampled in Bone Valley Creek in 2010, 2013 and 2014 within Great Smoky Mountains National Park. Note that blacknose and longnose dace biomass represents total biomass of all individuals.

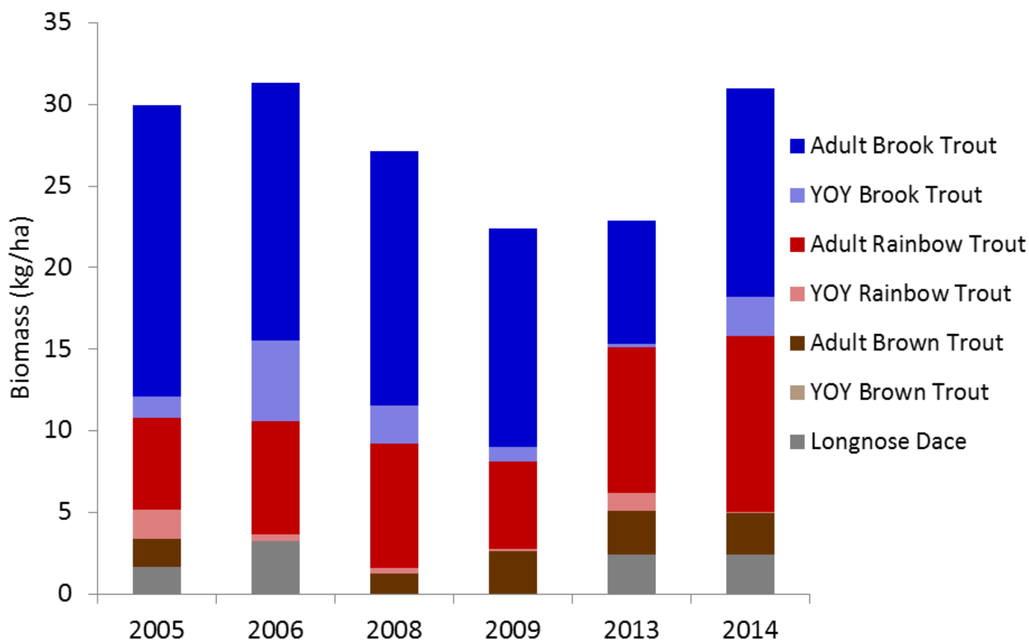

Figure 8. Annual biomass of four fish species sampled various years in Hazel Creek between 2005 and 2014 within Great Smoky Mountains National Park. Note that longnose dace biomass represents total biomass of all individuals.

Summary

Overall, the Vital Signs streams that were sampled in 2014 indicate that stream quality in the Smokies remains high. Aquatic macroinvertebrate diversity levels generally were high, resulting in stream condition ratings of good to excellent, for the most part. Also, fish communities were found to be healthy, and representative of typical low- to mid-elevation stream communities in the Blue Ridge ecoregion. Some indices for both aquatic macroinvertebrates and fish were found to be somewhat lower than expected, which will require further investigation to determine if these were one-time events, or if there is a long-term downward trend.

Literature Cited

Anderson, M.J. and A.A. Thompson. 2004. Multivariate control charts for ecological and environmental monitoring. Ecological Applications 14:1921-1935.

Atkinson, A.J., R.N. Fisher, C.J. Rochester, and C.W. Brown. 2003. Sampling design optimization and establishment of baselines for herpetofauna arrays at the Point Loma Ecological Reserve. United States Geological Survey, Western Ecological Research Center, Sacramento, CA.

Beauregard, M.R., R.J. Mikulak, and B.A. Olson. 1992. A practical guide to statistical quality improvement: Opening up the statistical toolbox. Van Nostrand Reinhold, New York, NY.

Bonada, N., N. Prat, V.H. Resh, and B. Statzner. 2006. Developments in aquatic insect biomonitoring: A comparative analysis of recent approaches. Annual Review of Entomology 51: 495-523.

Burrows, R. 1935. A biological survey of streams in the Great Smoky Mountains National Park. U.S. Department of Commerce, Bureau of Fisheries. Mimeo.: 33 pp.

Etnier, D.A. and W.C. Starnes. 1993. The Fishes of Tennessee. University of Tennessee Press, Knoxville, Tennessee.

Gyrna, F.M. 2001. Quality planning and analysis: From product development through use. McGraw-Hill Irwin, New York, NY.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. Fisheries 6(6): 21-27.

King, W. 1937. Notes on the distribution of native, speckled, and rainbow trout in the streams at Great Smoky Mountains National Park. Journal of the Tennessee Academy of Science 12(4): 351-361.

King, W. 1938. A program for the management of fish resources in Great Smoky Mountains National Park. Transactions of the American Fisheries Society 68: 86-95.

Larned, S., B. Biggs, N. Blair, C. Burns, B. Jarvie, D. Jellyman, C. Kilroy, J. Leathwick, K. Lister, J. Nagels, M. Schallenberg, S. Sutherland, J. Sykes, W. Thompson, K. Vopel, and B. Wilcock. 2006. Ecology of *Didymosphenia geminata* in New Zealand: habitat and ecosystem effects – Phase 2. NIWA Client Report CHC2006-086, NIWA Project MAF06507.

Manly, B.F.J. 2001. Statistics for environmental science and management. Chapman & Hall/CRC, Boca Raton, FL.

McBean, E.A. and F.A. Rovers. 1998. Statistical procedures for analysis of environmental monitoring data and risk assessment. Prentice Hall PTR, Upper Saddle River, NJ.

Montgomery, D. C. 2001. Introduction to statistical quality control. John Wiley & Sons, Inc., New York, NY.

NCDENR (North Carolina Department of Environment and Natural Resources). 2011. Standard operating procedures for collection and analysis of benthic macroinvertebrates, version 3.0. Raleigh, North Carolina. http://portal.ncdenr.org/c/document_library/get_file?uuid=c2fdf380-aa8a-481e-8388-a6e6596c6a96&groupId=38364

NPS (National Park Service). 2014. Conceptual plan for Vital Signs monitoring – Great Smoky Mountains National Park. Natural Resource Report NPS/GRSM/NRR—2014/854. National Park Service, Fort Collins, Colorado.

Nodvin, S.C., H. Van Miegroet, S.E. Lindberg, N.S. Nicholas, and D.W. Johnson. 1995. Acidic deposition, ecosystem processes, and nitrogen saturation in a high elevation Southern Appalachian watershed. Water, Air, and Soil Pollution 85: 1647-1652.

Parker, C. and D. Pipes. 1990. Watersheds of Great Smoky Mountains National Park: a geographical information system analysis. Research/Resources Management Report SER-91/01. Uplands Field Research Laboratory, Great Smoky Mountains National Park, Gatlinburg, TN, U.S.A.

Pettersson, M. 1998. Monitoring a freshwater fish population: Statistical surveillance of biodiversity. Environmetrics 9:139-150.

Powers, E. 1929. Freshwater studies: I. The relative temperature, oxygen content, alkali reserve, the carbon dioxide tension and the pH of the water of certain mountain streams at different altitudes in the Smoky Mountains National Park. Ecology 10: 97-111.

Robinson, R.B., J.L. Smoot, J. Shubzda, and T.W. Barnett. 2001. Water quality analysis of calcium and magnesium in the Great Smoky Mountains National Park. Report submitted to the National Park Service under contract no. 1443-CA-5460-98-006 (Amendment 4).

Rothermel, B.B., S.C. Walls, and J.C. Mitchell. 2008. Widespread occurrence of the amphibian chytrid fungus *Batrachochytrium dendrobatidis* in the southeastern U.S.A. Diseases of Aquatic Organisms 82(1): 3-18.

Silsbee, D. and G. Larson. 1983. A comparison of streams in logged and unlogged areas of Great Smoky Mountains National Park. Hydrobiology 102: 99-111.

Smoot, J., B. Robinson, M. McCann, G. Harwell, and J. Shubzda. 2000. Assessment of stream water quality and atmospheric deposition rates at selected sites in the Great Smoky Mountains National Park, 1991-1998. Report prepared for the National Park Service, Cooperative Agreement No. 1443- CA-5460-98-006 (Amendment 3).

Speare, R. and L. Berger. 2000. Global distribution of chytridiomycosis in amphibians. http://www.jcu.edu.au/school/phtm/PHTM/frogs/chyglob.htm.

Voshell, J.R. Jr. 2002. A guide to freshwater invertebrates of North America. MacDonald and Woodward.

Ward, J.V. 1984. Ecological perspectives in the management of aquatic insect habitat. Pages 558 577 *in* V.H. Resh and D.M. Rosenberg, editors. The ecology of aquatic insects. Praeger.

Weldon, C., L.H. du Preez, A.D. Hyatt, R. Muller, and R. Speare. 2004. Origin of the amphibian chytrid fungus. Emerging Infectious Diseases 10(12): 2100-2105.

Appendix A. Stream temperature data: 2012-2015

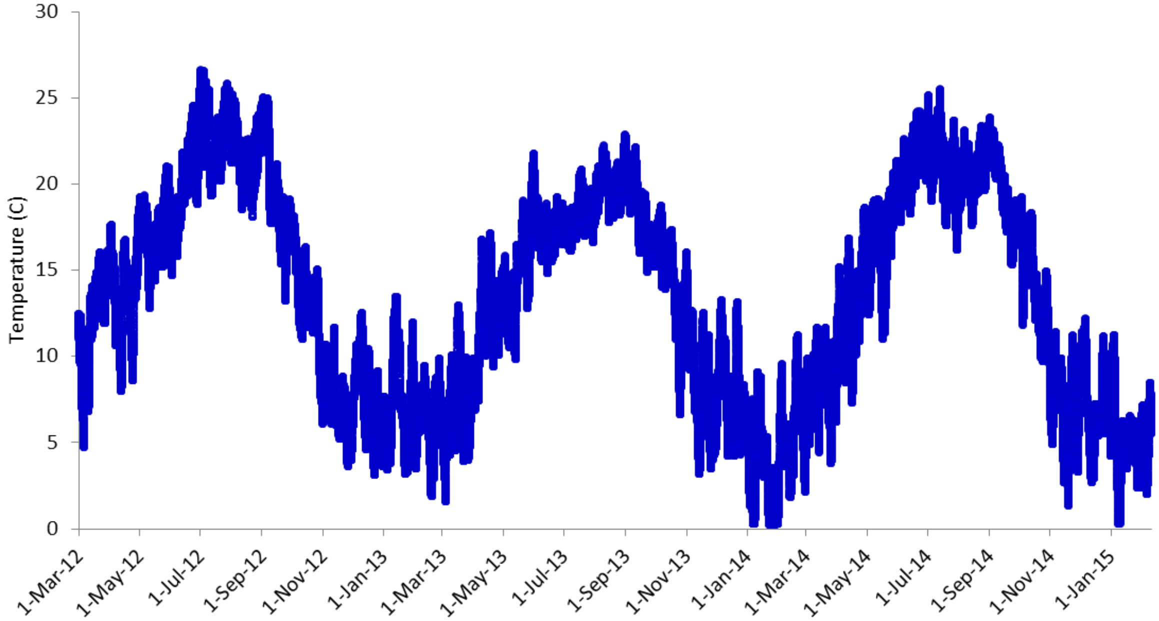

Figure 9. Stream water temperature data collected between 1 March 2012 and 10 February 2015 at the Little River USGS gaging station (http://waterdata.usgs.gov/tn/nwis/uv/?site_no=03497300) located at the park boundary within GRSM. Data represented are 15-minute intervals over the study period.

Appendix B. Fish species and abundance

Table 5. Fish species collected during annual fish Index of Biotic Integrity (IBI) surveys within GRSM in 2014. The total number collected for each species per site is listed.

FAMILY	COMMON NAME	SCIENTIFIC NAME	ABC_1 2014	CAT_2 2014	DPC_1 2014	HAZ_1 2014	LRV_2 2014	LRV_1 2014	MPLR_1 2014
Percidae	Banded Darter	*Etheostoma zonale*	19					2	
Percidae	Greenfin Darter	*Etheostoma chlorobranchium*	63		14	6			9
Percidae	Redline Darter	*Etheostoma rufilineatum*	144					19	3
Percidae	Tennessee Darter	*Etheostoma tennesseense*	11					3	6
Percidae	Tuckasegee Darter	*Etheostoma gutselli*			1	14			
Percidae	Olive Darter	*Percina squamata*				1			
Percidae	Greenside Darter	*Etheostoma blennioides*						6	
Percidae	Tangerine Darter	*Percina aurantiaca*							
Percidae	Wounded Darter	*Etheostoma vulneratum*						5	
Percidae	Gilt Darter	*Percina evides*						1	
Percidae	Fantail Darter	*Etheostoma flabellare*							9
Percidae	Swannanoa Darter	*Etheostoma swannanoa*							9
Cyprinidae	Bigeye Chub	*Hybopsis amblops*	12					28	
Cyprinidae	Central Stoneroller	*Campostoma anomalum*	41	4	6	3		26	76
Cyprinidae	River Chub	*Nocomis micropogon*	18			28		25	1
Cyprinidae	Telescope Shiner	*Notropis telescopus*	102					1	2
Cyprinidae	Tennessee Shiner	*Notropis leuciodus*	29			63		91	86
Cyprinidae	Warpaint Shiner	*Luxilus coccogenis*	9			23		44	
Cyprinidae	Whitetail Shiner	*Cyprinella galactura*	24					3	
Cyprinidae	Longnose Dace	*Rhinichthys cataractae*		68	38	15	12		11
Cyprinidae	Blacknose Dace	*Rhinichthys atratulus*			8				
Cyprinidae	Rosyside Dace	*Clinostomus funduloides*			5				
Cyprinidae	Saffron Shiner	*Notropis rubricroceus*							21
Catastomidae	Golden Redhorse	*Moxostoma erythrurum*	7						

Catastomidae	Northern Hogsucker	*Hypentelium nigricans*	14	7	21	6		1	2
Catastomidae	White Sucker	*Catostomus commersonii*			1				
Catastomidae	Redhorse spp.	*Moxostoma sp.*							
Centrarchidae	Rock Bass	*Ambloplites rupestris*	6						
Centrarchidae	Smallmouth Bass	*Micropterus dolomieu*	13			1		2	
Centrarchidae	Largemouth Bass	*Micropterus salmoides*							
Centrarchidae	Bluegill	*Lepomis macrochirus*			5				
Salmonidae	Brown trout	*Salmo trutta*		10	22		2		3
Salmonidae	Rainbow trout	*Oncorhynchus mykiss*		14	41		32		
Salmonidae	Brook trout	*Salvelinus fontinalis*		1					
Cottidae	Mottled sculpin	*Cottus bairdii*			137	103	49	22	
Cottidae	Banded sculpin	*Cottus carolinae*						12	70
Petromyzontidae	Mountain brook lamprey	*Ichthyomyzon greeleyi*			5				

Appendix C. Stream sampling sites

Table 6. Complete list of streams in GRSM where sampling for fish, macroinvertebrate, and water quality occurred in 2014.

Watershed	Stream	Site Codes			Elevation (ft)	Samples			
		Macros	Fish	Water		Macros	IBI (fish)	3-pass (fish)	water
Abrams Creek	Abrams Creek	AB1	ABC_1	156	1095	x	x		x
	Abrams Creek	AB2			1699	x			
	Anthony Creek	ANTH1	ABC_2	423	2096	x		x	x
	Anthony Creek	ANTH2	ABC_3	200	3307	x		x	x
	Mill Creek			173	1702				x
	Abrams Creek			174	1702				x
	Mill Creek			488	1791				x
	Abrams Creek			489	1709				x
Little River	East Prong Little River		EPLR_1	14	1147		x		
	East Prong Little River		EPLR_2	40	2307		x		x
	East Prong Little River		EPLR_3	213	3316			x	x
	East Prong Little River		EPLR_4		4158			x	
	Little River			13	1099				x
	Middle Prong Little River			23	1148				x
	West Prong Little River			24	1148				x
	East Prong Little River		EPLR_5	220	5496				x
Hazel Creek	Hazel Creek	HZ1	HAZ_1	479	1738	x	x		x
	Hazel Creek	HZ2			2448	x			
	Bone Valley Creek		HAZ_2	310	2287			x	x
	Hazel Creek	HZ3			3040	x			
	Hazel Creek		HAZ_3	222	3622			x	x
	Hazel Creek	HZ4	HAZ_4		4200	x		x	
	Hazel Creek			221	3998				x
	Hazel Creek			224	2998				x
	Hazel Creek			311	2188				x
	Sugar Fork			480	2184				x
	Little Fork			481	2380				x
	Sugar Fork			482	2539				x
	Sugar Fork			483	2319				x
	Hazel Creek			484	2473				x
	Walker Creek			485	2860				x
Cataloochee Creek	Cataloochee Creek	CC1	CAT_2	147	2454	x	x		x
	Bear Branch		CAT_3	286	3068			x	x
	Onion Bed Branch		CAT_4	130	4157			x	x

Table 6 (continued). Complete list of streams in GRSM where sampling for fish, macroinvertebrate, and water quality occurred in 2014.

Watershed	Stream	Site Codes			Elevation (ft)	Samples			
		Macros	Fish	Water		Macros	IBI (fish)	3-pass (fish)	water
Cataloochee Creek	Beech Creek			142	3337				x
	Lost Bottom Creek			143	3323				x
	Palmer Creek			144	3008				x
	Little Cataloochee Creek			148	2473				x
	Cataloochee Creek			149	2549				x
	Rough Fork			293	3068				x
	Palmer Creek			493	2840				x
	Pretty Hollow			PTH-1	3560				x
West Prong Little Pigeon River	West Prong Little Pigeon River			30	1430				x
	West Prong Little Pigeon River			66	2680				x
	Road Prong			71	3480				x
	Walker Camp Prong			73	3360				x
	Walker Camp Prong			74	3820				x
	Walker Camp Prong			233	4240				x
	Road Prong			234	5000				x
	Walker Camp Prong			237	4510				x
Oconaluftee River	Oconaluftee River			268	2170				x
	Beech Flats Prong			270	2800				x
	Beech Flats Prong			251	4010				x
	Beech Flats Prong			252	4760				x
	Beech Flats Prong			253	4840				x
Cosby Creek	Rock Creek			4	1679				x
	Cosby Creek			114	2509				x
	Rock Creek			137	2749				x
	Camel Hump Creek			492	2729				x
Deep Creek	Deep Creek		DPC_1		1802		x		
Middle Prong Little Pigeon River	Middle Prong Little Pigeon River		MPL_1		1373		x		

NPS 133/129677, September 2015

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov