AN ASSESSMENT OF WATER QUALITY ALONG THE GEORGIA SECTION OF THE APPALACHIAN TRAIL

C.N. Sytsma[1], D. Markewitz[1], A. Milewski[2], L.A. Sutter[1], M.E. Lott[3], and E.K. Lipp[3]

AFFILIATIONS: [1] Warnell School of Forestry and Natural Resources; [2] Department of Geology; [3] Department of Environmental Health Sciences, University of Georgia
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Abstract. The Appalachian Trail (AT) attracts over two million visitors annually, many of whom rely on water sources along the trail. While the importance of following proper waste disposal methods are stressed to hikers, prior studies have found *Escherichia coli* levels exceeding government standards in marked shelter sources within the Great Smoky Mountains National Park section of the AT. Little data exist on surface water quality along Georgia's section of the AT so here we report results on *E. coli* levels and nutrient concentrations from 20 sites along the trail. These sites include official AT water sources, streams directly near the trail, and streams farther away from hikers' influence. Specific conductivity values for all streams ranged from 6.7 to 15.2 µS/cm, pH from 5.07 to 6.49, and dissolved oxygen from 68.2 to 99.9%. Thirteen of the 20 samples had *E. coli* >1 CFU/100ml with only one (Rock Top Spring) >100 CFU/100ml. Water quality metrics were not related to distance from trail or privy. In addition, the Na:(Na+Ca) ratio was evaluated to estimate groundwater to surface water contributions of sources, but at this high flow time of year, few differences were evident. *E. coli* data support treating all water prior to consumption. Additionally, sample collections are planned for June and September after more intensive trail use and during lower flow conditions.

BACKGROUND

The Appalachian Trail (AT) attracts over two million visitors annually, many of whom begin in Georgia to hike northbound. While the importance of following proper waste disposal methods are stressed to hikers, the combination of sparse trash cans, privies, and high numbers of hikers can lead to occasional littering and improper disposal of human waste. A consistent issue reported by hikers on the AT is gastrointestinal distress, which can be attributed to the consumption of untreated water from backcountry sources. Despite the fact that most hikers are aware of the potential for abdominal distress, some still presume that water acquired from sources at high altitudes with relatively few hikers will be inherently clean, and thus consume untreated water on a regular basis (Boulware 2004).

Escherichia coli, however, has been measured up to 123 CFU/100mL in marked water sources along the AT in Great Smoky Mountains National Park (Reed and Rasnake 2016). While this finding contradicts the idea that backcountry water sources are inherently clean, it is possible that the stretch of the AT passing through this highly visited park is more likely to be contaminated, as there were nearly 100,000 backcountry campers in the park in 2019 (USNPS 2019).

As such, there is a need to assess water quality along the entirety of the AT in order to definitively say whether or not marked water sources can be used without treatment, and whether or not there are certain source types that are more or less safe than others. We hypothesized that sources farther from the AT trail, shelters, or privies would have lower *E. coli* concentrations. Further, we expected sources with greater groundwater contributions relative to surface water inputs would have lower *E. coli* concentrations.

METHODS

Sample site selection included every marked shelter source (11), named streams that the trail crossed (8), one marked spring along the trail, and two additional streams that were not on the AT (Fig. 1). Sites along the AT were chosen from the Georgia AT Club's list of water sources, and the two non-AT sources (Byron Reece Trailhead and Raven Cliff Falls) were chosen to represent water along highly trafficked, non-AT trails. The first sampling was completed in March 2019 and two additional sampling are planned for June and September 2019.

After hiking to sampling sites, pH, %dissolved oxygen (DO), specific conductivity (SPC), and temperature were measured with a YSI Professional Plus 2030 Multiparameter Prove (YSI, Yellow Springs, OH). Thereafter, two samples were collected in 250mL Nalgene bottles and stored on ice in a small cooler during transit. Every effort was made to collect samples in a manner that minimized storage time prior to processing in the laboratory. The nature of most sample site locations, however, required storage up to 10 hours in ice-filled coolers during transit back to the laboratory, where samples were then stored at 4ºC overnight. Total storage time from stream to filtering never exceeded 24 hours, and samples were kept cool for the entirety of that period.

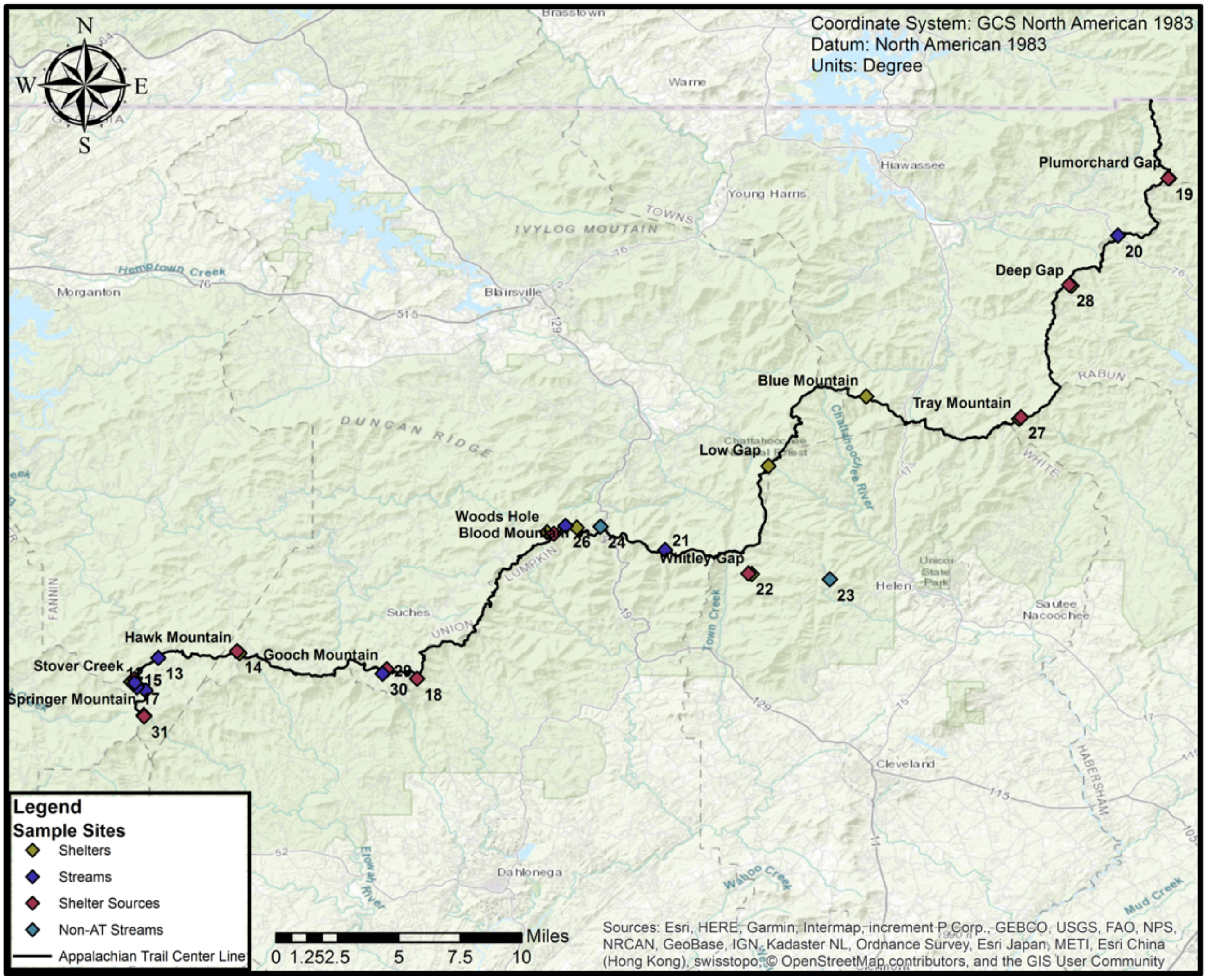

Figure 1: Sample site locations along the Georgia section of the Appalachian Trail

Escherichia coli Analysis

After sample retrieval and storage overnight, one of the two bottles taken from each site was used for *E. coli* analysis. Samples were vacuum filtered through a 0.45-µm nitrocellulose gridded membrane, which was then applied to a prepared mTEC agar plate and incubated for 24 hours in accordance with EPA Method 1603 (USEPA 2014). Two plates were made for each sample site, and 100 mL was filtered for each plate due to the expected low bacteria concentrations of the samples. Colony-forming units of *E. coli* were counted the following day, and negative and positive control plates were successfully run for each batch of samples.

Nutrient and Metal Analysis

The remaining 250-mL sample from each site was vacuum filtered through a 0.4µm pore size polycarbonate filter (Whatman Nucleopore) into two 60-mL bottles. One 60-mL sample of filtered water from each site was acidified with 0.2-mL concentrated HNO_3, and all samples were frozen until analysis. Following the first sampling of all sites, non-acidified samples were thawed in a water bath and analyzed for cation concentrations (Ca, Mg, Na, K, NH_4) with a Dionex 2100 ion chromatograph with CS16 column (Thermo Scientific, Waltham, MA). Remaining filtered water from the non-acidified samples will be processed for anions, and acidified samples will be processed for heavy metals using Inductively Coupled Plasmosis. The same analyses will be performed following subsequent collections.

Data Analysis

Data analysis for the first sampling included univariate statistic for all variables. Data were evaluated for normality. Thereafter, a one-way analysis of variance was used to test for differences in *E. coli*, chemical attributes, and Na:(Na+Ca) based on water source. Data analyses were completed in Excel.

RESULTS

Stream Chemical Attributes

Specific conductivity values for all streams were low, ranging from 6.7 to 15.2 µS/cm. Values for pH ranged from a low of 5.07 up to 6.49, and percent dissolved oxygen ranged from 68.2 to 99.9% (Table 1). No trends were found between source type and any of the three chemical quality types.

Escherichia coli

Thirteen of the sample sites had at least one colony forming unit of *E. coli*, exceeding EPA maximum level goals of 0 coliform CFU/100mL (USEPA, 1989). Rock Top Spring was the only site with counts exceeding 10 CFU/100mL. Counts of 300 CFU/100mL were observed for each plate from that site before they were both determined to have too many to continue. (Table 2).

A second attempt to run the sample from Rock Top Spring decreased the volume filtered from 100 to 10 mL, yielding a count of 45 CFU/100mL. Yet, the increased holding time for the sample may have impacted the results. As such, the approximate numbers from the first analysis of Rock Top Spring's water are used for discussion. No trends between source type and bacteria levels were found.

Cations

Cation data found that NH_4 was below detection limit in all sites (<0.1 mg/L), while Ca and Na ranged between 0.37 mg/L and 1.51 mg/L, and 0.51 mg/L and 1.35 mg/L, respectively (data not shown). Na:(Na+Ca) ratios ranged between 0.404-0.585 and had no correlation with pH (Table 3). Once again, no trends were found correlating source type to any cation concentrations or the ratio.

DISCUSSION

The March 2019 stream and spring water chemical attributes from these 22 sites along the Georgia section of the AT were mildly acidic, had relatively low SPC, and were well oxygenated (i.e., high %DO). These findings are consistent with similar low order streams in this region (NWQMC 2019).

Bacterial data from this study suggest that using untreated water from backcountry sources poses a significant risk of *E. coli* contamination, as the majority of sites sampled had detectable levels of bacteria. The presence of *E. coli* indicates that fecal contamination is likely in a water source, whether that contamination be from human or animal waste (Odonkor and Ampofo, 2013). Presence of the specific genus of *E. coli* bacteria also means there may be other similar strains in the water (Odonkor and Ampofo, 2013). As such, it is highly recommended that all hikers treat collected water by any recommended method, whether that be filtration, boiling, chemical treatment, or UV treatment.

Table 1. *In situ* water chemistry data from twenty sites along the Georgia section of the Appalachian Trail collected in March 2019 using a YSI XXX probe. SPC-specific conductance; DO-dissolved oxygen.

	pH	SPC (µS/cm)	%DO
Mean	5.77	11.64	86.33
Max	6.49	15.2	99.9
Min	5.07	6.7	68.2
Range	1.42	8.5	31.7
Std Dev	0.40	2.41	10.24

Table 2. *Escherichia coli* Colony Forming Units for sites along the Georgia section of the Appalachian Trail and two reference sites collected in March 2019.

Sample Site	Site Type	E coli (CFU/100 mL)	
		Rep 1	Rep 2
Stover Creek A	Stream	0	0
Dick's Creek Parking	Stream	0	0
Whitley Gap Shelter Source	Shelter	0	0
Byron Reece Trailhead Stream	Non-AT Stream	0	0
Woods Hole Shelter Source	Shelter	0	0
Tray Mountain Shelter Source	Shelter	0	0
Gooch Mountain Shelter Source	Shelter	0	0
Chattahoochee Gap	Stream	0	0
Blue Mountain Shelter Source	Shelter	0	0
Hawk Mountain Shelter Source	Shelter	0	1
Stover Creek Shelter Source	Shelter	0	1
Stover Creek B	Stream	0	1
Gooch Gap Campsite (Walden Creek)	Stream	0	1
Deep Gap Shelter Source	Shelter	1	0
Three Forks	Stream	1	1
Plum Orchard Gap Shelter Source	Shelter	1	1
Low Gap Shelter Source	Shelter	1	1
Slaughter Creek	Stream	1	2
Springer Mountain Shelter Source	Shelter	2	2
Blackwell Creek	Stream	5	3
Raven Cliff Falls Parking Lot	Non-AT Stream	6	3
Rock Top Spring	Stream	**> 300**	**> 300**

Table 3. Ratio of Sodium:(Sodium + Calcium) and pH for 20 sites along the Georgia section of the Appalachian Trail and two reference sites collected in March 2019. Lower values of the ratio indicate greater groundwater contributions (i.e., higher rock Ca) while values closer to one indicate surface water sources (i.e., sea salt rainwater contributions of Na (Drever 1997).

Sample Site	Na: (Na+Ca)	pH
Tray Mountain Shelter Source	0.499	5.07
Rock Top Spring	0.524	5.21
Springer Mountain Shelter Source	0.522	5.30
Byron Reece Trailhead Stream (Non-AT)	0.554	5.32
Stover Creek A	0.585	5.38
Stover Creek B	0.494	5.43
Stover Creek Shelter Source	0.528	5.50
Woods Hole Shelter Source	0.474	5.51
Plumorchard Gap Shelter Source	0.545	5.61
Whitley Gap Shelter Source	0.572	5.63
Three Forks	0.520	5.78
Chattahoochee Gap	0.581	5.83
Gooch Mountain Shelter Source	0.559	5.97
Hawk Mountain Shelter Source	0.466	6.01
Slaughter Creek	0.422	6.02
Dick's Creek Parking	0.536	6.04
Low Gap Shelter Source	0.468	6.07
Raven Cliff Falls Parking Lot (Non-AT)	0.565	6.16
Blue Mountain Shelter Source	0.525	6.20
Gooch Gap Campsite (Walden Creek)	0.404	6.33
Blackwell Creek	0.470	6.37
Deep Gap Shelter Source	0.514	6.49

The one site (Rock Top Spring) with *E. coli* levels exceeding 300 CFU/100mL presented no obvious source (i.e., nearby privy) as to why it had such high bacteria levels. While the majority of the sites sampled were headwater streams, Rock Top Spring appeared visually different from the other seeps found along the trail as it emerged parallel to the mountain slope and did not stem from along a valley between two hillslopes. Current chemical analysis for source determination during this high flow March sampling did not clearly differ from other sites (Table 3).

There was a high number of salamanders or newts found in the small pond created by the source, but there are no published reports suggesting that amphibians carry *E. coli*. If exceptionally high levels of bacteria are found in the site during summer sampling, we plan to have the bacteria analyzed for strain and organism source information (Stoeckel and Harwood 2007). In order to better understand the site, an additional sample location just north of Plumorchard Gap will be added, as the Georgia AT Club indicates that there is another spring between the northernmost shelter and North Carolina.

The current samples have all been taken during the area's high-flow period, which may dilute site differences found during lower flow periods. In the Great Smoky Mountains National Park, higher bacteria levels were found during the middle of summer (Reed and Rasnake, 2016). We expect that in future samplings during lower flows concentrations, *E. coli* will be higher. These expected higher bacteria concentrations may potentially better reflect trends, as variance in bacteria levels will likely increase. Additionally, as flow declines, we expect many concentrations to increase, and we will re-investigate comparison of water chemical attributes and bacterial concentration. Further, as flows decrease and hiker activity increases, indicators of contamination and proximity to privies and campsite may show clearer relationships.

Summer chemical data also will be used to attempt to discern the predominant water source for all sample sites between surface flow, interflow, and deep groundwater. The Na:(Na+Ca) ratio reflects these contributions with lower values of the ratio indicating greater groundwater contributions (i.e., higher rock Ca) while values closer to 1 indicate surface water sources (i.e., seasalt rainwater contributions) (Drever 1997).. Proposed future analysis of metals or geochemical traces (i.e., Si) for each site will contribute to these interpretations along with historic USGS groundwater and precipitation chemistry data.

The current values of the Na:(Na+Ca) ratio near 0.5 reflect relatively even surface and groundwater contributions. We expect the ratio to decline as surface and interflow decline with soil moisture depletion through the summer. This may be beneficial for both stream and spring water quality if groundwater is sufficiently deep. On the other hand, if groundwater baseflows are low and episodic near surface inputs during high precipitation events increase *E. coli* concentrations may temporarily increase, particularly if hikers dispose of their waste on the hillslopes when privies are overcrowded.

CONCLUSIONS

A March 2019 sampling of 20 water sources along the Georgia section of the Appalachian Trail found relatively low conductivity solutions with limited concentrations of *E. coli,* with the exception of Rock Top Spring. These concentrations did not correlate with distance from campsites or privies. Despite low *E. coli* concentration, the drinking water standard is for zero *E. coli*, so water treatment is recommended for hikers. No differences were found between the 20 AT sources and the two non-AT reference sources.

We plan two future samplings of these water sources during June and September when flows are lower and summer hiker activity has been higher.

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