Analysis of Long-term Benthic Trends in the Rivanna Watershed

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Introduction

Background

The Rivanna Conservation Alliance's (RCA) Benthic Monitoring Program (formally known as 'StreamWatch') is a volunteer, community-supported surface water quality monitoring program. The program collects data on benthic macroinvertebrates, the small organisms that live along the bottom of streams and rivers, at 50 long-term monitoring sites twice annually throughout the Rivanna River Watershed. These organisms are "biological indicators" with known pollution-tolerance values and have been used in bioassessment surveys for several decades (Burton and Gerritsen, 2003). RCA's Benthic Monitoring Program is certified by the Virginia Department of Environmental Quality (DEQ) at Level III, the highest level attainable for citizen monitoring groups. Level III status means that RCA's data are equivalent in quality to those collected by the state agency and can be used to support many essential water quality tracking and decision-making functions.

Benthic scores and the associated stream health characterizations are reported annually to state, city, and county officials, and are presented to the public via an annual Stream Health Report. Changes in the stream health characterization at individual sites, as derived from the comparison to prior year benthic data, are noted in the reports. While it is important to highlight and investigate the potential reasons behind short-term shifts in stream health, periodic assessments of long-term trends in benthic scores are also necessary to determine if stream health is changing more gradually. As the benthic data record now extends over 15 years at the majority of sites, it is an opportune time to evaluate the long-term trends in biological health of the Rivanna River and its tributaries.

This report provides a brief background of the benthic program and site selection, data collection methods, and the statistical analyses used to determine long-term trends. Trend results are summarized for individual sites and for the aggregation of all sites within the watershed. Graphs of the data and trends, as well as a map outlining the watershed boundaries, are provided for sites with statistically

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significant trends, along with a brief discussion of watershed factors that may have influenced those trends.

Methods

Long-Term Monitoring Sites

The long-term monitoring program currently consists of 50 sites selected to represent a cross section of Rivanna Watershed streams. The long-term site set consists of 41 representative tributary sites, three reference tributary sites, and six sites on the mainstem of the Rivanna. The selection of the 41 representative tributary sites was driven by three considerations: hydrogeographic representativeness, land use/land cover representativeness, and placement of sites near stream mouths wherever possible to capture the majority of upstream influences.

StreamWatch began collecting benthic macroinvertebrate samples at 24 of the representative sites in 2003. From 2012-2013, StreamWatch expanded the long-term monitoring program to include a total of 50 sites. The inclusion of additional sites improved both hydrogeographic and land use representativeness of the site set. RCA staff and volunteers sample benthic macroinvertebrate communities at the 50 sites two to four times a year during seasonal periods that correspond to DEQ's biological sampling windows (spring: March 1 - May 31; fall: September 1 - November 30).

Stream Condition Index

The monitoring program staff and volunteers collect benthic macroinvertebrate samples per the Virginia Save Our Streams Rocky Bottom Benthic Macroinvertebrate Method (VASOS-RBBMM). However, RCA analyzes benthic samples per a different and more robust protocol - the Virginia Stream Condition Index (VSCI). The VSCI requires identification of all organisms to the taxonomic level of "family" (except for individuals in the sub-class Oligochaeta, which are identified at that level), and generates eight metrics that are averaged to produce a final index score that ranges from 0 to 100 (Burton and Gerritsen, 2003). If the stream score is below 60, the stream is considered "impaired," meaning that it does not meet the Virginia water quality standard for aquatic life use, and is considered for placement on Virginia's 303(d) list of impaired waters.

Due to differences between RCA sampling and sorting protocols and those used by DEQ, RCA calls the family-level index the Adapted Stream Condition Index (ASCI). Co-sampling conducted by RCA and DEQ suggests that ASCI and VSCI scores are comparable despite differences in protocol. A method comparability analysis completed in 2009 by StreamWatch and DEQ biologists determined that there were no statistically significant differences between scores generated by RCA (ASCI) and scores generated by DEQ (VSCI). For purposes of this report, we will refer to the Stream Condition Index scores as 'ASCI'.

Data Organization

The long-term dataset consisted of samples collected by RCA/StreamWatch, beginning in 2004 and continuing through 2019. Twenty-five samples collected by DEQ were incorporated into the dataset for sites that are co-located with RCA monitoring locations, comprising approximately 2.2% of the long-term dataset. In order to ensure consistency in data for long-term trend analysis, samples collected outside of the seasonal sampling windows (spring: March 1 - May 31; fall: September 1 - November 30) were excluded and duplicate or replicate samples were averaged to compute a single score for each site for each season.

Statistical Analysis
Long-term trends in ASCI scores for the 50 sampling sites were determined by applying the Seasonal Kendall Tau test (Hirsch and Slack, 1984), a non-parametric test that accounts for seasonal data with serial dependence. Sen's method (Sen, 1968) was used to establish a single trend at each site, with statistical significance of the trends defined by $p<0.05$. Length of record varied between sites, with the longest record from 1999-2019 (LSD01) and the shortest records from 2013-2019 (IVC09, QTR03, and XLI01).

We applied a t-test to the population of the site-level ASCI trends to establish if the mean trend for all 50 sampling sites is significantly different from zero, with significance once again defined by $p<0.05$.

Hydrology is known to exert some degree of influence on benthic metrics, so a secondary analysis involved adjusting the ASCI scores based on river discharge prior to the sampling dates. The discharge time series for the Rivanna River at Palmyra (USGS 02034000) was used to represent the general flow conditions within the watershed. Candidate hydrological flow metrics were taken from The Nature Conservancy's Indicators of Hydrologic Alteration guide (Version 7.1, April 2009), and an initial analysis found that three metrics exhibited the greatest degree of correlation with benthic scores: baseflow index (defined as the 7-day minimum flow divided by the mean flow for the year), 7-day minimum flow, and 7-day maximum flow. The 7-day minimum flows represent 'baseflow', which are stream conditions after a rainfall event or snowmelt period has passed and associated surface runoff from the catchment subsided (The Nature Conservancy, 2009). The 7-day maximum flows represent periods which include 'stormflow', which are elevated stream conditions during or subsequent to a rainfall or snowmelt event.

We evaluated each of these over 6-month and 12-month windows that preceded each sampling date at each site. The minimum flow over a 7-day period for the 6-month window preceding sample collection was found to have the strongest and most widespread correlation with ASCI scores. The correlation was negative, indicating that elevated baseflow conditions (likely maintained by frequent precipitation events) are associated with lower ASCI scores. At each site, we performed a linear regression between the 6-month, 7-day minimum flow values and ASCI scores and applied the Seasonal Kendall Tau test to the residuals. Trend analysis of the flow-adjusted ASCI scores is intended to provide a measure of underlying trends in ASCI scores that are independent from hydrological variability.

Results and Discussion

Individual and overall trends were similar for the ASCI and flow-adjusted ASCI data sets indicating hydrologic variability during the study period had only a minor impact on the long-term trends at the 50 sites. Individual ASCI and flow-adjusted ASCI trends ranged from -3.00 and +3.00 per year (ASCI scores range from zero to 100), with the majority of sites having a positive trend (30 and 34 positive trends for ASCI and flow adjusted ASCI, respectively). The mean trend for all sites was similarly positive for ASCI and flow-adjusted ASCI data (0.21 and 0.31 per year, respectively), however only the flow-adjusted trend was statistically significant. The benthic data suggest that on average stream health is improving at these 50 sites, although the individual site trends reveal that both improvements and declines are present in subwatersheds.

Significant positive trends were observed for both ASCI and flow-adjusted ASCI data at 4 of the 50 sites (BKI01, MSC04, MWC03 and RVN01). A significant negative trend was observed for the ASCI data at only one site (MSH01) and a marginally significant ($p=0.05$) positive trend was observed only for the flow-adjusted data at one site (CYC01). For the individual sites with statistically significant trends for ASCI data, a summary of the data and a brief qualitative discussion of potential factors contributing to the trends is provided in the following section. All statistics are presented for unadjusted ASCI scores. While the large majority of sites (90%) did not have statistically significant trends, evaluation of individual plots revealed a high degree of interannual variability indicating it may take additional years of sampling to establish significant trends at individual sites and at the watershed scale. RCA plans to conduct long-term benthic trend assessments every three years with the inclusion of new data. Future reports will include additional quantitative analyses of factors that may be contributing to significant trends at RCA's benthic monitoring sites (e.g., changes in impervious cover, BMP installations, changes in localized streamflow).

Moores Creek (MSC04)

In Moores Creek, benthic ASCI scores averaged 26.99 and ranged from 13.07 (spring 2005) to 46.08 (fall 2019). This site had the largest statistically-significant positive increase over time (1.07 per year, $p<0.01$; Figure 1). The benthic monitoring site is located immediately downstream of the Moores Creek Advanced Water Resource Recovery Facility (a Wastewater Treatment Plant), which is operated by the Rivanna Water and Sewer Authority. The facility handles all of the urban areas of Charlottesville and Crozet, treating an average of 10.24 million gallons of wastewater per day (https://www.rivanna.org/wastewater/). From 2009-2012, the facility implemented upgrades to enhance nutrient removal from wastewater prior to its discharge into Moores Creek. Benthic ASCI scores collected at this monitoring location noticeably improved following these upgrades (Figure 1). It is important to keep in mind that Moores Creek lies within a heavily urbanized subwatershed (Figure 2) and though improving, remains impaired according to the DEQ's threshold.

Rivanna River at Milton (RVN01)

Benthic ASCI scores collected on the mainstem Rivanna River at Milton averaged 56.38 and ranged from 25.34 (spring 2009) to 76.71 (fall 2013). The ASCI scores at RVN01 are significantly improving over time (1.04 per year, $p=0.02$); Figure 1). Ten samples collected at this location scored above the impairment threshold (ASCI score = 60), most of which were collected from 2012 - present. The facility upgrades completed in 2012 at the Moores Creek WWTP, which is located 5.8km (approximately 3.6 miles) upstream of RVN01, may be a factor in the improving water quality at this site.

Buck Island Creek (BKI01)

Benthic ASCI scores in Buck Island Creek averaged 64.46 and ranged from 46.09 (fall 2007) to 76.24 (spring 2015) and displayed a gradual improvement over time (0.84 per year, $p=0.04$; Figure 1). While there is a bit of variability, most ASCI scores were above the impairment threshold. According to the Thomas Jefferson Soil and Water Conservation District, the Buck Island Creek subwatershed had 112 acres of riparian buffers created and 6.4 miles of streams protected from livestock access over the last 10-15 years (L. Longanecker, personal communication, February 22, 2021). It is possible that this significant installation of best management practices has contributed to improving ASCI scores at this site.

Meadow Creek (MWC03)

In Meadow Creek, benthic ASCI scores averaged 28.58 and ranged from 17.13 (spring 2004) to 54.33 (fall 2013) and indicated a gradual increase over time (0.56 per year, $p=0.02$; Figure 1). The sampling site is downstream of two significant stream restoration projects. In 2003, the University of Virginia restored 1,200 linear feet of Meadow Creek that had been piped, back to a surface stream with floodplain habitat and a 0.75-acre lake that can detain up to 1.45 million gallons of stormwater. The lake is equipped with a forebay that allows routine removal of collected sediment. This restoration led to annual reductions of

29.21 lbs. of phosphorus, 60.75 lbs. of nitrogen, and 7.38 tons of sediment (J. Sitler, personal communication, February 22, 2021). RCA's sampling site is approximately 6.1 km (3.8 miles) downstream of this restoration.

RCA's sampling site is also 2.7 km (approximately 1.7 miles) downstream from a stream restoration project completed in 2013 by The Nature Conservancy and the City of Charlottesville. The project restored over 7,000 linear feet of the stream channel, permanently protects over 70 acres of riparian buffer forest and wetlands, and is estimated to reduce 501 lbs. of phosphorus, 553 lbs. of nitrogen, and 1,790 tons of sediment per year (Cho and Graham, 2014). Improvements in benthic ASCI scores in Meadow Creek may be associated with these sizable restoration projects. However, it is important to note that the Meadow Creek subwatershed, similar to Moores Creek, is heavily urbanized and though improving, remains below DEQ's impaired status threshold.

Marsh Run (MSH01)
In Marsh Run, benthic ASCI scores averaged 63.46 and ranged from 48.80 (fall 2018) to 76.25 (fall 2012). Benthic ASCI scores in Marsh Run have shown a decline over time (-2.67 per year, p=0.04; Figure 1). The flow-adjusted ASCI also had a negative trend (-2.27 per year), however it was not statistically significant (p=0.10), indicating hydrologic conditions could have contributed to this trend. This stream is heavily incised, characterized by high banks, and is subject to excessive erosion during heavy precipitation and high-flow events. Aerial imagery of the Marsh Run watershed indicated the possible presence of livestock and a few deep eroded gullies next to the stream. Stream scouring and excessive sedimentation could be contributing to declining ASCI scores at this location. However, it should be noted that other sites in this study lie on incised and cattle-impacted streams, but were not found to have statistically significant changes in ASCI scores. It is also notable that the record at this location consists of nine years of data compared to 14 to 16 years of data at the other sites with statistically significant trends. (Table 1).

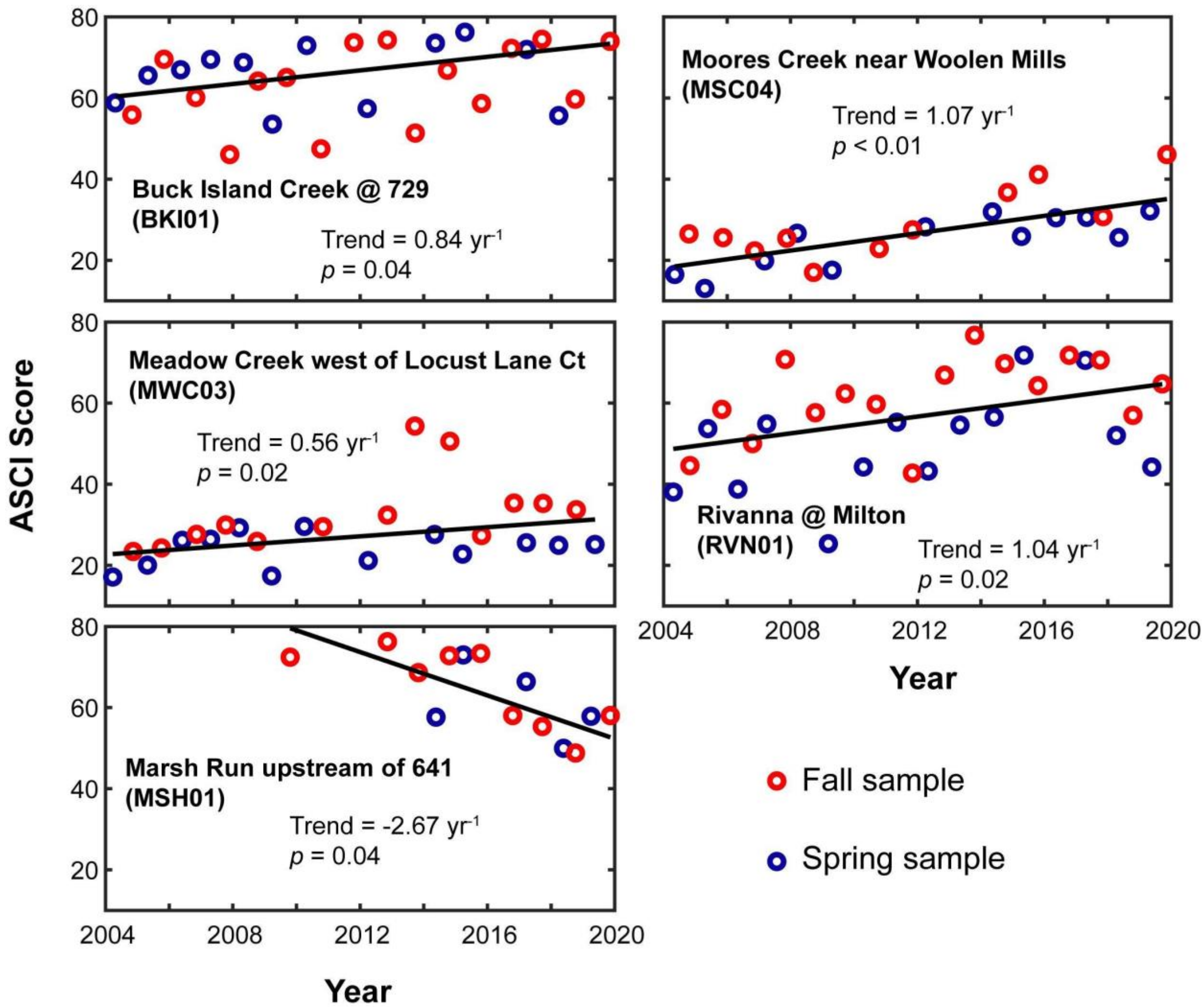

Figure 1. Seasonal unadjusted ASCI scores trendlines for sites with significant trends (p<0.05).

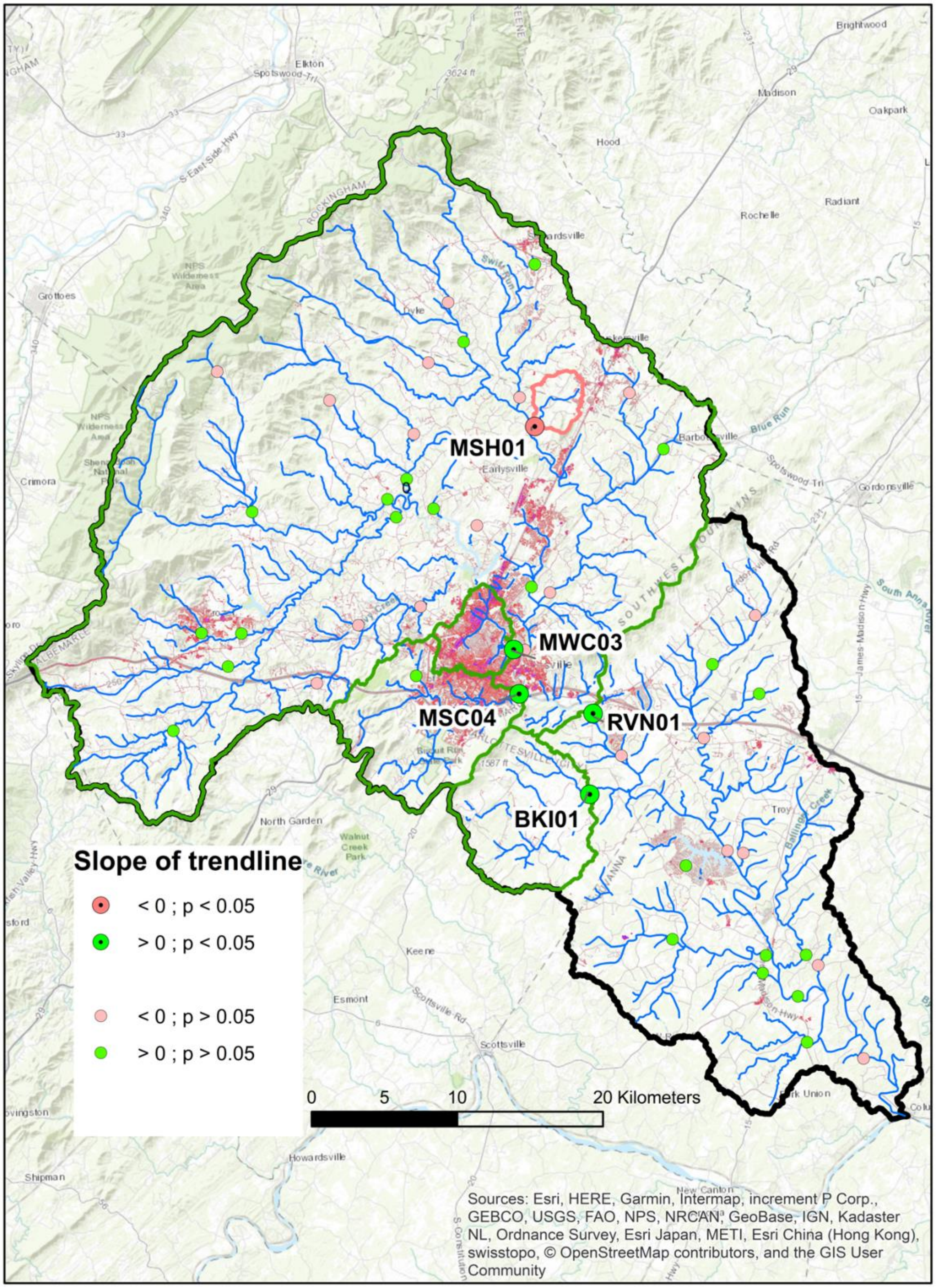

Figure 2. Rivanna Watershed and benthic sampling sites. Sites are distinguished based on the slope direction (negative slope (<0) = red; positive slope (>0) = green) and the significance of the trend (larger circle with center dot = significant; smaller circle = insignificant). The background image is impervious coverage for 2016.

Table 1. Summary of site records and statistically significant ($p<0.05$) ASCI trends. ASCI scores can range from zero to 100.

Site ID	Site Name	Record Period (years)	Samples in Record (#)	ASCI trend (change in score per year)	Flow-adjusted ASCI trend (change in score per year)
BKI01	Buck Island Creek @ 729	16	28	0.84	0.88
CYC01	Carys Creek @ 15	14	24	-	0.72
MSC04	Moores Creek near Woolen Mills	15	23	1.07	1.13
MSH01	Marsh Run upstream of 641	9	14	-2.67	-
MWC03	Meadow Creek west of Locust Lane Ct	15	26	0.56	0.52
RVN01	Rivanna at Milton	16	30	1.04	1.08
Mean for all 50 sites (min/max)		13 (6/21)	23 (10/37)	-	0.31

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