Lefthand Creek Field Project Report

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Abstract

Though many stream restoration projects are undertaken in the United States each year, few publish monitoring data after the fact (Bernhardt *et al.* , 2005). We sampled three restored and three reference sites in the Lefthand Creek Watershed to monitor the progress of restoration in terms of physical, biological, and chemical components. We observed several statistically significant differences between reference and restored sites in biological measurements. There were also some statistically significant improvements in restored sites since the beginning of the restoration work. However, most parameters we looked at were inconclusive. Including additional reference and restored sites, in conjunction with obtaining multi-year data, will be required to draw conclusions on the effectiveness of these restoration projects as they relate to ecosystem structure and functioning.

1 Background

The Lefthand Watershed Oversight group is a non-profit organization that monitors and restores a number of sites along Lefthand Creek (Boulder County, CO) with the goal of protecting and improving ecological structure and function. They are primarily concerned with mitigating any impacts of acid mine drainage and preventing future flood damage. Restoration projects often involve bank stabilization, channel rerouting, and establishment of riparian vegetation. Our project is aimed at increasing understanding around the effects of the restoration efforts on measures of ecological structure and function while simultaneously contributing to the ongoing monitoring of Lefthand Creek. In addition to the data we collected, we accessed site assessments from the previous year (2016) at the same time. There is also one USGS stream gauge and two Colorado Division of Water Resources stream gauges along Lefthand Creek, so further incorporation of long-term flow data is possible in order to better understand the watershed dynamics in Lefthand Canyon.

Riparian health is essential for the functioning of streams. Riparian vegetation stabilizes stream banks, filters sediment, reduces nutrient deposition in streams, provides instream food sources, regulates stream water temperature and light availability, and serves as a conduit for species migrations (Barling & Moore, 1994). While it is widely accepted that instream chemical processes are related to watershed land use and riparian vegetation, studies have had difficulty documenting chemical responses to stream restoration efforts. Due to the dynamic processes that control instream water quality and chemistry, it is difficult to model stream response to restoration efforts because each stream has different influences. These influences on stream water quality have varying timeframes in which changes in the environment display responses, causing a lag in stream response (Dosskey *et al.* , 2010). Through analyzing Left Hand Creek restoration efforts, we hope to provide a chance to document changes in water quality in response to restoration of riparian vegetation and lend insight to how these changes alter in stream biogeochemical processes.

Physical aspects of streams such as flow rate and temperature can also affect stream chemistry and biota. Physical diversity in all directions creates diversity of habitat and thus biological diversity. Different organisms prefer different flow regimes, thermal regimes, and substrate materials. As a result, sites that include many different habitats due to formations such as pools and riffles, partial blockages, or varying canopy cover will be more diverse than homogenized channels (Allan & Castillo, 2007). Many stream restoration projects aim at some kind of physical modification, such as bank stabilization or floodplain reconnection. These kind of changes are among the most expensive parts of a restoration effort, and so it is especially important that they have the desired effect (Bernhardt *et al.* , 2005). Since one of the goals of the LWOG's projects is to restore ecological structure and function, we would expect to see restored sites encompassing a large variety of habitat conditions from mountainous to plain-situated sites, on a trajectory towards reference conditions. However, one of the major challenges of stream restoration is establishing a reference condition or desired ‘restored’ state. This is particularly tricky in light of the fact that humans have been extensively modifying streams in this area for hundreds of years, and data documenting pristine stream conditions is difficult to find. Since many of stream modifications involve channel homogenization (e.g. for transporting lumber) or destruction of bank conditions (e.g. grazing cattle), finding a nearby section of river as a comparison point may be completely impossible (Allan & Castillo 2007 and FISRWG, 1998).

As LWOG’s restoration projects have mostly been implemented within the past 10 years, the data obtained from these systems should be viewed as another time step in the recovery trajectory. Thus, repeated monitoring can provide information about the rate and degree of recovery, hopefully wherein ecological structure and function improves gradually with time as plants establish, terrestrial and aquatic organic matter accumulates, periphyton recolonize cobbles and boulders, terrestrial and aquatic species recolonize, stream channel morphology stabilizes, and so on.

Only 10% of stream restoration projects publish any kind of monitoring data. As a result, it is impossible to comprehensively assess the progress of stream restoration efforts in the United States. In addition, the lack of data slows progress in understanding the effectiveness of different types of restoration at meeting their goals (Bernhardt *et al.* , 2005). Contributing to LWOG’s monitoring may eventually help other nearby organizations plan and execute effective restoration projects even if it is too early in the restoration process to draw our own conclusions.

In addition to consideration of riparian health, physical parameters, and water quality as they relate to ecosystem structure and functioning, assessment of system responses to disturbance is essential to gaining an understanding of ecological resilience and resistance, and how these components may then in turn influence overall ecosystem health and functioning. Since the Lefthand Creek Watershed experienced a 100-year flood in 2013, physical, biological, and chemical data obtained from our study may supplement future analyses looking at the recovery trajectory of Lefthand Creek following this recent disturbance. Altogether, data obtained from our study and continued monitoring efforts will provide key metrics of ecosystem structure and functioning along restoration trajectories, and will seek to aid predictions of future resistance to disturbances such as floods and droughts.

2 Objectives

2.1 Research Questions

- Has restoration brought back ecological structure and function to the LHC system (comparing/stratifying across reference and restored sites)?
- How does riparian zone structure and function vary longitudinally in LHC, and across reference and restored sites?
- How does riparian habitat quality affect water quality and overall stream health?

3 Hypotheses

- Riparian zone quality and quantity (extent) is decreased in restoration sites. Overall ecosystem structure and function is increased at reference sites.
- Physical, biological, and chemical measures of ecosystem health will increase over time for restored sites.
- Plant species diversity and total vegetative cover is increased at reference sites, while non-native species and bare ground are increased in restoration sites.
- Channel modifications that increase diversity of habitat and flow increase macroinvertebrate beta diversity in each reach, while channel homogenization decreases macroinvertebrate beta diversity.
- The amount of canopy cover within a given stream reach will alter water chemistry parameters, directly affecting the diversity and abundance within benthic invertebrate communities.

Increased canopy cover decreases stream temperature, increases dissolved oxygen, and increases macroinvertebrate diversity.

- The quantity and quality of riparian vegetation will serve as a buffer to nutrient loading to Lefthand Creek.

4 Site Characterization

We sampled six sites in Lefthand Creek in Boulder County, Colorado (Figure 1), stratified across restoration and reference sites, and across an elevational gradient (i.e. mountains to plains). Sampling of our six study sites was completed over two days at each site within the month of October 2017. Sites were visited at baseflow to reduce potential variance between sampling, allowing for accurate comparison across multiple sites.

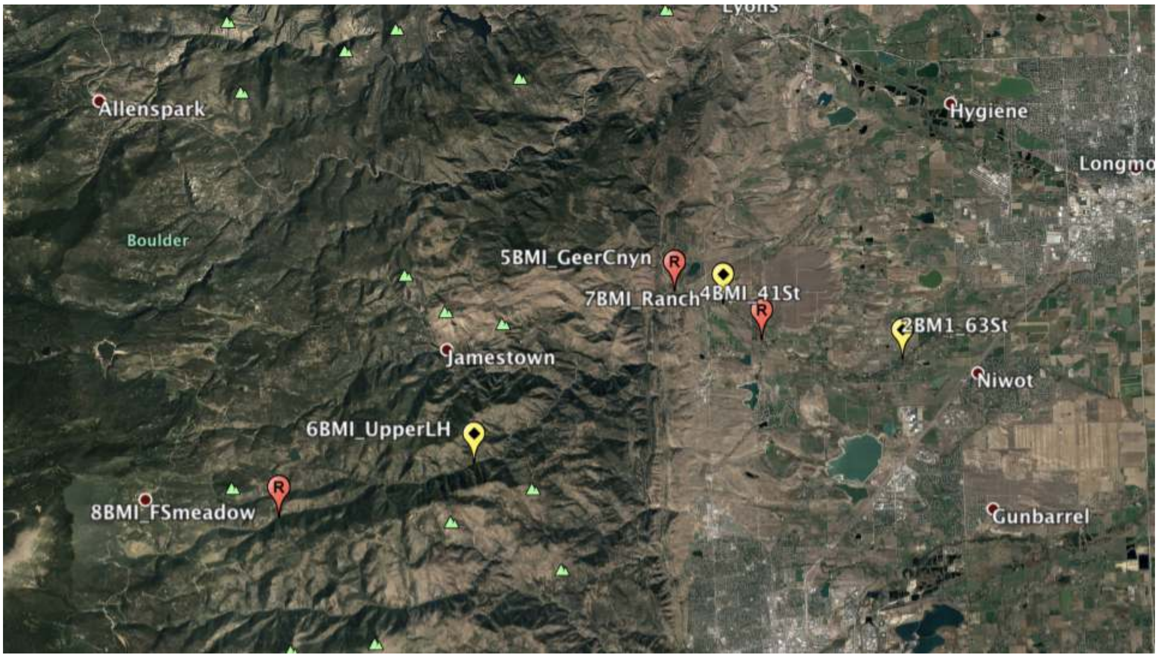


Figure 1: Map of the sites

Site BMI	Reach Name	Site type	Latitude	Longitude
2	63rd St	project site in plains	40.109125	-105.201897
4	41st St	reference site in plains	40.116456	-105.259822
7	Ranch	project site in plains	40.128009	-105.275335
5	Geer Canyon	reference site in foothills	40.132319	-105.295225
6	Upper Left Hand	project site in mountains	40.080417	-105.378736
8	Forest Service meadow	reference site in mountains	40.065633	-105.457061

5 Stream Visual Assessment Protocol (SVAP v.2)

We used the Stream Visual Assessment protocol (Bjorkland *et al.* , 2001), and it provides a low-cost but still fairly precise way to evaluate many of the physical, biological and chemical factors of interest. The protocol incorporates the following qualitative assessments, each on a scale of 1-10:

- Channel condition -incision or aggradation, bank vegetation, floodplain
- Connection
- Hydrologic alteration - flow regime, presence of dams
- Bank condition - extent of erosion
- Riparian area quantity and quality

- Canopy cover
- Water appearance - turbidity and color
- Nutrient enrichment - excessive algae growth
- Manure or human waste presence
- Pools - longitudinal variability
- Barriers to aquatic species movement
- Fish habitat complexity
- Aquatic invertebrate habitat
- Aquatic invertebrate community
- Riffle embeddedness - substrate size variability
- Salinity

Most of the assessments in SVAP(v.2) are well correlated with comparable assessments from other protocols, with the exception of hydrologic alteration, water appearance, nutrient enrichment, and manure presence. We supported the other visual assessments with quantitative measurements obtained from sampling the water (nutrient enrichment and manure presence) and flow data or data from nearby stream gauges (hydrologic alteration).

The SVAP scores for each site are shown in Figure 2, including data from both years, where available. With the exception of site 6, all the sites show improvement. In general, the reference sites show more improvement than the restored sites.

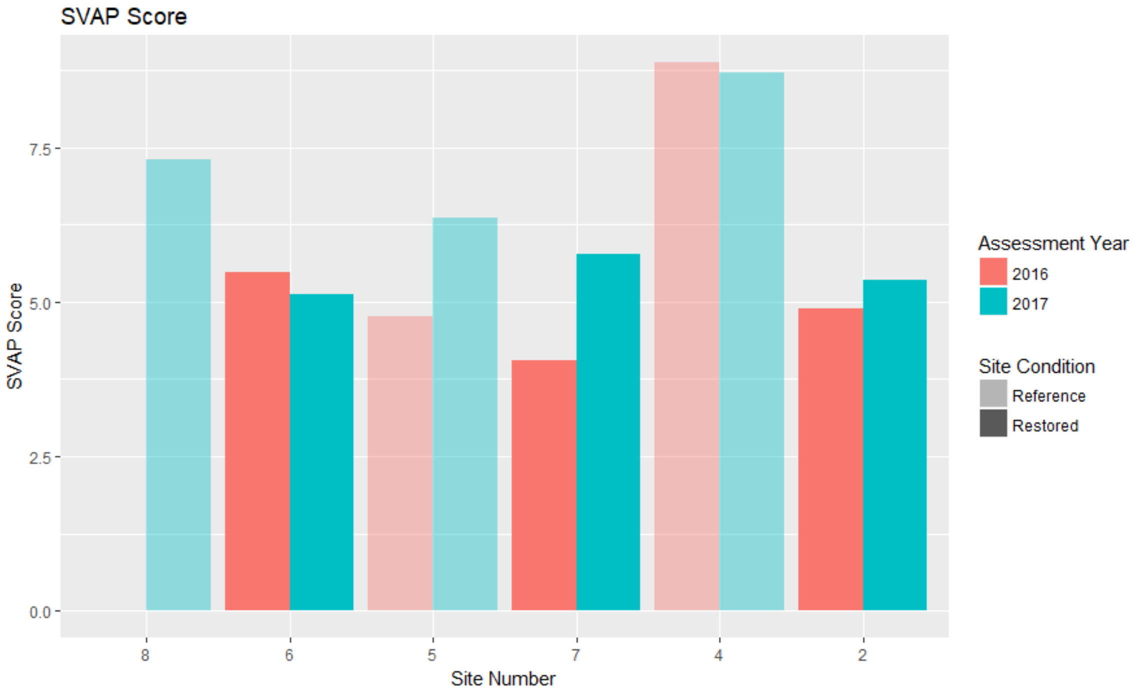


Figure 2

Most of the improvements in SVAP score between sample year were in physical parameters such a riparian area quantity, riparian area quality and channel condition. The effects of the 2013 flood were primarily associated with channel destabilization, and the early stages of the restoration efforts seem to focus on reshaping and stabilizing the banks. The SVAP improvements match a reasonable expectation of how reaches recently affected by flood might change over time.

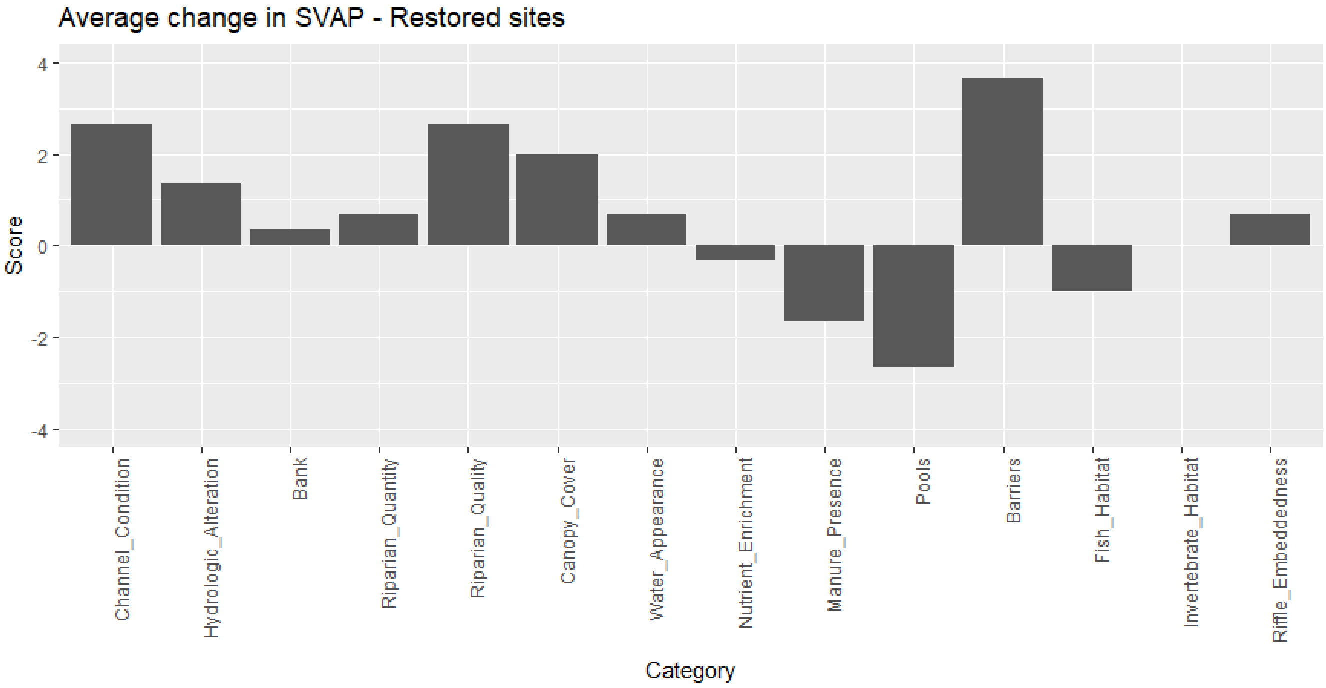
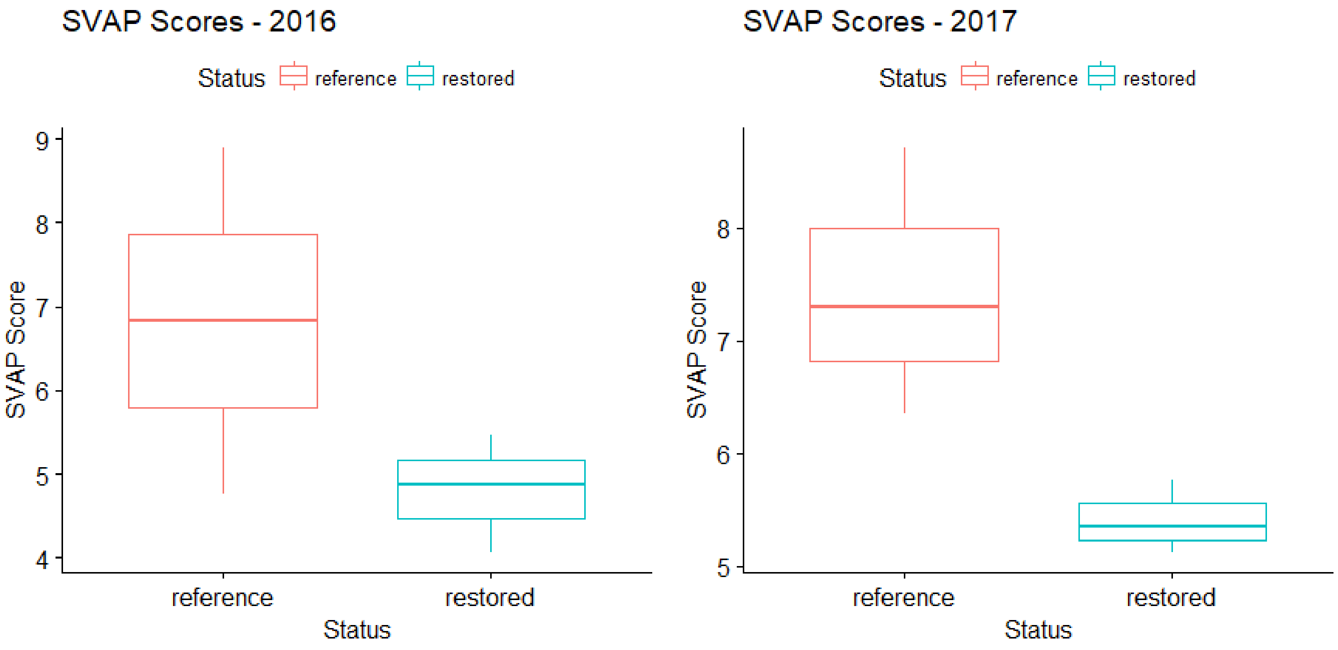


Figure 3 shows the difference between the SVAP scores for reference and restored sites in both years. This year the SVAP scores for reference sites were significantly higher than those for restored sites, in agreement with our hypothesis that reference sites would have greater ecosystem structure and function than restored sites ($\bar{x}_{\text{rest}} = 5.412$, $s_{\text{rest}} = 0.328$; $\bar{x}_{\text{ref}} = 7.451$, $s_{\text{ref}} = 1.184$, $t = 2.875$, $p = 0.023$ (Figure 3b)).

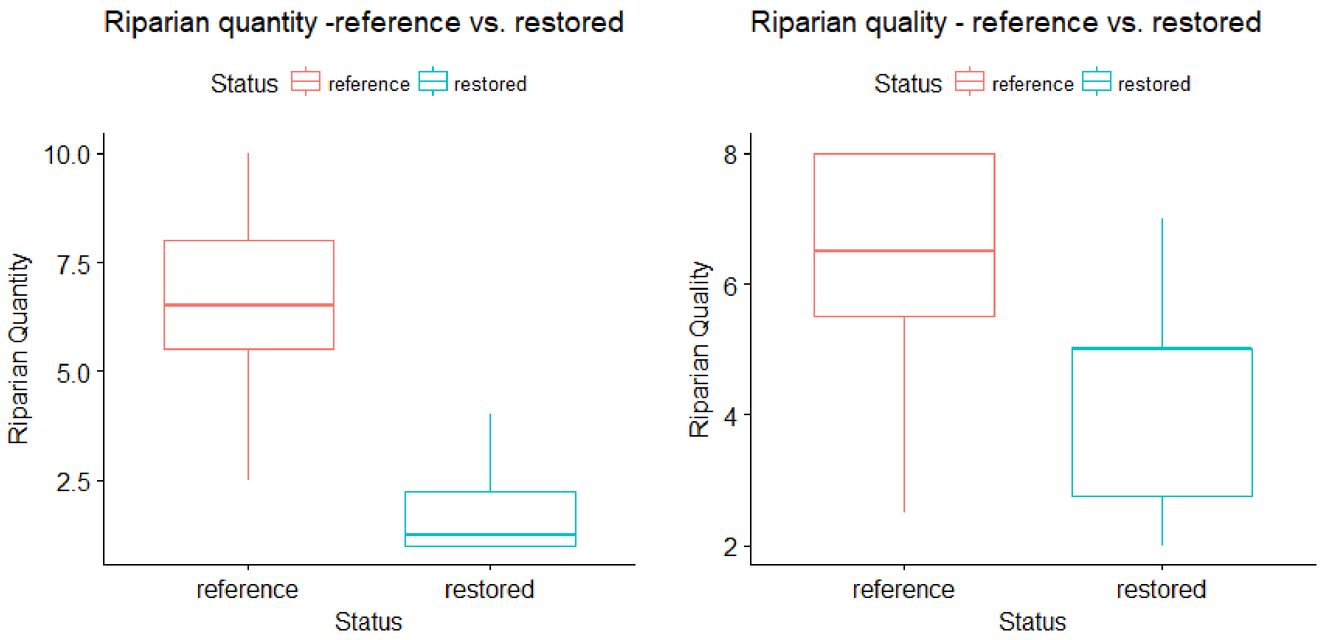


(a)

(b)

Figure 3

Figure 4 shows the differences in riparian quantity and quality between reference and restored sites. We compared both variables using two-sample t-tests. There was a statistically significant difference in riparian quantity between reference and restored sites ($\bar{x}_{\text{rest}} = 1.833$, $s_{\text{rest}} = 1.211$; $\bar{x}_{\text{ref}} = 6.500$, $s_{\text{ref}} = 2.806$, $t = 3.460$, $p = 0.008$ (Figure 4a)). Due to the split between quantity and quality data, this result is inconclusive as to our hypothesis that reference sites will have greater riparian zone quantity and quality. We hypothesize that the relatively lower riparian quality scores in reference sites are largely due to the presence of invasive species, some of which were removed from the restored sites when they were replanted.



(a) (b)

Figure 4

Figure 4 shows the differences in riparian quantity and quality over time. We compared both variables using two-sample t-tests. There was a statistically significant difference in riparian quality between 2016 and 2017 ($\bar{x}_{16} = 3.000$, $s_{16} = 1.732$; $\bar{x}_{17} = 5.667$, $s_{17} = 1.155$, $t = -2.219$, $p = 0.051$ (Figure 4a)). Since the restored sites were bulldozed and replanted in between the two years, in some cases months before we visited the sites, it makes sense that quality would have improved while quantity is still recovering. The difference in quality supports our hypothesis that restoration will improve riparian zone quality and help restore ecosystem function.

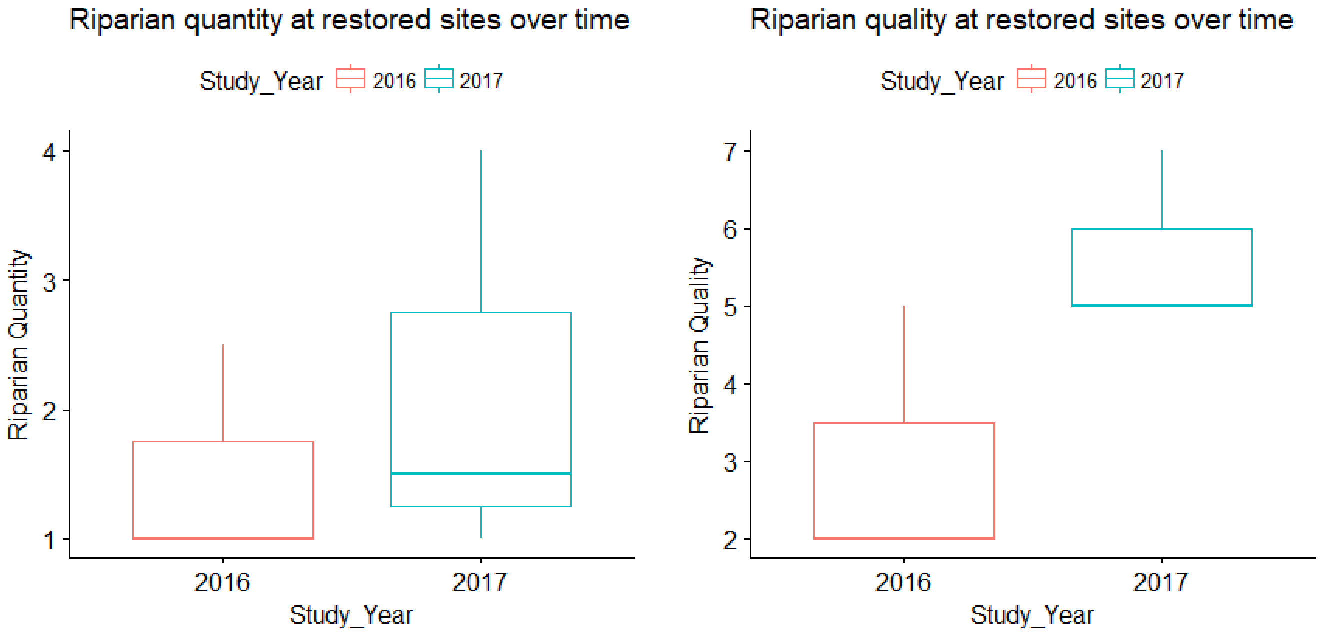


Figure 5

6 Physical Measurements

The SVAP(v.2) assesses a number of indicators of physical variability, including pools, fish habitat, and aquatic invertebrate habitat. In addition to visual assessments of the physical conditions of the river, we measured the depth and flow velocity across one cross section at each site. These measurements aid in quantifying the physical variability in a more precise way, and provide a comparison point for the pool assessment in SVAP(v.2). Physical variability could also be temporal. Though it is out of the scope of this study to take data at any of the sites over time to assess daily and seasonal flow variability, we have supplemented our flow measurements with that of stream gauges along the creek.

Since we hypothesized that canopy cover increases biological metrics of stream health via water temperature, we measured the water temperature at each location.

Table 1 contains our streamflow measurements in order from upstream to downstream, compared with nearby gage. Between sites 4 and 5, James creek converges with Left Hand Creek, and so the flow increases by several times after that point.

Site BMI	Date	Time	Flow (cfs)	Gage Flow (cfs)
2	20171014	10:10	15.6	9.73
4	20171014	13:00	13.6	9.73
5	20171007	15:45	38.2	12.4
6	20171007	13:00	20.3	13.5
7	20171014	15:45	15.8	9.22
8	20171007	10:00	17.5	15.2

Table 1

7 Biological measurements

Though the SVAP(v.2) semi-qualitatively assesses riparian zone quantity and quality, canopy cover, and the benthic macroinvertebrate community at each site, we sought to pair these data with additional quantitative data by performing riparian vegetation transects and collecting benthic macroinvertebrates at each site.

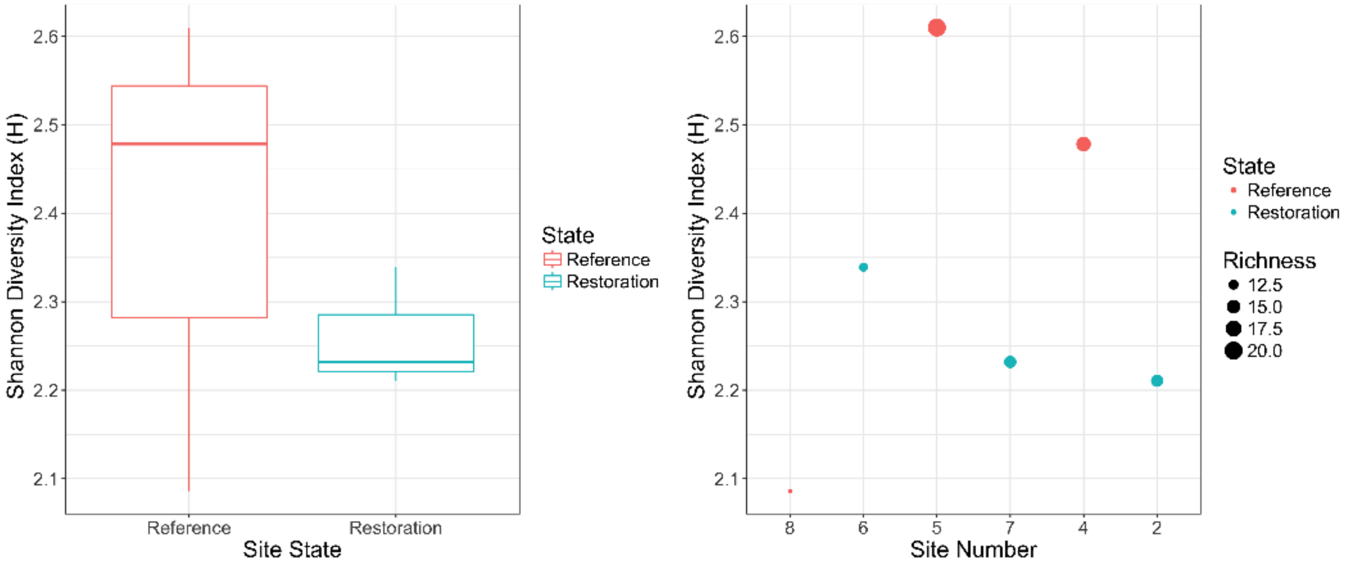
7.1 Riparian Vegetation

We performed two line intercept vegetation transects following Harris *et al.* (2005), perpendicular to the stream at each site. These transects were located 25ft upstream and 25ft downstream from our streamflow cross sections. From these data, an estimate of the total percent cover of riparian vegetation cover within the bankfull channel was obtained for each site. Species richness and origin of species (native vs. non-native) was also determined. These measurements gave us an approximation of alpha diversity at each site, calculated as the Shannon Diversity (Shannon–Weaver; Shannon–Wiener) index (H):

$$H = -\sum_{i=1}^{s} p_i ln p_i$$

where p_i is the proportional abundance of species i. Additionally, an estimate of percent barren soil (i.e. non-vegetated soil) within the bankfull channel for each site was obtained.

To test the hypothesis that plant species diversity and total vegetative cover is increased at reference sites, while non-native species and bare ground are increased in restoration sites, a series of two-sample t-tests were performed. Plant species diversity, as calculated by the Shannon Diversity Index (H), was not significantly greater in reference sites ($\text{mean}_{\text{rest}}= 2.26$, $\text{SD}_{\text{rest}} = 0.069$; $\text{mean}_{\text{ref}}= 2.39$, $\text{SD}_{\text{ref}} = 0.27$); t(2.25) = 0.80575, p= 0.4966 (Figure 6a). However, for visualization purposes, Figure 6b shows the variation in H observed across all sites, from upstream to downstream. Total vegetative cover was not significantly greater in reference sites ($\text{mean}_{\text{rest}}= 63.22$, $\text{SD}_{\text{rest}}= 19.12$; $\text{mean}_{\text{ref}}=116.39$, $\text{SD}_{\text{ref}} = 28.63$); t(3.49) = 2.67, p = 0.0642 (Figure 7). Non-native cover was not significantly greater in restoration sites ($\text{mean}_{\text{rest}}= 29.61$, $\text{SD}_{\text{rest}}= 20.10$; $\text{mean}_{\text{ref}}= 25.31$, $\text{SD}_{\text{ref}} = 10.54$); t(3.02) = -0.33, p = 0.7639 (Figure 8a). Percent barren soil was not significantly greater in restoration sites ($\mathrm{mean}_{\mathrm{rest}} = 16.3$, $\mathrm{SD}_{\mathrm{rest}} = 10.25$; $\mathrm{mean}_{\mathrm{ref}} = 0.64$, $\mathrm{SD}_{\mathrm{ref}} = 1.11$); $t(2.05) = -2.64$, $p = 0.1159$ (Figure 8b).



(a) (b)

Figure 6: Shannon Diversity of plant species appears to be increased in reference sites (a), and varies between reference and restored sites, longitudinally, from upstream (site 8), to downstream (site 2).

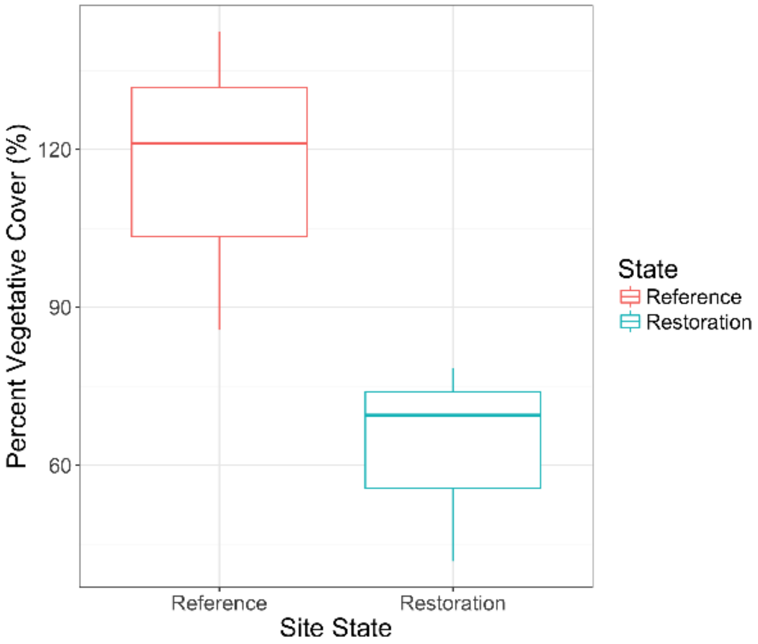
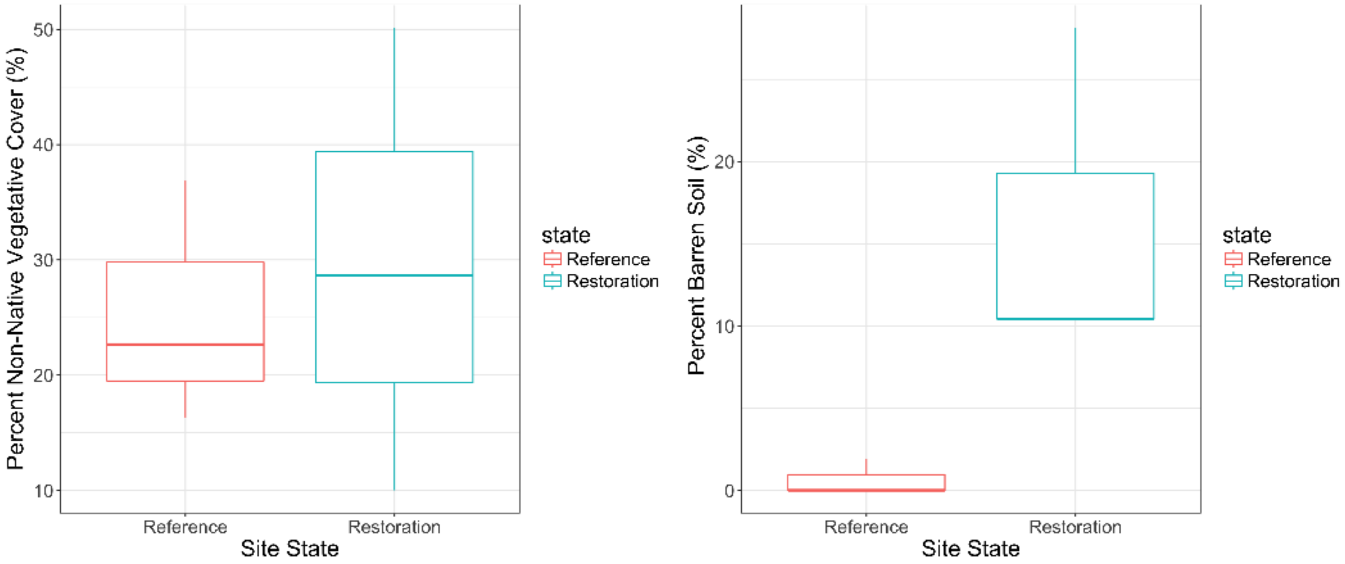


Figure 7: Total percent vegetation cover within the bankfull channel appears to be increased at reference sites, though not statistically significant.



(a) (b)

Figure 8: Percent non-native vegetation was not statistically different across reference and restoration sites (a). Percent barren soil appears to be increased at restoration sites (b), though not statistically significantly different across sites.

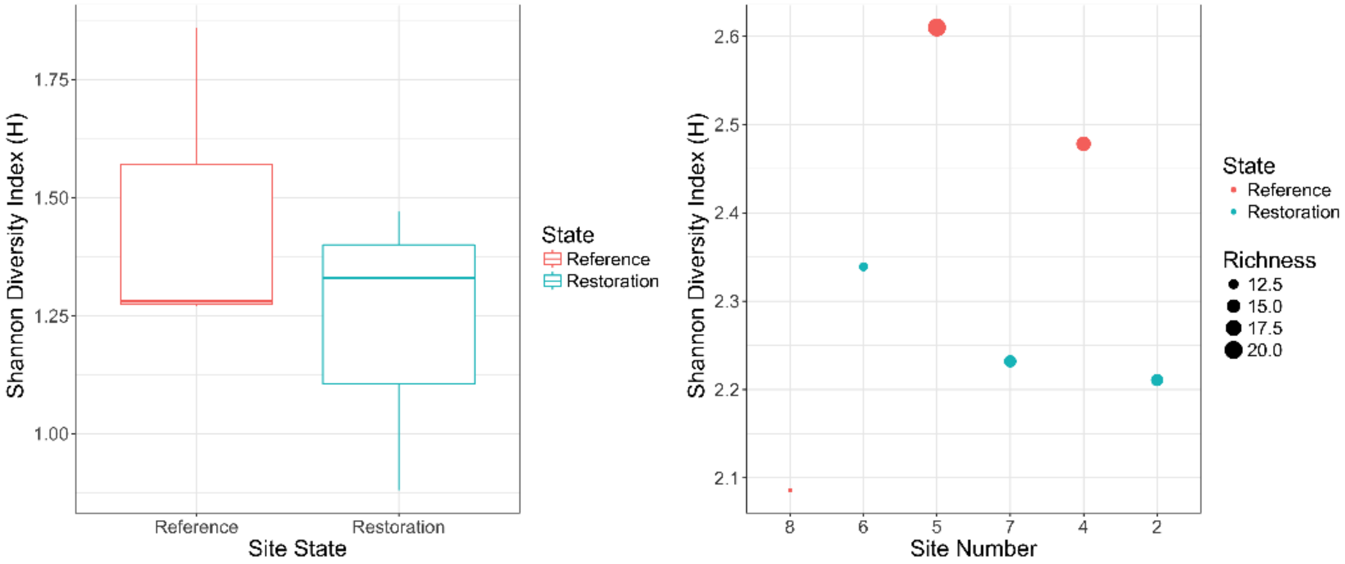
While the series of two-sample t-tests failed to show significant differences in riparian vegetation between reference and restored sites within LHC, qualitative interpretation of these results may be useful for management and future monitoring considerations. With time, plant species diversity in restoration and reference sites may become more similar with dispersal, establishment, and successional development. Further, management intervention in the form of native planting and non-native species removal may align reference and restored sites in terms of diversity, richness, and the amount of vegetative cover within the LHC watershed. Given that many of LWOG's restoration sites were just recently planted in 2017, future monitoring would allow for assessment of natural successional development and native planting success in these riparian areas.

Out of the restoration sites sampled, project site 7, The Ranch, may benefit from increased target for non-native species removal and native planting, given that there is an increased number of non-native species at this site (A.3.2). Similarly, out of the reference sites sampled, project site 5, Geer Canyon, may benefit from increased target for non-native species removal and native planting, given that there is an increased number of non-native species at this site (A.3.2).

Future monitoring efforts could further investigate the relationship between relative cover of barren soil, native species, and non-native species through time and potentially in conjunction with geomorphic surveys to evaluate bank stability and overall ecosystem structure and function. Assessment of vegetative cover across sites provides an approximation for biomass (above and below), which may be an important metric to evaluate through time, as the watershed may experience disturbances such as flood, drought, and fire. Data from before and after disturbance events such as these may be a useful tool to assess the LHC Watershed's resilience and guide management trajectories.

7.2 Benthic Macroinvertebrates

For each site, benthic invertebrate sampling was conducted. In order to capture all habitat variation within a site, sampling locations consisted of both riffles and pools with high and low flow. We aimed to sample a minimum of four locations at each site in order to acquire a minimum of 100 individuals per site. Benthic macroivertebrates were classified to the family level. Similar to our vegetation transects, richness and the Shannon Diversity index were calculated for each site. Benthic macroinvertebrate diversity (H), was not significantly different between reference and restoration sites ($\text{mean}_{\text{rest}}= 5.67$, $\text{SD}_{\text{rest}} = 0.31$; $\text{mean}_{\text{ref}}= 6.67$, $\text{SD}_{\text{ref}} = 0.34$); $t(3.12) = 0.73$, $p= 0.5176$ (Figure 9a). Additionally, there appears to be no clear longitudinal trend in benthic macroinvertebrate diversity or richness across sites, but reference sites 5 and 4 have the greatest richness and diversity (Figure 9b).



(a)

(b)

Figure 9: Shannon Diversity of benthic macroinvertebrates is not significantly different across reference and restoration sites (a). Shannon Diversity varies between reference and restored sites, longitudinally, from upstream (site 8), to downstream (site 2).

This similarity in benthic macroinvertebrate community composition across reference and restoration sites may be indicative of successful implementation of instream habitats such as pool and riffle sequences that were an integral part of the LHC's restoration intervention following the 2013 floods. Additionally, consistent water quality throughout the LHC watershed may also contribute to this continuity in the macroinvertebrate community. With time, benthic macroinvertebrate diversity in restoration sites may increase to meet reference site diversity levels as these systems equilibrate after experiencing historic flooding and physical construction from restoration work.

8 Water Chemistry Measurements

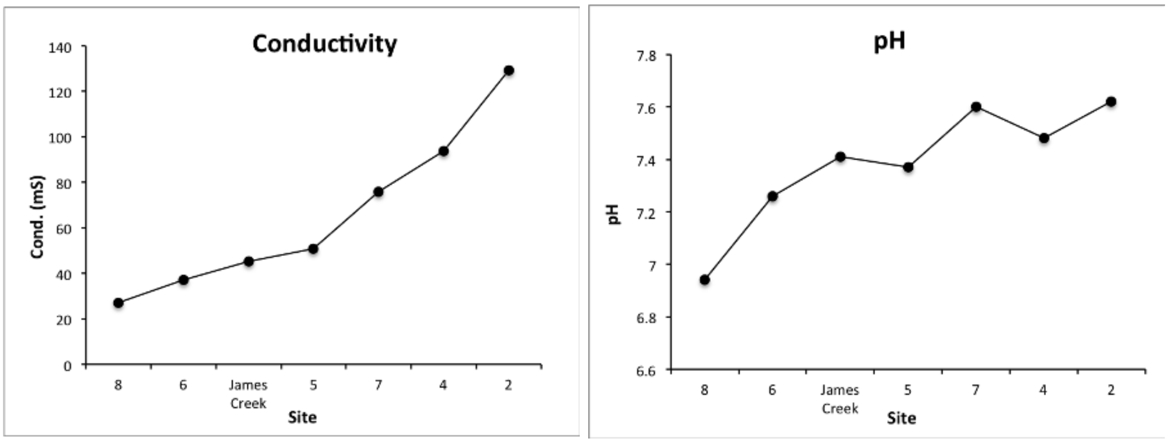
The terrestrial environment is most closely linked to stream ecosystems within headwater streams (Vannote *et al.* , 1980). Looking more closely, a particular stream reach will be most directly affected by its riparian buffer. We hypothesized that strength of riparian buffer and in particular degree of canopy cover are strongly correlated with stream temperature and dissolved oxygen concentration. Additionally, riparian vegetation acts as a buffer between terrestrial and aquatic systems (Allan & Castillo, 2007). Therefore we hypothesized that conductivity and nutrient concentrations will be correlated with strength of riparian vegetation.

To assess these hypotheses, we employed a variety of quantitative measurement techniques using canopy densitometer transects to determine average in stream canopy cover. We determined the average percent canopy cover within our reach by performing a transect with a densitometer centered instream, collecting measurements spanning 50 ft upstream and downstream from our streamflow cross sections, and along our vegetation transects. These data provide information about the extent of sunlight penetration to the stream water. In addition, we used a YSI Mulitmeter to collect water chemistry parameters including temperature, dissolved oxygen concentration, pH, conductivity, and specific conductance. We also collected water samples for nutrient and DOC to further analyze the role of the riparian buffer on water chemistry. DOM samples were collected in 125 mL acid washed and combusted amber glass bottles to prevent any photochemical alterations. Samples were filtered with combusted glass fiber filters to 0.45 nm to remove all particulate matter for accurate dissolved organic matter analysis and stored at 4°C until analysis. Nutrient samples were also filtered to 0.45 nm with combusted glass fiber filters and frozen in 125 mL HDPE bottles to prevent chemical alteration until analysis.

DOM samples were analyzed for both DOC concentration and UV absorbance at 254 nm. Samples were equilibrated to room temperature before analysis. DOC concentrations were measured with a Shimadzu TOC-V analyzer. Additionally, ultra violent absorbance at 254 nm via an Agilent

UV spectrometer was collected for each sample. With these measurements $SUVA_{254}$ was calculated by dividing the absorbance at 254 nm (cm^{-1}) by the DOC concentration (mg L^{-1}) multiplied by 100. This value correlates to the aeromatic structure of the DOM present. Additionally, the Shimadzu TOC-V analyzer collected total N present in our samples. Nutrient data were collected for each site and analyzed on a HACH Spectrophotometer for NO_2, NO_3, NH_3, and PO_4 according to standard techniques outlined with the instrument. Total N was obtained by the summation of NO_2, NO_3, and NH_3 values for each sample.

All graphs in this section are presented moving longitudinally from headwaters to plains on the x-axis.

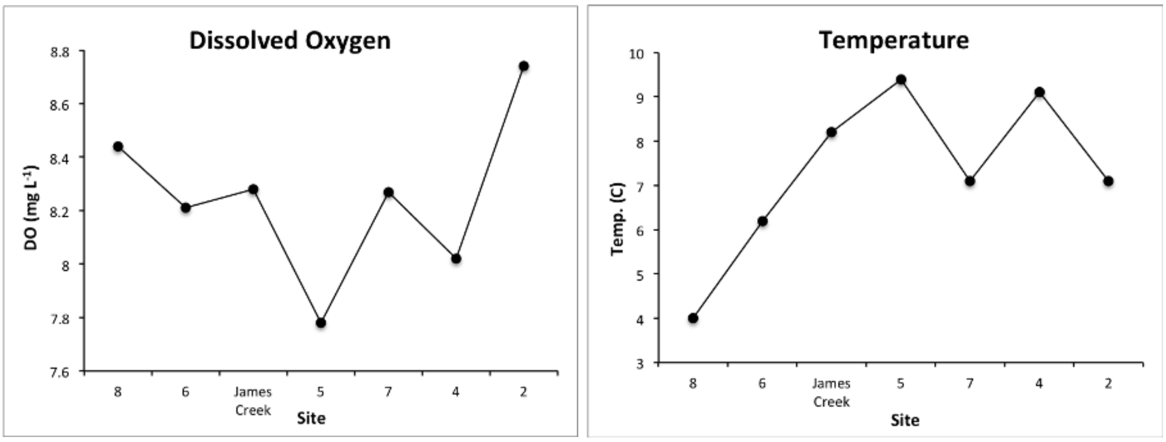


(a)

(b)

Figure 10

Conductivity correlates to total dissolved solids in a sample. These data suggest an overall trend of dissolved solid loading to the stream as we move from headwater reaches to the plains (Figure 10a). Groundwater inputs result in increased dissolved ions, in particular calcium and magnesium. To asses this in future studies, it would be beneficial to measure hardness of water at each site to further support this hypothesis. Additionally, pH of our stream shows an increasing trend as we move downstream (Figure 10b). Within the Lefthand Creek watershead, historic mining have impacted water quality resulting in reduced pH values. As we move downstream, this impact becomes less pronounced and thus result in a pH increase as groundwater inputs increase and dissolved metals are removed from the system. This groundwater input hypothesis is supported by a conductivity and pH correlation (R^2=0.62, p=0.038).



(a)

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Figure 11

Within mountain headwater streams, dissolved oxygen is typically at or near saturation based on water temperature (Allan & Castillo, 2007). Our data showed visual trends that seemed to support this, however with weaker correlations values (R^2=0.25, p=0.18). Despite insignificant statistical trends, our lowest dissolved oxygen concentrations (Figure 11a) were found at our highest surface water temperatures (Figure 11b) which is expected based from Henry's Law. Another possible error in this fit could be attributed to our most upstream and samples possibly being undersaturated with respect to dissolved oxygen due to bottom release from Lefthand Reservoir. None of our water chemistry parameters showed significant statistical trends between resorted and reference sites.

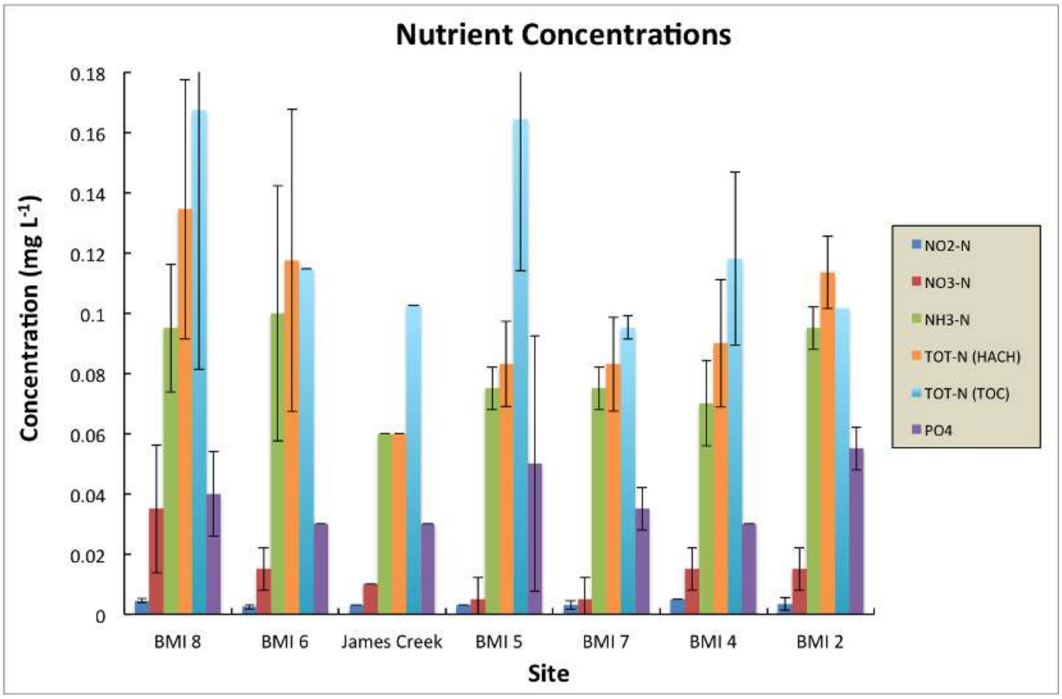


Figure 12

Overall, there was little change in nutrient concentrations between reference and restored sites or through longitudinal progression (Figure 12). We were able to compare total N from two different techniques, the first being a summation of our HACH measurements and second from the TOC analyzer. For most sites these values were very close, however some samples were more variable. These differences could be sure to sampling error, analytical error as some HACH measurements were near detection limit, or due to increased organic N components. Orthophosphate remained steady across sites with little change. Overall there was roughly a ratio of N:P of less than 5:1 suggesting that P was not a limiting nutrient in this system (Allan & Castillo, 2007). Sample 6.1 was omittted from this graphical representation due to suspected contamination of the sample (20 times higher than all other samples). Despite variations in flow between sampling dates, there was little change in nutrient concentrations between samples. Bases on these observations, we hypothesize that nutrient loading from the stream is controlled by reservoir releases as stream flow was independent from nutrient concentrations. Non-point overland loading would be highly variable depending on flow which is not observed.

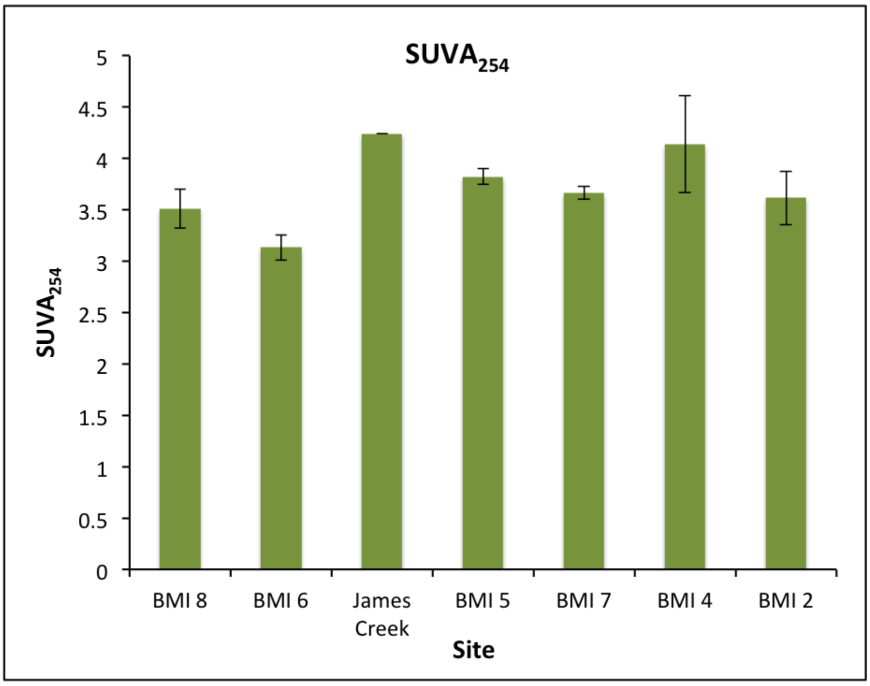


Figure 13

$SUVA_{254}$ measurements showed little change between samples sites either (Figure 13). Values were all between 3 and 4.5. These are considered relatively high and correlate to DOM with high aromatic structures. Values in this range are considered to relate to allochthonous DOM with strong linkages to the terrestrial environment.

These data combined seem to refute the Serial Discontinuity Concept (Ward & Stanford, 1983). This concept attempts to predict the nature of lotic systems pending release from an anthropogenic impoundments (i.e. reservoir). There are various assumptions made on the structure of these systems which are met within Lefthand creek. This theory predicts gradual increases in nutrient levels and a decrease in soluble organic compound diversity moving from very low stream orders up. Our data refute this hypothesis as there are not statistically significant trends in nutrient level change or changes in SUVA of our dissolved organic matter. However, this concept is supported in its prediction of deep water reservoir releases regulating temperature. Water is most dense at 4°C and thus regulates the change in water temperature seasonally. Our most headwater stream temperature measurement was at this level (Figure 11b). This lack of variation results in a decline of temperature variation seasonally.

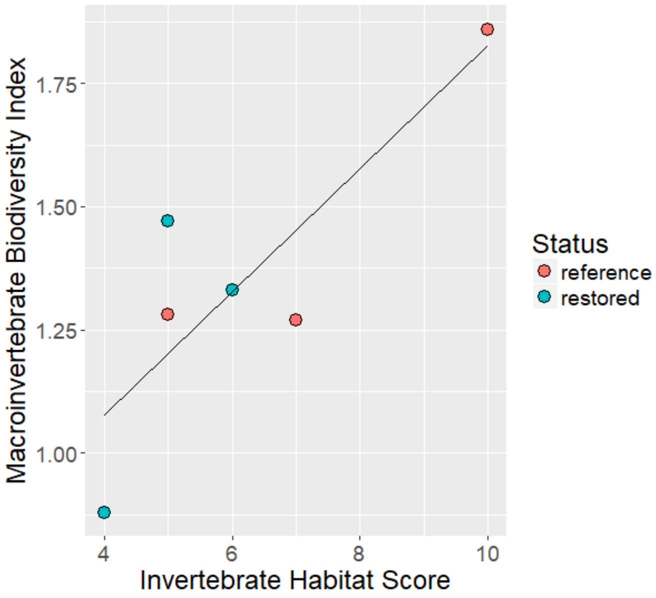
A variety of statistical analysis was conducted to correlate various water quality parameters to each other. While there are some visual trends, no data correlated to any statistical significance (i.e. $p < 0.05$) between water quality parameters, unless discussed. This is likely due to having a small sample size. For future work, more robust sampling and more data points could lend to stronger statistical significance in our trends.

9 Cross-Component Statistical Analyses

9.1 SVAP Verification

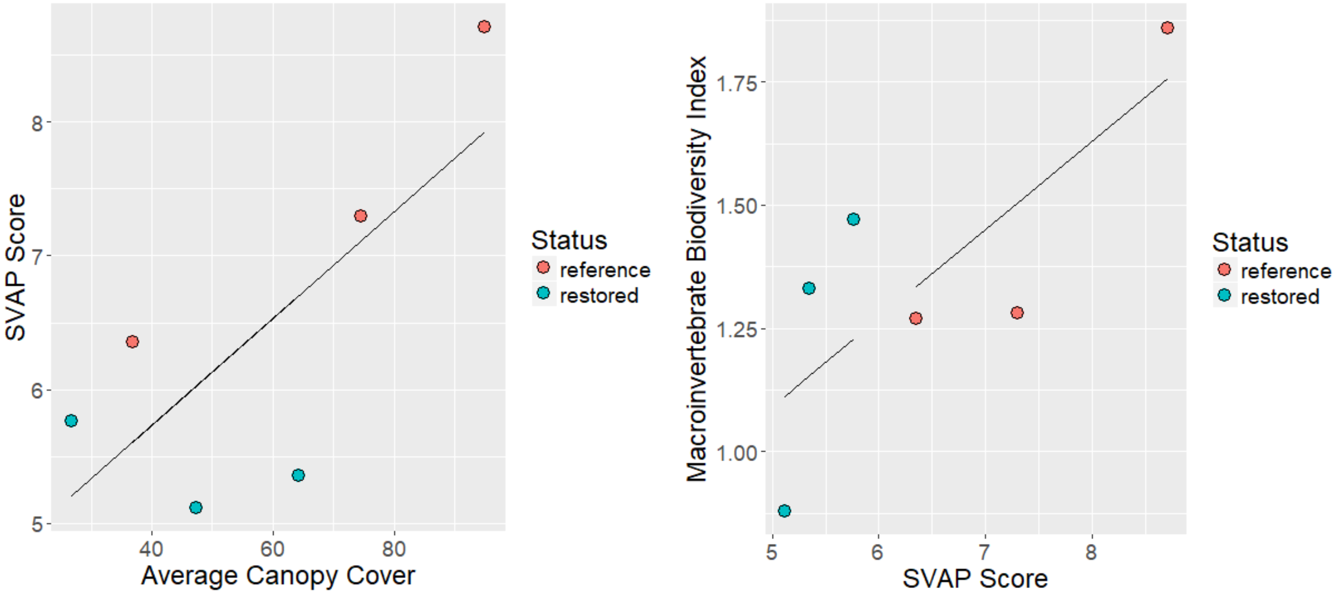
We performed analyses to verify that SVAP scores were correlated with quantitative measurements as we expected.

9.1.1 SVAP Invertebrate Habitat vs. Macroinvertebrate Diversity



9.2 SVAP correlations

We found two statistically significant correlations between our measurements and SVAP scores. Average canopy cover across the site was related to SVAP score. Canopy cover is itself an SVAP variable, and it is relevant for a number of other categories including riparian zone quantity and quality as well as fish and invertebrate habitat. This statistically significant positive correlation (R^2= 0.5508, p=0.09116) is therefore not surprising. Figure 14a shows the linear model.



(a)

(b)

Figure 14

There was also a statistically significant positive correlation between SVAP score and macroinvertebrate biodiversity (R^2=0.6297, p=0.0372). Figure 14b shows the linear model. To the extent that SVAP measures riparian habitat quality and macroinvertebrate biodiversity measures stream health, this finding helps answer the question of how riparian habitat quality affects water quality and overall stream health.

9.3 Additional Statistical Analyses

9.3.1 Canopy Cover, Benthic Invertebrate Diversity, and Water Quality

A series of linear regression models were built to test the hypothesis that the amount of canopy cover within a given stream reach alters water chemistry parameters, directly affecting the diversity and abundance within benthic invertebrate communities. However, there were no statistically significant models that correlated canopy cover with stream temperature (R^2=0.0013, p=0.95), dissolved oxygen (R^2=0.028, p=0.75), pH (R^2=0.04, p=0.70), or macroinvertebrate diversity (R^2=0.086, p=0.29). Models with multiple predictors (multiple regressions) were insignificant. Pairwise relationships of these variables are shown in A.2. Benthic invertebrate diversity was not significantly predicted by canopy cover in a simple linear regression, as initially hypothesized (R^2=0.086, p=0.29).

9.3.2 Riparian Quality/Quantity and Nutrients

Our hypothesis that the quantity and quality of riparian habitat would effect nutrient loading within LHC was not statistically supported by a linear regression. Our study does not support the hypothesis that the riparian zone serves as a buffer to nutrient loading in LHC.

10 Conclusions and Future Directions

Overall, we observed several statistically significant differences between reference and restored sites with respect to overall ecosystem structure and function as measured in the SVAP protocol. While many relationships with riparian vegetation, canopy cover, benthic macroinvertebrate, and water chemistry data were not statistically significant, these data provide a useful foundation for future monitoring of the Lefthand Creek Watershed. Continued monitoring of these six study sites, in addition to other Lefthand Creek reference and restored sites, would permit for statistical analyses with greater power. Additionally, consistency in data collection, specifically the semi-qualitative SVAP data, can be ensured by observer continuity year-to-year. This would seek to reduce measurement error and to increase data robustness.

This study demonstrates that evaluation of the Lefthand Creek Watershed with both semi-qualitative (e.g. SVAP) and quantitative physical, biological, and chemical components can be a feasible and effective approach to answering many ecological questions as they relate to evaluating restoration success. Future monitoring of Lefthand Creek, through disturbance events, will contribute to more robust analyses of ecosystem structure and function, and will permit for useful evaluation of ecosystem resilience and recovery.

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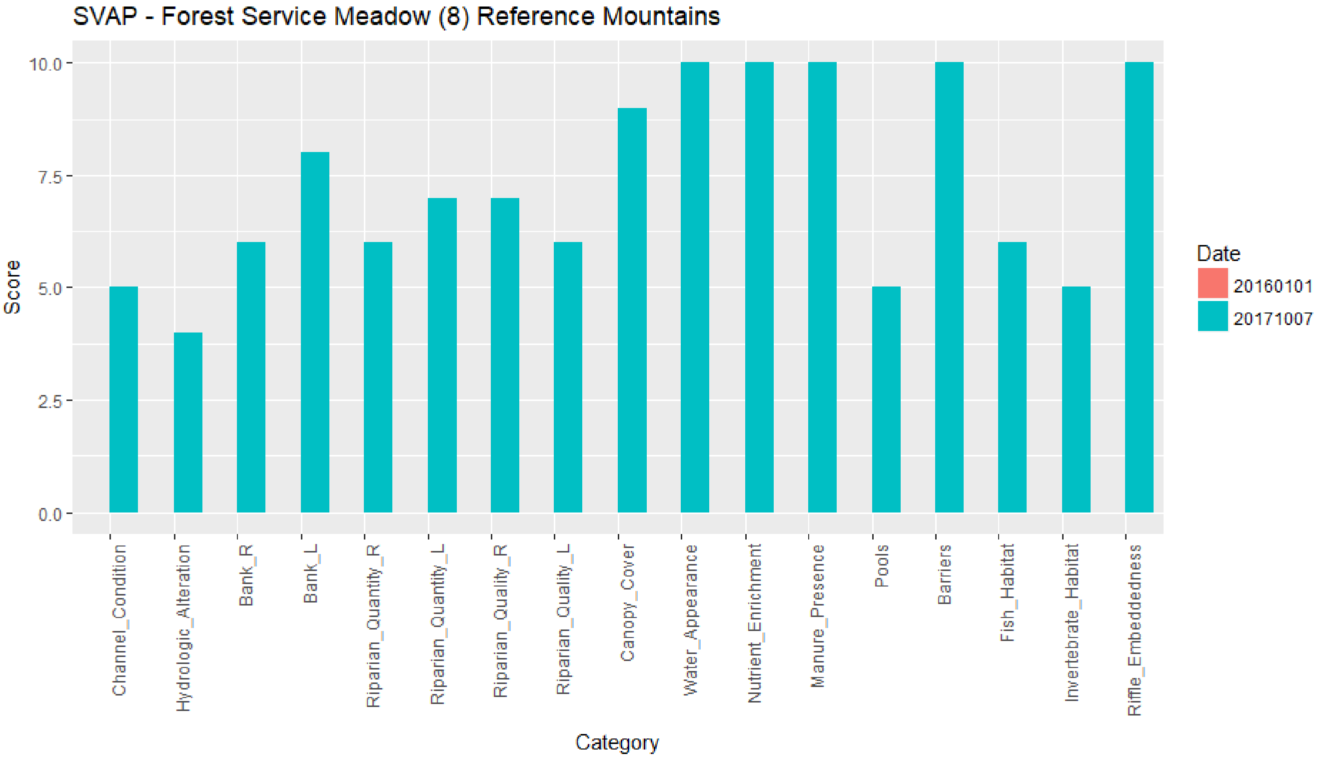
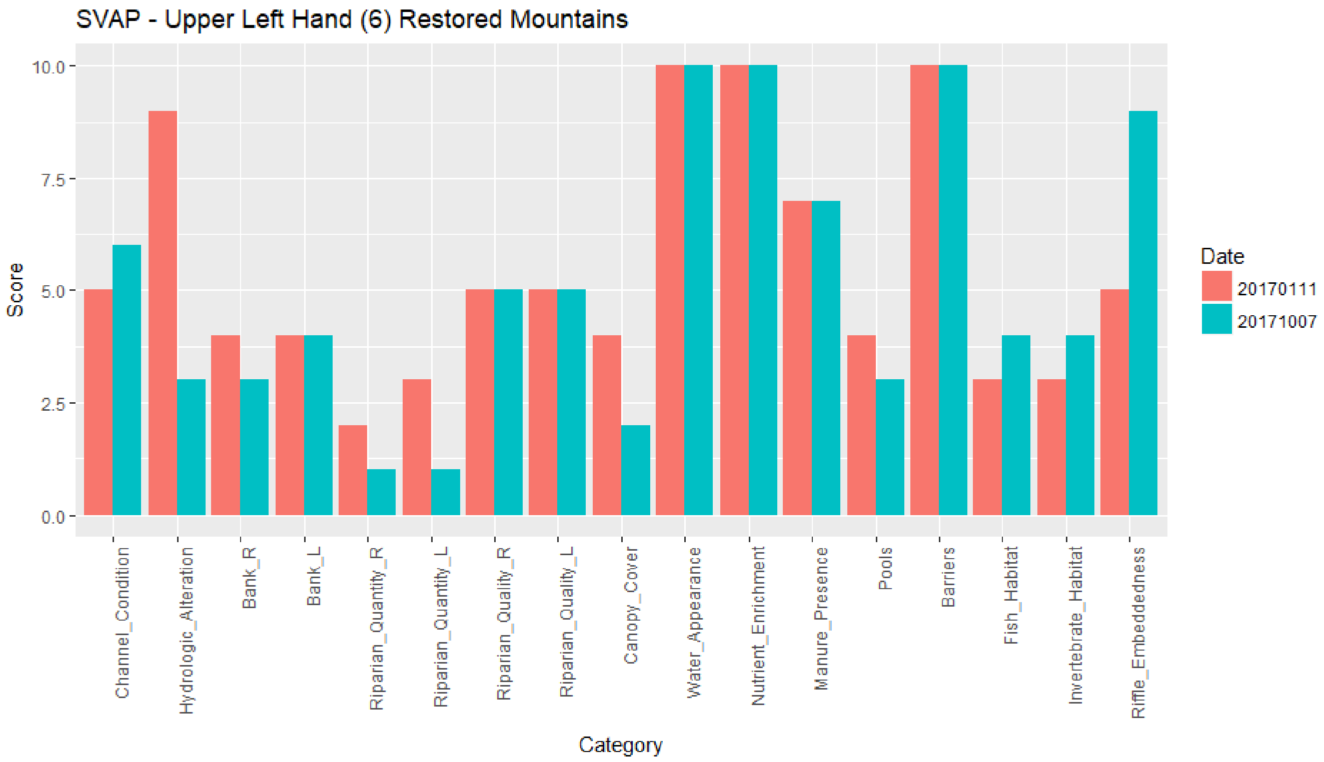
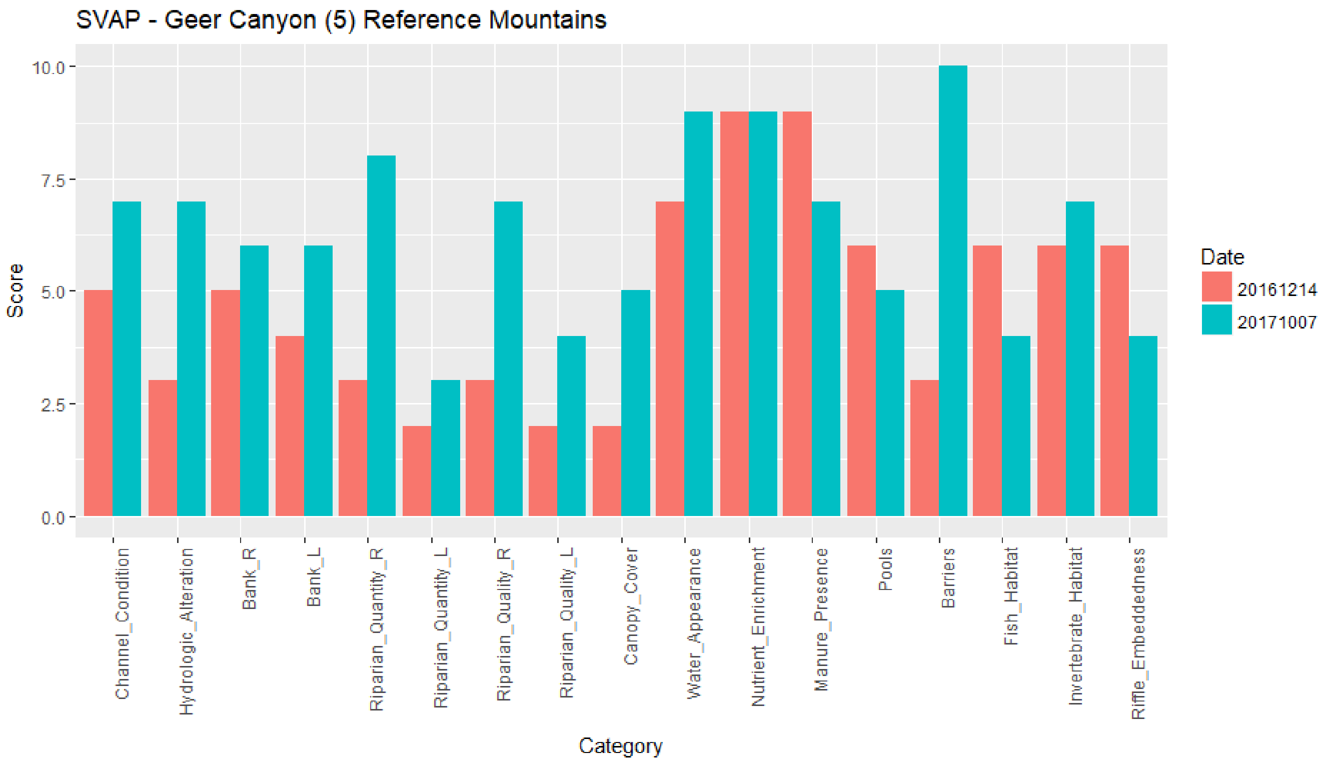
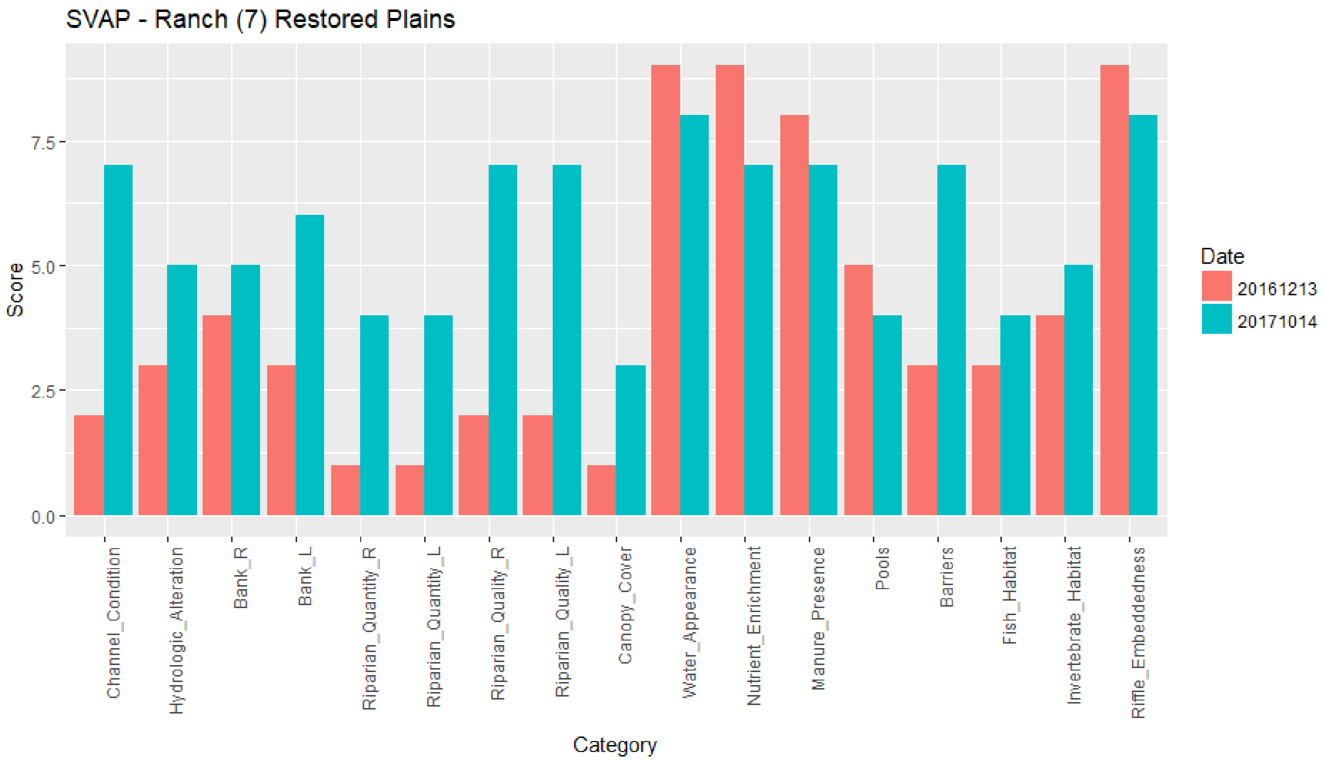
Appendix A Supporting Information

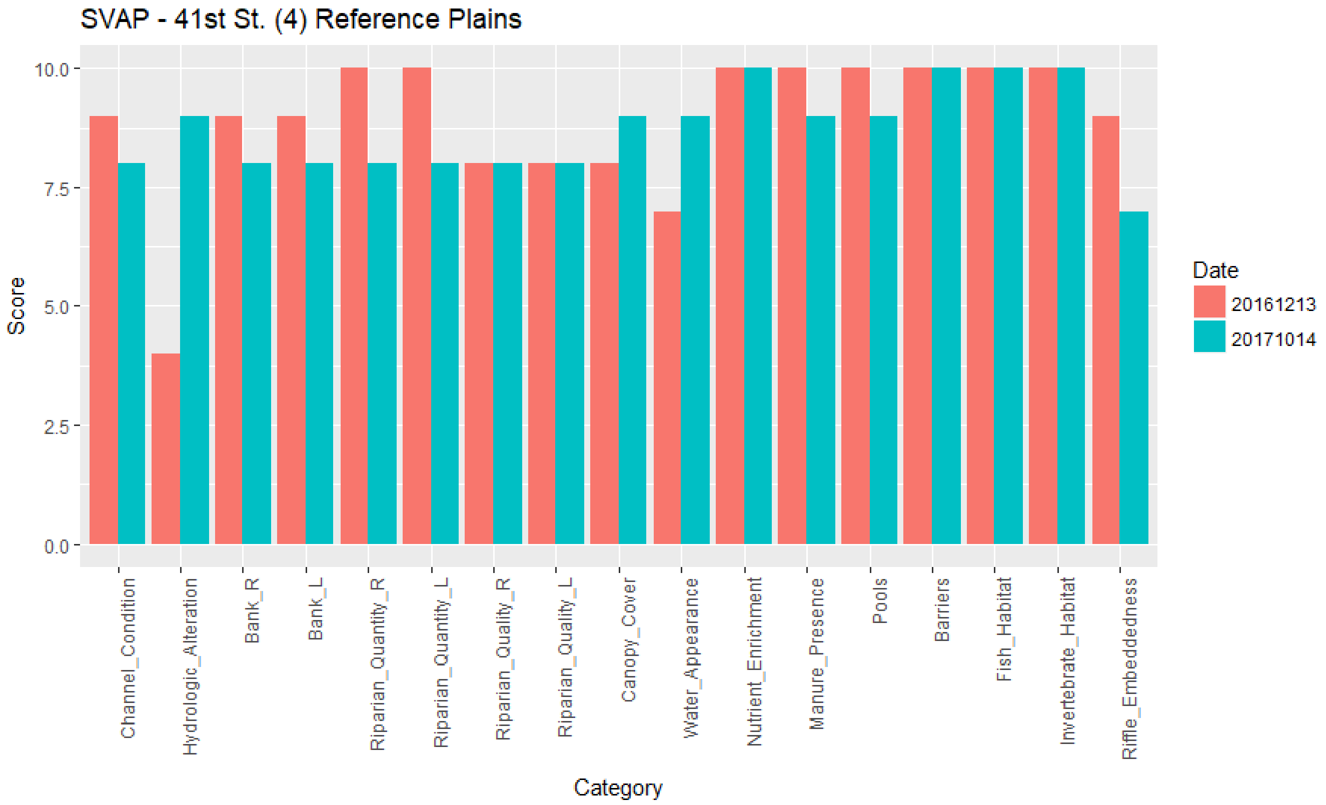
A.1 SVAP Data by Category

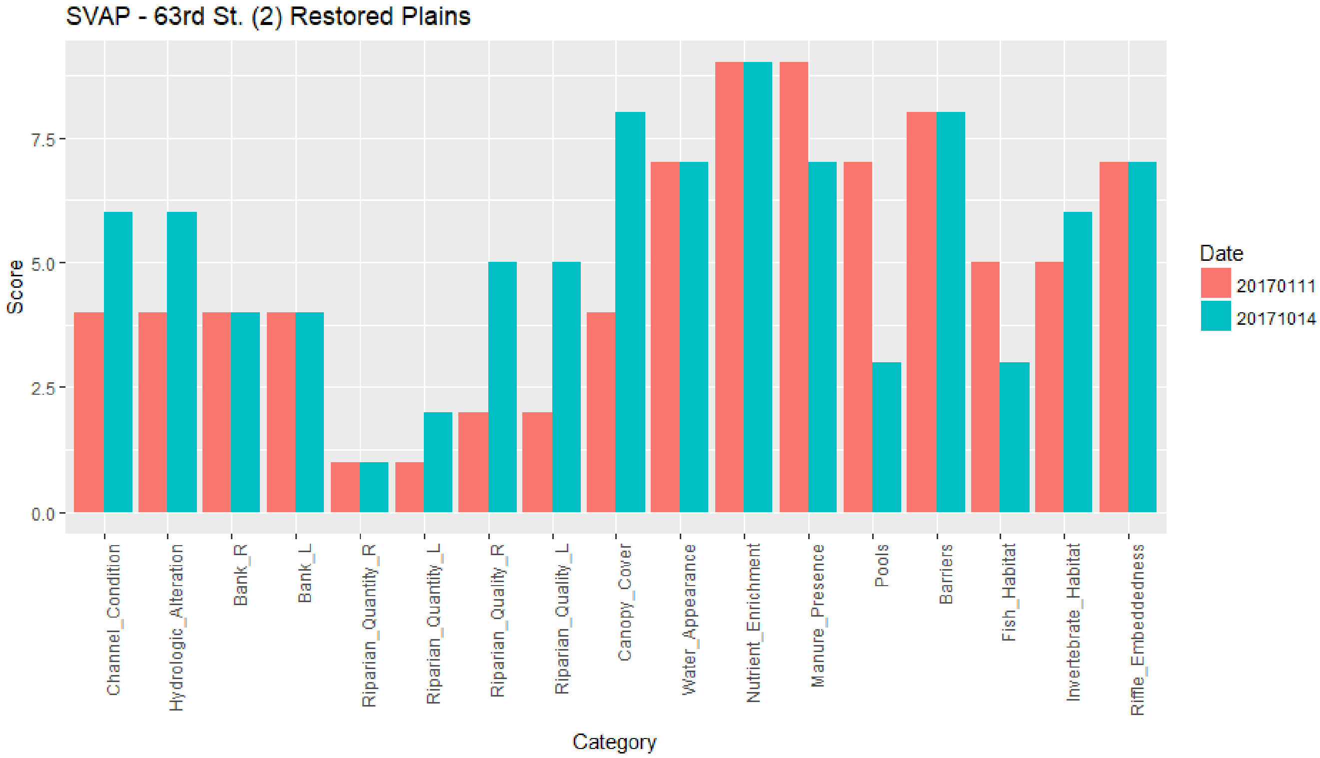



SVAP - Upper Left Hand (6) Restored Mountains
Score
10.0
7.5
5.0
2.5
0.0
Channel_Condition
Hydrologic_Alteration
Bank_R
Bank_L
Riparian_Quantity_R
Riparian_Quantity_L
Riparian_Quality_R
Riparian_Quality_L
Canopy_Cover
Water_Appearance
Nutrient_Enrichment
Manure_Presence
Pools
Barriers
Fish_Habitat
Invertebrate_Habitat
Riffle_Embeddedness
Category
Date
20170111
20171007


SVAP - Geer Canyon (5) Reference Mountains
Score
10.0
7.5
5.0
2.5
0.0
Channel_Condition
Hydrologic_Alteration
Bank_R
Bank_L
Riparian_Quantity_R
Riparian_Quantity_L
Riparian_Quality_R
Riparian_Quality_L
Canopy_Cover
Water_Appearance
Nutrient_Enrichment
Manure_Presence
Pools
Barriers
Fish_Habitat
Invertebrate_Habitat
Riffle_Embeddedness
Category
Date
20161214
20171007


SVAP - Ranch (7) Restored Plains
Score
0.0
2.5
5.0
7.5
Channel_Condition
Hydrologic_Alteration
Bank_R
Bank_L
Riparian_Quantity_R
Riparian_Quantity_L
Riparian_Quality_R
Riparian_Quality_L
Canopy_Cover
Water_Appearance
Nutrient_Enrichment
Manure_Presence
Pools
Barriers
Fish_Habitat
Invertebrate_Habitat
Riffle_Embeddedness
Category
Date
🟥 20161213
🟦 20171014


SVAP - 41st St. (4) Reference Plains
Score
0.0
2.5
5.0
7.5
10.0
Channel_Condition
Hydrologic_Alteration
Bank_R
Bank_L
Riparian_Quantity_R
Riparian_Quantity_L
Riparian_Quality_R
Riparian_Quality_L
Canopy_Cover
Water_Appearance
Nutrient_Enrichment
Manure_Presence
Pools
Barriers
Fish_Habitat
Invertebrate_Habitat
Riffle_Embeddedness
Category
Date
🟥 20161213
🟦 20171014


SVAP - 63rd St. (2) Restored Plains
Score
0.0
2.5
5.0
7.5
Channel_Condition
Hydrologic_Alteration
Bank_R
Bank_L
Riparian_Quantity_R
Riparian_Quantity_L
Riparian_Quality_R
Riparian_Quality_L
Canopy_Cover
Water_Appearance
Nutrient_Enrichment
Manure_Presence
Pools
Barriers
Fish_Habitat
Invertebrate_Habitat
Riffle_Embeddedness
Category
Date
20170111
20171014

A.2 Pairwise Cross-Component Data Relationships

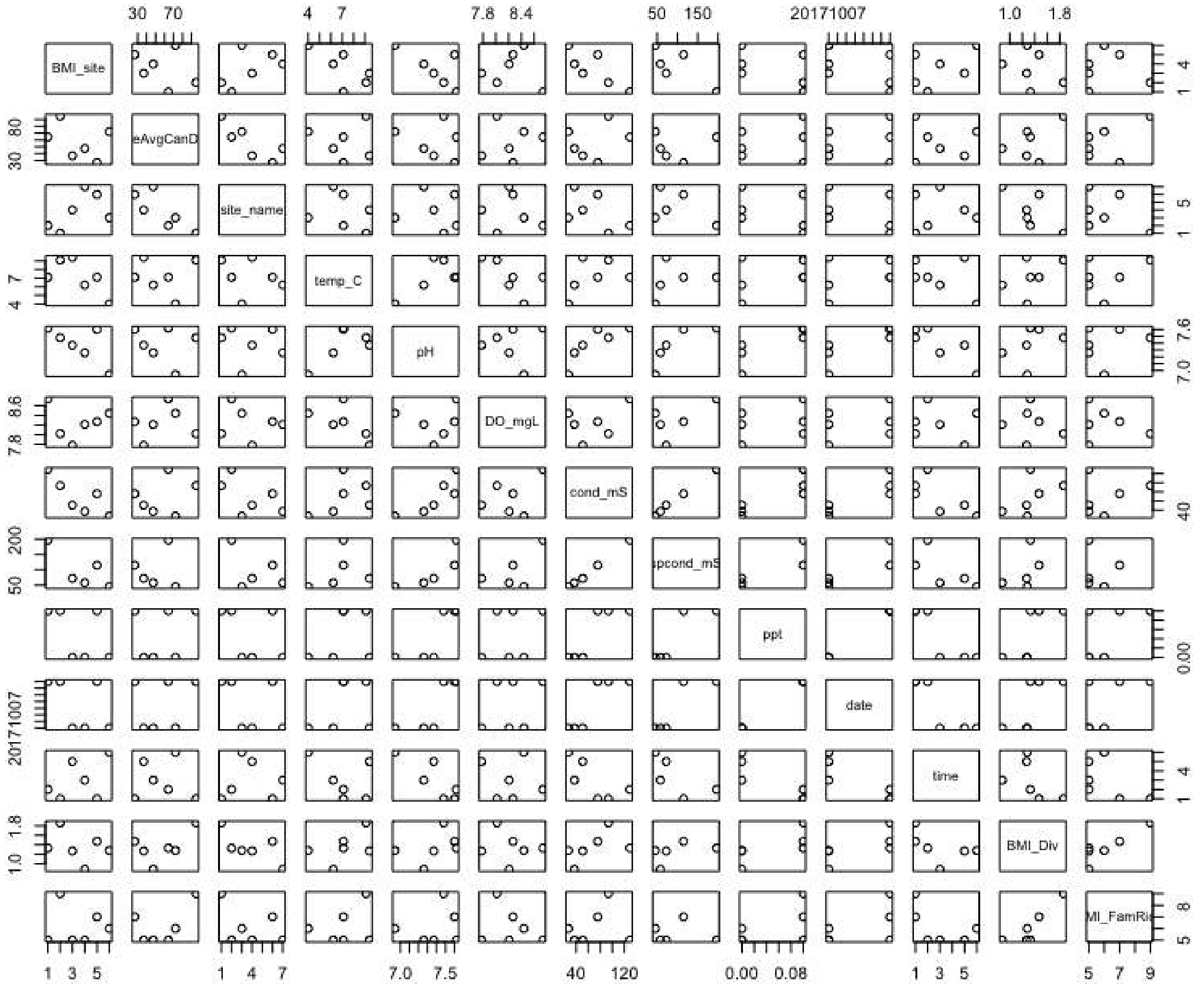


Figure 15: Pairwise relationships of variables used in cross-component analysis.

A.3 Raw Data and Summary Statistics

A.3.1 SVAP

Date	Site	1	2	3L	3R	4L	4R	5L	5R	6	7	8	9	10	11	12	13	14	15	16
20171014	2	6	6	4	4	1	2	5	5	8	7	9	7	3	8	3	6	NA	7	NA
20170111	2	4	4	4	4	1	1	2	2	4	7	9	9	7	8	5	5	NA	7	NA
20171014	4	8	9	8	8	8	8	8	8	9	9	10	9	9	10	10	10	NA	7	NA
20161213	4	9	4	9	9	10	10	8	8	8	7	10	10	10	10	10	10	NA	9	NA
20171007	5	7	7	6	6	8	3	7	4	5	9	9	7	5	10	4	7	NA	4	NA
20171007	6	6	3	3	4	1	1	5	5	2	10	10	7	3	10	4	4	NA	9	NA
20170111	6	5	9	4	4	2	3	5	5	4	10	10	7	4	10	3	3	NA	5	NA
20171014	7	7	5	5	6	4	4	7	7	3	8	7	7	4	7	4	5	NA	8	NA
20161213	7	2	3	4	3	1	1	2	2	1	9	9	8	5	3	3	4	NA	9	NA
20171007	8	5	4	6	8	6	7	7	6	9	10	10	10	5	10	6	5	NA	10	NA
20161214	5	5	3	5	4	3	2	3	2	2	7	9	9	6	3	6	6	NA	6	NA

A.3.2 Plant Richness and Diversity

Site	Total Shannon Diversity	Total Richness	Native Richness	Non-Native Richness
2	2.21	14	9	5
4	2.48	16	12	3
5	2.61	20	9	7
6	2.34	12	9	3
7	2.23	14	2	7
8	2.09	11	7	3

A.3.3 Vegetative Cover

Site	Total Percent Vegetative Cover	Percent Native Vegetative Cover	Percent Non-Native Vegetative Cover	Percent Barren Soil
2	69.5	3.58	50.17	10.42
4	121.17	90.5	16.33	0
5	85.67	60.17	22.67	1.92
6	78.42	63.5	10	10.42
7	41.75	8	28.67	28.17
8	142.33	82.92	36.92	0

A.3.4 Canopy Cover Summary Statistics

Site	Total Average Percent Canopy Cover	Riparian Average Percent Canopy Cover	Instream Average Percent Canopy Cover
2	64.28	62.98	65.10
4	95.02	92.93	96.33
5	36.82	26.89	43.91
6	47.44	47.32	47.52
7	26.82	20.08	31.04
8	72.18	69.52	73.70

A.3.5 Benthic Invertebrate Counts

Site	Plecoptera	Ephemeroptera	Trichoptera	Chironomid	Oligochaeta	Red Mite	Beetle	Damsle Fly	Leech	Scud	Stripe Fly	Total
2	18	35	9	1	22	0	0	0	0	0	0	85
4	0	10	9	2	5	0	4	1	1	2	1	35
5	47	9	12	28	0	0	2	0	0	0	0	98
6	167	23	19	9	5	0	0	0	0	0	0	223
7	23	26	42	9	1	3	2	0	0	0	0	106
8	56	13	7	6	11	2	0	0	0	0	0	95

A.3.6 Water Quality Parameters

Site	Temp (C)	pH	Dissolved Oxygen (mg L-1)	Conductivity (mS)	Specific Conductance (mS)
2	7.1	7.62	8.74	129.1	196.3
4	9.1	7.48	8.02	93.6	-
5	9.4	7.37	7.78	50.9	72.3
6	6.2	7.26	8.21	37.2	57.9
7	7.1	7.60	8.27	75.9	115
8	4.0	6.94	8.44	27.1	45.1
James Creek	8.2	7.41	8.28	45.3	66.2

A.3.7 Nutrient Data

Sample	NO2 (mg/L)	NO3 (mg/L)	NH3 (mg/L)	PO4 (mg/L)	TOT N (TOC) (mg/L)
2.1	0.002	0.02	0.10	0.05	0.0902
2.2	0.005	0.01	0.09	0.06	0.1131
4.1	0.005	0.02	0.08	0.03	0.0977
4.2	0.005	0.01	0.06	0.03	0.1385
5.1	0.003	0.00	0.07	0.02	0.1288
5.2	0.003	0.01	0.08	0.08	0.1999
6.1	0.002	0.01	0.07	0.03	2.6050
6.2	0.003	0.02	0.13	0.03	0.1147
7.1	0.002	0.00	0.07	0.03	0.0979
7.2	0.004	0.01	0.08	0.04	0.0925
8.1	0.005	0.05	0.11	0.05	0.2282
8.2	0.004	0.02	0.08	0.03	0.1065
James Creek	0.003	0.01	0.06	0.03	0.1025

A.3.8 Dissolved Organic Carbon

Sample	DOC (mg/L)	UV254 (cm-1)	SUVA254 (mg/L cm)
2.1	1.82	0.0690	3.80
2.2	2.27	0.0780	3.43
4.1	1.92	0.0729	3.81
4.2	1.80	0.0803	4.47
5.1	2.27	0.0880	3.88
5.2	1.64	0.0619	3.77
6.1	2.95	0.0950	3.22
6.2	1.33	0.0405	3.05
7.1	2.14	0.0794	3.71
7.2	1.73	0.0627	3.62
8.1	2.91	0.1059	3.65
8.2	1.15	0.0388	3.38
James Creek	1.93	0.0820	4.24