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Benthic Macroinvertebrates of Bull Run Creek: A Pre-Restoration Baseline

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Abstract

In North America, disturbed riparian zones have had a deleterious effect on the life cycles of anadromous fish, especially the commercially and culturally important salmon and steelhead. The result has been a significant reduction in the numbers and average size of these fish. Tributaries of the John Day River are important spawning waters for western populations of these fish, and the National Forest Service and the Confederated Tribes of the Umatilla Indian Reservation are cooperating to restore floodplains and riparian zones in a number of these headwater tributaries. Herein we have conducted a pre-restoration study of macroinvertebrates and basic water quality parameters in one of these important spawning locations in central Oregon, Bull Run Creek. Results of the turbidity, pH, dissolved Oxygen, and temperature determinations indicate that overall water quality is good, and benthic macroinvertebrate sampling yielded a number of sensitive organisms, including members of Chloroperlidae, Peltoperlidae, Ryachophilidae, Odontoceridae, and Brachycentridae. At all sites, chironomid larvae (non-biting midge) dominated the assemblages. The EPT Index suggests that Bull Run Creek ranges from fair to excellent in terms of its ability to support sensitive species. Sorensen's Similarity Coefficient indicates varying degrees of shared diversity between the sites, and Shannon's entropy calculations suggest moderate to low species diversity at all sites, including the reference site on nearby Boundary Creek. Overall, this study indicates that Bull Run Creek is in fair condition and that it should benefit significantly from the restoration efforts.

Keywords

Benthic Macroinvertebrates, Restoration, Diversity, Anadromous Fish, Beaver

1. Introduction

The John Day River is the longest undammed river in Oregon and is among the longest undammed rivers in the lower 48 states. It is a major tributary of the lower Columbia River, and supports the migrations of anadromous fish. Tributaries of the John Day River, including Bull Run Creek near Granite, Oregon, are critical spawning habitats for spring Chinook salmon (*Oncorhynchus tshawytscha*), summer steelhead trout (*Oncorhynchus mykiss*), and bull trout (*Salvelinus confluentus*). Several of these tributaries have been studied intensively [1] [2] [3] [4]. Among these tributaries, Bull Run Creek is considered to be an especially important waterway because of the site's capacity for supporting terrestrial and Endangered Species Act (ESA)-listed resident and anadromous fish in a higher elevation headwater setting. Anecdotal evidence suggests that the waterway originally contained a healthy riparian zone, a complex floodplain, a complex stream channel, and associated wetland habitats. Descriptions of site conditions prior to intensive beaver trapping in the 1800s are not known, but it is likely beaver dam complexes were also present. Recent imagery and site conditions suggest that before being extensively placer mining, the reach above Granite was composed of a series of stringer meadows, and the historic stream, given the valley width and slope, would have transitioned to a more sinuous form throughout the floodplain with ready access to that floodplain during spring runoff. By the early 1940s, however, the site had been intensively mined by floating placer dredges, and as a result, Bull Run Creek is now a narrow channel band constrained by tailing piles that is incapable of mobilizing and resorting the tailing piles to any meaningful degree.

Pockets of wetland habitat still exist in isolated ponds created by mining activities, but in general the creek channel is now the hydrologic low point throughout the lower half of the site. Relative elevation modeling indicates that the associated wetland habitats, the groundwater aquifer, and the creek channel have all been lowered by up to six feet in this area. By the early to mid-1960s lodgepole pine had become established atop tailings and native hardwoods had been restricted to the few portions of the floodplain that weren't disturbed by mining. Where the hardwoods do currently exist near Bull Run Creek channel, form and stream power preclude beaver presence despite pockets of off-channel vegetation that might otherwise support beaver dams and ponds. Additionally, the lowering of the aquifer and loss of fine sediments (due to mining activity) has restricted recovery of grasses, forbs, and sedges that would also support beaver populations. Thus, at this juncture beavers, though present in the area, seem to be unable to colonize the creek. Because beavers are a keystone species in many North American and Eurasian riparian ecosystems [5] [6], their absence from Bull Run Creek combined with the other deleterious effects of the tailings has prevented the return of healthy riparian wetlands and attendant spawning waters for the anadromous fish

Resident and anadromous aquatic species still utilize the site, although in lower numbers than in the past. Bull Run Creek supports ESA listed bull trout [7] and summer steelhead trout [8], while spatially isolated wetlands in the valley are inhabited by Oregon Conservation Species listed Columbia Spotted frog (*Rana luteiventris*) [9]. In portions of the site where tailings are less dominant, channel complexity is still present and contains large wood entrained or placed through past restoration efforts, although all but the very highest flows still remain contained within the channel. Where tailings are more dominant, flows have simplified the channel, resulting in larger substrates, fewer pool/riffle/run sequences, fewer alcoves, and less large wood within the channel. Mussels continue to inhabit the site, indicating good water quality and stable site conditions; however, site stability appears to be compromised to some degree because physical and biological processes are not producing and maintaining dynamically stable habitats capable of supporting healthy populations of various native species as observed in the inconsistent spring Chinook salmon spawning (Zakrajsek unpublished data).

In order to restore critical fish habitat, the Wallowa Whitman National Forest, the North Fork of the John Day Watershed Council, and the Confederated Tribes of the Umatilla Indian Reservation have entered into a partnership on a project aimed at restoring the original stream gradients in a two-mile reach of Bull Run Creek. This is expected to promote repopulation by beaver, various willows, floodplain grasses, and cottonwood, eventually improving the conditions for spawning salmonids. Since aquatic macroinvertebrate assemblages are widely used around the globe as indicators of lake, stream, and wetlands health (for examples see [10] [11] [12] [13]), we have collected macroinvertebrates and basic water quality data to establish a pre-restoration data set for eventual comparison with post-restoration profiles. This is expected to provide insights into the effects of restoration activities on fish habitat as well as overall riparian health.

2. Methods

2.1. The Study Sites

The Bull Run Creek restoration site is located approximately 2 miles upstream from Granite, Oregon (**Figure 1(a)**). Preliminary work in 2020 located four sampling sites—three pre-restoration sites on Bull Run Creek and one non-restoration site on nearby undisturbed Boundary Creek. The four sites were systematically sampled in late November of 2021 to establish the pre-restoration baseline. The first site, BRC1, is located approximately 400 meters downstream from the mouth of Boundary Creek (N44.78698, W-118.38226) at a dispersed camping pullout (**Figure 1(b)**). This stream channel at this location will not be modified during the restoration efforts. The second site, BRC2 (**Figure 1(c)**), is located on Bull run Creek approximately 100 meters downstream from the mouth of Boundary Creek (N44.786926, W-118.378534). This site is in a region of planned modification via the addition of inset floodplain and new channel

Figure 1. (a) Northeast corner of Oregon showing approximate location of the study locale (green star) two miles upstream from the small town of Granite; (b) Site BRC1 on Bull Run Creek; (c) Site BRC2 on Bull Run Creek; (d) Site BC1 on Boundary Creek. All photographs were taken in October of 2020.

meanders. The third site BRC3 is approximately 400 meters upstream from the mouth of Boundary Creek, approximately 50 m upstream from a rocky outcrop in the stream channel (N44.78587, W-118.36695). There are no planned changes in the stream channel at this site. The fourth site is on Boundary Creek (Figure 1(d)) approximately 600 meters upstream from the mouth (N44.79079, W-118.37306). Because it has not been significantly disturbed by historic mining activity, it is viewed as a reference location.

2.2. Water Quality Parameters

During the sampling period, air temperatures ranged from 1.6˚C to 5˚C. The water was clear despite intermittent rain during sampling and continuous rain for several weeks prior to collection. At each site water temperature, dissolved oxygen content, pH, and turbidity were measured at the time of macroinvertebrate collection. Temperature data were collected with Digisense 340 single input data logging thermistor thermometer (NIST certified), turbidity was measured with a Hach 2100Q handheld nephelometric turbidimeter (calibrated immediately prior to data collection), dissolved oxygen was measured with a Vernier LabQuest 2 data logger/dO sensor, and pH was measured with a Vernier LabQuest 2 datalogger/pH probe (calibrated immediately prior to use).

2.3. Sampling Benthic Macroinvertebrates

The macroinvertebrate sampling employed the approaches recommended by Oregon Department of Environmental Quality (ODEQ), which themselves were adopted from the EPA's Rapid Bioassessment Protocols for Use in Wadable Rivers and Streams. Specifically, at each of the four locations noted above, a reach was chosen with a length 40× the average wetted stream bank width. Bull Run Creek ranges from 1 - 3 meters in width so we used 2 m for the estimate, yielding a reach length of 80 m. Recommended sample area is 8 ft^2. There are four options for locating the subsamples within the reach; the systematic approach was used, which involved collecting from 8 evenly spaced locations within each reach (every 10 meters in this case). The location within stream was varied by randomly choosing stream right, center, or left for each subsample site. Each subsample was collected by kicking the stream substratum in a 1 ft × 1 ft zone immediately upstream from a D-frame kick net with 500 um mesh. We adopted the compositing approach, collecting the eight 1 ft^2 sub-samples in each reach and then emptying contents into a sample tray. Contents of the sample tray were then transferred into a one-liter polypropylene bottle, thus combining (compositing) them for the final taxonomic analysis. Organic debris too large for the specimen bottle was removed from net, and contents transferred to a one-liter sample bottle and specimens preserved by addition of 3 parts 95% ethanol or isopropanol to one part of sample.

For taxonomic analysis, each of the composited samples was randomly subsampled until approximately 370 organisms had been identified (BRC1 = 369, BRC2 = 360, BRC3 = 358, and BC1 = 384). All benthic macroinvertebrates were keyed out to the family level, and some, including the Plecoptera, Ephemeroptera, Trichoptera, Simulidae, and Elmidae, were keyed out to genus level. The dichotomous keys employed are included in the fifth edition of "An Introduction to the Aquatic Insects of North America" [14].

2.4. Analysis

After the organisms were identified and entered into a spreadsheet, three basic biodiversity calculations were used to quantify taxon diversity (which is taxon richness + taxon evenness): Percent Dominance, Shannon's Entropy/Equitability indices, and the Sorensen Similarity index. Percent Dominance was calculated by summing the total number of individuals in the three most abundant taxa at each site, dividing by the total number of individuals, and then multiplying by 100. Shannon's Entropy and Equitability index were calculated in Microsoft Excel using the following formulae:

$$H_{ent} = -\left[\left(p_1 * \ln p_1\right) + \left(p_2 * \ln p_2\right) + \cdots \left(p_n * \ln p_n\right)\right]$$

$$H_{equ} = -\left[\left(p_1 * \ln p_1\right) + \left(p_2 * \ln p_2\right) + \cdots \left(p_n * \ln p_n\right)\right] / \ln(n)$$

where p is the number of each taxon/total number of individuals at the site, and n is the total number of taxa at the site. The Sorensen's Similarity index is a measure of species similarity between locations. It was calculated using the formula:

$$Cs = 2j/a + b$$

where j = number of species in common (that occur in both sites), a = number of species in site 1, and b = number of species in site 2. The principle components analysis was conducted in R studio (script available upon request), and the covariance table was generated in Excel Office 2019.

3. Results

A summary of the number of individuals in each family at all four sites is shown in Figure 2. Both BRC3 and BC1 (Boundary Creek site) yielded 24 taxa, BRC2 yielded 23 taxa, and BRC 1 yielded 21 taxa. The data shows a very clear predominance of non-biting midge larvae at all of the sample sites. Percent dominance calculations for each of the sites show relatively high percent dominance (Table 1). At all sites, the Chironomidae (non-biting midges) far outnumber all other taxa. Diversity between sites varies somewhat, although not dramatically. A pairwise comparison of taxa (family) richness using the Sorensen's similarity coefficient is shown in Table 2 shows an overall moderate degree of shared diversity between the sites. The lowest scores (indicating fewer shared taxa) occurred when comparing Bull Run Creek site BCR3 to the Boundary Creek site (BC1) and between two Bull Run Creek sites, BCR1 and BCR3. Two Bull Run Creek sites, BCR1 and BCR2, showed the highest degree of shared taxa.

Many of the members of the mayfly, stonefly, and caddisfly orders require

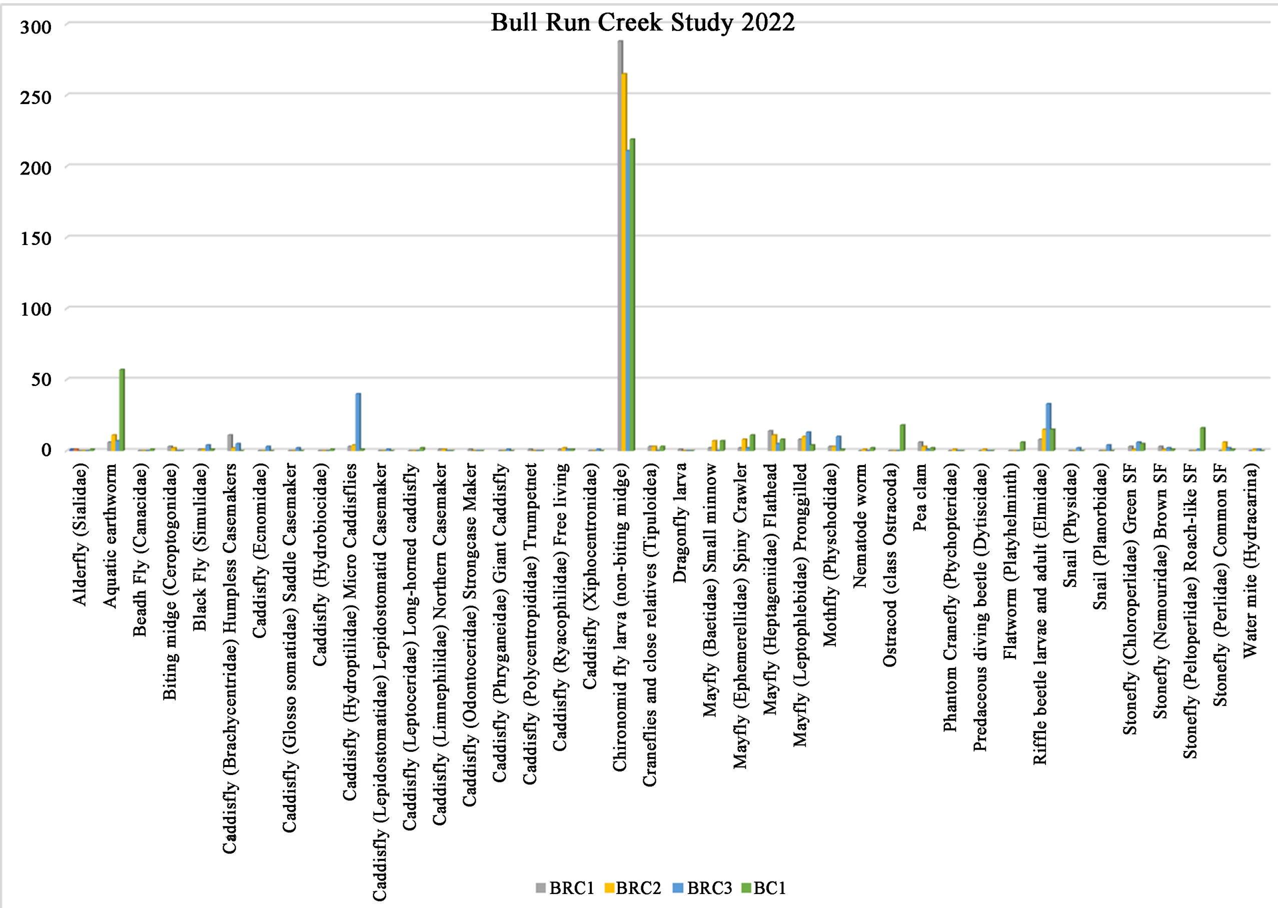

Figure 2. Summary of the number of individuals in each family at each site. All taxonomic rankings are family level.

Table 1. Dominant taxa at each of the study locations. Dominant taxa are listed in the order of dominance. NB = non-biting.

Site	% Dominance	Dominant Organisms
BRC1	85	(NB Midge, Flathead Mayfly, and Humpless Casemaker Caddisfly)
BRC2	81	(NB Midge, Riffle Beetle, Flathead Mayfly, Aquatic Earthworm)
BRC3	79	(NB Midge, Microcaddisfly, Riffle Beetle)
BC1	77	(NB Midge, Aquatic Earthworm, Ostracod)

Table 2. Pairwise comparison of taxa richness using Sorensen's Similarity coefficient.

Sorensen's coefficient BRC1/BC1	0.71
Sorensen's coefficient BRC2/BC1	0.72
Sorensen's coefficient BRC3/BC1	0.63
Sorensen's coefficient BRC1/BRC2	0.82
Sorensen's coefficient BRC1/BRC3	0.62
Sorensen's coefficient BRC2/BRC3	0.68

high water quality in order to survive. Often, species level ranking is required to determine the sensitivity profile of a stream, but in some cases all members of the family are considered very sensitive. These include the Humpless Casemaker Caddisflies (Brachycentridae), the Lepidostomatid Caddisfly (Lepidostomatidae), the Strongcase Maker Caddisfly (Odontoceridae), the Free-living Caddisfly (Rhyacophilidae), the Roachlike Stoneflies (Peltoperlidae), and the Green Stoneflies (Chloroperlidae). In this work, Rhyacophilid caddisfly and Chloroperlid stonefly were observed in all locations. Brachycentrid caddisfly were observed in all three Bull run Creek samples, but not in the Boundary Creek sample. One Lepidostomatid caddisfly was observed in the BRC3 sample, and one Odontocerid caddisfly was observed in the BRC1 sample. The Boundary Creek sample had 16 Peltoperlid stoneflies, and BRC3 had one Peltoperlid. The Ephemeroptera, the Plecoptera, and the Trichoptera are in general sensitive organisms, and we used them to calculate the EPT index at each site (Lenat 1988). It is calculated by summing the Ephemeroptera, the Plecoptera, and the Trichoptera at each site, and then dividing by the total number of individuals at each site. In this study, $BRC1_{EPT}$ = 13%, $BRC2_{EPT}$ = 15%, $BRC3_{EPT}$ = 24%, and $BC1_{EPT}$ = 15%. The BCR3 site scored in the excellent range, BRC2 and BC1 in the Good/Fair range, and BRC1 in the Fair range (scale from The Watershed Science Institute, Technical Note 3). As with the other indices calculated in this analysis, the large numbers of chironomid larvae dominate at each site and greatly influenced the EPT index.

Four water parameters were measured and results from each site are presented in **Table 3** and **Figure 3**. Water temperatures were remarkably consistent amongst the sites, ranging between 3.74˚C and 5.41˚C. The pH values at all sites were all nearly identical, ranging from 7.11 to 7.32. Turbidity ranged from 0.46 - 1.5 nephelometric turbidity units (NTU), and dissolved oxygen concentration (dO) ranged from 9.59 - 11.19 mg/ml. Despite the fact that neither the water quality parameters nor the taxa diversity varied dramatically from site to site, strong correlations were found between the number of taxa and water temperature (negative correlation) as well as the number of taxa and dissolved oxygen concentration (positive correlation—see **Table 4**). Note that the physical properties of oxygen dissolution in water dictate that as the temperature increases, the amount of dissolved oxygen decreases. Principle components analysis of the number of taxa and the water quality parameters shows that the number of taxa covaries with the dO and negatively covaries with the temperature (**Figure 4**). In contrast, principle components analysis with Shannon's Entropy, a measure of both richness and evenness, suggests that overall diversity is not as strongly correlated with temperature and dissolved oxygen but instead negatively correlates

Table 3. BRC1, BRC2, and BRC3 are on Bull Run Creek. BC1 is the control site on Boundary Creek. dO = dissolved oxygen concentration, NTU = National Turbidity Units.

	Temperature in degrees Celsius	pH	Turbidity in NTU	dO mg/L
BRC1	5.41	7.19	0.85	9.59
BRC2	3.87	7.2	1.5	10.44
BRC3	4.24	7.11	0.65	10.77
BC1	3.74	7.32	0.46	11.19

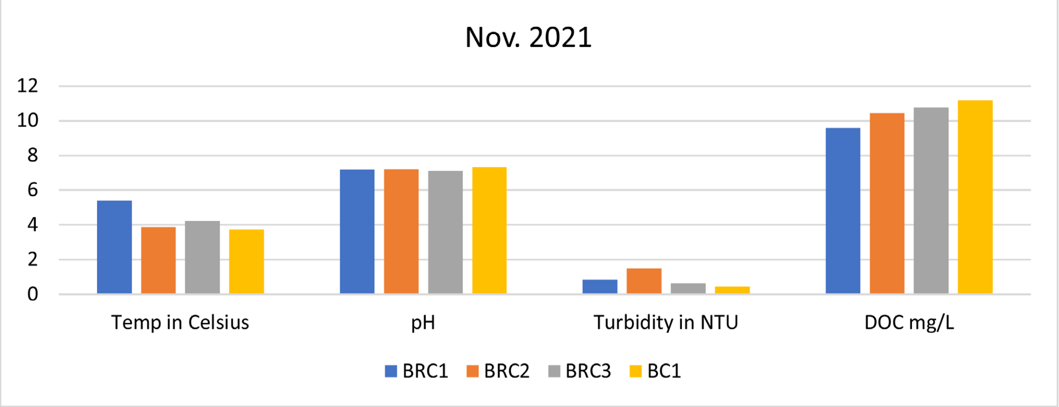

Figure 3. Visual representation of the data in **Table 1**. Scale is absolute, and units vary as indicated according to parameter. NTU is nephelometric turbidity unit. DOC is dissolved Oxygen concentration.

Table 4. Sample level analysis of covariance between the number of taxa (richness) and each water quality parameter.

covar coefficient #taxa vs dO	0.93
covar coefficient #taxa vs Turbidity	(0.20)
covar coefficient #taxa vs pH	0.02
covar coefficient #taxa vs temp	(0.95)

with turbidity (less turbidity, more diversity—see Figure 5). The scree plots of both principle components analyses indicate that most of the variation is accounted for in the first principle component (Figure 4 and Figure 5). In addition, the samples do not cluster in either of the principle components analyses, suggesting that, with the scales used, the samples are moderately unique. This supports the Sorensen's analysis, which suggested moderate shared diversity between the sites.

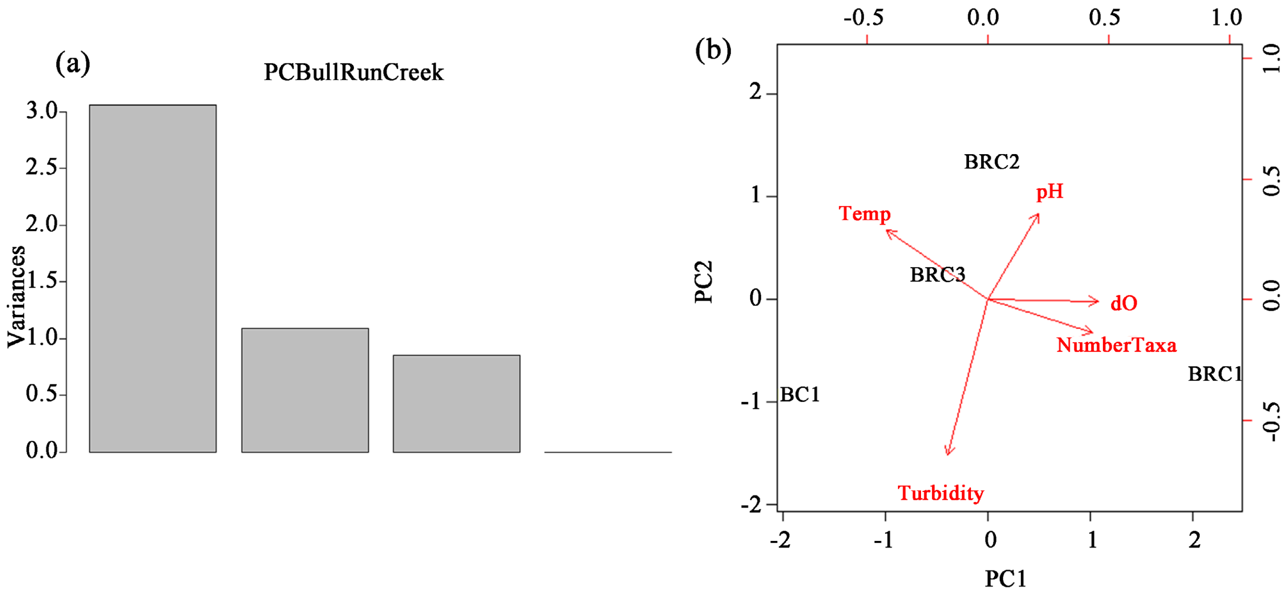

Figure 4. (a) Scree Plot showing principle components analysis of number of taxa and water quality data from principle components analysis Bull Run Creek. (b) Biplot from principle components number of taxa and water quality data.

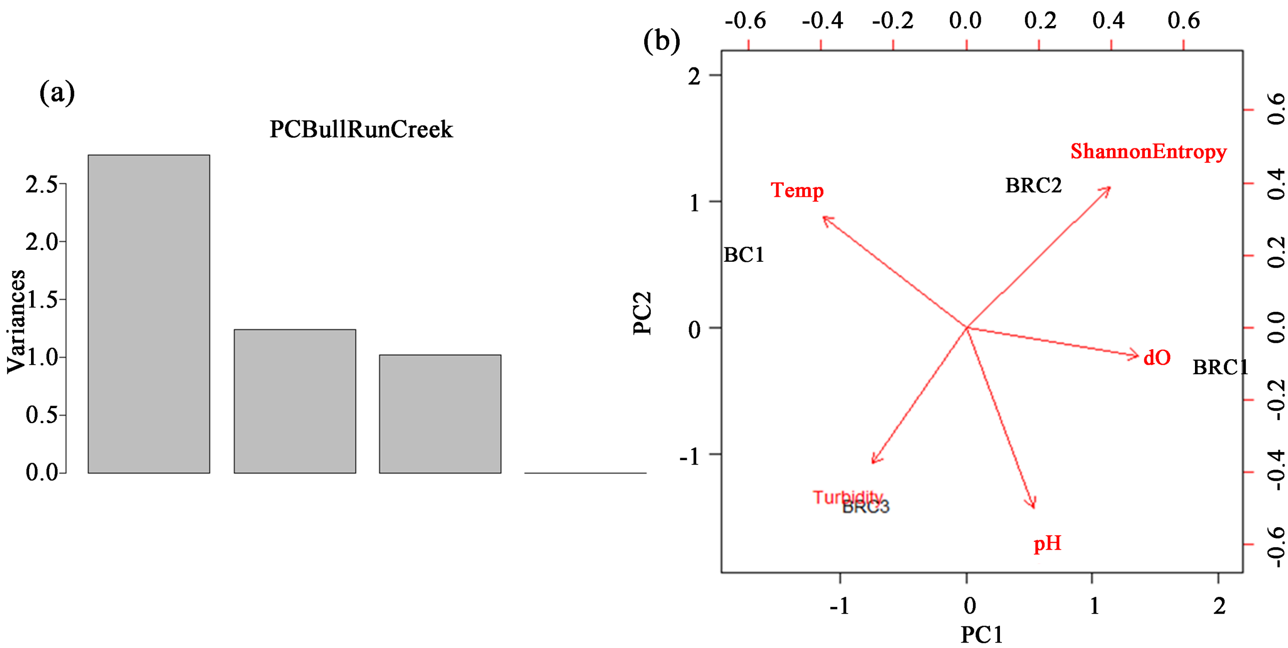

Figure 5. (a) Scree Plot showing principle components analysis of Shannon's Entropy and water quality data from principle components analysis Bull Run Creek. (b) Biplot from principle components number of taxa and water quality data.

4. Discussion

The pH values are close to neutral, indicating that there is no leeching of acid from natural sources, such as rock glaciers or certain types of bedrock [15] [16], or after historic mining activity in the Bull Run Creek study reaches. These tightly circumneutral pH values suggest high water quality for both streams. The turbidity values were also low, ranging from 0.46 to 1.5, though not quite low enough for drinking water (the US Environmental Protection Agency requires that drinking water scores consistently below 0.5 nephelometric turbidity units). Recent rains in the area likely raised the turbidity somewhat. The dissolved Oxygen concentration values of both creeks in this study range between 9.5 and 11.2, values that are typical for cold mountain streams. Dissolved oxygen concentrations (dO) in mountain streams can vary widely, but are typically in the range 9 - 12. An example of this is seen in an analysis of 55 years of historical spring/summer dO averages for streams in California's Sierra Nevada, where the dO was seen to average 11.1 (±1.1) and 9.8 (±1.3), respectively [17]. Because the theoretical solubility of molecular Oxygen in water is between 3˚C - 5˚C is 9.35 - 8.99 mg/ml [18], it is likely that the high gradient (and attendant aeration) is responsible for the somewhat higher O_2 concentrations in Bull Run and Boundary creeks. The levels of dissolved Oxygen in both creeks are well within the range that would be considered supportive for aquatic life, including the Salmonids [12]. It is important to note that worldwide, riparian degradation caused by rising temperatures (which decrease the concentration of dissolved oxygen) and anthropogenic eutrophic events has significantly increased hypoxic stress on freshwater aquatic communities [19] [20] [21]. This underscores the importance of preserving and improving existing healthy waterways.

Species diversity, in ecological terms, is considered to be the combination of species richness (number of species) and species evenness (number individuals in each species). Shannon's entropy calculations [22] take into account both richness and evenness so are often used to estimate taxon diversity, with higher numbers suggesting higher diversity. **Table 5** shows that the sample sites in current study ranged between 1.04 and 1.58, suggesting relatively low overall diversity (due probably to relatively low taxonomic richness (21 - 24 taxa)), and that the Bull Run Creek site BCR3 had the most diversity. Interestingly, this was the upstream site with lower stream gradient, hence slower moving water than the other study sites. Taxon evenness can also be accounted for using the Shannon's Equitability index calculation, with numbers closer to one representing higher evenness and overall species diversity. Inspection of **Table 5** shows fairly low Shannon's Equitability indices for all sites, with the highest score occurring at BRC3. This suggests that the BCR3 site had higher overall benthic macroinvertebrate species diversity than the other sites. It is worth noting that our study did not detect any freshwater mussels. These sensitive animals have been observed in the Bull Run Creek reaches destined for restoration, but because our sampling did not reveal their presence, it appears that they are present in fairly low numbers.

Table 5. Shannon's entropy and Shannon's Equitability index, calculated with natural log base as shown in Methods section.

	BRC1	BRC2	BRC3	BC1
Shannon's entropy	1.04	1.18	1.58	1.41
Shannon's Equitability	0.34	0.38	0.50	0.44

Another indicator of species richness is the percent dominance. Table 1 shows relatively high percent dominance at each site, and that the chironomid larvae outnumber the other organisms at each site. While high percent dominance can potentially be a sign of an unbalance in the ecosystem, it is not clear what this means in terms of the Bull Run Creek and Boundary Creek ecosystems. Chironomids are mostly burrowing collector-gatherers, feeding on detritus, so are important recyclers of biomass. As commonly observed in other studies, chironomids dominated the communities of the Bull Run Creek and Boundary Creek samples. Though many studies (for examples see [23] [24] [25]) suggest that chironomids are more abundant in disturbed waterways, they are also known to dominate in undisturbed stream, lakes and rivers, so it is not clear at this juncture whether the high numbers of chironomids are truly indicative of poor community health in the Bull Run Creek ecosystem.

5. Conclusion

Restoration activities at Bull Run Creek are scheduled to begin in 2023/2025. Because it is important to monitor ecosystem changes during restoration work, we have conducted a pre-restoration study aimed at characterizing four water quality parameters (temperature, dissolved oxygen, turbidity, and pH) and benthic macroinvertebrate assemblages. This initial collection was conducted in the fall of 2021. Values for the four standard water quality parameters and the benthic macroinvertebrate communities at Bull Run Creek suggest that overall, the water quality is good in both streams, and both streams are inhabited by organisms that are known to be highly sensitive to a variety of stresses (for example the green stoneflies, the free-living caddisflies, and the roach-like stoneflies). The EPT Index suggests good overall water quality, and we expect this to shift into the excellent range as restoration efforts progress. Finally, we note that this analysis accounts for only benthic macroinvertebrates and that a more robust understanding of the pre-restoration riparian ecosystem would be gained through the sampling of aquatic microbes (including algae, bacteria and diatoms), aquatic plants, and aquatic vertebrates (fish and amphibians).

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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