Macroinvertebrate Response to Large Wood Stream Restoration on Cobble Dominated Streams in Southern Oregon's Klamath Siskiyou Mountain Range

Rachel Parks, Gene Brady, Collier Williams, and Jess Holte
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Southern Oregon University
Environmental Science and Policy Department

Abstract

The removal of channel forming structures has simplified streams in Southern Oregon's Klamath Siskiyou coastal mountain range. This has had a negative effect biologically, reducing habitat for a range of aquatic organisms. Because of this, the replacement of large debris has become fundamental in terms of stream restoration. Yet, there is still some controversy on how large wood application restoration practices affect different species of macroinvertebrates. This study looked to determine whether or not large wood placements on cobble dominated stream systems in Southern Oregon's Klamath Siskiyou coastal range has an effect on macroinvertebrate species composition by statistically modeling changes in macroinvertebrate

species complexity and using biotic indexes to assess the success of a restoration project on Elk Valley Creek.

I Introduction

During the nineteenth century, the role of logs in streams was not well understood in the North West United States. As settlement increased, so did the removal of large logs from the area's surrounding streams and other waterways. Forests were clear-cut all the way to the water's edge, destroying riparian areas (ODFW, 2010). Timber harvest played a paramount role in the development of the United States economy. Unsustainable forest management practices eliminated future wood input for streams, reducing the possibility of naturally recreating these debris jams. The removal of these trees was thought to be beneficial, not only improving the local economies but also to remove barriers for fish migration (ODFW, 2010). However, these forest practices resulted in the depletion of channel forming structures, which led to the destruction of habitat and decreased water quality in many streams. Removing in-stream woody debris negatively altered channel formation, stream flow, and sedimentation deposits. It resulted in the loss of small gravel, which serve part in a crucial role for the spawning of native fish. With the destruction of natural processes, aquatic habitat restoration activities are essential in order to restore a natural and healthy ecosystem (ODFW, 2010).

Extensive river modifications and historical changes in land management practices have substantially changed our river systems. In response to this, there has been a wide range of river restoration projects in recent decades. These documented restoration activities have primarily focused on in-stream habitat restoration or habitat creation (Lepori, et al., 2005). Many of these schemes have emphasized restoring physical processes, this is due to the assumption that restoring physical habitat heterogeneity will increase biodiversity. However, assessments of such restoration projects have found that these schemes have variable success, with some studies finding limited evidence of ecological benefits to macroinvertebrates and others reporting positive effects (Lepori, et al., 2005). Low restoration effectiveness on the rehabilitation of macroinvertebrate community structure and function has generally been attributed to the limited scale of many restoration projects, lack of effective monitoring, and inappropriate design or measures. These processes have failed to create the habitats and/or spatiotemporal arrangement needed for the life cycles of target organisms (Lepori, et al., 2005). However, determinations of project success are difficult because of increases in functional diversity (a component of biodiversity that generally concerns the range of roles that organisms perform in communities and ecosystems) are more difficult to assess and achieve than outcomes based on taxonomic analyses (Lepori, et al., 2005). Beechie et al (2010) explains that in order to ensure a more successful restoration project, planners should incorporate process-based principles to re-establish physical, chemical, and biological processes. A holistic approach such as this can promote the sustainable recovery of dynamic river ecosystems. Biodiversity is one of the primary ways to quantify ecological shifts in a community; however, quantifying species diversity can be complicated. Issues within the statistical sampling, inconsistent and arbitrary delineation of ecological communities, as well as issues arising from problems sampling and positively identifying all of the species present can lead to challenges calculating one, the number of species present (species richness) and two, their relative abundances (termed dominance or evenness), which are the two primary and separate components of species diversity. However this complexity has led to the development and use of many different measures known as indices of biodiversity. Magurran (2013) discusses and explains the development, meaning(s), and strengths and weaknesses associated with each of the different biological indices.

As part of this assessment we examined the composition of macroinvertebrates through biotic indices quantifying order richness and evenness (Shannon-Wiener Index of Diversity and Pielou's Evenness Index) and biotic estimates of water quality (Family-Level Biotic Index (FBI) and EPT Richness Index). In addition, we calculated proportions of Scrapers, Filterers, Shredders, Gatherers, and Collectors to assess if the dominant functional groups have changed since restoration implementation.

Considering the positive effects of in-stream large woody debris on stream structure and biological composition; the placement of large woody debris has become a fundamental tool in stream restoration projects. Most projects focus on the placement of artificially fixed wood structures in order to enhance sediment composition and species habitat. Log placements will catch flowing debris, along with upstream logs that can become displaced during high-flow or weathering events, this will eventually result in a natural log jam (Stream, 2001). Log placement has the capability to reshape simplified streams by improving stream complexity, diversity of habitat, water quality and quantity, floodplain interaction and quality of riparian vegetation (Stream, 2001). Large woody debris (log jams) play a number of important roles in forested stream ecosystems. Large woody debris change the direction and focus of flows, they force water under and around logs creating a scour in the riverbed, which in turn, creates pools. These pools serve as crucial habitat during low-flow events (Stream, 2001). For example, woody debris help to provide streams with a range of habitats and protection from intense flow for a variety of aquatic organisms. Furthermore, log jams are the primary site of biofilm production, which serves as a food source for grazing organisms (Johnson, Breneman, & Richards, 2003). Large woody debris added to streams through natural processes or human designed log application are rapidly colonized by invertebrates. These log jams also have the ability to completely reshape the sediment composition of a stream, helping to further advance the range of aquatic habitats. The change in habitat structure associated with the addition of log jams is accompanied by changes in community composition and functional processes (Johnson, Breneman, & Richards, 2003).

Johnson, Breneman, and Richards (2003) employed a multiple habitat, qualitative sampling approach in their evaluation of macroinvertebrate communities associated with in-stream wood habitats for 71 stream reaches in central Michigan and southeastern Minnesota. They evaluated macroinvertebrate taxa by classifying them based on locomotive behavior (e.g. sprawler, clinger, swimmer) and trophic/feeding characteristics. These traits were then used to assess community structure as a function of woody debris abundance and distribution. Essentially, looking at the role each type of macroinvertebrate plays within the system and then assessing the overall change in functional diversity. They found that the presence of in-stream wood habitats and log jams increased local invertebrate diversity in Michigan, but not in Minnesota. However, the presence of woody debris at a site was shown to increase the average taxa richness by 15 and 10 taxa in Michigan and Minnesota, respectively (Johnson, Breneman, & Richards, 2003). Their results concluded that macroinvertebrate ecological function and behavioral attributes related to in-stream wood habitats may vary due to differences in community traits such as localized difference in flow and the position of wood in the channel (Johnson, Breneman, & Richards, 2003). The ecological behavior analyzed in this study is related to feeding more than locomotion, but the conclusion regarding variance is likely to hold constant for either.

Family level biotic index (FBI) is a technique developed by W. L. Hilsenhoff (1988) and is often used in rapid bioassessment of organic pollution. It is considered a cost-effective method of evaluating stream mitigation efforts and monitoring trends. In a study conducted over 10 years in four Mexico streams, Henne et al. (2002) measured R^2 correlation coefficients between FBI and dissolved oxygen ranging from 0.57 to 0.92. Because families which are intolerant to DO changes are often also intolerant to turbidity changes, the correlation between FBI and DO is not always perfect. Usually however, a 2-point change in FBI represents approximately a change of 1 ppm dissolved oxygen.

For this study we assessed changes in species structure and composition to determine if restoring physical processes through large wood application restoration in cobble dominated streams significantly enhances macroinvertebrate total abundance, richness (defined as the number of individuals categorized by order present in the sample), diversity, and evenness in turn signifying rehabilitation of macroinvertebrate community structure and function. We examined the effectiveness of a stream restoration project on Elk Valley Creek, a tributary to West Fork Cow Creek in the Umpqua River Basin in Douglas County, Oregon in meeting their ecological benefit outcome objectives. West Fork Cow Creek is a dendritic tributary of the South Umpqua River of Southwest Oregon. This watershed drains 55.842 acres; 54% of which is federally owned (48% by Bureau of Land Management (BLM) and 6% by US Forest Service (USFS)) in a checkerboard pattern. Much of the remaining 46% is owned by private timber companies (BLM, 2004).

This project examined the effectiveness of large wood application as part of restoration in relation to macroinvertebrate composition and changes in stream health as assessed by biotic indices estimates of water quality. Many studies indicated the potential use of macroinvertebrates as bioindicators of water quality and pollution, supporting the scientific theory that freshwater macroinvertebrate species have specific and varying sensitivity to organic pollution (Azrina, et ` al., 2005). High diversity and richness of species is associated with good water quality (ie. high levels of dissolved oxygen, low turbidity, temperatures conducive to Core Cold Water Habitat Use, and other biologically based numeric criteria) (DEQ, 2007). Therefore, metrics of macroinvertebrate relative abundances has been widely used to assess water quality parameters. For this study we used the Family biotic index, which measures waste in streams by through the relative proportion of tolerant and intolerant taxa. Increases in FBI are associated with a trend of worsening physical and chemical habitat conditions for photosynthetic organisms. However, one limitation of comparing macroinvertebrate metrics is the possible delay in species assemblage changes following modifications to water quality (Azrina, et al., 2005).

The significance of performing restoration and this study in Elk Valley Creek is tied to the Oregon Department of Environmental Quality (ODEQ) designation of both the East Fork and West Fork of this Creek as beneficial for salmon and trout rearing and migration (see Figure 1) (State). Meaning that the water quality in the stream, specifically from January 1 to May 15, must meet specific ODEQ criteria for such a cold water habitat. For example, the seven-day-average maximum for dissolved oxygen (DO) and intergravel dissolved oxygen levels must be greater than 11.0 mg/L to comply with State standards (DEQ, 2007). Under Division 41: Water Quality Standards of the ODEQ administrative rules, specific water quality criteria must be maintained to protect this fish use designation. Furthermore, the National Oceanic and Atmospheric Administration (NOAA) has flagged West Fork Cow Creek as critical habitat for the Oregon coast Coho salmon (*Oncorhynchus kisutch*) (Stein, 2011). Therefore, restoration efforts include log placements to improve aquatic habitat for salmon and migrating Steelhead. In order to improve habitat for these fish species, large woody debris structures were designed and installed into two tributaries of West Fork Cow Creek. One of these tributaries was the East Fork Elk Valley, which underwent log jam restoration in 2016. These large woody debris structures were designed to mimic naturally occurring log jams in hopes of improving sediment characteristics for Coho spawning redds, increasing organic material within the aquatic ecosystem, and reducing water temperature by increasing stream shade and pool dimensions (Stein, 2011). Furthermore, macroinvertebrates play roles as fundamental food sources for a variety of aquatic organisms (Hrodey, Kalb, & Sutton, 2008).

The Oregon Department of Fish and Wildlife (ODFW) conducted an Aquatic Inventory Project Stream Report for Elk Valley Creek in which they assessed the habitat of the stream prior to restoration. This habitat survey started at the confluence with West Fork Cow Creek and continued upstream 6680 meters ending at a road crossing above an unnamed tributary junction. It was found that the stream channel was predominately constrained by hillslopes in a moderate V-shaped narrow valley. Land uses in the area were determined to be a mix of large trees (30-50cm dbh), second growth timber (15-30 cm dbh), partial cut timber, and timber harvest (Stein, 2011). The stream substrate was evaluated and found to consist primarily of fine sediments (28%), gravel (25%), and cobble (24%). Additionally, stream habitats were scour pools (39%), rapids (26%), riffles (17%), and dammed beaver pools (13%). Furthermore, large woody debris volume was low ranging from 3.9-11.3m^3/100m of stream channel length. Bank undercut ranged from 0-9% of the reach stream length. Based on 11 riparian transects, riparian zones in the area were dominated by 3-15 cm dbh hardwoods and 15-30 cm dbh conifers (Stein, 2011). This 2011 Elk Valley Creek Habitat Report was critical in the development and design of the restoration plan.

The Bureau of Land Management (BLM) in partnership with West Fork Cow Creek Partners (WFCC partners) began collecting data on Elk Valley Creek in 2015 to provide baseline data and support restoration plans. In 2016, a survey of fish habitat and populations for West Fork Cow Creek Watershed was conducted and used to inform a framework for ranking potential restoration projects that would be designed to improve fish passage and habitat (West, 2017). This survey data produced monitoring information that helped direct restoration efforts in this watershed and could be used to inform other restoration efforts in the Pacific Northwest.

Our objective for this project was to determine whether or not large wood placements on cobble dominated stream systems in Southern Oregon’s Klamath Siskiyou coastal ranges has an effect on macroinvertebrate species complexity. Through this process we used research gained through the sampling of aquatic macroinvertebrates, which followed the National Aquatic Monitoring Center protocols. By using various indexes such as Shannon-Wiener’s index of diversity, Pielou’s evenness index, and FBI we worked to illustrate a change in species composition. Additionally, as part of our analysis we decided to run t-tests in order to find the p-value and determine the significance of our results. Through this data analysis we expected to see a trend illustrating that log-placement restoration successfully increases aquatic habitat complexity for a variety of macroinvertebrates.

Our end goal is to determine if large wood placements on cobble dominated stream systems in Southern Oregon’s Klamath Siskiyou coastal ranges cause a shift in macroinvertebrate species composition and complexity. To examine the effectiveness of log jam stream restoration, we analyzed baseline data from West Fork of Elk Valley Creek as well as pre-restoration macroinvertebrate species sampling in the East Fork Elk Valley Creek. These data were then compared to post-restoration invertebrate composition monitoring results for these two locations.

The relationship between large wood application restoration and shifts in macroinvertebrate species composition was examined through significance tests such as a Paired Two Sample for Means t-test. Through this investigation, we illustrate whether or not there is a significant difference in macroinvertebrate order composition and abundance between 2015 and 2017 in East Fork Elk Valley Creek (restored fork/treatment group), West Fork Elk Valley Creek (non-restored/control group), and at the Confluence of the two forks. We expected to see a correlative relationship between large wood placement restoration and macroinvertebrate composition which could be used to evaluate changes in stream health due to restoration efforts. Our predictions are expressed and explicitly stated in the following hypotheses.

Null Hypothesis (H0): increasing the physical heterogeneity of homogenized stream reaches in cobble dominated stream systems in Southern Oregon's Klamath Siskiyou coastal ranges through large wood application restoration does not significantly affect macroinvertebrate total abundance, richness, diversity, and evenness.

Alternative Hypothesis (H1): increasing the physical heterogeneity of homogenized stream reaches in cobble dominated stream systems in Southern Oregon's Klamath Siskiyou coastal ranges through large wood application restoration significantly enhances macroinvertebrate total abundance, richness, diversity, and evenness.

II Project Design and Methodology

In-Stream Experimental Design

Stream restoration efforts within the East Fork Elk Valley Creek were established, designed, and performed by the WFCC Partners, which include Bureau of Land Management's Medford District, the non-profit Partnership of the Umpqua Rivers (PUR), Oregon Department of Fish and Wildlife, US Forest Service, Weyerhaeuser and the Cow Creek Tribe, among others. Additionally, in 1994 the BLM established a reference paired watershed monitoring site in Bobby Creek. Bobby Creek is a key tributary to West Fork Elk Creek and is managed by the BLM as a Research Natural Area (RNA) (West, 2017). Data collection from these monitoring sites include streamflow, stream temperature, air temperature, precipitation, water quality and macroinvertebrates (West, 2017).

In 2015 streamflow sites were established on the East Fork and West Fork of Elk Valley. These sites are similar to the Bobby Creek sites in size, stream flow, and types of data collected. In addition, in September of 2015 automatic samplers were put in East Fork, West Fork, and mainstem (below the confluence) Elk Valley Creek in order to measured turbidity, conductivity, and pH; providing a year of baseline data collection before log placements in 2016. In 2016 cross-sections, pebble counts, longitudinal survey, and photo points were done in East Fork Elk Valley Creek to establish baseline data for assessing changes to fish habitat from wood jams (West, 2017).

Macroinvertebrates in both East and West Fork Elk Valley were first sampled on September 4th, 2015 and were collected by Heather Bartlett from the Cow Creek Tribe. Sampling for this project was conducted using protocols created by National Aquatic Monitoring Center, as outlined in the below table (see Figure 2). All sample sites were kept at a constant, sampling the same area of each stream, during all rounds of sampling. Samples were gathered using a Surber sampler net (.7432 m^2) with a mesh size of 500um. The sampling target habitat was defined as fast-water (riffle). To avoid bias, the location of each of theses fast-water sampling areas was determined by the generation of random coordinates. Sites were located at West Fork Elk Valley (42.8533952210291, -123.709639663691) and East Fork Elk Valley (42.8529440395257, -123.701017916659). Samples were collected in approximately 100 foot long segments at each site; there were eight sample locations within each site.

In 2016 two restoration installments were implemented on two reaches on East Fork Elk Valley Creek. This restoration project on East Fork Elk Valley includes 36 large wood jams along 1.3 miles of the stream channel (West, 2017). A private contractor using a small cable yarding system installed these structures. A second sampling session occurred one year after restoration on August 15th, 2017. Once again macroinvertebrates were collected on both the East and West Fork stream reaches of Elk Valley creek. Bartlett from the Cow Creek Tribe conducted samples. Samples were once again collected from both sites of both forks on August 28th, 2018. Collier Williams gathered these samples with assistance from Tavis Mackie and Bartnett. This assistance was necessary in order to achieve similar sampling and provide study continuity.

Samples were then preserved and sent to the Utah State BugLab for identification of macroinvertebrate species. Results are presented in operational taxonomic unit (OTU) names.

Data Analysis Experimental Design

Using the results of these macroinvertebrate samples we were able to measure shifts in macroinvertebrate species composition and changes in stream health due to restoration efforts. This was done by using Shannon-Wiener Index of Diversity and Pielou's Evenness Index to calculate order richness and evenness, FBI to obtain biotic estimates of water quality, and composition calculations of scrapers, filterers, shredders, gatherers, and collectors to assess how the dominant orders have changed. Macroinvertebrate organisms were categorized by measures of stream health (i.e., the abundance of Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa, overall pollution-intolerant taxa (Family Biotic Index), and functional feeding guilds (i.e., scraper, filterer, shredder, collector-gatherer, collector-feeder, and predator,). Functional feeding guild classification was a workaround to help the resolution of our analysis since not all results were received for species or family taxonomic levels. Feeding guilds also help distinguish macroinvertebrate results in terms of specific habitat types (ex. headwaters, water-logged wood, canopied areas, shallow waters) along the river continuum as well as seasonally. When assessing stream health through the use of macroinvertebrate bioindicators such as the FBI and the EPT Index, we followed similar analysis procedures as Johnson, Breneman, and Richards (2003) and Lepori, et al. (2005). These studies set a precedent for us to assess both functional diversity and taxonomic diversity by classifying macroinvertebrate taxa based on their ecological function.

We ran preliminary t-tests in order to find the p-value and determine the significance of the results we receive from the BugLab. We chose a statistical approach to analyze our sample results based on the form and characteristics of the data. The statistical approach we applied was Parametric because the population data for the three sampled stream sites are independent and measured on a continuous metric scale. Given that there were less than 30 observations across the creeks, we had to perform a t-test on this data. Furthermore, we decided to use a one-tailed t-test because the alternative hypothesis is directional, indicating that restoration treatment will increase macroinvertebrate total abundance, richness, and diversity.

With a 95% confidence interval, representative of a significance level set at $\alpha = 0.05$, the total area in which H0 is rejected encompasses 5% of the area under the curve. Since the alternative hypothesis is directional the rejection region is a one-tailed test therefore, the acceptance region is the body of the distribution and the other tail.

Using a Paired Two Sample for Means t-test allowed us to test the mean abundance of individual macroinvertebrates within each taxonomic order for East Fork Elk Valley Creek (restored fork/treatment group), West Fork Elk Valley Creek (non-restored/control group), and the Confluence of the two forks before (2015) and after (2017) restoration.

We used statistical data analysis to assess macroinvertebrate total abundance, richness and total abundance, and diversity. For our purposes, richness is representative of the number of different orders represented in each of the three ecological communities/locations. In order to find the p-value and determine the significance of the differences in results between sites (East Fork, West Fork, and Confluence of Elk Valley Creek) and years (2015 and 2017) we used a Paired Two Sample for Means one-tailed t-test. We then examined diversity through comparing changes in macroinvertebrate composition in regards to order abundance. One way we did this was by graphing changes in macroinvertebrate composition; a stacked bar chart was developed measuring and comparing order abundance by year of the three stream locations.

We ran the one-tailed t-test using the Data Analysis tool in Excel. Selecting "t-Test: Two Sample for Means" we entered the cells for the pre-restoration (2015) macroinvertebrate samples in Variable 1 Range and entered the cells for post-restoration (2017) in Variable 2 Range. Once setting the Hypothesized Mean Difference to 0, in accordance with the null hypothesis, and entering the alpha level to 0.05 we ran the test.

To analyze changes in macroinvertebrate diversity we used Shannon Wiener's Diversity Index. This is one of the most commonly used indices to evaluate species richness and dominance. Species richness is the number of different species represented in an ecological community and dominance is the degree to which a taxon is more prevalent than other species in its ecological community. Changes in biodiversity can be used to make assumptions on changes in habitat structure and quality. Diversity is measured as H and represents the Shannon Index. The equation is as follows

$$H = - \Sigma [(p_i) \ln(p_i)]$$

where, H is equal to the diversity value and p_i is the proportion of individuals found in order i (S/N) where S is equal to total individual number of orders and N is equal to the total individual number of all taxonomic orders. The Shannon Wiener Index assumes that all species are represented in a sample and that the sample was obtained randomly. We calculated p_i values for each order within all three stream sample locations for 2015 and 2017 and then quantified $[(p_i) \ln(p_i)]$. Due to the nature of the equation and data these values were all be between zero and one. Next we summed these values, which where negative due to the natural log, and took the inverse of the sum(s).

Values for this index range from 0 to infinity, however ecological studies generally see values between 1.5 and 3.5, with results rarely exceeding 4 (Magurran ,2013). Result value(s) increase as diversity, defined as richness and the evenness, increase. We chose to use this specific index because incorporates both of these components of biodiversity, providing comprehensive understanding of changes. However, one weakness is that it makes it more difficult to compare communities with large variations in richness. Therefore we chose to also individually measured richness and dominance of macroinvertebrate orders. To assess dominance or evenness we used Pielou's Evenness Index.

To compare the actual diversity value to the maximum possible diversity we used a measure of evenness. To further analyze the data collected we used values obtained through Shannon's Index to calculate Pielou's Evenness Index. We used the following equation to calculate the evenness represented as (E) of the samples

$$E = H/Hmax$$

where H equals Shannon Wiener's Diversity values and Hmax is equal to ln(S) or the natural logarithm of S or total number of orders observed. This evenness index assumes that all all orders within the stream are represented in the sample. Eight orders were present in our samples. This index helps to indicate the extent to which a community is dominated by only a few of its taxonomic orders or if sampled individuals are distributed in equal abundance throughout all of the orders. Values range from 0 to 1, with higher values indicating a more even distribution of individual macroinvertebrates within each of the represented orders.

In order to assess the biological integrity of the creek, we will be calculating a macroinvertebrate multimetric index (MMI) for all 3 samples. The MMI we chose to use was the FBI. The FBI indexes water quality by attaching scores to invertebrate families based on their relative sensitivities. FBI Tolerance scores of the various taxa were taken from Bode *et al*. (1996) Plafkin *et al*. (1989), and Mackie (2000). The equation is as follows:

$$FBI = (\sum n_i \ x \ t_i) / N$$

Where n is the number of specimens in taxa *i*, a, is the tolerance value of taxa *i,* and N is the total number of specimens in the sample. This biotic index equation was developed to provide a single tolerance score for the stream. This value is based on each arthropod family's tolerance to organic pollution, specifically how well the organisms in the family can tolerate organic pollutants, increased nutrient and sediment loads and dissolved oxygen (DO) limitations. Scientific evidence indicates that only 20 organisms within each sample are necessary to obtain accurate results. We averaged these specific benthic macroinvertebrate scores from our samples to find the associated water quality value for each stream reach and sampling year. This resulted in overall indices from zero to ten, with zero representing excellent water quality and ten representing very poor quality.

Percent abundance of each macroinvertebrate feeding guild was calculated based on operational taxonomic units (OTUs) identified by the lab. Taxa are considered as either scrapers, collector-gatherers, collector-feeders, predators, or shredders following the designations of Mandaville (2002). A miscellaneous category is included for OTUs which include multiple feeding guilds. Because feeding guild proportions are a rapid bioassessment method, this type of simplified OTU identification is often considered acceptable in management situations (Višinskienė and Bernotienė, 2012).

III Results and Discussion

The mean of the sampled macroinvertebrates as categorized by taxonomic order for East Fork Elk Valley Creek for 2015 and 2017 was 104.6824543 and 71.375, retrospectively (see Fig. 3). This indicates that there was a decrease in the total abundance of macroinvertebrates between 2015 and 2017. Additionally, the West Fork of Elk Valley Creek had a mean of 55.83961249 in 2015 and 19.5 in 2017, signifying a large drop in the macroinvertebrate population in this region of the creek (see Fig. 4). However, this trend was not observed at the confluence, which had a 2015 value of 34.98385361 and a 2017 value of 188.375 (see Fig. 5). Because this decrease in aquatic macroinvertebrate abundance was evident in the East and West forks of Elk Valley Creek, but not at the confluence, it may indicate that external environmental factors, such as climatic changes are affecting the macroinvertebrate population.

This change in the total abundance is also visually represented when comparing the values displayed in Figure 6 and Figure 7. Additionally, these stacked bar graphs illustrate changes in the taxonomic composition and distribution of macroinvertebrate orders of individuals sampled within each of the three locations. We identified which orders changed the most by examining abundance and richness through charting and graphing changes in macroinvertebrate composition. Through calculating distribution proportions and developing a stacked bar chart measuring and comparing the abundance of sampled individuals by year for the three locations we found that overall order richness values in the East Fork did not change. The presence of Coleoptera and Odonata, the two orders that are designated as organic pollutant tolerant, decreased or were not observed from 2015 to 2017. However, there were also decreases in the occurrence of Ephemeroptera and Trichoptera, two pollution sensitive taxonomic orders. An increase in Plecoptera, another sensitive order was observed possibly indicating an increase in water quality. Additionally, the 2017 sample for the East Fork saw the appearance 50 individuals in the Neotaenioglossa order. Overall, out of the eight orders present, five decreased, two increased, and one order remained stable. Although not found to be significant, these large decreases in the majority of the order are likely associated with overall lower individual abundance in 2017.

Within the west fork seven out of the eight orders decreased, likely due to significant decreases in overall abundance of individuals. Neotaenioglossa being the only order to increase, with zero individuals observed in 2015 and three in 2017. The significance of this decrease in West fork but not on the east may indicate that restoration mitigated some of the environmental factors that led to these population decreases.

As you can see the confluence displayed overall higher total abundance and order richness. This overall increase in abundance is associated with increases in abundance within all three organic pollutants sensitive orders (or the EPT orders) as well as increases in the orders Coleoptera and Odonata, pollutant tolerant orders. Within samples from the confluence, orders Neotaenioglossa, Trichoptera, and Diptera saw the greatest increases between 2015 and 2017. Two new taxonomic orders (Veneroida and Neotaenioglossa) were also represented within the 2017 sample (see Fig. 6 & Fig. 7). These results are supported by the results of our t-test, which indicated a significant increase in abundance. The cause of this significant increase in individual abundance and order richness is unknown; however, analysis of additional years of data would help to establish a population trend and eliminate errors in results (see Fig. 6 & Fig. 7).

As seen in the t-test: Two Sample for Means output table the one-tailed p-value was for the East Fork was 0.162707929 (see Fig. 3). This value is greater than our chosen significance level of 0.05, meaning that we fail to reject the null hypothesis (H0) because there is not a statistically significant difference in macroinvertebrate total abundance or order composition between the sample from 2015 and the sample from 2017. Therefore, increasing the physical heterogeneity of homogenized stream reaches in cobble dominated stream systems in Southern Oregon's Klamath Siskiyou coastal ranges through large wood application restoration does not significantly affect macroinvertebrate total abundance, richness, and diversity. Furthermore, the East Fork t-statistic is equal to -1.057477389 (see Fig. 3). The p-value of 0.162707929 is less than the absolute value of this t-statistic meaning that the null hypothesis cannot be rejected.

On the contrary, the results we obtained from the t-test we performed on the West Fork of Elk Valley Creek indicated that there was a statistically significant change in macroinvertebrate composition. The one-tailed p-value was equal to 0.004705738, which is less than $\alpha = 0.05$, meaning that we reject the Null Hypothesis. However, due to the directional nature of the Alternative Hypothesis (which indicated that restoration treatment would increase macroinvertebrate total abundance, richness, and diversity), we are not able to accept the Alternative Hypothesis because total abundance decreased. The t-statistic for this fork was equal to -3.544611465, which is less than the p-value, further implying that the null hypothesis will be rejected.

As seen in Figure 5 the one-tailed p-value for the confluence assessment was 0.010267242. The p-value for this t-test analysis is small ($0.010267242 < 0.05$) indicating strong evidence against the null hypothesis; therefore we can reject the null hypothesis. Furthermore, because the p-value is less than (alpha) (0.05) we say that the data is statistically significant at the $\alpha = 0.05$ level. This rejection of H0 is further supported by the t-statistic (t-stat = 2.97932536). The p-value (0.010267242) is not greater than the absolute value of the t-statistic meaning that the null hypothesis will be rejected. Because the total abundance and composition of all individual orders increased from 2015 to 2017 as seen in Figures 5, 6, and 7 we accept the Alternative Hypothesis. Therefore, the results of this Two Sample for Means t-test output suggest that increasing the physical heterogeneity of homogenized stream reaches in cobble dominated stream systems through large wood application restoration significantly enhances macroinvertebrate total abundance, richness, and species diversity.

As seen in the table in Figure 8, the results of our Shannon-Wiener's Diversity Index and Pielou's evenness testing indicate relatively high diversity, evenness, and associated water quality within all sample locations for both 2015 and 2017. Results from the use of Pielou's index followed similar trends to that of the Wiener index. From 2015 to 2017 in the West Fork evenness scores decreased from .9372 to .6864, whereas in the restored section of the creek scores slightly increased from .7395 to .7963. The most significant changes within these calculated values were the decrease in evenness between 2015 and 2017 for the West Fork and the increase in evenness within the confluence. The results we obtained from our Shannon Wiener's Diversity Index indicated that the largest changes in diversity were observed in the confluence. As seen in Figure 8, Shannon's Diversity Index output values for the confluence almost doubled, rising from 0.88 in 2015 to 1.7363 in 2017. A slight decrease in diversity was witnessed in the West Fork, where results fell from 1.9489 to 1.4274. Interestingly, while the West Fork saw a slight decrease in diversity, the restored East fork saw a slight increase (1.5379 to 1.6559).

In regards to diversity and evenness, calculated with Shannon Wiener's and Pielou's indices, values within the West fork prior to restoration (2015) were 1.9489 and 0.9372 respectively and were greater than those of the East Fork, which had a diversity value of 1.5379 and evenness of 0.7396 (see Fig. 8). If we hold true to the theology of Shannon, Weaver and Pielou, that greater diversity and evenness of a community indicates lesser pollution and generally high water quality levels, than it would appear that the West Fork of Elk Valley Creek had slitty better water quality than the East Fork. Additionally, at values of 0.8800 and 0.4232 diversity and evenness results for the confluence were substantially lower, indicating lower water quality and higher concentrations of organic pollutants at this sampling location. However in 2017 after restoration, community diversity and evenness increased within both the East Fork and the confluence (see Fig. 8). However, the Shannon Weaver diversity value for the West fork fell to 1.4274 and the Pielou's evenness index results decreased to 0.6864, indicating a decrease in overall water quality between 2015 and 2017. Furthermore, this shift in macroinvertebrate composition caused the East Fork (H = 1.6559 and E = 0.7963) to surpass the West Fork (H = 1.4274 and E = 0.6844) in terms of community diversity, evenness, and water quality. In turn, indicating that large wood application restoration to increase structural diversity of homogenized streams positively influenced or enhanced macroinvertebrate diversity and evenness. However, this result was not witnessed within the confluence, which increased in total abundance, richness, diversity and evenness, making our results inconclusive.

To more closely evaluate diversity we multiplied the number of individuals identified within each family by the tolerance value for that family, summed the products, and divided by the total arthropods in the sample to ultimately calculate the family biotic index (FBI). The results of the FBI are displayed in figure 9. The West fork saw only a slight change from 4.1 to 4.0 but the East fork saw a significant decrease from 4.54 to 3.72, bringing the quality from very good to excellent. The confluence saw a large increase from 3.4 to 4.68, which could be attributed to the skewed confluence abundance in 2017. The improvements in Elk Creek's East Fork contrast against the other two sites and suggest that enhancements to stream dissolved oxygen were provided by restoration.

Comparisons of feeding guilds over the three stream sites and two study years are shown in Figure 10. The most noticeable disparity between the restored East Fork of Elk Creek and the other two sites was its large increase of predator species. In the West fork (control fork) of Elk Creek, predator composition saw a decrease from 30% to 2% while the collector-gatherer guild saw a large increase from 4% to 22%. Both collector-gatherers and predators are recruited in winter (Merritt et al., 2008). Our results suggest that throughout 2017 predators lacked an adequate food source, such as early-recruiting scraper larvae which spawn in temporary pools. Meanwhile, in the restored East Fork of Elk Creek, predators saw an opposite trend. There, predator composition increased from 3% to 26% while collector-gatherers increased from 10 to 20%. This may suggest that temperature decreases provided by the log jams was most beneficial for winter recruitment. Also worth noting is that collector-gatherers, which increased at all three sites, are usually the primary inhabitants of low stream reaches. One collector-gatherer family which increased, Chironomids, are known for colonizing large logs (Merritt et al., 2008). Since chironomidae saw the highest increase in the restored East fork, this suggests that log jam restoration is particularly beneficial to this macroinvertebrate family.

IV Conclusion

We examined the effectiveness of log jam stream restoration by analyzing pre-restoration macroinvertebrate species diversity data from the East and West Forks of Elk Valley Creek and comparing it to post-restoration invertebrate composition sampling results. We conducted analyses in the form of results from our t-tests, Shannon Wiener Index of diversity, Pielou's evenness index, FBI, and EPT as well as feeding guild classification to show that in-stream log placement increases aquatic habitat complexity, particularly for macroinvertebrate species.

Our analysis shows that there was no statistically significant difference between East Fork order abundance; because of this we then fail to reject our null hypotheses. We did find a statistical significance between the data sets on West Fork, here we reject our null hypothesis but cannot accept our alternative hypothesis because of the directionality of our alternative hypothesis. We also found a statistically significant relationship between 2015 and 2017 data sets for the confluence. For this test, we reject our null and accept our alternative hypothesis that increasing the physical heterogeneity of homogenized stream reaches in cobble dominated stream systems in Southern Oregon's Klamath Siskiyou coastal ranges through large wood application restoration significantly enhances macroinvertebrate total abundance, richness, and diversity. The results of feeding guild calculations suggest that predator taxa, the chironomid family of midge flies, late-recruiting taxa, and low stream reaches saw the greatest benefits from restoration. The decreased FBI in the West Fork of Elk Creek suggests that these benefits to macroinvertebrate population were concurrent with an increase in stream dissolved oxygen. This biochemical change reflects the physical, hydrological, and ecological characteristics of Elk Creek and thus it is primarily useful as a reference condition for restoring similar streams.

The significance of decrease in total community abundance and richness observed in the West fork but not on the East may indicate that restoration mitigated some of the environmental factors that led to these population decreases however, continued monitoring will help shed light on whether the restored creek fork continues to display diversity and water quality scores that indicate greater stream health than that of the West Fork. The cause of the significant increase in total abundance and order richness that occured between 2015 and 2017 in the confluence is unknown. Changes in species diversity and composition could have occurred due to a variety of natural occurrences, which would vary depending upon specific species. We hypothesize that the reason for these discrepancies in macroinvertebrate abundance and composition (decreasing in the East and West Forks yet increasing at the confluence) could be due to increased flow, which increased from around 52 cfs in 2015 to 130 cfs in 2017, resulting in decreased water temperature and possible increases in turbidity from greater levels of erosion along exposed banks and hillsides of the upper watershed (see Fig. 11) (USGS, 2019). This increase in diversity within the confluence not consistent with changes observed in the East and West forks, therefore when interpreting results we must conclude that increasing the physical heterogeneity of homogenized stream reaches through large wood application restoration on the East Fork of Elk Valley Creek had an indiscernible or inconclusive affect macroinvertebrate total abundance, richness, diversity, and evenness. Analysis would greatly benefit from further research to identify the uncontrolled environmental factors influencing macroinvertebrate populations. Due to the paired watershed approach of this monitoring study, in which we are able to directly compare samples from the East and West forks of Elk Valley Creek, analysis of the confluence could also be omitted to eliminate variation in the interpretation of results that resulted in an inconclusive outcome.

Similarly to the results of Johnson, Breneman, & Richards (2003) the results of our macroinvertebrate assessment indicate localised variables such as difference in flow, temperature, turbidity, and the position of wood in the stream channel may have resulted in the inconsistencies within sample sizes and resulting inconclusive nature of our results. In order to determine the cause of these shifts in populations and look for trends in variations in macroinvertebrate population composition further monitoring and analysis will need to take place. The addition of 2018 data to this examination, as we had originally planned, would have been helpful. However due to lag in sample processing we were not able to assess if changes in stream macroinvertebrate biodiversity, in the context of abundance, richness, and evenness continued in 2018 to form a trend or indicate further variation. Furthermore, continued restoration and stream health monitoring should include assessments of changes in the physical structure of the stream. Although such assessments are more labor intensive, they may provide better metrics for examining if changes in physical processes from increasing the physical heterogeneity of the stream are correlated with variation in ecological outcomes.

Acknowledgments

We would like to thank our project partners. We acknowledge the Bureau of Land Management (BLM) for providing funding for sampling and testing as well as by planning and guiding the restoration and monitoring plan as well as West Fork Cow Creek Partners (WFCC partners) including the Cow Creek Tribe for there help in sampling and collecting data. Furthermore, we would like to thank the Utah State BugLab for their critical role in identifying the sampled macroinvertebrates.

Appendices (timetable and project partners)

Appendix A - Project Partners

The Bureau of Land Management (BLM)

Sampling and testing were both funded by BLM

Cow Creek Tribe

Utah State BugLab

Appendix B - Timetable

February 2018 – Presentation in capstone on paper progress

March 2018 – Submission of 1st draft of written report

May 2018 – Submission of final written report

May 2018 – Present at Environmental Science and Policy Symposium

Figures

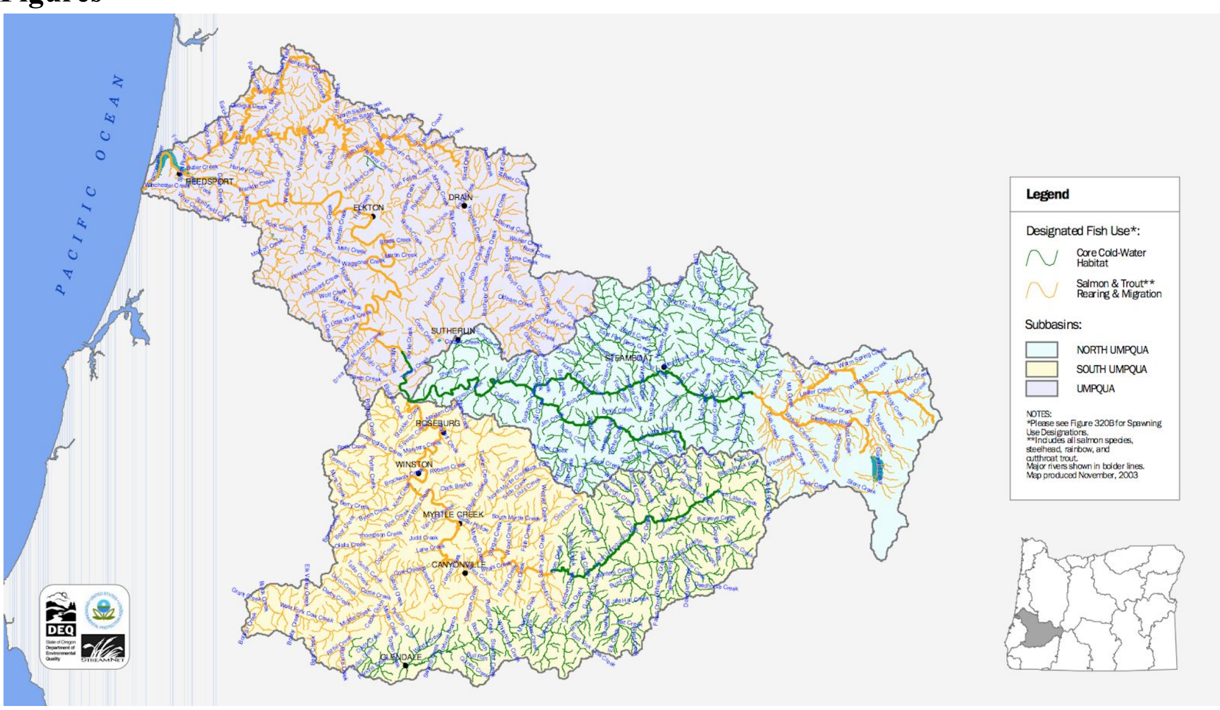

Figure 1: Fish beneficial use designations for the Umpqua Basin in Oregon as classified by ODEQ. Elk Valley Creek can be seen in the South West corner on this watershed basin and is categorized as being a critical habitat for salmon and trout rearing and migration, specifically from January 1 through May 15.

Sampling Procedure	Recommendation
When to sample	July 1st – October 15th; Earlier for extremely arid regions (May 1st)
Sampler type	Surber, kick net (D-frame), or Hess sampler
Mesh size	500 µm
Sample reach length	40 × wetted width or 20 x bankfull (minimum of 150 m)
Target habitat	Fast-water (riffle) habitats
Number of fixed area samples to composite	Total of eight 1 ft^2 (8 ft^2) fixed-area samples: • Riffle/fast-water: one to two (1 ft^2) samples collected from 4 to 8 different fast-water habitats • No riffle/fast-water habitats: one (1 ft^2) sample collected from eleven evenly spaced transects
Placement of sampling device	All sampling locations must be randomly determined to avoid bias: • Riffle/fast-water: generate eight random four digit numbers between 0 and 9999. The first two numbers represent the percent upstream along the habitat unit's length. The second two numbers represent the percent of the stream's width from the left bank. Sample where the length and width intersect. • Transect approach (no riffle/fast-water habitats): Take one sample (1 ft^2) from each of eleven transects. Collect samples alternately from the left quarter, center, and right quarter of each transect, with the first location randomly selected.
Collecting the sample	At each of the eight or eleven sample locations, orient the mouth of the sampler into (perpendicular) the flow. Collect invertebrates from within the area delineated by the net frame. If using a kick net, carefully delineate the 1 ft^2 sample area. Thoroughly wash all rocks, fine sediment, and organic debris to a depth of ~ 10 cm.
Field processing	Place all contents in a bucket filled with water and decant invertebrates and organic matter into a 500 µm sieve or net (optional step). Repeat this process until only sand and gravel remains in the bucket. Inspect the remaining gravel for cased caddisflies, snails, or other invertebrates.
Sample preservation	75-95% ethanol; 3:1 preservative to sample by volume.
Sample submission	http://www.usu.edu/buglab/SampleProcessing/sendSamples.cfm

Figure 2: National Aquatic Monitoring Center (NAMC): Protocol for the Collection of Aquatic Macroinvertebrates Samples. These were used for the sampling portion of this research project.

t-Test: Paired Two Sample for Means		
East Fork	17	15
	ELKE	*ELKE*
Mean	71.375	104.6824543
Variance	4106.839286	14358.44713
Observations	8	8
Pearson Correlation	0.685550534	
Hypothesized Mean Difference	0	
df	7	
t Stat	-1.057477389	
P(T<=t) one-tail	0.162707929	
t Critical one-tail	1.894578605	
P(T<=t) two-tail	0.325415858	
t Critical two-tail	2.364624252	

Figure 3: This two sample output table shows the results of a t-test run on macroinvertebrate order abundance species values from streams sampled within East Fork Elk Valley Creek, which was restored in 2016 and serves as the treatment group in this study, to assess if macroinvertebrate diversity has changed significantly from 2015 (pre-restoration) to 2017 (post-restoration). The Bureau of Land Management (BLM) and West Fork Cow Creek Partners (WFCC) collected the data for this table.

t-Test: Paired Two Sample for Means		
West Fork	17	15
	ELKW	*ELKW*
Mean	19.5	55.83961249
Variance	491.1428571	2132.72023
Observations	8	8
Pearson Correlation	0.87107619	
Hypothesized Mean Difference	0	
df	7	
t Stat	-3.544611465	
P(T<=t) one-tail	0.004705738	
t Critical one-tail	1.894578605	
P(T<=t) two-tail	0.009411475	
t Critical two-tail	2.364624252	

Figure 4: This two sample output table shows the results of a t-test run on macroinvertebrate order abundance species values from streams sampled within West Fork Elk Valley Creek, which serves as the control group in this study, to assess if macroinvertebrate diversity has changed significantly from 2015 to 2017. The Bureau of Land Management (BLM) and West Fork Cow Creek Partners (WFCC) collected the data for this table.

t-Test: Paired Two Sample for Means		
Confluence	17	15
	MainELK	*MainELK*
Mean	188.375	34.98385361
Variance	22950.26786	1355.25758
Observations	8	8
Pearson Correlation	0.277899725	
Hypothesized Mean Difference	0	
df	7	
t Stat	2.97932536	
P(T<=t) one-tail	0.010267242	
t Critical one-tail	1.894578605	
P(T<=t) two-tail	0.020534485	
t Critical two-tail	2.364624252	

Figure 5: This two sample output table shows the results of a t-test run on macroinvertebrate order abundance species values from streams sampled within the confluence of East and West Fork Elk Valley Creek. This confluence is located downstream of restoration in East Fork Elk Valley Creek and can be used to indicate how restoration and possible changes in macroinvertebrate composition due to restoration effect the entire watershed by assessing if macroinvertebrate diversity has changed significantly from 2015 (pre-restoration) to 2017 (post-restoration). The Bureau of Land Management (BLM) and West Fork Cow Creek Partners (WFCC) collected the data for this table.

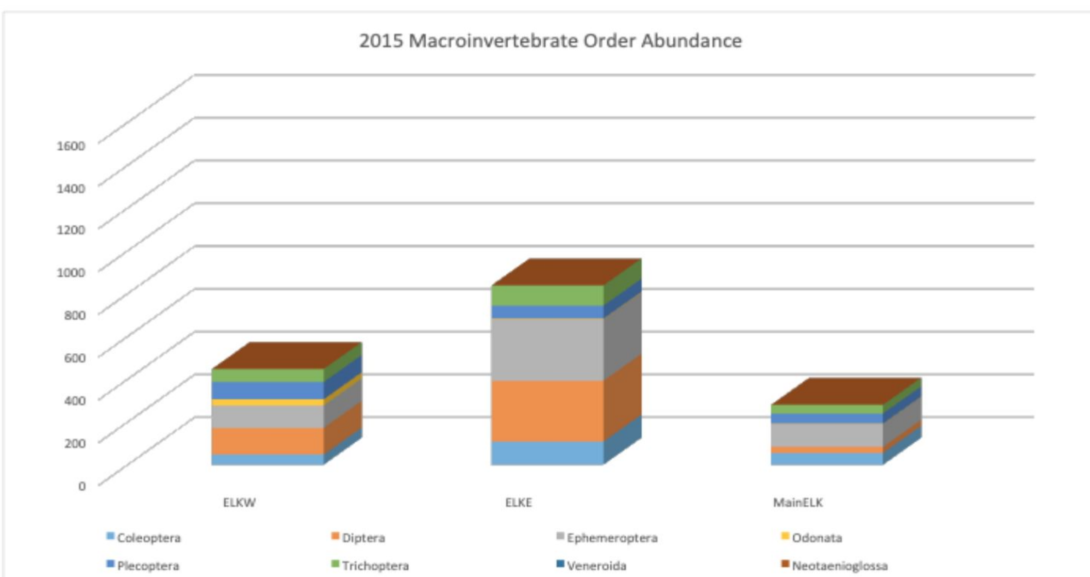

Figure 6: This diagram is a stacked bar chart measuring and comparing macroinvertebrate abundance as categorized by order for East Fork Elk Valley Creek (ELKE), West Fork Elk Valley Creek (ELKW), and the Confluence of the two forks (MainELK) prior to restoration in 2015. The Bureau of Land Management (BLM) and West Fork Cow Creek Partners (WFCC) collected the data for this table.

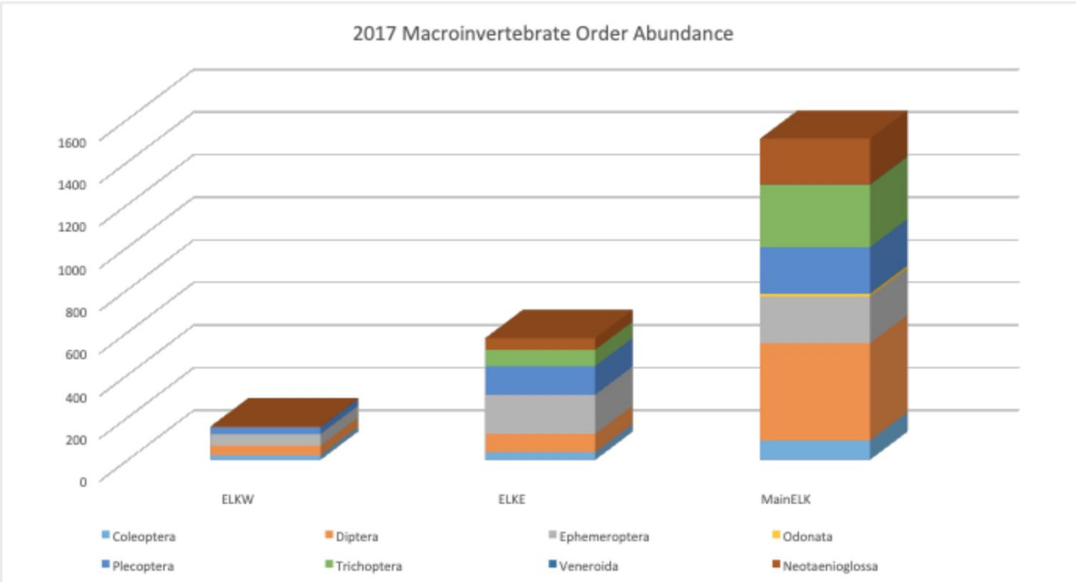

Figure 7: This diagram is a stacked bar chart measuring and comparing macroinvertebrate abundance in 2017 (post-restoration treatment) as categorized by order for East Fork Elk Valley Creek (ELKE), West Fork Elk Valley Creek (ELKW), and the Confluence of the two forks (MainELK). The Bureau of Land Management (BLM) and West Fork Cow Creek Partners (WFCC) collected the data for this table.

	2015	2017	Annual Change
ELKW			
Shannon diversity index (H)	1.948918087	1.42741681	Decrease
Pielou's Evenness Index	0.9372314862	0.6864423843	Decrease
ELKE			
Shannon diversity index (H)	1.537920403	1.655952462	Increase
Pielou's Evenness Index	0.7395833798	0.7963448014	Increase
MainELK			
Shannon diversity index (H)	0.8800116988	1.736319118	Increase
Pielou's Evenness Index	0.4231961713	0.8349929936	Increase

Figure 8. Shannon-Wiener and Pielou Macroinvertebrate Index Results

Site	2015	2017
West	4.1	4.01
East	4.54	3.72
Confluence	3.4	4.68

Figure 9. Family-Level Biotic Index (FBI) Results

West	East	Confluence

	Fork			Fork					
	2015	2017		2015	2017		2015	2017	
Scraper	34%	20%	d*	19%	13%	d	3%	27%	i*
Collector Gatherer	4%	22%	i*	10%	20%	i*	6%	26%	i*
Predator	30%	2%	d*	3%	26.00 %	i*	15%	7%	d
Shredder	11%	14%	i	3%	8%	i	3%	5%	i
Collector Feeder	3%	8%	i	6%	6%	n/a	5%	10%	i
Misc	19%	35%		59%	27%		41%	24%	

Figure 10. Percent compositions of macroinvertebrate feeding guilds in each stream and year. Increases are marked *i* while decreases are marked *d*. Asterisks denote the largest changes.

Water Year	00060, Discharge, cubic feet per second
Period-of-record for statistical calculation restricted by user	
2015	52.6
2016	91.2
2017	130.3

Figure 11. USGS Streamflow data for the Elk Creek gauging station near Drew, OR

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