Fall 2023

Analysis of Benthic Macroinvertebrate Response to Restoration Flows and Scour in the Trinity River, Northern California

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Trinity River at the Junction City site (photo by Ben King, November 2022)

Ecological Restoration Capstone (ESM 455)
Department of Environmental Science & Management
Cal Poly Humboldt
December 2023

ABSTRACT

This study investigates the ecological impact of restoration flows and scouring events on benthic macroinvertebrate (BMI) communities within the Trinity River, an ecosystem historically impacted by anthropogenic activities. Central to this study is the examination of how hydrologic alterations, especially the construction of the Lewiston Dam, have influenced these vital ecological indicators. Using data collected earlier in 2023 from a current study by Benjamin King, we analyzed BMI samples from three river sites (Junction City, Pear Tree, and Lorenz Gulch), both prior to and following a major scouring event in January 2023. This paper utilizes statistical analyses, including ANOVA and t-tests, to assess changes in BMI biomass and species diversity. Notably, the results demonstrate a significant reduction in BMI biomass post-scour, with a significant shift in the community composition towards species more beneficial as salmonid prey. These findings highlight the ecological shifts occurring in response to managed river restoration efforts and stress the importance of considering BMI dynamics in river restoration management. This study contributes valuable insights into riverine ecosystem responses to environmental management strategies, offering an understanding of the impacts on aquatic biodiversity.

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INTRODUCTION

The Trinity River has faced anthropogenic exploitation since the arrival of non-indigenous settlers. This exploitation has significantly impacted and degraded river conditions (Adkins, 2007). Prior to the arrival of Euro-American settlers in the 1800s, the Trinity River had vast resources that were used by numerous Native American tribes (Adkins, 2007). These tribes included the Nor Rel Muk Wintu, Chimarijo, Hoopa Valley, Karuk, and Yurok (Trinity River Restoration Program (TRRP): Background, 2023). However, by the twentieth century, the Trinity River's resources were being heavily exploited by settlers (Abel et al., 2022). The combination of hydraulic gold mining, commercial fishing, logging, and water diversions to Sacramento has degraded the health of the river's ecosystem (Trinity River Restoration Program (TRRP): Background, 2023). This degradation has led to the severe decline of the river's anadromous fishery (Adkins, 2007). An Environmental Impact Statement prepared by the U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, and Hoopa Valley Tribe measured a 60-80% decline in fish populations and an 80-90% decline in habitat (USFWS, et al., 2000).

Impacts of the Lewiston Dam on the Trinity River

The Lewiston Dam is about eight river miles downstream of the Trinity Dam, near Weaverville and Lewiston in Trinity County (Bureau of Reclamation, 2023). The Lewiston Dam controls water released into the Trinity River (Trinity River-Northern California Area Office, 2023). Before the Lewiston Dam was built on the Trinity, the natural flow of the river ranged from 30 cfs to 70,000 cfs (Trinity River Restoration Program (TRRP): Background, 2023). This spontaneous and dynamic river flow was essential to facilitating a healthy river ecosystem (Abel, et al., 2022).

However human alterations to hydrology have altered hydrologic regimes and impacted the health of the fisheries (Adkins, 2017). In 1963, the Lewiston Dam was completed as part of the Central Valley Project's diversion of the Trinity River (Trinity River Restoration Program (TRRP): Background, 2023). After construction, water releases from the dam were kept between 150 and 300 cfs (Trinity River Restoration Program (TRRP): Background, 2023). Releases from the dam were kept low, while 50% of the water flowing into Trinity Lake was diverted to the Central Valley Project (Trinity River Restoration Program, 2017).

Restoration Flows

Due to a substantial decrease in salmonid populations in the Trinity, in 2000, a Record of Decision mandated the release of higher flows permanently and annually, as overseen by the Trinity River Restoration Council (Trinity River Restoration Program, 2017).

The U.S. Department of the Interior established the Trinity River Restoration Program, seeking to restore the health of the river and fisheries (Trinity River Restoration Program, 2017). In 2023, the TRRP began the Winter Flow Project (Trinity River Restoration Program (TRRP): Winter Flow Variability, 2023). This project was established to restore fish populations to pre-dam levels and to adjust the timing of restoration releases to better match natural flow variability (Trinity Restoration Program, 2017). By better matching natural flows of the Trinity River, the natural cleaning and transport of gravels will be increased, reducing fine sediment build up, and producing scouring events (Trinity River Restoration Program (TRRP): Winter Flow Variability, 2023). A scouring event occurs when a high flow mobilizes the position of a stream bed and sediment is eroded and degraded (Streambed Scour, 2023). Scouring events by winter flows are important parts of a functioning and healthy river and benefit food webs (Power et al., 2008).

The synchronization of restoration releases with years of high rain levels would maximize the benefits of high flow releases for fisheries (Trinity River Restoration Program, 2017).

Scouring Events

Scouring events are important ecological disturbances that can act to regulate benthic macroinvertebrate communities (USFWS, et al., 2000). Natural flow regimes are important for maintaining routine scouring of a riverbed and subsequently are important for the ecological balance and reorganization of BMI communities (USFWS et al., 2000). Dams can lead to a reduction in scouring events, which allows for larger and slower growing taxa to survive and outcompete other taxa (Power et al., 2008). The larger, slower growing taxa are often invulnerable to salmonid predation and the lack of available prey leads to salmonid decline (Power et al., 2008). The invulnerable taxa are able to maintain their habitat, as a reduction in scouring events leads to lower taxa replacement rates and lower species diversity (Wang et al., 2020).

The Ecological Role of BMI Communities

BMIs are valuable indicators of ecosystem health, as they influence nutrient cycles, primary productivity, decomposition, mixing of minerals, and are indicators of ecosystem degradation (Wallace, 1996). Rivers inundated by increased flow released from dams can have impacts on species composition, BMI drift, hydrologic cycles, as well as habitat conditions (Power et al., 2008). These natural fluctuations regulate communities by allowing for species richness to decline immediately after an event and recolonize quickly (Schneider & Petrin, 2017).

One of the main determining factors of benthic macroinvertebrate communities is frequency and severity of inundation of habitat (Wallace, 1996). Community-level flooding produced by a scouring event affects taxonomic groups differently, presumably due to different taxa having different morphological, behavioral, and life-history strategies (Death, 2008).

Although a scouring event disrupts a hydrologic system, it may lead to the availability of salmonid prey, or BMI taxa that are readily available as prey for salmonids. BMIs are a valuable source of food for salmonid species so their community composition and abundance have impacts on salmonid health and populations (Wallace, 1996).

Study Objectives

We sought to analyze BMI samples taken from three sampling locations on the Trinity River to explore the impacts of a scouring event in January 2023 on invertebrate communities (Figure 1). We analyzed the three sampling locations pre- and post-scouring event (recorded as January of 2023). We hypothesized that invertebrate communities would have a lower species richness but increase in salmonid available prey following the scouring event of January 2023.

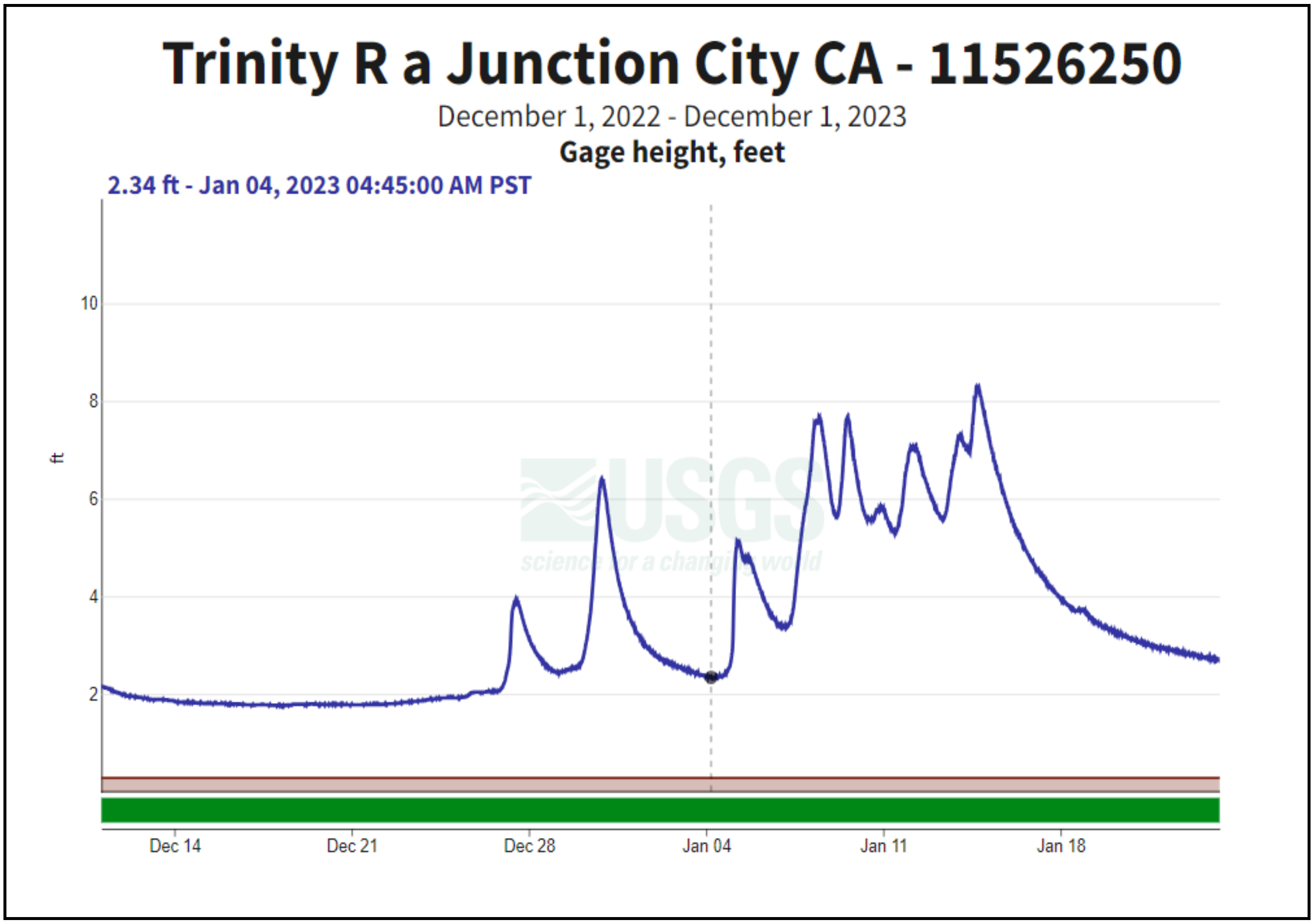

Figure 1. United States Geological Survey (USGS) hydrograph in cubic feet per second with a custom time span showing heavy rainfall in the latter part of December (December 28, 2022) and a scouring event in mid- January (January 4, 2023). Our sampling was divided into pre-scour (October, November, December 2022) and post-scour (January, February, March 2023).

METHODS

Site Description

The Trinity River is the largest tributary in the Klamath River, with a basin size of 7,600 km^2 and a river length of 266 km (Williamshen, 2021). The Trinity River flows through the Trinity Alps in Northern California and confluences with the Klamath River at Weitchpec (Trinity River, California North Coast Regional Water Quality Control Board, 2023). This river has historically supported populations of economically and culturally important fish, such as steelhead (*Oncorhynchus mykiss*), Coho Salmon (*O. Kisutch*), and Chinook Salmon (*O. tshawytscha*) (Abel et al., 2022). Each of these species have specific habitats for spawning, egg incubation, rearing, and timing of life history events (Abel et al., 2022). However, the Trinity River is a habitat for juvenile salmonids and salmonids returning to spawn.

Sampling Methods

Three sampling sites were chosen along the Trinity River "restoration reach" or stretch of river from the Lewiston Dam to the confluence with the North Fork Trinity. The three sites are: Lorenz Gulch (river mile 129), Junction City (river mile 115), and Pear Tree (river mile 111) (Figure 3). Sampling mainly occurred in riffle habitats of the river because riffle habitats create productive feeding stations for juvenile salmonids and are the areas most likely to be affected by a scouring event (Figure 2).

Figure 2. A photo showing sampling conducted in 2022 by Benjamin King at the Trinity River. This photo gives context to what a ripple habitat may entail along the Trinity River during the time of sampling and data collection (November 2022). Sampling was conducted monthly using a Hess sampler.

Data Analysis

For our project, we used BMI data collected by graduate student Benjamin King from the O' Dowd lab at Cal Poly Humboldt. Benthic sampling was conducted monthly from October 2022 to June 2023. After sampling concluded, Benjamin King and undergraduate students in the

Cal Poly Humboldt River Institute laboratory identified each individual to family. Benjamin King then divided the taxa into portions representative of juvenile salmonid forage, highlighting the importance of BMIs as food source for salmonid species. We used these data to record life stages and calculate biomass using length-mass regressions in Excel.

For data entry, data sheets were provided that included the sample ID, sample date, site location, sample type, sample number, subsample, taxon name, life stage, size class/length, and count. Formulas for coefficient A, coefficient B, size class biomass, and total biomass were formulated by Benjamin King.

Data from channel benthic samples pre-scour were compared to communities post-scour. We analyzed the data collected by Benjamin King and divided the samples into pre- (October, November, December 2022) and post-scour (January, February, March 2023). The scouring event occurred in January 2023. Our analysis consists of comparing samples taken before the scouring event and after the event. We ran two ANOVA tests in Excel to determine if there was a significant difference between the average biomasses of BMIs at the three sampling sites pre- and post-scouring event. After the ANOVA tests, we were able to run a t-test to determine BMI biomass before and after a scouring event (January of 2023).

We then compared BMI community biomass, as well as species diversity before and after a documented scouring event. Ben separated the BMI taxa into two categories: prey for salmonids, and non-edible taxa. We analyzed this shift to compare prey availability before and after the scouring event. This analysis will be important in evaluating effective restoration strategies when releasing flows from the Lewiston Dam.

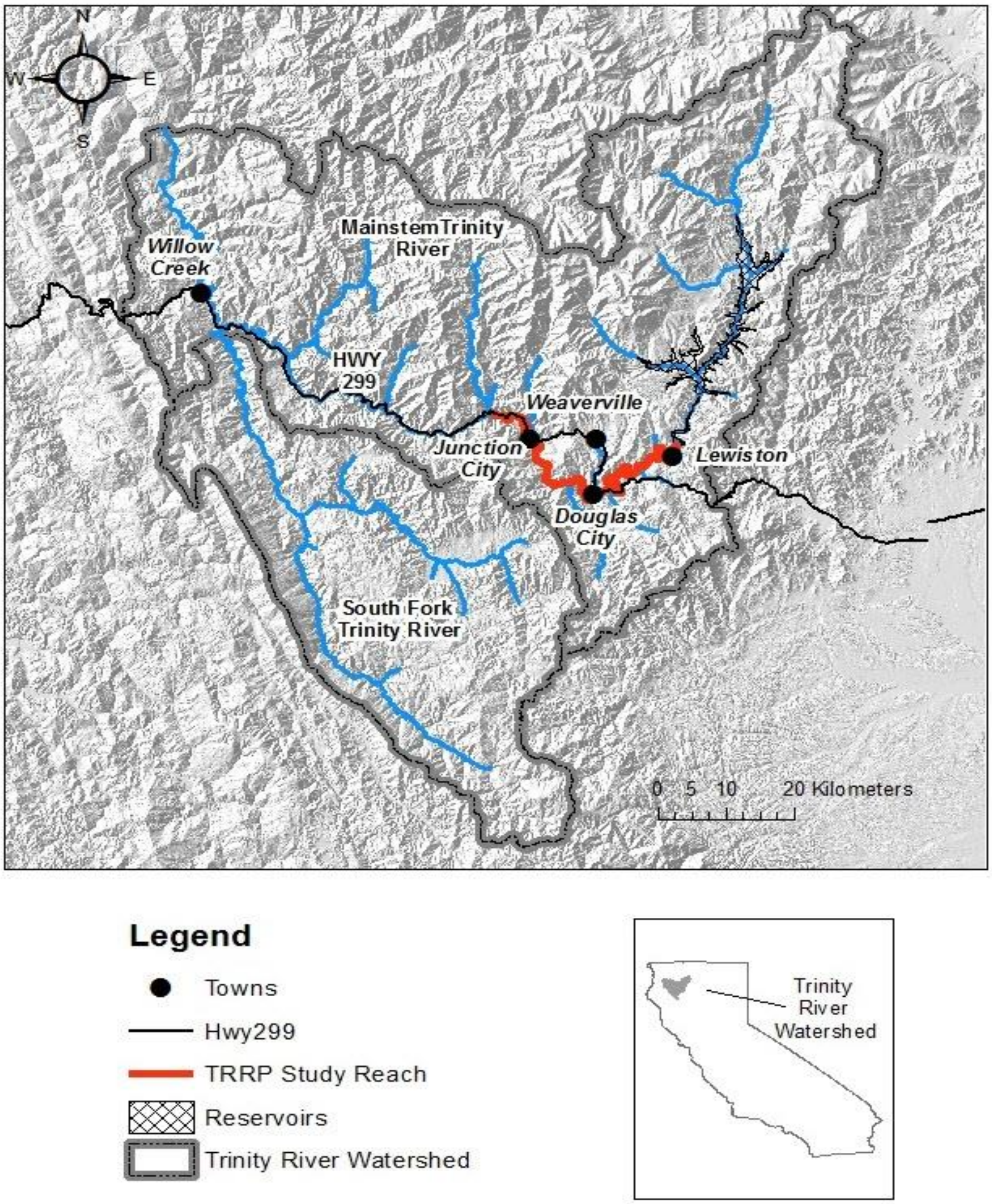

Figure 3. Map sourced from USGS (2023) with a locator map showing the Trinity River Watershed located in northern California. The Trinity River Restoration study reach is highlighted in red. Sampling was conducted along the Trinity River Restoration Reach.

RESULTS

We ran an ANOVA to test if there were significant differences between the BMI biomass recorded at all three sites and dates pre- versus post-scour. The ANOVA results showed p values of $p=0.63$ for pre-scour samples and $p=0.51$ for post-scour samples, both variables showing that there is not a significant difference between the three separate locations within either time frame (pre- and post-scour). With p-values showing that there is no significant difference for the sites, we are able to combine all sites in the pre-scour time period to run a t-test to compare the mean biomass of BMIs pre- and post-scour throughout all of the locations.

The t-test comparing pre- and post-scour for all combined locations showed a resulting p value of $p < 0.001$ which is statistically significant with an alpha of 0.05. We created a bar graph (Fig. 4) in Excel to visually represent the trends in average biomass in relation to the documented scouring event on the Trinity River.

Biomass of BMI Communities Pre- and Post-Scouring Event

Average biomass of BMI communities was significantly lower in the three sampling sites post-scour compared to pre-scour. The average biomass of BMI communities was then calculated on Excel.

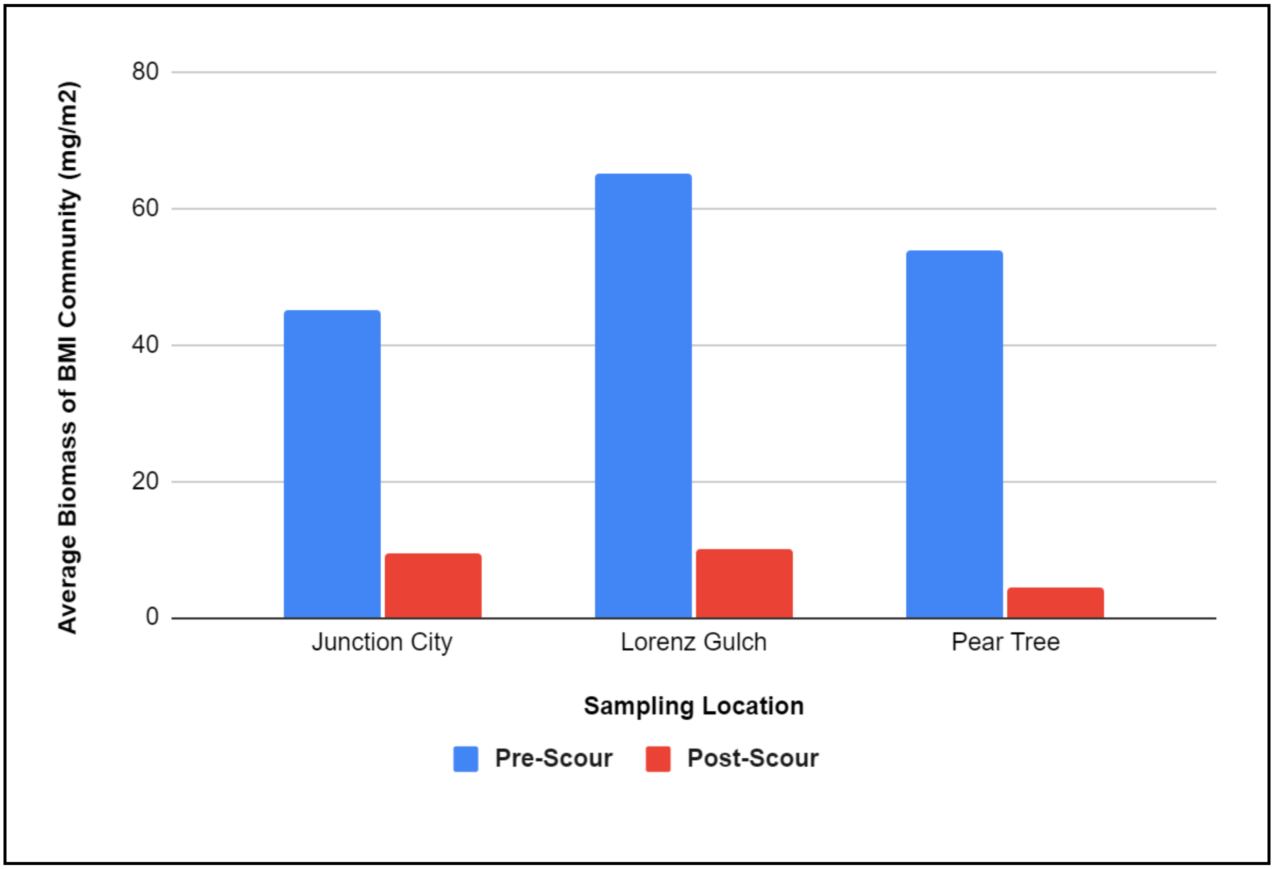

Figure 4. Comparison of BMI average biomass (mg/ m^2) at sampling sites Junction City, Lorenz Gulch, and Pear pre-scour and post-scour. The blue bars represent samples taken at these locations pre-scour and show an overall higher average biomass when compared to the post-scour samples. The red bars represent samples taken from the same sampling locations post-scour and show comparatively lower average biomass.

Salmonid Prey Availability Pre- and Post-Scouring Event

After separation of data from pre- and post-scouring events, we further separated the data into prey availability. The prey which was not available to be consumed by salmonids were

Pteronarcyidae, Elimdae, Limnephilidae, Brachycentridae, Gastropoda, Bivalvia, and any invertebrate > 18mm.

Pre-Scour and Post-Scour BMI Counts

Table 1.

Count of Non- Prey Taxa and Salmonid Prey Taxa Related to Scouring Event.

Taxa	Prey	Total Count Pre-Scour	Total Count Post-Scour
Pteronarcyidae	X	120	23
Elmidae	X	2,326	208
Limnephilidae	X	0	1
Brachycentridae	X	51	40
Gastropoda	X	74	81
Bivalvia	X	20	20
Any taxa > 18mm	X	42	9
Total non-prey:		5,056	377
Salmonid prey	✓	13,287	5,318

Composition of BMI Prey Taxa Pre-Scour

Our analysis of taxon sampled pre-scouring event concluded a total count of 5,056 individuals of non-prey taxa and 13,287 of prey taxa, with a total count of 18,343 individuals sampled (Table 1). Pre-scouring event, the data shows that 72.4% of individuals were available as prey for salmonids, with non-edible BMI's being a total of 27.6% (Figure 5).

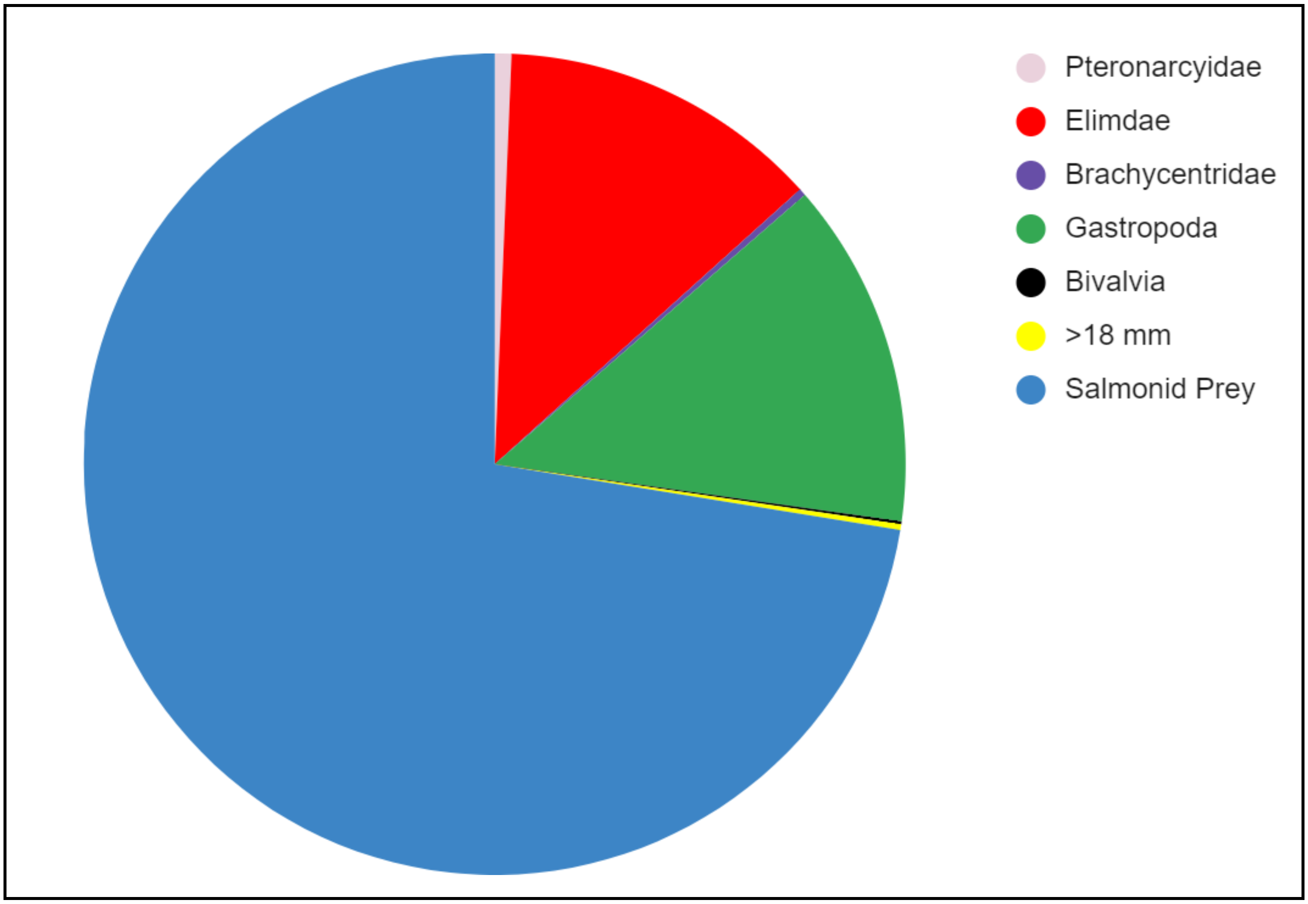

Figure 5. Pie chart showing the pre-scour count of taxonomic groups. BMI which were vulnerable to salmonid predation were described as "salmonid prey" and represented by the dark blue color in the chart. The chart also shows the "salmonid prey" as representing 72.4% of the individuals sampled pre-scour. The taxa which were invulnerable to juvenile salmonid predation were represented with differing colors.

Composition of BMI Prey Taxa Post-Scour

Our analysis of taxon sampled post-scouring event concluded a total count of 377 individuals of non-prey taxa and 5,318 prey taxa with a total count of 5,695 individuals sampled (Table 1). Post-scouring event, the data shows that 93.4% of individuals were available as prey for salmonids, with non-edible BMI's being 6.6% (Figure 6). The number of available prey increased by 21% while the number of non-edible taxa decreased by 21% as well.

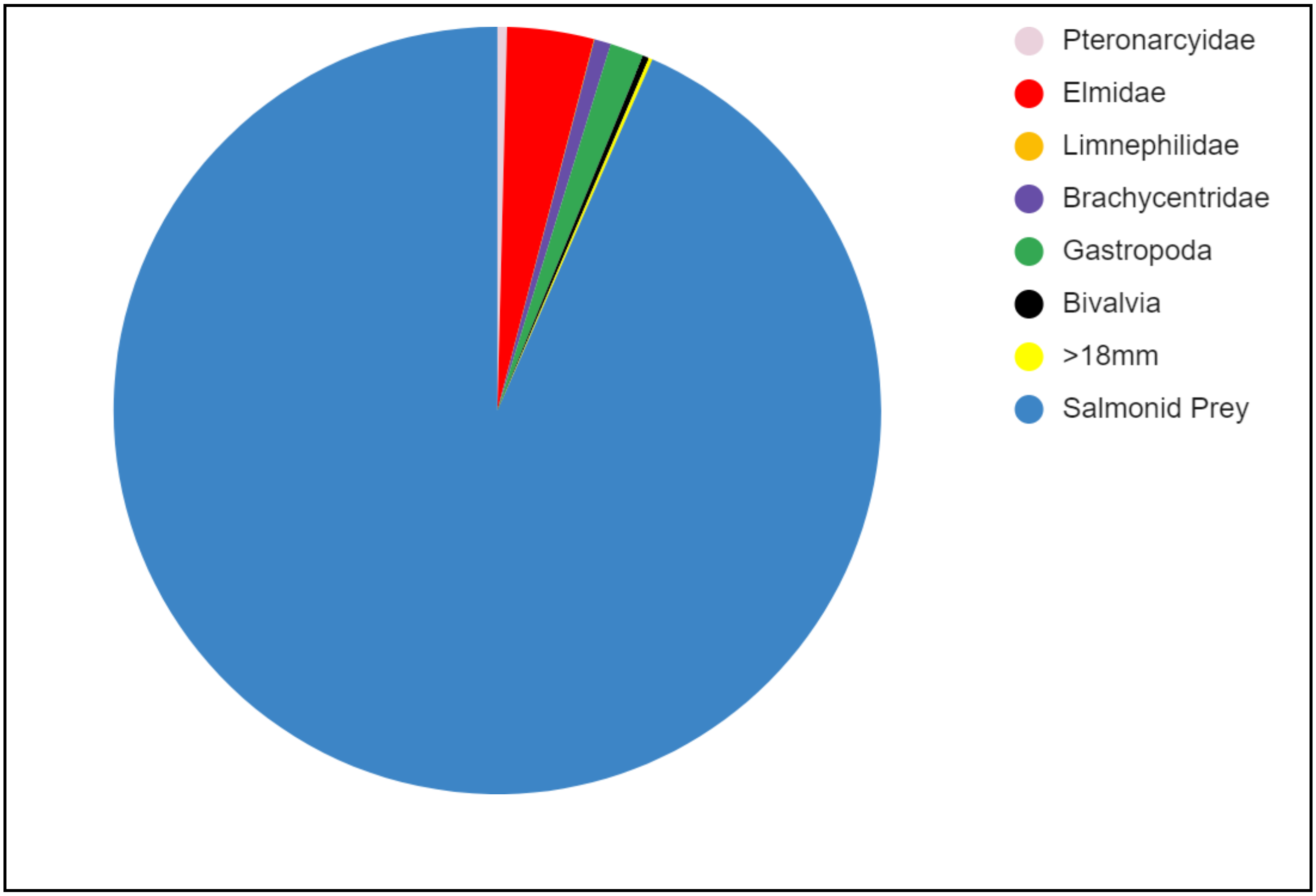

Figure 6. Pie chart showing the post-scour count of taxonomic groups. BMI which were vulnerable to salmonid predation were described as "salmonid prey" and represented by the dark blue color in the chart. The chart also shows the "salmonid prey" as representing 93.4% of the individuals sampled. The taxa which were invulnerable to juvenile salmonid predation were represented with differing colors.

DISCUSSION

Benthic macroinvertebrate communities were analyzed at the Trinity River to determine if initiating scouring events through higher flows is effective restoration management. The primary goal of this study was to assess the potential benefits of a restoration flow that triggers a scouring event in the Trinity River. Specifically, we sought to determine if the scouring event would be beneficial in terms of food availability for salmonids (*Oncorhynchus mykiss, O. Kisutch, O. tshawytscha)* in the Trinity River.

After running two ANOVA tests, we determined that there was not a significant difference of BMI community biomass between the three sampling locations during the pre-scour period. Moreover, there were no significant differences between sites and samples in the post-scour period. There was not a finding of significance when analyzing sampling site location (closer or further to the Lewiston dam). After running a t-test, we determined that there was a significant difference ($p < 0.001$) after separating samples into pre- and post-scour and comparing the associated biomasses.

There was a decrease in the average biomass of the BMI communities post-scour. In all three sampling sites, the average biomass decreased after the scouring event (Table 1). There was also a decrease in the count of organisms pre- and post-scour from samples. The total number of organisms collected and identified pre-scour from the three sampling sites was 18,343. The total number of organisms collected and identified post-scour from the same three sampling sites was 5,695.

Implications for Restoration Management

Although a significant decrease in BMI biomass and abundance post-scour may seem detrimental for salmonid populations that rely on BMIs as prey, this may have a positive effect in the longer term in terms of food availability for juvenile salmonids. When a flow regime is managed to reduce scouring events, densities of early successional species of BMIs are reduced while larger, slower growing taxa are able to dominate river BMI communities (Parker, M. S., & Power, M. E., 1997).

While the overall number of organisms decreased post-scouring event, the food available prey were able to quickly re-establish in place of the slower growing taxa. Specifically, Chironomids are able to quickly recover and establish as a favored prey of juvenile salmonids (Parker, M. S., & Power, M. E., 1997). Pre-scour, 72.5% of the community were available as prey for salmonids while post-scour 93.5% of the community were available as prey. This shift suggests that after the overall decrease in population, the proportion of the BMI community crucial for salmonids expanded, potentially resulting in improved conditions for the fish. The BMI communities decreased by the scouring event are able to re-establish with time (Silvia, 2021).

This study shows that the restoration flow of January 2023 was effective in terms of increasing food availability for salmonids. The reduction or elimination of ecological disturbances such as floods and subsequent scouring events will reduce energy flow to juvenile salmonids from lower trophic levels (Parker, M. S., & Power, M. E., 1997). Future restoration flows should be managed to support the timing of hydrological peaks and natural rain events. Ecological disturbance by restoration flows is imperative for maintaining the prey of juvenile salmonids and must be included in dam mitigation and management.

For restoration management of the anadromous fishery of the Trinity River, the main focus of restoration flows should be on timing flows to better match natural winter flow variability. As anadromous fishery, restoration flows must be matched with the timing of fry as well as the returning spawning salmon. The specific species we are aiming these restoration efforts at (*Oncorhynchus mykiss, O. Kisutch, O. tshawytscha)* have different life history patterns as well as spawning times (Native Salmon, 2023). However, the fry of each of the three anadromous species spend 3 months - 2 years total in freshwater streams and rivers (Columbia River, 2022). Therefore, restoration flows should be released during the winter months (October, November, December) to align with the natural rain flow of the region as well as to provide a cycle of disturbance to allow for ecological resets of BMI communities. Importantly, the species of fish we looked at spend their early lives in the river and their offspring will need BMI communities to have prey when they establish as fry in the river before migrating to the ocean (Central California, 2023). A consistent flow and scour regime will limit the growth and competition of large, slow growing taxa and allow for anadromous fish in the fry stage to feed on invertebrates. By enhancing BMI communities in limiting the establishment of invulnerable taxa, juvenile outmigration may be more successful and there may be stronger adult returns and higher spawning success.

Future studies should include several years of data to assess the inter-annual effects of restoration flows. Data should be collected after multiple restoration flows to assess how quickly and efficiently BMI communities are able to re- establish when disturbances are returned to a more natural state. Longer sampling periods would show greater periods of BMI community establishment and the rate of juvenile salmonid success and return for spawning should be further examined.

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