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Comparison of Benthic Macroinvertebrate Composition and Concentration in Marginally-Versus Perennially-Inundated Sites on the Trinity River

By

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Trinity River at Junction City study site. Photo by Jasmine Shen.

Applied Ecological Restoration Capstone (ESM 455)

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Humboldt State University

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ABSTRACT

Flow regulation has significant impacts on river ecosystems including aquatic vegetation, benthic macroinvertebrates, and salmonids (Caldwell et al., 2018). The Trinity River is an example of a flow-regulated river that has experienced a decline in fish populations and ecological health (Beechie et al., 2015). This study uses benthic macroinvertebrates (BMIs) as indicators of fish habitat quality. We compare the abundance and composition of BMI communities before and after a rain event that inundated marginal habitat. Samples were collected at marginally- and perennially-inundated sites on the Trinity River in Junction City, California in January and February 2020. The resulting data illuminated that there was not a significant (p-value=0.27) increase in BMI abundance or diversity in marginal habitats post-inundation. This non-significant result may be attributed to the small sample size and high variability in the data. As we learn more about how flow regimes affect BMI abundance and diversity within marginal habitats, dam managers can be more informed on managing flow regimes to promote more healthy fisheries.

INTRODUCTION

Impacts of Flow Regulation on Rivers

Alteration of flow regimes have a significant impact on river ecosystems. Much of the ecology of a river system depends on the seasonal fluctuation of natural flows (Caldwell et al., 2018; Imbert and Perry, 2000). Historically, rivers have been extensively modified with the construction of dams, diversions, and reservoirs (Miller and Judson, 2014). Modifying rivers of their natural flow causes habitat fragmentation, changes in the frequency and duration of marginal inundation, and affects the regional biota (Wooster et al., 2016). For salmonid species, high flow events are needed to produce velocities suitable for upstream passage (Bjornn and Reiser, 1991) and to provide adequate food (Caldwell et al., 2018). Altered flows tend to negatively affect salmonids by reducing overall fish growth (Caldwell et al., 2018).

Streamflow also has an impact on aquatic vegetation. Flow regulation in which dam releases mute the winter hydrograph causes aquatic vegetation to recede with the water line and reduce perimeter cover for salmonids (EPA, 2007). The species composition of any freshwater aquatic plant community is defined by water flow, which dictates plant form, governs growth-controlling factors, and determines the quality of a habitat (Dawson, 1988). In-stream vegetation provides important habitat features within perennial waterways by influencing the presence of algal mats and hydrophytic plants with large surface areas that experience higher species composition of benthic macroinvertebrates (BMIs) (Alfaro, 2006). Dammed rivers can alter hydrologic and geomorphic conditions that dramatically impact vegetation over time (Miller and Judson, 2014). River reaches downstream of dams experience abnormal species dispersal colonization patterns (Mallik & Richardson, 2009). These vegetation patterns affect organic matter input as a litter layer for invertebrates that utilize detritus as a food resource (Miller and Judson, 2014).

Another important component to the river ecosystem is the presence of benthic macroinvertebrates (BMIs), which are also heavily impacted by altered flow regimes. BMIs are defined as organisms without backbones, visible to the naked eye, and live on or around the bottom surface of water bodies (Plafkin, 1989). BMIs affect feeding behaviors of fish, serve as indicators of habitat and water quality, and impact nutrient cycling (Harvey and Railsback, 2014; Wooster et al., 2016). Drifting invertebrates are significantly important in the juvenile salmonid diet (Naman et al., 2017). Diversity, abundance, and body mass of invertebrates decline in regulated rivers where natural flow is altered (Caldwell et al., 2018). As BMIs are common prey items for most fish species in running waters, the growth rate of fish is often in direct relation to BMI abundance (Caldwell et al., 2018). Fish in regulated rivers are at higher risk of stunted growth and premature death due to a reduced community of invertebrates (Rosenfield, 2009).

Marginal Inundation

Perennial streams exhibit less variability in water temperature compared to intermittent streams due year-round flow conditions (Garie & McIntosh, 1986). Additionally, perennially-wetted areas often possess oxygenated water in the substrate from a constant flow unlike marginal areas. Marginal areas are defined as areas along the banks of rivers that can be wetted at higher flows and exposed or dry at lower flows (Nilsson, 1991). Periods of inundation contribute to increased BMI richness and abundance. Dissolved oxygen levels show a positive relationship with the presence of BMI community densities and biomass (Moretto et al., 2003). Prolonged inundation of marginal areas has the potential to increase BMI concentration, density, and composition. In marginal areas, BMI composition and spatial arrangement can be affected by depth, the amount of dissolved oxygen, and streamflow (Moretto et al., 2003). A review found that higher densities in aquatic taxa were found in briefly filled pools, but species richness increased with prolonged periods of inundation (Boulton & Lloyd, 1992). Seasonally-wetted marginal areas show increases of BMI biomass up to 193 mg/m^2 within several weeks of inundation (Maher & Carpenter, 1984).

Water storage dams and regulated flow releases have adverse impacts on BMI communities and fish food resources. Juvenile salmonids utilize BMIs as a primary food source in coldwater rivers when maturing (Beck, 2017). Substrate along the banks of channels downstream from water storage dams experience drier conditions when water storage occurs during the wet season; thus, this makes marginal areas unsuitable for BMIs, lowering the resource capacity for salmonids in these waters (Beck, 2017). Marginal habitats have the potential to increase food resources for salmonids and increase rearing habitat downstream from regulated rivers.

Study Objectives

Evaluating the ecological effects of water storage dams is important for dam managers and restorationists since they provide resources for both human use and wildlife. The objectives of this research project are to: 1) compare BMI composition and abundance in marginally inundated and perennial areas in a flow-regulated river, and 2) investigate how inundation of marginal habitats affects BMI colonization.

METHODS

Site Description

The project site was located on the Trinity River in northern California, which is a major tributary to the Klamath River (Figures 1 and 2). Beginning below the Lewiston Dam in the Trinity Alps, the Trinity River runs for a total of 203 miles down to the confluence with the Klamath River. The Trinity River used to be an “unregulated, meandering, dynamic alluvial river within a broad floodplain” (USFWS and HVT, 1999). During the California Gold Rush, European and Asian settlers extensively used hydraulic gold mining and scoured the local landscape of sediment (Beechie et al., 2015). The sediment loss was transferred to the Trinity River, altering morphology and salmonid habitats (Beechie et al., 2015). The flow of the Trinity River was further altered by the authorization of the Trinity River Diversion (TRD) to the Central Valley Project in 1955 (USFWS and HVT, 1999). Up to 90% of the river's annual flow was diverted to the Central Valley beginning in 1963 and changed the river’s geomorphology and degraded salmonid habitat (USFWS and HVT 1999).

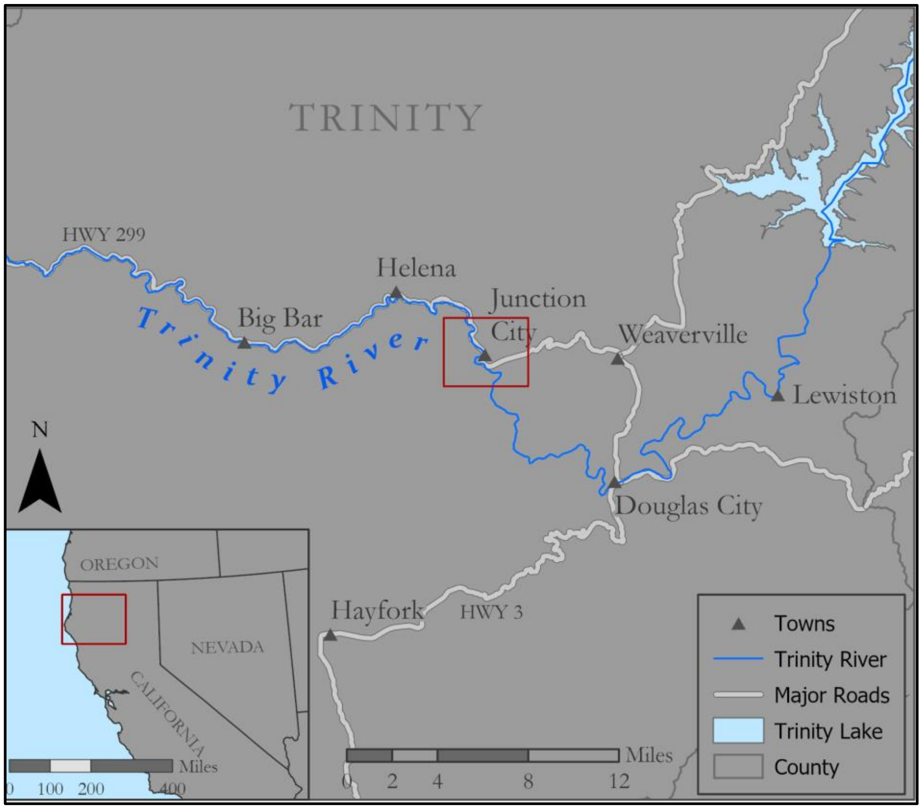

Figure 1: Locator map of our sampling site located near Junction City. Map created by Lesli Mounivong in ArcGIS Pro version 2.4.1.

Figure 2: Locator map showing the sample location on the Trinity River relative to Dutch Creek Road and Hwy 299 in Junction City, California (Source: Humboldt County Planning and Building Dept.).

The Trinity River is known for its beauty, salmon and steelhead resources, and recreation opportunities. The terrain of the Trinity River watershed includes steep mountainous and heavily forested areas characterized by mixed evergreen conifer forest, Klamath montane mixed conifer forest, Oregon white oak forest, and evergreen brush (USDA, 2005; BLM, 1995). The Trinity River is also known for its run of anadromous fish migrating upstream to spawn. These anadromous species include Pacific lamprey (*Entosphenus tridentatus*), the endangered Chinook (*Oncorhynchus tshawytscha*) and Coho salmon (*Oncorhynchus kisutch*), and steelhead trout (*Oncorhynchus mykiss*) (BLM, 1995). The Trinity River provides important habitat for salmonids, so the effects of marginal inundation on BMIs can be informative in how to improve salmonid habitat.

Field Methods

Paired benthic samples were collected in marginally-inundated and perennially-wetted locations (Figure 3). Four samples were collected at week 0 (01/13/20) prior to inundation; two samples in perennially-inundated substrate, and two samples in marginally-inundated substrate (dry land) to get baseline data for analysis (Table 1). Samples were taken at the same locations one week after a high flow event inundated the whole river (02/04/20) (Figure 4) (Shen, 2020).

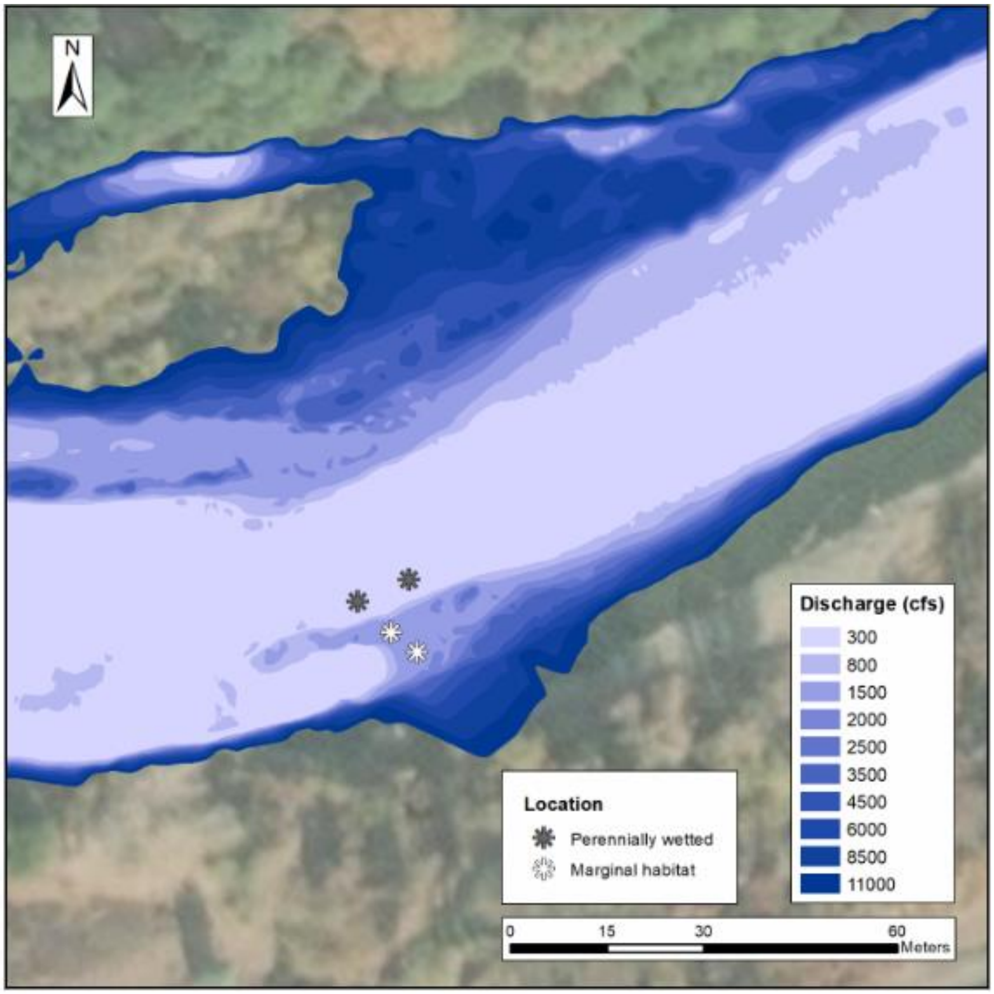

Figure 3: A visual representation of the sampling sites for perennially- (grey star) and marginally-inundated (white star) areas at a variety of flows (source: Shen, 2019).

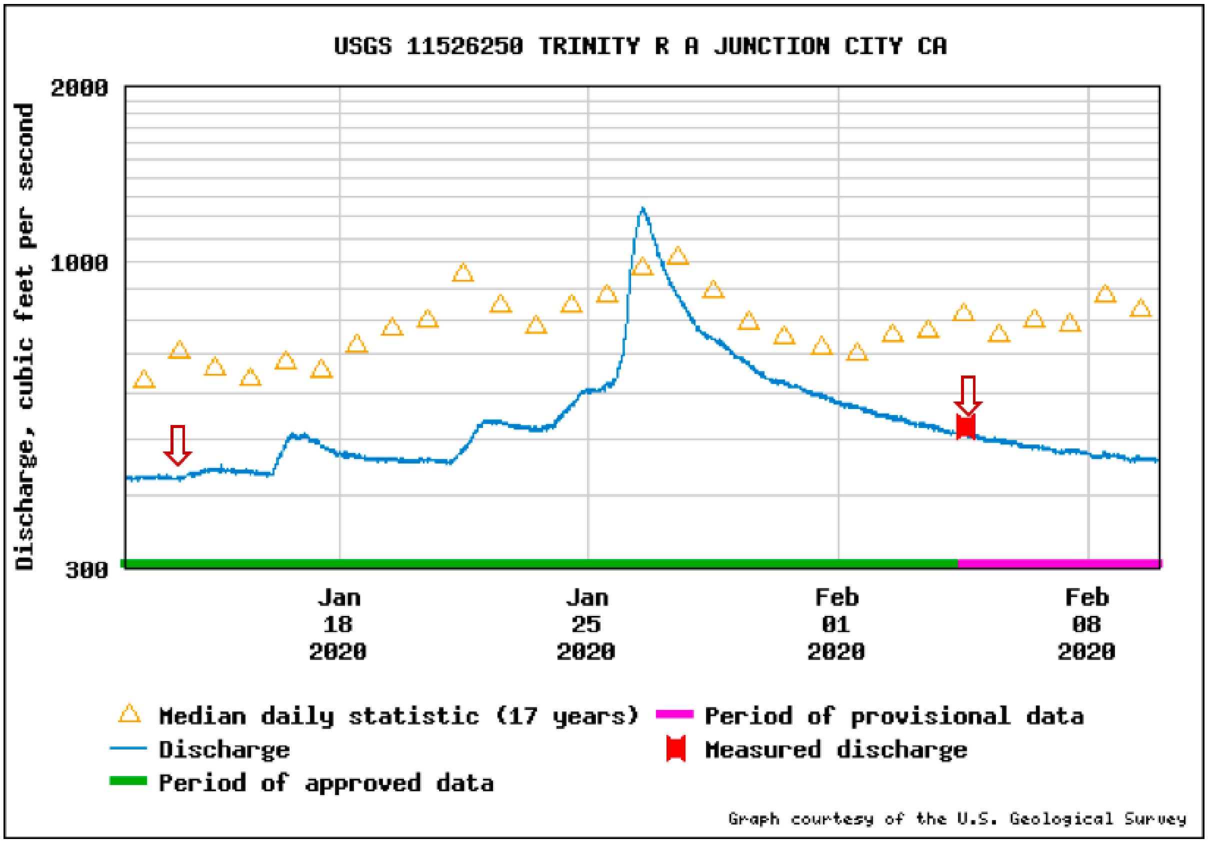

Figure 4: A hydrograph showing the discharge levels at Junction City during January and February. The red arrows indicate the discharge level during the first and second collection dates (01/13/20 and 02/04/20).

Table 1: Number of benthic samples collected during each sampling date across both inundation periods. Four samples were collected at the site in each sampling date.

Treatment	Junction City (perennial)	Junction City (marginal)
Before inundation (1/13/20)	2	2 (dry)
1 week after inundation (2/4/20)	2	2

Samples were collected towards the beginning of Chinook salmon rearing period by HSU graduate student Jasmine Shen, whose Masters research and collection is the basis of our project. On January 13, 2020 the first samples were taken while the marginal habitat was completely dry. It began to rain on January 26, 2020 producing higher flows. On February 4, 2020 the second round of samples were taken while the marginal habitat was inundated about 8 days after the storm. Jasmine used a Hess sampler which allows flow to run through the device and catches stirred up organisms from the substrate. Collection methods were conformed to a $1ft^2$ area and a 4-5 inch depth (Shen, 2020). Samples were transferred to jars, preserved in 90% ethanol, and taken to the laboratory for analysis.

Laboratory Methods

Sorting and identification of BMIs from the samples was completed at the Humboldt State University (HSU) River Institute laboratory and the homes of the researchers using dissecting microscopes. All organisms found were identified to the family level for insects and class for non-insects (Appendix A). The life stage of each individual was also recorded. Due to time constraints, some samples were subsampled or elutriated to reduce processing time. The process of subsampling included evenly dividing the sample and extrapolating the data, assuming it is representative to the whole sample. To subsample, a whole sample was poured into a divided wheel, which randomly split the sample in half. Elutriation is the process of removing small particles from the sample; this is done by swirling the sample to suspend the smaller particles and then pouring them out before they are able to settle again. Perennial samples were sorted first and completed in full. Two of the marginal samples, marginal 1 and 2 (02/04/2020), were subsampled at 50% and two marginal samples, marginal 1 and 2 (01/13/2020), were elutriated.

The samples that were collected and sorted had potential for human error due to varying abilities, judgement, and methods. These could have skewed abundance values, false identification, dried organisms, and trends between marginal and perennial samples. Although each sample was collected the same way, possible discrepancies were a factor in the sorting and identification process.

RESULTS

The raw data from each site were analyzed using a t-test to determine any differences in abundance, richness, and diversity between the marginal samples before and after a winter stormflow. The t-test was run with an alpha of 0.05 to compare changes in abundance of individuals found at a site. This resulted in a p-value of 0.27. This leads us to the conclusion that the difference between marginal samples before and after stormflow was not statistically significant; therefore, we fail to reject our hypothesis that the re-colonization of BMIs after a stormflow is significant.

Our study compared species abundance, richness, and evenness of pre-inundation marginal and perennial habitat to post-inundation habitats. Each taxa found was listed in each sample and symbolized its relative percent abundance (Table 2). Increases in overall abundance was found in both marginal and perennial habitats (Figure 5). Species evenness, or the distribution of the relative abundance of taxa, is another indicator of species diversity (Wilsey, 2000). Increases were found for both diversity and evenness in marginal habitats, and decreases in both diversity and evenness for perennial habitats (Table 3). The measurements for species evenness ranges from zero to one. The higher measure relates to a higher diversity. We saw increasing trends in abundance within post-inundated marginal habitats that we also observed in the perennial post-inundated samples. P-values observed (Marginal: 0.27, Perennial: 0.24) rendered our results insignificant for abundance, but showed a notable difference. Composition between pre-inundation and post-inundated marginal habitats displayed a change in the dominating taxa richness, but ultimately increased in sample size from 17 to 1804 (Figure 6 and 7).

Table 2: BMI taxa found within the Junction City samples. Organisms that made up > 1% of the sample are indicated by the symbol (X); organisms that comprise <1% of the sample are indicated by the symbol (-); blank entries indicate that the species was not found in the sample. Perennial and marginal samples are indicated by the letter "P" and "M" followed by its sample number.

Macroinvertebrate Taxa	January				February			
	P #1	P #2	M #1	M #2	P #1	P #2	M #1	M #2
Acari	X	X						-
Athericidae					-			
Baetidae	X	X			X	-	X	X
Capniidae					-			
Ceratopogonidae						-		X
Chironomidae	X	X	X		X	X	X	X
Chloroperlidae	-				-		X	X
Chydoridae						-		
Cladocera	-							X
Coleoptera	-							
Copepoda								-
Diptera					X			
Dolichopodidae								-
Dytiscidae		-						
Elmidae	-		X			-		-
Empididae	-		X			-		-
Ephemerellidae	X	X			X			
Ephemeroptera					-			
Glossosomatidae	-					-		-
Heptageniidae	X	X			-	-	X	-
Hydropsychidae	X	X	X					-

Macroinvertebrate Taxa	January				February			
	P #1	P #2	M #1	M #2	P #1	P #2	M #1	M #2
Hydroptilidae						-		
Leptoceridae		-				-		
Leptophlebiidae		X						-
Nematocera	-					-		-
Nematoda					-	-		
Oligochaeta	X	X	X	X	X	X		X
Perlidae	-	X			X	-	X	
Perlodidae	X	X	X			X		-
Pteronarcyidae	-							
Simuliidae	-	-						
Tabanidae					-		X	
Tipulidae	X	X						-
Trichoptera					-			

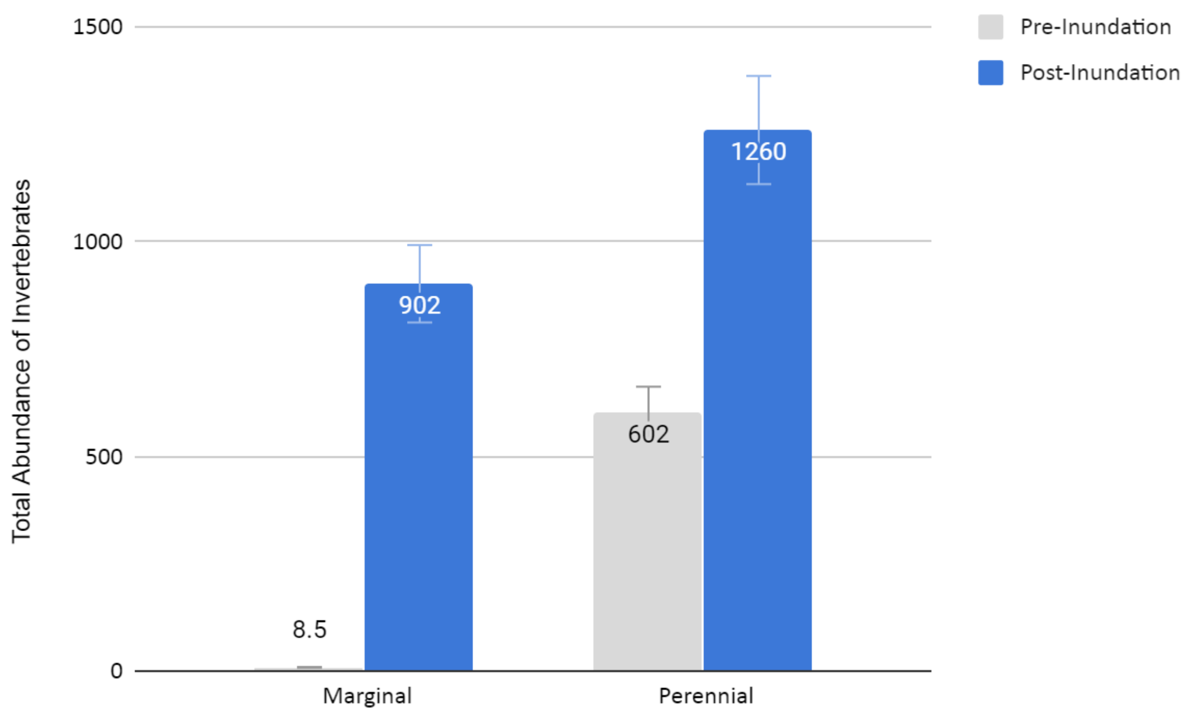

Figure 5: The number of total individuals or abundance of BMIs found within each sample for pre-inundation (01/13/2020) and post-inundation (02/04/2020) in marginal and perennial samples.

Table 3: Averages of species diversity and evenness for all samples. Averages are followed by the standard deviation.

	Pre-inundation (January)		Post-inundation (February)	
	Perennial	Marginal	Perennial	Marginal
Species Diversity	1.781 ± 0.2748	0.7440 ± 1.052	0.9893 ± 0.02751	1.190 ± 0.2614
Species Evenness	0.6304 ± 0.04108	0.4152 ± 0.01016	0.3653 ± 0.5872	0.5183 ± 0.06030

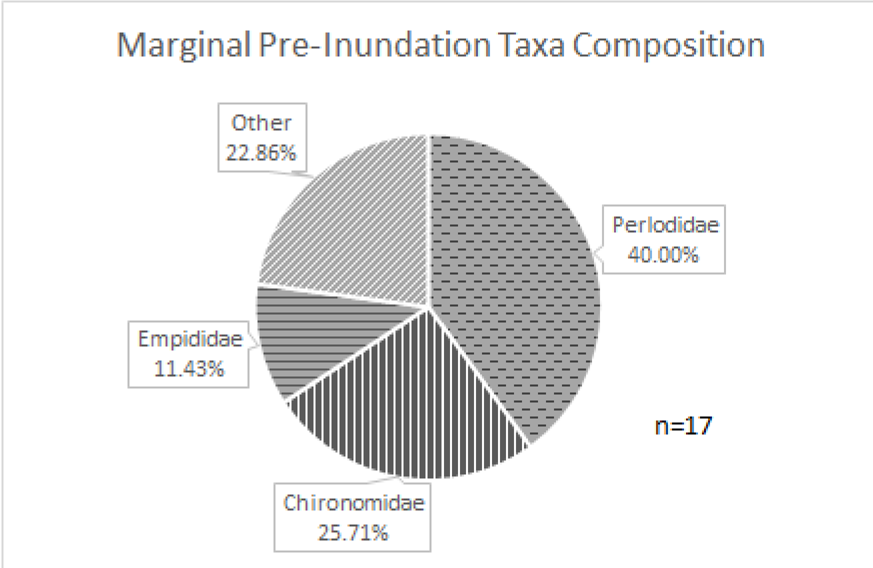

Figure 6: Taxonomic composition of BMIs in marginal habitats pre-inundation, displaying the most dominant taxa.

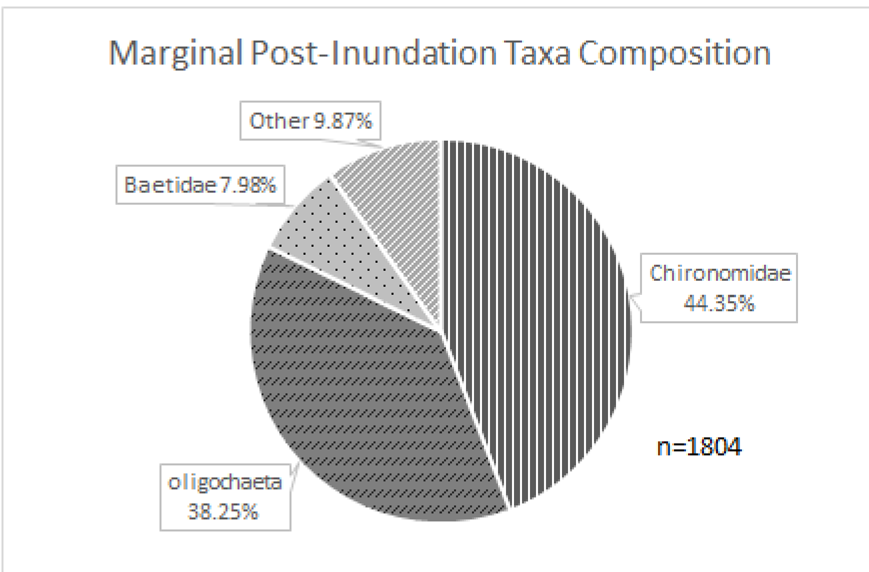

Figure 7: Taxonomic composition of BMIs in marginal habitats post-inundation, displaying the most prominent taxa.

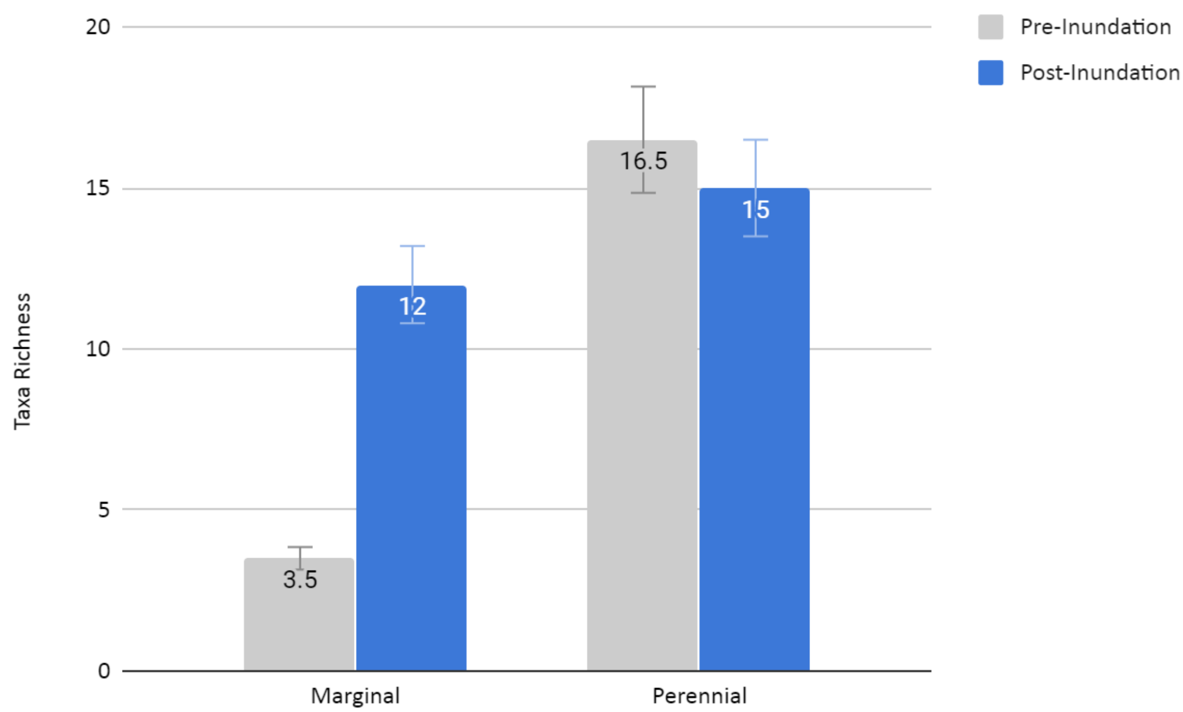

Figure 8: Taxa Richness of BMIs in pre-inundated (1/13/2020) marginal and perennial samples and post-inundated (2/04/2020) marginal and perennial samples.

DISCUSSION

The growth rate of juvenile salmonid species can have a positive correlation with BMI abundance (Caldwell et al., 2018). There was an increase in the number of individual invertebrates found in post-inundation samples compared to pre-inundation from both marginal and perennial habitats in our study (Figure 5). Data on the perennial habitat shows non-significant (p-value>0.05) changes to post-inundated marginal and perennial habitat for overall abundance of BMI; however, they showed notable changes that demonstrate ecological significance. Reasons for this could be attributed to the flow increase from rainfall events in the area (Stubbington et al., 2009). Marginal sites after inundation compared to pre-inundated locations resulted in higher BMI abundance and higher diversity (Figure 5 and Table 3). Factors that could have influenced an increase in abundance and diversity is having a medium to relocate benthic invertebrates, creation of aquatic habitat, and a larger abundance in resources such as leaf litter (Silva and Henry, 2013).

BMI Abundance

The post-inundated marginal samples contained dramatic changes in the BMI community's abundance, richness, diversity, and evenness. The data provided for marginal habitats is central to this study's purpose. Figure 5 shows dramatic increases in BMI abundance post-inundation within the marginal habitat. After 8 days of inundation, there is an average increase of 885 individuals sampled in the two collection sites. This is attributed to the influx of water into the area, allowing for intermittent habitat and available resources for the aquatic invertebrates (Wooster et al., 2016).

Because the Trinity River is a flow-regulated river with a stagnant hydrograph (Figure 4), marginal habitats in stretches of the Trinity River downstream of Lewiston Dam are relatively dry throughout the winter season. Data from Figure 5 shows that BMI abundance within dry marginal habitat is very low. After just two weeks, there was an average 1058% increase in abundance. These results clearly indicate the effect of two weeks of high flows has on BMI abundance in marginal habitats.

BMI Taxonomic Composition

Composition in these samples varied from marginal to perennial and pre- and post-inundation times. All samples consisted predominantly of Chironomidae, however in the marginal sample, diversity, abundance, and composition increased dramatically post-inundation

(Figure 7 and Table 3). Inundated microhabitats such as algal mats and eroding cobbles are known to have higher abundance and richness within samples (Cogerino and Bournaud, 1995). The Shannon-Weiner Diversity Index calculated for each site was relatively low, but the post-inundation samples had substantially higher diversity than the pre-inundated marginal samples. Our results yielded higher diversity for only marginal samples, which can be caused by an influx of microhabitats along the marginal aquatic banks, acting as temporary habitat for BMIs (Cogerino and Bournaud, 1995).

Our results found that Chironimidae was the dominant family in every sample for both marginal and perennial sites. Further analysis showed the three most abundant families (Chironomidae, Oligiochaeta, and Baetidae) in each sample for perennial and marginal on the two collection dates. The distribution of families across both locations seem to be related to fitness and requirements for resources (Dudgeon, 2006). We see that post-inundated marginal habitats exhibit a similar number of taxa as the pre and post inundated perennial sites. We can draw inferences that post-inundated marginal habitats have similar environmental resources and features that are found in perennial habitats.

CONCLUSION

The results of this study demonstrated the effect of short-term inundation on marginal habitats and the corresponding abundance, taxa richness, and composition of benthic macroinvertebrates. Marginal inundation is an indication of habitat quality for rearing juvenile salmonids because of the effect it has on invertebrate populations. This study provides evidence to natural resource managers in the Trinity River watershed when considering additional flow releases to provide these marginal habitats. Since our study did not focus on flow rates, we cannot recommend specific flow rates to managers. However, we can state that areas inundated for at least 14 days show an increased abundance and composition of BMIs and thus increased forage for fish. Therefore, we recommend a flow rate increase for at least 14 days to increase salmonid food supply. Future studies could provide more information on the importance of marginal habitats and their relation to the resource requirements and fitness levels of benthic invertebrates and fish. Such findings could include optimal flow rates and duration of flows for invertebrates to inhabit marginal habitats, which can lead to improved rearing habitat for salmonids.

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APPENDIX A

Table 4. Raw BMI data of the pre-inundated samples collected from the Trinity River (January 2020).

Family Taxa	Perennial #1	Perennial #2	Marginal #1	Marginal #2
Acari	43	6	0	0
Athericidae	0	0	0	0
Baetidae	29	18	0	0
Capniidae	0	0	0	0
Ceratopogonidae	0	0	0	0
Chironomidae	296	261	4	0
Chloroperlidae	8	0	0	0
Chydoridae	0	0	0	0
Cladocera	2	0	0	0
Coleoptera	6	0	0	0
Diptera	0	0	0	0
Dolichopodidae	0	0	0	0
Dytiscidae	0	1	0	0
Elmidae	3	0	1	0
Empididae	8	0	2	0
Ephemerellidae	69	13	0	0
Ephemeroptera	0	0	0	0
Glossosomatidae	8	0	0	0
Heptageniidae	47	26	0	0
Hydropsychidae	26	12	1	0
Leptoceridae	0	1	0	0
Leptophlebiidae	0	7	0	0
Nematocera	2	0	0	0
Oligochaeta	177	33	1	1
Perlidae	0	15	0	0
Perlodidae	47	16	7	0
Polycentropodidae	1	0	0	0
Pteronarcyidae	1	0	0	0
Simuliidae	1	2	0	0
Tabanidae	0	0	0	0
Tipulidae	1	18	0	0
Tricoptera	0	0	0	0

Table 5. Raw BMI data of the post-inundated samples (February 2020).

Family Taxa	Perennial #1	Perennial #2	Marginal #1	Marginal #2
Acari	0	0	0	12
Athericidae	1	0	0	0
Baetidae	6	23	30	114
Capniidae	1	0	0	0
Ceratopogonidae	0	4	0	22
Chironomidae	236	1007	110	682
Chloroperlidae	1	0	2	28
Chydoridae	0	1	0	0
Cladocera	0	0	0	18
Coleoptera	0	0	0	10
Diptera	15	0	0	0
Dolichopodidae	0	0	0	4
Dytiscidae	0	0	0	0
Elmidae	1	1	0	6
Empididae	1	4	0	10
Ephemerellidae	7	0	0	0
Ephemeroptera	1	0	0	0
Glossosomatidae	0	1	0	6
Heptageniidae	1	4	4	12
Hydropsychidae	0	1	0	2
Leptoceridae	0	3	0	8
Leptophlebiidae	0	0	0	0
Nematocera	3	22	0	6
Oligochaeta	28	1091	0	690
Perlidae	4	4	12	0
Perlodidae	0	43	0	10
Polycentropodidae	1	0	0	0
Pteronarcyidae	0	0	0	0
Simuliidae	0	0	0	0
Tabanidae	1	0	4	0
Tipulidae	0	0	0	2
Tricoptera	3	0	0	0