Macroinvertebrates as Predictors of Bull Trout, *Salvelinus confluentus*, Abundance and Greater Fish Community Assemblages

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9 August 2009

Abstract

The Jocko River in Western Montana is home to the threatened Bull Trout, *Salvelinus confluentus.* This study considers macroinvertebrate communities as potential predictors for *S. confluentus* abundance patterns. Macroinvertebrate diversity, richness, and FFG abundance vary significantly between the three forks of the Jocko River. *Salvelinus confluentus* abundanc also varies significantly between the forks. Principal Components Analysis shows unique macroinvertebrate communities at South Fork high *Salvelinus confluentus* abundance sites. PCA also indicates unique macroinvertebrate communities along the Middle Fork where *Salvelinus confluentus* are not present. Analysis of FFGs indicates differences between pool and riffle sampling sites and suggests that some *Salvelinus confluentus* may preferentially utilize riffle habitats. These results indicate that macroinvertebrate community assemblages can vary along with fish community assemblages. However, further study is needed to fully understand these relationships and to create any predictive models.

Introduction

The Jocko River is a fifth-order tributary of the Flathead River situated within the Flathead Indian Reservation in northwestern Montana and arising from the Mission Mountains. The relatively untouched wilderness of the Jocko River Headwaters Region in makes it a suitable habitat for the threatened Bull Trout, *Salvelinus confluentus*. The Headwaters Region is owned by the Confederated Salish and Kootenai Tribes of the Flathead Nation (CS&KT) and managed to encourage *S. confluentus* persistence.

S. confluentus is a species which exhibits varied lifestyle characteristics across spatial and temporal scales. Some populations migrate between stream and lake habitats, while others spend their entire lifespan within one habitat type. Maturity and food availability may be important factors in determining migration patterns, but these relationships are not well understood at this time. Juvenile *S. confluentus* have been found to prey upon both terrestrial and aquatic insects. In contrast, adults are often piscivourous and even cannibalistic, but often have diverse diets that include aquatic insects (Dunham et al. 2008).

S. confluentus requires a stringent set of habitat characteristics to persist. It is associated with cold-water habitats, and is sensitive to changes in stream width (Dunham and Rieman, 1999). *S.confluentus* is a species that is limited to certain habitats by its evolutionary history and migratory needs. Activites such as road construction, logging, and grazing have degraded many reaches of stream, which historically met these characteristics. In addition to directly degrading streams, these anthropogenic activities can have legacy impacts which reduce tree cover and stream complexity for years following the initial impacts, (Nislow and Lowe, 2006).Furthermore, diversion of water for irrigation practices often fragments stream habitats, interfering with the migratory phases of some *S,. confluentus* life histories (Dunham et al. 2008). (Adult *S. confluentus*, prefer to utilize slow velocity water with cover; overall, habitat complexity is believed to promote *S. confluentus* persistence (Chokhachy and Budy, 2007; Costello et al. 2003). \ The sensitive nature of ideal *S. confluentus* habitat has led to their status as a “Threatened” species under the United States Endangered Species Act (USFWS, 1998; Post and Johnston, 2002).

Bull Trout are also threatened by competition and hybridization with non-native salmonids, particularly the Brook Trout, *S. fontinalis* (Rodtka and Volpe, 2007). Anthropogenic activities such as alteration of riparian habitat affects streams by increasing sediment loads and increasing stream temperatures (Nislow and Lowe, 2006). Warmer waters, around 15^0C, may place the Bull Trout at a competitive disadvantage (Rodtka and Volpe, 2007)). Hybridization wastes *S. confluentus'* reproductive effort, depletes the gene pool of purebreds, and results in offspring with lower viability and fertility (Kanda et al. 2002).

Tribal efforts to quantify the fish assemblages in each of the three main Headwaters Forks have determined the presence of *S. confluentus* in the North (N) Fork and South (S) Fork of the Jocko River, but not in the Middle (M) Fork of the Jocko River. Stream hydrology, substrate, geology, structure, water quality, water temperature, and fish community data associated with tribal study of the region have attempted to characterize differences in stream conditions where *S. confluentus* presence is observed between the Headwaters forks (Barfoot, Personal Comm.) however, the macroinvertebrate communities (the intermediate food web link) have been overlooked.

Macroinvertebrate community data may help explain the differences observed in *S. confluentus* presence between the three forks of the Jocko. Macroinvertebrates and fish community linkages are not well-studied, but macroinvertebrate densities have been linked to fish production (Gore et al. 2001; Mundie, 1974). Recent studies have linked increases in macroinvertebrate abundance and a shift to a grazer and chironomid-dominated macroinvertebrate community with increased trout abundance (Nislow and

Lowe, 2006). *S. confluentus* populations may have distributions reflecting differing macroinvertebrate communities.

In order to further investigate the differences in Bull Trout abundance seen among the forks of the Jocko River, I conducted an observational survey of the macroinvertebrate communities at each of three headwaters forks of the Jocko River. I aimed to determine if changes in macroinvertebrate communities are tied with changes in fish communities. This study tests the hypothesis that fish communities assemblages vary in conjunction with macroinvertebrate communities.

Methods

In order to evaluate this question, I sampled the three main headwater forks of the Jocko River. I evaluated macroinvertebrate communities and water quality characteristics at six sampling locations within each of the 3 forks. These sampling locations correspond to GPS coordinates of sites that have been previously sampled by the CS&KT. Six samples were taken from each sampling site and these were composed of three samples from both pool and riffle habitats. Macroinvertebrates were sampled using a 0.1 m^2 Surber sampler and preserved in a 95% ethyl alcohol solution for processing. Macroinvertebrates were identified to genus or the lowest possible taxonomic level under a dissecting scope and classified by Functional Feeding Group (FFG) according to “An Introduction to the Aquatic Insects of North America” (Merritt, et al. 2008). Water quality data were obtained using a YSI 85 meter measurement of temperature, conductivity, and dissolved oxygen content . Mean stream flows were measured by replicated floats of a neutral buoyancy jar.

Data were analyzed using Systat 11. I used a Shannon Diversity Index to compare macroinvertebrate diversity across sites. I also used ANOVA testing to compare macroinvertebrate and physical characteristic data with tribal data on fish communities and abundances. I employed a Principal Components Analysis (PCA) to analyze the relationship between macroinvertebrate communities and fish communities. PCA was also used to test the community structure of macroinvertebrates in pool and riffle habitats. Linear regression was used to compare the abundance of *S. confluentus* with macroinvertebrate and physical data.

Results

Dissolved oxygen and conductivity were the only physical characteristics that varied significantly between the three forks of the Jocko. The North Fork has significantly higher percentages of dissolved oxygen than either of the other forks. ((Figure 1a, $P<0.001$; Bonferroni: N vs S: $P<0.001$; N vs M: $P<0.001$). The South Fork has a significantly greater specific conductivity than the North or Middle Fork (Figure 1b, ($P<0.0001$; Bonferroni: S vs N: $P<0.0001$; S vs M: $P<0.0001$). The Middle Fork also has greater specific conductivity than the North Fork (Bonferroni: M vs N: $P=0.022$). Other measured characteristics: flow, temperature, percentage pools, percentage riffles, percentage pocket water, Large Woody Debris (LWD), and Coarse Woody Debris (CWD) scores did not vary significantly between forks.

S confluentus abundance is greater on the South Fork than the Middle Fork (Figure 2a, $P=0.013$; Bonferroni: S vs M: $P=0.013$). Abundance of Westslope Cutthroat trout, *Oncorhynchus clarki lewisi*, also varies significantly among forks, with greatest abundance on the Middle Fork (Figure 2b, $P<0.001$; Bonferroni M vs N: $P<0.00$; M vs S: $P=0.030$). Total fish CPUE shows significant deviation among forks, with the Middle Fork exhibiting a significantly greater fish CPUE than either the North or South Fork (Figure 2c, $P<0.001$; Bonferroni: M vs N: $P<0.001$; M vs S: $P<0.001$).

Shannon Index of Diversity for macroinvertebrates shows significant differences in diversity among forks (Figure 3a, $P=0.001$). The South Fork has significantly higher levels of macroinvertebrate diversity than either the North or Middle Fork (Figure 3a, Bonferroni: S vs N: $P=0.003$; S vs M: $P=0.005$). Macroinvertebrate richness is significantly greater on the South Fork than the Middle Fork (Figure 3b, $P=0.005$; Bonferroni: S vs N: $P=0.004$). Figure 3b illustrates that macroinvertebrate abundances show a trend toward greater levels on the Middle Fork ($P=0.065$). These variations are further detailed in Table 2.

When clustered based on fish community, PCA grouping is influenced by *S. confluentus* abundance. All Middle Fork populations cluster together, while North Fork populations are split into several clusters. All high abundance South Fork populations cluster closely. One low abundance South Fork site clusters with several North Fork sites where *S. confluentus* is not present and one North Fork site where it is.

Based on macrointertebrate communities, all South Fork high *S. confluentus* abundance sites cluster together (Figure 5). Most Middle Fork sites, without *S. confluentus,* also cluster near each other. North Fork sites do not show as strong of a pattern, but most cluster together regardless of *S. confluentus* abundance differences. One South Fork low abundance site and one North Fork low abundance site cluster together.

In addition to analyzing macroinvertebrates according to taxonomic classifications, I analyzed FFG communities. Collector-gatherers show significantly greater abundance on the Middle Fork than either other fork (Table 3, P=0.001; Bonferroni: M vs N: P=0.001; M vs S: P=0.008). Scrapers are significantly more abundant on the North Fork than the Middle Fork (Table 3, P=0.005; Bonferroni: M vs N: P=0.004). Shredders are significantly most abundant on the South Fork (Table 3, P<0.0001; Bonferroni: S vs M: P<0.0001; S vs N: P<0.0001). The South Fork contains a significantly more diverse FFG community than the Middle Fork (Figure 6b, P=0.008; Bonferroni: S vs M: P=0.007).

Collector-gatherers show significantly lower abundance where *S. confluentus* are present (Table 4, Figure 7, P=0.007). Conversely, scrapers show significantly greater abundance at sites where *S. confluentus* are present (Table 4, figure 7, P=0.015). Shredders are also present in significantly greater abundances at sites where *S. confluentus* are present (Table 4, Figure 7, P=0.016). Higher FFG diversity is also correlated with *S. confluentus* presence (Table 4, Figure 7, P=0.006). Linear regression testing of FFG factors does not show a significant relationship between *S. confluentus* abundance and any other factor.

All stream sites were also analyzed for differences between pool and riffle sampling sites. Flow rates are significantly greater in riffle habitats (Figure 8, P<0.0001). Rriffle habitats also have significantly greater macroinvertebrate abundance (Figure 8, P=0.047). PCA analysis of macroinvertebrate abundances did not show any clustering by pool or riffle. FFGs were also analyzed according to pool and riffle habitats. Collector-gatherers show significantly greater abundance in pool sites (Figure 9, P=0.002).

Conversely, scrapers are significantly more abundant in riffle sites (Figure 9, $P=0.045$). Shredders are also significantly more abundant in riffle sites (Figure 9, $P=<0.0001$).

Discussion

The headwater forks of the Jocko River show many differences in abiotic and biotic factors. Several of these factors also vary in relation to *S. confluentus* abundance. Macroinvertebrate communities cluster in patterns that correlate with *S. confluentus* distributions

S. confluentus are present on the North and South Forks. The South Fork has significantly greater specific conductivity values than the other forks (Figure 1b). Previous studies have demonstrated that conductivity is important in explaining diverse macroinvertebrate assemblages and these differences may influence the macroinvertebrate and *S. confluentus* populations on the South Fork (Melo, 2009). The North Fork shows significantly greater percent dissolved oxygen values than either of the other two forks. This finding is notable, as the percent of riffles in each fork did not vary significantly. Percent dissolved oxygen can also be indicative of differing levels of primary productivity or water inputs, which were not measured in this study. However, all percent dissolved oxygen readings were high enough to support healthy fish populations and this variance is not likely a primary driver of *S. confluentus* abundances

Macroinvertebrate communities on the South Fork show greater diversity than either other fork (Figure 3a), which may be related to high specific conductivity here. Macroinvertebrate diversity may help to support overall high *S. confluentus* abundances on this fork by providing an array of prey species that are particularly beneficial for juveniles (Dunham et al. 1999). This diversity could be particularly beneficial in providing a range of edible sizes of macroinvertebrates across temporal scales. Macroinvertebrate species richness also peaks on the South Fork and is related to diversity. Interestingly, macroinvertebrate abundances trend toward greater levels on the Middle Fork. High levels of chironomids in the Middle Fork likely drive this trend. High levels of *O. clarki lewisi*, and overall high CPUE present on this fork may be correlated with the increased macroinvertebrate abundance..

Principal Components Analysis of macroinvertebrate communities shows clustering in patterns similar to *S. confluentus* abundance levels (Figure5). All South Fork high abundance sites cluster into a unique macroinvertebrate assemblage. This result supports the original hypothesis. Middle Fork sites, without *S. confluentus,* also support the hypothesis by clustering into unique communities. Interestingly, low abundance sites from the North and South Fork cluster with a North Fork site without *S. confluentus.* These results suggest that unique types of macroinvertebrate communities may be related to levels of *S. confluentus* abundance. Three North Fork sites with high, low, and no *S. confluentus* abundance also cluster together which may indicate unique conditions to these sites on the North Fork.

FFGs also show significant variation among forks as illustrated in Figure 6. High levels of shredders on the South Fork could be indicative of higher canopy cover and subsequent allocthonous input for this fork. High levels of scrapers on the North Fork could be indicative of a relatively open canopy and possibly higher periphyton levels on this fork. These explanation is also supported by the high levels of dissolved oxygen on the North Fork. The high levels of chironomids in the Middle Fork likely influence its high level of collector-gatherers. Lower collector-gatherer levels on the North and South Forks could be the result of *S. confluentus* foraging preference. This is possible as grazers and chironomids have been shown to be important forage for fish production (Bilby and Bisson, 1992). .

Investigation of different habitat types showed that riffle habitats possessed significantly higher flow velocities than pool habitats. This result (Figure 8) supports expectations for this habitat. Macroinvertebrate abundances were also higher in riffle habitats, as can be expected from previous work (Mundie, 1974). Further differences in abiotic factors may have been obscured by difficulty in locating suitable sections of pool or riffle in the Jocko Forks.

FFGs also differed between pool and riffle habitats. Figure 9 shows these relationships. Interestingly, riffle habitats share the same FFG abundance pattern as sites where *S. confluentus* are present. This could indicate that *S. confluentus* show a preference for these habitats. Previous work has shown that smaller *S.confluentus* utilize shallow water habitats, such as riffles preferentially during daytime hours (Banish et al, 2008).

These results do not fully support the hypothesis that fish community assemblages vary in conjunction with macroinvertebrate communities and show the need for further investigation of this question. Future investigation of this question should focus on refining the complex relationships between fish and macroinvertebrate assemblages. Year-round monitoring of macroinvertebrate and fish communities may help deepen understanding of these relationships and provide a more accurate model for predicting community assemblages. Expanding this type of analysis across stream types may also uncover stronger relationships between macroinvertebrates and fish communities. Comparison of pool and riffle habitat types could be improved by studying lower-gradient streams with more classic pool and riffle habitat types.

Overall, macroinvertebrate communities appear to be related to *S. confluentus* abundances. *S. confluentus* are also associated with unique macroinvertebrate communities as determined by PCA. Furthermore, macroinvertebrate FFGs are associated with *S. confluentus* presence and habitat type. Macroinvertebrates appear to also be related to *O. clarki lewisi* abundances. The results of this study indicate that macroinvertebrates can serve as predictors of *S. confluentus* presence and can serve as a tool to predict greater fish communities. This information is important to recognize and take into consideration for stream management decisions.

Acknowledgements

The University of Notre Dame Environmental Research Center in collaboration with the Confederated Salish and Kootenai Tribes of the Flathead Nation made this project possible. Special thanks to Dr. Gretchen Gerrish, Dr. Gary Belovsky, Craig Barfoot, and Tim Szewcyk for their assistance and insight. I am also grateful to Edward Kratschmer, Collin McCabe, and Justin Poinsatte for their tireless assistance.

Table 1. Table of physical factors with mean values and standard error for physical characteristics of the North, Middle, and South Forks of the Jocko River. Results of ANOVA tests comparing each factor among the three forks are also displayed. Significant P-values are highlighted.

Physical Factors	North Mean	Middle Mean	South Mean	df	F-Stat	P-value
Flow	1.929±0.034	2.011±0.058	1.997±0.035	2	0.989	0.400
DO(%)	84.897±0.612	80.4±0.079	80.0±0.453	2	18.520	P<0.001
Temp.	11.2±0.6231	11.1±0.412	11.7±0.730	2	0.280	0.760
Specific Conduct.	42.27±7.501	70.6±2.284	213.33±7.328	2	218.932	P<0.0001
% POOL	6.8±3.670	5.6±2.522	6.4±2.731	2	0.045	0.957
% RIFFLE	56±12.083	79±5.568	50±6.124	2	3.277	0.073
% POCKET WATER	22.6±11.035	14.4±3.295	29±3.317	2	1.119	0.359
LWD#	5.4±1.887	3.6±0.872	8.2±3.247	2	1.085	0.369
CWD#	9.8±3.839	11.6±2.768	35.8±18.378	2	1.756	0.214

Table 2. This table of biological factors illustrates mean values and standard error for several biological characteristics of the three forks of the Jocko River. Results of ANOVA tests comparing each factor among the three forks are displayed. Significant P-values are highlighted.. Macroinvertebrate abundance and fish richness also show a trend.

Biological Factors:	North	Middle	South	df	F-Stat	P-value
W. Cutthroat Abund.	0.228±0.092	0.902±0.055	0.548±0.092	2	1.695	0.0003
Bull Trout Abund.	0.046±0.020	0±0.000	0.128±0.040	2	6.365	0.013
Fish CPUE	0.732±0.099	2.190±0.292	1.034±0.369	2	21.03	0.0001
Fish Richness	3.400±0.510	2±0.000	5.200±2.448	2	3.524	0.0625
Fish Shannon Div.	0.712±0.092	0.644±0.020	0.636±0.136	2	0.191	0.8284
Macro Abund.	5.838±0.138	6.357±0.232	5.761±0.136	2	3.459	0.0651
Macro Richness	18.600±1.077	22.200±1.655	25.800±0.800	2	8.564	0.005
Macro Shannon Div.	2.094±0.702	2.115±0.074	2.524±0.070	2	11.597	0.0015

Table 3. Mean values and standard error for abundances of FFGs and a FFG Diversity Index for the three Forks of the Jocko River. Significant values are highlighted.

FFGs:	North Mean	Middle Mean	South Mean	df	F-Stat	P-value
Collector-Gatherers	0.351±0.011	0.595±0.038	0.404±0.048	2	12.906	0.001
Scrapers	0.449±0.028	0.225±0.043	0.363±0.041	2	8.679	0.005
Collector-Filterers	0.012±0.003	0.059±0.037	0.047±0.009	2	1.291	0.311
Predators	0.175±0.035	0.117±0.011	0.111±0.012	2	2.464	0.217
Shredders	0.014±0.001	0.003±0.001	0.075±0.011	2	36.380	P<0.0001
FFG Shannon Div.	1.125±0.037	1.021±0.061	1.286±0.045	2	7.487	0.008

Table 4. FFG means and standard error for areas of *S. confluentus* presence and absence. Collector-gatherers, scrapers, shredders, and FFG diversity all vary significantly from areas of *S. confluentus* presence and absence.

FFG and *S. confluentus*	Present	Absent	df	F-Stat	P-value
Collector-Gatherers	0.381±0.027	0.554±0.051	1	10.402	0.007
Scrapers	0.406±0.031	0.256±0.047	1	7.824	0.015
Collector-Filterers	0.031±0.008	0.052±0.031	1	0.680	0.424
Predators	0.136±0.021	0.133±0.018	1	0.010	0.922
Shredders	0.047±0.012	0.005±0.003	1	7.607	0.016
FFG Shannon Div	1.224±0.038	1.023±0.050	1	10.707	0.006

Table 5. This table illustrates differences observed between pools and riffles across all sites. Flow rates are significantly greater in riffle sites (P<0.0001). Macroinvertebrate abundance is also significantly greater in riffle sites (P=0.047)

Factors:	Pool Mean	Riffle Mean	df	F-Stat	P-value
Flow	0.679±0.045	1.272±0.086	1	37.743	P<0.0001
DO(%)	81.424±0.698	82.113±0.745	1	0.455	0.505
Temp.	11.304±0.346	11.404±0.320	1	0.452	0.833
Specific Conductivity	117.304±23.124	115.223±22.395	1	0.004	0.948
Macro Shannon Div.	2.111±0.083	2.135±0.072	1	0.0483	0.828
Macro Richness	16.533±1.323	18.533±0.940	1	1.518	0.228
Macro Abundance	4.892±0.189	5.507±0.117	1	4.314	0.047

Table 6. FFG factors between pool and riffle habitats. Significant differences are highlighted.

FFG Factors:	Pool	Riffle	df	F-Stat	P-value
Collector-Gatherers	0.521±0.038	0.355±0.031	1	11.347	0.002
Scrapers	0.301±0.038	0.410±0.036	1	4.401	0.045
Collector-Filterers	0.036±0.018	0.030±0.009	1	0.004	0.952
Predators	0.136±0.018	0.146±0.020	1	0.136	0.716
Shredders	0.007±0.002	0.054±0.010	1	22.413	P<0.0001
FFG Shannon Div	1.098±0.042	1.116±0.051	1	0.072	0.790

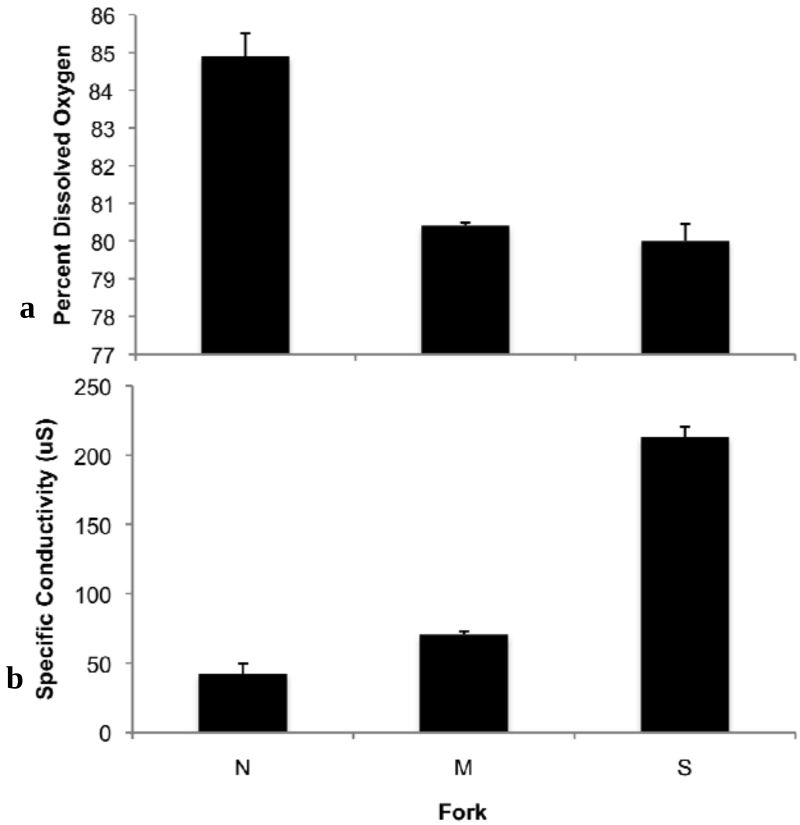

Figure 1. Physical characteristics that varied significantly between the three forks of the Jocko; a. dissolved oxygen . b. specific conductivity.

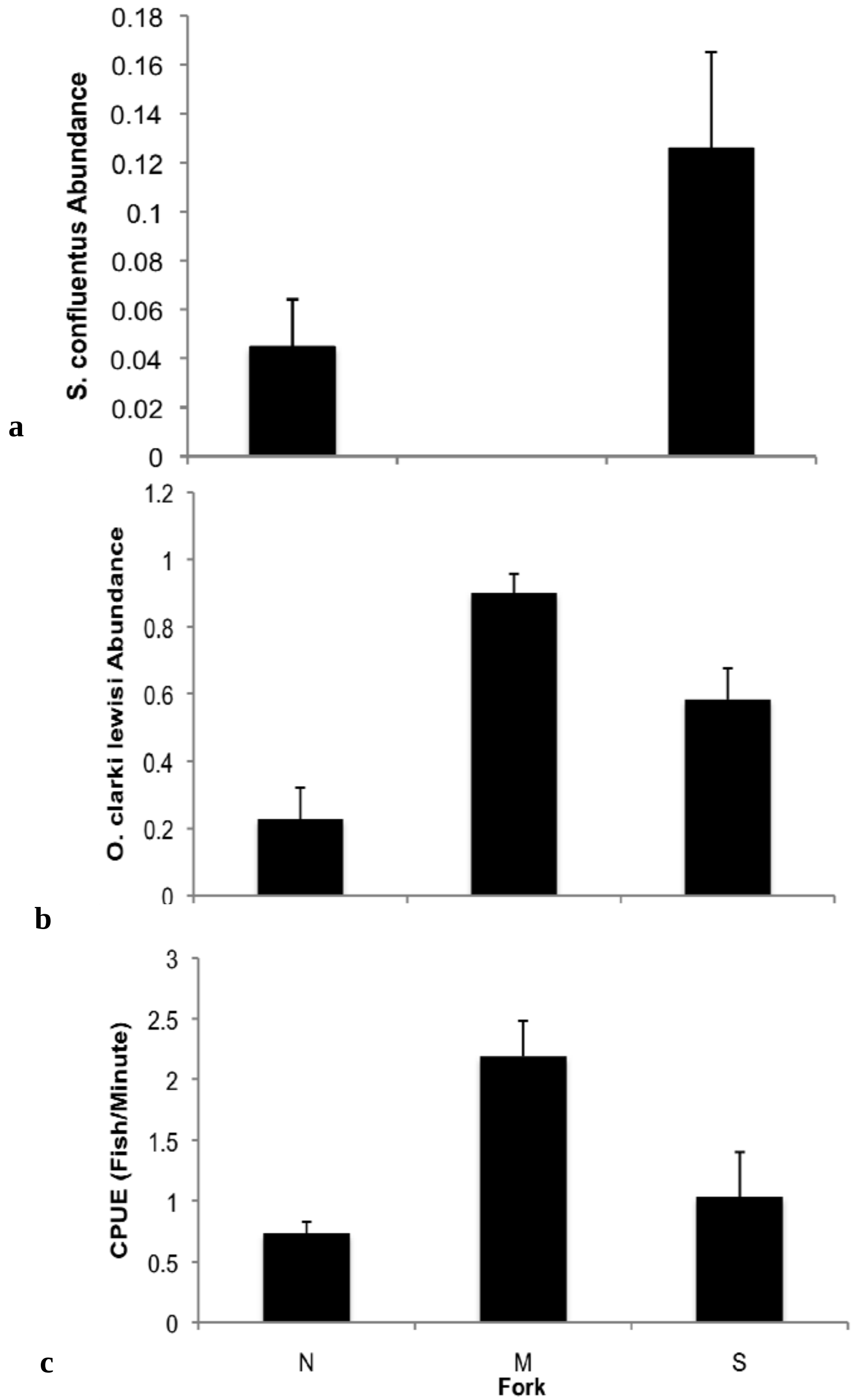

Figure 2. Variation in fish species abundance and overall CPUE among forks of the Jocko River; a. *S. confluentus* abundance b *O. clarki lewisi* abundance c. overall salmonid CPUE among forks.

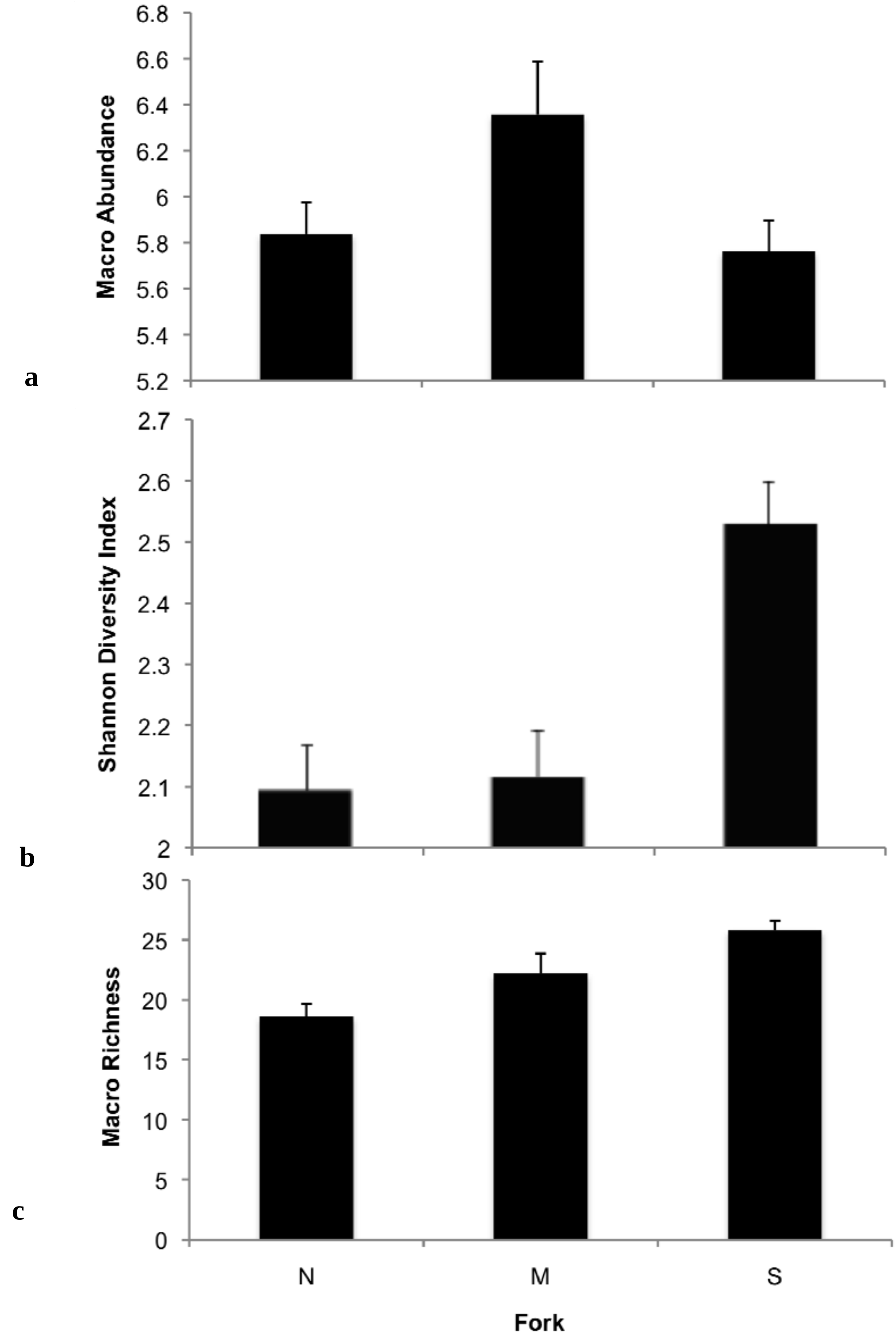

Figure 3. Variation in macroinvertebrate communitie between the three forks of the Jocko River; a. Shannon Index of Diversity b. macroinvertebrate abundance c. macroinvertebrate species richness

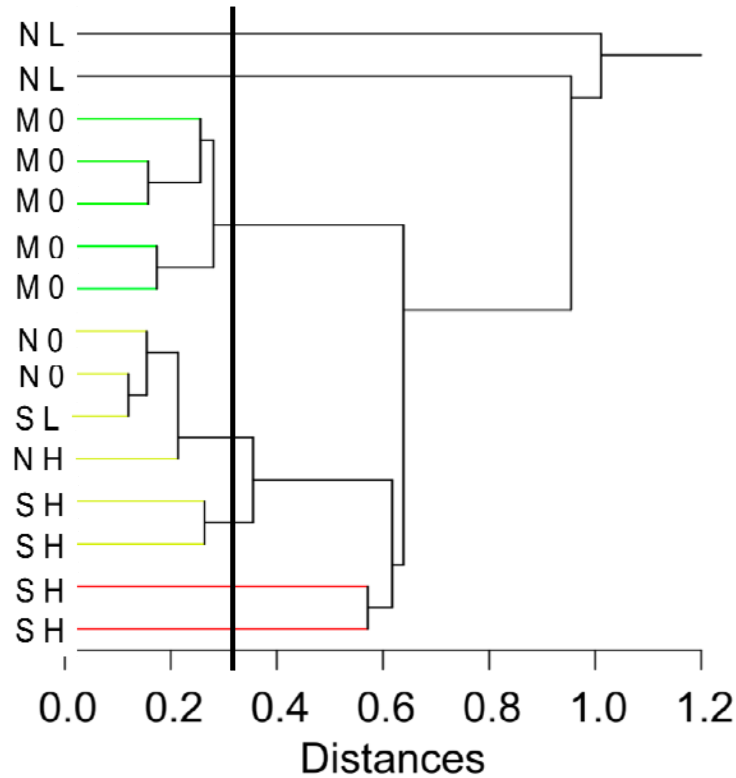

Figure 4. PCA cluster showing fish communities; cutoff distance is indicated by vertical line at 0.3. The first letter of each cluster label designates the fork of a population. The second character designates relative *S. confluentus* abundance (0=not present; L=Low; H=High).

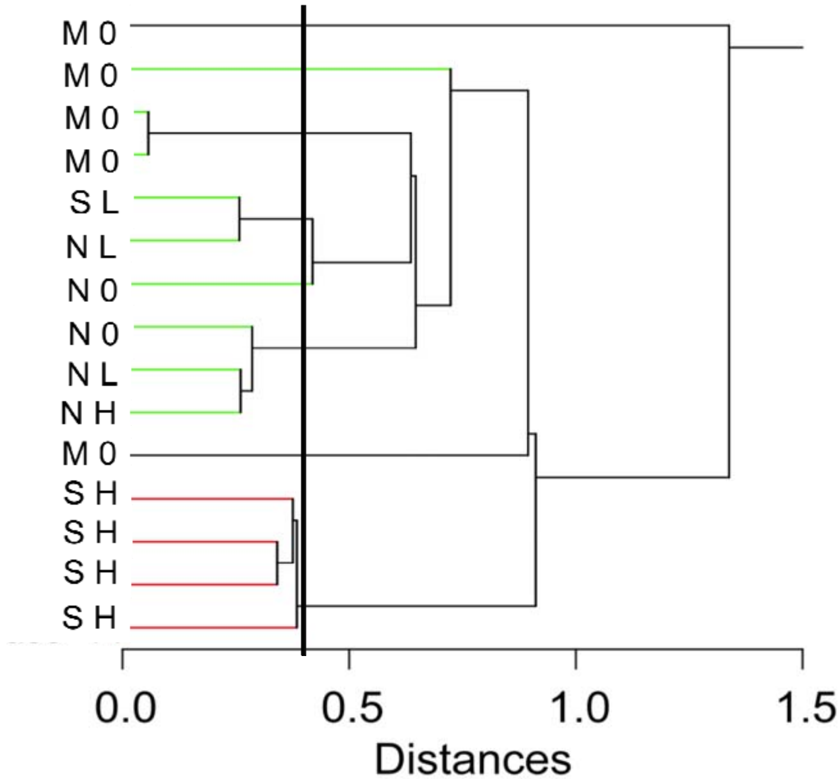

Figure 5. PCA cluster of macroinvertebrate communites; cutoff distance is indicated by vertical line. The first letter of each cluster label designates the fork of a population. The second character designates relative *S. confluentus* abundance (0=not present; L=Low; H=High).

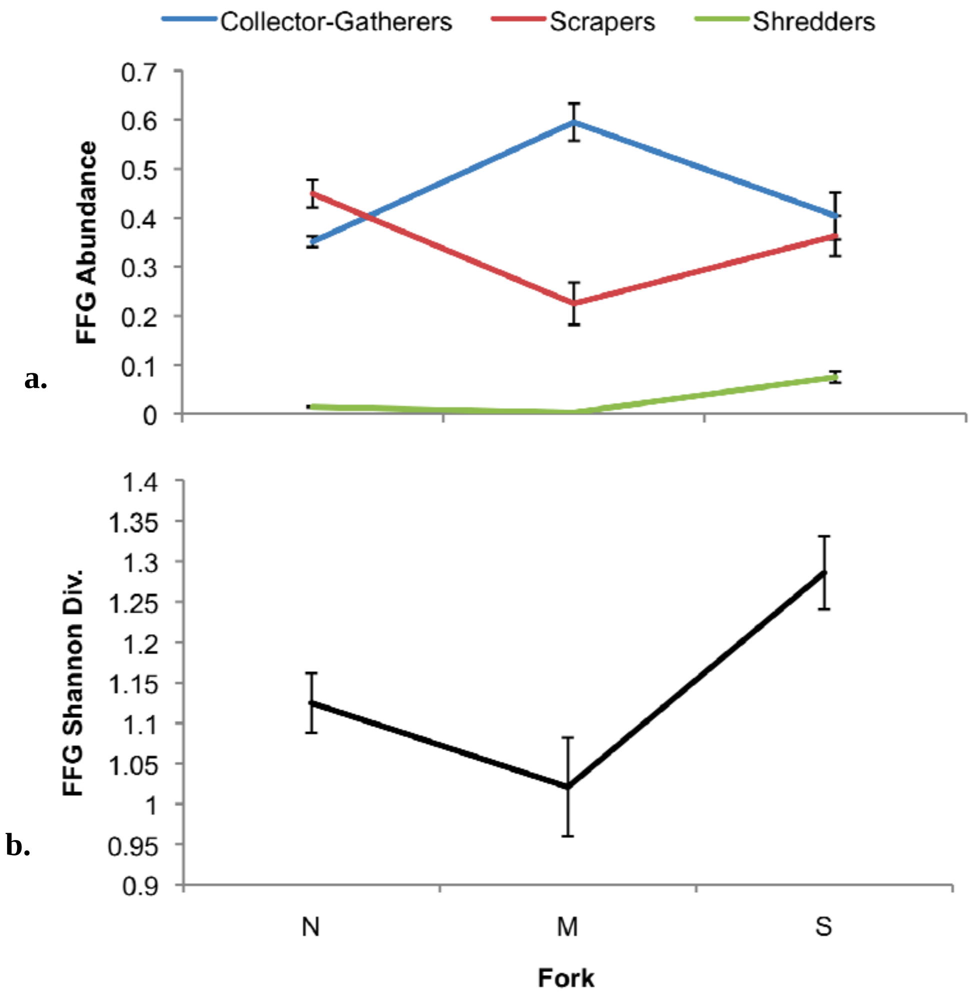

Figure 6. Variation in FFG abundance and diversity between forks of the Jocko River; a. collector-gatherer, scraper abundance, and shredder abundance b. FFG diversity Collector-gatherers show significantly lower abundance where *S. confluentus* are present

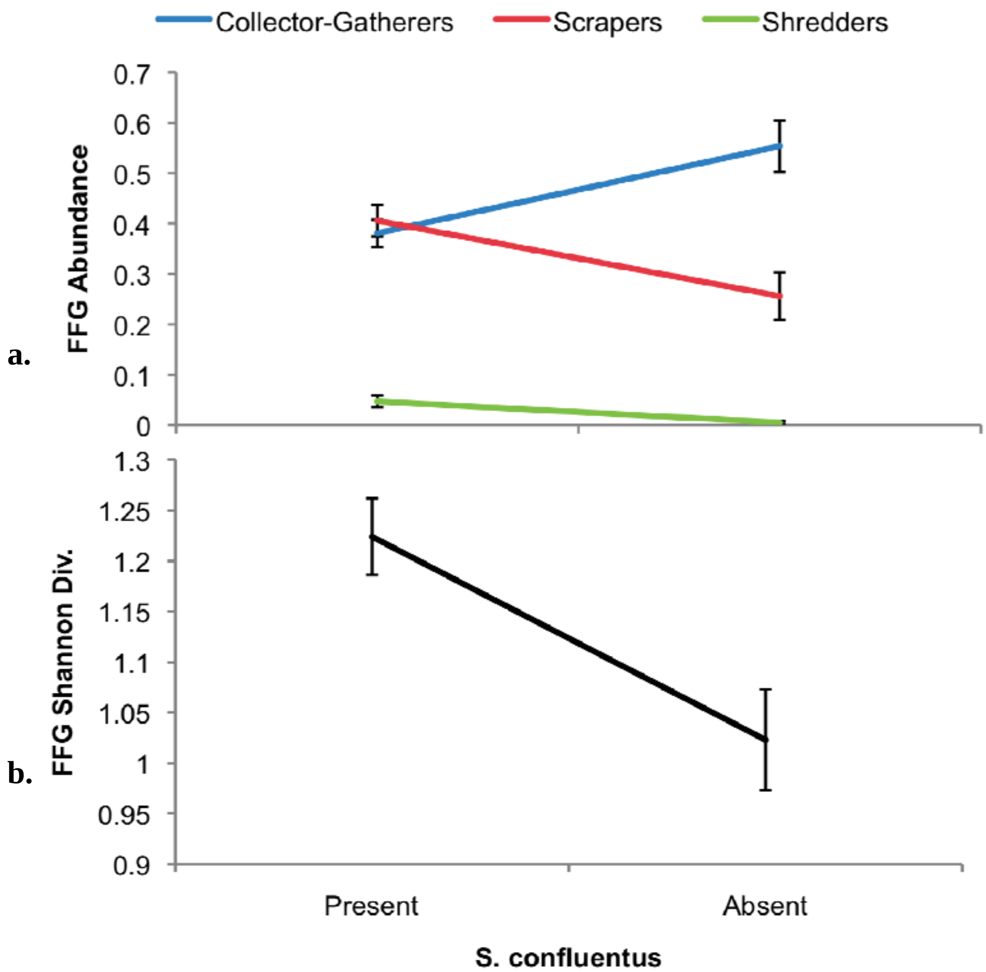

Figure 7. Differences in FFG factors across areas where *S. confluentus* is present or absent; a. collector-gatherer, scrapers and shredder abundance b. diversity of FFGs

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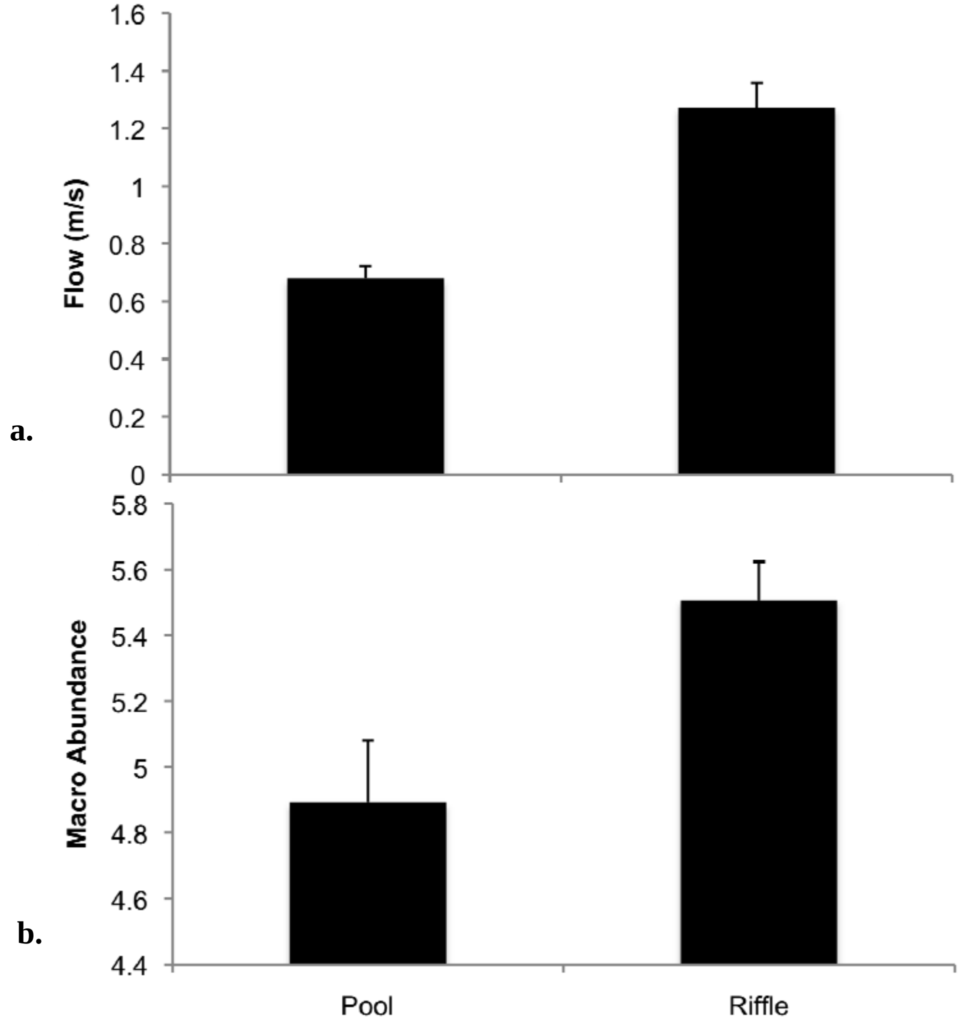

Figure 8. Flow and macrovertebrate abundance between pool and riffle habitats. a. flow rates b. of macroinvertebrate abundances

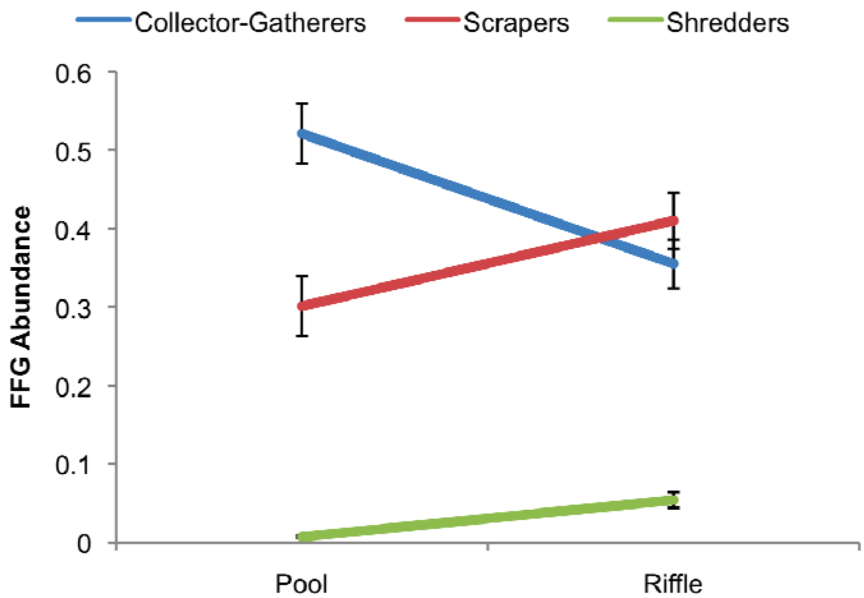

Figure 9. Collector-gatherer, scraper, and shredder abundance by pool and riffle site.

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