RIFFLE COMMUNITY RECOVERY AFTER REESTABLISHMENT OF A SWIFT RIVER CHANNEL FOLLOWING RESERVOIR DRAWDOWN AT THE BOARDMAN RIVER, TRAVERSE CITY, MI

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Abstract

The Boardman River is a high water quality, groundwater fed stream that meanders through Michigan’s Grand Traverse and Kalkaska Counties. The Boardman Dam impedes the river’s flow and, due to safety concerns, it is scheduled for removal in the next few years. In 2007, the reservoir created by the dam was lowered 17 feet, resulting in the reestablishment of a more typical river channel upstream. Because research indicates that dams negatively affect stream ecosystems by changing discharge and temperature regimes, increased sedimentation and alteration of natural habitat, it is anticipated that removal of this dam will bring the stream back to a more natural condition.

The purpose of this study was to estimate possible impacts of current reservoir drawdown on the newly exposed stream channel by comparing the macroinvertebrate community at a newly observed riffle at the head of the old reservoir (Lone Pine Site) with an undisturbed riffle site upstream (Shumsky Site). Additionally, samples were compared with those taken in similar studies done in 2008-2010 to determine the amount of recovery in the reestablished river channel at the Lone Pine Site. Macroinvertebrates were identified to lowest possible taxonomic level and distinguished by morphospecies. In the 2009 field season, 130 individuals were identified. Shumsky had 28 individual morphospecies observed and Lone Pine had 22 observed morphospecies. During the 2010 field season, 864 individuals were identified. Shumsky had 31 observed morphospecies, Lone Pine had 36 morphospecies. In the 2011 field season, 360 individuals were identified. Shumsky had 28 morphospecies observed and Lone Pine had 18 morphospecies.

A comparison of the recovering site with the undisturbed, natural sites using Sørensen’s Quotient of Similarity indicated that the Lone Pine Site was similar in regard to community structure. Results from this study suggest that three years after the Boardman Dam reservoir was drawn down, the Lone Pine site has gradually recovered to a “natural state” in comparison to the control site. However, in regard to invertebrate community structure, the benthos is still not recovered to a similar level of community stability as the more natural site.

Introduction

Dams fundamentally change the structure and function of stream ecosystems (Allen 1995). The dams on the Boardman River in Michigan are no exception, significantly impacting organic matter transport, upstream migration, discharge and stream load. The Boardman River is a blue ribbon trout stream that is significantly contributes to Northern Michigan's $587 million dollar tourist economy. The Boardman Dam (the dam of focus in this study) was constructed in 1884 and now stands as one of four dams that impede flow on the lower portions of the river in the vicinity of Traverse City, Michigan (Traverse City Dam Project 2005).

A river is an ever-changing mosaic of water flow types and microhabitats. In swift flowing rivers the channel is generally broken down into two basic parts, the riffle and the pool. Pools are characterized by slower, deeper water with a substrate consisting of finer particles. In contrast riffles typically exhibit a shallower channel, with a swifter current and a substrate of larger stones and coarse materials (Cushing and Allen 2001; Allen 1995).Within the riffle habitat the larger particles are made up primarily of: cobbles (64-256 mm), pebbles (16-64 mm), and gravel (2-16 mm), with intermittent occurrences of very coarse sand (1-2 mm) through very fine sand (0.0625-0.125 mm) (Waters 1995).

The normal variability in substrate composition resulting from the riffle-pool sequence is important to many benthic invertebrates for three main reasons. First, the turbulent, fast-flowing, oxygen-rich water is available to them in the larger spaces in the coarse substrate. Second, algal growth is more significant on the larger particles thus making feeding easier (Waters 1995). Third, the larger particles offer more diverse bottom structure and trap particulate detritus as a vital food source. Macroinvertebrates commonly found in riffles are generally oxygen loving, and tend to have a body that is small and flat, allowing them to cling to the substrate in the strong current of the river (Allen 1995). Since stream dwelling benthic macroinvertebrate communities that are diverse tend to be good indicators of mature, less-disturbed habitats, they are often used to assess the overall health of the stream both in qualitative and quantitative analyses (Hauer and Lamberti 2007; Lenat 1988).

Although swift rivers naturally exhibit sequences of riffles and pools, humans have impacted their natural channel and flow patterns by constructing dams for energy generation. Dams fundamentally change river ecosystems by greatly altering the discharge regime and often reducing the discharge of water. In turn, discharge changes impact channel structure and composition. As the flow decreases suspended particles settle, changing the bottom substrate and altering nutrient loads, even in the river channel upstream from the dam. This dam-induced settling changes the structure of the substrate from one consisting of primarily large particles to one that is primarily made up of small particles (Waters 1995). The water behind the dam impoundment is often more nutrient rich. With the softer, finer substrate the conditions favor macrophyte growth, subsequently altering macroinvertebrate taxa types, richness and diversity (Mackay and

Waters 1986). Though dams may at times increase both primary and secondary productivity downstream, it comes at the cost of reduced biodiversity and stability of the ecosystem above the dam (Benenati et al. (2000; Pollard and Reed 2004; Stanley et al. 2002).

Since dams have been demonstrated to significantly impact the stream ecosystem, it is reasonable to expect changes in the ecosystem once these dams have been removed. Several studies support the view that the removal of dams will result in an increase in biological diversity throughout the effected portion of the river (Mackay and Waters 1986; Pollard and Reed 2004; Stanley et al. 2002; Thomson et al. 2005). Research has also indicated that even when a dam does not affect the chemistry of water; it still affects the biological diversity within that portion of river by changing the channel morphology and altering the substrate type (Stanley et al. 2002).

As part of the natural restoration process following dam removal, the river tends to regain its meandering form with the subsequent new channels cut or at least altered. The initial return to normal discharge patterns (more high and low flows) can wash away naturally occurring organic matter and sediment, making the river channel less suitable for bottom dwelling organisms in early portion of recovery (Furey et al. 2006). However, following channel stabilization ecological recovery is manifested in many ways including an increase in the biological diversity in the benthic macroinvertebrate community. (Stanley et al. 2002).

Past research on riffle dwelling macroinvertebrates in the Boardman River by representatives from Au Sable Institute has been conducted by Nelson (2007) who examined the effectiveness of sand traps on restoring biodiversity in the benthic invertebrate community and Lousma (2008), who examined the response of the macroinvertebrate community immediately following the drawdown of the Boardman dam. Lousma found that faunistic communities between the drawn-down site and the undisturbed site were significantly different, thus concluding that the stream had not yet recovered to a “natural state” (Lousma 2008). This present three-year study built upon Lousma’s work and further examined changes in the riffle dwelling macroinvertebrate population in response to the 2007 dam drawdown at the same sites: an up-river, natural, undisturbed site (Shumsky) and at the site of a newly exposed channel (Lone Pine) that resulted from dam reservoir drawdown. This study set out to address four primary objectives: 1) to compile a comprehensive species list of the riffle dwelling macroinvertebrates at two sites on the Boardman River; 2) to compare faunistic similarities between the two natural sites; 3) to compare the faunistic composition of the recovering site to the natural sites; 4) to determine if the macroinvertebrate community at the newly established riffle site (Lone Pine) has progressed toward a more recovered state.

Materials and Methods

Study Sites

To compare similarities in benthic macroinvertebrate communities, samples were taken at two sites: 1) an undisturbed, natural riffle site well above the Boardman dam, and 2) a riffle within the recently reestablished stream channel that resulted from the drawdown of the Boardman Dam Reservoir.

Site 1, the first natural, undisturbed site was sampled just above the public access at Shumsky Road (Figure 1); site 2 the newly recovering site was located at the public access site at Lone Pine Road public access site (Figure 1) was sampled where the stream is stabilizing from the drawdown of the Boardman dam. At the Shumsky Site, samples were taken at midstream in the riffle that runs between the two docks immediately visible from the canoe launch. At the Lone Pine Site, samples were taken midstream 20 m downstream from the canoe launch.

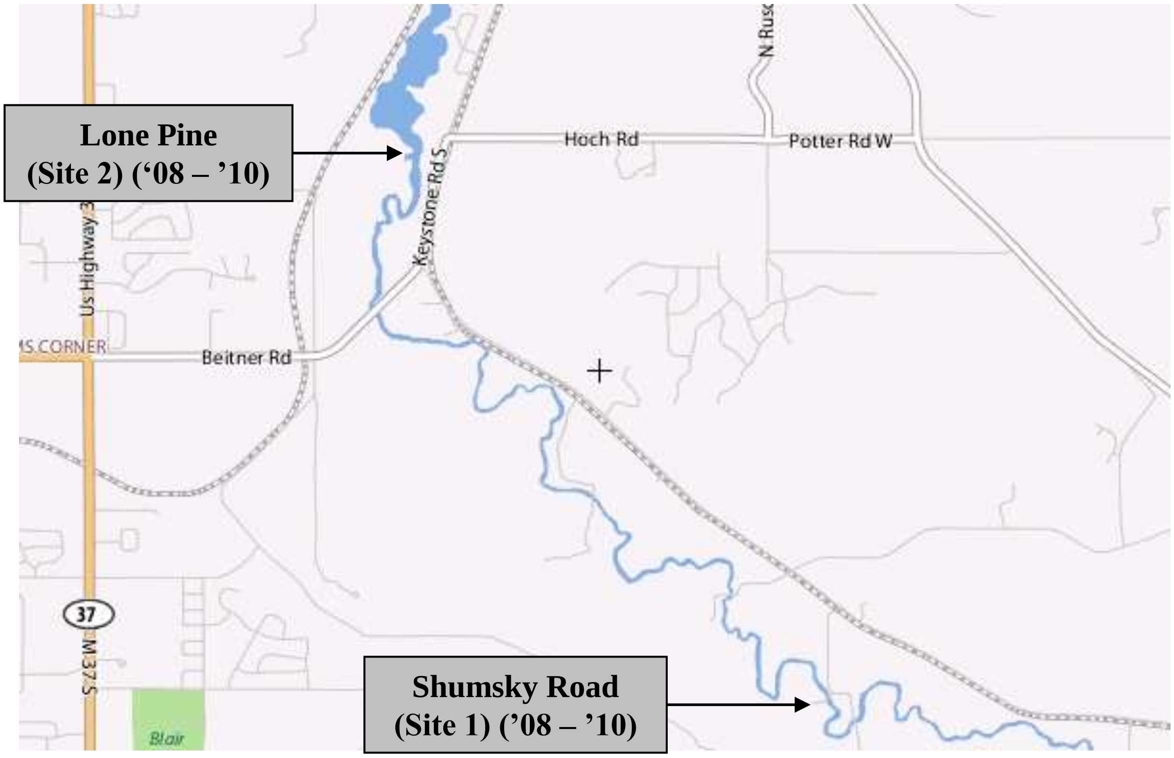

Figure 1: Macroinvertebrate Sampling Sites along the Boardman River.

Sampling Method

The riffles were sampled with a standard 0.5 mm Surber sampler with a 1 ft^2 sampling area. The sampler was placed on the bottom of the stream and a three pronged substrate agitator was used to agitate the bottom for one minute interval for each of the three replicates. The three-pronged agitator was used for consistency because some of the sample sites are too deep for hand-generated agitation. The net's entire contents (substrate, macrophytes, and macroinvertebrates) were emptied into water filled sample bottles. Macroinvertebrate samples retrieved were preserved in 70% ethyl alcohol and identified in the lab.

Identification of Samples

Benthic macroinvertebrates were identified in the lab using the standard aquatic invertebrate guides by Merritt and Cummings (1996), Hilsenhoff (1974), Clifford (1991), and Pennak (1978). The benthic aquatic insects were keyed out to genus with the exception of pupae, which were identified down to family but treated as morphospecies. Chironomids were identified to subfamily. Additionally, annelids and mollusks were keyed down to the rank of class. All other macroinvertebrates were identified to the lowest possible taxonomic level. Unidentified individuals will be treated as morphospecies for biodiversity evaluation (Lenat 1988; Stribling et al. 2008).

Data Analysis

A total inventory of macroinvertebrates was compiled for the riffle communities based on samples from the two sites. The total number of macroinvertebrates (including the total number of unique genera and morphospecies) were then compared between the two sites, including the presence or absence at the two sites.

To test for overlap of species the Sørensen's Quotent of Similarity was used (Sørensen 1948).

$$QS = \frac{2C}{A+B}$$

Sørensen's Quotent of Similarity was calculated as a measure of the percent similarity within macroinvertebrate communities between two sites (Kerans and Karr 1994).

To test for relative species abundance, evenness, and richness, rank abundance curves were used. In this metric, the x-axis is the abundance rank of a particular organism and the y-axis is the relative abundance, on a logarithmic scale.

Chi-square contingency tests were used to test for independence in samples.

$$E_{i,j} = \frac{\sum_{k=1}^{c} O_{i,k} \sum_{k=1}^{r} O_{k,j}}{N}, X^2 = \sum_{i=1}^{r} \sum_{j=1}^{c} \frac{(O_{i,j} - E_{i,j})^2}{E_{i,j}}.$$

The test first calculates observed and expected values and compares to determine a χ^2value. This value is then determined to be either significant or insignificant using a table of critical values based on calculated degrees of freedom and the χ^2. This test was run to determine if the samples observed values differed from expected values. From this it could be ascertained if each of the samples were independent of one another.

Additionally an Ephemeroptera, Plecoptera, Trichoptera divided by Chironomid (EPT/Chironomid) richness index was generated.

$$EPT/C$$

This index is useful to evaluate richness within the sampled riffle communities. It uses indicator species to create a more focused evaluation of richness within the macroinvertebrate community (Somers et al. 1998).

Results and Discussion

2009 Field Season

A total of 130 individual organisms representing a total of 38 morphospecies were found in samples taken in 2009. On June 12, 2009, 22 individuals were collected at the undisturbed Shumsky Road site, and 15 individuals were collected at the recovering Lone Pine site. On June 28, 2009, 85 individuals were collected from undisturbed Shumsky Road site, and 30 individuals were collected from the recovering Lone Pine site. Appendix A summarizes the taxa found in the samples.

Once samples are combined the results yielded 28 morphospecies and 85 individuals from the Shumsky Road access, the undisturbed upstream site. Lone Pine the site of the reservoir drawdown, yielded 22 morphospecies and 45 individuals. Shumsky had the highest number of morphospecies unique to its riffles in comparison to the recovering Lone Pine site (16SH:10LP) Trichoptera and Diptera dominated the recovering site whereas Coleoptera and Diptera dominated the undisturbed site (Figure 2).

2010 Field Season

A total of 681 individual organisms representing 47 morphospecies were found in the samples taken. On June 10, 2010, 140 individuals were collected at undisturbed Shumsky Road site, and 320 individuals were from the recovering Lone Pine site. On June 25, 2010, 127 individuals were collected from Shumsky Road site, and 94 individuals were collected from the Lone Pine site. Appendix B summarizes the taxa recovered in the 2010 sampling.

Once samples are combined, the results from the combined samples showed 31 morphospecies and 267 individuals from the Shumsky Road access, while the Lone Pine yielded 36 morphospecies and 414 individuals. In contrast to the previous year, Lone Pine had the highest number of morphospecies unique to its riffles, (16 LP: 11 SH).

2011 Field Season

360 individuals representing 31 morphospecies were found in samples collected. Results from the 2011 field season showed that a higher number of morphospecies were collected in both 2009 and 2010. In 2011 more individuals were collected than 2009 though more individuals were collected in 2010 than either 2011. On June 9, 2011 107 individuals were collected at the Shumsky Road site, while at the recovering Lone Pine site 85 individuals were collected. On June 28, 2011 151 individuals were collected from the Shumsky Road site, 24 individuals were collected from the Lone Pine site. Appendex C summarizes taxa recovered in 2011 sampling.

Results from the combined samples yielded 27 morphospecies and 258 individuals from the Shumsky Road site in comparison to 18 morphospecies and 102 individuals at Lone Pine. Between the two sites, Shumsky Road had a higher number of unique morphospecies (12 SH: 3 LP).

Observations: 2009

Community compositional differences were observed between the Lousma (2008) study and the consequent years of this study. In 2009, the highest species richness was observed at the undisturbed location. Richness was also measured using an EPT/Chironomid richness index. The EPT/Chironomid Richness index helps to focus richness by utilizing indicator species that are found throughout streams. Ephemeroptera, Plecoptera, and Trichoptera are generally pollution and disturbance intolerant orders, whereas Chironomids are more pollution and disturbance tolerant. Results from this analysis indicated that the EPT/Chironomid richness was highest at the undisturbed Shumsky site (Table 1).

A rank abundance curve was generated to compare differences in the relative species abundance, richness, and evenness in the data. Figure 3 illustrates significant variation between the two sites. To also examine community similarity, Sørensen's Quotients of Similarity was calculated. If the calculated similarity is 50% or greater, then two sites are generally regarded as representing the same community type (Sørensen 1948). 48% similarity between the two sites was observed, thus the two sites were considered to be dissimilar suggesting differences in community type represented at each site.

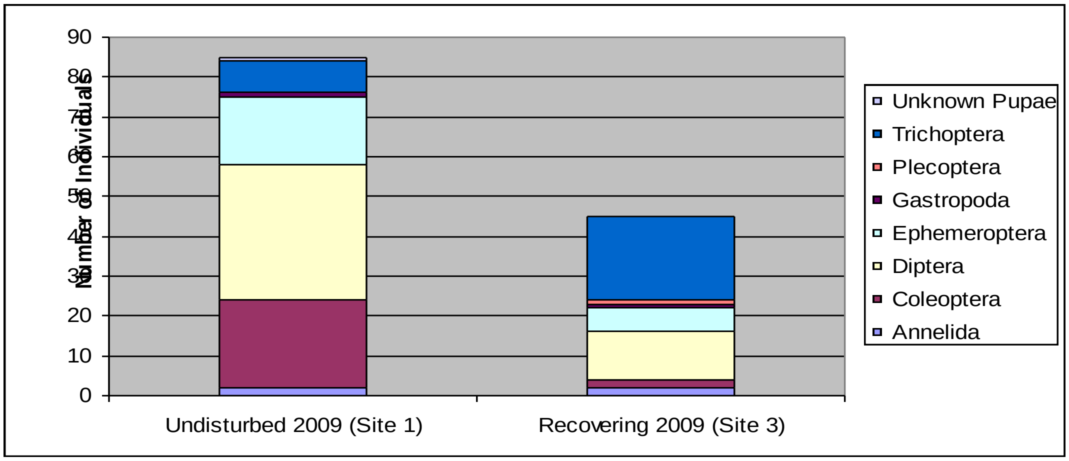

Figure 2: Total number of individuals represented by site for 2009 data

Table 1: EPT/Chironomid Richness Score for 2009 data.

	Undisturbed (Site 1)	**Recovering (Site 2)**
# of Ephemeroptera	17	6
# of Plecoptera	0	1
# of Trichoptera	8	21
# of Chironomidae	7	12
EPT/Chironomid Richness Score	**3.57**	**2.33**

Finally, a chi-square contingency test was run to test for independence between the two sites. Table 2 demonstrates that the two sites are independent of one another, further -supporting the difference between the two sites.

To summarize the 2009 results, our analysis showed a significant difference between the two locations. These conclusions are supported by the differences - in EPT/Chironomid Richness, ranked abundances, and chi square values. Thus, the recovery and recolonization process of riffle dwelling macroinvertebrates was not complete at the Lone Pine site in 2009.

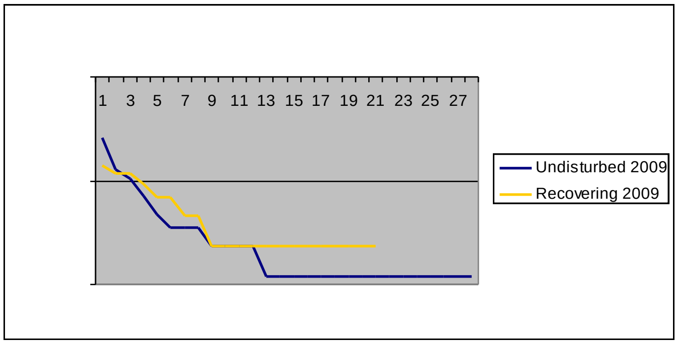

Figure 3: Rank abundance curve for 2009 data

Table 2: Chi-Square values and p-values for 2009 data

	X^2	p-value
Lone Pine and Shumsky	80.6	<0.01

Observations: 2010

In contrast to the previous year, species richness was highest at the recovering location. And it was also found that the two sites were dominated by the same four orders of organisms (Figure 4) with Ephemeroptera, Coleoptera, Trichoptera, and Diptera comprising the majority of the taxa richness of the two sites.

To further analyze richness, an EPT/Chironomid richness index was performed. Results indicated that the greatest EPT/Chironomid richness scores were at the undisturbed site (Table 3).While this higher EPT/Chironomid richness score at the undisturbed site may indicate that it was slightly healthier, the families of Chironomids that dominated the recovering location were Orthocladiinae, and Tanypodinae, both generally intolerant of significant disturbance. Thus, though the EPT/Chironomid richness is higher at the undisturbed sites, both sites may be characterized as healthy.

Table 3: EPT/Chironomid Richness Score for 2010 data.

	Shumsky (Site 1)	**Lone Pine (Site 2)**
# of Ephemeroptera	29	14
# of Plecoptera	0	0
# of Trichoptera	34	43
# of Chironomidae	47	31
EPT/Chironomid Richness Score	**1.34**	**0.897**

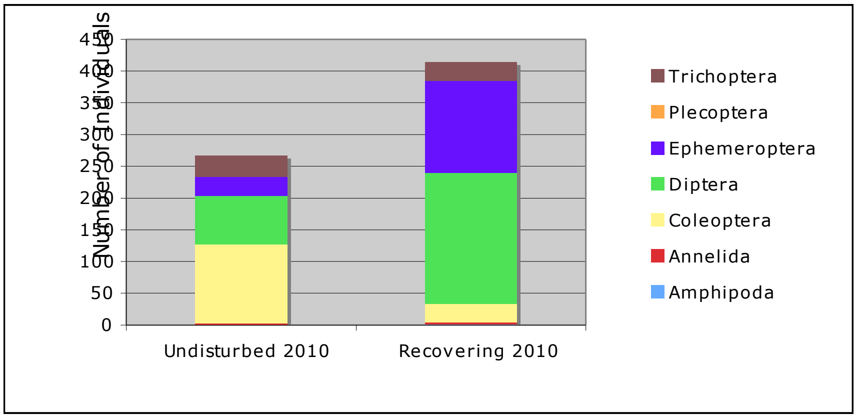

Figure 4: Total number of individuals represented by site for 2010 data

To examine how the two sites related to one another in respect to the relative species abundance, evenness, and richness, a rank abundance curve was created. Figure 5 illustrates a tight correlation between the two sites. This indicates that there is similar relative abundance of species, evenness of distribution, and richness of species present at the two sites.

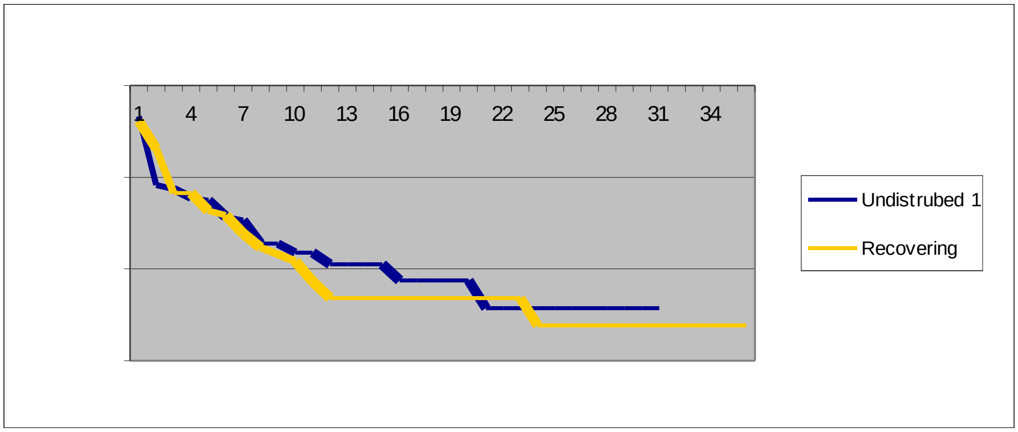

Figure 5: Rank abundance curve for 2010 data

Similarity between the two sites was tested and observed by applying Sørensen's Quotients of Similarity. Table 4 shows that there was over 50 % similarity between both sites, indicating that the two sites can be regarded as representing the same community type (Sørensen 1948).

Table 4: Sørensen's Quotients of Similarity 2010 data.

	Shumsky Site (Site 1)	**Lone Pine (Site 3)**
Shumsky Site (Site 1)	-	20 taxa
Lone Pine (Site 3)	60%	-

A Chi square contingency test was run to test for independence between the two samples. As a result of this test, significant differences between both sites are observed (Table 5). This suggests that though similar in respect to their community type, macroinvertebrate community differences remain between the sites.

Table 5: Chi-Square values and p-values for 2010 data

	X^2	p-value
Lone Pine and Shumsky	323.6	<0.01

In conclusion, the 2010 samples suggested a similarity of community type between the two sites. Similar dominant orders, tight rank abundance correlation, close

EPT/Chironomid index scores and high values for Sørensen’s Quotient of Similarity all suggested a community type similarity–at both locations. However, this does not suggest that they are completely the same; we observed differences in EPT/Chironomid richness, proportions of dominate orders, and statistically significant differences in Chi-square values. Thus, while there may have been a significant degree of community similarity between the two sites, each was independent from the other. However, the most important finding from this year’s sampling was that this high degree of community similarity suggests that the Lone Pine site has recovered to a more “natural state”.

Observations: 2011

As in 2009, results from 2011, as measured by species richness, indicated a higher value at the undisturbed verses the recovering site. Ephemeroptera, Trichoptera, Diptera, and Coleoptera contributed most significantly to richness at both sites (Figure 6).

EPT/Chironomid richness was used to further assess species richness at the two sites. Results indicated that the greatest EPT/Chironomid richness scores were at the undisturbed site (Table 6). By this analysis, it would appear that recovery is still in process at the disturbed location. However, as found in 2010, the families of Chironomids that dominated the recovering site are generally thought of as intolerant of significant disturbance. This information would help to confirm that the recovering site is still in a “healthy” condition.

As another measure of community type similarity, Sørensen’s Quotient of Similarity was used. It was observed that there was 62% similarity between the two sites in regards to community type (Table 7) confirming their high degree of similarity.

A rank abundance curve was created to examine how the two sites related to one another in respect to the relative species abundance, evenness, and richness. Figure 7 illustrates a weak correlation between the two sites. This shows difference in relative abundance of species, evenness of distribution, and richness of species present at both sites.

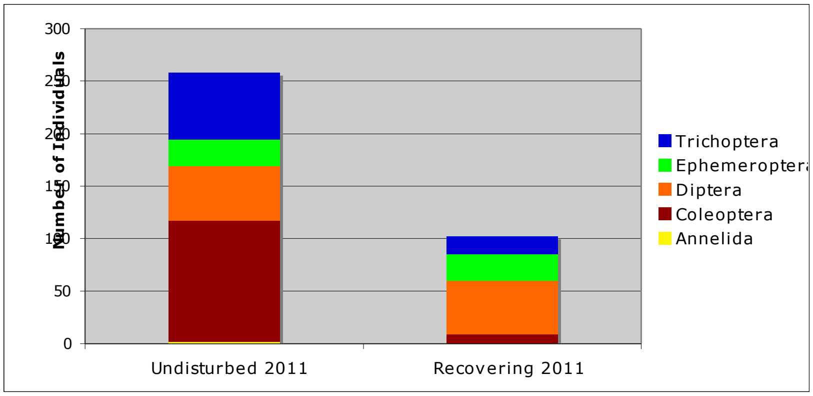

Figure 6: Total number of individuals represented by site for 2011 data

Table 6: EPT/Chironomid Richness Score for 2011 data.

	Shumsky (Site 1)	**Lone Pine (Site 2)**
# of Ephemeroptera	25	25
# of Plecoptera	0	0
# of Trichoptera	64	17
# of Chironomidae	49	50
EPT/Chironomid Richness Score	**1.82**	**0.84**

Table 7: Sørensen's Quotients of Similarity 2011 data.

	Shumsky Site (Site 1)	**Lone Pine (Site 2)**
Shumsky Site (Site 1)	-	14 taxa
Lone Pine (Site 2)	62%	-

Table 8: Chi-Square values and p-values for 2011 data

	X^2	p-value
Lone Pine and Shumsky	181.2	<0.01

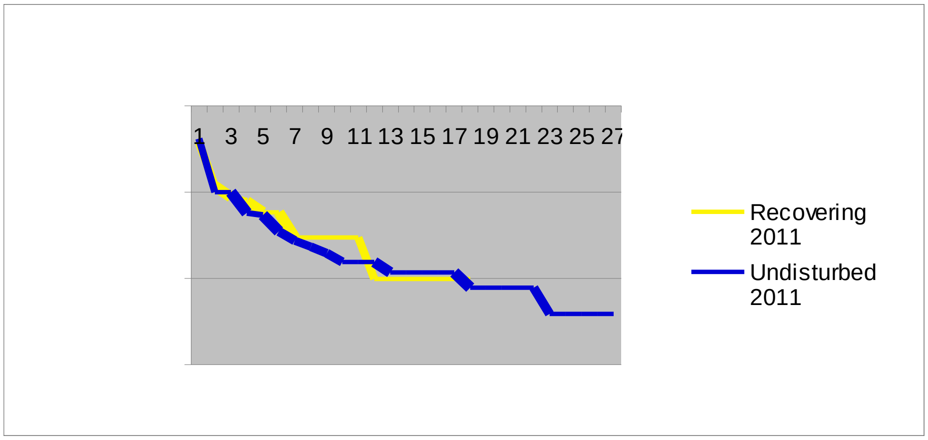

Figure 7: Rank abundance curve for 2011 data

To test for independence between the two samples a Chi-Squared contingency test was run. Significant differences between sites are observed as a result of this test (Table 8). These results suggest that two sites are independent of one another.

In summary, similar dominate orders and a high Sørensen's Quotient of Similarity score suggest some similarity between the two sites. However, differences in rank abundance curves, EPT/Chironomid index scores, proportions of dominate orders, and statistically significant differences in Chi-square values are indicative of significant differences between the two sites.

Just prior to 2011 sampling, a large rainfall produced an unusual bankfull discharge in the Boardman. Such a disturbance may have caused significant movement of the bottom sediments, especially at the recovering site, since it normally has a higher stream velocity than the control site. Visual comparisons by the authors of the stream bottom from the two years seemed to confirm more disturbance in 2011 however, such comparisons are only speculative.

Lone Pine: A four year journey

The high degree of community similarity between the undisturbed site and the recovering site observed in 2010 indicates that there has been a noteworthy three year recovery process. Positive change was made over each of the three years in respect to relative species abundance, richness, and evenness (Figure 8). Additionally, community similarity between the undisturbed Shumsky site and the recovering Lone Pine site has continued to increase each of the three years (Table 9). Fluctuation has been seen over the last three years in regards to the EPT/Chironomid index, however, the overall species abundance has continued to increase from 2008 to 2010 (Table 10). This observed trend can be largely attributed to the increase of Chironomids in the 2010 sample. The subfamilies of Chironomids that have been observed increasing in 2010 are characteristic of cold water, lotic environments. This indicates that, though the proportions of Ephemeroptera, Plecoptera, and Trichoptera are lower this year than past years, the increased levels of Chironomids are at the very least species that should be present in the natural stream. These trends support previous findings about stream ecosystem resiliency after significant disturbance (Pollard and Reed 2004; Stanley et al. 2002).

This strong three year recovery trend was somewhat challenged by data collected in 2011. While these results showed some decline in community health, they also offered some signs that the community at the recovering site has elements of stability characteristic of the control (natural) site. A statistically significant decline was observed in regard to relative species abundance, richness, and evenness in 2011 (Figure 8), as compared to 2010. Both EPT/Chironmid richness values and Sørensen's Quotient of Similarity scores stayed constant (Tables 9 & 10**)** for 2009 through 2012**.** These results suggest a level a community health and stability in the established organisms. Interestingly, 2011 results from the recovering channel demonstrated a constant loss in organisms from all taxonomic groups. Such an indiscriminate impact adds support to the suggestion that the community was subject to a catastrophic event such as the observed flooding.

To summarize the information collected in these studies, our results indicate that there has been significant recovery of the macroinvertebrate community at the disturbed location over a relatively short time period. Also, though our data demonstrates that the benthic community is "natural" in regard to macroinvertebrat**e** composition, the stream channel is not yet fully recovered**,** at least in the full sense of the more natural upstream location.

These four years of research serve as an important documentation of the recovery in a stream macroinvertebrate community immediately after dam removal. Results from 2011 may also illustrate the fragility of an ecosystem that has had significant recovery. This study broadens understanding of how future reservoir drawdown and dam removal efforts will affect the Boardman River and what can be expected during that process.

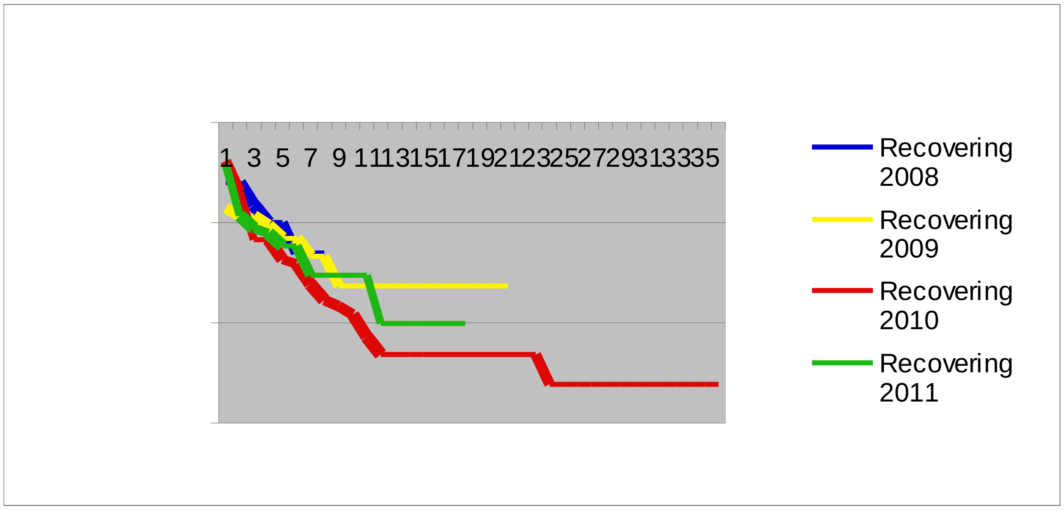

Figure 8: Rank Abundance Curve for three years at the recovering site

Table 9: Sørensen's Quotient of Similarity for three years

Shumsky '08 to Lone Pine '08	27%
Shumsky '09 to Lone Pine '09	48%
Shumsky '10 to Lone Pine '10	60%
Shumsky '11 to Lone Pine '11	62%

Table 10: EPT/ Chironomid values observed at Lone Pine site over three years

	Lone Pine 2008	Lone Pine 2009	Lone Pine 2010	Lone Pine 2011
EPT/Chironimid Value	0.33	2.17	0.89	0.84

Acknowledgments

I would like to thank the Adams Chapter of Trout Unlimited for funding the project. Special thanks to Dave Mahan for mentorship and guidance on the project as well Garrett Crow for directing my research.

Appendix A: Listing of Morphospecies collected from 2009 from Shumsky (SH), and Lone Pine (LP) Sampling Sites.

Order	**Family**	**Genus**	**Species**	**SH '09**	**LP '09**
Amphipoda	Gammaridae	Gammarus		0	0
Annelida	Hirudinae (Class)			0	1
Annelida	Oligochaeta			2	1
Coleoptera	Elimidae	Microcylloepus		11	0
Coleoptera	Elimidae	Optioservus		9	0
Coleoptera	Elimidae	Stenelmis		2	1
Coleoptera	Elimidae	Unknown 1		0	1
Coleoptera	Elmidae	Stenelmis		0	0
Diptera	Athericidae	Atherix		0	0
Diptera	Chironomidae	Chironominae		3	6
Diptera	Chironomidae	Chironomini		0	0
Diptera	Chironomidae	Diamesinae		0	1
Diptera	Chironomidae	Orthocladiinae		2	4
Diptera	Chironomidae	Tanypodinae		0	0
Diptera	Chironomidae	Tanytarsini		0	0
Diptera	Chironomidae	Unknown 1		1	0
Diptera	Chironomidae	Unknown 2		0	0
Diptera	Chironomidae		(Pupae)	1	1
Diptera	Chironomidae sp.			0	0
Diptera	Empididae	Hemerodromia		1	0
Diptera	Empididae		(Pupae)	0	0
Diptera	Simuliidae	Prosimulium		0	0
Diptera	Simuliidae	Simulium		3	0
Diptera	Simuliidae	Twinnia		0	0
Diptera	Simuliidae	Unknown 1		0	0
Diptera	Simuliidae		(Pupae)	0	0
Diptera	Tabanidae	Athericiae		1	0
Diptera	Tabanidae		(Pupae)	22	0
Diptera	Tipulidae	Antocha		0	0
Diptera	Tipulidae		(Pupae)	0	0
Diptera	Unknown 1		(Pupae)	0	0
Diptera	Unknown 2			0	0
Diptera	Unknown 3			0	0
Ephemeroptera	Baetidae	Baetis	MSP 1	4	2
Ephemeroptera	Baetidae	Baetis	MSP 2	0	0
Ephemeroptera	Baetidae	Baetis	MSP 3	0	0
Ephemeroptera	Baetidae	Unknown 1		1	2
Ephemeroptera	Ephemerellidae	Drunella	MSP 1	6	1
Ephemeroptera	Ephemerellidae	Drunella	MSP 2	0	1
Ephemeroptera	Ephemerellidae	Drunella	MSP 3	0	0
Ephemeroptera	Ephemerellidae	Drunella	MSP 4	0	0
Ephemeroptera	Ephemerellidae	Drunella	MSP 5	0	0
Ephemeroptera	Ephemerellidae	Drunella	MSP 6	0	0
Ephemeroptera	Ephemerellidae	Ephemerella		0	0
Ephemeroptera	Ephemerellidae	Serratella		0	0
Ephemeroptera	Ephemerellidae	Unknown 1		1	0
Ephemeroptera	Ephemerillidae	Atenella		1	0
Ephemeroptera	Heptageniidae	Heptagenia		1	0
Ephemeroptera	Heptateniidae	Stenonema		0	0

Order	**Family**	**Genus**	**Species**	**SH '09**	**LP '09**
Ephemeroptera	Unknown 2			0	0
Ephemeroptera	Unknown 1			3	0
Gastropoda	Physidae	Physa		1	1
Plecoptera	Perlodidae	Isogenoides		0	1
Plecoptera	Unknown 1			0	0
Trichoptera	(Pupae)			0	0
Trichoptera	Brachycentridae	Brachycentrus	MSP 2	0	1
Trichoptera	Brachycentridae	Brachycentrus		2	2
Trichoptera	Brachycentridae	Micrasema		1	5
Trichoptera	Glossosomatidae	Glossosoma		0	0
Trichoptera	Glossosomatidae		(Pupae)	0	0
Trichoptera	Helicopsychidae	Helicopsyche		0	3
Trichoptera	Hydropsychidae	Cheumatopsyche		0	1
Trichoptera	Hydropsychidae	Diplectrona		0	1
Trichoptera	Hydroptiloidea	Ochrotichia		0	3
Trichoptera	Lepidostomatidae	Lepidostoma		1	5
Trichoptera	Leptoceridae	Ceraclea		0	0
Trichoptera	Leptoceridae	Mystacides		1	0
Trichoptera	Odontoceridae	Namamyia		0	0
Trichoptera	Odontoceridae	Psilotreta		0	0
Trichoptera	Philopotamidae	Dolophilodes		0	0
Trichoptera	Philopotamidae	Wormaldia		0	0
Trichoptera	Polycentropodidae	Polycentropus		1	0
Trichoptera	Rhyacophilidae	Rhyacophila		1	0
Trichoptera	Unknown 1			1	0
Unknown Pupae				1	0
Totals				**85**	**45**

Appendix B: Listing of Morphospecies collected from 2010 from Shumsky (SH), and Lone Pine (LP) Sampling Sites.

Order	**Family**	**Genus**	**Species**	**SH '10**	**LP '10**
Amphipoda	Gammaridae	Gammarus		**0**	**1**
Annelida	Hirudinae (Class)			**0**	**1**
Annelida	Oligochaeta			**3**	**2**
Coleoptera	Elimidae	Microcylloepus		**0**	**0**
Coleoptera	Elimidae	Optioservus		**124**	**28**
Coleoptera	Elimidae	Stenelmis		**0**	**0**
Coleoptera	Elimidae	Unknown 1		**0**	**1**
Coleoptera	Elmidae	Stenelmis		**0**	**0**
Diptera	Athericidae	Atherix		**5**	**2**
Diptera	Chironomidae	Chironominae		**0**	**0**
Diptera	Chironomidae	Chironomini		**1**	**0**
Diptera	Chironomidae	Diamesinae		**2**	**0**
Diptera	Chironomidae	Orthocladiinae		**22**	**171**
Diptera	Chironomidae	Tanypodinae		**1**	**0**
Diptera	Chironomidae	Tanytarsini		**16**	**6**
Diptera	Chironomidae	Unknown 1		**2**	**1**
Diptera	Chironomidae	Unknown 2		**1**	**0**
Diptera	Chironomidae		(Pupae)	**2**	**16**
Diptera	Chironomidae sp.			**0**	**0**
Diptera	Empididae	Hemerodromia		**0**	**0**
Diptera	Empididae		(Pupae)	**5**	**0**
Diptera	Simuliidae	Prosimulium		**0**	**0**
Diptera	Simuliidae	Simulium		**3**	**5**
Diptera	Simuliidae	Twinnia		**1**	**0**
Diptera	Simuliidae	Unknown 1		**1**	**0**
Diptera	Simuliidae		(Pupae)	**0**	**1**
Diptera	Tabanidae	Athericiae		**0**	**0**
Diptera	Tabanidae		(Pupae)	**0**	**0**
Diptera	Tipulidae	Antocha		**0**	**0**
Diptera	Tipulidae		(Pupae)	**0**	**1**
Diptera	Unknown 1		(Pupae)	**15**	**2**
Diptera	Unknown 2			**0**	**1**
Diptera	Unknown 3			**0**	**1**
Ephemeroptera	Baetidae	Baetis	MSP 1	**10**	**28**
Ephemeroptera	Baetidae	Baetis	MSP 2	**1**	**85**
Ephemeroptera	Baetidae	Baetis	MSP 3	**1**	**0**
Ephemeroptera	Baetidae	Unknown 1		**0**	**0**
Ephemeroptera	Ephemerellidae	Drunella	MSP 1	**1**	**1**
Ephemeroptera	Ephemerellidae	Drunella	MSP 2	**9**	**18**
Ephemeroptera	Ephemerellidae	Drunella	MSP 3	**3**	**2**
Ephemeroptera	Ephemerellidae	Drunella	MSP 4	**1**	**0**
Ephemeroptera	Ephemerellidae	Drunella	MSP 5	**1**	**2**
Ephemeroptera	Ephemerellidae	Drunella	MSP 6	**0**	**2**
Ephemeroptera	Ephemerellidae	Ephemerella		**0**	**0**
Ephemeroptera	Ephemerellidae	Serratella		**2**	**2**
Ephemeroptera	Ephemerellidae	Unknown 1		**0**	**1**
Ephemeroptera	Ephemerillidae	Atenella		**0**	**0**
Ephemeroptera	Heptageniidae	Heptagenia		**0**	**0**
Ephemeroptera	Heptateniidae	Stenonema		**0**	**1**

Order	**Family**	**<u>Genus</u>**	**Species**	**SH '10**	**LP '10**
Ephemeroptera	Unknown 2			**0**	**2**
Ephemeroptera	Unknown 1			**0**	**0**
Gastropoda	Physidae	<u>Physa</u>		**0**	**0**
Plecoptera	Perlodidae	<u>Isogenoides</u>		**0**	**0**
Plecoptera	Unknown 1			**0**	**1**
Trichoptera	(Pupae)			**0**	**0**
Trichoptera	Brachycentridae	<u>Brachycentrus</u>	MSP 2	**0**	**0**
Trichoptera	Brachycentridae	<u>Brachycentrus</u>		**3**	**3**
Trichoptera	Brachycentridae	<u>Micrasema</u>		**20**	**10**
Trichoptera	Glossosomatidae	<u>Glossosoma</u>		**0**	**2**
Trichoptera	Glossosomatidae		(Pupae)	**2**	**0**
Trichoptera	Helicopsychidae	<u>Helicopsyche</u>		**4**	**2**
Trichoptera	Hydropsychidae	<u>Cheumatopsyche</u>		**0**	**2**
Trichoptera	Hydropsychidae	<u>Diplectrona</u>		**0**	**0**
Trichoptera	Hydroptiloidea	<u>Ochrotichia</u>		**0**	**0**
Trichoptera	Lepidostomatidae	<u>Lepidostoma</u>		**4**	**7**
Trichoptera	Leptoceridae	<u>Ceraclea</u>		**1**	**0**
Trichoptera	Leptoceridae	<u>Mystacides</u>		**0**	**0**
Trichoptera	Odontoceridae	Namamyia		**0**	**0**
Trichoptera	Odontoceridae	Psilotreta		**0**	**0**
Trichoptera	Philopotamidae	<u>Dolophilodes</u>		**0**	**1**
Trichoptera	Philopotamidae	<u>Wormaldia</u>		**0**	**2**
Trichoptera	Polycentropodidae	<u>Polycentropus</u>		**0**	**0**
Trichoptera	Rhyacophilidae	<u>Rhyacophila</u>		**0**	**0**
Trichoptera	Unknown 1			**0**	**0**
Unknown Pupae				**0**	**0**
Totals				**267**	**414**

Appendix C: Listing of Morphospecies collected from 2011 from Shumsky (SH), and Lone Pine (LP) Sampling Sites.

Order	**Family**	**Genus**	**Species**	**SH '11**	**LP '11**
Amphipoda	Gammaridae	Gammarus		**0**	**0**
Annelida	Hirudinae (Class)			**0**	**0**
Annelida	Oligochaeta			**2**	**0**
Coleoptera	Elimidae	Microcylloepus		**0**	**0**
Coleoptera	Elimidae	Optioservus		**108**	**9**
Coleoptera	Elimidae	Stenelmis		**0**	**0**
Coleoptera	Elimidae	Unknown 1		**0**	**0**
Coleoptera	Elmidae	Stenelmis		**7**	**0**
Diptera	Athericidae	Atherix		**3**	**1**
Diptera	Chironomidae	Chironominae		**0**	**0**
Diptera	Chironomidae	Chironomini		**0**	**0**
Diptera	Chironomidae	Diamesinae		**0**	**0**
Diptera	Chironomidae	Orthocladiinae		**4**	**39**
Diptera	Chironomidae	Tanypodinae		**0**	**0**
Diptera	Chironomidae	Tanytarsini		**2**	**6**
Diptera	Chironomidae	Unknown 1		**0**	**0**
Diptera	Chironomidae	Unknown 2		**0**	**0**
Diptera	Chironomidae		(Pupae)	**4**	**3**
Diptera	Chironomidae sp.			**0**	**0**
Diptera	Empididae	Hemerodromia		**0**	**0**
Diptera	Empididae		(Pupae)	**0**	**0**
Diptera	Simuliidae	Prosimulium		**14**	**0**
Diptera	Simuliidae	Simulium		**15**	**1**
Diptera	Simuliidae	Twinnia		**6**	**1**
Diptera	Simuliidae	Unknown 1		**0**	**0**
Diptera	Simuliidae		(Pupae)	**0**	**0**
Diptera	Tabanidae	Athericiae		**0**	**0**
Diptera	Tabanidae		(Pupae)	**0**	**0**
Diptera	Tipulidae	Antocha		**3**	**0**
Diptera	Tipulidae		(Pupae)	**0**	**0**
Diptera	Unknown 1		(Pupae)	**0**	**0**
Diptera	Unknown 2			**1**	**0**
Diptera	Unknown 3			**0**	**0**
Ephemeroptera	Baetidae	Baetis	MSP 1	**5**	**12**
Ephemeroptera	Baetidae	Baetis	MSP 2	**0**	**1**
Ephemeroptera	Baetidae	Baetis	MSP 3	**0**	**0**
Ephemeroptera	Baetidae	Unknown 1		**0**	**0**
Ephemeroptera	Ephemerellidae	Drunella	MSP 1	**0**	**0**
Ephemeroptera	Ephemerellidae	Drunella	MSP 2	**4**	**0**
Ephemeroptera	Ephemerellidae	Drunella	MSP 3	**1**	**1**
Ephemeroptera	Ephemerellidae	Drunella	MSP 4	**9**	**6**
Ephemeroptera	Ephemerellidae	Drunella	MSP 5	**3**	**3**
Ephemeroptera	Ephemerellidae	Drunella	MSP 6	**0**	**0**
Ephemeroptera	Ephemerellidae	Ephemerella		**2**	**1**
Ephemeroptera	Ephemerellidae	Serratella		**1**	**0**
Ephemeroptera	Ephemerellidae	Unknown 1		**0**	**0**
Ephemeroptera	Ephemerillidae	Atenella		**0**	**0**
Ephemeroptera	Heptageniidae	Heptagenia		**0**	**1**

Order	**Family**	**Genus**	**Species**	**SH ‘11**	**LP ‘11**
Ephemeroptera	Heptateniidae	Stenonema		**0**	**0**
Ephemeroptera	Unknown 2			**0**	**0**
Ephemeroptera	Unknown 1			**0**	**0**
Gastropoda	Physidae	Physa		**0**	**0**
Plecoptera	Perlodidae	Isogenoides		**0**	**0**
Plecoptera	Unknown 1			**0**	**0**
Trichoptera	(Pupae)			**2**	**0**
Trichoptera	Brachycentridae	Brachycentrus	MSP 2	**0**	**0**
Trichoptera	Brachycentridae	Brachycentrus		**2**	**3**
Trichoptera	Brachycentridae	Micrasema		**26**	**8**
Trichoptera	Glossosomatidae	Glossosoma		**0**	**0**
Trichoptera	Glossosomatidae		(Pupae)	**0**	**0**
Trichoptera	Helicopsychidae	Helicopsyche		**26**	**0**
Trichoptera	Hydropsychidae	Cheumatopsyche		**3**	**0**
Trichoptera	Hydropsychidae	Diplectrona		**0**	**0**
Trichoptera	Hydroptiloidea	Ochrotichia		**0**	**0**
Trichoptera	Lepidostomatidae	Lepidostoma		**3**	**3**
Trichoptera	Leptoceridae	Ceraclea		**0**	**0**
Trichoptera	Leptoceridae	Mystacides		**0**	**0**
Trichoptera	Odontoceridae	Namamyia		**1**	**0**
Trichoptera	Odontoceridae	Psilotreta		**1**	**0**
Trichoptera	Philopotamidae	Dolophilodes		**0**	**0**
Trichoptera	Philopotamidae	Wormaldia		**0**	**3**
Trichoptera	Polycentropodidae	Polycentropus		**0**	**0**
Trichoptera	Rhyacophilidae	Rhyacophila		**0**	**0**
Trichoptera	Unknown 1			**0**	**0**
Unknown Pupae				**0**	**0**
Totals				**258**	**102**

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