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Response of Boardman River water temperature and insect communities and to dam removal

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ABSTRACT

Dam removal is becoming a common technique to restore streams to a more natural state. Few studies have looked at the effects of removing hydroelectric dams on macroinvertebrate communities or on stream temperature. The Boardman River, Kalkaska and Grand Traverse Counties, Michigan, USA, has four dams, three are scheduled for removal. The objective of this study was to examine the benthic insect communities and stream temperature regime (1) as a baseline prior to the removal of Brown Bridge Dam, (2) following a drawdown of the reservoir (Brown Bridge Pond), and (3) following the deconstruction of Brown Bridge Dam.

Water temperature has been recorded hourly since May 2011 using data loggers. We determined that the dam increased downstream water temperature (~3°C) during summer months and slightly decreased temperature during winter months. Although not immediate, downstream water temperature following the dam removal has started to mirror upstream temperatures.

We sampled macroinvertebrates during the early summers of 2011, 2012 and 2013. Following the reservoir drawdown, metrics for macroinvertebrate communities (%EPT, EPT/C, sensitive:tolerant taxa ratio) increased downstream of the dam and became more similar to upstream sites. In 2013, following the dam removal, increased sediment in downstream reaches resulted in decreased habitat quality and thus insect metrics. This study provides meaningful information for short-term effects of the dam removal. Continued monitoring will enhance understanding of long-term effects.

KEY WORDS: EPT/C; hydroelectric dam; macroinvertebrates; Michigan; trout stream

INTRODUCTION

Dams have been erected on most of the world's major river systems to provide flood control, hydroelectricity, fisheries and recreation, and drinking water (Dodds 2002). Despite these benefits, dams fragment riparian habitat (Jansson et al. 2000) and moderate changes in discharge (Allan 1995; Dodds 2002). Because reservoirs are wider and slower moving than the upstream river channel, they absorb more sunlight resulting in higher temperatures within the reservoir. When water is discharged from impoundments, the warmer water increases warm-season water temperature downstream of the impoundment (Lessard and Hayes 2003) and can limit which organisms can survive there or affect insect lifecycles (Allan 1995). In contrast, reservoirs tend to lower cold-season water temperatures which can also impact downstream organisms.

Reservoirs created by dams diminish a river's velocity, causing the sediment load to be deposited in a reservoir (Dewson et al. 2007). Without regular dredging, excess sediment deposition will fill in a reservoir. Overtime, the downstream reaches will become "sediment starved" which disrupts the river continuum (Ward and Stanford 1983; Dodds 2002).

Riffles are a distinctive habitat in rivers characterized by cobble and gravel with shallow, turbulent water. They are ideal habitats for macroinvertebrates because riffles provide macroinvertebrates with shelter and high levels of dissolved oxygen (Surber 1937). In reaches with increased fine sediment and sand, natural alternating riffle and pool patterns are disrupted (Dodds 2002). Increased fine sediment has been shown to be a key factor influencing pollution-sensitive macroinvertebrates and significantly impacts macroinvertebrate community composition due to decreased habitat availability (Burdon et al. 2013).

Today dam owners must decide whether to renovate or deconstruct dams due to the aging infrastructure (Orr et al. 2008). Dam removals are often heavily debated locally and receive significant media attention (Jørgensen and Renöfält 2013). Starting in 1848, the Boardman River (then known as the "Ottawa River") had been used to transport logs to sawmills (CRA 2013). As Traverse City grew, several hydroelectric dams were constructed to provide energy for the city (CRA 2013). In 2005, three of the four dams along the Boardman River were decommissioned and scheduled to be removed. Renovation of the dams was not economically feasible as the dams only produced 3.4% of the energy used by Traverse City Light & Power customers (CRA 2013).

With estimated costs of $4.2 million, the deconstruction of Brown Bridge Dam and restoration of Brown Bridge Pond was intended to restore about 2.5 km of cold-water trout stream, 156 acres of wetland, and 25 acres of upland habitat (CRA 2013). The Boardman River Dams Implementation Team (IT), along with AMEC Environment and Infrastructure Inc. (AMEC), Molon Excavating, Inc. (Molon), and others began preparing for the dam's removal in July 2012. Deconstruction was completed on schedule and restoration efforts will be a continuing effort. Unfortunately, during reservoir dewatering, a much greater than anticipated discharge of water and sediment occurred with yet unknown impacts on the restoration process.

The purpose of this study was to examine the effects removing Brown Bridge Dam on the Boardman River. We did this by surveying macroinvertebrate communities upstream and downstream of Brown Bridge Pond to compare changes in macroinvertebrate community structure prior to and after dam removal. Our first field session (10 and 19 June 2011) was conducted about one month prior to a 3 m drawdown of the reservoir in preparation for its removal. Our second field season (25 May 2012) was completed just prior to deconstruction efforts began in July 2012. The third field season of this study (5 and 6 June 2013) collected macroinvertebrates following dam removal and initial restoration efforts. Sampling macroinvertebrates is the best method to assess stream quality and has been used since the early 1900s (Merrit et al. 2008). Macroinvertebrates are easily collected, relatively immobile and constantly subject to different stresses, live in diverse communities, and have a relatively long life cycle (Merrit et al. 2008). Additionally, we examined upstream and downstream temperature data to determine if dam had impacted river temperature. We expected a significant difference in temperature between an upstream and downstream site due to the dam, and this difference to lessen following the dam removal. Based on other similar macroinvertebrate analyses (Bushaw-Newton et al. 2002; Chiu et al. 2013), we expected the dam removal process could have short-term negative impacts on the river followed by a recovery of insect communities as the river stabilizes from this disturbance.

METHODS

Study Area

The Boardman River (Fig. 1) flows southwest from its headwaters in Mahan Swamp in Kalkaska County, Michigan for 64 km before turning north for 14 km and discharging into Lake Michigan's west arm of Grand Traverse Bay (Grand Traverse County, Michigan).

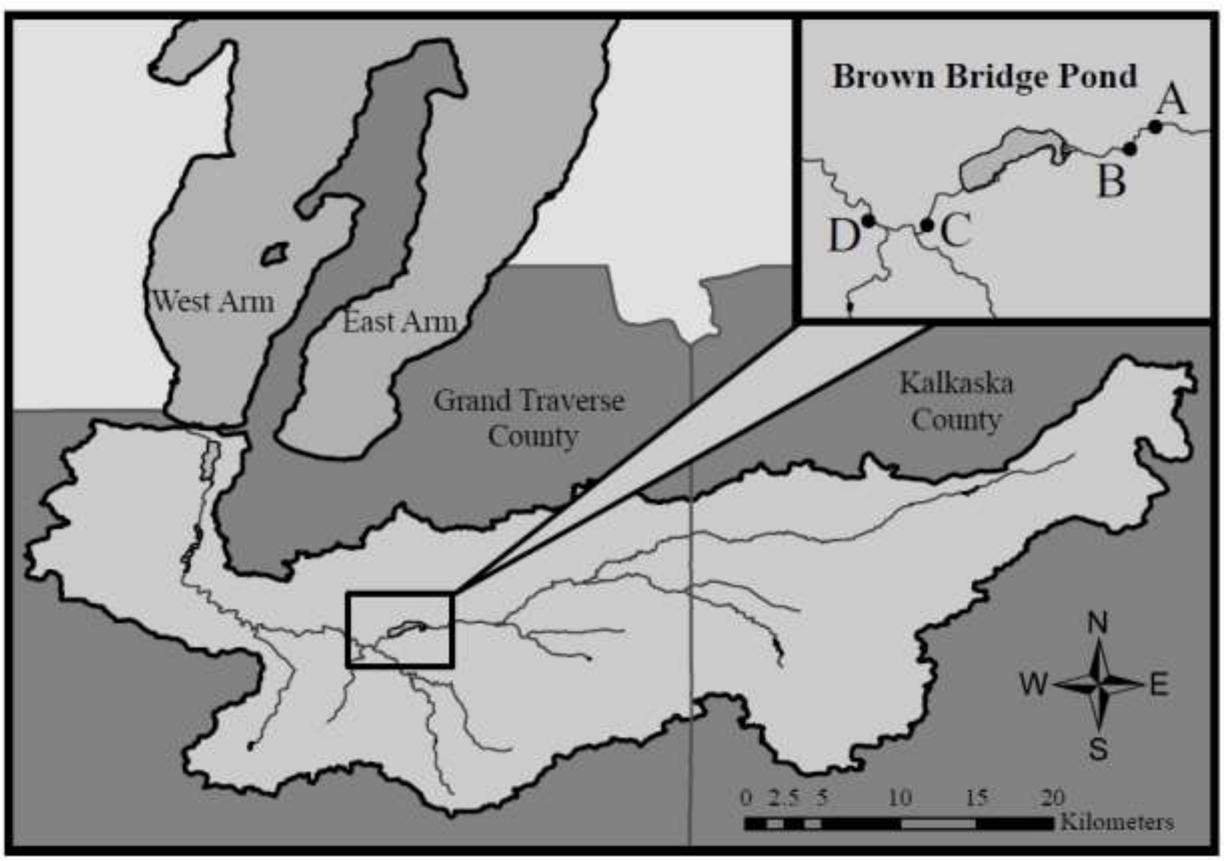

Figure 1. Map of Boardman River watershed, Kalkaska and Grand Traverse Counties, Michigan, USA. Inset of Brown Bridge Pond area. Macroinvertebrates were collected from Grasshopper Ranch Upper (A), Grasshopper Ranch Lower (B), Garfield Road Upper (C), and Garfield Road Lower (D) annually in May- June 2011- 2013 (excluding

site D in 2011). Data sources for this map include ArcGIS Online and the Michigan Center for Geographic Information.

With a predominately forested watershed of 743 km^2, the Boardman River and its tributaries flow for 258 km (CRA 2013). As a result of its coarse soils and relatively undeveloped watershed, the Boardman River is primarily fed by groundwater. Groundwater is added to a river at the mean annual temperature (~8°C in Traverse City, MI; GLISA 2012). This results in the Boardman River remaining relatively cool in the summer and warm in the winter. Due to the Boardman River's brook and brown trout populations, Michigan's Department of Natural Resources has classified 58 km as a Blue Ribbon trout stream. In addition, the Boardman River is considered one of Michigan's top ten trout fishing streams and is part of Michigan's Natural Rivers Program (MDNR 2002).

Sampling Site Selection

Starting June 2011, macroinvertebrates have been sampled from the Boardman River annually from locations (Fig. 1 inset) upstream and downstream of the reservoir (Brown Bridge Pond) created by Brown Bridge Dam to assess biotic response to dam removal and restoration efforts. Since effects of reservoirs can extend upstream (Pringle 1997), two upstream sites were chosen in Grasshopper Ranch. The first site, Grasshopper Ranch Upper (A), is located furthest upstream (4.00 km from the dam) and was chosen as a control site because it is upstream of any potential impact of the dam. The second site, Grasshopper Ranch Lower (B), is located downstream of the first site (3.17 km upstream from the dam) near Brown Bridge Pond. One site was chosen downstream of the dam to assess impact on macroinvertebrate communities. This site, Garfield Road Upper (C), is located 0.40 km downstream of the dam. For the 2012 field season, a second downstream site, Garfield Road Lower (D), was added to increase sample size and better assess impacts further downstream. This final site is located 2.36 km downstream of the dam location. Each of the four sites were sampled in June 2013.

Stream Profile

At each sample site, the channel width, average stream depth, and average surface velocity were collected. From this data, an estimation of discharge (width x depth x velocity) was calculated. Measurements for channel width were taken using a surveyor's tape and stream depth was recorded at five equidistant points across the transect (three instream points and at each bank) using a meter stick. Surface velocity was calculated by recording the time a 30 mL glass jar took to float 4.572 meters (15 ft). Three surface velocity trials were taken at three equidistant points across the transect at each site. When calculating discharge, average velocity was estimated as 0.8 times of the average surface velocity (Allan 1995).

Water Temperature

The Grand Traverse Conservation District has been monitoring water temperature upstream and downstream of Brown Bridge Dam in the Boardman River using HOBO Pendent Temperature Loggers (Model: UA-001-08; Onset Computer Corporation) since 06 May 2011 (J Rouse, unpublished data 2013; unreferenced). Data loggers are located near Grasshopper Ranch Upper (A) and near Garfield Road Lower (D) and are programmed to record water temperature (accuracy: ± 0.53°C) on an hourly basis. They are housed in homemade holds placed on the stream bottom. Temperature data from these sites were compared to assess any impact the dam and reservoir had on water temperature and changes prior to and throughout the dam removal and restoration process.

Riffle sampling

We sampled macroinvertebrate communities on 10 and 29 June 2011, 25 May 2012, 05 and 06 June 2013. We sampled each of four sites (three sites in 2011) using a Surber sampler with a 500 µm mesh and 0.09 m^2 sampling area. A stratified random sampling method was used to select six comparable riffle habitat along a transect (Norris et al. 1992). We agitated substrate within sampling area (duration 60 s) and allowed stream current to carry any macroinvertebrates downstream into the Surber sampler's collection net. The contents of each of six replicates per site were transferred to a collection jar and preserved in 70% ethanol solution. In the lab, we identified organisms to the lowest possible taxonomic level (genus in most cases; order or family for damaged organisms) using Merritt et al. (2008). Only organisms with attached heads were be enumerated to maintain consistency. The data from the six replicates per site were combined before comparing the four sites.

Data Analysis

Macroinvertebrate data were analyzed using Simpson's measure of diversity (λ) (Simpson 1949) to determine the relative dominance of taxa present at each sample site:

$$\lambda = \frac{\sum n(n-1)}{N(N-1)}$$

where *n* is the number individuals of a given taxa and *N* is the total number of individuals sampled. Values can range from 0 (no dominance or infinite diversity) to 1 (complete dominance or no diversity). The percent EPT (%EPT) was calculated for each site and a Chi-Square was used to determine the presence of a significant difference between sites. The EPT/C ratio (Klemm et al. 2003), a common index to compare water quality, compared the number of individual Ephemeroptera, Plecoptera, and Trichoptera to the number of individual Chironomidae. A Chi-Square test was used to determine if a difference between these taxa groups existed between sites. Due to differences of tolerance to different stresses within orders, each family of macroinvertebrate has been assigned a tolerance value (Bouchard 2004) between 0 (least tolerant) and 10 (most tolerant). Using the number of tolerant (tolerance value ≥ 7) individuals and the number sensitive (tolerance value ≤ 3), a Chi-Square test determined whether there is a difference in organism sensitivity between the sites. Temperature data from data loggers was analyzed using HOBOware (Onset Computer Corporation) and Microsoft Excel to plot select data.

RESULTS

Stream Profile

Abiotic data was collected on 05 and 06 June 2013 at each of four sample sites (Table 1).

	Sampling Site			
	A	B	C	D
Coordinates (°N, °W)	44.65205, 85.470433	44.64880, 85.475617	44.63801, 85.516864	44.63870, 85.528733
Channel Width (m)	16.60	12.80	23.00	18.00
Mean Depth (m)	0.422	0.478	0.292	0.371
Mean Surface Velocity (m/s)	1.066 ± 0.133	1.092 ± 0.082	1.027 ± 0.106	1.199 ± 0.111
Est. Discharge (m^3/s)	5.949	5.318	5.509	6.408

Table 1. Abiotic stream profile. Data collected 05 and 06 June 2013 from Boardman River, Grand Traverse County, MI, USA at four sites: Grasshopper Ranch Upper (A), Grasshopper Ranch Lower (B), Garfield Road Upper (C), and Garfield Road Lower (D). Channel width was measured using a surveyor's tape (n=1), average depth was measured using a meter stick at five equidistant points along a transect (n= 5), surface velocity was measured by the time a float takes to flow 4.527 m (15 ft) for three trials at three equidistant points along a transect (n= 9), and discharge was calculated as the product of width, depth, and velocity.

Grasshopper Ranch Lower (B) was the most narrow and had the deepest mean depth (12.80 m; 0.478 m, respectively) and Garfield Road Upper (C) was the widest and had the most shallow mean depth (23.00 m; 0.292 m, respectively). Garfield Road Upper (C) had the lowest mean surface velocity (1.027 ± 0.106 m/s; n= 9) and Garfield Road Lower (D) had the highest mean velocity (1.119 ± 0.111 m/s; n= 9). Discharge was lowest at Grasshopper Ranch Lower (B) and greatest at Garfield Road Lower (D) (6.675 m^3/s; 8.003 m^3/s, respectively).

Water Temperature

The Grand Traverse Conservation District has been monitoring water temperature on an hourly basis using data loggers since May 2011. Plotting the monthly mean temperature for water temperature both above the dam (near Grasshopper Ranch Upper (A)) and below the dam (near Garfield Road Lower (D)) (Fig. 2), we determined several things.

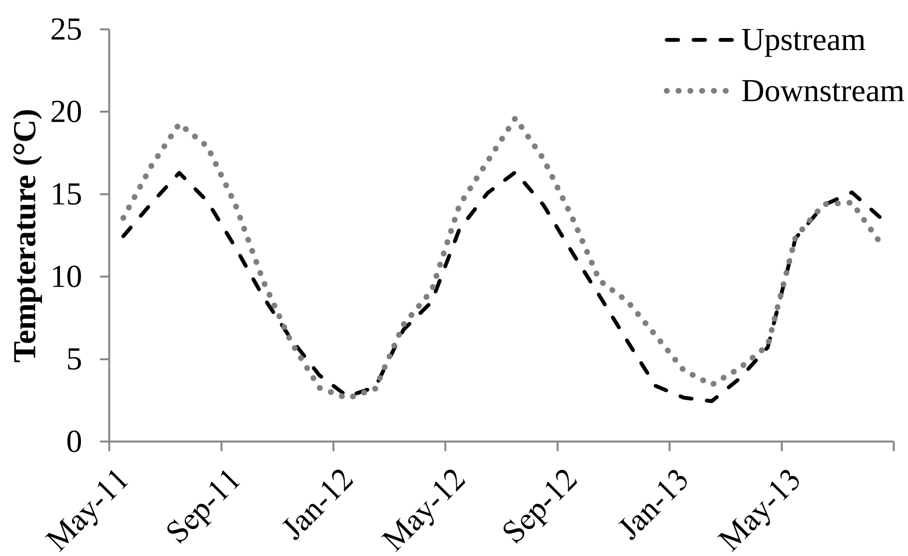

Figure 2. Monthly mean water temperature profile upstream and downstream of Brown Bridge Dam. Water temperature was recorded each hour using HOBO Pendent Temperature Loggers (Model: UA-001-08; Onset Computer Corporation) May 2011 – August 2013 at an upstream site (near Grasshopper Ranch Upper (A)) and a downstream site (near Garfield Road Lower (D)).

We determined that in summer months while the dam was still present, water temperature downstream of the dam was warmer than upstream (~3°C). Following the dam removal, however, the July 2013 temperature downstream did not display the usual peak, but rather was slightly cooler than the upstream site. In the 2011-2012 winter, the upstream site was slightly warmer than the downstream site. In the 2012-2013 winter, however, following the dam removal, the downstream temperature stayed higher than that of the upstream site.

To further examine the impact of Brown Bridge Dam on stream temperature, we compared hourly data from the two sites during one week in July, the month of greatest difference in temperature. In 2011 (Fig. 3a), the upstream temperatures oscillated regularly, while downstream temperatures varied irregularly. In 2013 (Fig. 3b), the upstream and downstream temperatures were much more similar to each other and regular daily oscillations were observed for both sites. In January, the water temperature fluctuated much more irregularly (Fig. 4).

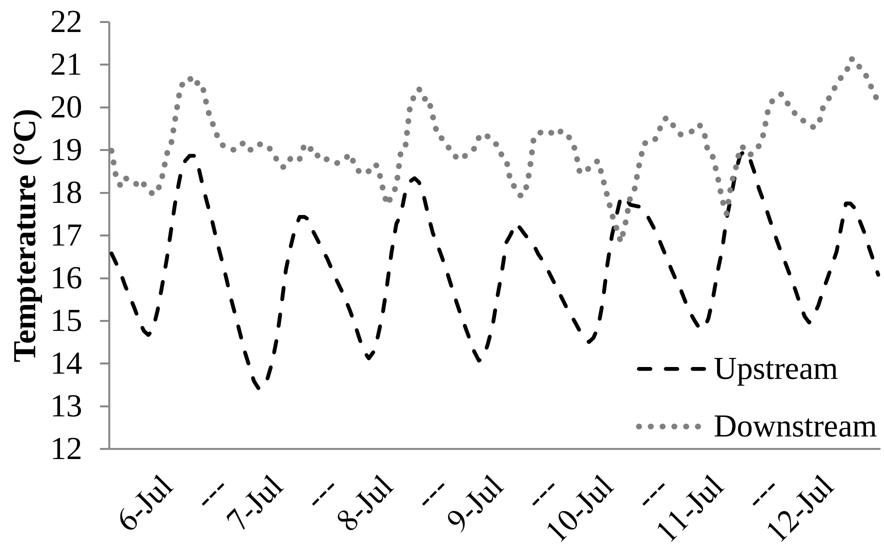

Figure 3a. Hourly water temperature during the week of 06 July 2011. Water temperature was recorded each hour using HOBO Pendent Temperature Loggers (Model: UA-001-08; Onset Computer Corporation) at an upstream site (near Grasshopper Ranch Upper (A)) and a downstream site (near Garfield Road Lower (D)).

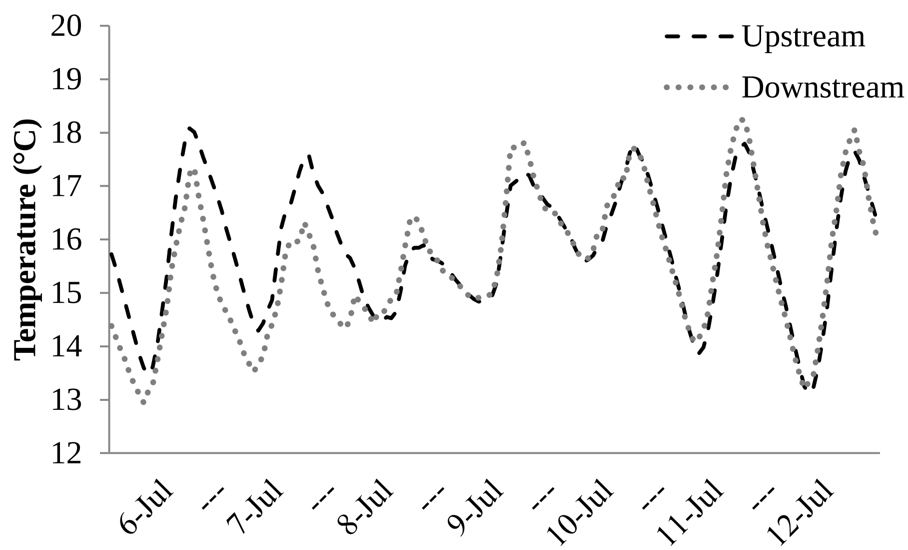

Figure 3b. Hourly water temperature during the week of 06 July 2013. Water temperature was recorded each hour using HOBO Pendent Temperature Loggers (Model: UA-001-08; Onset Computer Corporation) at an upstream site (near Grasshopper Ranch Upper (A)) and a downstream site (near Garfield Road Lower (D)).

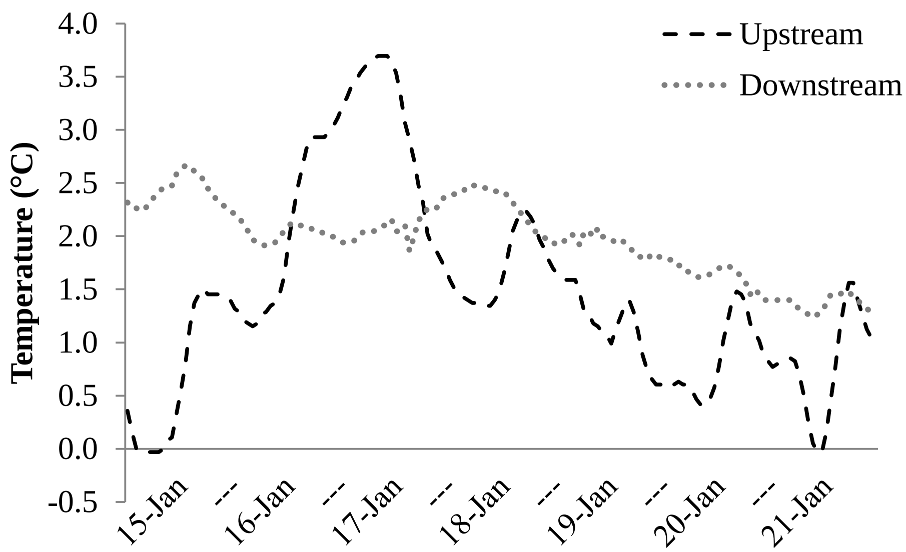

Figure 4a. Hourly water temperature during the week of 15 January 2012. Water temperature was recorded each hour using HOBO Pendent Temperature Loggers (Model: UA-001-08; Onset Computer Corporation) at an upstream site (near Grasshopper Ranch Upper (A)) and a downstream site (near Garfield Road Lower (D)).

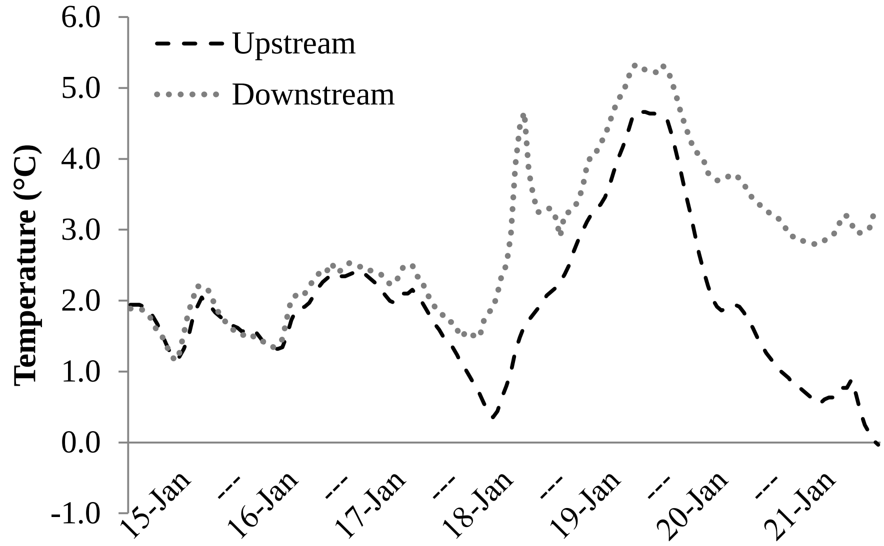

Figure 4b. Hourly water temperature during the week of 15 January 2013. Water temperature was recorded each hour using HOBO Pendent Temperature Loggers (Model: UA-001-08; Onset Computer Corporation) at an upstream site (near Grasshopper Ranch Upper (A)) and a downstream site (near Garfield Road Lower (D)).

Riffle Sampling

2011 Field Season

During the 2011 field season (10 and 19 June 2011), we collected 1320 individuals from Class: Insecta with large differences between our three sampling sites (Table 2).

	Sampling Site				
	A	**B**	**C**	**D**	**Total**
2011	301	45	974	-	**1320**
2012	245	19	252	298	**814**

2013	178	28	57	119	**382**

Table 2. Total number of Insecta. Macroinvertebrates were sampled 10 and 29 June 2011, 25 May 2012, 05 and 06 June 2013 from Boardman River, Grand Traverse County, MI, USA at four sites: Grasshopper Ranch Upper (A), Grasshopper Ranch Lower (B), Garfield Road Upper (C), and Garfield Road Lower (D). Six replicates were collected along a transect from each site using a stratified random sampling method to sample similar riffle habitats. Note: Garfield Road Lower (D) was not sampled in 2011.

Simpson's measure of diversity was lower at the two upstream sites indicting that they were more diverse (Fig. 5).

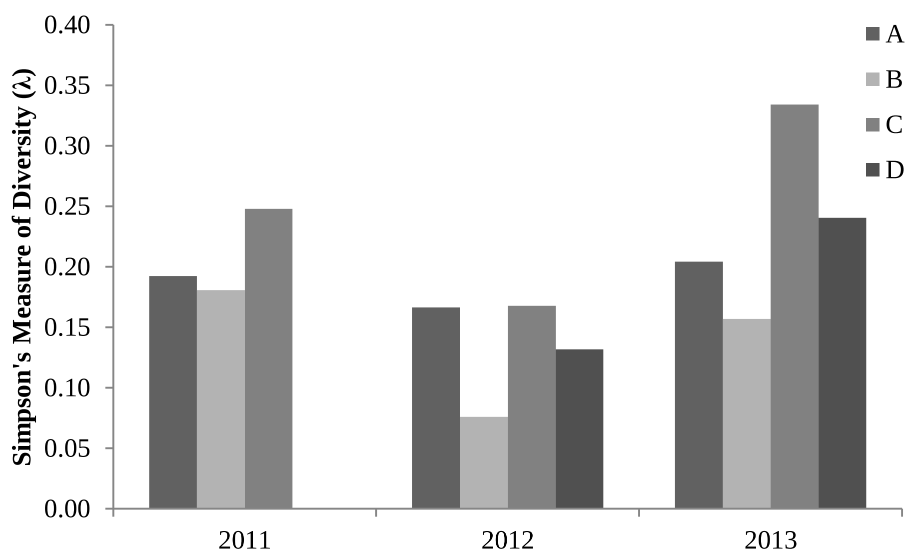

Figure 5. Simpson's measure of diversity of Insecta. Macroinvertebrates were sampled from the Boardman River, Grand Traverse County, MI, USA at four sites: Grasshopper Ranch Upper (A), Grasshopper Ranch Lower (B), Garfield Road Upper (C), and Garfield Road Lower (D). Values can range from 0 (no dominance or infinite diversity) to 1

(complete dominance or no diversity). Note: Garfield Road Lower (D) was not sampled in 2011.

Grasshopper Upper (C) had a significantly lower %EPT (Fig. 6), EPT/C ratio (Fig. 7), and sensitive/tolerant ratio (Fig. 8) than both upstream sites: Grasshopper Ranch Upper (A) ($\chi 2$ = 42.346, *d.f.* = 1, $p > 0.01$; $\chi 2$ = 21.776, *d.f.* = 1, $p > 0.01$; χ^2 = 52.856, *d.f.* = 1, $p > 0.01$ respectively); and Grasshopper Ranch Lower (B) ($\chi 2$ = 21.000 *d.f.* = 1, $p > 0.01$; $\chi 2$ = 61.864, *d.f.* = 1, $p > 0.01$, $\chi 2$ = 145.231, *d.f.* = 1, $p > 0.01$ respectively).

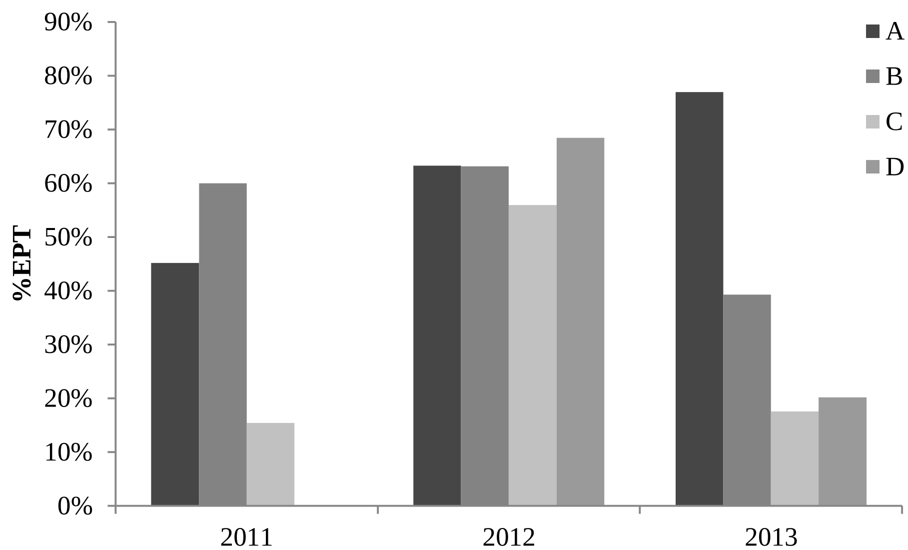

Figure 6. %EPT (Ephemeroptera, Plecoptera, and Trichoptera) of total number of Insecta. Macroinvertebrates sampled from the Boardman River, Grand Traverse County, MI, USA at four sites: Grasshopper Ranch Upper (A), Grasshopper Ranch Lower (B), Garfield Road Upper (C), and Garfield Road Lower (D). Significant difference exists between sites A and C, and B and C in 2011. In 2012 there were no significant differences, and in 2013, site A was significantly higher than sites B, C, and D, and site B was significantly higher than sites C and D.

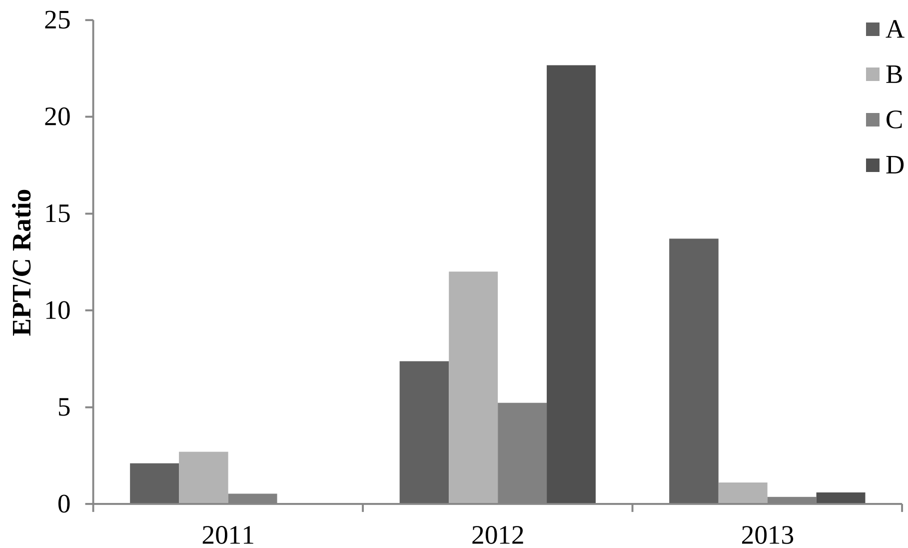

Figure 7. EPT/C Index. Comparison of number of sensitive taxa (Ephemeroptera, Plecoptera, Trichoptera) to tolerant taxa (Chironomidae). Macroinvertebrates were sampled from the Boardman River, Grand Traverse County, MI, USA at four sites: Grasshopper Ranch Upper (A), Grasshopper Ranch Lower (B), Garfield Road Upper (C), and Garfield Road Lower (D). In 2011, site C was significantly lower than sites A and B. Site D was significantly higher than sites A and C in 2012. In 2013, site A was significantly higher than each of the other three sites.

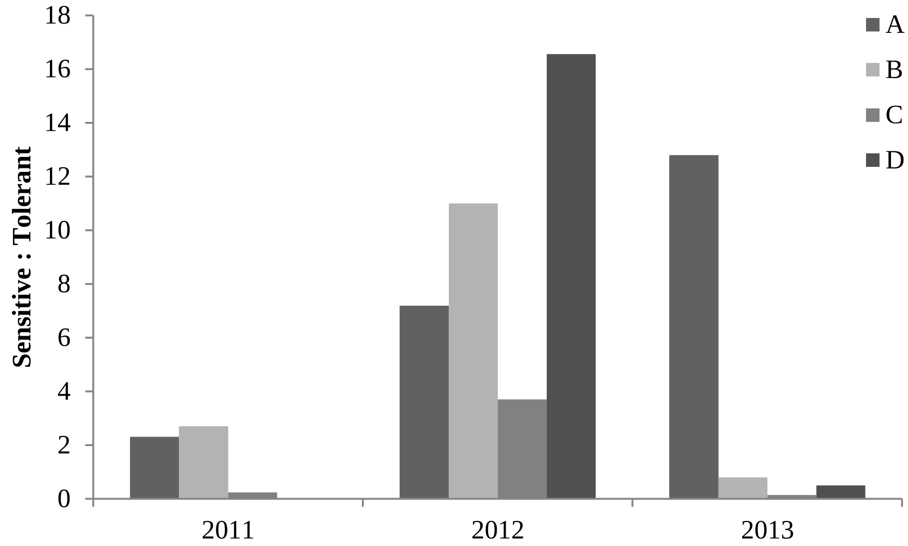

Figure 8. Ratio of sensitive to tolerant Insecta. Tolerance values are based on the family level (Bouchard 2004) and sensitive taxa have a tolerance value of ≤ 3) and tolerant taxa have a tolerance value of ≥7. Macroinvertebrates were sampled from Boardman River, Grand Traverse County, MI, USA at four sites: Grasshopper Ranch Upper (A), Grasshopper Ranch Lower (B), Garfield Road Upper (C), and Garfield Road Lower (D). In 2011, site C was significantly lower than sites A and B. Site D was significantly higher than sites A and C and site A was significantly higher than site C in 2012 . In 2013, site A was significantly higher than each of the other three sites, and site C was significantly lower than each of the other three sites.

2012 Field Season

On 25 May 2012, 814 insects were collected from four sampling locations. Grasshopper Ranch (B) had many fewer insects than the other sites (Table 2), but was also the most diverse (Fig. 5). We determined no significant differences of %EPT between any of the sites in 2012. Garfield Road Lower (D) had a significantly lower EPT/C ratio (Fig. 7) than Grasshopper Ranch

Upper (A) ($\chi 2 = 8.041$, *d.f.* = 1, $p > 0.01$) and Garfield Road Upper (C) ($\chi 2 = 15.404$, *d.f.* = 1, $p > 0.01$). Garfield Road Lower (D) had the highest sensitive/tolerant ratio (Fig. 8) and was significantly higher than both Grasshopper Ranch Upper (A) ($\chi 2 = 4.227$, *d.f.* = 1, $p = 0.04$) and Garfield Road Upper (C) ($\chi 2 = 15.453$, *d.f.* = 1, $p > 0.01$). Grasshopper Ranch Upper (A) had a significantly higher ratio than Garfield Road Lower (C) ($\chi 2 = 4.441$, *d.f.* = 1, $p = 0.04$). We noted an unusually warm spring which likely resulted in earlier hatching of insects and could explain the fewer number of individuals collected in 2012 compared to 2011.

2013 Field Season

We collected 382 total insects from the four sampling locations during the 2013 field season (05 and 06 June 2013). Both Grasshopper Ranch Lower (B) and Garfield Road Upper (C) exhibited fewer numbers than the furthest upstream and downstream sites (Table 2). Simpson's measure of diversity was higher at downstream sites which indicated less diversity downstream (Fig. 5). The upstream control site (Grasshopper Ranch Upper (A)) had a significantly higher %EPT than each of the other sites ($\chi 2 = 29.167$, *d.f.* = 1, $p > 0.01$; $\chi 2 = 70.852$ *d.f.* = 1, $p > 0.01$; $\chi 2 = 46.578$, *d.f.* = 1, $p > 0.01$, from Grasshopper Ranch Lower (B) to Garfield Road Lower (D), respectively; Fig. 6). Similarly, %EPT at Grasshopper Ranch Lower (B) was also significantly higher than both downstream sites (Garfield Road Upper (C): $\chi 2 = 11.638$, *d.f.* = 1, $p > 0.01$; Garfield Road Lower (D): $\chi 2 = 8.749$ *d.f.* = 1, $p > 0.01$). No significant difference, however, existed between the two %EPT of downstream Garfield Road sites. Grasshopper Ranch Upper (A) had a significantly higher EPT/C ratio than each of the further downstream sites ($\chi 2 = 25.427$, *d.f.* = 1, $p > 0.01$; $\chi 2 = 80.564$, *d.f.* = 1, $p > 0.01$; $\chi 2 = 76.498$, *d.f.* = 1, $p > 0.01$, respectively from Grasshopper Ranch Lower (B) to Garfield Road Lower (D)). Grasshopper

Ranch Upper (A) had a significantly higher ratio (Fig. 8) than each of the other sites (Grasshopper Ranch Lower (B): $\chi 2$ = 29.066, *d.f.* = 1, $p > 0.01$; Garfield Road Upper (C): $\chi 2$ = 94.386, *d.f.* = 1, $p > 0.01$; Garfield Road Lower (D): $\chi 2$ = 78.223, *d.f.* = 1, $p > 0.01$). Garfield Road Upper (C) had a significantly lower ratio every other site (Grasshopper Ranch (B): $\chi 2$ = 4.539, *d.f.* = 1, $p = 0.03$; Garfield Road Lower (D): $\chi 2$ = 4.393, *d.f.* = 1, $p = 0.04$).

DISCUSSION

The water temperature data gathered by the data loggers revealed a temperature regime that varied with the season. The maximum temperature difference between the upstream and downstream reach prior to the removal of Brown Bridge Dam occurred in July with the downstream temperature ~3°C warmer due to solar radiation warming the water in Brown Bridge Pond. The relative temperature switched during the winter months, with the upstream reach ~0.5°C warmer than the downstream reach do to the cooling of the reservoir. As we hypothesized, the removal of the dam in October 2012 has resulted in cooler temperatures, more regular diel fluctuations and similar temperature regimes between the upstream and downstream sites. River sections with a high gradient, such as the Brown Bridge Pond section of the Boardman River, often have high groundwater inputs. Brown Bridge Pond may have muted the effects of this input of groundwater and the removal of Brown Bridge Pond was likely the cause of the cooler temperatures we observed downstream of the dam site in the late summer and fall of 2013 (Fig. 2).

The 2011 field season gave us baseline macroinvertebrate insect data to compare future seasons. From this baseline season, we determined there to be higher diversity at upstream sites than downstream site (Fig. 5). Similarly, the %EPT, EPT/C ratio, and ratio of sensitive to tolerant insects were all significantly higher ($p < 0.01$) at the upstream sites (Fig. 6-Fig. 8). Dams often cause the immediate downstream reach to have an increased overall abundance while showing a decrease in species richness due to alterations in the physical and chemical environment (Allan 1995). From the demonstrated differences, we concluded Brown Bridge Dam had a substantial negative impact on insect communities below the dam.

Following the drawdown of Brown Bridge Pond in 2011, we noted a notable change in insect communities in 2012. While Grasshopper Ranch Lower (B) had the fewest number of individuals (Table 2), it was the most diverse site (Fig. 5). We determined there to be no significant difference in %EPT (Fig. 6) between any of the sites. The furthest downstream site, Garfield Road Lower (D), produced large numbers of Ephemeroptera and Trichoptera and few Chironomidae which resulted in a very high EPT/C ratio (Fig. 7) and sensitive/tolerant ratio (Fig. 8), both significantly higher than Grasshopper Ranch Upper (A) and Garfield Road Upper (C). The sensitive/tolerant ratio of Grasshopper Ranch Upper (A) was also significantly higher than Garfield Road Upper (C). We concluded that the drawdown of Brown Bridge Pond created a more homogeneous habitat for insects among the sites. In some metrics, sites downstream from the dam actually displayed better water quality than upstream sites. This may be due to the increased organic material and nutrients that moved downstream from the reservoir as well as more regular flow regimes.

The structural removal of Brown Bridge Dam had a significant impact on the insect communities we sampled in 2013. Many fewer individuals were collected than previous years and there was a large decrease in diversity at Garfield Road Upper (C) relative to the other sites, most likely due to its proximity to the dam removal location. The %EPT, EPT/C ratio, and sensitive/tolerant ratio all indicate much higher water quality at Grasshopper Ranch Upper (A) than all other sites (Fig. 6 – Fig. 8). This downstream reduction in riffle macroinvertebrates is likely due to significant channel downcutting at Grasshopper Ranch Lower and the major influx of sediment deposited downstream, both resulting from dewatering the reservoir.

Consistent with previous research, we observed downcutting of an unstable streambed upstream of the dam removal site (Burroughs et al. 2009) at Grasshopper Ranch Lower (B). At the two downstream sites from the dam, we observed much more fine sediment and sand, both in the channel and along the banks, than previous years. As a result of the large amount of silt and sand, we had to move the Garfield Road Upper (C) site 300 m downstream in order to find adequate riffle habitat. The furthest downstream site (Garfield Road Lower (D)) also had increased sand and silt and underwater sand dunes were seen migrating downstream while sampling.

This decreased water quality downstream was expected following a dam removal, however, is consistent with previous studies (Hart et al. 2002). As restoration efforts continue, sediment settles, and the stream bottom stabilizes, we expect insect communities to recover and return to a similar condition as the upstream control site (Grasshopper Ranch Upper (A)) in years to follow. We recommend the continued monitoring of the Boardman River upstream and downstream of the Brown Bridge Dam site to determine the recovery period for macroinvertebrate communities and other long-term impacts of the dam removal.

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Appendix 1. Macroinvertebrates from Class Insecta collected from Grasshopper Ranch Upper (A), Grasshopper Ranch Lower (B), and Garfield Road Upper (C) along the Boardman River, Grand Traverse County, Michigan, USA on 10 and 19 June 2011. Total number of individuals: 1320.

			Sampling Site		
Order	**Family**	**Genus**	**A**	**B**	**C**
Coleoptera	Elmidae	*Optioservus sp.*	57	6	205
	Unknown	Unknown sp.	1	0	0
Diptera	Athericidae	*Atherix sp.*	17	0	5
	Chironomidae	Unknown sp.	65	10	287
	Empididae	*Chelifera sp.*	13	0	0
	Simuliidae	*Simulium sp.*	9	1	286
		Unknown sp.	0	0	37
	Tipulidae	*Antocha sp.*	0	0	2
	Unknown	Unknown sp.	1	0	0
Ephemeroptera	Baetidae	*Baetis sp.*	3	0	36
	Ephemerellidae	*Drunella sp.*	30	1	3
		Ephemerella sp.	92	14	3
		Eurylophella sp.	0	1	2
	Heptageniidae	*Heptagenia sp.*	0	0	10
	Leptohyphidae	Unknown sp.	5	0	0
Odonata	Gomphidae	*Erpetogomphus sp.*	2	0	1
	Unknown	Unknown sp.	0	0	1
Plecoptera	Perlodidae	*Isoperla sp.*	2	1	0
Trichoptera	Apataniidae	*Apatania sp.*	0	0	18
	Brachycentridae	*Brachycentrus sp.*	0	5	4
		Micrasema sp.	2	5	5
	Helicopsychidae	*Helicopsyche sp.*	0	0	10
	Hydropsychidae	*Hydropsyche sp.*	2	0	28
		Unknown sp.	0	0	2
	Lepidostomatidae	*Lepidostoma sp.*	0	0	1
		Unknown sp.	0	0	3
	Leptoceridae	*Ceraclea sp.*	0	0	13
	Philopotamidae	*Chimarra sp.*	0	0	10
		Unknown sp.	0	0	1
	Polycentropodidae	Unknown sp.	0	0	1
Unknown	Unknown	Unknown sp.	0	1	0

Appendix 2. Macroinvertebrates from Class Insecta collected from Grasshopper Ranch Upper (A), Grasshopper Ranch Lower (B), Garfield Road Upper (C), and Garfield Road Lower (D) along the Boardman River, Grand Traverse County, Michigan, USA on 25 May 2012. Total number of individuals: 814.

			Sampling Site			
Order	**Family**	**Genus**	**A**	**B**	**C**	**D**
Coleoptera	Elmidae	*Optioservus sp.*	41	2	80	63
Diptera	Athericidae	*Atherix sp.*	8	1	2	6
	Ceratopogonidae	*Probezzia sp.*	0	1	0	0
	Chironomidae	Unknown sp.	21	1	27	9
	Dolichopodidae	Unknown sp.	0	0	0	1
	Empididae	*Chelifera sp.*	6	1	0	0
		Hemerdromia sp.	7	0	0	11
	Simuliidae	*Simulium sp.*	3	1	0	0
	Tipulidae	*Antocha sp.*	2	0	1	3
		Tipula sp.	1	0	0	0
Ephemeroptera	Baetidae	*Baetis sp.*	13	1	10	2
		Paracloeodes sp.	1	0	0	0
	Ephemerellidae	*Drunella sp.*	69	4	20	50
		Ephemerella sp.	53	3	6	26
		Serratella sp.	6	0	42	14
	Heptageniidae	*Heptagenia sp.*	1	1	1	0
		Maccaffertium sp.	0	0	0	4
Odonata	Gomphidae	*Erpetogomphus sp.*	1	0	0	0
		Ophiogomphus sp.	0	0	0	1
Trichoptera	Brachycentridae	*Brachycentrus sp.*	3	0	3	5
		Micrasema sp.	6	3	6	33
	Glossosomatidae	*Glossosoma sp.*	2	0	2	0
		Protoptila sp.	0	0	1	0
	Helicopsychidae	*Helicopsyche sp.*	0	0	14	10
	Hydropsychidae	*Hydropsyche sp.*	0	0	33	56
	Leptoceridae	*Ceraclea sp.*	0	0	0	1
		Oecetis sp.	0	0	0	2
	Philopotamidae	*Chimarra sp.*	0	0	3	1
	Unknown	Unknown sp.	1	0	0	0
Unknown	Unknown	Unknown sp.	0	0	1	0

Appendix 3. Macroinvertebrates from Class Insecta collected from Grasshopper Ranch Upper (A), Grasshopper Ranch Lower (B), Garfield Road Upper (C), and Garfield Road Lower (D) along the Boardman River, Grand Traverse County, Michigan, USA on 05 and 06 June 2013. Total number of individuals: 382.

			Sampling Site			
Order	**Family**	**Genus**	**A**	**B**	**C**	**D**
Coleoptera	Curculionidae	*Stenopelmus sp.*	0	1	0	1
	Elmidae	*Optioservus sp.*	27	2	2	41
Diptera	Athericidae	*Atherix sp.*	4	0	1	2
	Ceratopogonidae	*Probezzia sp.*	0	2	0	3
	Chironomidae	Unknown sp.	10	10	27	40
	Empididae	*Chelifera sp.*	0	1	0	0
		Hemerdromia sp.	0	1	0	5
	Simuliidae	*Simulium sp.*	0	0	13	3
	Tabanidae	Unknown sp.	0	0	1	0
	Unknown	Unknown sp.	0	0	3	0
Ephemeroptera	Baetidae	*Baetis sp.*	5	0	5	7
		Paracloeodes sp.	2	0	0	0
	Ephemerellidae	*Attenella sp.*	1	0	0	0
		Drunella sp.	47	1	0	6
		Ephemerella sp.	56	0	0	3
		Serratella sp.	3	0	0	0
		Unknown sp.	0	0	0	1
	Heptageniidae	*Heptagenia sp.*	1	1	0	0
		Rhithrogena sp.	1	0	0	0
	Unknown	Unknown sp.	3	1	2	0
Trichoptera	Brachycentridae	*Brachycentrus sp.*	7	2	0	1
		Micrasema sp.	5	1	0	1
		Unknown sp.	1	0	0	0
	Helicopsychidae	*Helicopsyche sp.*	0	0	0	3
	Hydropsychidae	*Hydropsyche sp.*	1	0	0	0
	Lepidostomatidae	*Lepidostoma sp.*	4	3	3	2
	Molannidae	*Molanna sp.*	0	1	0	0
	Unknown	Unknown sp.	0	1	0	0