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# Effects of Reservoir Drawdown on Riffle Macroinvertebrate Communities

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**ABSTRACT** In 2007 Keystone Pond, a reservoir behind the Boardman dam, Boardman River, Grand Traverse County, Michigan, USA was drawn down in preparation for dam removal. The objective of this study was to quantify the effects of drawdown on benthic macroinvertebrate riffle communities by comparing a downstream site in a newly formed channel to an upstream control. Since 2008 a total of 2338 macroinvertebrates have been sampled and identified to the lowest practical taxonomic level. Data were analyzed using Chi-Square goodness of fit tests, Simpson's Index of diversity, and Sørensens' Quotient of Similarity. We found that macroinvertebrate communities in the new channel have recovered to a more natural condition and show increasing similarity to the upstream control site

**KEY WORDS**: biodiversity, dam removal, drawdown, EPTC, Keystone Pond, macroinvertebrate indicators, Michigan

## INTRODUCTION

Since the latter half of the 20th century, dam construction worldwide has increased at an unprecedented rate to meet the water and electrical needs of a rapidly growing world population (Gregory, et al. 2002; Stanley and Doyle 2003; Hansen and Hayes 2012). At the end of World War II approximately 5000 dams over 15 m tall existed, but by 2000 >45,000 dams existed. (Stanley and Doyle 2003). In the last sixteen years increases in global water shortages, advances in alternative energy, and concerns about environmental degradation have prompted the removal of old, outdated dams worldwide. In the United States (US) alone more than 700 dams have been removed during this time period (Hansen and Hayes 2012).

In the US when a dam reaches the end of its life expectancy (40-50 years), it must either be brought up to code and re-licensed by the Federal Energy Regulatory Commission or removed from the river (CRA 2013). Further exacerbating updating and re-licensure issues are the sheer number of dams that will soon be out of date. By 2020, 80% of documented dams in the US will reach the end of their life expectancy and will have to be removed or updated (Bednarek, 2001; Hansen and Hayes 2012). Often the costs of updating and re-licensing dams far outweigh any economic benefit, prompting the removal of many dams throughout the country (Stanley and Doyle 2003). In the US alone >700 dams have been removed and many more are slated for removal (Hanson and Hayes 2012).

Dams as artificial barriers substantially alter stream geomorphology, change hydrological regimes, reduce nutrient flow, disrupt natural sediment deposition, and inhibit native fish spawning (Bushaw-Newton et al. 2002, Gregory et al. 2002, Stanley et al. 2002, Stanley and Doyle 2003). Though much is known about the detrimental environmental effects of dams, few have studied the effects of dam removals on stream ecosystems (Bushaw-Newton et al. 2002, Stanley et al. 2002, Palmer et al. 2005, Hansen and Hayes 2012). Potential negative effects of dam removal include increased downstream sediment deposition, declines in lentic fish and macroinvertebrate populations, and erosion of natural stream habitats. Potential benefits of removal are stabilized flow regimes, healthier riffle assemblage structures, and increased habitat recovery (Bushaw-Newton et al. 2002, Moutka et al. 2002, Hansen and Hayes 2012).

The goal of our study was to quantify the recovery process of a newly emerged stream channel following reservoir drawdown by assessing benthic macroinvertebrate communities. Benthic macroinvertebrates provide a very effective way of gauging water quality due to their ubiquitous presence, sedentary nature, and rapid response to environmental changes (Merritt et al. 2008). Also, because of their relatively long life cycles macroinvertebrates can serve as accurate indicators of changes in water quality over time. (Merritt and Cummins 2008)

Boardman Dam (N44° 41’ 53.53”, W85° 37’ 14.85”) was constructed on the Boardman River 1894 by Queen City Light and Power and rebuilt in 1930 after the original Keystone Dam washed out (CRA 2013). The dam is one of three remaining hydroelectric dams on the Boardman River that provided power for Grand Traverse County. In 2005 Traverse City Light and Power decommissioned the dams due to their aging infrastructure and inability to meet the county's electricity needs (CRA 2013). The furthest upstream dam, Brown Bridge Dam, was removed in fall 2012 as part of the Boardman River restoration project, the largest dam removal project in

Michigan (CRA 2013). Removal for Boardman Dam is scheduled for 2014.

In preparation for the removal of Boardman Dam, the Keystone Reservoir was lowered 5.8 meters in 2007 (CRA 2013). After drawdown the reservoir filled in with vegetation and the upstream river formed a new stream channel exhibiting normal stream flow and subsequent down-cutting. Macroinvertebrate response to large disturbances indicates that downstream communities tend to recover slowly to resemble healthier upstream communities (Maloney 2008). We hypothesize that the drawdown of Keystone Pond will increase macroinvertebrate community similarity between an upstream control site and the newly formed test site as the river recovers to a more natural condition. Based on this hypothesis we expect ratios of sensitive (Ephemeroptera, Plecoptera, Trichoptera) to tolerant (Coleoptera and Diptera) macroinvertebrate species and macroinvertebrate similarity indices to show a trend of increasing similarity for 2008-2013. To test this hypothesis we sampled two macroinvertebrate assemblages, one upstream of the Boardman dam and one downstream in the new channel, and analyzed our results with five years of previous data. By examining changes in macroinvertebrate community composition at both sites for 2008-2013 we can observe what effect reservoir drawdown has on macroinvertebrate communities.

## MATERIAL AND METHODS

### Study Area

The Boardman River originates in Mahan Swamp (Kalkaska, Michigan), flows southwest for 64.4 km into Grand Traverse County, and turns north for another 14.5 km to empty into the west arm of Grand Traverse Bay of Lake Michigan (Grand Traverse County, Michigan; Fig. 1). A 5$^{th}$ order river, the Boardman is composed of 258 km of river and tributary streams that drain a 743

$km^2$ watershed. The stream as a whole has been rated a top ten trout fishing streams in Michigan because of its excellent water quality and >58 km have been classified as a Blue Ribbon trout stream (MIDNR 2013).

On 7 June 2013 we sampled two riffle sites upstream of Traverse City, Michigan, USA: Shumsky (N44° 39' 2.09", W85° 35' 26.82") and Lone Pine (N44° 41' 7.02", W 85° 37' 35.71"). The Shumsky site, which served as our control site, was located 11.12 km upstream from Boardman Dam in a wide section of the river, and our experimental site, Lone Pine site was located 2.10 km upstream from the dam in the newly formed channel created by the drawdown of the Keystone Pond in 2007.

**Sampling and Identification Methods**

At each site we took six replicate samples in riffle habitats along a straight transect bisecting the stream channel. We chose to sample macroinvertebrates only in cobble and gravel riffle habitats free of macrophytes and debris to reduce the amount of site-site variation due to macroinvertebrate habitat preferences (Downes et al. 1998). To sample each site we used a three-pronged agitator and a 500µm Surber Sampler to collect macroinvertebrates for one minute. Contents of each sample were preserved in 70% ethanol and transferred to the lab for identification. We keyed macroinvertebrates down to the lowest practical taxonomic levels, typically genus for insects, using macroinvertebrate keys from Merritt et al. (2008) and Pennak (1978). All specimens were also assigned a pollution tolerance value (1-10) as described by Bouchard (2004), Connecticut Department of Environmental Protection (2012), West Virginia Save Our Streams (2012), and Digital Key to Aquatic Insects of North Dakota (2013). Damaged specimens were only keyed if they possessed a head.

In addition to sampling macroinvertebrate communities we also measured river metrics and abiotic factors at each site including transect width (m), replicate depth (m), maximum surface velocity (m/s), air temperature (C°), and water temperature (C°) to gain a better understanding of different factors affecting macroinvertebrate community composition (Heino et al. 2004). Temperature readings were taken using a YSI Professional ODO Instrument™ and maximum surface velocity was measured by floating a small glass vial (30 ml, 3.5 cm x 7 cm) 10 m downstream and recording travel time. River width and depth were measured using surveyor's tape and a meter rod.

**Statistical Analysis**

Previous samplings for macroinvertebrate communities at the Shumsky and Lone Pine sites were collected annually in June since 2008 using similar techniques and identification methods (Louwsma and Mahan 2008, Sather and Mahan 2010, Petry and Mahan, 2012), and during the 2012 season all 2008-2011 macroinvertebrates were reclassified to the morphospecies level to maintain data consistency (Petry and Mahan 2012).

EPT/C is a common stream quality metric that compares the number of pollution sensitive Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) to pollution tolerant Chironmidaes (midges) to calculate a stream quality index for a river. A higher EPTC ratio indicates better water and habitat quality and a lower EPTC ratio indicates lower stream quality and health (Resh and Unzicker 1975; Klemm et al. 2003). To account for non-EPTC macroinvertebrate families we also assigned each family a pollution tolerance number based on known tolerance values with 1-3 indicating sensitive and 8-10 indicating tolerant (Merritt and Cummins 2008). By comparing macroinvertebrates communities at multiple sites over several years one can construct an approximate representation of the Boardman River's health throughout time (Hansen and Hayes 2012). We ran goodness of fit Chi-Square tests ($\alpha$ = 0.05), assuming independence, normal distribution, and equal variance, on EPT/C and Sensitive/Tolerant ratios for both Shumsky and Lone Pine data sets comparing 2008-2013 seasons. We also calculated Simpson's Index of Diversity (Simpson 1949), and Sørensen's Quotient of Similarity (Sørensen 1948) to compare relative abundance, percent similarity, and organism overlap for both Shumsky and Lone Pine over the 2008-2013 seasons.

**RESULTS**

We collected abiotic measurements at both the Shumsky and Lone Pine sites on 7 June 2013 to gain a more comprehensive picture of factors effecting macroinvertebrate community compositions (Table 1). Water temperature for both sites was similar (Shumsky, 15.9 °C; Lone Pine, 14.8 °C), but river width and current differed substantially between sites (Shumsky 16.2 m, 0.83 m/s; Lone Pine 20.7 m, 0.94 m/s). Discharge at Shumsky was slightly higher than Lone Pine (Shumsky 9.30 $m^3/s$; Lone Pine 7.66 $m^3/s$).

On 7 June 2013 we collected 230 macroinvertebrates at Shumsky ($N = 182$) and Lone Pine ($N$ = 48) sites (Appendices 1-2). Both sites exhibited high macroinvertebrate diversity levels ($D$ = 0.92; $D$ = 0.93) and high similarity ($QS$ = 0.52), (Fig. 2-3). EPT/C ratio and %EPT did not differ significantly between sites ($\chi^2_1 = 0.04$, $P = 0.84$; $\chi^2_1 = 0.92$, $P = 0.34$), (Table 2, Fig. 4). Ratio and percentage of sensitive to tolerant families for both sites did not differ significantly between sites ($\chi^2_1 = 1.62$, P = 0.20; $\chi^2_1 = 2.24$, $P = 0.13$), (Table 3, Fig. 5). Elmidae (26.4%) and Chironomidae (18.7%) were the most abundant families at Shumsky, and Chironomidae (29.2%) and Simulidae (29%) were the most abundant families at Lone Pine (Appendix 1). We found a total of 19 macroinvertebrates not in Class Insecta, of which 17 were sensitive species (Appendix 2).

**DISCUSSION**

Our results indicate that drawdown of Keystone Pond in 2007 and the subsequent formation of the new channel has resulted in increased similarity between macroinvertebrate communities at Shumsky and Lone Pine sites.

We found that EPT/C composition was not significantly lower for either site than in previous years and was very similar between sites for 2013 (Fig. 4). Percent comparisons of sensitive to tolerant species for 2008-2013 also failed to indicate any significant difference between macroinvertebrate community composition for 2012-2013 suggesting that Shumsky and Lone Pine macroinvertebrate communities are becoming more similar over time (Fig. 5). These findings are consistent with previous studies showing that downstream macroinvertebrate communities can show substantial recovery within a year after dam removal (Stanley et al. 2002, Hansen and Hayes 2012).

Our results show macroinvertebrate communities in the new stream channel are becoming more stable over time, with Lone Pine showing increased similarity to Shumsky macroinvertebrate over the last six years ($QS$ > 50%; Fig. 3). EPT/C and %EPT also show increasing similarity over time with 2008 representing the year of lowest similarity and 2013 the year of highest similarity (Table 2). Macroinvertebrate communities at both sites also exhibited high diversity levels, ($D \geq 70\%$) indicating that recovery of the new channel is ongoing (Fig. 2).

We found that the most abundant and consistent macroinvertebrate families at Shumsky have been indicators of medium to high water quality, (Brachycentridae, Elmidae, and

Heliopsychidae) whereas the most abundant family found at Lone Pine has been an indicator of poor to moderate water quality (Chironomidae), suggesting that recovery is still ongoing (Merritt et al. 2008). Some Chironomidae, however, are more pollution tolerant than others suggesting the need for additional genera identification at both sample sites (Resh and Unzicker 1975). Indicator species, when taking into account variability within Chrionomidae, show marked signs of recovery since the 2007 drawdown. Further analysis is needed to see if this trend continues when the Boardman Dam is removed.

Our results support our alternative hypothesis that the drawdown of Keystone Pond would increase macroinvertebrate community similarity between an upstream control site and a test site in the newly formed channel. Macroinvertebrates at both sites have continued to grow in similarity over the six year sampling period indicating that the stream channel is gradually returning to a more natural and stable condition. Many macroinvertebrates are long-lived and may take several years (>7) to fully recover from a large disturbance, necessitating the need for longer term studies (Hansen and Hayes 2012). We recommend that this study be continued in future years to obtain a more holistic picture of how downstream macroinvertebrate communities respond to reservoir drawdown.

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**Table 1.** Abiotic stream measurements taken 7 June, 2013 at Shumsky and Lone Pine sites, Boardman River, Grand Traverse County, Michigan, USA.

| **Measurement** | **Shumsky** | **Lone Pine** |
|---|---|---|
| Mean Depth (m) | 0.41 | 0.37 |
| Transect Width (m) | 20.9 | 16.2 |
| Water Temperature (°C) | 15.9 | 14.8 |
| Mean Surface Velocity (m/s) | 1.1 | 1.3 |
| Discharge ($m^3$/sec) | 9.3 | 7.7 |

**Table 2.** EPTC ratio and %EPT for macroinvertebrates collected 2008-2013 from Shumsky (SH) and Lone Pine (LP) sites, Boardman River, Grand Traverse County, Michigan, USA.

| | **2008** | | **2009** | | **2010** | | **2011** | | **2012** | | **2013** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measurement** | **SH** | **LP** | **SH** | **LP** | **SH** | **LP** | **SH** | **LP** | **SH** | **LP** | **SH** | **LP** |
| *N* | 401 | 16 | 32 | 40 | 110 | 368 | 98 | 90 | 121 | 22 | 87 | 29 |
| EPT/C | 4.08 | 0.33 | 3.57 | 2.33 | 1.34 | 0.90 | 8.80 | 0.88 | 7.64 | 3.40 | 1.56 | 1.07 |
| %EPT | 58.44 | 20.00 | 29.76 | 62.22 | 23.60 | 42.03 | 34.63 | 41.18 | 31.47 | 62.96 | 29.12 | 31.25 |

**Table 3.** Sensitive (S)/Tolerant (T) and %Sensitive for macroinvertebrates collected 2008-2013 from Shumsky (SH) and Lone Pine (LP) sites, Boardman River, Grand Traverse County Michigan, USA.

| | **2008** | | **2009** | | **2010** | | **2011** | | **2012** | | **2013** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measurement** | **SH** | **LP** | **SH** | **LP** | **SH** | **LP** | **SH** | **LP** | **SH** | **LP** | **SH** | **LP** |
| *N* | 452 | 17 | 24 | 34 | 105 | 255 | 96 | 77 | 167 | 21 | 104 | 24 |
| S/T | 2.56 | 0.31 | 1.40 | 1.27 | 1.10 | 0.29 | 7.00 | 0.60 | 3.51 | 3.20 | 1.08 | 0.60 |
| %Sensitive | 58.98 | 20.00 | 16.67 | 42.22 | 20.60 | 14.01 | 32.68 | 28.43 | 38.24 | 59.26 | 30.22 | 22.92 |

**FIGURES LEGEND**

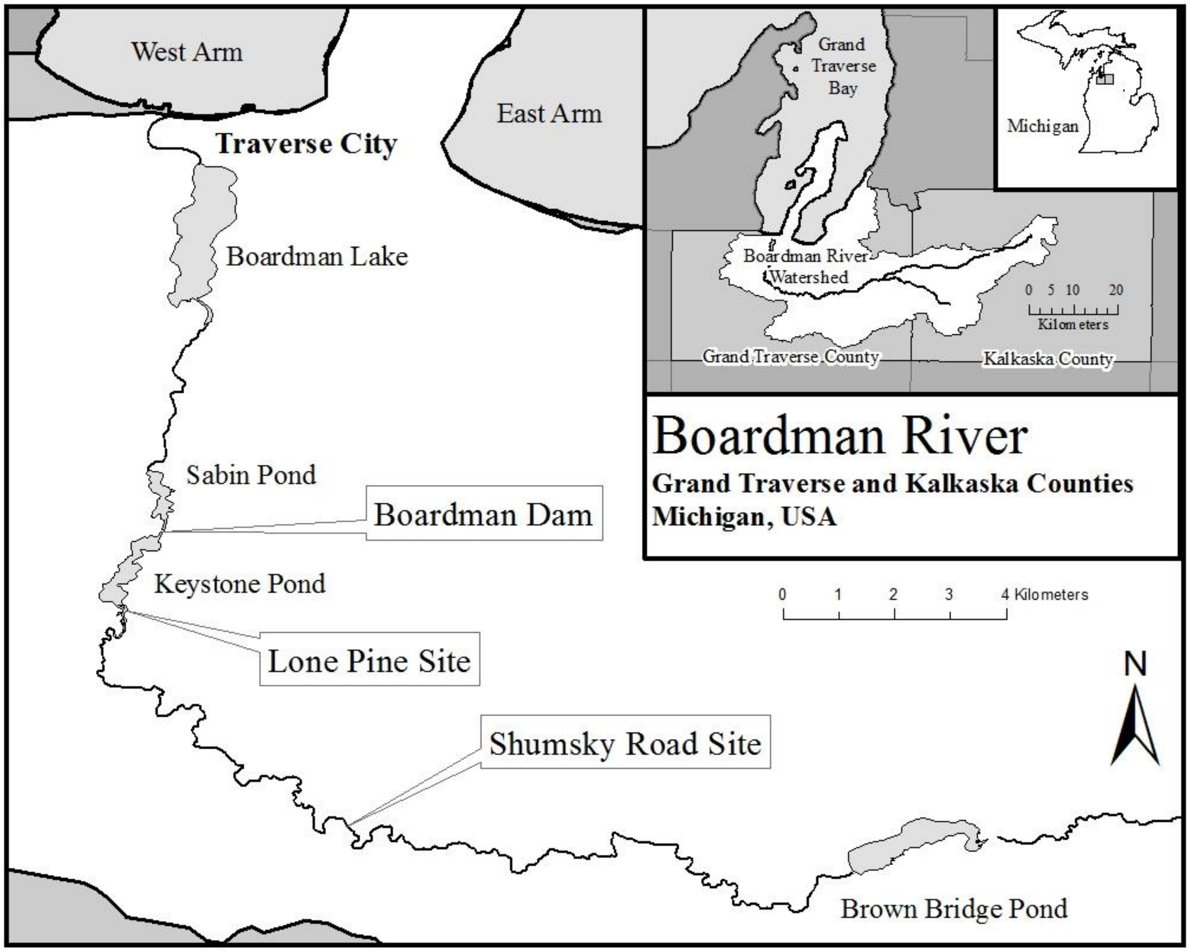
Figure 1. Map of Boardman River, Grand Traverse and Kalkaska Counties, Michigan, USA. Macroinvertebrates collected from Shumsky and Lone Pine sites annually June of 2008-2013. Source: Petry and Mahan, 2012.

Figure 2. Simpson's Index of Dominance comparison for Boardman River macroinvertebrate assemblages 2008-2013 at Shumsky Road and Lone Pine sites, Boardman River, Grand Traverse County Michigan, USA. Index is based on a scale of 0 to 1 with 0 indicating no dominance and 1 indicating complete dominance.

Figure 3. Sørensen's Quotient of Similarity for 2008-2013 Macroinvertebrate communities at Shumsky and Lone Pine sites Boardman River, Grand Traverse County, Michigan, USA. Percentages >50% indicate similarity.

Figure 4. EPT/C Richness for 2008-2013 macroinvertebrate communities at Shumsky and Lone Pine sites, Boardman River, Grand Traverse County, Michigan, USA.

Figure 5. Sensitive and Tolerant macroinvertebrates collected 2008-2013 from Shumsky and Lone Pine sites, Boardman River, Grand Traverse County, Michigan, USA. All individuals were assigned a tolerance value between 1-10 with 8-10 indicating tolerant and 1-3 indicating sensitive.


West Arm
East Arm
Traverse City
Boardman Lake
Sabin Pond
Boardman Dam
Keystone Pond
Lone Pine Site
Shumsky Road Site
Brown Bridge Pond
Grand Traverse Bay
Michigan
Boardman River Watershed
0 5 10 20
Kilometers
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Kalkaska County
Boardman River
Grand Traverse and Kalkaska Counties
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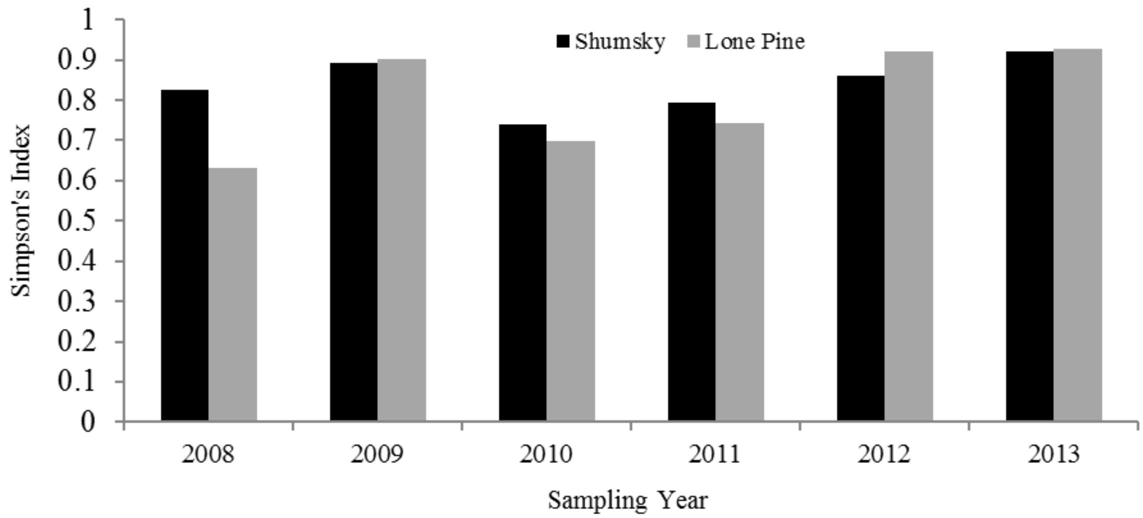
1
0.9
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Simpson's Index
Shumsky
Lone Pine
2008
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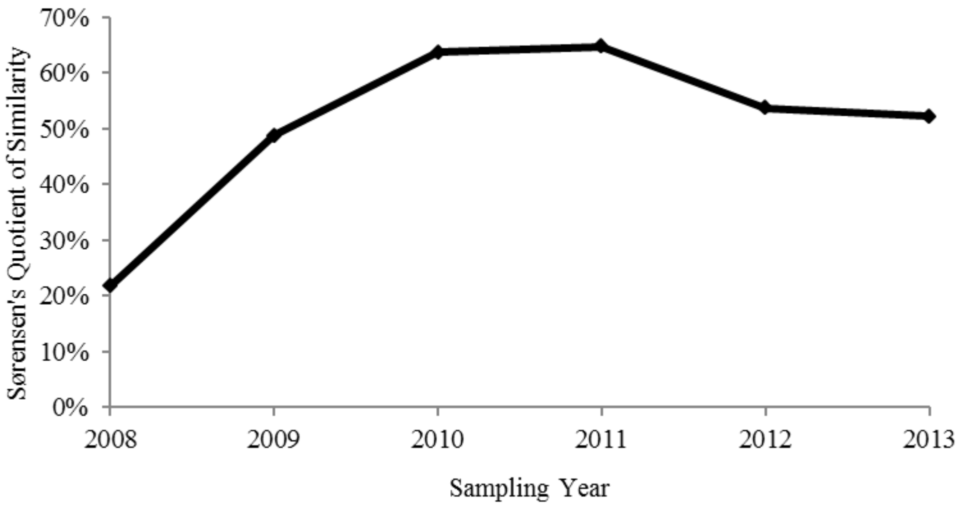
Sampling Year


70%
60%
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40%
30%
20%
10%
0%
Sørensen's Quotient of Similarity
2008
2009
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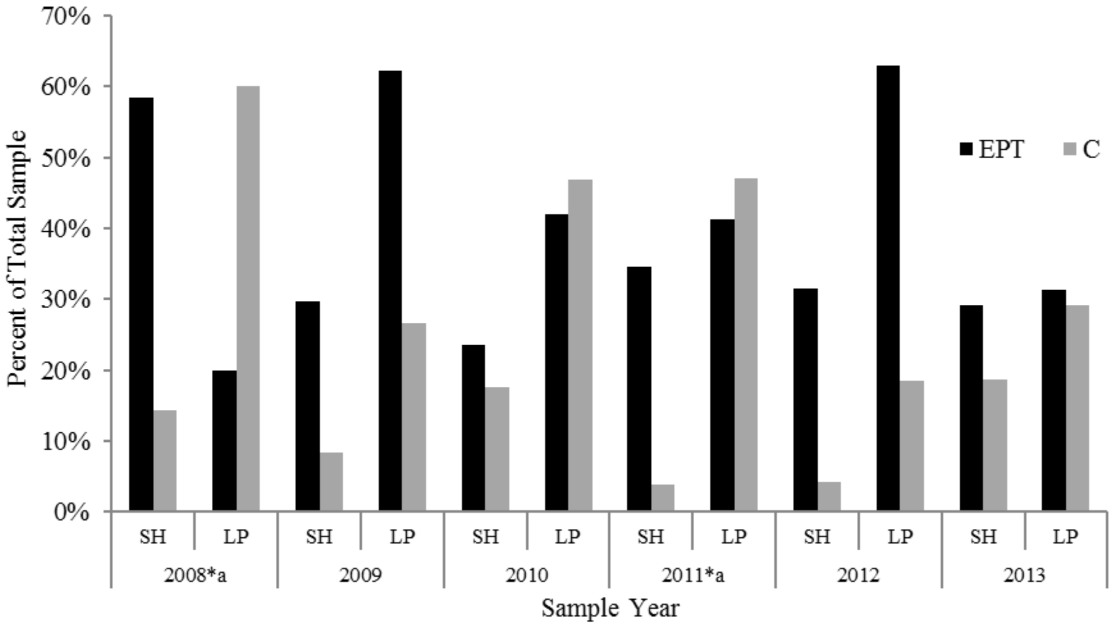
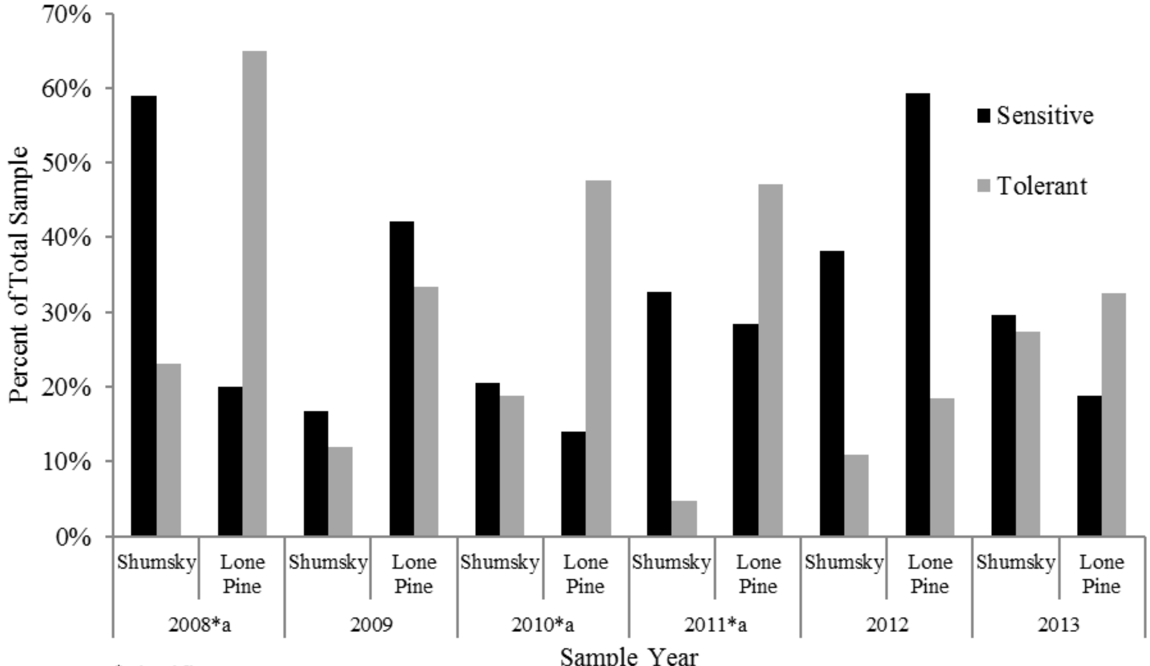
2012
2013
Sampling Year




*Significant χ2 test, $P < 0.05$
[a]Yates Correction Applied




*Significant χ2 test, P < 0.05

[a]Yates Correction Applied

**Appendix 1.** Macroinvertebrates in class Insecta collected June 7 2013 from Shumsky and Lone Pine sites, Boardman River, Grand Traverse County, Michigan, USA. All organisms were assigned a tolerance value 1-10 with 1-3 considered sensitive and 8-10 tolerant. Total number of individuals: 209

| **Order** | **Family** | **Tolerance** | **Shumsky** | **Lone Pine** |
|---|---|---|---|---|
| Coleoptera | Elimidae | 5 | 48 | 3 |
| | Curculionoidea | 4 | 1 | 2 |
| Diptera | Athericidae | 2 | 7 | 0 |
| | Ceratopogonidae | 6 | 1 | 1 |
| | Chironomidae | 8 | 34 | 14 |
| | Empididae | 6 | 2 | 0 |
| | Simuliidae | 6 | 11 | 11 |
| | Tipulidae | 3 | 7 | 1 |
| Ephemeroptera | Baetidae | 4 | 7 | 3 |
| | Ephemerellidae | 1 | 13 | 2 |
| Trichoptera | Brachycentridae | 1 | 19 | 3 |
| | Helicopsychidae | 3 | 7 | 1 |
| | Hydropsychidae | 4 | 1 | 0 |
| | Hydroptilidae | 4 | 3 | 0 |
| | Lepidostomatidae | 1 | 0 | 2 |
| | Leptoceridae | 4 | 1 | 1 |
| | Limnephelidae | 4 | 1 | 0 |
| | Odontoceridae | 0 | 1 | 0 |
| | Polycentropodidae | 6 | 0 | 1 |

**Appendix 2**. Macroinvertebrates not in Class Insecta collected June 7 2013 from Shumsky and Lone Pine Sites, Boardman River, Grand Traverse County, Michigan, USA. All organisms were assigned a tolerance value 1-10 with 1-3 considered intolerant and 8-10 tolerant. Total number of individuals: 19

| **Phylum** | **Class (Subclass)** | **Order** | **Family** | **Tolerance** | **Shumsky** | **Lone Pine** |
|---|---|---|---|---|---|---|
| Arthropoda | Arachnida | Trombidiformes | Hydrachnidae | 4 | 2 | 0 |
| Amphipoda | Malacostraca | Amphipoda | Gammaridae | 4 | 0 | 0 |
| Annelida | Clitellata (Oligochaeta) | Unknown | Unknown | 8 | 12 | 0 |
| | Clitellata (Hirudinae) | Unknown | Unknown | 10 | 0 | 0 |
| Mollusca | Gastropoda | Lymnaeidae | Unknown | 7 | 4 | 0 |
| | | Physidae | Unknown | 7 | 0 | 0 |
| | | Valvatidae | Unknown | 7 | 0 | 1 |
| | Pelecypoda | Sphaeriidae | Unknown | 8 | 0 | 0 |
| Nematomorpha | Gordioidea | Gordiidae | Gordius | 9 | 0 | 0 |