Ecosystem Recovery Analysis of Amos Palmer Drain, in Milan, Michigan

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Abstract

The purpose of this study was to determine how the North Branch of Amos Palmer Drain (Wayne County, Michigan) stream ecosystem changed after a mining company stopped discharging waste water into the stream in 2003. Macroinvertebrates, stream morphology, habitat, and water chemistry samples were collected in 2010 at a site on Amos Palmer Drain and other similar sites within the watershed and were compared to samples collected at the same locations from 1997, 1999 and 2002 using t-tests, correlations and box plots. At NB of Amos Palmer Drain, significant increases were found in the number of families from 1997 to 2010, and average tolerance scores of the macroinvertebrate community from 1997, 1999, and 2002 to 2010. Significant decreases were found in all of the flow measurements, pH, and conductivity between 1999 and 2002, and 2010. Macroinvertebrate assemblage changes were likely due to changes in overall habitat, caused primarily by a decrease in flow to a more natural flow regime with levels reflecting conditions found in similar sites in the watershed. The variables measured were comparable to other local sites of similar size. Evidence supports the hypothesis that the NB of Amos Palmer Drain has reverted back to its state prior to mining drainage, though the state of the site previous to pollution was not assessed.

Introduction

Streams are thought to be among the most threatened ecosystems on our planet (Hawkins and Vinson, 1998). Humans have historically used streams to dispose of unwanted materials including trash, sewage and industrial waste. Chemicals and toxins enter the watershed in rain water runoff as well. The physical state of streams is often altered by channelization, removal of the riparian buffer, alteration of stream flow, and alteration of watershed landuse (Sahagian and

Vorosmarty, 2000). Streams also may be highly vulnerable to climate change, through its anticipated impact on the hydrological cycle (Chen and Shen, 2010; Arnell, 1999). Some researchers believe the hydrological cycle will be intensified with climate change, due to changes in evaporation and precipitation rates (Arnell, 1999).

Many aspects of the environment, economy, and society are dependent on water resources (Zabihollah, 1999; Arnell, 1999). In less than 15 years, it is estimated that 62% of the world's population of eight billion will live in countries experiencing water stress (Arnell, 1999). Information about the ecological quality of water resources is critical to understanding the state of our environment and understanding our environment is critical to protecting our economy and society (Carlisle et al., 2009). In order to effectively manage bodies of water, it is important to quantify changes and alterations (natural or anthropogenic) which have significant impact on ecosystems (Doledec and Statzner, 2010).

Assessment of biological integrity is an integral part of watershed management plans (Davies and Jackson, 2006; Doledec and Statzner, 2010). Here I define a stream system with biological integrity to be an adaptive system with a full, balanced range of functions expected of a system with minimal human influence, commonly referred to as "reference condition" (Davies and Jackson, 2006; Doledec and Statzner, 2010). Aquatic fauna are useful tools for studying the biological integrity of an aquatic system because they integrate ecosystem changes over time (Doledec and Statzner, 2010). Macroinvertebrates in particular are accepted to be one of the most useful fauna for assessing biological integrity and have been commonly used to determine the health of freshwater systems (Brand et. al, 2008; Chon et. al, 2009). The state of macroinvertebrates communities can reveal a past disturbance such as a pollution event even when all chemical traces in the water are gone (Doledec and Statzner, 2010).

An important process which influences the state of an ecosystem is disturbance. Disturbance can be defined as a discrete temporal event that severely disrupts the structure and functions of an ecosystem (Brown et al., 1988). Natural disturbance regimes are common in most ecosystems; however, repeated human disturbance has made streams some of the most threatened systems on earth (Hawkins and Vinson, 1998). This study examines the capacity of a stream to recover from a typical human disturbance.

London Aggregates operated a limestone quarry in Milan, Michigan, and discharged effluent into the Amos Palmer Drain which was found to have flow, and concentrations of total dissolved solids (TDS), hydrogen sulfides, and dissolved oxygen (DO) that exceeded the limits set by their National Pollutant Discharge Elimination System (NPDES) permit under the Clean Water Act of 1992 (CWA, 1992; PIRGIM, 2005; Tobler, 1997). The Intercounty Citizens Action Group (ICAG: made up of residents from London and Augusta Townships) described this stream as milky white water without life during periods when London Aggregates was discharging effluent (Tobler, 1997). In 1998, London Aggregates was sued by the ICAG and the Public Interest Group in Michigan (PIRGIM) for 2,700 violations of the CWA (Gearheart, 2009; PIRGIM, 2005). In 2003, the court handling the lawsuit found London Aggregates to be at fault and subsequently the mining company closed (PIRGIM, 2005).

Roughly seven years have passed since London Aggregates stopped discharging effluent into Amos Palmer Drain. I hypothesized that this time period was sufficiently long enough for the ecosystem to improve its biological integrity. I expected that the water quality would have improved and macroinvertebrate assemblages would have diversified. I tested my hypothesis by sampling macroinvertebrate assemblages, water chemistry, habitat, and stream morphology. I compared samples from 2010 to samples collected from 1997, 1999, and 2002 when the effluent was being discharged. I also sampled neighboring streams that did not receive effluent to test if Amos Palmer Drain, near the site of limestone effluent discharge, had recovered in comparison to the state of streams with similar characteristics in the same watershed. Looking at this incidence of human disturbance and comparing the ecosystem from the time of the disturbance to the current condition gives insight into the time it takes for a stream ecosystem to recover from limestone mining practices.

Materials and Methods

Site Description

Amos Palmer Drain is a small, intermittent tributary of Stoney Creek in Wayne County, Michigan (Table 1, Figure 1). Sampling was conducted at seven sites in the upper portion of the Stoney Creek watershed, which were located east of Milan. Chosen site locations both matched sites from previous studies and roughly matched landscape conditions with the NB of Amos Palmer Drain watershed (Gustavson and Ohren, 2005). However many of the sites did not overlap with all of the studies and therefore data was not available for every site for every year. In all of the studies every site was located within the Stoney Creek drainage system. The NB of Amos Palmer Drain is a small intermittent stream with a drainage area of 6.10 km^2 (Table 1). I sampled macroinvertebrate communities and habitat only in intermittent upstream sites and tributaries (sites 1-5) with drainage areas less than 25 km^2 (Table 1, Figure 1). Stream morphology and water chemistry were sampled in intermittent streams and downstream sites (sites 6-8), which could be classified as river sites and were considered too large (drainage areas over 200 km^2) to compare biological samples (Table 1; Figure 1). Sampling was scheduled to be conducted in August of 2010 but was pushed back to October, because the smaller, intermittent sites (sites 1-5) were nearly dry and would have been incomparable to samples from the earlier studies taken in wetter seasons.

Amos Palmer Drain was the lowest tributary on Stoney Creek sampled. The site 1 was located on the north branch of Amos Palmer Drain, close to where the limestone effluent was discharged and had one of the smaller drainage areas (Figure 1, Table 1). Site 2 was the closest site to the NB of Amos Palmer Drain, located on the south branch of Amos Palmer Drain and it had the smallest drainage area, 2.63 km^2 (Table 1). The site nearest the headwaters of Stoney Creek was site 3 and it had the largest drainage area of the sites sampled for macroinvertebrates (24.86 km^2). Sites 4 and 5 were located on separate tributaries from site 3 and had similar drainage areas (Table 1, Figure 1). Sites 6, 7 and 8 were located on the central branch of Stoney Creek. Sites 7 and 8 were located downstream from Amos Palmer Drain convergence with Stoney Creek.

Historical Data

London Aggregates discharged effluent from mining operations into the north branch of Amos Palmer Drain from 1992 until 2003 (PIRGIM, 2005; Tobler, 1997). I obtained historical biological, water chemistry, and habitat data from two sources: the University of Michigan's fluvial ecosystems class in 1999 and 2002 (Wiley, personal communication, 2010), and the Michigan Department of Environmental Quality's 1997 survey. The 1999 and 2002 surveys were conducted in March and the 1997 survey was conducted in July. This historical data on Stoney Creek, collected during the time of the London Aggregates unauthorized effluent discharge was compared to data collected in 2010, seven years after the mining discharge ended. Landuse data were obtained from summarized Anderson Level variables in ArcView GIS and drainage area data were calculated by the Michigan Department of Natural Resources using 1:100,000 scale topographic maps (Brenden et al., 2006).

Field Methods

Latitude and longitude coordinates for each site were taken with a GPS unit (Garmin, Nuvi). Sites were about 25m stretches of stream starting from where the road crossed the stream. Habitat characteristics in percentage of stream area, including riffles, back water, undercut bank, submerged vegetation, overhanging vegetation, rocks, log pieces, and leaf packs were recorded along with the percentage of total bank cover of riparian vegetation represented, including forest, shrubs, forbs/grasses, and bare soil. Habitat characteristics were estimated visually. Water samples were taken in jars that were washed with stream water three times, kept on ice for travel and placed in a refrigerator until analysis could be conducted. However, the samples were misplaced and due to time constraints could not be recollected. Water temperature (YSI-58), dissolved oxygen concentrations (DO; YSI-58), pH (Hanna-HI98127), and TDS (TDSTestr, low) were measured with meters on site. Stream width, depth, and flow velocity were measured (YSI-2000) at one meter intervals along a single transect, established 5 to 10 meters from the road. These measurements were used to calculate mean depth and discharge. General substrate composition was visually estimated and recorded.

Macroinvertebrate Analysis

Macroinvertebrate samples were collected following rapid bioassessment methods (Catherine Riseng, personal communication, 2010; Fluvial Ecosystems, University of Michigan, 1999 and 2002). Samples were collected using kick screens, D-nets, and hand picking in all observed habitats. Depositional and erosional habitats were sampled proportionately to their occurrence. Each site was sampled for one hour with two people; fifteen minutes total were devoted to collecting specimens and forty five minutes were devoted to processing these samples. Each sample was emptied into a white tray, picked for all living macroinvertebrates, preserved in 70% ethanol, and returned to the lab for identification and enumeration. Locations sampled at each site were recorded.

Invertebrates in the samples were classified to family to match historical samples (Hilsenhoff, 1995). Tolerance score, behavior, common habitat, and functional feeding group were assigned to families (Berg et al., 2008; Hilsenhoff, 1988; EPA, 2010). Tolerance score refers to a number assigned from 1 through 10 that indicates how tolerant of poor conditions such as low oxygen and pollution a taxa is, with 10 being extremely tolerant and 1 being extremely intolerant (Berg et al., 2008; Hilsenhoff, 1988). Behavior is the type of life an insect lives including burrowing, clinging, sprawling, skating, climbing, and swimming. Habitat indicates where they live, including depositional, erosional, lotic, lentic, and surface habitats. Functional feeding group refers to the way an insect feeds including collectors, predators, gatherers, filterers, shredders, scrapers, and piercers. Ephemeroptera, Plecoptera and Trichoptera were grouped together and their presence was used as an indicator of good dissolved oxygen conditions in the stream. When families were without a tolerance score, I used the average of the generic tolerance scores within that family; if the metrics did not agree I used Hilsenhoff (1988).

Data Analysis

I conducted simple t-tests to determine if there were any significant changes in the variables measured across all of the sites over the years (PASW-18, 2009). The 2010 samples were compared to each of 1997, 1999, and 2002's samples separately. I examined change at the NB of Amos Palmer Drain by comparing 2010 data to each of the previous years, using simple t-tests for each variable. I also graphed the linear relationship between conductivity and number of families for the 2010 samples using scatter plots with fitted linear least squares regression lines and 95% confidence intervals (PASW-18, 2009). Line graphs and box plots were used to visualize the variation in variables across sites and years. Variables used in correlation analyses were transformed using natural log for simple linear regressions to conform to normality assumptions. All of the tests were run at 95% confidence levels.

Results

Stream Habitat and General Characteristics

Most of the Stoney Creek watershed was dominated by agricultural landuse, ranging from 38% to 72% with average of 56% (Table 3.). Agricultural drainage tiles were found at site 6 and were likely present at other sides. Substrate was generally uniform (silt) in the all streams surveyed, except site 4 which was sandy. Many of the smaller sites (sites 1-4) were intermittent streams and were nearly dry in August.

Water was not flowing at the NB of Amos Palmer Drain downstream of the road, and the site had wetland characteristics with marsh flora such as cattails, rushes and sedges. On the upstream side of the road, however, stream flow was visible and no vegetation was in the channel. The water color had a slight brown tint that was seen in all of the sites sampled in 2010, noticeably different from the milky white color described by ICAG (Gearheart, 2009), which was due to the addition of limestone washed effluent from London Aggregates. The NB of Amos Palmer Drain had the lowest agricultural landuse percentage (38%) and the highest urban landuse percentage (15%). The NB of Amos Palmer Drain had the most backwater habitat, since it was ponded, and 90% overhanging forb and grass vegetation was present.

Site 2 also had a large portion of overhanging (60%) and emergent vegetation (60%) and was one of the shallowest sites (about 50 cm deep). It had straight, steep banks that appeared to have been altered for flood prevention. The silt substrate was nearly completely covered in undecomposed leaves and there was such limited habitat variation that sampling was ended 15 minutes early. Site 3 on the other hand, had a high variety of habitats including backwater, overhanging vegetation, and log pieces (Table 3). Site 4, along with being the only site to have sandy substrate, had even more habitat variety than site 3 with backwater, undercut bank, overhanging vegetation, leaf packs and it was the only site with riffles (Table 3). The channel at site 5, like site 2, was filled with undecomposed leaves, that mostly covered the edges of the channel and an island in the middle. This site also had undercut banks, submerged vegetation, overhanging vegetation and log pieces (Table 3). Site 6, 7 and 8 were larger and were perennial. Site 6 had the most diverse habitats of the river sites, but also contained garbage such as sharp pieces of metal and buckets. Site 7 was surrounded by woods and site 8 was next to a subdivision.

Stream Morphology

Overall, average velocity and average depth were lower at all sites in 2010 than 2002 but not significantly different (Table 2, Table 6). In the NB of Amos Palmer Drain depth significantly decreased by 0.16 m from 0.24 m, velocity significantly decreased by almost half from 0.24 m/s to 0.16 m/s, and discharge was drastically reduced from 0.36 m^3/s to 0.002 m^3/s from 2002 to 2010. The flow of previous years was artificially high from London Aggregates' additional load of limestone wash, which was four to five times above their permitted discharge (Gearheart, 2010).

Sites 2 and 4 were chosen to compare to site 1 on the NB of Amos Palmer drain because they had the most similar drainage areas (Table 1). Site 2 was one of the shallowest sites; it was too shallow to measure velocity and calculate discharge. Site 4 was the deepest and had the highest average velocity and discharge of the smaller sites.

Water Chemistry

At all of the sites, water temperatures significantly lower in 2010 compared to 1999 (Table 4, Table 6). Conductivity was also significantly lower in 2010 compared to 2002. The NB of Amos Palmer Drain had the highest conductivity of all of the sites from 1997 through 2002 ranging from 1,690µs to 2,035µs, but had dropped to 595.95µs in 2010. In fact, in 2010 it had the lowest conductivity of all sites and would be considered to be within normal ranges for southern Michigan streams. DO at the NB of Amos Palmer Drain was within range of the other sites sampled in 2010 but was not sampled in the historical studies. However, at all most all of the sites, pH remained relatively similar from 1997 through 2010. The pH at the NB of Amos Palmer Drain decreased from 8.3 to 7.72, and of the smaller streams was the highest site 4 in 2010.

Macroinvertebrate Assemblages

The number of families collected increased significantly from 1997 to 2010 but the average tolerance increased significantly from 1997, 1999, and 2002 to 2010 (Table 5 & 6, Figure 2 & 3). In the NB of Amos Palmer Drain macroinvertebrate family richness increased dramatically from 2 families in 1997 to 19 families in 2010, but the average tolerance increased from a low of 4.47 in 1997 and 2002 to the highest observed at any of the sites in all of the years at 6.52 in 2010 (Table 5, Figure 2 & 5). Site 2 had the lowest number of families (7) in 2010 and a relatively average tolerance score (5.48; Table 5). Site 4 had the third highest number of families (14), the highest number of Ephemeroptera, Plecoptera, and Trichoptera of all sites (6), and the second lowest tolerance in 2010 (4.72) (Table 5, Figure 5). However, average tolerance was actually higher at all sites in 2010 compared to previous, years except for Stoney Creek at Fuller Road (Figure 3). Conductivity was negatively correlated with number of families (0.9), though linear regression analysis could not be run due to the small number of sites (Figure 4).

Discussion

Mining affects on stream

The NB of Amos Palmer Drain changed since London Aggregates closed and mining pollution stopped. London Aggregates' additional load of limestone wash increased the stream's flow by four to five times their permitted increase and now without that input (Gearheart, 2009), discharge, average velocity, average depth, conductivity, and pH decreased significantly. The visible appearance of the water also changed from milky white to the brown tint found in all of the other sites sampled. Stream morphological characteristics shape stream habitat, and stream morphology has been cited as having the strongest relationship to macroinvertebrate diversity, suggesting a correlation between stream morphology and macroinvertebrate community structure (Buffagni et al., 2010). My research found that the number of macroinvertebrate families present had significantly increased from 1997 to 2010. Discharge in the NB of Amos Palmer Drain prior to 2003 was significantly elevated by a mining discharge, thus the observed decrease in discharge actually resulted in a more natural flow regime. Flow increased and decreased in the NB of Amos Palmer Drain depending on London Aggregate's discharge and not on natural precipitation patterns. Conductivity was found to have a significant negative correlation with number of families (Figure 4). Since conductivity significantly decreased after the unnatural addition of calcium carbonate from London Aggregates discharge, this may be one of the causes of increased macroinvertebrate community richness.

The tolerance score at the NB of Amos Palmer Drain also increased which usually indicates a decline in ecosystem health (Hilsenhoff, 1988). During low flow the NB of Amos Palmer Drain in September 2010 resembled a wetland ecosystem on the downstream side of the road. Tolerance scores were developed to assess organic loading in flowing stream ecosystems, and therefore rate taxa on their tolerance of low oxygen conditions. In this case, the removal of the mining discharge resulted in a reduction in flow and re-establishment of a more natural intermittently flowing but lower oxygen environment typical of wetland drains. With low flow and a high amount of organic matter, oxygen levels become depleted by decomposition during the night. Taxa which live in these settings are typically air breathing forms (beetles, bugs, ect.) which also can tolerate organically polluted streams. My findings suggest that the NB of Amos Palmer Drain is reverting back to its natural flow regime and to an ecosystem reflecting the characteristics expected of an intermittently ponded, wetland drainage stream.

In comparison to sites of similar size (sites 2-5), the NB of Amos Palmer Drain had the most backwater habitat and the lowest habitat variety, discharge, average depth, and average velocity in 2010. It was the only site that appeared to be ponded. This could be due in part to earlier channel erosion by the high rates of flow generated from London Aggregates. The NB of Amos Palmer Drain also had the lowest conductivity and percent watershed agricultural landuse. One would expect streams with larger drainage area to have more taxa because they are likely to have more habitats, as stated in the habitat heterogeneity hypothesis of the species-area relationship pattern (Kallmanis et al., 2008). The NB of Amos Palmer Drain had a larger drainage area and had naturally corresponding higher macroinvertebrate counts compared to the site closest site to it, site 2. Site 2 had the lowest number of families, twelve lower than the NB of Amos Palmer Drain. It was also the site with the smallest drainage area (2.63 km^2) and its substrate was choked with undecomposed leaves (Table 1). In comparison to site 4, however, the NB of Amos Palmer Drain had a smaller drainage area and this difference was demonstrated by habitat and sensitive taxa. Site 4 had the highest number of Ephemeroptera, Plecoptera and Trichoptera, the second lowest tolerance score, and a high variety of habitats. It was also the only site with riffles. These characteristics make sense given the stream had a larger drainage area (Table 1). NB of Amos Palmer Drain had a drainage area in between those of sites 2 and 4 and habitat and macroinvertebrate community characteristics also fell between the two sites. Given the ecological differences between ponded streams and free streams, evidence indicates the NB of Amos Palmer Drain has returned to a state within the range of similar stream sites in the area.

Combined number of families from sites 1-5 significantly increased from 1997 to 2010. Since nothing is thought to have changed at any of these sites except the NB of Amos Palmer Drain, this increase could be due to differences in sampling technique. Average tolerance also showed a significant increase across all years. These differences could be due to the fact that many macroinvertebrate families are present only seasonally and since the studies were conducted in three different seasons, this likely was a confounding factor (Berg et al., 2008). In Michigan, spring is the wettest season and watersheds receive an increased water runoff from snow melt and spring rains. As the year continues, the weather becomes drier. The 1997 samples were taken in July, 1999 and 2002 samples were taken in March, and 2010 samples were taken in October. The differences in seasonal precipitation patterns and resulting stress from a drier condition leading could explain an increase in tolerance score along with an increase in temperature and a decrease in stream depth.

Ecology

Landuse has had documented negative effects on macroinvertebrate richness because of the changes in flow, substrate, water temperature, and water chemistry and commonly the increase in non-point source pollutants that usually appear with them (Brown et al., 2010; Chon et al., 2009). In this study, landuse was not correlated with macroinvertebrate community characteristics. In fact, two of the sites with the highest numbers of families had the highest percentages of agricultural landuse, but the study was not designed to appropriately test landuse effects since I only sampled a few sites located in the same watershed with generally similar landuse. Agricultural landuse ranged from 38% to 72% and was 56% on average. Other studies have found agricultural landuse greater than 30-75% to have negative affects on macroinvertebrate communities, so all of the sites are likely impacted. (Riseng et al., 2010). Nevertheless, invertebrate diversity, water chemistry, and stream morphology all improved; many of these changes were statistically significant. The logical conclusion is that the termination of London Aggregates' discharge caused these changes.

Weaknesses of this Analysis

In addition, the samples were taken at different times of the year, which is particularly critical to the state of intermittent streams, and different sampling methods were used. Many macroinvertebrates have seasonally cycling lives and therefore their community composition is sensitive to season even at the family level used in this study (Minshall et. al, 1985; Reece et. al, 2001; Berg et al., 2008). Sampling techniques varied substantially, because they were conducted by three different groups and it was difficult to account for the different sampling techniques between all sites and years. In addition there were gaps in the data, because different studies sampled different characteristics and it was difficult to find characteristics that were sampled in every study. It is likely that more patterns could be seen in the data if the studies were cohesive with standardized sampling goals, times, and methods.

Conclusion

In conclusion, seven years after London Aggregates ceased discharging limestone effluent into the NB of Amos Palmer Drain, the stream has increased in macroinvertebrate community richness, although the macroinvertebrate community tolerance index has also increased. My evidence suggests that this increase in richness was due to effects corresponding to elimination of limestone effluent discharge and the following transition to more natural flow regimes. For the NB of Amos Palmer Drain this is an intermittent regime and intermittent streams are often ponded seasonally. Natural Flow Regime resulted in an increase in macroinvertebrate richness and an increase in number of taxa tolerant of fluctuating DO concentrations typical of an intermittent stream (Lytle and Poff, 2004). Possible new avenues for study could include more sites and other intermittent streams to better understand how macroinvertebrate richness is affected by seasonal ponding. Further, this study could have been improved upon by having one cohesive study instead of studies conducted by three different groups. In addition to the pollution of Amos Palmer Drain by London Aggregates, all of my stream sites were heavily impacted by agricultural activity and likely were all degraded to some point. It is important that the consequences of human activities on water systems be weighed against their gain.

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Tables

Table 1. Site Information: Placement indicates the site location in relation to where Amos Palmer Drain enters Stoney Creek. – means the data was not available.

Site	Stream	Location	Latitude	Longitude	Drainage Area (km^2)	Years Sampled
1	Amos Palmer Drain	Grames Road	42.057617	- 83.5495	6.10	1997,1999, 2002, 2010
2	Amos Palmer Drain	Gramlick Road	42.052567	- 83.556933	2.63	1997, 2010
3	Sugar Creek	Gooding Road	42.103417	- 83.637283	24.86	1997, 1999, 2002, 2010
4	Buck Creek	Hitchingham Road	42.102883	- 83.6183	8.28	2002, 2010
5	Stoney Creek	Fuller Road	42.079011	- 83.608	9.56	1999, 2002, 2010
6	Stoney Creek	Palmer	42.064633	- 83.53875	207.88	1997, 2010
7	Stoney Creek	Timbers Road	42.048483	- 83.50925	253.02	2010
8	Stoney Creek	Exeter	42.022883	- 83.586017	-	1997, 2010

Table 2. Data summarizing stream morphology at each sample site in 2010 and 2002. - indicates measurements were not taken due to equipment failure.

Characteristic	2010								2002			
Site	1	2	3	4	5	6	7	8	1	3	4	5
Average Depth (m)	0.10	0.05	0.17	0.23	0.05	0.28	0.66	0.81	0.26	0.29	0.48	0.6
Average Velocity (m/s)	0.16	-	0.04	0.09	-	0.11	0.04	0.032	0.24	0.38	0.12	0.18
Discharge (m^3/s)	0.002	-	0.026	0.07	-	0.16	0.30	0.21	0.36	0.24	0.31	0.38

Table 3. Habitat Characteristics: numbers are percent of the stream found as the described habitat or percent of the watershed landuse.

site	1	2	3	4	5	6
Habitat						
Riffles	0	0	0	30	0	0
Back water	100	0	30	2	0	5
Undercut bank	0	5	0	30	30	0
Submerged or emergent vegetation	25	60	0	2	20	10
Overhanging vegetation	90	60	10	2	90	20
Rocks	0	0	0	0	0	10
Logs pieces	0	1	10	0	20	50
Leaf packs	0	100	90	10	100	0
Landuse						
Agriculture	38	58	72	60	58	48
Urban	15	3	6	6	5	11

Table 4. Physical and chemical data. – indicates information was missing from previous studies.

Site	Year	Month	Temperature (^{o}C)	DO (mg/l)	pH	Conductivity (µs)
1	1997	July	-	-	7.3	2035
	1999	March	8	-	7.7	1690
	2002	March	-	-	8.3	1940
	2010	October	15	7.2	8.14	595.95
2	2010	October	13.7	-	-	640.65
3	1997	July	-	-	8.17	792
	1999	March	6	-	8.4	650
	2002	March	-	-	7.8	430
	2010	August	12	8	7.92	715.14
4	2002	March	-	-	8.4	720
	2010	October	12.02	6.7	8.07	968.41
5	2002	March	-	-	7.9	790
	2010	October	10.01	-	8.92	-
6	2010	October	22.6	7.03	7.9	864.12
7	2010	October	13.7	-	-	938.62
8	2010	October	12.5	-	8.09	1028.01

Table 5. Macroinvertebrate summaries for each sample site for years 1997 through 2010.

Characteristic	2010					2002			1999			1997	
Site	1	2	3	4	5	1	3	5	1	3	4	1	3
Number of Families	19	7	15	14	9	2	6	1	3	7	8	2	13
Average Tolerance	6.52	5.48	5.76	4.72	4	4.47	5.3	-	5.47	5.33	3.88	4.47	5.89
Number of EPT	0	0	1	6	1	0	1	1	0	1	3	0	0
Number of Skaters	2	0	2	1	0	0	0	0	0	0	0	0	0

Table 6. Comparison of biological characteristics: simple t-tests statistics comparing 2010 samples to the years below.

Measurement	Year Compared to	t	p-value
Number of Families	2002	1.964	0.188
Number of Families	1999	3.928	0.059
Number of Families	1997	3.608	0.037
Average Tolerance	2002	6.619	<0.00
Average Tolerance	1999	9.282	<0.00
Average Tolerance	1997	7.962	<0.00

Table 7. T-test statistics comparing the NB of Amos Palmer Drain in 2010 to previous years.

Measurement	Year Compared to	t	p-value
Discharge	2002	45.320	<0.000
Average Velocity	2002	10.729	0.009
Average Depth	2002	9.610	0.011
pH	2002	142.028	<0.000
Temperature	1999	7.591	0.005
Conductivity	2002	4.631	0.006
Conductivity	1999	3.579	0.037

Figures

1. Location of sites: Site 1 is the NB of Amos Palmer Drain
2. Number of families at each site across the years sampled
3. Mean tolerance for each site in all of the years sampled.
4. Linear relationship between number of families and conductivity: A linear plot of number of families against conductivity shows the relationship between the natural log of conductivity and the natural log of number of families for 2010 ($p = 0.009$).
5. Tolerance scores for macroinvertebrate families at each site in 2010.

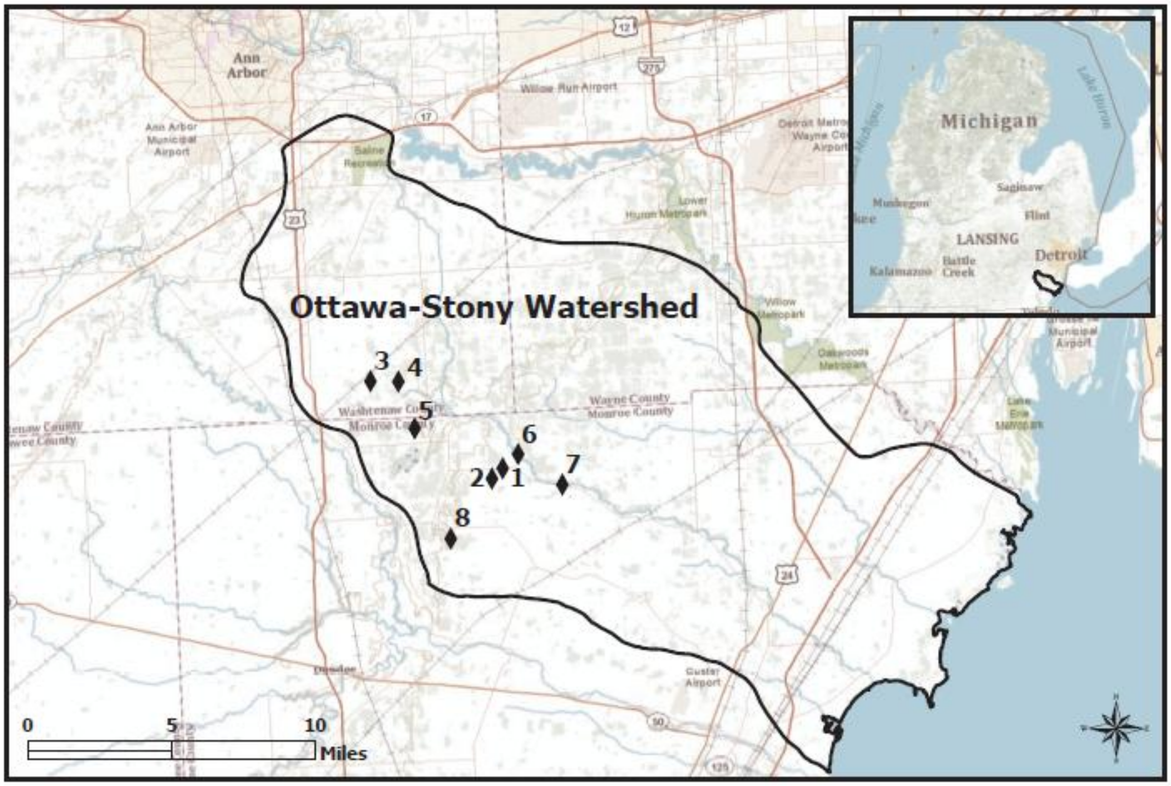
Ottawa-Stony Watershed
Michigan
Ann Arbor
LANSING
Detroit
3
4
5
6
2
1
7
8
0
5
10
Miles

Figure 1.

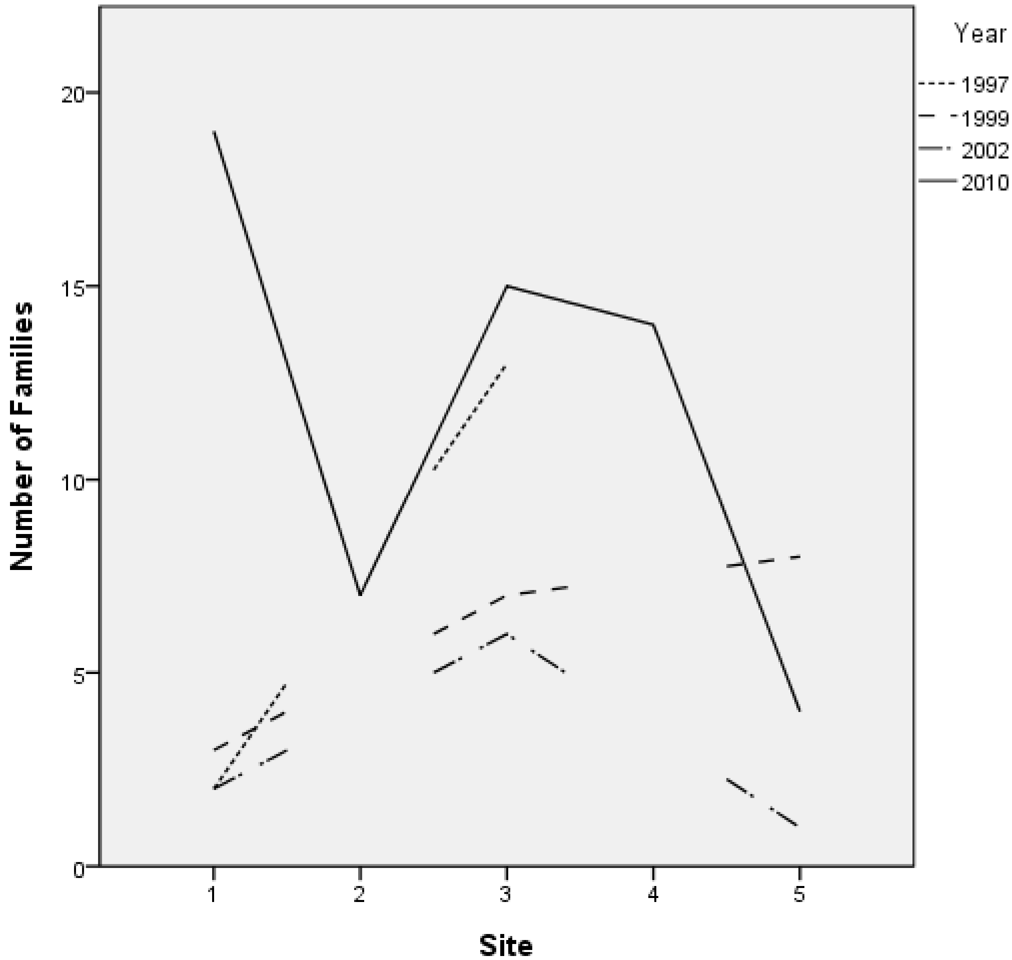
Year
1997
1999
2002
2010
Number of Families
0
5
10
15
20
Site
1
2
3
4
5

Figure 2.

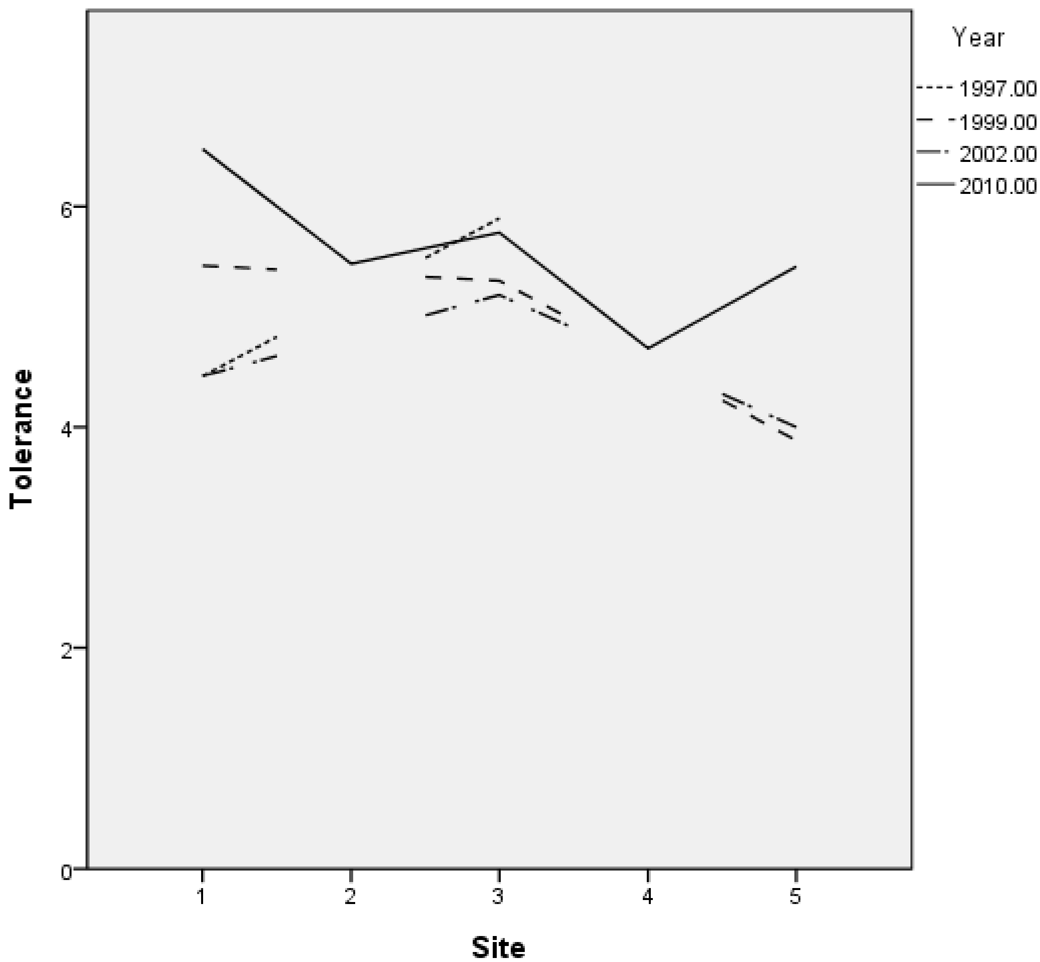
Year
1997.00
1999.00
2002.00
2010.00
Tolerance
0
2
4
6
1
2
3
4
5
Site

Figure 3.

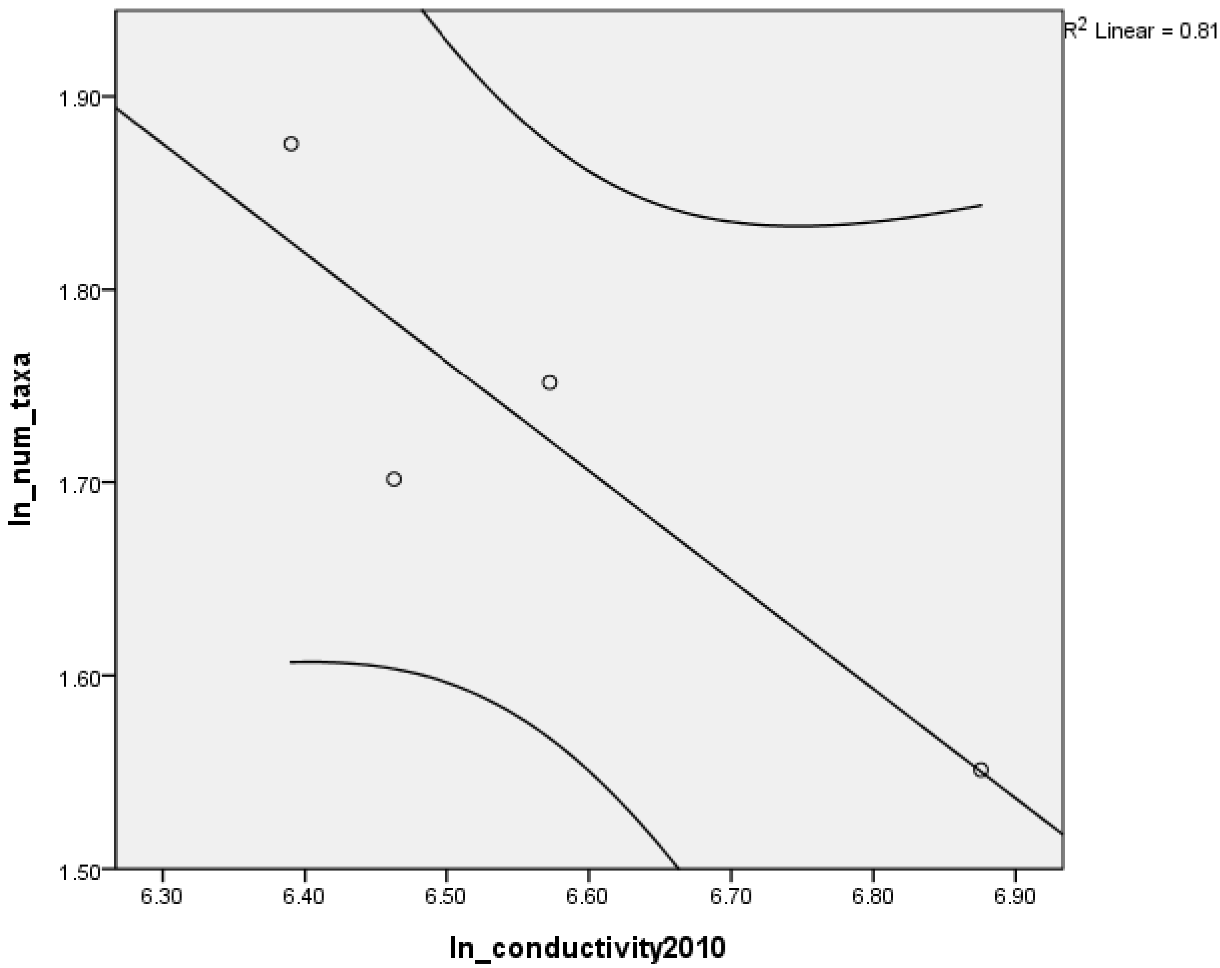
R^2 Linear = 0.81
1.90
1.80
1.70
1.60
1.50
ln_num_taxa
6.30
6.40
6.50
6.60
6.70
6.80
6.90
ln_conductivity2010

Figure 4.

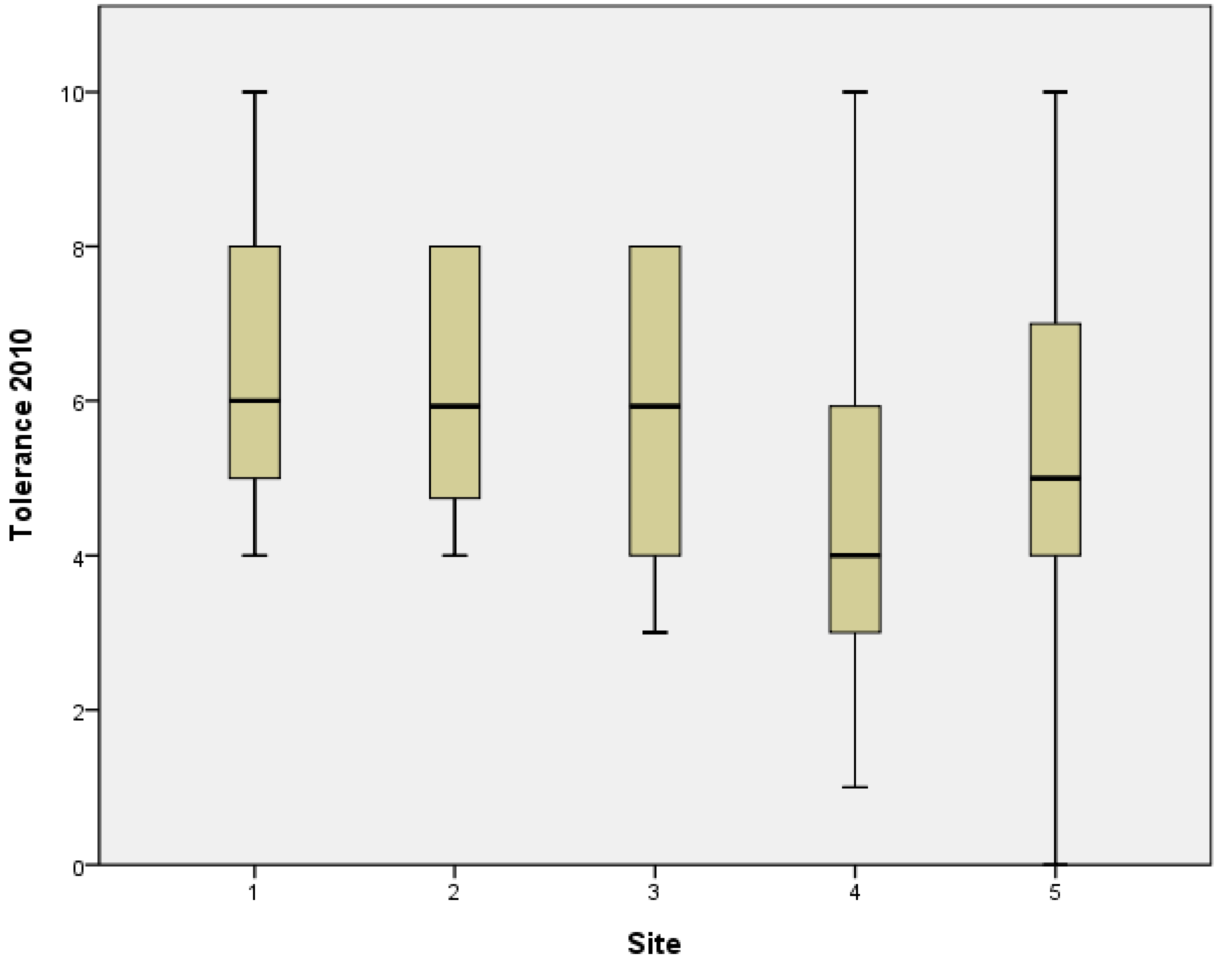

Figure 5.

Appendix

Table A1. Family Presence: Shows the presences of specified families at each site and their tolerance values, habitat, habit and trophic relationships.

Family	Year	2010					2002			1999			199 7		Tolerance values	Habitat	Habit	trophic relationships
	Site	1	2	3	4	5	1	3	5	1	3	5	1	3	-	-	-	-
Dytisciade		1	-	-	-	-	-	-	-	-	1	-	-	-	5.38	-	-	-
Elmidae		1	1	-	1	-	-	1	-	-	1	-	-	1	4	-	-	-
Gyrinidae		1	-	-	-	-	-	-	-	1	-	-	-	-	5	-	-	-
Halipidae		1	-	-	-	-	-	-	-		-	-	-	-	7	lentic	Climbers	shredders
Ceratopogonidae		1	-	1	-	-	-	-	-	-	-	-	-	-	6	-	Burrowers	-
Chironomidae		1	1	1	1	-	1	-	-	1	1	1	1	1	5.93	-	Burrowers	Collectors
Culicidae		1	1	1	-	-	-	-	-	-	-	-	-	-	8	Depositional	-	collectors
Dixidae		-	-	-	1	-	-	-	-	-	-	-	-	-	1	lentic	Swimers	Collectors
Ptychopteridae		-	-	-	-	1	-	-	-	-	-	-	-	-	7	depositional	Burrowers	collectors
Simulidae		-	-	1	1	-	-	-	-	-	1	-	-	-	6	erosional	Clingers	Collectors
Tabanidae		1	-	1	1	-	-	-	-	-	-	1	-	-	8	erosional	Burrowers	Shredder
Tipulidae		1	1	1	1	1	-	-	-	-	-	1	-	-	4.12	erosional	Burrowers	Shredder
Baetiscidae		-	-	-	1	-	-	-	-	-	1	-	-	-	3	depositional	Sprawlers	Collectors
Heptageniidae		-	-	-	1	-	-	1	-	-	-	-	-	1	4	erosional	Swimers	Collectors
Leptophlebiidae		-	-	-	1	-	-	-	-	-	-	1	-	-	2	erosional	Swimers	Collectors
Corixidae		1	-	-	1	-	-	1	-	-	-	-	-	1	10	depositional	Swimmers	Collectors
Gerridae		1	-	1	-	-	-	-	-	-	-	-	-	1	5	surface	Skaters	Predators
Hebridae		-	-	-	1	-	-	-	-	-	-	-	-	-	-	detritus	Climbers	Predators
Pleidae		1	-	-	-	-	-	-	-	-	-	-	-	-	-	Hydrophytes	Swimmers	Predators
Veliidae		-	-	1	1	-	-	-	-	-	-	-	-	1	-	Surface	Skaters	Predators
Sialidae		-	-	1	-	-	1	-	-	1	1	-	1	-	4	Erosional	Burrowers	Predators
Aeshnidae		-	-	1	-	-	-	1	-	-	-	-	-	1	3	-	Climbers	Predators
Calopterygidae		-	-	1	1	1	-	1	-	-	-	1	-	1	5	-	Climbers	Predators
Coenagrionidae		1	-	-	-	-	-	-	-	-	1	-	-	-	9	-	Climbers	Predators
Corduliidae		1	-	-	-	-	-	-	-	-	-	-	-	-	5	-	Sprawlers	Predators
Gomphidae		-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	Burrowers	Predators
Capniidae		-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	Sprawlers	Shredders
Hydropsychidae		-	-	-	1	-	-	-	-	-	-	-	1	1	4	-	clingers	Collectors
Limnephilidae		-	-	-	-	-	-	-	1	-	-	-	-	1	4	-	Climbers	-
Uenoidae		-	-	-	-	1	-	-	-	-	-	-	-	-	0	-	Clingers	Scrapers
Phryganeidae		-	-	-	1	1	-	-	-	-	-	1	-	-	4	-	-	-
Polycentropodidae		1	-	-	-	-	-	-	-	-	-	-	-	-	6	-	-	-
Psychomyiidae		-	-	-	1	-	-	-	-	-	-	-	-	-	2	-	-	-
Amphipoda		1	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Gastropoda		1	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-
Hirudinea		1	-	-	1	1	-	-	-	-	-	-	-	1	-	-	-	-
Isopoda		1	1	1	-	1	-	-	-	-	-	-	-	1	-	Surface	-	-
Shaeriidae		-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-