Macroinvertebrate communities and water quality upstream and downstream of *Castor canadensis* dams of various ages

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ABSTRACT

Beaver dams greatly alter stream ecosystems and the surrounding environment. This study aims to assess the effect of beaver dams of various ages on water quality and macroinvertebrate communities. Five beaver dams were located on Carp Creek and Maple River in Pellston, Michigan and classified according to their state of preservation, which roughly reflects dam age. At each dam, we took macroinvertebrate samples, dissolved oxygen (DO), flow, and substrate type measurements from four places both upstream and downstream from the dam. Water quality samples (total P, total N, conductivity, turbidity, and pH) were taken at two areas both upstream and downstream from the dam. We used the Shannon-Weiner Index and Sorensen's Index along with SPSS to statistically analyze differences in macroinvertebrate densities and numbers. Water quality samples, flow, and DO were also analyzed.

None of the water quality measures attained statistical significance. There was significantly more macroinvertebrate diversity downstream than upstream for two dams on Carp Creek ($p<0.05$). When macroinvertebrate data for all dams were grouped together, it was again found that there was significantly more diversity downstream ($p<0.05$). We observed that as dam class (i.e. age) increased, upstream and downstream macroinvertebrates trended towards becoming more similar.

INTRODUCTION

Due to the ability of the American beaver, *Castor canadensis*, to cause drastic changes to its environment, they have frequently been referred to as stream or ecosystem "engineers."

Beavers have been known to have important effects on the rivers and streams where dams are built (Woo and Waddington 1990) as well as the surrounding terrestrial environment (Wright et al. 2002). Terrestrial banks surrounding the dammed water are flooded as a result of the rise in water level due to the dam. This water buildup creates a swamp-like area upstream of the dam, changing the previous composition of the riverbank as a number of terrestrial plants drown and are replaced with other highly water-tolerant or aquatic plants (Baker 1983).

Beavers create dams by cutting down trees of varying sizes with their powerful incisors and then systematically overlapping tree trunks and branches at a narrow point in the stream or river to minimize construction materials while maximizing the flooding of surrounding areas upstream of the river. Additional material such as smaller twigs, mud, silt and rocks are then packed into the holes in the dam by both the beaver and the river current itself until a watertight seal is created (Baker 1983).

Beaver dams have also been found to alter the export and retention of nutrients in streams as well as modify hydrology of rivers, changing stream flow upon flooding the original habitat and decrease in stream velocity (Hill and Duval 2009). The change in stream composition may also have a strong affect on organisms living in this ecosystem. Specifically, studies have shown that as beaver dams significantly influence ecosystems upstream, benthic stream invertebrate populations are also influenced (Margolis et al. 2001). Not only is the extent of environment alteration extreme, but the changes in habitat may have an effect on the dammed river as well as the beaver-created surrounding wetlands for years. Long after a dam is abandoned, beaver-created ponds drain, resulting in meadows that last for decades (Terwilliger and Pastor 1999). The effect of beaver dams on biogeochemical cycles and distributions of chemical elements may also last for decades or centuries to come (Naiman et al. 1994).

UMBS students have conducted much research on the topic of beaver dams and their ecological impact on the surrounding areas. Kuo and Feldmann (1991) examined how beaver dams change stream morphology, how they affect various water quality measures as well as surrounding tree populations. They found significant differences in upstream and downstream flow velocity and temperature, and observed influences of the beaver dam on nearby tree communities. Cole et al. (1991) studied the effects of a Carp Creek beaver dam on the upstream and downstream water quality levels and macroinvertebrates. The only significant difference they found in water quality levels was an increase in nitrates downstream of the dam. They also noted that the total number of macroinvertebrates was higher downstream. Carpenter et al. (1993) examined water chemistry differences upstream and downstream between vacant and active beaver dams. While they found no significant differences in any variables upstream and downstream of each individual dam, they did find significantly higher nitrogen and silica levels at active sites compared to abandoned sites.

Although there has been much research by UMBS students on the effects of beaver dams, studies of the effects dam age on differences between the upstream and downstream water quality levels and macroinvertebrate communities are lacking. Our study expands the work of other UMBS student researchers by examining the composition of benthic macroinvertebrates both upstream and downstream of each dam, and then classifying the dams along a state-of-preservation scale (Table 2).

We hypothesize that the beaver dam class (which roughly reflects age) influences the degree of difference between the environments just upstream and just downstream of the dams. We predict that as the dam class increases, the water quality values (pH, total phosphorus, total nitrogen, turbidity, conductivity, temperature, DO, and flow rate) upstream and downstream of the dam will become more similar. We also predict that differences between upstream and downstream macroinvertebrate community composition will decrease as the dam class increases.

METHODS

This study was conducted at five beaver dams within Cheboygan County:

1. Carp Creek off Riggsville Road; inactive (Fig. 1)
2. Carp Creek off Hogsback Road; inactive (Fig. 1)
3. East branch of Maple River off Plain Street; active (Fig. 2)
4. East branch of Maple River off Douglas Lake Road downstream from UMBS Stream Research Facility; inactive (Fig. 2)
5. East branch of Maple River off Douglas Lake Road just downstream from UMBS Stream Research Facility; inactive (Fig. 2)

We sampled at the two Carp Creek dams on May 23, 2009, and at the three Maple Creek dams on May 25, 2009. Sampling and measurements of the macroinvertebrate community and water quality were taken at two and four meters both upstream and downstream of each dam as explained by Figure 3. In order to minimize our disturbance to areas not yet sampled, we always progressed from downstream to upstream. Water samples were collected in 60-mL acid-washed bottles, and were later tested at the Alfred H. Stockard Lakeside Laboratory for pH, total phosphorous, total nitrogen, turbidity, and conductivity to determine water quality in each area. Dissolved oxygen (DO) and temperature readings were generated with the Handheld Dissolved Oxygen and Temperature System (YSI Model 55) and water velocity was measured using a flow meter (Marsh-McBirney, Inc.'s Flow-Mate Model 200). Each sample and measurement was taken as close to the river bottom as possible to accurately assess the macroinvertebrate environment.

Using a glass-bottom bucket, the substrate at each area was noted according to Cummins' modified classification scheme for substrate type (Table 1). We assigned each dam a class according to the preservation state (Table 3), which gave us an idea of how old the dams were. Due to the somewhat subjective nature of using Table 2 to assign each dam a class, each of us assessed the dam independently, and then we collaborated to assign the class.

Macroinvertebrate samples were taken using an 88cm x 60cm kick net. To standardize the collection, we always kicked the river-bottom substrate eight times into the kick net. Macroinvertebrates collected at each site were counted and the large majority was classified to order. Because of difficulties with classifying some of the macroinvertebrates, all aquatic earthworms were classified in the Oligochaeta class, all leeches were classified in the Hirudinea subclass, and snails were either labeled as the Prosobranchia subclass or the Pulmonata order. Although classifying every macroinvertebrate to species would have been ideal, nobody in our team was qualified to classify to that level.

All statistical analysis was performed by SPSS Version 15.0. Our first goal in statistical analysis was to test the variables upstream and downstream of each of the five individual dams. To analyze the water quality data from the lab, Mann-Whitney U-Tests were performed to compare the SD1 and SD2 values with the SU1 and SU2 values. To analyze the DO, flow, and temperature values, independent-samples t-tests were performed with the D1-D4 values and the U1-U4 values. The macroinvertebrate population was analyzed through the computation of Shannon-Weiner indices for each of the eight sampling locations per dam. Groth and Roelfs (1982) give the formula for this index:

$$\text{Shannon Index} = -\sum_{i=1}^{s} p_i \ln p_i$$

The "p_i" in this formula are the proportions of each individual species (or individual orders, in our case). Independent-samples t-tests were performed by comparing the four downstream Shannon-Weiner Indices with the four upstream indices. Independent-samples t-tests were performed for each dam using the numbers of macroinvertebrates found at each of the eight sampling locations.

The macroinvertebrate data for dam #5 at U4 was determined to be an outlier because of significant anthropogenic effects; stream researchers had deliberately inserted large tubes through the dam structure in order to more quickly drain the beaver pond, and these large tubes were held down by cinder blocks. The cinder block at U4 had accumulated many larger twigs and other debris, creating an unusually good place for macroinvertebrates to live. In order to maintain balance when the outlier was removed, D4 data for dam #5 was also discarded. All statistical tests involving macroinvertebrate populations at dam #5 were performed with and without the outlier included in the data.

Our second goal in statistical analysis was to examine the data with all five dams grouped together. Only macroinvertebrate communities were analyzed at this level. First, Shannon-Weiner indices were calculated for each dam in a different way than before; the macroinvertebrate collections for D1, D2, D3, and D4 and for U1, U2, U3, and U4 were grouped together for each dam, and then one index was calculated for downstream and upstream of each dam. The two indices for all five dams were used in a paired-samples t-test to assess whether the Shannon-Weiner index is significantly different downstream than upstream when all dams are considered together. The numbers of macroinvertebrates found downstream and upstream of each dam were also tallied, and these ten values were also used in a paired-samples t-test.

The ultimate goal in statistical analysis was to examine whether there is an effect of beaver dam class on the degree to which the upstream and downstream environments are different. The downstream-to-upstream differences in the Shannon-Weiner indices calculated for the multi-dam analysis were used in regression analysis with the dam class. Regression analysis also tested the correlation between the downstream-to-upstream differences in number of macroinvertebrates and the dam class. Finally, Sorensen's Index was calculated from the formula given by Fisher and Triplett (1999):

$$\text{Sorensen's Index} = (2N_{ab}) / (N_a + N_b)$$

In this formula, "N_{ab}" indicates the number of orders held in common between group A and group B, while "N_a" and "N_b" indicate the total number of orders in group A and group B, respectively. The calculation yields the percent similarity between two groups. One Sorensen's Index was calculated for each dam by comparing the grouped macroinvertebrate data for downstream and upstream. The correlation between these indices and the dam class was assessed using regression analysis.

RESULTS

Tables 4-9 display the values used in all the statistical tests performed, while tables 10-14 exhibit the results of these statistical tests. Table 10 shows that two of the five dams showed significantly higher Shannon-Weiner indices downstream than upstream; dam #1 yielded a p-value of .005 while dam #2 presented a p-value of .0095. Dams 3, 4 and 5 (both with and without the outlier) had p-values of greater than .05 and so they could not be considered statistically significant. Although only two the dams reached statistical significance, dams #3, #4, and #5 (without outlier) trended in the same direction.

Table 11 shows that there were no significant results when comparing the number of macroinvertebrates found downstream and upstream in each dam. While p-values for each dam were all greater than .05, there appears to be a trend of more macroinvertebrates being found downstream than upstream (except for dam #5, with the outlier).

The statistical tests we ran for water quality all yielded p-values of greater .05. We were also unable to observe any trends for any of the water quality data (Table 12). Temperature measurements were not taken into consideration since sampling took over an hour and a half for each dam, allowing the sun plenty of time to heat the water.

Looking at all five dams together (Table 13), the only relationship that was statistically significant was that Shannon-Weiner diversity is higher downstream than upstream if you exclude the outlier in dam #5 (p-value = .012). While there again is a trend towards more total macroinvertebrates downstream than upstream, it is again insignificant when looking at all dams.

Table 14 summarizes all statistical results from the regression analyses. For all variables assessed—difference in Shannon-Weiner indices, difference in numbers of macroinvertebrates, and Sorensen's indices—the correlation with dam class (age of dam) was insignificant (all p-values > .05). Also, the R^2 values were fairly low (all $R^2 < .3$), indicating that the regression lines are poor fits for the data. For both the Shannon-Weiner and number of macroinvertebrates correlations, the analysis excluding the outlier yielded lower p-values and higher R^2 values. Although no significance was achieved, looking at the slope values in Table 14 along with the corresponding scatter plots in Figures 4-8 can give an idea of possible trends that may exist in the data. A slope of -.077 was found for the regression lines correlating the dam class and the difference in Shannon-Weiner indices upstream and downstream (both with and without the outlier). The slope of the regression line correlating dam class and the difference in number of macroinvertebrates was -4.143 (with and without the outlier). Finally, the slope for the regression analysis involving Sorensen's indices was .009, indicating a positive trend between percent similarities in macroinvertebrate orders downstream and upstream and age of the dam.

Table 15 combines the notes that were taken regarding substrate types at each of the eight sampling locations per dam. While it appears that a difference does exist between the upstream and downstream substrate types, it is difficult to say if there is a trend dictating how it differs. While the average size of substrate appears to increase downstream for dams #2, #3, and #4, the trend does not seem to hold for dams #1 and #5.

DISCUSSION

The three measures for which we achieved statistical significance all dealt with difference in Shannon-Weiner indices upstream and downstream. While dams #1 and #2 had statistically significant differences, perhaps the more important result came when all five dams were considered together, and Shannon-Weiner diversity was found to be significantly higher downstream than upstream. With a sample size of five dams, this result is more generalizable than individual dams showing significance.

Beyond these three significant measures, all other analysis must be based on discussing insignificant trends in the data. While none of the regression analyses yielded statistical significance, the trends displayed in the scatter plots all headed in the hypothesized overall direction, and are interesting to discuss. As displayed in Figures 5 and 6, the negative sloping lines indicate that as the dam class increases, the difference in Shannon-Weiner diversity between downstream and upstream tends to diminish. Similarly, the negative sloping lines in Figures 7 and 8 indicate that as dam class increases, the difference in number of macroinvertebrates between downstream and upstream also tends to decreases. Figure 9 displays a positive slope, indicating that percent similarity tends to increase as dam class increases. All three of these trends indicate that there might be some validity to our second prediction that differences between upstream and downstream macroinvertebrate community composition will decrease as the dam class increases. Based on Woo and Waddington's (1990) description in Table 2 of the gradual deterioration of the dam as time goes on, it would make sense that conditions downstream and upstream of beaver dams would become more homogenous over time. To confirm these trends, however, attaining statistical significance would be necessary. With such low p-values for the regression analyses, it could have been partly coincidence that we observed all the trends that we expected to observe.

While we originally predicted that the degree of difference in water quality between downstream and upstream would be affected by the age of the beaver dam, none of our water quality measures reached significance when testing individual dams. Because of this lack of significance, it was not possible to test our prediction about water quality and the age of beaver dams. Some studies suggest a difference in water quality in locations upstream versus downstream, specifically nitrate levels. Student led experiments conducted on a number of the same dams visited in our study found little data supporting our original prediction (Cole et al.1991, Carpenter et al. 1993). Also, since the majority of beaver dams were breached in some way, it might be expected that water quality measures would remain relatively constant since water was allowed to flow between the upstream and downstream sites. Having reexamined both of our predictions in light of our findings, it seems that our hypothesis that dam age affects the degree of difference between the downstream and upstream environments is neither supported nor unsupported.

Possibly the most significant sources of error in our study were the effect of human intervention and not knowing the complete history of the dams. Dam #1 was clearly tampered with since it now partially serves as a bridge for a walking trail. Dam #2 is located just downstream of a bridge, under which water is diverted through a tunnel rather than flowing naturally. Dams #4 and #5 have pipes drilled through them by stream researchers to attempt to drain the beaver pond, and these pipes and the cinder blocks used to hold them in place created artificial environments for macroinvertebrates to live.

Looking at our substrate data collected in Table 15, it is evident that there is some kind of substrate change between upstream and downstream of a beaver dam. Without a more sophisticated substrate sampling procedure, however, it is impossible to determine if there is a trend or some kind of significant relationship between the substrate composition downstream and upstream of dams of various ages. Taking a closer look at substrate could even be as simple as determining percent cover values of the different types of river-bottom matter at each of the sampling locations. This would help to make the substrate descriptions more quantitative and could set the stage for statistical analysis.

Since our study looked at water quality and macroinvertebrate populations in a latitudinal fashion, it would also be interesting to conduct a longitudinal study. Looking at the same dams over long periods of time could help to eliminate potential confounding variables that might have obscured the data. Although we did try to diminish this problem by only comparing *differences* in Shannon-Weiner indices and macroinvertebrate numbers when assessing the effect of dam class, this still is not as controlled as a longitudinal study would be. Another benefit of a longitudinal study would be the ability to take samples at various seasons during the year.

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Table 1: Substrate Classification Scheme. The red rectangle surrounding the left side of the image was added to emphasize that we used Cummins' modified classification scheme rather than Wentworth's original scheme. (Adapted from Cummins 1962)

Modified classification (Cummins, 1961)	Wentworth classification: Name	Wentworth classification: Particle size range in mm
Boulder	Boulder	> 256
Cobble	Cobble	64 - 256
Pebble	Pebble	32 - 64
		16 - 32
Gravel*		8 - 16
		4 - 8
	Granule	2 - 4
Very coarse sand	Very coarse sand	1 - 2
Coarse sand	Coarse sand	0.5 - 1
Medium sand	Medium sand	0.25 - 0.5
Fine sand	Fine sand	0.125 - 0.25
Very fine sand	Very fine sand	0.0625 - 0.125
Silt	Silt	0.0039 - 0.0625
Clay	Clay	< 0.0039

Table 2: Dam Class and Preservation Stage. Woo and Waddington (1990) developed this classification scheme from their analysis of 50 beaver dams.

Class	Materials	Preservation stage
1	stones, new branches, fresh mud	active
2	no stones, new branches, fresh mud	active
3	stones, old branches, mud and debris	old
4	no stones, old branches, mud and debris	old
5	no stones, old branches, some mud and debris remains	old
6	only large branches remain	old
7	only small branches remain	relict
8	*most branches gone, only half of original* structure remains	relict

Table 3: Dam Class of the Five Studied Dams. The dam classes were assigned by following the Woo and Waddington's (1990) classification scheme depicted in Table 2.

	Dam #1 Carp Creek off Riggsville	**Dam #2** Carp Creek off Hogsback	**Dam #3** Maple River off Plain	**Dam #4** Maple River downstream of Stream Research Facility	**Dam #5** Maple River just downstream of Stream Research Facility
Dam Class	5	6	2	7	5

Table 4: Shannon-Weiner Indices for all Sampling Locations. The indices were calculated after classifying macroinvertebrates to order. These values were used for the independent-samples t-tests for all dams individually (see Table 10 for results).

	D1 Shannon	**D2 Shannon**	**D3 Shannon**	**D4 Shannon**	**U1 Shannon**	**U2 Shannon**	**U3 Shannon**	**U4 Shannon**
Dam #1	1.6770	1.4271	1.2425	1.6490	1.1126	0.6365	0.5456	0.0000
Dam #2	1.2343	1.5380	1.3366	1.7482	1.0986	0.8516	0.000	0.5586
Dam #3	1.0382	0.0000	0.6931	0.0000	0.0000	0.0000	0.0000	0.6931
Dam #4	0.0000	1.0735	1.3863	0.4506	0.5623	1.3322	0.0000	0.6931
Dam #5	0.0000	0.0000	0.6365	0.0000*	0.0000	0.0000	0.0000	1.4708*

*Indicates the values omitted due to U4 of Dam #5 being an outlier

Table 5: Number of Macroinvertebrates Caught at all Sampling Locations. These values were used for the independent-samples t-tests for all dams individually (see Table 11 for results).

	D1 Number	**D2 Number**	**D3 Number**	**D4 Number**	**U1 Number**	**U2 Number**	**U3 Number**	**U4 Number**
Dam #1	9	9	6	19	21	3	17	1
Dam #2	12	49	30	12	3	21	0	28
Dam #3	34	1	14	1	1	1	5	2
Dam #4	0	8	4	6	4	5	0	2
Dam #5	0	0	3	1*	0	2	0	10*

*Indicates the values omitted due to U4 of Dam #5 being an outlier

Table 6: Water Quality Measures Analyzed in Lab. These values were used for the Mann-Whitney U-Tests for all dams individually (see Table 12 for results).

		Total P (µg/L)	**Total N** (mg/L)	**Turbidity** (Jackson Units)	**Conductivity** (microsiemens)	**pH**
Dam #1	**SD1**	3.9	0.251	12	323.4	8.02
	SD2	< 3	0.231	8	317.9	8.01
	SU1	< 3	0.171	8	322.3	8.03
	SU2	< 3	0.206	12	320.1	8.06
Dam #2	**SD1**	< 3	0.195	8	321.2	8.02
	SD2	< 3	0.159	12	324.5	7.99
	SU1	< 3	0.113	8	325.6	8.08
	SU2	< 3	0.174	8	326.7	8.1
Dam #3	**SD1**	18.4	0.515	12	256.5	7.72
	SD2	10.3	0.463	12	255.5	7.78
	SU1	9.6	0.455	12	257.6	7.81
	SU2	7.8	0.171	12	268.2	7.66
Dam #4	**SD1**	11.9	0.475	12	252.3	7.7
	SD2	11.6	0.412	8	259.7	7.66
	SU1	10.7	0.421	12	254.4	7.67
	SU2	8	0.411	12	247.0	7.65
Dam #5	**SD1**	10.4	0.424	12	254.4	7.8
	SD2	8.9	0.402	8	254.4	7.78
	SU1	8.4	0.434	12	253.3	7.73
	SU2	93.9	0.609	12	305.3	7.05

Table 7: Flow Rate and Dissolved Oxygen at all Sampling Locations. These values were used for independent-samples t-tests for all dams individually (see Table 12 for results).

	Dam #1							
	D1	**D2**	**D3**	**D4**	**U1**	**U2**	**U3**	**U4**
Flow (m/s)	.18	.18	.21	.18	.21	.06	.23	.01
Dissolved Oxygen (mg/L)	9.42	9.53	9.35	9.43	9.45	9.33	9.23	8.72

	Dam #2							
	D1	**D2**	**D3**	**D4**	**U1**	**U2**	**U3**	**U4**
Flow (m/s)	.21	.31	.73	.29	.31	.11	.62	.20
Dissolved Oxygen (mg/L)	8.78	8.71	8.80	8.68	8.74	8.69	8.87	8.68

	Dam #3							
	D1	**D2**	**D3**	**D4**	**U1**	**U2**	**U3**	**U4**
Flow (m/s)	.25	-.02	.49	-.06	.11	.17	.03	.07
Dissolved Oxygen (mg/L)	8.83	8.11	8.74	8.44	8.52	8.46	8.59	8.74

	Dam #4							
	D1	**D2**	**D3**	**D4**	**U1**	**U2**	**U3**	**U4**
Flow (m/s)	.11	.40	.20	.16	.20	.23	.12	.14
Dissolved Oxygen (mg/L)	8.30	8.71	8.56	8.85	8.62	8.77	8.72	8.67

	Dam #5							
	D1	**D2**	**D3**	**D4**	**U1**	**U2**	**U3**	**U4**
Flow (m/s)	.31	-.02	.43	.09	.14	.23	.12	.40
Dissolved Oxygen (mg/L)	9.14	8.23	9.15	8.57	8.60	8.66	8.52	8.58

Table 8: Combined Shannon-Weiner Indices for all Dams. These values were calculated by grouping all four downstream and upstream macroinvertebrate collections together, and calculating two combined indices per dam. These values were used for a paired-samples t-test involving all five dams (see Table 13 for results).

	Downstream Combined Shannon	**Upstream Combined Shannon**
Dam #1	1.9345	1.2170
Dam #2	1.6727	1.4003
Dam #3	1.3335	.8487
Dam #4	1.5644	1.5157
Dam #5 (with outlier)	1.0397	1.6762
Dam #5 (without outlier)	.6365	.0000

Table 9: Sorensen's Index for all Dams. These values were calculated to assess the percent similarity between the downstream and upstream macroinvertebrate communities for each dam. These values were used in regression analysis (see Figure 8 for results).

	Dam #1	**Dam #2**	**Dam #3**	**Dam #4**	**Dam #5**
Sorensen's Index	0.5882	0.5333	0.5000	0.5454	0.667

Table 10: Analysis of Shannon Indices of Individual Dams. These are the results from the independent-samples t-tests ran for all five dams individually. The mean downstream and upstream Shannon-Weiner indices were displayed in this table to show the direction of the relationship.

	Dam #1	**Dam #2**	**Dam #3**	**Dam #4**	**Dam #5** (With Outlier)	**Dam #5** (Without Outlier)
Mean Shannon Downstream	1.4989	1.4989	.4328	.7276	.1591	.2122
Mean Shannon Upstream	.5737	.5737	.1733	.6469	.3677	0
P-Value	.005*	.0095*	.219	.426	.3105	.35

* indicates statistical significance with α = .05

Table 11: Analysis of Number of Macroinvertebrates of Individual Dams. These are the results from the independent-samples t-tests ran for all five dams individually. The mean downstream and upstream numbers of macroinvertebrates were displayed in this table to show the direction of the relationship.

	Dam #1	**Dam #2**	**Dam #3**	**Dam #4**	**Dam #5** (With Outlier)	**Dam #5** (Without Outlier)
Mean Number Downstream	10.75	25.75	12.5	4.5	1	1
Mean Number Upstream	10.5	13	2.25	2.75	3	.3333
P-Value	.4835	.1485	.14	.2115	.2255	.5

Table 12: Analysis of Water Quality of Individual Dams. These are the p-values from the Mann-Whitney U-Tests performed for total N, total P, conductivity, turbidity, and pH. The p-values from the independent-samples t-tests for flow and dissolved oxygen also are below.

	Dam #1	Dam #2	Dam #3	Dam #4	Dam #5
Total N	.167	.333	.167	.333	.167
Total P	.333	.500	.167	.167	.5
Conductivity	.5	.167	.167	.333	.5
Turbidity	.5	.333	.5	.333	.333
pH	.167	.167	.5	.333	.167
Flow	.1765	.329	.3065	.2885	.437
Dissolved Oxygen	.09	.4815	.397	.2445	.240

Table 13: Analysis of Shannon Indices and Number of Macroinvertebrates of All Dams Grouped Together. These are the results from the paired-samples t-tests performed for the Shannon-Weiner indices and also the number of macroinvertebrates over all five dams. The mean differences were displayed to show the direction of the relationship.

	Shannon (With Outlier)	**Shannon** (Without Outlier)	**Number** (With Outlier)	**Number** (Without Outlier)
Mean Difference (Downstream – Upstream)	.1774	.4320	18.4	20.2
P-Value	.2435	.012*	.0945	.066

* indicates statistical significance with $\alpha = .05$

Table 14: Regression Analysis Results. This table displays the results from the five regression analyses. The Shannon-Weiner indices and numbers of macroinvertebrates regression analyses were run twice each to highlight the effect of excluding the outlier. Because the inclusion or exclusion of the outlier did not change any Sorensen's Index values, only one regression analysis was performed. See Figures 4 through 8 for the corresponding scatter plots and regression lines.

	P-Value	**R^2**	**Slope**
Difference in Upstream and Downstream Shannon-Weiner Indices (With Outlier) *vs.* **Dam Class**	.649	.078	-.077
Difference in Upstream and Downstream Shannon-Weiner Indices (Without Outlier) *vs.* **Dam Class**	.358	.281	-.077
Difference in Upstream and Downstream Numbers of Macroinvertebrates (With Outlier) *vs.* **Dam Class**	.626	.089	-4.143
Difference in Upstream and Downstream Numbers of Macroinvertebrates (Without Outlier) *vs.* **Dam Class**	.595	.105	-4.143
Sorensen's Index *vs.* **Dam Class**	.674	.067	.009

Table 15: Substrate Composition Downstream and Upstream at All Dams. From our observations of substrate composition at all eight locations per dam, we compiled this table to give a rough idea of the types of substrate found downstream and upstream of each of the dams. "OM" stands for "Organic Matter," indicating a fine, muddy substrate.

	Dam #1	**Dam #2**	**Dam #3**	**Dam #4**	**Dam #5**
Substrate Downstream	Fine sand, silt, OM	Fine sand to gravel, tree branches and twigs in one area	Gravel to cobbles, OM, tree branches in one area, fine to medium sand	Half with fine sand and silt and OM, half with gravel to small cobbles	Fine sand, silt, OM, one area with lots of tree branches
Substrate Upstream	Fine to coarse sand, silt, lots of OM	Fine to medium sand mostly, OM in one area, silt in one area	Fine to medium sand, wood chips and leaves	Fine to medium sand, some silt, OM, some areas with gravel and pebbles	Fine sand, gravel to medium pebbles, OM, one area with large pieces of wood

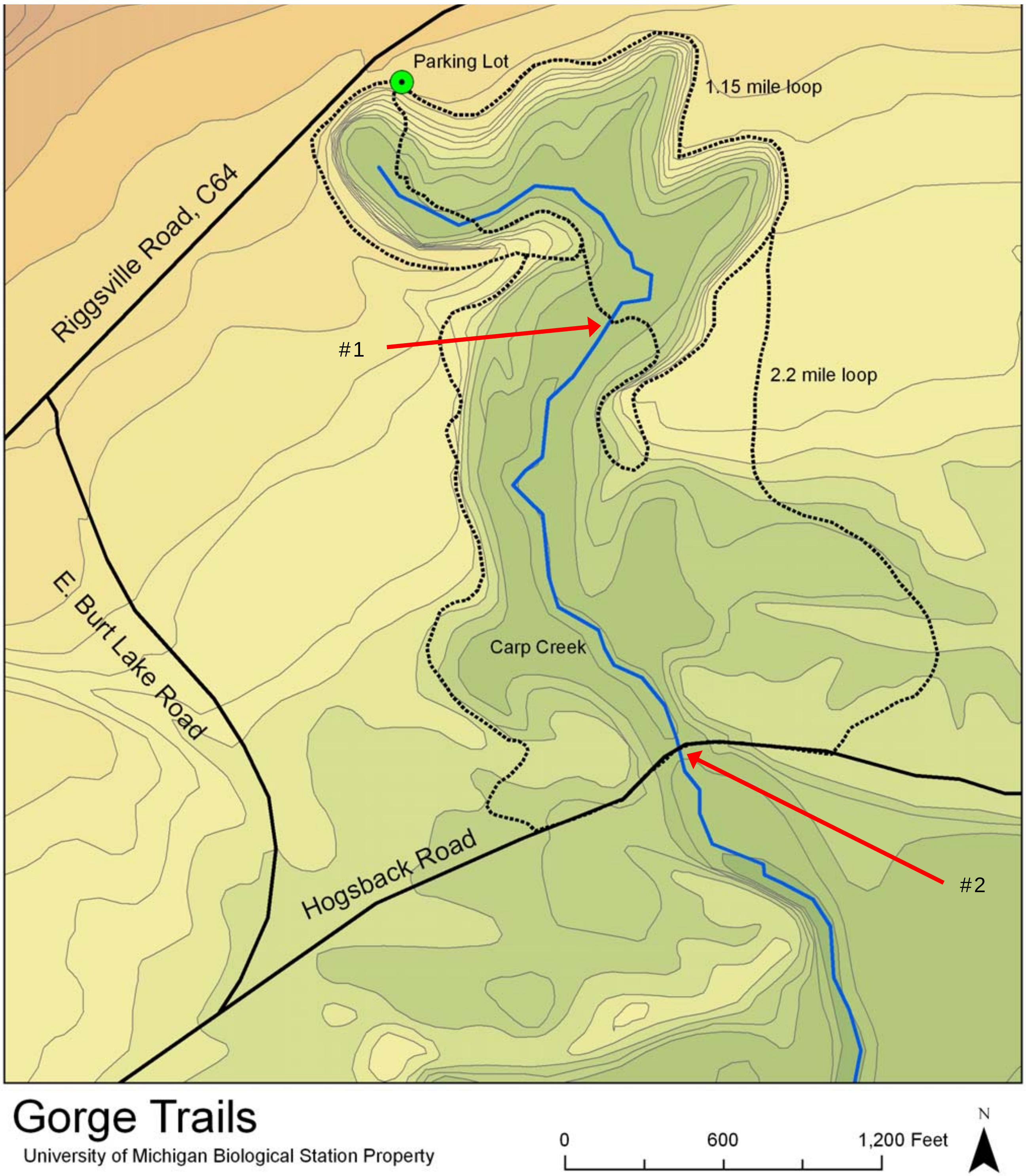

Figure 1: Map of Beaver Dam Locations on Carp Creek. (Gorge trail map adapted from the UMBS Sitemaker website).

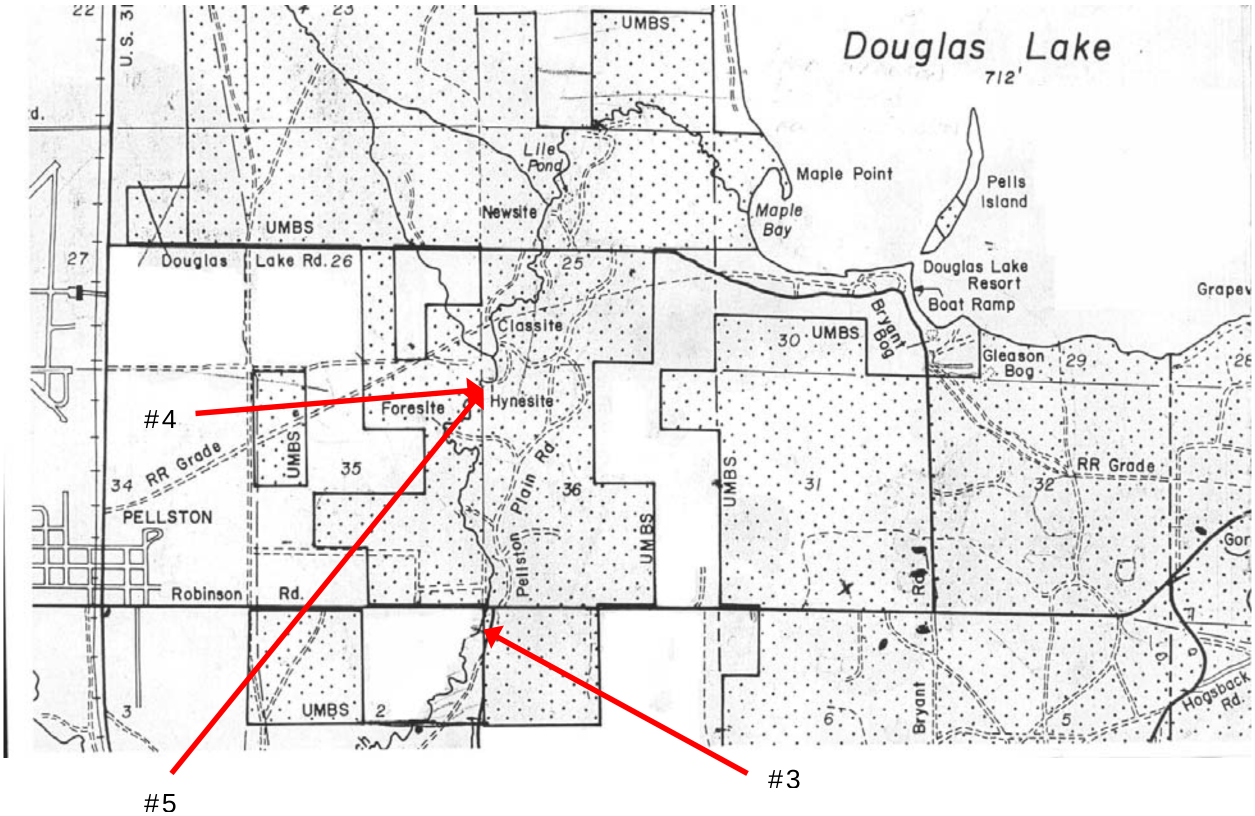

Figure 2: Map of Beaver Dam Locations on Maple River. (Adapted from Bob Vande Kopple's personal map collection)

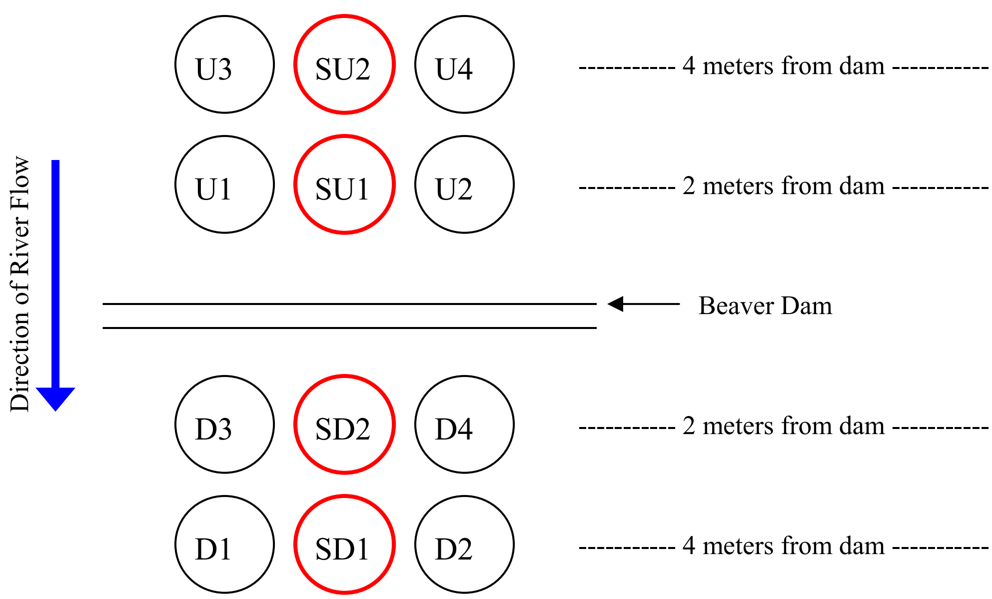

Figure 3: Diagram of Sampling Locations. The circles represent sampling locations relative to the beaver dam. Red circles indicate water sampling locations. The black circles show sampling locations for DO, flow rate, temperature and macroinvertebrates.

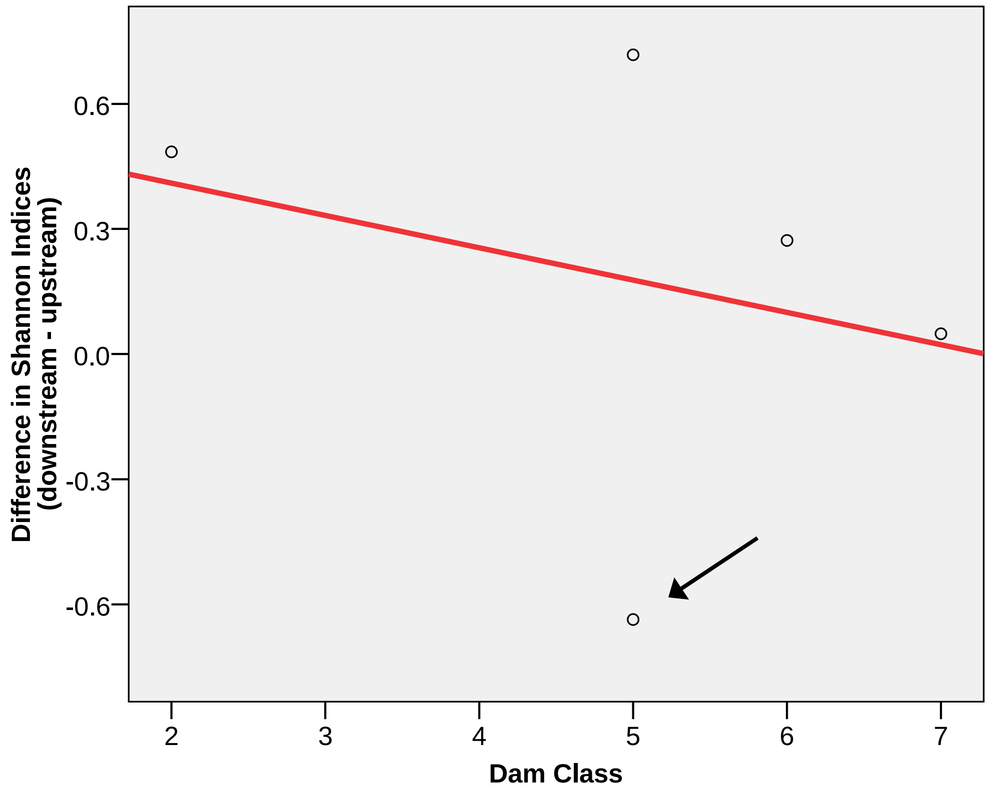

Figure 4: Correlation Between Difference in Shannon Indices (With the Outlier) and Dam Class. The location of the data point influenced by the outlier is shown with an arrow.

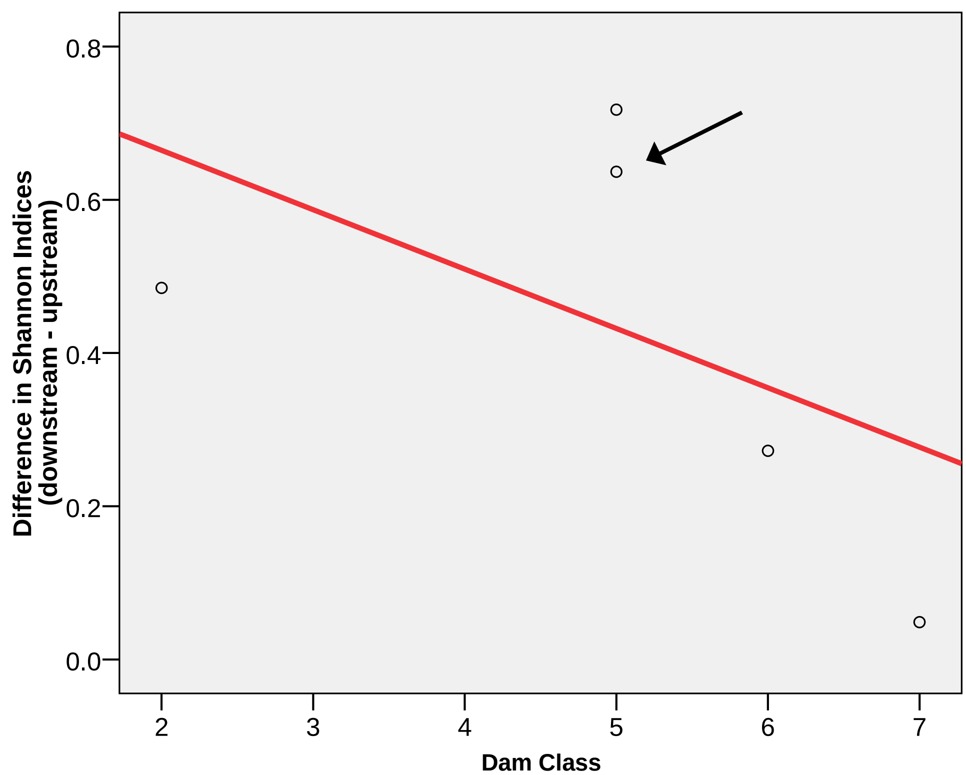

Figure 5: Correlation Between Difference in Shannon Indices (Without the Outlier) and Dam Class. The new location of the data point without the outlier is shown with an arrow.

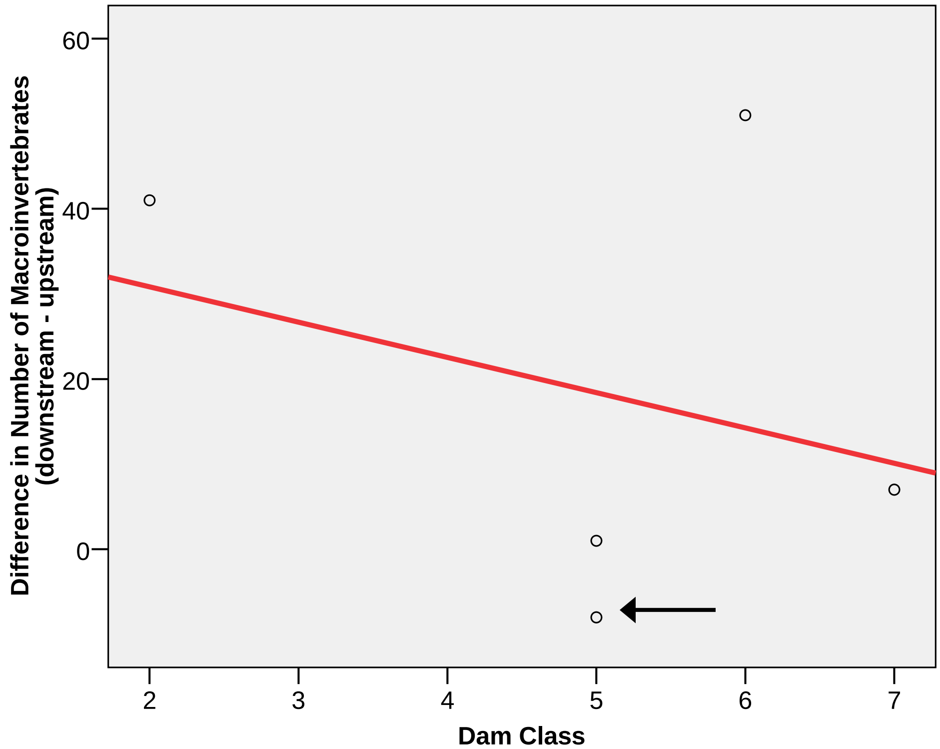

Figure 6: Correlation Between Difference in Number of Macroinvertebrates (With the Outlier) and Dam Class. The location of the data point influenced by the outlier is shown with an arrow.

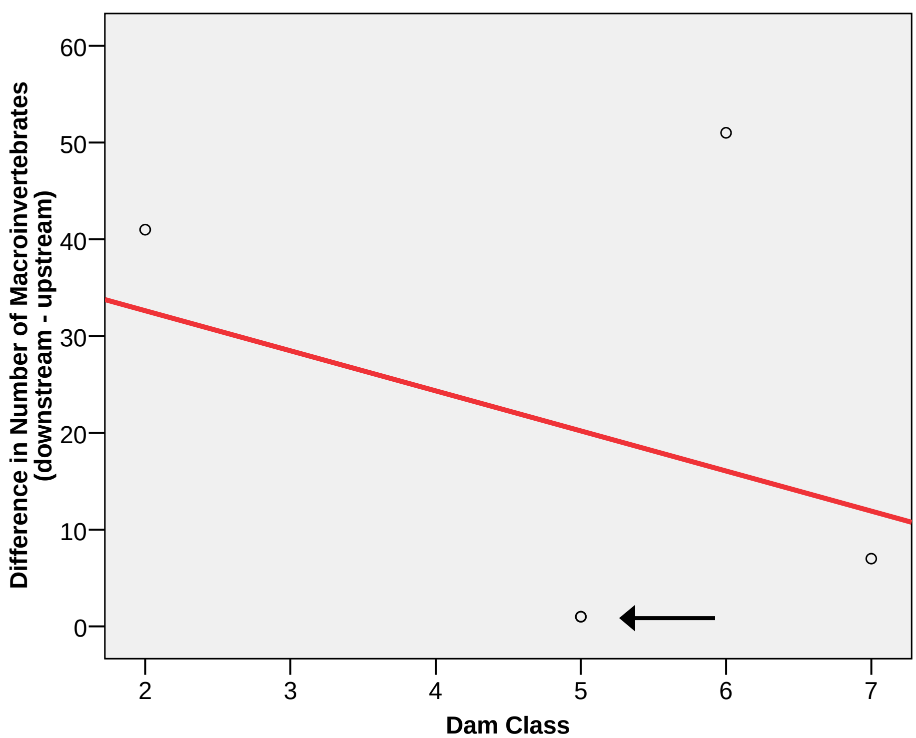

Figure 7: Correlation Between Difference in Number of Macroinvertebrates (Without the Outlier) and Dam Class. The new location of the data point without the outlier is shown with an arrow. Note that the two data points for dam class 5 are overlapping.

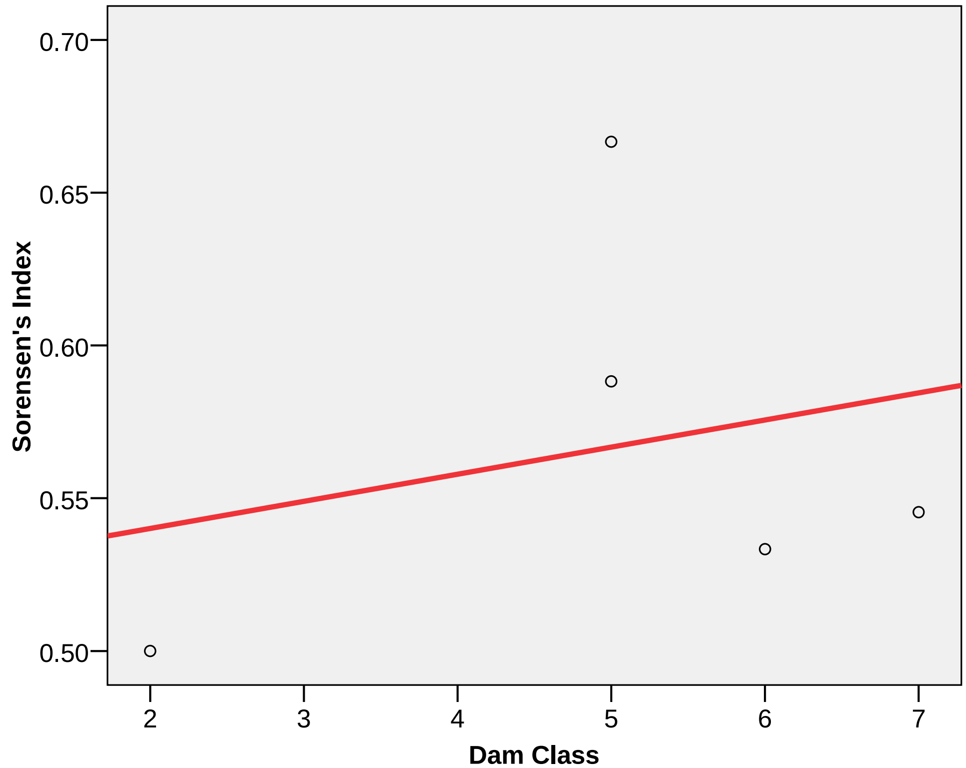

Figure 8: Correlation Between Sorensen's Index and Dam Class.