

Barton Springs Pool Beach Recirculation Pilot Project

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Nuisance algae and sediment deposition have been persistent problems at Barton Springs Pool, for both patron enjoyment and Barton Springs Salamander habitat. One method of control proposed in the recent Barton Springs Master Plan involved using water velocity manipulation to scour sediment and deter algae growth. Previous studies indicated that increasing velocities along the sediment layer had potential to naturally select for less nuisance algae and result in more natural algal cover of the substrate. The objective of this study was to determine the effect of water re-circulation on potential salamander habitat at Barton Springs Pool. Experiments were conducted in Barton Springs Pool using plots of substrate under different velocity regimes. The results indicated that community composition exhibited short-term succession from epilithic algae (Batrachaspermum sp., periphyton, and brown/green carpet algae) to Spirogyra sp. to Cladophora sp. The results have shown increasing water velocity over the substrate reduces sediment accumulation and nuisance algae. These experiments have also shown that full scale implementation of a recirculation project is impractical. The amount of water movement necessary to achieve the level of sediment and algae control noted in these experiments is beyond what could be supplied through a reasonably sized pump and manifold system. Given the size of the area to be improved, pumping costs would exceed benefits dramatically. A more practical approach may be modifying the outlet structure to direct velocities along the sediment layer.

Introduction

Periphyton, as a primary producer in stream and lake systems, is an integral part of the stream ecosystem and dominates the base of many freshwater trophic webs. Composition and abundance of periphyton are related to substrate, nutrient availability, water flow velocities, light, and disturbance, among other parameters (Biggs *et al.*, 1998; Graham and Wilcox, 2000).

Barton Springs Pool has undergone anthropogenic transformation over the last 100 years resulting in a transition of flow regime from a creek system to a pond-like system. One of the major complaints by patrons and a focus of management efforts by staff at the Pool is the overabundance of nuisance algae. Biggs *et al.* (1998) showed that a velocity of 0.3 m/s (0.984 ft/s) was sufficient in controlling filamentous dominated algal communities. To reconstruct a more natural system and attempt to naturally control the nuisance algae, City staff believes the existing flow regime at Barton Springs Pool should mimic creek-like flow, to the extent possible and practicable

In addition to controlling nuisance algae, increased water velocity along the substrate may improve habitat for the endangered species *Eurycea sosorum* (City of Austin data).

Eurycea sosorum habitat includes interstitial space in gravel and cobble substrate at the spring mouths of Barton Springs. Sediment accumulation within this interstitial space potentially affects the hiding, foraging, and potential courtship of *E. sosorum* (City of Austin data). Salamander prey items also utilize the interstitial space of the substrate; therefore, sedimentation of the interstitial space may directly and indirectly affect *E. sosorum*.

Sediment deposition in salamander habitat and nuisance algae proliferation were identified as two problems requiring additional investigation in the recent Barton Springs Pool Master Plan (Limbaucher & Godfrey, 2008). Therefore, pilot testing of mechanical methods of increasing substrate water velocity were suggested. Two experiments were conducted, the first from December 2007 – March 2008 and the second from May 2008 – July 2008, to assess potential effects of increased water velocity on the periphyton community and accumulation of sediment. Both experiments were conducted in the same location on the downstream “beach” area of Barton Springs Pool (Figure 1), an artificially formed ledge covered in gravel along the north side of the pool and U.S. Fish and Wildlife Services (USFWS) designated *E. sosorum* habitat (USFWS, 1998).

This pilot project was designed to gain an understanding of how increasing water velocity in a small area over substrate on the “beach” in Barton Springs Pool will 1) improve salamander habitat by lowering percent sediment cover and average sediment depth and 2) reducing the abundance of green filamentous algae within the algal community.

Figure 1. Aerial Image of study site (outlined in yellow) within Barton Springs Pool.



Image courtesy of Google Earth.

The two experiments designed for this study address the following hypotheses:

Water velocity has been shown to impact the biological and physical characteristics of the benthos (Graham and Wilcox, 2000). Velocity treatments (μ_t) compared to the control (μ_c) will be tested, where the null hypothesis states that there is no difference in flow velocity, sediment depth, percent sediment cover, or algal community composition between the treatment and the control areas.

$H_0: \mu_c = \mu_t$

Alternative hypothesis 1 is that the velocity in the treatment area is different from the control area.

$H_1: \mu_c \neq \mu_t$

Alternative hypothesis 2 states that taxonomic composition of algae will be different between control and treatment areas due to differences in water velocity.

$H_2: \mu_c \neq \mu_t$

Alternative hypothesis 3 states that sediment depth and sediment cover will be statistically different between control and treatment sites due to velocity controlled settling of suspended sediments.

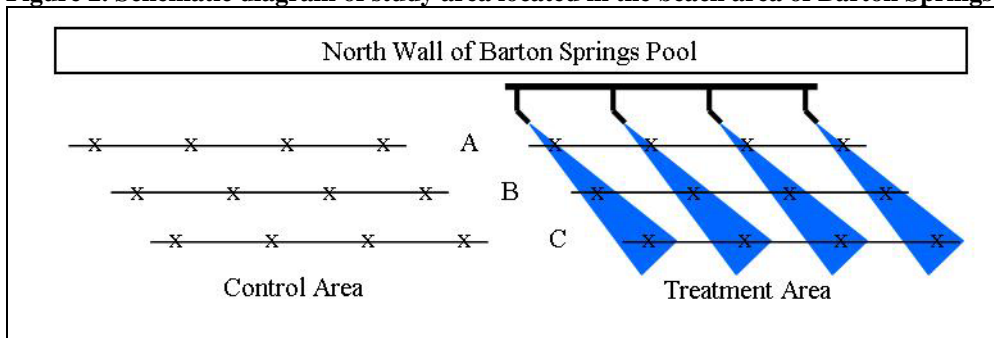
$H_3: \mu_c \neq \mu_t$

Methods

The study area consisted of a treatment area and an adjacent control area (Figure 2). The treatment area was approximately 4 ft. long, running along the base of the beach wall, and approximately 3 ft. wide. A submerged Grundfos 4" 3-wire submersible deep well pump (10 gpm) located on the lower dam of Barton Springs Pool pumped water from the downstream end of Barton Springs Pool through a standard garden hose into the re-circulation device, a rigid PVC manifold. Four outlets forced flow downstream from the re-circulation device at 45° angles from the wall at the substrate level. The outlets were 1" PVC caps with a slit cut across the diameter of the cap, to force the flow across the substrate. Slit size in the nozzle was determined by maximizing flow velocity from the nozzle at maximum pumping capacity, through trial and error.

An adjacent area of similar size, substrate, and canopy cover was the control area. The control received no artificial flow treatment and natural water velocity remained unaltered by the recirculation device.

Figure 2. Schematic diagram of study area located in the beach area of Barton Springs Pool.



Sampling locations are designated as X. Not to scale.

During experiment 1 (Dec 2007 – Mar 2008), transects were located parallel to the manifold every foot from immediately in front of the manifold outlets to two feet from the manifold along the flowpath (Figure 2). All measurements were taken at the substrate surface. Transects were measured identically in the control area, with the absence of the recirculation manifold. Each transect has four sampling sites, one in front of each outlet. These sampling sites remained the same throughout the length of this project. Setting transects one foot apart in the study area provides data at various substrate water velocities.

After the first three months, the pump malfunctioned and flow ceased. Once the pump was repaired and previously collected data were reviewed, experiment 2 (May 2008 – July 2008) sampling began with transects A-C being two feet apart each (instead of one foot as in experiment 1). In other words, transect A was just in front of the nozzles, transect B was 2 ft. from transect A following the 45° direction of water flow. This allowed lower flows to be monitored, and a minimum threshold of effects potentially determined.

Sampling was conducted monthly for 4 months (experiment 1) and 3 months (experiment 2) usually on Thursdays when Barton Springs Pool was closed for cleaning.

Water Velocity

Velocity was measured monthly at each sampling location within the study area at the substrate using a Marsh-McBirney flow meter. The flow meter was oriented in the direction of flow from the nozzles. Water velocity was averaged over a 30 second time interval for each measurement and recorded in ft/sec.

Community Composition

Monthly periphyton sampling during Experiment 1 followed the Environmental Protection Agency's (EPA) Field Based Rapid Periphyton Survey method (Stevenson and Bahls 1999) with a few alterations. Community composition was split into 4 categories: Microalga 1 and 2 and Macroalga 1 and 2. Microalga refer to short, attached algae typically blue-green algae or carpet forming algae. Macroalga refer to long filamentous algae. A 10 dot randomized grid was used instead of 50 dot grid. Mat thickness of microalgal biomass was recorded to the nearest millimeter but not categorized as in the EPA method. Statistics used in this project's analysis were independent of the statistical characterization of algal density calculated by the EPA method, negating the need for categorization. The substrate of the beach area of Barton Springs Pool is beneath approximately 5 feet of water. Therefore, SCUBA diving was used to achieve the most accurate results, except when the pool was drawn-down.

Community composition during Experiment 2 was determined loosely following the EPA Field Based Rapid Periphyton Survey. A 10 dot randomized grid was still used, but instead of classifying algae based on Microalga 1 and 2 and Macroalga 1 and 2, algae were identified to genus, or type of algae if genus was unknown (attached filamentous,

unattached filamentous, etc.). This provided for easier comparisons among sampling periods.

Photographic Documentation

Photographs of the study area were taken during each sampling event to document visual changes in the benthic environment. Photographs were taken about 5 feet above the study site just before collecting monthly data. If the suspended solids and turbidity of the water interfered with photographic documentation, no photographs were taken.

Cover Types

Substrate type was collected following the EPA Field Based Rapid Periphyton Survey Method (Stevenson and Bahls 1999). At each sampling location fine sediment depth was measured to the nearest millimeter in addition to estimated sediment cover. This method provided data which addressed the depth of sediment and how much substrate area has a cover of sediment. These measurements are consistent with sampling at other salamander sites and were collected monthly with algal sampling.

Light

Algae grow by photosynthesis, which is directly related to light penetration in the water column. Canopy cover was measured using a spherical densitometer, at control and treatment sites, to insure light was comparable between sites.

Other data

Observational data collected weekly throughout the study were weather (temperature high/low, cloud cover, recent precipitation) and water depth. Discharge was obtained from the US Geological Survey; and human disturbance, re-circulation device performance and maintenance were noted.

All parameters discussed above were collected prior to beginning experiment 1 to evaluate initial differences (using paired comparisons) between control and treatment areas before treatment began.

Statistical Analysis

Statistical analyses were performed using STATISTICA release 8 (Statsoft 2007), with a significance level (α) of 0.025. A Bonferroni correction was used to identify false significant differences. T-tests were used to determine differences between control and treatment areas for the following parameters: sediment depth, sediment coverage, and community composition. Community composition was also tested by the Mann-Whitney U Test to view statistical differences paired spatially over time. Experiments 1 and 2 were analyzed independently because of the different methodologies employed during each experiment. Experiment 1 was split into “active” and “inactive” periods, both periods were analyzed independently.

Results

Results from Experiment 1 and Experiment 2 are discussed separately, and general comparisons are discussed in a following section.

Pre-experiment Area Comparison

Control and treatment areas of the study site were not significantly different for most tested parameters before the experiment began (Table 1). A statistically significant difference was measured between mean water velocity in the Total treatment area (-0.02 fps \pm 0.02) and mean water velocity in the Total control area (0.00 fps \pm 0.017) ($p = 0.016$), but the mean \pm Standard Deviation (SD) was within the error of the Marsh McBirney flow meter used. These differences are not relevant because of the low range of water velocity values compared to our treatment velocity conditions.

Table 1. Pre-experiment comparison of A) parameter mean values and B) p-values between control and treatment (Tmt) areas.

A) Mean	Transect	Water Velocity (fps)	Sediment Cover (%)	Sediment Depth (mm)	Macro 1	Micro 1
Control	A	-0.01	89	3	0	8
Control	B	0.00	79	2	0	9
Control	C	0.00	79	2	0	9
Tmt	A	-0.03	89	4	0	8
Tmt	B	-0.01	79	2	0	8
Tmt	C	-0.01	84	3	1	9
Control	All	0.00	82	2	0	9
Tmt	All	-0.02	84	3	0	8

B) P-values	Water Velocity	Sediment Cover	Sediment Depth	Macro 1	Micro 1
Tmt A vs Control A	0.113	1	0.769	1	0.800
Tmt B vs Control B	0.033	1	0.065	1	0.537
Tmt C vs Control C	0.655	0.114	0.295	1	1
Total Tmt vs Total Control	0.016	0.441	0.568	1	0.857

P-values compare transects and total area of treatment areas to control areas. Bolded values are significantly different with a Bonferroni correction (<0.025).

Experiment 1

Three months of data (12/6/2007, 01/03/2008, and 01/31/2008) were collected before the pump failed and are considered the “active period”. The “inactive period” consists of the remaining data (03/13/2008 and 3/21/2008), after the pump failed. Flow velocities for both the active and inactive periods can be seen in Table 2. During the “active period” sediment depth and % sediment cover were significantly greater in the control area than in the treatment area ($p = 0.000$ and $p = 0.000$, respectively). Macroalga cover 1 and macroalga cover 2 were statistically different ($p = 0.000$ and $p = 0.000$, respectively). The MWU Test supported the T-test result that macroalga cover 2 ($p = 0.002$) was

significantly different between the control and treatment areas, but the tests give different results for macroalga cover 1 (Table 3). In this situation, with mostly null values, a paired comparison test is the more appropriate analysis technique.

Table 2. Average flow velocities for individual transects separated by area and date.

		Mean Water velocity (fps)				
		Active Period			Inactive Period	
Area	Transect	12/6/2007	1/3/2008	1/31/2008	Total Active	3/13/2008
Control	A	-0.01	-0.06	-0.01	-0.03	-0.03
Control	B	0.00	-0.06	-0.02	-0.03	-0.02
Control	C	0.00	-0.05	-0.02	-0.02	-0.03
Tmt	A	1.97	1.94	2.11	2.01	-0.03
Tmt	B	0.47	0.57	0.49	0.51	-0.03
Tmt	C	0.30	0.35	-0.01	0.21	-0.02

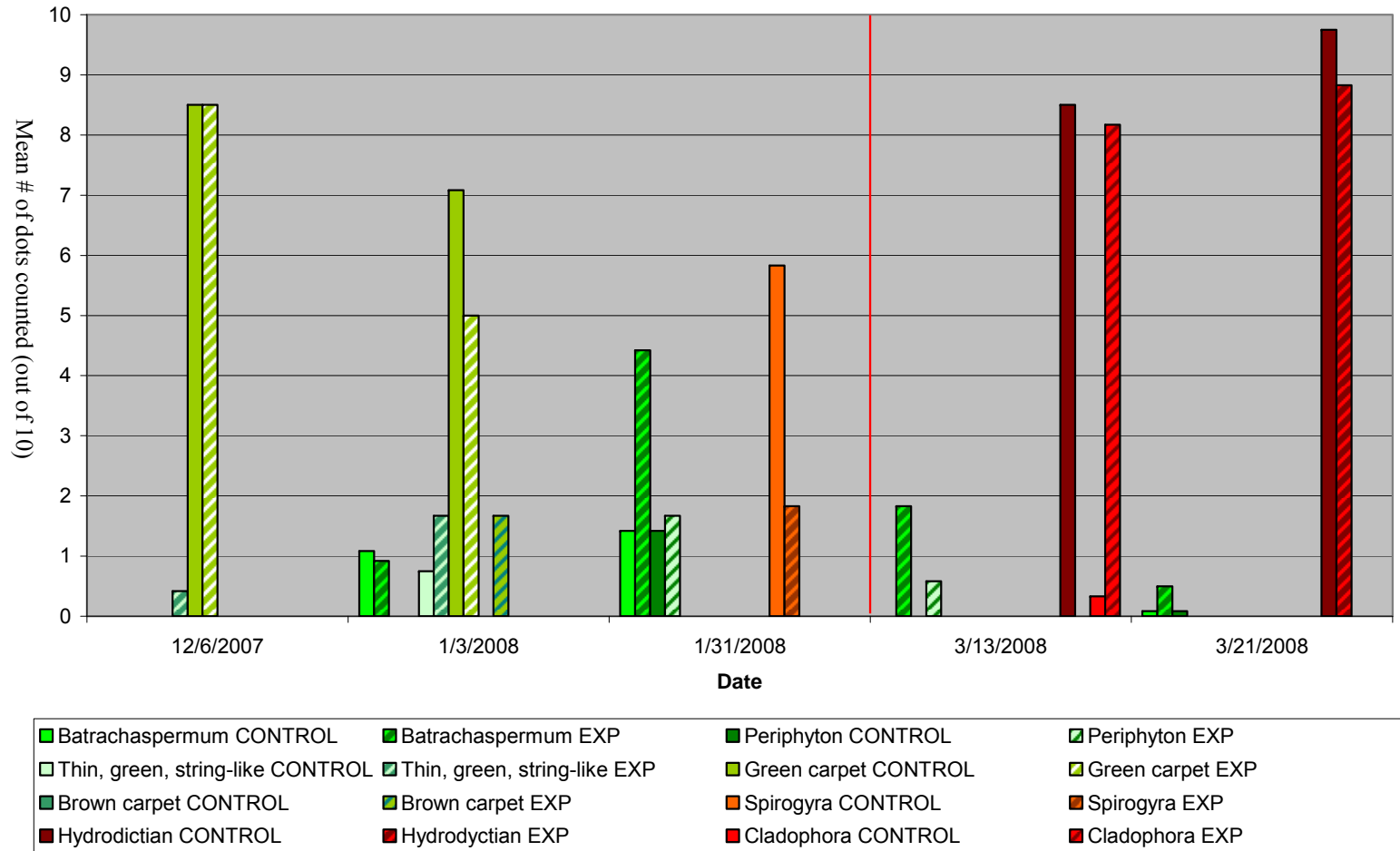
Table 3. Descriptive and nonparametric statistics for parameters during experiment 1 active period.

Parameter	Control mean	Treatment mean	p-value T-Test	p-value MWU Test
Sediment depth (mm)	3.86	1.54	0.000	----
Sediment cover (%)	81.56	55.73	0.000	----
Macroalga cover 1 (# dots)	3.77	1.43	0.000	0.044
Macroalga cover 2 (# dots)	0.71	3.38	0.000	0.002
Microalga cover 1 (# dots)	4.25	3.79	0.550	0.654
Microalga cover 2 (# dots)	0.00	0.42	0.048	0.481

Bolded values are significantly different with a Bonferroni correction (<0.025).

The difficulty in interpreting algal composition as categorized here (with EPA method categories) with respect to Barton Springs ecology is that the algal type within each community composition category changed over sampling periods. For example, Macroalga cover 2 was *Batrachospermum sp.* on 1/13/2008 and *Cladophora sp.* on 3/13/2008. Changes in community composition are presented graphically in Figures 3 - 5. Generally speaking, there is greater diversity in distribution and types of algae in the treatment area than the control area. The control area reverts to nuisance algae faster than the treatment area. A bloom of *Spirogyra* was recorded on 1/31/2008, but was less than half as dominant in the treatment area as in the control area. An example of visual differences observed between the treatment and control areas show thick unattached benthic mats of *Spirogyra* in no flow (control area) while periphyton and *Batrachospermum sp.* dominate in higher flows (treatment area) (Figure 6).

Figure 3. Barton Springs Pool algae displayed by algal type and date over the course of Experiment 1.



Values displayed are averages of all sample sites and transects in the control or treatment area for a given date. Solid bars represent control areas and striped bars represent treatment areas. Green tones indicate beneficial algae and red tones indicate nuisance algae. The vertical red line represents the point in time that the pump shut down.

Figure 4. Barton Springs Pool Algae: Experiment 1 Active Period

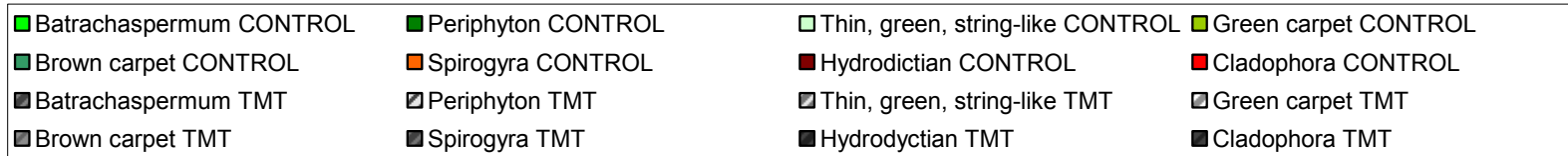
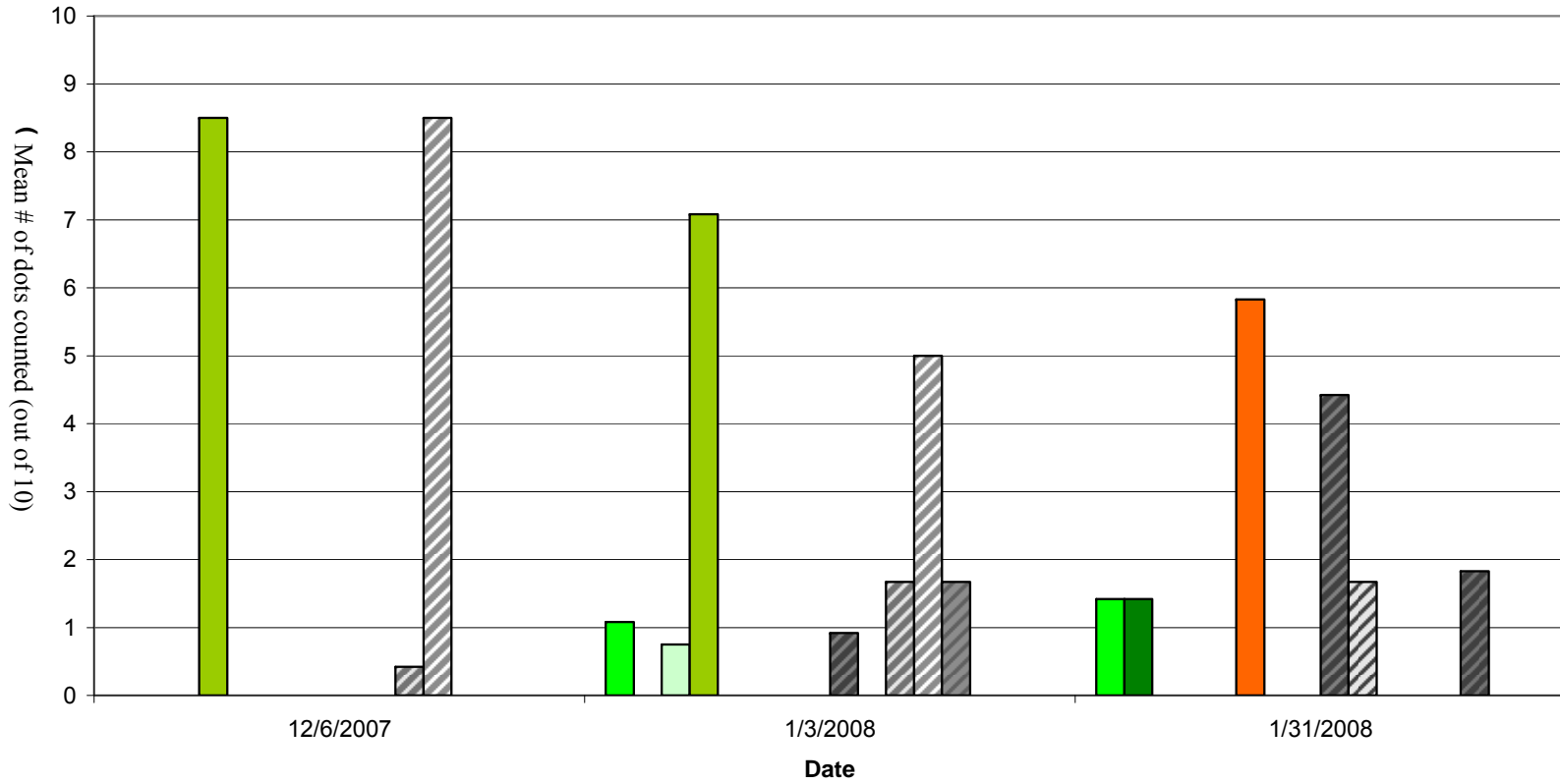


Figure 5. Barton Springs Pool Algae: Experiment 1 Inactive Period

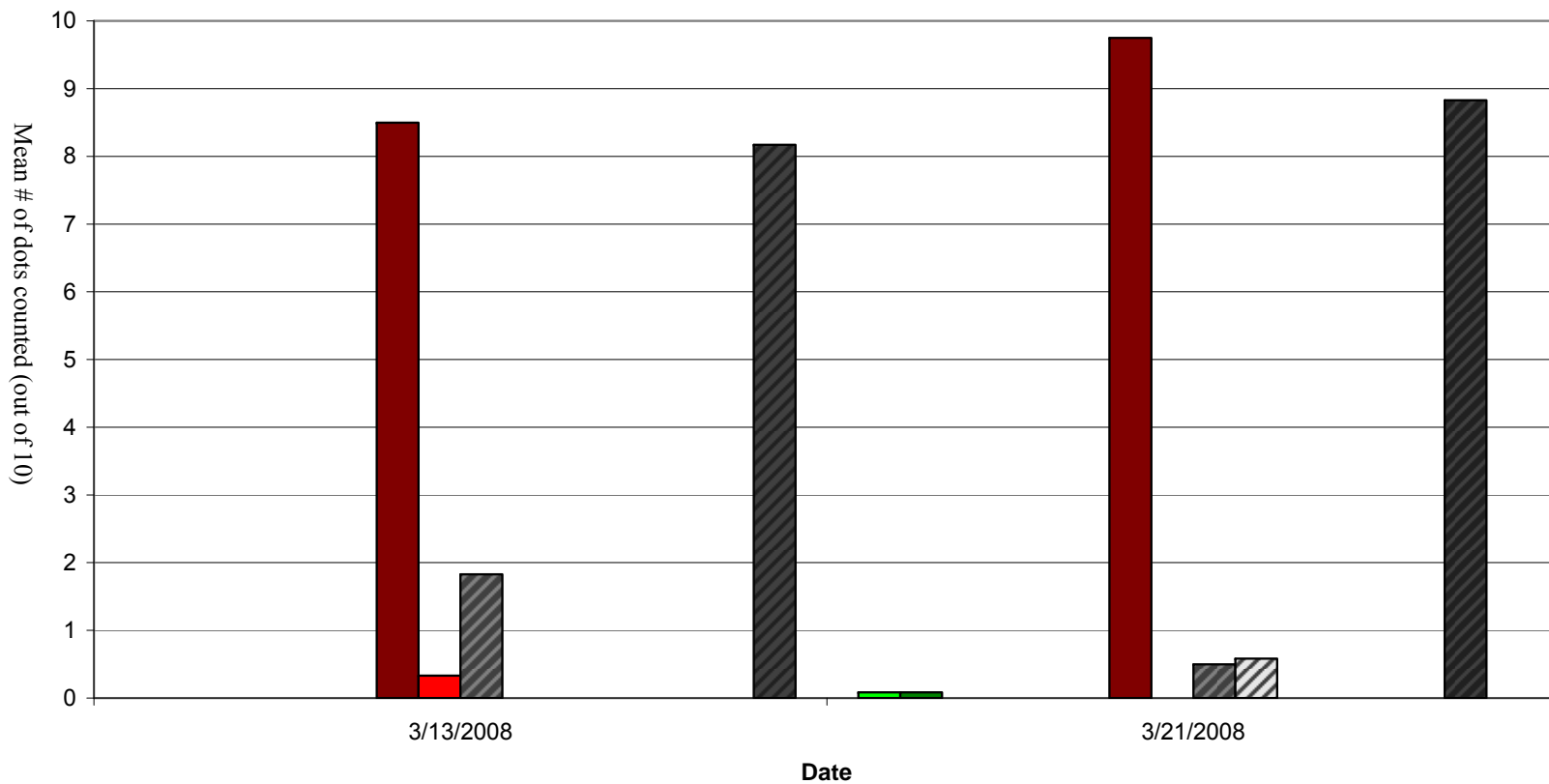
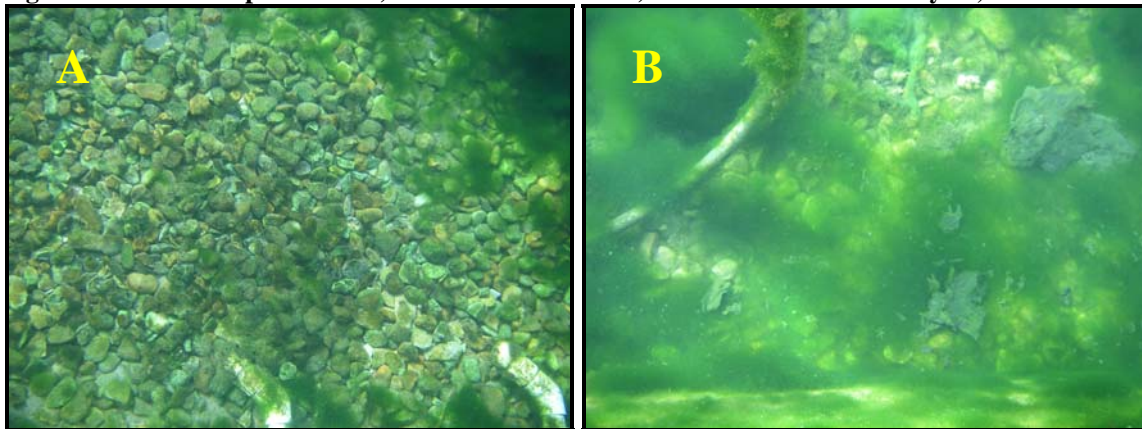


Figure 6. Visual comparison of a) treatment area and b) control area on February 14, 2008.



Neither sediment depth nor sediment cover was statistically different among transects in either the treatment or control areas, except from treatment transects A to C ($p = 0.018$) (Table 4). Community composition was not significantly different from transect to transect in either treatment area (Table 4).

Table 4. Parameters examined from transect to transect displaying a) means over the active period and b) p-values of t-tests from transect to transect.

A) Means		sediment cover (%)	sediment depth (mm)	macro alga 1	macro alga 2	micro alga 1
Control	A	81.56	4.76	1.63	0.44	5.375
	B	78.44	3.41	2.69	0.19	5.5
	C	84.69	3.23	2.81	0.44	5.19
treatment	A	44.06	1.41	1.44	2.19	3.625
	B	53.44	1.51	1.25	2.25	3.125
	C	69.69	1.7	1.63	2.25	4.75

B) p-values		sediment cover	sediment depth	macro alga 1	macro alga 2	micro alga 1
Control	A → B	0.69	0.12	0.42	0.32	0.93
	B → C	0.22	0.99	0.93	0.42	0.82
	A → C	0.66	0.12	0.36	1	0.89
treatment	A → B	0.43	0.73	0.75	0.96	0.71
	B → C	0.11	0.58	0.47	1	0.24
	A → C	0.02	0.41	0.76	0.96	0.4

Bolded values are significantly different with a Bonferroni correction (<0.025).

During the inactive period, sediment depth, sediment cover and macroalga cover 1 were statistically different ($p = 0.001$, $p = 0.000$, and $p = 0.021$, respectively) between the treatment and control areas (Table 5). Viewing 03/21/2008 on Figure 3, the composition had changed from primarily beneficial algae (*Batrachaspermum sp.*) to nuisance algae (*Cladophora sp.*) in the treatment area. Despite this change in algal composition, *Batrachaspermum sp.* and periphyton in the treatment area persisted into the inactive

period (Figures 3 and 5). Regression analyses show no significant correlation between algae type and flow velocity for all data in Experiment 1.

Table 5. Parameter means during inactive period and t-test results of differences between the control and treatment areas.

Parameter	Control mean	Treatment mean	p-value T-Test
Sediment depth (mm)	3.72	1.48	0.001
Sediment cover (%)	80.83	58.33	0.000
Macroalga cover 1 (# dots)	9.75	8.83	0.021
Macroalga cover 2 (# dots)	0.08	0.50	0.142
Microalga cover 1 (# dots)	0.08	0.58	0.052
Microalga cover 2 (# dots)	----	----	----

Bolded values are significantly different with a Bonferroni correction (<0.025). No data is shown as ----.

Experiment 2

Flow velocity did not remain stable over the course of Experiment 2 due to a leak in the pump system increasing in volume of water lost over time. ANOVA, conducted in STATISTICA, verified significant statistical differences in flow velocity over sampling dates for transect A (p = 0.000) (Table 6).

Table 6. Individually measured velocities and mean velocities across treatment transects and time with ANOVA results of transect means over time.

Transect	Flow velocity (fps)				ANOVA
	5/29/2008	6/26/2008	7/31/2008	9/4/2008	
A	1.03	0.96	0.35	0.45	p-value 0.000
	1.15	0.92	0.40	0.55	
	1.04	0.85	0.56	0.62	
	1.07	0.53	0.54	0.39	
	mean	<i>1.07</i>	<i>0.81</i>	<i>0.46</i>	
B	0.09	0.12	-0.02	0.11	p-value 0.050
	0.10	0.18	0.06	0.07	
	0.15	0.18	0.14	0.13	
	0.15	0.18	0.09	0.14	
	mean	<i>0.12</i>	<i>0.16</i>	<i>0.06</i>	
C	0.00	0.00	0.02	-0.01	p-value 0.096
	0.02	0.00	-0.03	0.01	
	0.10	0.00	-0.04	0.03	
	0.00	0.00	-0.10	0.05	
	mean	<i>0.03</i>	<i>0.00</i>	<i>-0.03</i>	

Bolded values are significantly different with a Bonferroni correction (<0.025).

In this experiment, sediment cover included dead flocculent material on the substrate surface. Sediment cover was not different among transects in the control area, but was significantly different between transect A and B (p = 0.000) and transect A and C (p = 0.000) in the treatment area (Table 7). Sediment depth in the control area decreased significantly (p = 0.000) with distance from transect A (Table 7).

Table 7. Parameters examined from transect to transect displaying a) means over Experiment 2 and b) p-values of t-tests from transect to transect.

Means	Transect	% sediment cover	sediment depth (mm)
control	A	100	49.92
	B	100	26.66
	C	100	14.48
treatment	A	51.88	3.33
	B	95.94	13
	C	98.44	13.24

p-values	Transect	% sediment cover	sediment depth (mm)
control	A → B	1.000	0.000
	B → C	1.000	0.000
	A → C	1.000	0.000
treatment	A → B	0.000	0.000
	B → C	0.217	0.886
	A → C	0.000	0.000

Bolded values are significantly different with a Bonferroni correction (<0.025).

Algae data was analyzed individually for each sample date (Tables 8 and 9) Macroalga 1 exhibited significant differences between treatment and control areas for all transects on 29-May-2008 and transects A and C on 31-Jul-2008. Remaining sampling dates exhibited no transects that were significantly different between the control and treatment areas. The majority of the points for Microalga 1 and 2 are zero, and are, therefore, not significantly different. Microalga 2 was significantly different for transect A on 26-Jun-2008.

Table 8. Mean Macroalga 1 and 2 counts across transects and time with T-test results comparing treatment and control transect means over time.

Date	Transect	MACROALGA 1			MACROALGA 2		
		Control Mean	Exp Mean	p-value	Control Mean	Exp Mean	p-value
29-May-2008	A	10	1	0.001	0	0	-
	B	10	2.5	0.000	0	0	-
	C	10	3.5	0.012	0	0	-
26-Jun-2008	A	6	3	0.315	0	0.75	0.107
	B	5	10	0.030	0	0	-
	C	10	8.75	0.146	0	0	-
31-Jul-2008	A	10	5.5	0.009	0	0	-
	B	10	5.75	0.098	0	0	-
	C	8.25	10	0.000	0	0	-
4-Sep-2008	A	10	9.5	0.355	0	0	-
	B	10	10	-	0	0	-
	C	10	9.75	0.355	0	0	-

Bolded values are significantly different with a Bonferroni correction (<0.025).

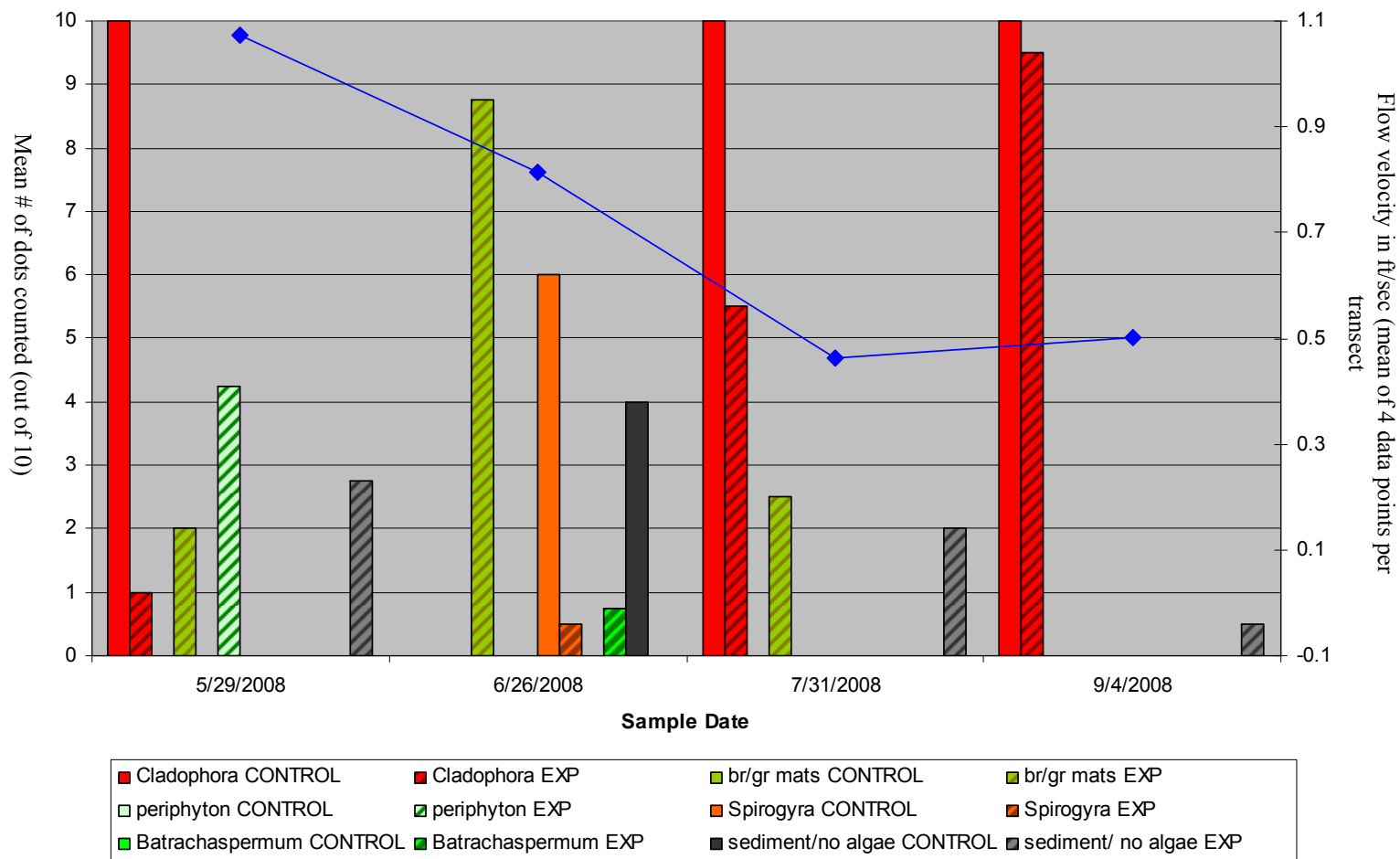
Table 9. Mean Microalga 1 and 2 counts across transects and time with T-test results comparing treatment and control transect means over time.

Date	Transect	MICROALGA 1			MICROALGA 2		
		Control Mean	Exp Mean	p-value	Control Mean	Exp Mean	p-value
29-May-2008	A	0	4.25	0.135	0	2.75	0.092
	B	0	4.25	0.070	0	0	-
	C	0	2.75	0.115	0	3.75	0.063
26-Jun-2008	A	0	6.25	0.032	4	0	0.025
	B	0	0	-	5	0	0.030
	C	0	0	-	0	1	0.134
31-Jul-2008	A	0	2.5	0.134	0	0	-
	B	0	2.5	0.355	0	0	-
	C	0	0	-	0	0	-
4-Sep-2008	A	0	0	-	0	0	-
	B	0	0	-	0	0	-
	C	0	0	-	0	0	-

Bolded values are significantly different with a Bonferroni correction (<0.025).

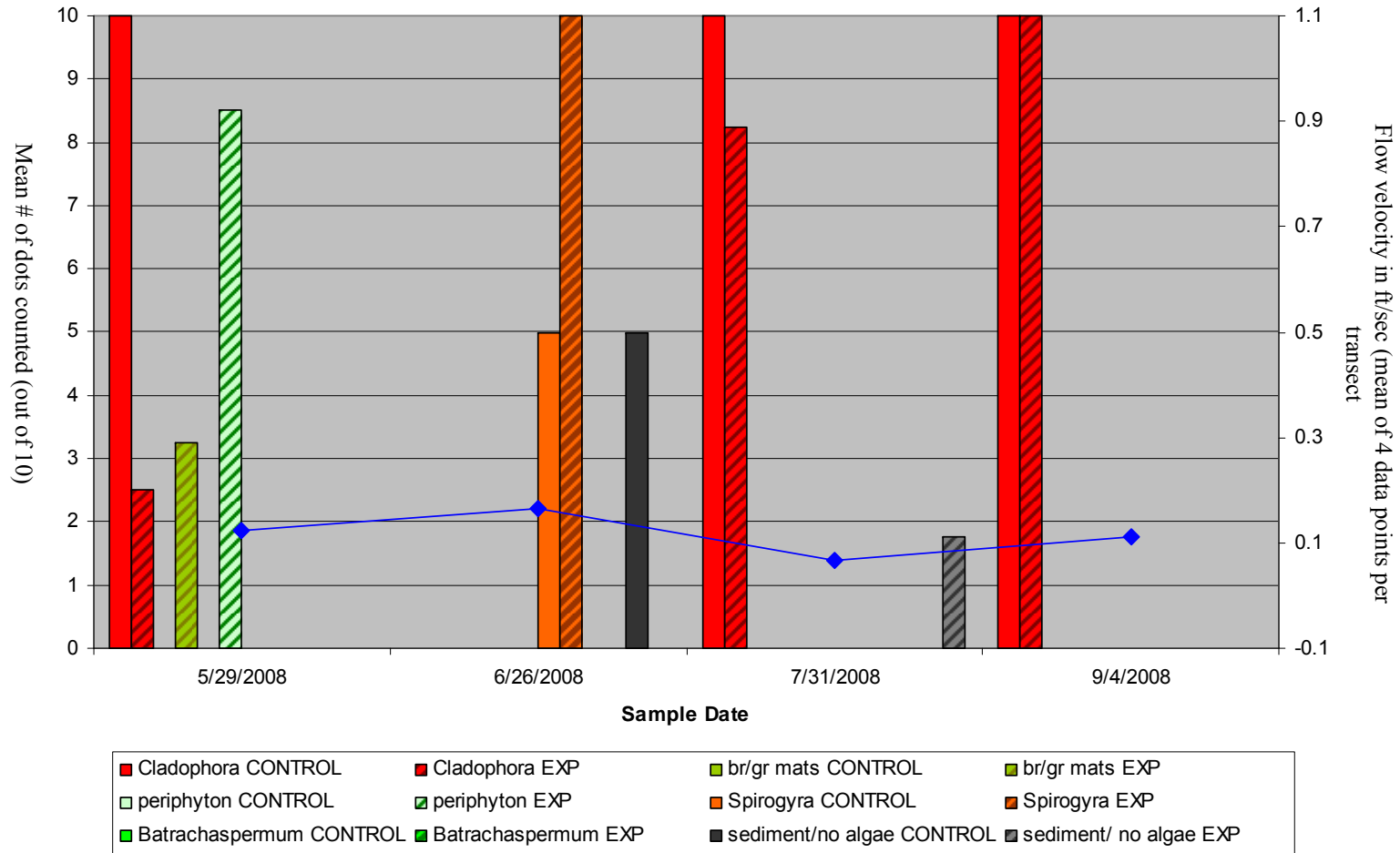
Due to changing algal types for each sampling period, assessing the data based on Macroalga and Microalga classification can be difficult. To better visualize changes in community composition, each algal type and treatment flow velocity have been plotted over time for each transect (Figures 7 – 9). All three transects show a greater diversity of algal types in the treatment area than the control area, and the control area tends to revert to nuisance algae faster than the treatment area. Regression analyses show no significant correlation between algae type and flow velocity for all data in Experiment 2.

Figure 7. Mean Barton Springs Pool algae of transect A (0 ft from apparatus) displayed by algal type and date over the course of Experiment 2.



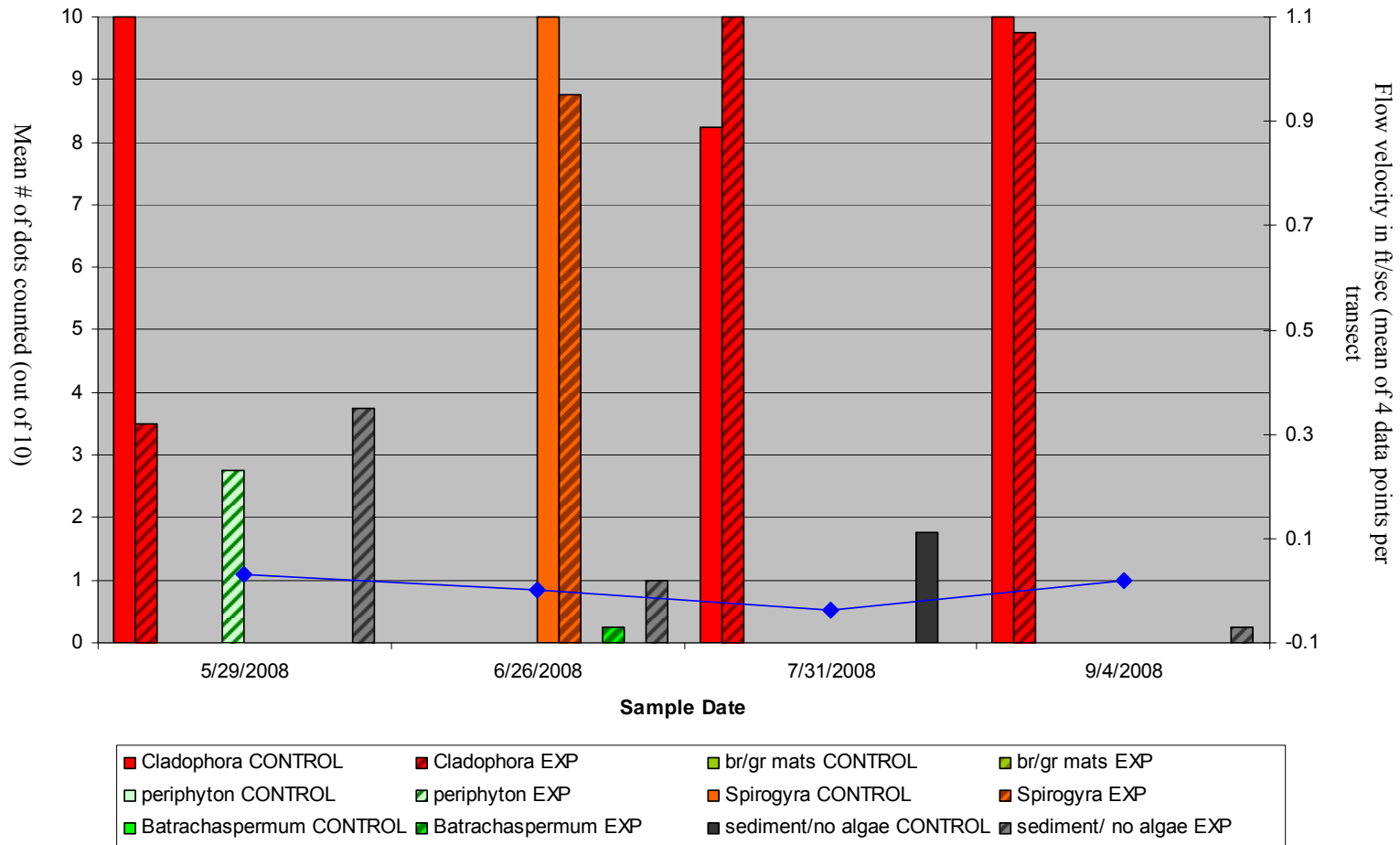
Solid bars represent control areas and striped bars represent treatment areas. Green tones indicate beneficial algae, red tones indicate nuisance algae, and gray tones indicate sediment/no algae. The blue line plot represents mean flow measurements in the treatment area during sampling events.

Figure 8. Mean Barton Springs Pool algae of transect B (2 ft from apparatus) displayed by algal type and date over the course of Experiment 2



Solid bars represent control areas and striped bars represent treatment areas. Green tones indicate beneficial algae, red tones indicate nuisance algae, and gray tones indicate sediment/no algae. The blue line plot represents mean flow measurements in the treatment area during sampling events .

Figure 9. Mean Barton Springs Pool algae of transect C (4 ft from apparatus) displayed by algal type and date.



Solid bars represent control areas and striped bars represent treatment areas. Green tones indicate beneficial algae, red tones indicate nuisance algae, and gray tones indicate sediment/no algae. The blue line plot represents mean flow measurements in the treatment area during sampling events.

Discussion

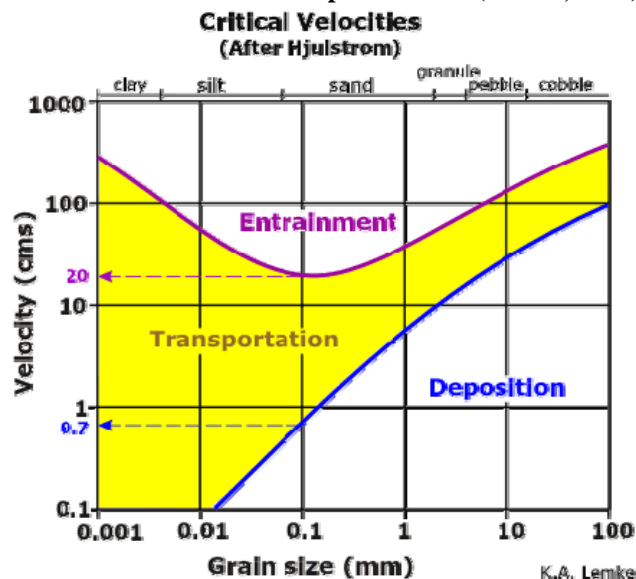
Experiment 1

During the “active period” sediment depth, % sediment cover, macroalga cover 1 and macroalga cover 2 were significantly greater in the control area than in the treatment area. This suggests that 0.21 ft/sec (average water velocity of treatment transect C) is a sufficient water velocity to reduce sediment and nuisance algae. Provided this experiment occurred in late winter, time of year may have contributed to the lack of sediment and nuisance algae.

After the pump was out of service, the algal community in the treatment area transitioned to nuisance algae. While the turnover to nuisance dominated algae was seen within one week after the pump failed, beneficial algae were persistent. The nuisance algae observed (*Cladophora sp.* and *Hydrodictyon sp.*) was loosely attached or not attached at all. Persisting beneficial algae (*Batrachaspermum sp.* and periphyton) were tightly attached to the substrate. This suggests that if increased water velocity was applied to the treatment area substrate after a period of low water velocity (<0.10 ft/sec), the nuisance algae would be scoured from the treatment area and the beneficial algae may recolonize as the dominant algae.

Sediment depth and percent sediment cover remained significantly less in the treatment area than in the control area through the inactive period. This suggests that continuous increased water velocity treatment is unnecessary in controlling sedimentation. Periodic application may be sufficient in reducing sediment cover and depth. Sediment was significantly reduced down to 0.21 ft/sec. Using a modified Hjulstrom diagram (Figure 10), 0.21 ft/sec (6.4 cms) is expected to transport materials with grain sizes just below 1.0mm, supporting the field observations.

Figure 10. Hjulstrom diagram depicting critical velocities for erosion, transport and deposition of sediment based on sediment particle size. (Lemke, 2009)



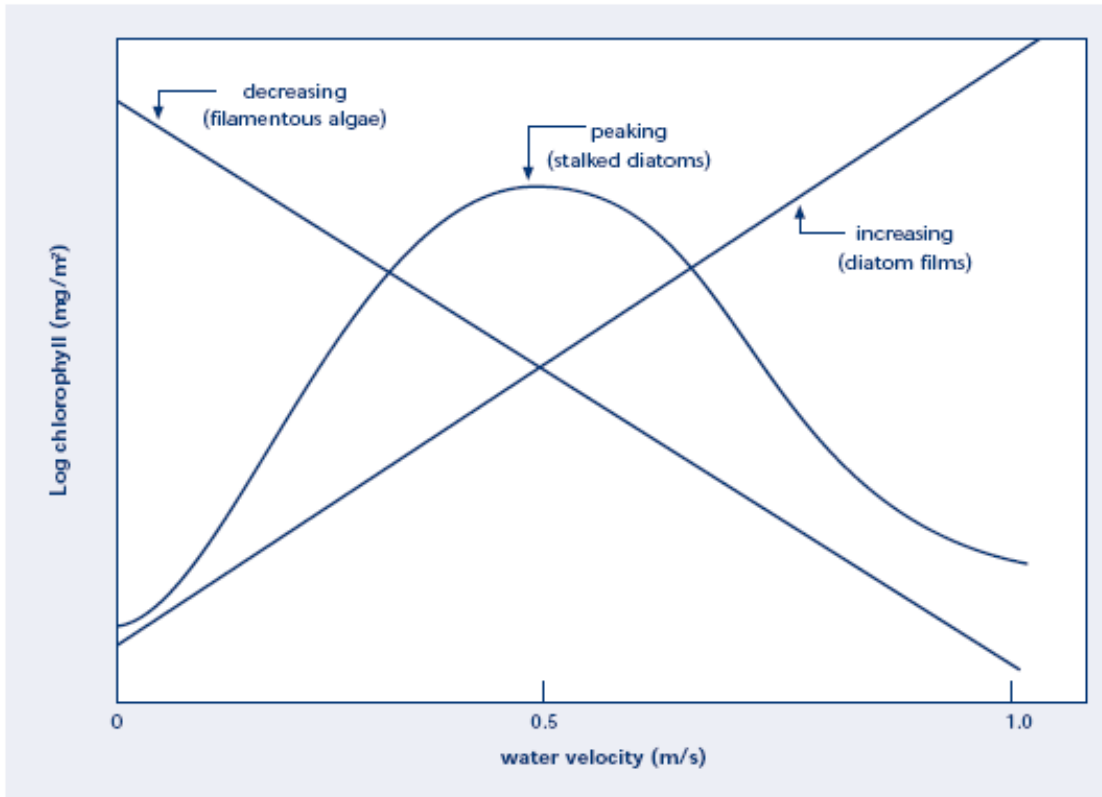
Experiment 2

Sediment cover was significantly different between transect A and B and transect A and C in the treatment area. These data suggest that the minimum flow velocity necessary for a reduction in sediment depth to provide suitable salamander habitat (<18 mm, COA data) is 0.11 ft/sec (3.3 cms)(mean of transect B flow velocities over course of experiment 2). Sediment cover is only reduced significantly at treatment transect A with a flow velocity of 0.71 ft/sec (21.6 cms) (mean of transect A flow velocities over course of experiment 2). A conservative interpretation of these data suggest that to reduce sedimentation (sediment depth and % sediment cover) a flow velocity of ≥ 0.71 ft/sec is required.

Sediment depth significantly decreased with distance in the control area from transect A. Transect A may be artificially deep as sediment and flocculent algae may have accumulated against the North wall of the beach area where it could settle and remain undisturbed. Although all control velocities were below 0.10 ft/sec, disturbance from swimmers was more likely affecting transect C than transect A, possibly contributing to the reduction in sediment at transect C.

Nuisance algae exhibits (observations made from plots) an increasing trend with a decrease in flow velocity (Figures 7-9), although it is important to recognize that succession is time sensitive and may be contributing to the community turnover. Although community composition was similar towards the end of the experiment, the length of the nuisance filaments are unknown. This may indicate that either decreasing flow velocity over time reduced the flow effect seen at the start of the study or that succession occurred resulting in similar community composition over time. Biggs (2000) found that algal community composition was dominated by filamentous algae when flow velocity was less than approximately 1 ft/sec (0.3 m/sec) (Figure 11). This supports the increase in nuisance filamentous algae observed during experiment 2 as flow velocity decreased.

Figure 11. Three biomass responses to spatial variations in water velocity in streams (Biggs, 2000)



Experimental Comparisons

There are a few notable differences between the first and second experiments. The first experiment was conducted during the winter/early spring months. Less algal growth and less disturbance by swimmers occur during this time of year. The second experiment was conducted during the summer months, when there is more nuisance algal growth and disturbance by swimmers.

Unintended water velocity differences occurred that were related to the consistency of pump function and start point of each experiment. During the first experiment, the pump failed 2 times before the pump was out of service, but the pump was restarted within 24 hrs both times. It is assumed that the pump was functioning normally between sampling dates, but the water velocity was not measured between monthly sampling dates. Throughout the duration of the second experiment, an evident leak in the line from the pump to the water control manifold was observed. This leak grew in size from the start to the end of experiment 2 and was recorded by flow velocity from the recirculation manifold during monthly sampling.

The last difference to note is the start point of each of the experiments. The first sampling event for experiment 1 began within a few hours of turning the pump on. Before starting the pump, the research area was clear of any filamentous algal flocculent; sediment movement was the only immediate observable effect from the increased water

velocity along the substrate. The second experiment began 10 days after the pump was turned on. Before starting the pump, the research area was completely covered with a thick flocculent mat of filamentous algae. These flocculent algae took approximately 48 hours to clear from the benthic substrate.

Comparing the data from experiments 1 and 2, we can state that the influence of the increased flow velocities on sediment depth, sediment cover, and algal community composition reaches approximately 2 feet from the recirculation device. Time of year appears to affect the rate of turnover to nuisance algae. In the first experiment, nuisance algae (*Cladophora sp.* and *Hydrodictyon sp.*) were not observed until after the pump shut down, over three months into the experiment. The data was collected 3-4 days after the pump failed. In the second experiment, nuisance algae (*Cladophora sp.*) were present when the pump was started and was recorded in the treatment area on every sampling date except for the second sampling date on 26-June-2008. The first three sampling dates showed a decrease in water velocity, while the fourth sampling period showed a slight increase. This indicates that increased flow velocity (speed in a single direction) along the substrate had the ability to remove the nuisance algae, but as the flow decreased, summer progressed, pool utilization increased, and the nuisance algae returned.

The two experiments resulted in different water flow velocity thresholds needed to affect the algal community. In the first experiment, the threshold was 0.21 ft/sec while in the second experiment, the threshold was 0.71 ft/sec. Taking the above mentioned differences within the experiments into consideration, the different thresholds are not surprising. The threshold is not going to be an exact number because flow velocity is not the only factor in algal community composition. Also, the distance between transects in experiment 2 is twice the distance than experiment 1. This creates a problem for defining a single numerical value of flow velocity. Conservatively, the threshold range for maintaining non-nuisance algae is between 0.21 ft/sec and 0.71 ft/sec, dependent upon other factors.

Concern has been expressed about the observance of *Cladophora sp.* in the treatment area with higher water velocities than the control area. This concern is warranted by the observance of *Cladophora sp.* mats causing a nuisance in surface streams and lakes around Austin, yet there are numerous reasons to believe that *Cladophora sp.* would not likely become a nuisance alga under the conditions of increased flow along the beach area of Barton Springs Pool. Typically, longer filaments of *Cladophora sp.* are products of lower velocity runs and pools, and higher algal biomass accumulates under low flood frequencies and high nutrients (Graham and Wilcox, 2000). The overall water velocity of Barton Springs Pool is low (less than 0.10 ft/sec), excluding groundwater inputs at the spring entrances and fissures, and the overall nitrogen load during lower flow periods is high compared to the average surface water streams in Austin (COA SR-06-09). In 2006, periphyton in Barton Springs Pool was operating at nutrient saturated growth rates during a low flow period, but available phosphorus (and pool turnover rates) is suggested to be limiting phytoplankton growth (COA SR-06-09). *Cladophora sp.* is a periphytic algae, typically binding to rocky substrates. If nutrients continue to increase in Barton Springs Pool, there may not be an increase in *Cladophora sp.* production because the system is

already nutrient saturated. Depending on the climatic variability (i.e rainfall events), natural flooding frequency can be high (18+ floods in 2007) or low (1 flood in 2008) so that natural flooding is unpredictable. In addition, nuisance growths of *Cladophora sp.* typically occur in warmer waters (Graham and Wilcox, 2000). In the summer when nuisance *Cladophora sp.* mats are observed in the surface waters around Austin, the water ways are generally warmer than the relatively constant temperature of the groundwater fed Barton Springs Pool (COA data).

Conclusions

- Sediment depth and cover were significantly decreased within two feet of the recirculation device, where the water velocity along the substrate was between 0.21 ft/sec (6.40 cms) and 0.71 ft/sec (21.64 cms).
- Community composition of algae responded in a similar manner, less nuisance algae was observed at water velocities between 0.21 ft/sec (6.40 cms) and 0.71 ft/sec (21.64 cms).
- Community composition exhibited succession from epilithic algae (*Batrachaspermum sp.*, periphyton, and brown/green carpet algae) to *Spirogyra sp.* to *Cladophora sp.*
- Time of year and flow velocity are suggested influences on the speed of community turnover to nuisance algae.

The objective of this study was to determine the effect of water re-circulation on potential salamander habitat at Barton Springs Pool. This pilot study specifically investigated whether or not increased velocity across the substrate affected sediment accumulation and the benthic algae community, in turn improving salamander habitat. The results of two experiments have shown increasing water velocity over the substrate reduces sediment accumulation and nuisance algae. It has also shown that increasing water velocity over the beach or any other salamander habitat within Barton Springs Pool is not feasible. The data from this study show that using a large well pump at maximum pumping (10 gallons/minute) only affected the substrate/habitat two feet from the pump discharge point (the recirculation device in this study) with a total affected area of approximately 12 sq ft. There is over 11,000 sq ft of salamander habitat on the “beach area” in Barton Springs Pool. Artificially increasing water velocity over the substrate would take 917 of the same 10 gpm well pumps using the same manifold system.

Although increasing water velocity improves habitat, dams at either end of Barton Spring Pool inhibit natural flows and drastically reduce water flow. Since pumping water across the substrate affects a relatively small amount of salamander habitat, appears to be maintenance intensive, and has considerable energy costs, other means of increasing water velocity across beach habitat should be evaluated. One suggestion is adding gates to the bottom of the lower dam, allowing water to move faster along the benthic environment. Periodic disturbance (low pressure hosing of substrate, frequently surveying, etc) may also improve salamander habitat, with the limitation of only temporarily improving substrate conditions. Spring and stream salamander respiration requires continuous flowing water (Duellman and Treub, 1994), not provided by periodic

disturbances. While habitat would be temporarily improved, the environmental conditions would still not be favorable for *Eurycea sosorum*. Providing a passive method of increasing water velocity across the substrate would be the best solution to sediment and algae accumulation in salamander habitat.

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