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CLASSIFICATION OF CYANOBACTERIA SPECIES IN ORANGE ALGAL MATS FROM CANADA STREAM, MCM-LTER

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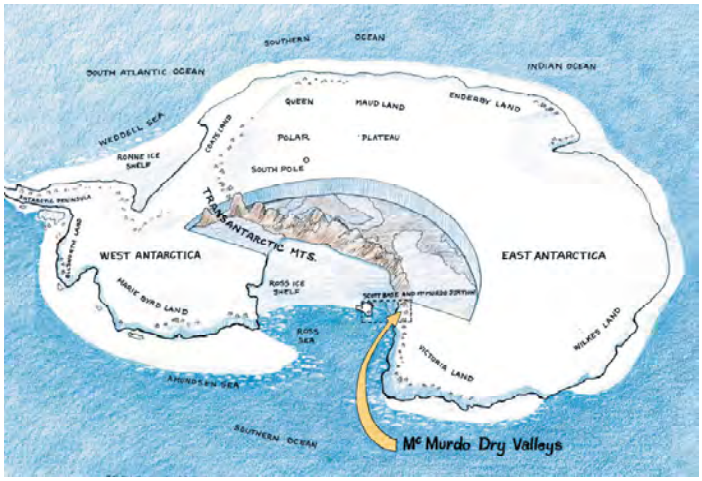
ABSTRACT

The scope of this research is the classification of cyanobacteria species in orange algal mats from Canada Stream in the McMurdo Dry Valleys of Antarctica. The main purpose of this study is to identify the cyanobacteria species present in four sample sites in one stream from three different seasons and estimate the percent cover of each taxa to later correlate the findings to stream flow data. High variations of percent cover between each individual taxa within each season were observed. It was determined that the changes in cyanobacterial mats were not due to stream flow. Since no correlation exists, the relationship between the types of diatoms present and the stream flow is not dependant on changes in the cyanobacterial mats.

INTRODUCTION

The McMurdo Dry Valleys form the largest relatively ice-free area on the Antarctic continent. Located on the western coast of the Ross Sea, they are among the coldest and driest deserts on earth. The region is subject to extremely low temperatures (ranging from -45°C to 3°C), limited precipitation and salt accumulation, making the environment harsh for living organisms. Despite their being one of the most extreme deserts in the world, the McMurdo Dry Valleys are home to photosynthetically-based ecosystems that exist in the glacial meltwater streams. During



Map of Antarctica and the McMurdo Dry Valleys
Courtesy of Dr. Diane McKnight

the austral summers glacial meltwater streams flow for a period of 6-10 weeks. The algal mats present on the stream bed and in the rivulets draining the hyporheic zone become active in as little as 20 minutes after becoming wet [Vincent and Howard-Williams, 1986]. The algal mats are composed primarily of filamentous cyanobacteria or chlorophytes. Only 15 morphotypes of Cyanobacteria have been found in the streams [*Broady*, 1982; *McKnight et al.*, 1998]. The mats also contain diatoms, with 40 endemic and widespread species found.

Because of the harsh conditions and relatively low flow, the ephemeral streams provide a unique habitat for research. Since the late 1950's numerous short-term investigations have been conducted in the McMurdo Dry Valleys. In 1992, the region was selected as a site in the National Science Foundation (NSF) Long-Term Ecological Research (LTER) program. Research has been conducted on the distribution of diatoms present in the Dry Valley streams, and has been documented in The Antartic Freshwater Diatom Website[1]. It has been demonstrated that the percentage of Antarctic diatom species increased with decreasing annual stream flow and increasing harshness of the stream habitat. [*Esposito, et al.,* 2006].

Taylor Valley is the focus of the field research of the McMurdo (MCM)LTER. Twelve Taylor Valley streams were chosen to investigate, but only one will be the focus of this research. Canada Stream is located in lower Taylor

The terminus of the Canada Glacier.
Photograph courtesy of Thomas Nylen

[1] http://huey.colorado.edu/diatoms

Valley and is one of three streams that drain the Canada Glacier. It is 1.5 km in length and is known to be a stream with extensive algal mats. This stream is one of the eight primary sources of inflow to Lake Fryxell and is typically the first stream in the basin to begin flowing in the austral summer. The stream drains the east side of Canada Glacier and the gauge is located at the site of a previous rock weir about 1.5 km above the lakeshore. Algal mat samples taken at this point have been the focus of this study.

INTRODUCTION TO CYANOBACTERIA

Cyanobacteria are prokaryotic oxygenic phototrophs that contain chlorophyll *a* and phycobilins. Some species of these photosynthetic prokaryotes can fix atmospheric nitrogen in a free-living state or in a symbiosis with plants known as Azolla. [*Becking*,1978]. They are known to be tolerant of extreme conditions. Cyanobacteria were critical in the evolution of life. They were the first oxygenic phototrophs to evolve on Earth, producing oxygen on an originally anoxic environment. This paved the way for the evolution of organisms that could respire using oxygen.

Cyanobacteria comprise a large and morphologically heterogeneous group of phototrophic *Bacteria*. Both unicellular and filamentous forms with considerable variations are known to exist. Five morphological groups have been established, as seen in Table 1.

Table 1. Genera and grouping of cyanobacteria

Group	Genera
I. Unicellular: single cells or cell aggregates	*Gloeothece, Gloeobacter, Synechococcus, Cyanothece, Gloeocapsa, Synechocystis, Chamaesiphon, Merismopedia*
II. Pleurocapsalean: reproduce by formation of small spherical cells called baeocytes produced through multiple fission	*Dermocarpa, Xenococcus, Dermocarpella, Pleurocapsa, Myxosarcina, Chroococcidiopsis*
III. Oscillatorian: filamentous cells that divide by binary fission in a single plane	*Oscillatoria, Spirulina, Arthrospira, Lyngbya, Microcoleus, Pseudanabaena*
IV. Nostocalean: filamentous cells that produce heterocysts	*Anabaena, Nostoc, Calothrix, Nodularia, Cylinodrosperum, Scytonema*
V. Branching: cells divide to form branches	*Fischerella, Stignoema, Chlorogloeopsis, Hapalosiphon*

Madigan, Michael T., Martinko, John M. (2006) Brock Biology of Microorganisms. 11th ed. Pearson Prentice Hall. New Jersey, USA. p. 396

Cyanobacteria do not need vitamins to subsist. They can use nitrate or ammonia as a source of nitrogen, and also require phosphorus and micronutrients, such as iron. Most species are phototrophs, but some filamentous species can grow in the dark using sugar from glucose or sucrose as a carbon and energy source.

STRUCTURE OF CYANOBACTERIA

Cyanobacterial cells range in size from 0.5-1 μm to 40 μm in diameter. The cell wall structure is similar to that of a gram-negative bacterium [Gerba, Maier and Pepper, 2000]. Some cyanobacteria form a complex and multilayered photosynthetic membrane system composed of mucilaginous envelopes or sheaths that bind filaments or groups of cells together. Some filamentous cyanobacteria form heterocysts. These are rounded, seemingly empty cells that are generally distributed along a filament or at one end of the filament. Heterocysts are the single site for nitrogen fixation in heterocystous cyanobacteria.

MICROBIAL MATS IN THE ANTARCTIC

Cyanobacteria occupy the upper region of microbial mats, where they can have more access to sunlight. A microbial mat is an interfacial aquatic habitat where many

microbial groups are laterally compressed into a thin mat of biological activity. The photosynthetic activity of the cyanobacteria generates an oxygenic environment in the upper layer of the mat. Microbial mats are often found in extreme or highly fluctuating environments. The interdependent microbial components of the mat form clearly stratified and distinctively colored zones.

Microbial mats composed primarily of cyanobacteria, several species of pennate diatoms, and heterotrophic bacteria occur abundantly throughout much of the benthic regions of Lakes Bonney, Chad, Hoare, Fryxell, Joyce and Vanda in the McMurdo Dry Valleys. [Wharton et al., 1983; Parker and Wharton, 1985]. Most common cyanobacterial communities found in perennial streams are composed entirely of Oscillatoriaceae. The cohesive mats range in color from pink to orange, and are common in stable subtrates with flowing water. A second type of cyanobacterial mat is composed primarily of *Nostoc commune,* which form black mucilaginous layers at the edge of streams in the McMurdo Sound region.

DESCRIPTIONS OF ALGAL SPECIES FOUND IN TAYLOR VALLEY

In the Antatctic lakes, ponds and streams cyanobacteria form extensive microbial mats, where members of the Oscillatoriaceae seem to be the most predominant. [Vincent, Downes, Castenholz and Howard-Williams, 1993] Fifteen morphotypes of the family Oscillatoriaceae were found to be present in Taylor Valley [Alger, 1997] as seen in Table 2. Other families of cyanobacteria were also identified [Alger, 1997] as seen in Table 3.

Table 2. Family Oscillatoriaceae found in Taylor Valley

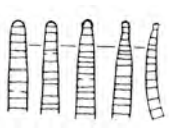
Morphotype		Description	Diagram
Morphotype A	*Oscillatoria subproboscieda*	Trichomes between 7.5-10 μm in width (including sheath in this and following taxa). Terminal cell rounded and sometimes swollen with calyptra. Trichomes often found within a sheath. Granules present along transverse walls	
Morphotype B	*Oscillatoria subproboscieda*	Trichomes between 9-12 μm in width. Similar to morphotype A but wider and with more numerous granules. These granules may be gas vacuoles, providing protection from the high levels of ultraviolet light encountered in Antarctica	
Morphotype C	*Oscillatoria irrugua*	Trichomes between 7-9 μm in width and often surrounded by a sheath. Many cells had transverse walls with a convex shape (perhaps separation disks). Terminal cells often attenuated.	
Morphotype D	*Oscillatoria irrugua*	Trichomes between 7.5-9.5 μm in width, sometimes surrounded by a sheath. Dark, refractory surface obscures the cell interior. Cell walls thin. Terminal cell often with a calyptra.	
Morphotype E	*Oscillatoria crouani*	Trichomes between 8-10 μm in width. Dark refractory surface obscures cell interior. Granules scattered throughout the trichome. Terminal cells slightly attenuated.	
Morphotype F	*Oscillatoria koettlitzi*	Trichomes between 7-9.5 μm in width. Terminal cell swollen and often with a calyptra. Cells narrow with a distinct light-dark pattern. Necridia common (1-5) within each trichome.	
Morphotype G	*Oscillatoria koettlitzi*	Trichomes between 7-9.5 μm in width. Similar to morphotype E but with much shorter cell length. Terminal cells swollen	
Morphotype H	*Oscillatoria koettlitzi*	Trichomes between 8-10 μm in width. Dense cells with a dark refractory surface and no apparent sheath. Terminal cells often capitate with no visible calyptra. Distinct constrictions at the cell walls. Necridia rare.	
Morphotype I	*Phormidium autumnale*	Trichomes between 4-6 μm in width and often with a slight terminal hook. Variable position and quantity of granules. Terminal cell with a calyptra. Could be independent trichomes of *Microcoleus vaginatus.*	
Morphotype J	*Phormidium autumnale*	Trichomes between 2.5-3.5 μm in width. Generally, cell walls clearly visible, granules rare. Terminal cell with a calyptra.	
Morphotype K	*Phormidium autumnale*	Trichomes between 2-3.5 μm in width. Nearly identical to morphotype J except that trichomes arose from common "clump". Trichomes also appeared to taper slightly at the terminal end. Rare occurrence.	
Morphotype L	*P. Frigidum*	Trichomes all less than 2.5 μm in width. Very thin trichomes– probably more than one species. Usually, no cell structures were visible, but occasionally, cells were box-shaped with distinct constrictions at the transverse walls.	
Morphotype M	*Microcoleus vaginatus*	Trichomes between 4-6 μm in width. Nearly identical to morphotype I except that all trichomes were contained within a common sheath. A few trichomes would protrude from the apex of the sheath. Terminal cell with a distinct calyptra. Could be colony of *Phormidium autumnale*.	

Table 3. Other Cyanobacteria families present in Taylor Valley

Family		Description	Diagram
Chroococcaceae	*Gloeocapsa kuetzingiana*	Generally, dark orangeish-brown colony of individual cells, 2-5 μm in diameter. Cells arranged irregularly in a mucilaginous sheath. Colonies range from 7-78 μm in width and contained 3-100+ cells.	
Nostocaceae	*Nostoc spp.*	Ranged in growth from individual trichomes to dense irregularly shaped colonies. Trichomes yellowish, 3-5 μm wide, 2-3 μm long and closely packed with colonies. Heterocyst present at both endings and within the trichomes; akinetes observed. Thin sheath surrounded the trichomes while a thick yellow mucilaginous sheath surrounded the colonies. Size of colonies ranged from 10 μm in diameter to over 10 cm2. Juvenile colonies with intercalary heterocyst also found. Difficult to identify to species level without cultures.	

OBJECTIVE

Identify percent coverage of cyanobacteria species present in the orange algal mats collected from Canada Stream in 1998, 2001 and 2002-2003.

Correlate the obtained data with stream flow measurements.

HYPOTHESIS

The relationship between the types of diatoms present and the stream flow is not dependant on any changes in the cyanobacterial mats. Unlike the relationship between diatoms and stream flow obtained by Esposito et al., [Esposito et al., 2006], the species composition of the cyanobacterial mats will not present changes due to variations in stream flow.

MATERIALS AND METHOD

Transects with an approximate length of 40 meters were established along streams in Taylor Valley. Algal mats were visually identified as red, orange, green or black within each transect. Samples of each color were collected using a #13 cork borer and

preserved in 10% formalin for laboratory analysis. A maximum of five samples of each color were collected from several locations in the streambed along each transect.

Algal mat samples were collected from Canada Stream at the delta and at the gauge. The samples collected during the summer of 1993-1994 have been analyzed previously [*Alger et al.* 1998]. During the sampling period of 1998 no orange mat algal samples were collected at the delta due to low stream flow. For proper comparison, samples collected from the Canada Stream gauge in the seasons of 2002-2003, 2000-2001 and 1997-1998 were analyzed for percent coverage of filamentous cyanobacteria species. Four samples were collected at each time, so a total of twelve samples were chosen for analysis. The 1998 samples were quickly discarded for study due to a white buildup that prevented proper species identification. A cloudy buildup is evident in Image 1 when comparing fluid obtained from 1998 versus that of 2001.

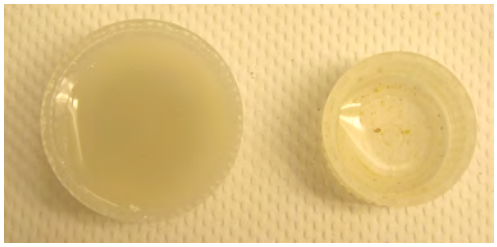


Image 1. Comparison between 1998 and 2001 sample

From each original sample bottle, 2 mL were extracted using a clean 1-5 mL Fisherbrand Finnipipette, and placed in a 5 mL plastic bottle with 3 mL of DI water. The subsample bottle was agitated for 3 minutes with a Scientific Industries VWR Vortex Mixer at speed 5 in order to reduce the clumps of algae. From this subsample, 4 mL were withdrawn using the Fisherbrand Finnipipette and placed in a settling chamber with a 19 mm diameter (Utermöhl, 1958) and allowed to settle overnight. The sample was analyzed at x400 magnification with a Nikon Phase Contrast inverted microscope and photographs of the specimens were taken with a Nikon E 995 digital camera.

The descriptions from Table # [*Alger et al.* 1998; *Broady*, 1982] were used as a base for identification. A flow diagram, as seen in Figure 1, was developed based on predominant characteristics of the thirteen different morphotypes and to be used as a visual tool to accompany the written descriptions.

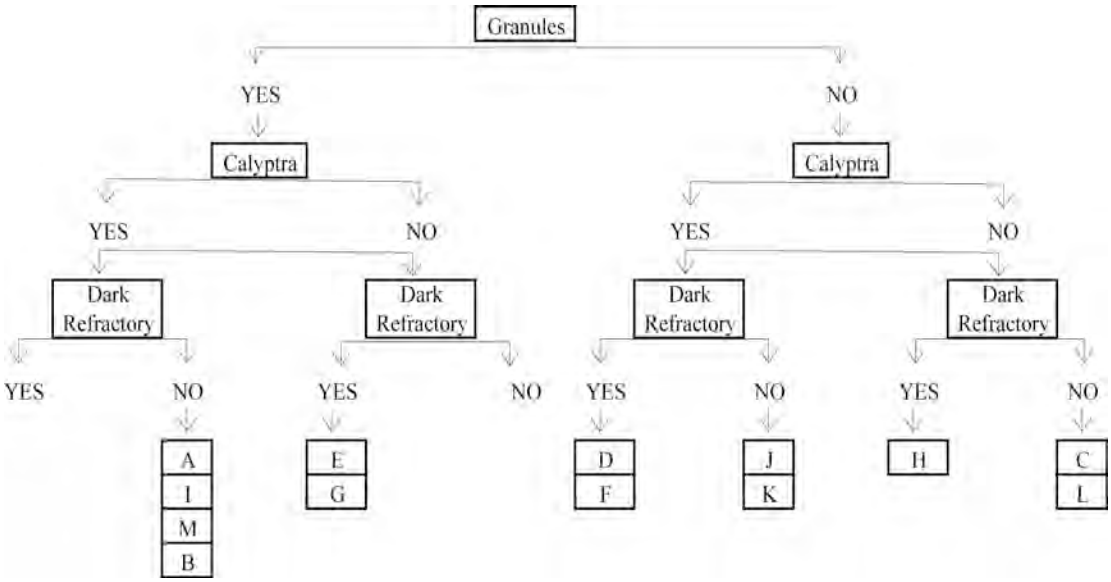


Figure 1. Flow diagram for identification of cyanobacteria species present in Canada Stream.

To get a representative sample of relative species percent coverage, the complete slide was examined. Within each slide, cyanobacteria were identified to species, and percent cover was determined by measuring the length and width of each specimen using an ocular micrometer and then estimating it as a percent of the total biomass.

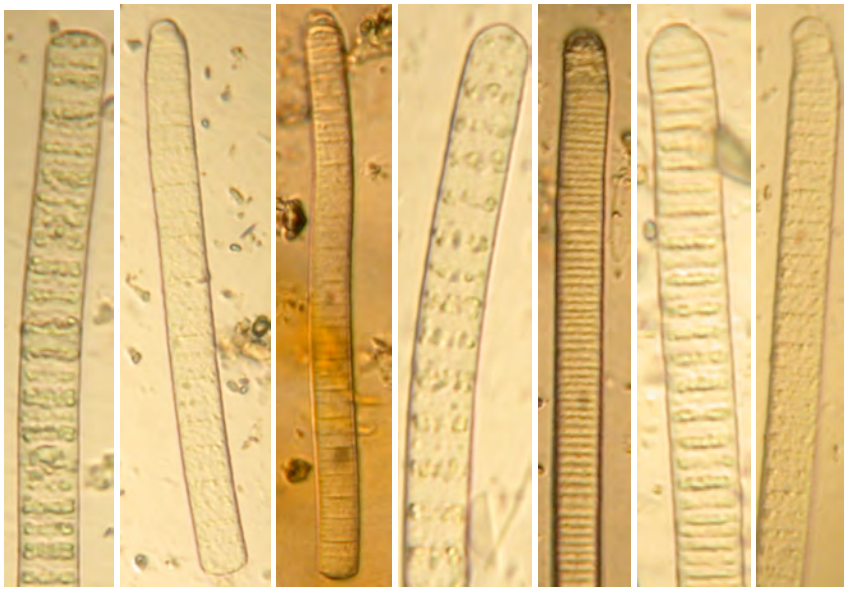
RESULTS

COMPILATION OF CYANOBACTERIA SPECIES AND THEIR RESPECTIVE PICTURES AS SEEN IN CANADA STREAM

From literary review, a limited amount of images of the different morphotypes were found. In this study, pictures of the different specimens where taken as the samples were being analyzed. The following is a compilation of the cyanobacteria present in Canada Stream with their respective images[2]. A more complete database will be available as an extension of the LTER website.

Morphotype	**Description**
Morphotype A: *Oscillatoria subproboscieda*	Trichomes between 7.5-10 μm in width (including sheath in this and following taxa). Terminal cell rounded and sometimes swollen with calyptra. Trichomes often found within a sheath. Granules present along transverse walls

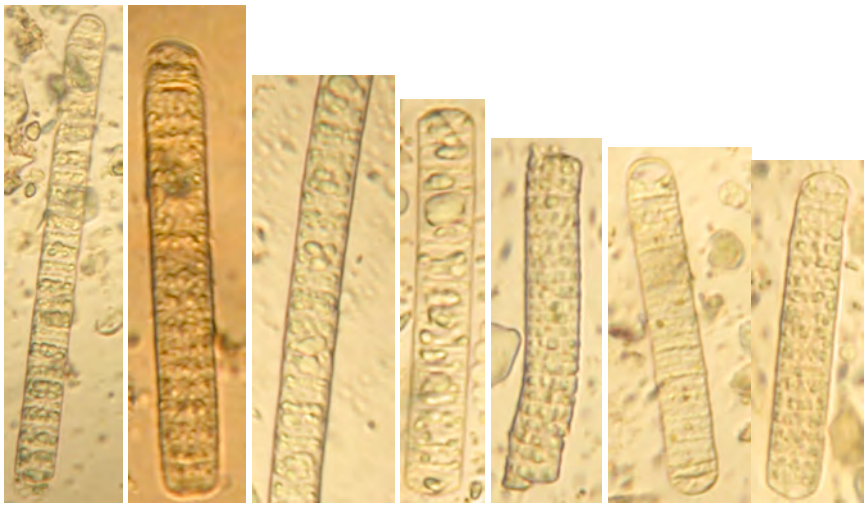
Images:



[2] Pictures are not shown to scale

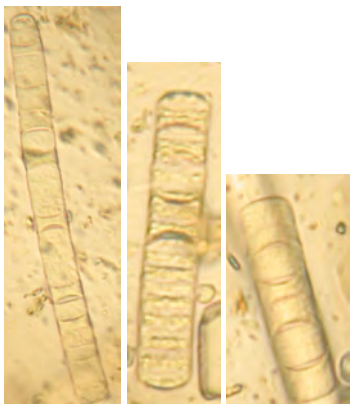
Morphotype	Description
Morphotype B: *Oscillatoria subproboscieda*	Trichomes between 9-12 μm in width. Similar to morphotype A but wider and with more numerous granules. These granules may be gas vacuoles, providing protection from the high levels of ultraviolet light encountered in Antarctica

Images:



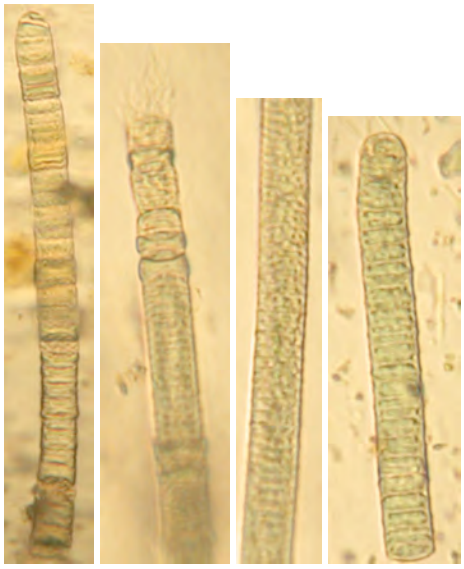
Morphotype	Description
Morphotype C: *Oscillatoria irrugua*	Trichomes between 7-9 μm in width and often surrounded by a sheath. Many cells had transverse walls with a convex shape (perhaps separation disks). Terminal cells often attenuated.

Images:



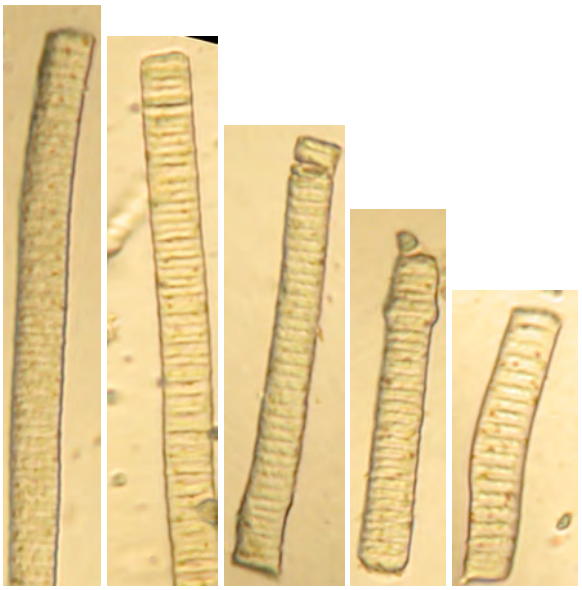
Morphotype	Description
Morphotype D: *Oscillatoria irrugua*	Trichomes between 7.5-9.5 μm in width, sometimes surrounded by a sheath. Dark, refractory surface obscures the cell interior. Cell walls thin. Terminal cell often with a calyptra.

Images:



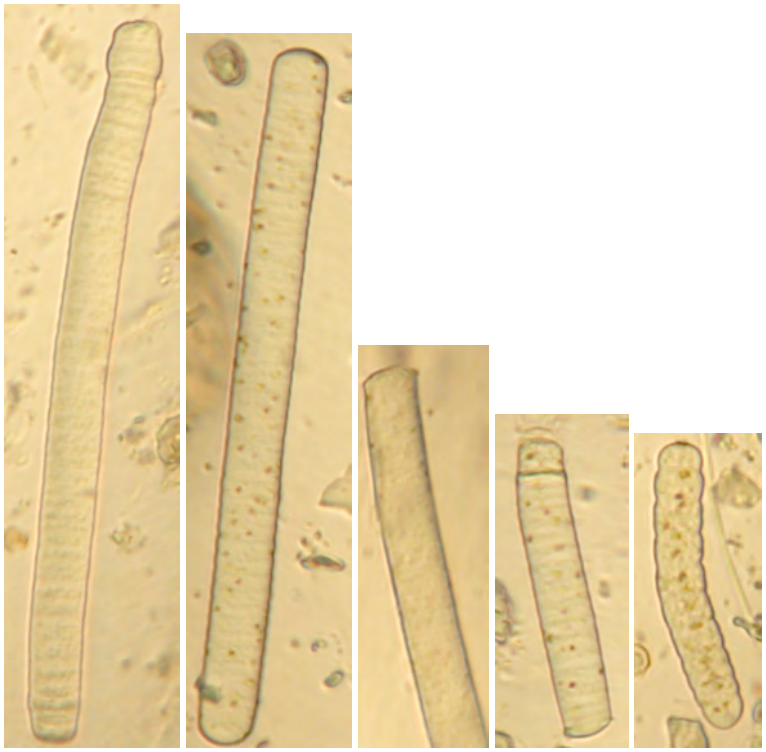
Morphotype	Description
Morphotype E: *Oscillatoria crouani*	Trichomes between 8-10 μm in width. Dark refractory surface obscures cell interior. Granules scattered throughout the trichome. Terminal cells slightly attenuated.

Images:



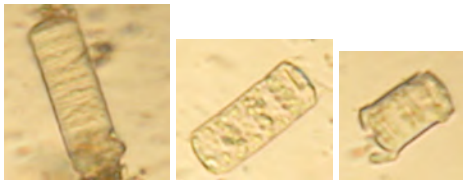
Morphotype	Description
Morphotype F: *Oscillatoria koettlitzi*	Trichomes between 7-9.5 μm in width. Terminal cell swollen and often with a calyptra. Cells narrow with a distinct light-dark pattern. Necridia common (1-5) within each trichome.

Images:



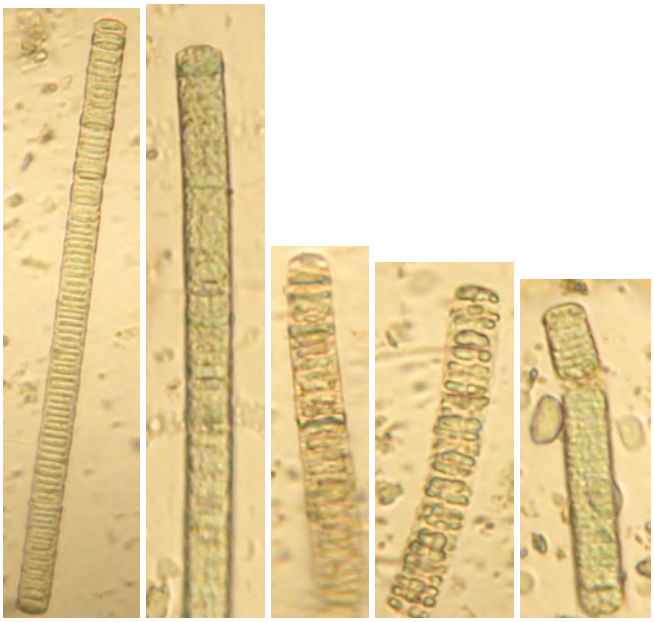
Morphotype	Description
Morphotype G: *Oscillatoria koettlitzi*	Trichomes between 7-9.5 μm in width. Similar to morphotype E but with much shorter cell length. Terminal cells swollen

Images:



Morphotype	Description
Morphotype H: *Oscillatoria koettlitzi*	Trichomes between 8-10 μm in width. Dense cells with a dark refractory surface and no apparent sheath. Terminal cells often capitate with no visible calyptra. Distinct constrictions at the cell walls. Necridia rare.

Images:

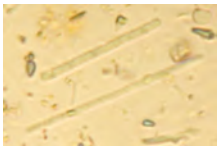


Morphotype	Description
Morphotype I: *Phormidium autumnale*	Trichomes between 4-6 μm in width and often with a slight terminal hook. Variable position and quantity of granules. Terminal cell with a calyptra. Could be independent trichomes of *Microcoleus vaginatus.*

Images:

Morphotype	Description
Morphotype J: *Phormidium autumnale*	Trichomes between 2.5-3.5 μm in width. Generally, cell walls clearly visible, granules rare. Terminal cell with a calyptra.

Images:



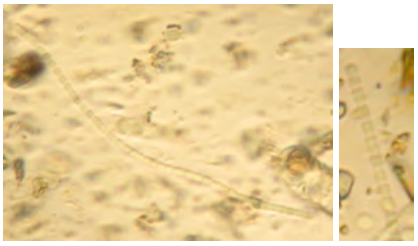
Morphotype	Description
Morphotype K: *Phormidium autumnale*	Trichomes between 2-3.5 μm in width. Nearly identical to morphotype J except that trichomes arose from common "clump". Trichomes also appeared to taper slightly at the terminal end. Rare occurrence.

Images:

No pictures are available for this species because it was not found.

Morphotype	Description
Morphotype L: *P. Frigidum*	Trichomes all less than 2.5 μm in width. Very thin trichomes– probably more than one species. Usually, no cell structures were visible, but occasionally, cells were box-shaped with distinct constrictions at the transverse walls.

Images:



Morphotype	Description
Morphotype M: *Microcoleus vaginatus*	Trichomes between 4-6 μm in width. Nearly identical to morphotype I except that all trichomes were contained within a common sheath. A few trichomes would protrude from the apex of the sheath. Terminal cell with a distinct calyptra. Could be colony of *Phormidium autumnale*.

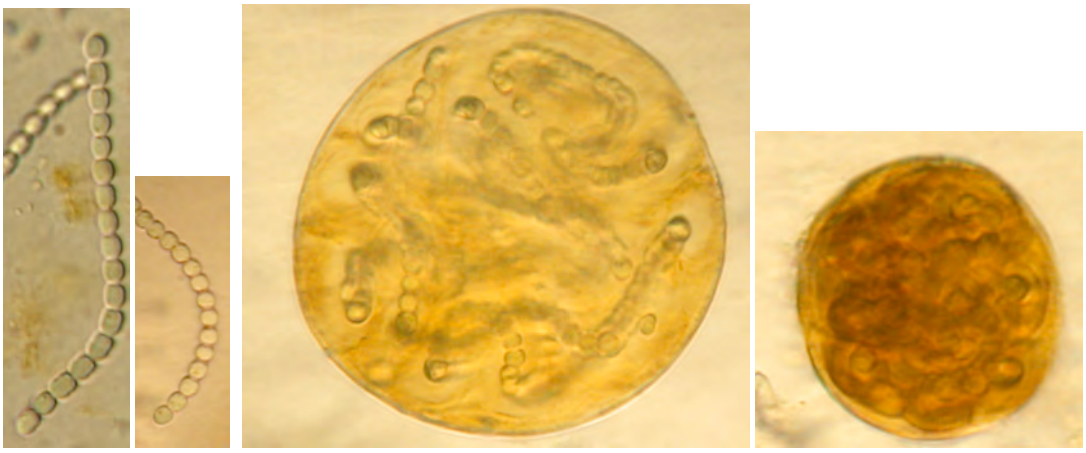
Images:

Species	Description
Chroococcaceae: *Gloeocapsa kuetzingiana*	Generally, dark orangeish-brown colony of individual cells, 2-5 μm in diameter. Cells arranged irregularly in a mucilaginous sheath. Colonies range from 7-78 μm in width and contained 3-100+ cells.

Images:

Species	Description
Nostocaceae: *Nostoc spp.*	Ranged in growth from individual trichomes to dense irregularly shaped colonies. Trichomes yellowish, 3-5 μm wide, 2-3 μm long and closely packed with colonies. Heterocyst present at both endings and within the trichomes; akinetes observed. Thin sheath surrounded the trichomes while a thick yellow mucilaginous sheath surrounded the colonies. Size of colonies ranged from 10 μm in diameter to over 10 cm2. Juvenile colonies with intercalary heterocyst also found. Difficult to identify to species level without cultures.

Images:

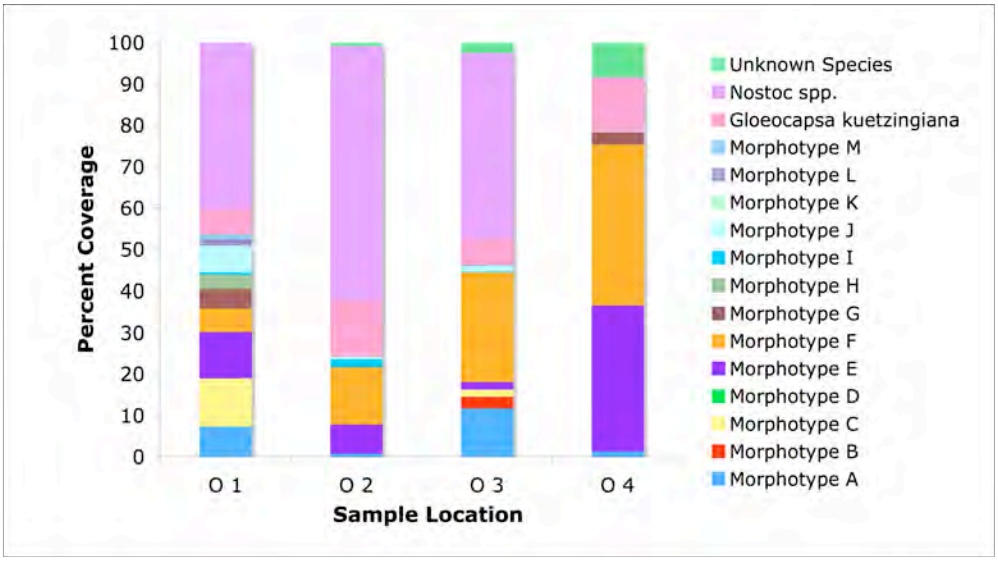


CYANOBACTERIA DISTRIBUTION IN ORANGE ALGAL MATS FROM CANADA STREAM

The Canada Stream samples from 1998 had a murky white colored substance that grew within the sample bottles (perhaps fungi). After settling one sample, it was concluded that the white cloud made it nearly impossible to identify any species present within the samples. For this reason, Canada Stream samples from 1998 were disregarded from the rest of the analysis.

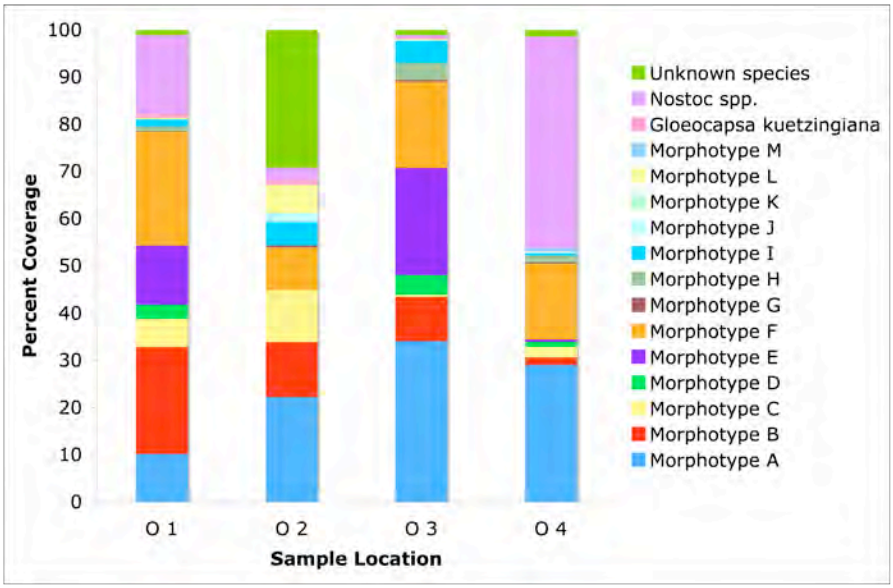
The cyanobacteria distribution in Orange Algae mat from Canada Stream at gauge in 2001 can be seen in Figure 2. The large and apparently random species distribution among the four samples results in no clear pattern in species coverage being evident between each sample location.

Figure 2. Cyanobacteria distribution in Orange Algae mat from Canada Stream at gage in 2000-2001



The cyanobacteria distribution in Orange Algae mat from Canada Stream at gage in 2002-2003 can be seen in Figure 3. Once again, the large and apparently random species distribution among the four samples results in no clear pattern in species coverage being evident between each sample location.

Figure 3. Cyanobacteria distribution in Orange Algae mat from Canada Stream at gage in 2002-2003



DATA ANALYSIS

DIVERSITY

In order to study the biodiversity of the samples analyzed, the Shannon-Weiner index (*H'*) was used:

$$H' = \sum_{i=1}^{S} p_i \ln p_i$$

where S is the species richness and p_i is the relative abundance of each species (n_i/N) where n_i is the abundance of each species and N is the total number of all individuals. The index is increased by having a greater species evenness. The maximum index $H_{max} = \ln(S)$ is given when all species are present in equal numbers. For fifteen species, $H_{max} = 2.708$. The Shannon-Weiner index calculated for the samples (Table 4) show a high diversity in species present. Data from Alger has also been included in the analysis.

Table 4. Shannon-Weiner Diversity Index for 2000-2001 and 2002-2003 samples

Stream	Year	Site	S-W DI	Average	Standard deviation
Canada Stream at Gage	1993-1994	O1	1.991383378	1.743181183	0.165427807
Canada Stream at Gage	1993-1994	O2	1.653525033		
Canada Stream at Gage	1993-1994	O3	1.569429747		
Canada Stream at Gage	1993-1994	O4	1.681799392		
Canada Stream at Gage	1993-1994	O5	1.819768366		
Canada Stream at Gage	2000-2001	O1	1.970456566	1.537759446	0.31788782
Canada Stream at Gage	2000-2001	O2	1.228505952		
Canada Stream at Gage	2000-2001	O3	1.555643889		
Canada Stream at Gage	2000-2001	O4	1.396431376		
Canada Stream at Gage	2002-2003	O1	1.973202043	1.797335615	0.241571057
Canada Stream at Gage	2002-2003	O2	1.963583246		
Canada Stream at Gage	2002-2003	O3	1.796545192		
Canada Stream at Gage	2002-2003	O4	1.456011977		

Harshness rankings were used to correlate species diversity to stream flow. Harshness accounts for variations in stream flow throughout the time period. Harshness rankings were obtained from Esposito et al. [*Esposito, et al.,* 2006] as developed by Fritz

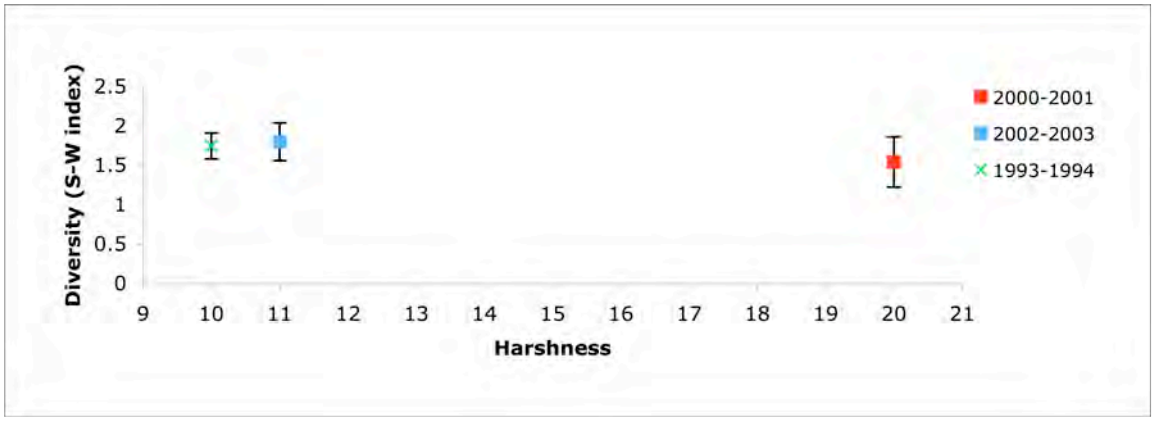
and Dodds [2005]. Of their twelve flow-related criteria, three annual and three historical criteria were chosen. The criteria used to calculate the harshness index can be seen in Table 5. When calculating the overall harshness index, four streams (Canada, Von Guerard, Delta and Green) and various seasons were analyzed for a total of twelve different sites, which corresponds to a rank range of 1 to 12. Ranks were assigned to sites for each variable with the harshest site assigned the highest rank. The harshness index for a particular site is calculated as the sum of ranks allocated to each criteria. The lowest harshness index is 10 and corresponds to Canada Stream 1993-1994. The highest harshness index is 56 and corresponds to Von Guerard Stream 2002-2003.

Table 5. Harshness Index Ranking for Canada Stream

Season (Dec-Jan)	93-94	94-95	97-98	00-01	02-03
ARann- mean annual flow for season	1	9	5	3	2
AQmax- annual max flow for season	2	9	6	7	1
ANQzero- days w/o flow for season	1	4	2	4	2
HRann- mean annual flow for hist. record	1	1	1	1	1
HNQzero- mean ANQzero for hist. record	1	1	1	1	1
HNBF- flood events/year for hist record	4	4	4	4	4
Harshness Index Sum	10	28	19	20	11

Harshness values for Canada Stream were then correlated to Shannon-Weiner diversity indices. From Figure 4 it can be observed that harshness is not an indicator of diversity.

Figure 4. Shannon-Weiner diversity index as a function of Harshness score including data set from Alger, et. al. for 1993-1994 sample period



PERCENT COVERAGE

Percent coverage of each individual species was seen to vary greatly among each sample location within the same season. The average percent coverage and standard deviation when compared between the three sample seasons also presents widespread variability (Table 6).

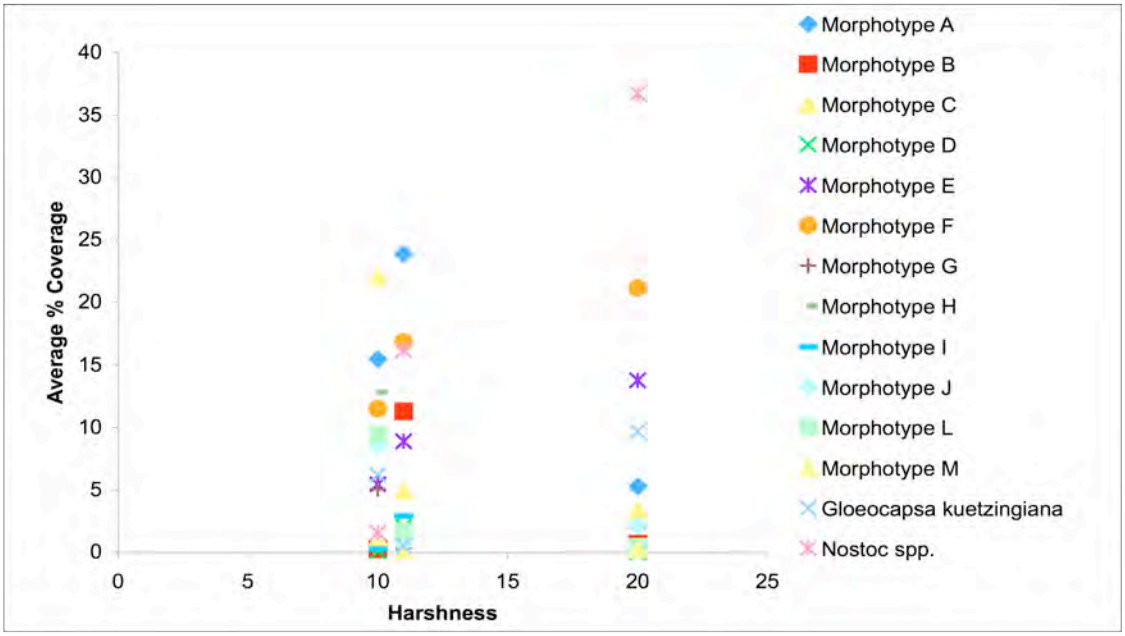
Table 6. Cyanobacteria average distribution and standard deviation for each sample season

	1993-1994		2000-2001		2002-2003	
Taxa	**Average**	**St. Dev.**	**Average**	**St. Dev.**	**Average**	**St. Dev.**
Morphotype A	15.4973	6.7724	5.3175	5.2307	23.8894	10.3597
Morphotype B	0.2535	0.5668	0.6776	1.3552	11.3073	8.7247
Morphotype C	22.0453	15.6654	3.3707	5.6029	4.9050	4.6093
Morphotype D	0.1057	0.2363	0.0000	0.0000	2.0521	1.8792
Morphotype E	5.4551	7.8686	13.7977	14.8143	8.8900	10.8344
Morphotype F	11.5089	9.8088	21.1603	14.5262	16.8742	6.2579
Morphotype G	5.0697	11.3362	1.9575	2.2905	0.3407	0.1467
Morphotype H	12.8270	12.4455	0.8372	1.6745	1.4704	1.5083
Morphotype I	0.2535	0.5668	0.6659	0.8067	2.8975	2.2184
Morphotype J	8.5833	8.5473	2.1556	2.8506	0.6333	0.8814
Morphotype K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Morphotype L	9.4507	4.3502	0.4687	0.7846	1.6618	2.8885
Morphotype M	1.1897	1.8828	0.2800	0.5600	0.1576	0.3152
Gloeocapsa kuetzingiana	6.1999	12.6680	9.6794	4.0483	0.5231	0.4807
Nostoc spp.	1.5606	2.8106	36.7137	25.8831	16.1991	20.4784
Unknown	0.0000	0.0000	2.9183	3.7598	8.1986	14.0337

The behavior of each individual taxa was analyzed as a function of harshness (Figure 5) and a pattern can be observed for seven of the fifteen taxa. Morphotypes C, H,L and M were seen to decrease in percent coverage as harshness increases. Morphotypes E and F, and Nostoc were seen to increase as harshness increased. However, due to the high standard deviation within each season, average values are not good indicators of the actual species distribution. Therefore, within the fifteen taxa there is no clear indicator species, which suggest that other conditions aside from stream flow, such as water quality, are pertinent to the study of cyanobacteria distribution within the orange algal mats from Canada Stream. As explained by the patch dynamics model, ever-

changing environmental conditions can be present within a stream section. The fluctuating nature of the running water environment allows more species to co-exist than would be true under more unwavering conditions.

Figure 5. Average percent coverage of the 15 species as a function of Harshness for the sample periods of 1993-1994, 200-2001 and 2002-2003



CONCLUSIONS

High variations of percent cover between each individual taxa within each season were observed. It was determined that the changes in cyaobacterial mats were not due to stream flow. Since no correlation exists, the relationship between the types of diatoms present and the stream flow is not dependant on changes in the cyanobacterial mats. Further studies should be conducted on the stream dynamics and geochemistry and correlate the findings to the cyanobacteria distribution at each site. This would increase the understanding of the behavior of the individual cyanobacteria species.

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