Investigating the aquatic ecology of University Slough before and after its connection to Ravenna Creek

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This is to certify that I have examined this copy of a master's thesis by

Julia Helen Tracy

and have found that it is complete and satisfactory in all respects,
and that any and all revisions required by the final
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Date ____________________________

University of Washington

Abstract

Investigating the aquatic ecology of University Slough before and after its connection to Ravenna Creek

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This study examined periphyton communities in University Slough before and after connection with Ravenna Creek (RC). Periphyton includes benthic algae - primary producers, a vital foundation of many stream food webs, and useful as biological water quality indicators. The first goal of the study was to initiate a monitoring plan for the microorganisms living in the University Slough. The second goal was to examine periphyton as a biological metric of water quality changes when water from RC was connected to the Slough in early 2006. Preliminary studies began in May of 2004, followed by two field seasons carried out mid-February through mid-July in 2005 and 2006. The 2005 field season was used as a baseline while the 2006 field season was to be comparative following the addition of the RC water. Artificial substrata placed in a Sampling Station were used to measure total organic productivity (TOP) and chlorophyll-*a* concentration, leading to autotrophic index (AI) levels. The AI, a ratio of TOP to chlorophyll-*a*, is a measure of water quality. The study also examined periphyton community structure and taxa present in the Slough. Results of the period during which RC was connected to the Slough revealed lower AI values, as well as changes in the biological community structure. Visually, there was a much greater clarity to the water. Results point to the potential for water quality improvements as a result of increased water flow to the Slough.

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And speaking of Utermöhl chambers, I must not forget to thank the Hydro-Bios company, who kindly provided me with 50 base plates at no charge after I broke the one in Trice's chamber. This was a great kindness, especially given that the base plates were shipped to me all the way from Germany.

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DEDICATION

This work is dedicated to the spirits of the people who long ago inhabited the area around Lake Washington - the hah-choo-AHBSH - and to the microorganisms living in the University Slough, particularly those beings that were sacrificed in the course of my experiments.

Introduction

Urban hydrology is inarguably impacted by development, and the fragmentation of hydrological systems in urban areas is a well-known and well-studied phenomenon (Booth et al. 2004, May 1998). Of particular note, urban streams and creeks are routinely disconnected, as well as being polluted, straightened, diverted, channelized, piped, culverted or otherwise isolated from their natural courses. But as attitudes toward streams and creeks in urban areas change, urban creek daylighting is becoming increasingly common. Daylighting describes projects that deliberately expose some or all of the flow by bringing a previously covered river, creek, or stream back to the surface. In the United States, Canada and Europe, numerous daylighting projects have been completed recently, with many more projects either underway or under consideration (Pinkham 2000). The benefits of these projects vary depending upon location, but may include increased hydraulic capacity by creation of a floodplain, reduced runoff velocities and prevention of erosion, replacement of deteriorating culverts, improved water quality, increased wildlife habitat, increase in property values, an opportunity for reconnecting humans with nature, and a diversion of urban runoff from combined sewer systems (Pinkham 2000).

University Slough, a drainage canal excavated in 1971 to take surface runoff from the surrounding area to Lake Washington, has always been a slow-moving watercourse. In spite of the fact that some areas in the Slough are stagnating, it provides a potential source of primary production for local avian residents and fish, as well as a good deal of riparian habitat. The focus of this study was the aquatic ecology of University Slough in Seattle, Washington, USA, and how that ecology might change following the daylighting and connection of nearby Ravenna Creek (RC) to the Slough.

Project Hypothesis and Goals

The rationale for this project was that a before-and-after comparison of the water quality in the Slough could be relevant to studies of both urban water quality and the emerging science of stream daylighting. The basic hypothesis of the study was that the addition of the RC water to the Slough would improve water quality and overall habitat. A biological metric was chosen for this assessment. Periphyton, including benthic algae (primary producers), are an important foundation of many stream food webs and useful as biological water quality indicators. Thus, they were chosen as the indicator organisms.

There were two main study goals. The first was to initiate an overall monitoring plan for the microorganisms living in the Slough, particularly the primary producers. The second was to follow, over time, the periphyton communities at one sample point, tracking changes in taxa abundance and composition when the RC water was added. While the focused scope of a master's project precluded the creation of an extensive index of biological integrity, data from this study may ultimately be useful to such an endeavor.

The Study Organisms

The inclusion of biological criteria to analyze water quality has been increasing steadily since passage of the Clean Water Act in 1977 (Karr 1991). Without doubt, stream habitat alterations will lead to changes in the biota present, including algal communities and increasingly, periphyton are being used in indices of biological integrity (Potapova 2005, Hill 2000). Stream periphyton assemblages are ideal for water-quality assessments, being sensitive to changes in water flow, nutrient and gas concentrations, pH, temperature, water chemistry and habitat disturbance. This sensitivity, along with their fundamental role as primary producers in stream ecosystems, makes them excellent indicator organisms

(Potapova 2005, Welch 1992, Wehr and Sheath 2003). They also tend to reproduce quickly and thus, reflect change in short amounts of time. For the purposes of this study, algae are considered to be a somewhat loosely-defined assemblage of organisms that have certain distinguishing features. They are aquatic (in this case, freshwater), they are autotrophic (in this case, photosynthetic), they have simple vegetative structures without a vascular system, and their reproductive bodies lack a sterile layer of protective cells. According to current phycological wisdom, algae are regarded not as a phylogenetic concept but rather, represent an "ecologically meaningful and important collection of organisms" (Sheath 2003) and include both prokaryotic and eukaryotic taxa. In this particular study, periphyton, the larger category that includes not only algae, but also bacteria, fungi, and protozoa, as well as organic detritus attached to surfaces, is considered.

Chapter One: Background Information

Historical Context

Puget Sound was carved during the time of the last glaciation, around 10,000 years ago. Before the turn of the 20th century, a large watershed drained the area around what is now Green Lake (O'Neill 1991). Water leaving the lake ran along today's Ravenna Boulevard to become Ravenna Creek, eventually running into a vast marshland bordering Lake Washington (Figure 1).

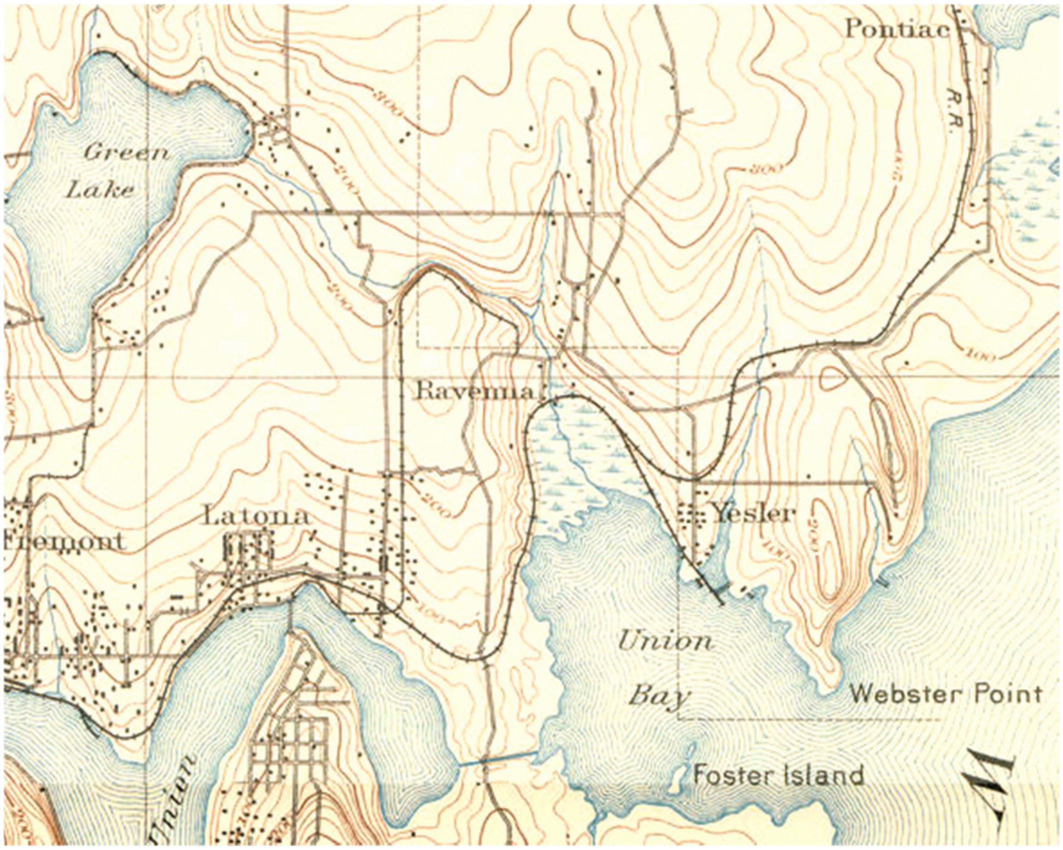


Figure 1. Taken from McKee's Correct Road map, 1894. Note the marshland north of Union Bay. Today, University Village Shopping Center is in this area. The railroad track outlines today's Burke Gilman Trail.

A thriving community of indigenous people lived in this area, collectively known as hah-choo-AHBSH. They were the people of HAH-choo, meaning "people of a large lake" and referring to Lake Washington (Waterman 2001). Five longhouses were located on the north edge of present day Union Bay (though this shoreline was nearly a mile further north at that time), including one near the former Batelle Institute campus in Laurelhurst, and one near the mouth of Union Bay. This last may have been used as a potlatch house (Buerge 1984, Waterman 2001). The area relevant to this study was historically home to the principal village of a group known as hloo-weelh-AHBSH, an influential group whose name grew from s'hloo-WEELH (literally, "a tiny hole drilled to measure the thickness of a canoe", but referring also to narrow passages through the marshland). The hloo-weelh-AHBSH (and others) followed these passages to today's Ravenna Creek, all the way to Green Lake for fishing. Nearby Foster Island served as a burial ground, where the dead were placed in boxes and tied up in tree branches (Buerge 1984).

While historians give various estimates of population numbers before the Europeans arrived, no one knows how many indigenous people actually lived in the area (Anderson 2001). Even before the first settlers arrived, in 1851, local populations had been decreased by smallpox and other epidemics, which had come with earlier explorers such as fur traders. But over time, the European settlers did much to change both the ecology and the social fabric of the area. By 1916, they had completed construction of the Lake Washington Ship Canal and the Hiram Chittenden locks in Ballard (Chrzastowski 1983). The high-impact ship canal project allowed free access between the Lake and Elliot Bay and resulted in the lowering of Lake Washington by 2.7 meters (Montlake Landfill Working Group 1999). Ecologically speaking, lowering the Lake changed the character of the original marshland, and much of Union Bay became a cattail marsh. From both a sociological and an ecological point of view, the local community of hah-choo-AHBSH was virtually destroyed. After 1916 the hah-choo-AHBSH disappeared from the area (Buerge 1984).

Over time, what was left of the marshland (now Union Bay Marsh) was used as a dump, then operated as a sanitary landfill (Montlake Landfill) until it was closed and capped in 1971. Several drainage canals were dug through the cap to channel surface runoff from the surrounding area (Dunn 1966). One drainage canal became University Slough. Today, across NE 45th St from the Slough, University Village Shopping Center occupies the northern piece of the former marshland.

Throughout the mid-twentieth century the area was a popular spot for birdwatching and other naturalist's activities (Higman and Larrison 1951). The reclaimed land is now part of the University of Washington (UW) campus, renamed the Union Bay Natural Area (UBNA). Union Bay Natural Area is still a popular community walking and birdwatching area, also serving as an outdoor classroom and laboratory for students of restoration ecology, landscape architecture, and other fields. It has joined a growing list of recovered "urban wildlands" (De Wet 1998).

At the northwest end of the RC watershed, Green Lake was also lowered, about 2.1 meters in 1911, creating more parkland. This severed the RC connection between Green Lake and Ravenna Park, but the Creek continued to flow from springs and groundwater. From 1948 until very recently the Creek was routed from Ravenna Park into the sewer system. In 1991, a working group from the UW School of Aquatic and Fisheries Sciences, Department of Landscape Architecture, and local community councils (this working group later grew into the Ravenna Creek Alliance) began studying the feasibility of daylighting

Ravenna Creek. The working group wasn't the only interested stakeholder in the proposed daylighting project. King County was drawn by the potential for saving a substantial amount of money by not continuing to route the Creek water through the sewer system. The original estimate of the savings amounted to $2 million over a twenty year period (Douglas Houck, personal communication, 3 April 2007).

The initial vision of the working group was to daylight RC from Ravenna Park, where it entered the sewers, across the University Village Shopping Center, then connect it to the Slough. But costs associated with this route included installation of a parking garage to replace ground level parking lost by the introduction of a creek bed. As it did not seem appropriate to spend public funds (see Appendix B for details) on such a structure, a compromise was reached. A small portion would be daylighted at the south end of Ravenna Park, then the water routed through a trunk line connecting with the Slough. The plan included several installations by artist Mark Brest van Kempen, including buried native seed vaults, a blue-line notating the path of the Creek, open grating where the water can be seen flowing (along 25th Ave NE), and a custom-made outflow leading the Creek from Ravenna Park to the trunk line. The project included creation of 650 feet of new streambed, increasing the Creek by 20% within Ravenna Park, and 200 feet of rehabilitated pre-existing stream. A new wetland pond was created, as well as four acres of native plant riparian and woodland habitat. The daylighting is a very real thread of hydrological reconnection that may have significant impacts on the aquatic ecology downstream.

The connection came on 22 March 2006, allowing the RC to flow through University Slough and back to Lake Washington for the first time since 1948. It ran, initially, for the better part of ten weeks. Between 29 March and 8 April

2006 the Creek was disconnected by the City for some repairs, reconnected by vandals, then disconnected again by the City so they could finish their repairs. Once the repairs were done they reconnected RC, on 8 April 2006. When a 20-year rain event flooded nearby University Village Shopping Center it was blamed on the Creek's connection to the Slough and on 2 June 2006 the City disconnected RC once again. The flooding was later proved to be unrelated to the RC connection and finally, on 2 October 2006, the Creek was connected and remains so to the time of this writing.

Preliminary Studies

Preliminary studies were conducted in spring 2004 to get a sense of what was present in the water of University Slough and determine how best to monitor those organisms. On 24 May 2004 a "grab sample" of water was pulled from the Slough and examined under light microscopy. Taxa seen (Figure 2) included the diatom *Asterionella*, a colonial green algae *Apiocystis*, as well as rotifers, which are sometimes called "wheel animacules" (Edmondson 1959). These members of the phyto- and zooplankton community produced some inspiring initial photographs, and led to thought-provoking phycological studies. It rapidly became clear that the topic was enormous and narrowing it down to a master's degree focus would not be trivial.

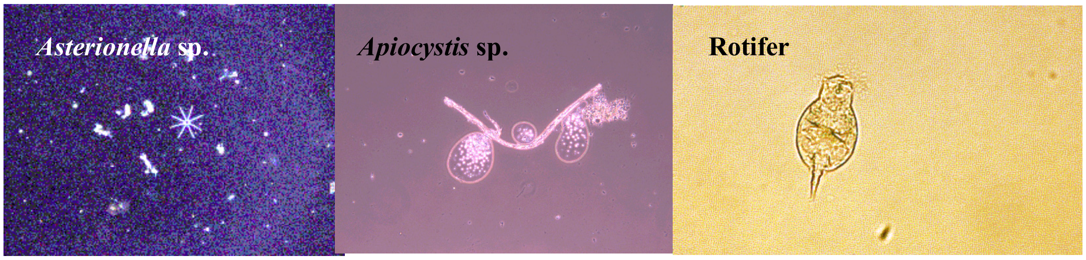


Figure 2. Examples of phytoplankters and a zooplankter (rotifer) found in preliminary "grab sample" of the University Slough water.

On 29 August 2004 a canoe was taken up the Slough and water collected in bottles at several different points. "Leaf washings" were gathered by rinsing periphyton from leaves and branches along the edge of the Slough and collecting them in small glass bottles. Samples were taken back to the lab for analysis. Under light microscopy, *Chlamydomonas* sp., *Oscillatoria* sp., *Chlorella* sp., *Volvox* sp. and euglenoids were seen. Studies verified (Stevenson etal 1996, Wehr and Sheath 2003) that many species of these genera are tolerant of poor water quality - not a surprise, given the stagnant nature of the waterway.

On 26 September 2004, after reviewing some published methods, more preliminary studies were done (EPA 2000a, EPA 2000b, Fore 2001, Fore et al. 2002 Stevenson and Babis 1999). Six sediment samples were taken from the east edge of the Slough, using a 3ml disposable transfer pipet. Poplar leaves that were in the water but close to the shore were rinsed, using deionized (DI) water, and collected. Scrapings were taken from a branch in the water, three samples from three different depths. At another sample point, three "scum" samples were taken from the surface of the water and three more leaf washings collected. All samples were placed in the wells of polystyrene culture plates, covered and returned to the lab, along with a bottle containing approximately 1L of Slough water for phytoplankton analysis. In all the above samples, euglenoids were present, diatoms were present in the sediment samples, and the "scum" from the water's surface proved to be filamentous green algae.

Several experts were consulted. Dr. James Karr, an aquatic ecologist, suggested using artificial substrata to collect the periphyton. On 10 July 2004 the depth of the Slough was measured at four points and several different types of glass substrata were left to accumulate organisms. Unfortunately, most of these substrata were washed away in a heavy rainstorm, but one glass rod was retrieved and examined after two weeks. It was covered with what appeared to be mineral deposits and no organisms were visible. Clearly, modifications were necessary.

On 20 September 2004, Dr. Richard Horner, a specialist in aquatic monitoring, recommended focusing on one sample point and sampling repeatedly, as well as replicating substrata to define variability. On 23 October 2004 phycology expert Dr. Rita Horner agreed that sampling repeatedly at one sample point would be the best strategy. Dr. Rita Horner was extremely helpful, suggesting the fixative (Lugol's) that was eventually used in the study and providing emotional support; she empathized with the challenge of attempting to identify unknown algal species. Hours were spent under the microscope, books and websites were consulted, hundreds of small drawings made. But a systematic study design was still missing.

Finally, after ten months of trial-and-error, this was accomplished with the expert assistance of Sally Abella, a phytoplankton expert formerly with Dr. W.T. Edmondson's lab. Dr. Edmondson was instrumental in bringing back Lake Washington from severe eutrophication in the 1960's and Ms. Abella spent 25 years in his lab, studying the algae in Lake Washington. With her technical guidance, it was finally possible to design a practical experiment that might yield useful results.

Chapter Two: Materials and Methods

The Study Site

The study site was not chosen at random. The UW's Environmental Health and Safety Department (EH&S) was conducting water chemistry sampling, via an independent consultant (Edge Analytical), to establish baseline water quality in the University Slough so potential future impacts of the RC water could be measured. This was important as the UW could be held liable for any problems that might arise following the RC connection. EH&S measured at specific points and it made sense to utilize one of their sample points so relevant data could later be included in the present study. Figure 3 is an aerial view of UBNA and the surrounding area (left) and a map of Edge's sample points (right).

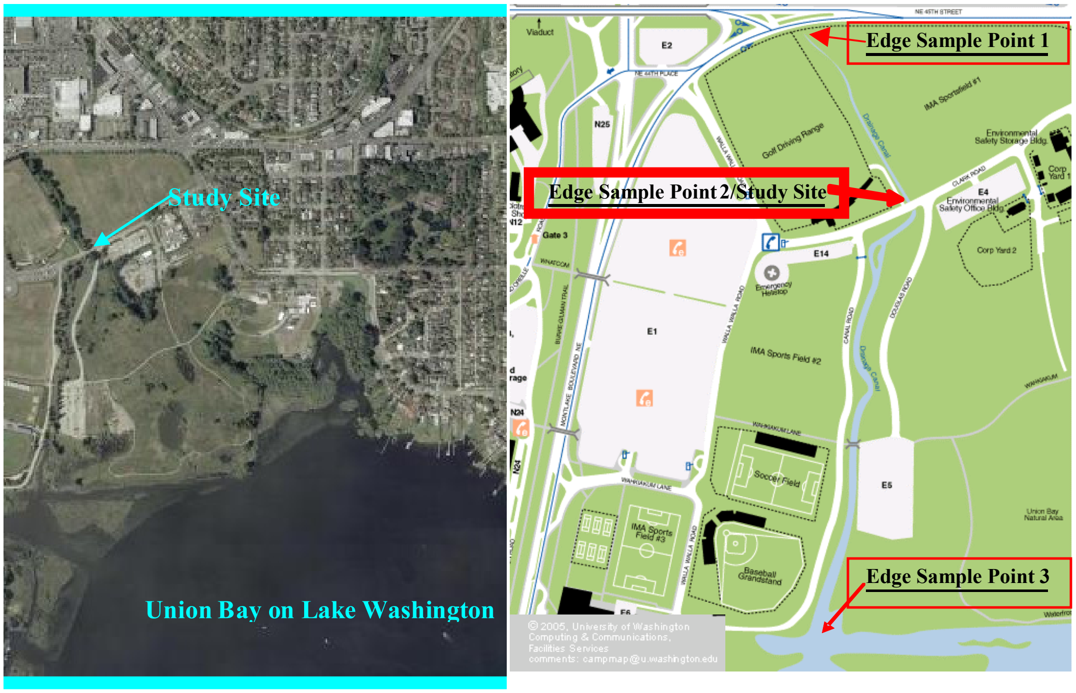


Figure 3. Aerial view of the study area (left) and map showing Edge Analytical's sample points (right). Edge's Sample Point 2 was also used as the Study Site.

Experimental Design

This study utilized a before-and-after treatment comparative design, carried out over two field seasons. The first field season, mid-February through mid-July 2005, was conducted to get baseline information on the periphyton communities present in the Slough. The 2006 field season was conducted during the same February to July time period to gather both year-to-year and after-Creek-connection comparative data. The connection of the Creek was considered the "treatment", although comparative data was ultimately only available for a ten-week period (more on that to follow).

Many studies have compared the methods of sampling algae from natural versus artificial substrata and depending upon the location and goals of the investigation, there are merits to both strategies (Burkholder 1989, Morin 1986, Tippett 1970, Siver 1977). Whether or not artificial substrata accurately represent the ecology of natural periphyton communities is debatable, though it has been reported that loosely attached epiphyte communities in streams and eutrophic lakes showed no substrate preference (Burkholder 1990, Eminson and Moss 1980, Fontaine and Nigh 1983). Certainly, it is desirable to eliminate confounding environmental variables when collecting periphyton as well as to reduce as many sources of variation as possible (Lowe 1996). Thus, artificial substrata were chosen for this study. Glass microscope slides were inserted into a Sampling Station at two-week intervals during the two field seasons. The accumulated organisms were harvested and analyzed for total organic productivity, chlorophyll-α, and taxa represented. Environmental conditions were measured at each sampling time, including surface water temperature, air temperature, and depth of the Slough. This last measurement was done to determine the seasonal variation in the level of Lake Washington. Thus, in April the cord connecting the Sampling Station to its bottom weight had to be lengthened to avoid having the Station float away.

The Sampling Station (Figure 4) consisted of a Styrofoam box, 19cm by 19cm square by 9.5cm high. The box was turned upside down and a pick-up ring inserted through the center, threaded onto a stem; a metal washer was placed under the Styrofoam and a second ring threaded onto the lower end of the stem. A cord was tied onto the lower ring, and the ultimate length of this cord, determined by the depth of the Slough, varied over the course of the field seasons from 91cm to 137cm. Two round rubber stoppers (measuring 6.35cm in diameter by 2.54cm thick) were attached to the cord, approximately 10cm and 56cm below the water's surface. Four microscope slides were inserted into slits (created using a surgical blade) in each of the rubber stoppers. Two slides were inserted horizontally and two vertically into each stopper, for a total number of eight slides per deployment of the Sampling Station. At the end of the cord, a two pound diving weight was attached. The Sampling Station was deployed and retrieved by standing on the Clark Road culvert bridge and using a pole (approximately 2m long) with a pick-up hook inserted into one end.

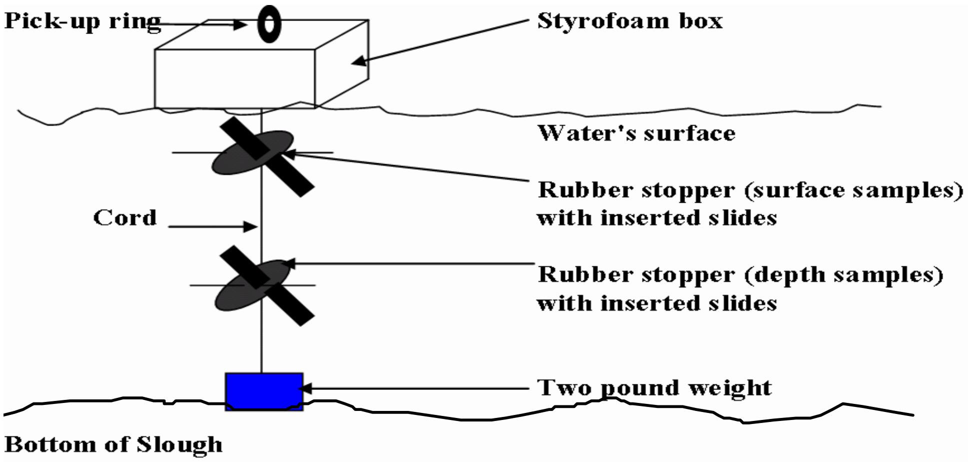


Figure 4. Diagram of Sampling Station

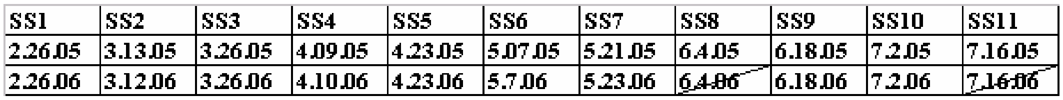
During the first field season, it became clear that the Styrofoam portion of the Sampling Station was shading the substrate slides, though no obvious effects were observed as a result of this shading. To avoid having to redesign the Sampling Station and start the entire experiment over, it was decided to continue while acknowledging this shading.

Artificial substrata have many advantages, but are notoriously subject to vandalism (Lowe 1996). This study was no exception, though vandalism was only a problem during the second field season.

Sample Set Identification and Statistical Notes

Dates that Sample Sets were collected, along with their identifications, are listed below, in Table 1:

Table 1. Sample Set identification and dates samples were collected. Sample Sets lost due to vandalism are notated with a vertical slash.



SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8	SS9	SS10	SS11
2.26.05	3.13.05	3.26.05	4.09.05	4.23.05	5.07.05	5.21.05	6.4.05	6.18.05	7.2.05	7.16.05
2.26.06	3.12.06	3.26.06	4.10.06	4.23.06	5.7.06	5.23.06	~~6.4.06~~	6.18.06	7.2.06	~~7.16.06~~

As noted above, each Sample Set consisted of eight samples, four taken near the surface and four taken at depth. Of these four, two were taken from horizontally-placed slides, two from vertically-placed slides. Slides are designated, and presented in the Results section, as follows in Table 2:

Table 2. Slide designations within each Sample Set.

Surface Horizontal Slides	**SH1 and SH2**
Surface Vertical Slides	**SV1 and SV2**
Depth Horizontal Slides	**DH1 and DH2**
Depth Vertical Slides	**DV1 and DV2**

During the course of the first field season, 11 Sample Sets were collected, and two slides fell out of the Sampling Station, resulting in a final n=86. Two entire Sample Sets were lost in the second field season, one was reduced to three slides (all a result of vandalism), and three other slides fell out, reducing the sample size to n=64. Thus, for the entire study, n=150.

For within-year comparisons, for TOP and chlorophyll-*a*, paired-sample t-tests were used to compare means between the duplicate slides (e.g., SH1 vs SH2), between horizontal and vertical slides (e.g., SH1 vs SV1), and between surface and depth slides (means of replicates). For year-to-year comparisons, F-tests were used to compare variances, then two-sample t-tests were used to compare means. Results are presented as the means of replicates, four each for both surface and depth, in both years [exceptions include triplicates for depth SS6 and SS7 (2005), depth SS1 (2006), duplicates for depth SS2 (2006), surface SS10 (2006), and the single depth sample SS10 (2006)]. Significances at both $\alpha=0.05$ and $\alpha=0.10$ were noted and power set at $1-\beta=0.90$ (Peterman 1990). Within these parameters, for year-to-year comparisons, differences of 27% ($\alpha=0.05$) and 24% ($\alpha=0.10$) of the standard deviation would be detected 90% of the time. In real numbers, this means that for TOP, differences of 154.9µg/ml ($\alpha=0.05$) or 139.7µg/ml ($\alpha=0.10$) would be detected and for chlorophyll-*a*, differences of 2.81ng/ml ($\alpha=0.05$) or 2.49ng/ml ($\alpha=0.10$) would be detected. Nearly all data collected fell within these limits of detection. For taxa identification, sub-samples of the four surface and the four depth slides were pooled and analyzed together.

Harvesting and Processing the Periphyton Samples

Every two weeks the Sampling Station was retrieved and the eight slides transferred into eight 50ml Falcon tubes (BD Biosciences, Catalog #352098), each containing 50ml of sterile deionized (DI) water. The Sampling Station was wiped free of most accumulations; new slides were inserted into the rubber stoppers, then it was redeployed. If the depth of the Slough had changed significantly, the cord was adjusted before redeployment. All waste generated throughout this procedure (such as paper towels used to wipe down the Sampling Station) was taken back to the laboratory and disposed of as biohazardous waste. Harvested samples were kept at 4ºC until processing, which generally occurred on the same day they were collected. A razor blade was used to scrape each slide as cleanly as possible into the 50ml of DI water. The tubes were then vortexed (Fisher Vortex Genie 2) thoroughly to homogenize the accumulated periphyton.

Total Organic Productivity (TOP)

Because the equipment was not available to do an ash-free dry weight analysis (requires a 500°C oven), this study instead determined total organic productivity (TOP). Total organic productivity measures how much organic matter accumulates on the artificial substrata. In this experiment, it included algae, associated grazers such as ciliated protozoans, benthic macroinvertebrate larvae, and aquatic worms, as well as organic detritus. But because the ash-free dry weight was not available, TOP from this also study includes any accumulated particulates (including inorganic silt) on the slides.

To determine TOP, 20ml of the periphyton homogenate was put into each of eight pre-weighed tins and baked for 48 hours at 60ºC. The dried tins were re-weighed to determine the amount of TOP present per 20ml of homogenate and calculations done to determine the concentration of TOP that accumulated per two-week interval. TOP is reported in µg/ml.

Chlorophyll-*a* Analysis

Algae are autotrophic, synthesizing organic matter via photosynthesis. Chlorophyll-*a* is the primary photosynthetic pigment and light receptor, with a maximum absorption at about 663nm. Depending upon the algal species, chlorophyll may also be present as the secondary photosynthetic pigments chlorophyll-*b* or chlorophyll-*c*, but chlorophyll-*a* is often used as a chemical marker of algal biomass in ecological studies, so it was used in this investigation. To determine the chlorophyll-*a* concentration in these samples, 20ml of each periphyton homogenate was left frozen at -20ºC in the 50ml Falcon tubes until the end of each field season. At that time, the tubes were thawed for two days at 4ºC and 1ml of each homogenate added to 9ml of 100% acetone in a Falcon 2059 tube (BD Biosciences, Catalog # 352059). Tubes were put in an ice bath and sonicated (SmithKline Bransonic 220) for three minutes, and then returned to 4ºC for 48 hours. To analyze, 100µl of each sample was put into a 96-well fluorescence plate reader (Molecular Devices SpectraMax Gemini XS) and the plate read at λ_{ex}= 430nm and λ_{em}= 663nm, measured against a chlorophyll-*a* standard curve prepared from commercial chlorophyll (Sigma, Catalog #C5753). Calculations were done to determine total chlorophyll-*a* concentration of the homogenate, and reported in ng/ml.

Taxa Identification

For a phycology study to have scientific validity, the community structure must be enumerated (Lowe 1996). But the identification of periphyton taxa is by no means trivial, and volumes exist on the minutiae of these organisms (Canter-Lund and Lund 1995, Edmondson 1959, Prescott 1962, Wehr and Sheath 2003). During the course of this investigation it became clear that the best strategy was to organize repeatedly seen organisms into several basic categories. First, organisms were described as either autotrophs or grazers, which allowed some information to be gleaned about trophic interactions. Autotrophs included cyanobacteria (blue-green algae), diatoms, euglenoids (though euglenoids are also capable of heterotrophy under certain conditions), and green algae, while grazers typically seen included vorticellids and other ciliated protozoans, crustaceans, aquatic worms, and bloodworms. Two further categories were decomposers and organic detritus, both of which were always present. Note that certain types of fungi - notably, chytrids - while not functionally grazers, may parasitize algae.

During the initial processing of samples, 10ml of periphyton homogenate was added to 1ml of acid Lugol's (Sigma, Catalog #L6146, plus acetic acid, 10% in final solution) for preservation in glass screw-top tubes. Preserved samples were stored at 4ºC and examined using a Nikon Labophat 2 light microscope. During part of the 2005 field season, phytoplankters were examined using an Utermöhl chamber. The phytoplankton community was remarkably similar to periphyton assemblages colonizing the artificial substrata. During the 2006 field season, 1ml of each periphyton homogenate sample was saved for live viewing to get an initial idea of what taxa were present. Preserved samples were later viewed for more comprehensive information concerning identification.

Solar Radiation

Being autotrophic, photosynthetic organisms, algae utilize the sun as their energy source, so it was pertinent to include solar radiation data in this investigation. The UW's Atmospheric Sciences Department maintains a monitoring station for collecting various weather data, including solar radiation and they also maintain a website where this data may be obtained for research purposes. Solar radiation data were obtained from the website and total insolation per day was calculated.

Edge Analytical

This study incorporated several of the data collected by Edge Analytical, including total phosphorus, nitrate/nitrite, specific conductance (a measure of a material's ability to conduct an electrical charge), flow rate at the Slough's in-flow point, pH, dissolved oxygen, and turbidity.

Summary of Data Collected

Data for this study was collected from three different sources. The primary investigator took environmental measurements and collected periphyton to analyze for TOP, chlorophyll-α, and taxa represented. Edge Analytical performed water chemistry analyses. The UW's Atmospheric Sciences monitoring website was used to collect solar radiation data. Table 3 summarizes all data collected.

Table 3. Summary of data collected during University Slough periphyton study.

Collected by ↓	**Preliminary Studies May - December 2004**	**Field Season 1 February - July 2005**	**Field Season 2 February - July 2006**
Julia	**Algal varieties, depth of Slough**	**Total organic productivity, chlorophyll-a, algal varieties, air and surface water temperature, depth of Slough**	**Total organic productivity, chlorophyll-a, algal varieties, air and surface water temperature, depth of Slough**
EH&S	**Total phosphorus, NO_3/NO_2, flow at Slough inflow point, conductivity, dissolved oxygen, turbidity**	**Total phosphorus, NO_3/NO_2, flow at Slough inflow point, conductivity, dissolved oxygen, turbidity**	**Total phosphorus, NO_3/NO_2, flow at Slough inflow point, conductivity, dissolved oxygen, turbidity**
Atmos. Sci.		**Solar radiation**	**Solar radiation**

Chapter Three: Results

Results from the first field season indicated, as expected, that taxa present were those tolerant of poor water quality, particularly the cyanobacteria (blue-green algae) *Oscillatoria* spp., euglenoids, ciliated protozoans, and bloodworms. The second field season was intended to be a comparative study following the connection of RC to the Slough. As noted above, the daylighting project was completed and the Creek's water ran through the Slough for the better part of ten weeks between 22 March and 2 June 2006, but was then re-routed back to the sewers, effectively ending the comparative study. In addition to the disconnection of the Creek, the second field season was plagued by vandalism of the Sampling Station, so some data were lost. While this reduced the statistical power of the comparative study substantially, some trends were seen none-the-less, and will be discussed in detail in the following sections.

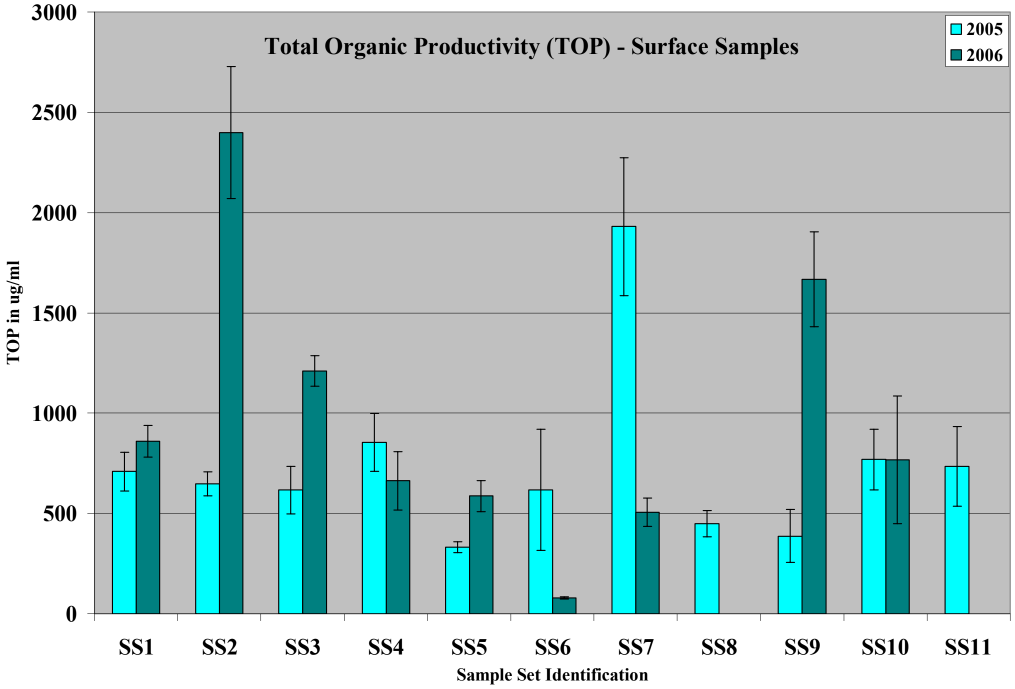
Total Organic Productivity (TOP)

With the exception of SS7, a definite outlier, TOP remained relatively constant over the 2005 field season, at both surface and depth (Figure 5). Horizontal or vertical placement of slides in the Sampling Station made little difference. Surface versus depth was significantly different in two Sample Sets at $\alpha=0.10$ (SS8, $P=0.098$ and SS11, $P=0.088$) and one Sample Set at $\alpha=0.05$ (SS10, $P=0.033$).

In 2006, two Sample Sets were significantly different between surface horizontal and vertical slides at $\alpha=0.10$ (SS2, $P=0.111$ and SS4, $P=0.066$) and between horizontal and vertical slides at depth (SS3, $P=0.056$ and SS5, $P=0.050$).

There were significant differences in TOP between 2005 and 2006 in most Sample Sets (despite the two lost 2006 Sample Sets, SS8 and SS11) when analyzed individually, but no significant differences between 2005 and 2006 when means were compared, at surface, depth, or combined. At the beginning of the 2006 field season, TOP rose sharply, but declined during the comparative period when RC flowed through the Slough (SS3 through SS7). SS10, with only three slides present at harvest, was not appropriate for a statistical comparison.

Overall, more year-to-year significant differences were seen during the comparative period. Table 4 is a summary of statistical comparisons for TOP.



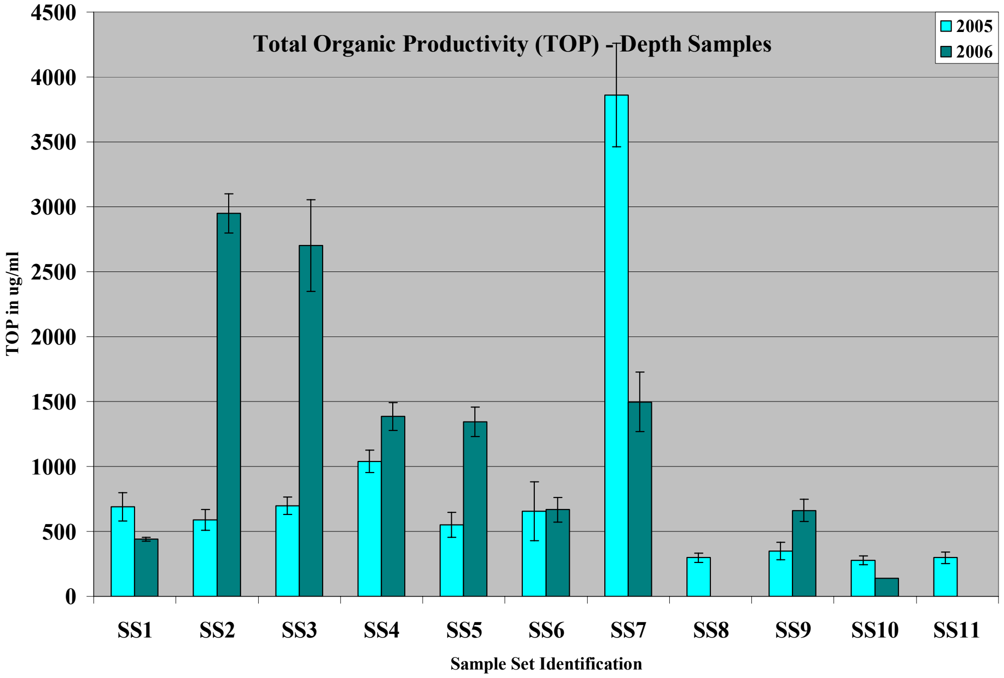


Figure 5. Total organic productivity accumulated on slides at the surface (top chart) and depth (bottom chart) from University Slough during periphyton study. Values are the mean of replicates ± S.E.M.

Table 4. Summary of TOP data t-test results, evaluating the differences between horizontal and vertical slides, surface and depth samples, and between 2005 and 2006. Significant differences at α=0.05 are indicated in bright green; at α=0.1, in pale green. Findings of non-significance are indicated by NS and unavailable data (due to lost slides) indicated by N/A. The dotted area outlines data from the ten-week treatment period in 2006. Overall, more significant differences are seen during this time.

2005											
	SS1	**SS2**	**SS3**	**SS4**	**SS5**	**SS6**	**SS7**	**SS8**	**SS9**	**SS10**	**SS11**
SH1,SH2 vs SV1,SV2	**0.025**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
DH1,DH2 vs DV1,DV2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Surface vs Depth	NS	NS	NS	NS	NS	NS	NS	**0.098**	NS	**0.033**	**0.088**
2006											
SH1,SH2 vs SV1,SV2	NS	**0.111**	NS	**0.066**	NS	NS	NS	N/A	NS	N/A	N/A
DH1,DH2 vs DV1,DV2	NS	N/A	**0.056**	NS	**0.052**	NS	NS	N/A	NS	N/A	N/A
Surface vs Depth	**0.042**	NS	**0.035**	**0.017**	**0.0003**	**0.009**	**0.014**	N/A	**0.029**	N/A	N/A
2005 vs 2006 by Sample Set	NS	**0.012**	**0.002**	NS	**0.008**	NS	**0.026**	N/A	**0.004**	N/A	N/A
2005 vs 2006, mean of surface replicates		NS									
2005 vs 2006, mean of depth replicates		NS									
2005 vs 2006, combined mean		NS									

Chlorophyll-*a*

Chlorophyll-*a* tended to increase at the surface throughout the course of both field seasons, as would be expected due to light increase throughout the summer season, but the difference was more significant in 2006 (this issue is further discussed in the Solar Radiation section, beginning on page 27). Chlorophyll-*a* data is presented in Figure 6.

There were no significant differences in quantities of chlorophyll-*a* isolated from horizontal versus vertical slides for most Sample Sets in either 2005 or 2006 and when analyzed as the means of replicates, chlorophyll-*a* levels were not significantly different at surface versus depth, either in 2005 or 2006. Note that, as with TOP, SS7 at depth was also an outlier in the chlorophyll-*a* data.

However, between 2005 and 2006, some significant chlorophyll-*a* differences were seen, including the means of depth samples (P=0.038) and the combined means of complete Sample Sets (P=0.054). There were more significant year-to-year differences in complete Sample Sets during the ten-week comparative period. See Table 5 for complete statistical summary.

Overall, chlorophyll-*a* concentration was higher in 2006, particularly during the ten-week comparative period, and especially in the depth samples, where it appeared to increase in a linear manner, though the standard error is large. At the surface, the levels appeared rather more random and the standard error is smaller.

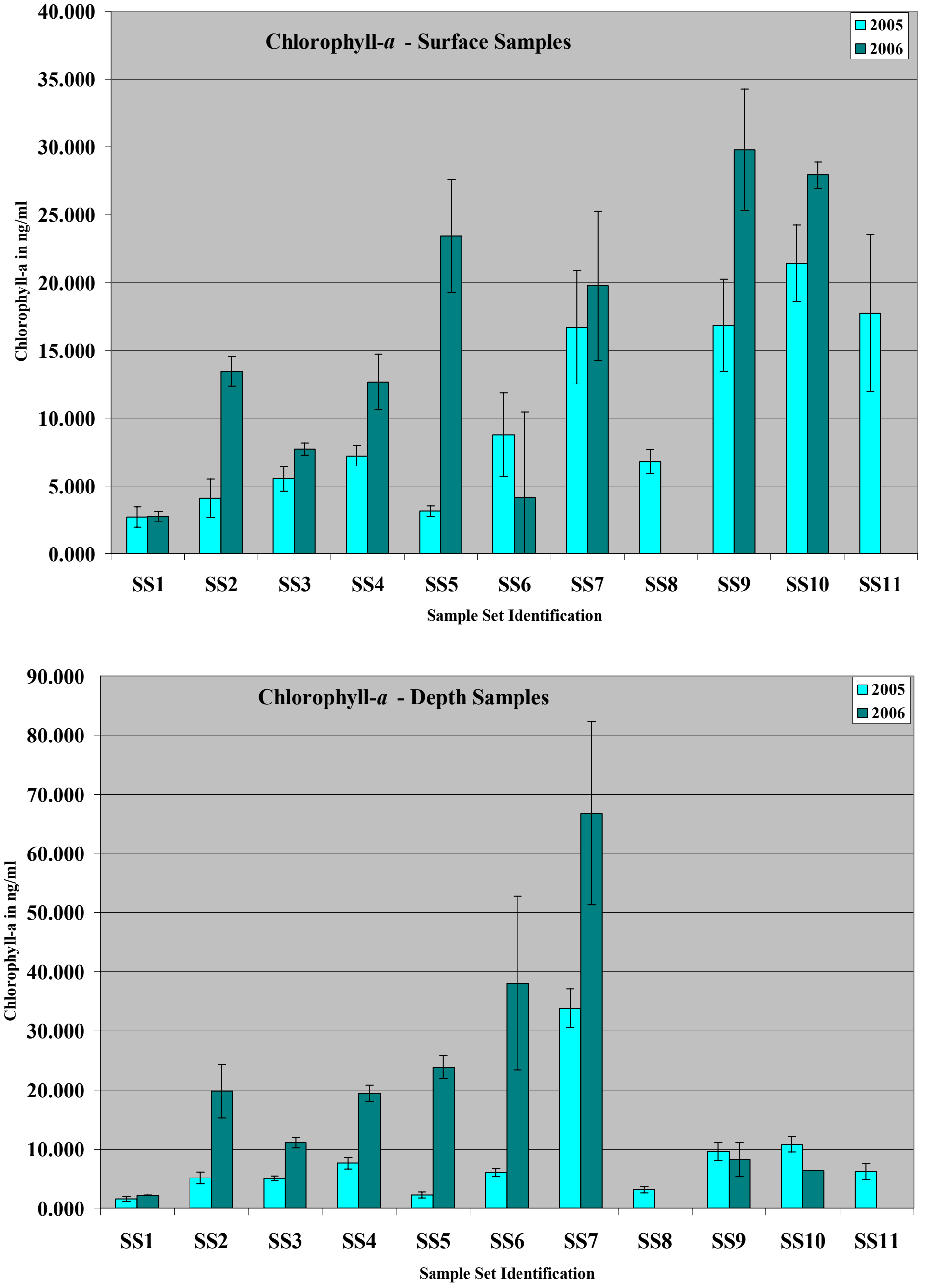


Figure 6. Chlorophyll-*a* accumulated on slides at surface (top chart) and depth (bottom chart) from University Slough during periphyton study. Note the difference in Y-axis scale between 2005 and 2006 to accommodate the extreme value seen in SS7 2006 at depth. Values are the mean of replicates ± S.E.M.

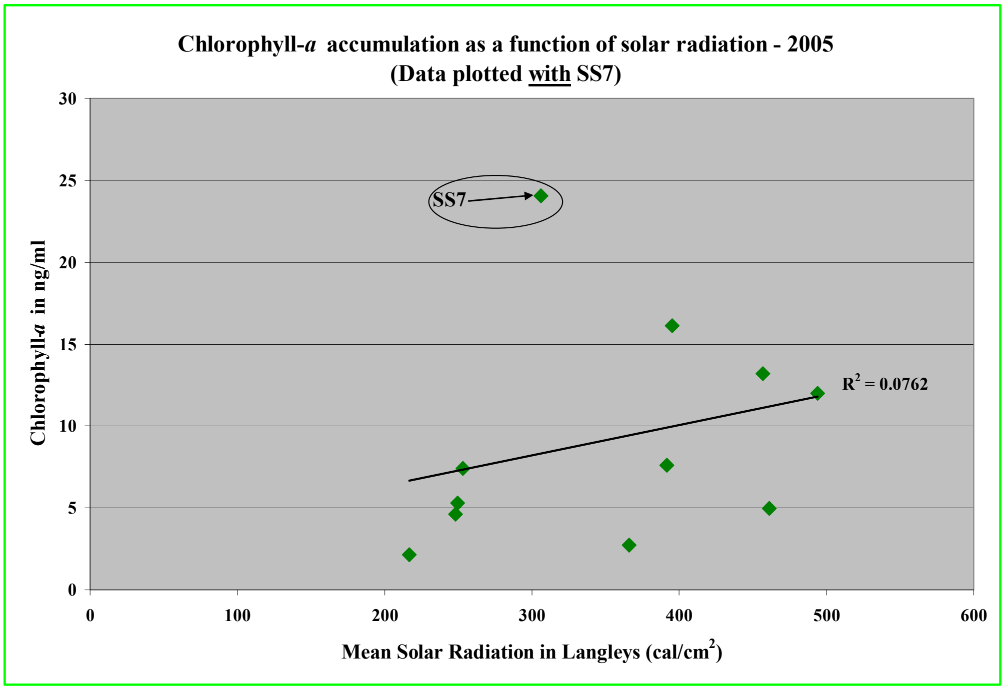
Table 5. Summary of Chlorophyll-*a* data t-test results, evaluating the differences between horizontal and vertical slides, surface and depth samples, and between 2005 and 2006. Significant differences at α=0.05 are indicated in bright green; at α=0.1, in pale green. Findings of non-significance are indicated by NS and unavailable data (due to lost slides) indicated by N/A. The dotted area outlines data from the ten-week treatment period in 2006. Between year comparisons show significant differences during this time period.

2005											
	SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8	SS9	SS10	SS11
SH1,SH2 vs SV1,SV2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
DH1,DH2 vs DV1,DV2	NS	NS	0.103	NS	0.070	NS	NS	NS	0.045	0.092	NS
Surface vs Depth	NS	NS	NS	NS	NS	NS	NS	0.013	0.102	0.050	0.095
2006											
SH1,SH2 vs SV1,SV2	NS	NS	NS	NS	NS	NS	NS	N/A	NS	N/A	N/A
DH1,DH2 vs DV1,DV2	NS	N/A	NS	NS	NS	NS	NS	N/A	NS	N/A	N/A
Surface vs Depth	0.088	NS	0.069	0.007	NS	NS	0.088	N/A	0.017	N/A	N/A
By Sample Set 2005 vs 2006	NS	0.085	0.0003	0.002	0.000001	0.063	0.068	N/A	NS	N/A	N/A
2005 vs 2006, mean of surface replicates			NS								
2005 vs 2006, mean of depth replicates			0.038								
2005 vs 2006, combined mean			0.054								

Solar Radiation Data

There was less than a 10% correlation between solar radiation and chlorophyll-*a* in 2005, though this may have been due to the outlier of SS7. When SS7 was eliminated from the analysis, there was a 63% correlation (Figure 7). There was a 75% correlation in 2006 (Figure 8). Overall, there appeared to be a fairly strong correlation between solar radiation and chlorophyll-*a* accumulation.

To determine whether solar radiation might be contributing to the increase seen in chlorophyll-*a* accumulation during the comparative phase of this study, total daily insolation was calculated and mean insolation was plotted for both field seasons. This was compared with mean chlorophyll-*a* levels (Figure 9). While there was no significant difference in insolation levels between 2005 and 2006 ($P=0.25$), the overall mean of chlorophyll-*a* seen in the comparative period was significantly different at $\alpha=0.10$ ($P=0.091$). This suggests that factors other than solar radiation may have been contributing to the increase in chlorophyll-*a* during the comparative period.



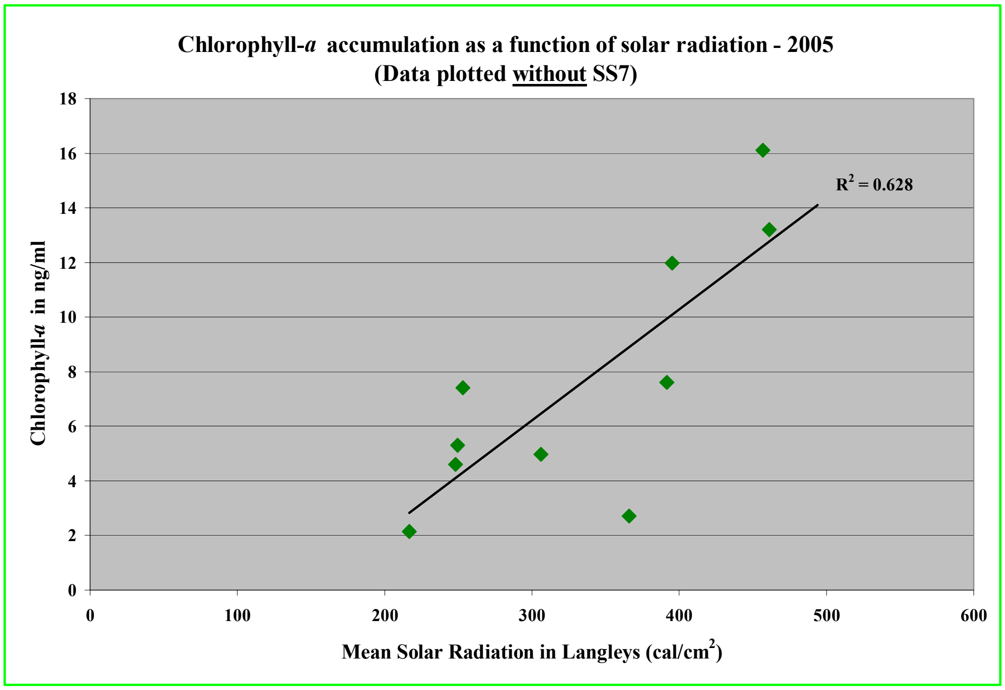


Figure 7. **Correlation between chlorophyll-α and mean solar radiation in 2005, plotted with (top graph) and without (bottom graph) SS7.**

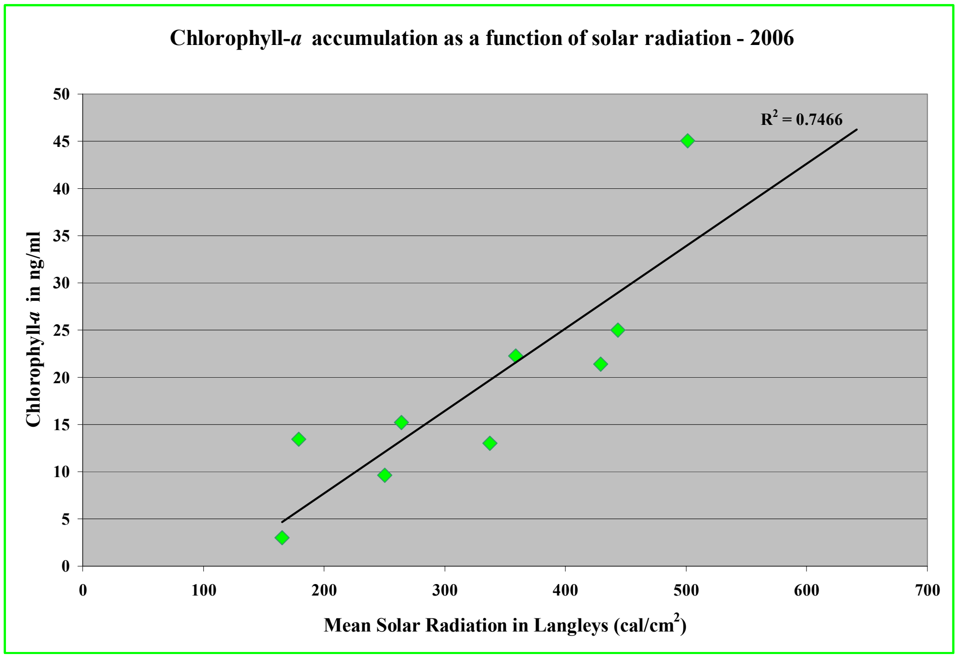


Figure 8. Correlation between chlorophyll-α and mean solar radiation in 2006.

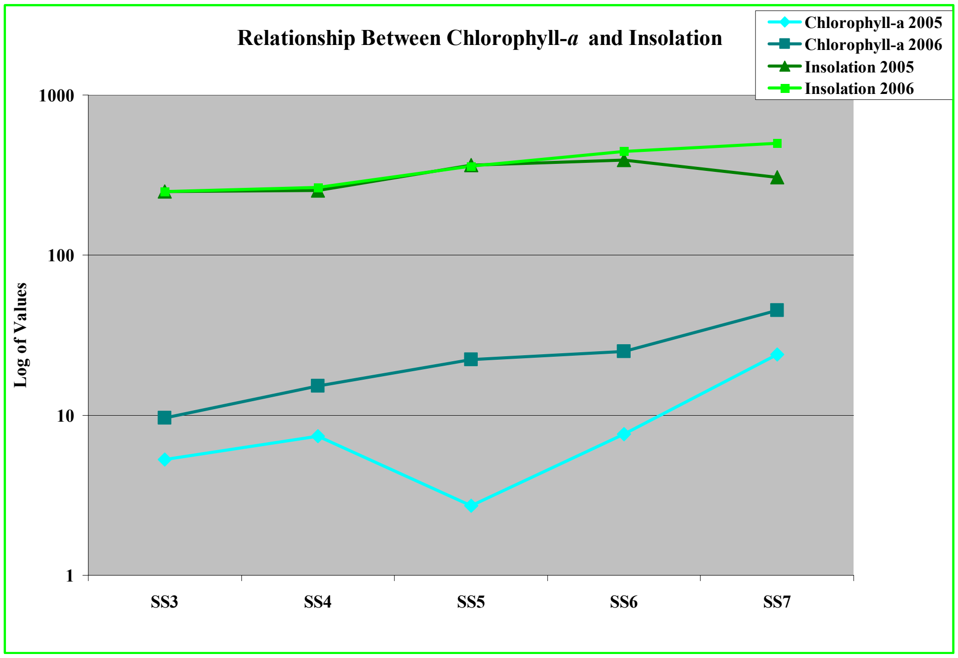
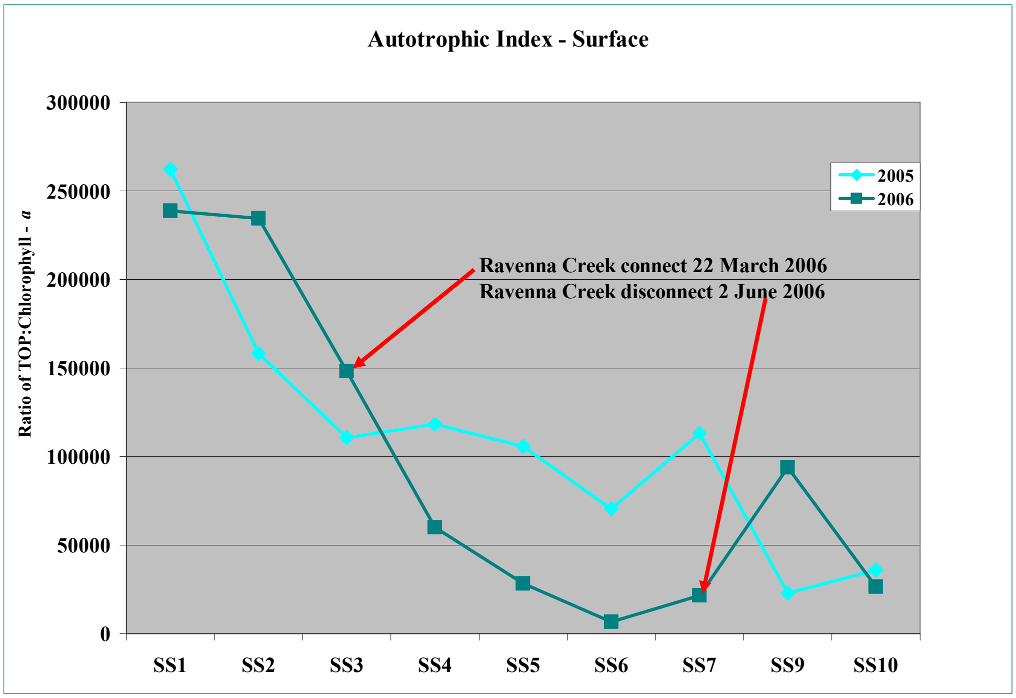


Figure 9. Chlorophyll-*a* was significantly higher during the comparative period of 2006 (P=0.09). Values are presented in log to account for differences in scale.

The Autotrophic Index

The Autotrophic Index (AI) is a measure of water quality based on the ratio of total organic productivity to chlorophyll-*a*. The AI increases in proportion to the concentration of organic matter because heterotrophs occupy a greater portion of the biomass as organic waste increases (Welch 1992**).** In other words, the greater the concentration of organic matter, which increases the biological oxygen demand, the higher the AI values of the periphyton community will be (Lowe 1996). Generally, a value above 1,000 indicates polluted water while lower values indicate better water quality.

The AI values in this study were whopping, reaching levels as high as 450,000. It is likely that these extreme values resulted from the high concentration of both organic detritus present in the samples and the accumulated inorganic particulates, driving up the TOP values. Even so, AI values dropped dramatically during the ten-week period that Ravenna Creek ran through the Slough (Figure 10). At one point (SS6, 7 May 2006) surface sample values measured as low as 6,600 and depth samples 17,000. While these values still reflect polluted water, the decrease seen during the time RC was connected is some of the strongest evidence from this study that points to the potential for water quality improvement as a result of the increased fresh water flow. Though SS8 and SS11 were not available for AI comparisons, at $\alpha=0.10$ surface samples showed a significant decrease during comparative period ($P=0.09$). Depth samples showed a similar trend, though the difference was not statistically significant.



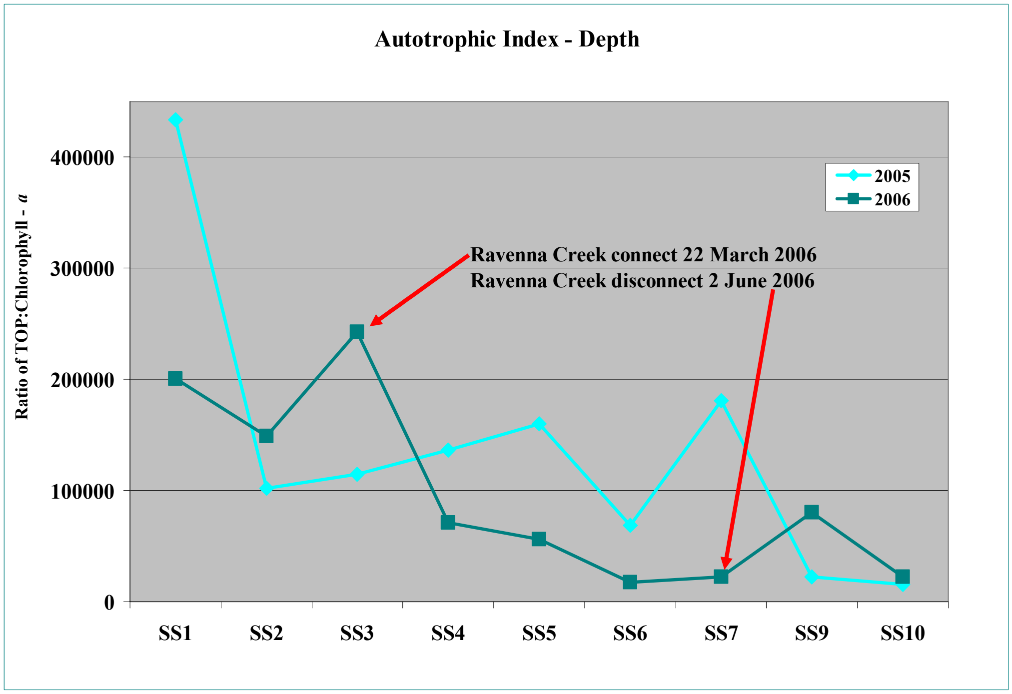


Figure 10. AI at surface (top chart) and depth (bottom chart). Note that because SS8 and SS11 were not available for 2006, no AI values are calculated for those data points.

Taxa Identification

In this analysis, results of both TOP and chlorophyll-*a* are quantitative, while results in this section are qualitative. A Taxa Table was constructed (Table 6) and organisms were listed along with a designation of Common (C), Present (P), or Rare (R) to capture the range of organisms seen in the samples. While the second field season was truncated and did not yield complete comparative results, visible changes in the community structure occurred during the ten-week period the Creek flowed through the Slough. A substantially larger number and a greater variety of diatoms was seen almost immediately in 2006. These organisms had possibly flowed in from the Creek and attached to the artificial substrata. More euglenoids, both in number and in variety, were seen. Though filamentous green algae could clearly be seen on the surface of the Slough in several areas, very little green algae colonized the slides in either field season. Even so, a slight increase in green algae was seen in 2006. This overall increase in autotrophs indicated the presence of more photosynthesizing organisms, perhaps the result of increased water clarity.

Some changes also occurred in the grazer community. Fewer vorticellids were seen, though it appeared there might be a greater variety of other ciliated protozoans present. The significance of this latter is not clear. The number of bloodworms (the larval stage of the midge) decreased dramatically. During 2005 they were present in great numbers, accounting for a good deal of the TOP accumulating on sample slides. But in 2006 they were rare. Aquatic worms, on the other hand, increased in 2006. This shift is another indication of improved water quality.

Table 6. Taxa Table. Highlighted area between SS3 and SS7 indicates comparative period in 2006. Areas outlined in red indicate noteworthy community changes.

S=Surface D=Depth

C=Common P=Present R=Rare

◄Period Creek Ran, 2006►

	Sample Set		1	2	3	4	5	6	7	8	9	10	11
	Autotrophs												
2005	Blue Green, filamentous	S	C	C	P	C	P	P	C	C	C	C	P
		D	C	C	P	P	P	C	C	C	C	C	P
2006		S	C	C	C	C	C	C	C		R	R	
		D	R		C	C	C	C	C		P	R	
2005	Diatoms	S	R	R	P	R	R	R		R	P	P	R
		D	R		R	R		R	R	R	P	P	R
2006		S	P	R	R	C	C	C	C		R	R	
		D	R		R	P	P	P	C		R	R	
2005	Euglenoids	S	R	P	C	R	P	P	C				R
		D	R	P	P	R	P	P	P	R			P
2006		S		R	P	C	C	C	C		P	R	
		D	R		C	C	C	C	C		R	R	
2005	Green algae	S						R			R		R
		D						R					R
2006		S				R		R	R			R	
		D				R		R					
	Grazers												
2005	Aquatic worms (Aeolosoma spp.)	S	R				R	R	R		P	P	P
		D		R							P	R	
2006		S				R	R	R	P		P		
		D				R	P	R			P	P	
2005	Bloodworms	S				P	P	P	P	C	C	C	P
		D				P	P	P	P	C	C	C	P
2006		S							P		C	C	
		D							P		C		
2005	Vorticellids	S	P	C	C	C	C	C	C	C	R	P	R
		D	C	C	C	P	C	C	C	C	R	C	R
2006		S	R	C	P	C			R		R	R	
		D	C	C	P	C	R				C	R	
2005	Other Ciliated Protozoans	S	P		P		P						
		D	R									R	
2006		S	P	C	P	C	P	R	P		C	R	
		D	P	C	C	C		R	P		C		
	Decomposers												
2005	Fungi	S	P	P	P	P	P	P	P	P	P	P	P
		D	P	P	P	P	P	P	P	P	P	P	P
2006		S	C	C	C	C	P	P	P		P	R	
		D	P	P	P	P	P	C	P		P	R	
	Organic Detritus												
2005		S	C	C	C	C	C	C	C	C	C	C	C
		D	C	C	C	C	C	C	C	C	C	C	C
2006		S	C	C	C	C	C	P	P		C	R	
		D	C	C	C	C	C	C	P		P	R	

Edge Analytical Data

This study reviewed several of the data collected by Edge Analytical, including total phosphorus, nitrate/nitrite, specific conductance (a measure of a material's ability to conduct an electrical charge), flow rate at the Slough's inflow point, pH, dissolved oxygen, and total suspended solids (turbidity). Table 7 is a summary of the Edge data for both years.

Phosphorus levels were not significantly different during the comparative period, and while electrical conductivity was slightly lower, the difference is small enough that no conclusions can be drawn from this.

The in-flow rate was higher during the comparative period, as expected, and it decreased after disconnection of RC. However, the in-flow rate increased and decreased similarly in 2005, so it is unclear whether the 2006 flow rate changes were a result of the connection of RC or some other factor.

pH values were slightly higher while the RC was connected and even small changes in pH may have profound effects on aquatic ecology, particularly the cyanobacteria.

Dissolved oxygen went up, an indication of water quality improvement which favors autotrophs, though the increase was not statistically different from the same time period in 2005. Turbidity decreased, an indication of improved water quality, and the 2005 vs 2006 difference was statistically significant (P=0.12). This is a possible explanation for increased chlorophyll-*a* production as a result of more light penetration into the water. Once the Creek was disconnected again, dissolved oxygen went down and turbidity went up.

While temperature is known to affect algae growth (Moore 1978) there were no obvious effects of temperature variation in this study. Temperatures were statistically nearly identical between 2005 and 2006 for the period under consideration.

Table 7. Data provided by Edge Analytical, including electrical conductivity, dissolved oxygen, phosphorus, nitrate/nitrite, and other solution properties of University Slough. Area in green indicates 2006 data and the time period that RC ran through the Slough is outlined in red. Field dates indicate when slides were changed for the periphyton study.

	Electrical Conductivity	**Dissolved Oxygen**	**Total Phosphorus**	**Nitrate-N**	**pH**	**Turbidity**	**In-Flow Rate**	**Julia's Data**	
								$H_2$0 Temp	**Field Dates**
Units→	**µS/cm**	**mg/L**	**mg/L**	**mg/L**	**pH units**	**NTU**	**ft/min**	**°C**	
Edge Date↓									
02.16.05	480	4.2	0.1	0.82	6.7	30	0.97	10	2/12/2005
								11	2/26/2005
03.16.05	525	2.32	0.15	0.64	6.64	36.3	<0.1	11	3/13/2005
								10	3/26/2005
04.07.05	469	3.17	0.11	0.7	6.7	17.8	24	10	4/9/2005
								15	4/23/2005
								13.5	5/7/2005
05.18.05	90.2	5.92	0.09	0.19	6.21	11.5	21.4	13	5/21/2005
								15	6/4/2005
06.08.05	370	2.73	0.14	0.71	6.58	15	1.17	16	6/18/2005
								16	7/2/2005
07.20.05	428	0.58	0.13	0.54	6.5	15.5	0.65	16.5	7/16/2005
02.15.06	453	3.45	0.2	0.57	6.94	30.3	6	12	2/12/2006
								11	2/26/2006
03.15.06	428	3.6	0.14	0.6	7.04	19.7	9.6	12	3/12/2006
								10	3/26/2006
04.12.06	318	**6.57**	**0.1**	**1.8**	7.27	**6.99**	**15**	13	4/10/2006
								11	4/23/2006
								12	5/7/2006
05.17.06	316	**5.68**	**0.11**	**1.79**	7.27	**2.92**	**21.8**	13	5/21/2006
								17	6/4/2006
06.21.06	449	0.43	0.16	0.56	6.96	24	5.07	15	6/18/2006
								17	7/2/2006

Visual Examination

Visually, the Slough water was clearer as soon as Ravenna Creek was connected, as can be seen in before-and-after pictures (Figure 11). Within days of the final reconnection, leaves on the bottom of the Slough could be seen (Kern Ewing, personal communication, 18 October 2006).

Figure 11. The Slough, pre-RC connection (left) and twenty-two days post-connection (right).

Photos courtesy of Kit O'Neill and the Ravenna Creek Alliance
http://home.earthlink.net/~ravennacreek/

Chapter Four: Discussion

Ecological Implications

Although a third field season in 2007 might have yielded more extensive comparative results, it was beyond the scope of this project. However, even curtailed results from the truncated second field season indicate that the water quality of University Slough may be improved by the connection of Ravenna Creek.

During the comparative period, several important changes were noted. Periphyton community structure changed during the ten weeks of increased water flow. Specifically and importantly, biological community diversity increased.

Chlorophyll-*a* levels were higher, indicating increased growth of autotrophs. It has been known for years that water is nutrient richer when flowing than when quiescent, and as long as the water velocity is not great enough to cause shear, algae may benefit from increased water flow. The mechanism is that in weakly moving or quiet water, a film of liquid forms closely around the bodies of microorganisms. This film prevents them from absorbing nutrients from their environment, as well as decreasing respiration. When the water is moving more rapidly, this film is prevented from forming and both respiration and nutrient uptake are enhanced. The actual oxygen and nutrient content of the water may not have changed, but the moving water is physiologically - if not actually - richer in oxygen and nutrients (Ruttner 1953). It is also likely that the increased flow from RC brought new species (especially diatoms) that landed opportunistically onto the sampling slides.

Dissolved oxygen levels were higher, favoring primary producers over secondary producers (the first level of grazers) such as blood- and aquatic worms.

The nutrient kinetics of benthic algae is a complex area of interest and no one set of optimal physiological traits exists that allows continual successful competition by any particular species (Borchardt 1996). Light, disturbance, and grazing may all override nutrients as a causative factor of algae growth. The two nutrients included in this study were phosphorus and nitrogen. However, while they tested for total phosphorus, Edge Analytical did not test for total nitrogen. Instead, they tested for nitrate and nitrite (NO_3 and NO_2). This meant it was not possible to calculate an N:P ratio, which would have been useful. The higher nitrate/nitrite levels seen during the comparative period in 2006 were not seen during the same time period in 2005. This could have been caused by a number of factors including fertilization of adjacent athletic fields and nitrogen fixation of nearby vegetation, such as *Alnus rubra* (red alder), releasing more nitrogen into the Slough. If the additional water flow causes more nitrogen to be washed into the Slough, more nitrogen may be pushed to the mouth of the Slough and into Union Bay. Future studies will have to determine whether this is the case. Additionally, cyanobacteria are nonsymbiotic nitrogen fixers that may contribute significant amounts of nitrogen (Mitsch 2000). They are also reported to be one of benthic algae most sensitive to acidification (Planas 1996). While they were seen throughout the course of this study, cyanobacteria were more common during the comparative period, when the pH was slightly higher.

SS7 was an interesting outlier in 2005, with no clear explanation. What was obvious, however, was an enormous bloom of vorticellids present in the Sample Set. It is possible that this bloom drove up TOP. Fecal coliform was particularly high (Edge Analytical, data not shown) during this time period and it dropped the following month. It is possible the vorticellids bloomed in response to this high level of fecal coliform, and then decreased as the food source was depleted. Because vorticellids do not photosynthesize, they would not have been responsible for the higher chlorophyll-*a* content of the Sample Set. However, because they eat photosynthetic organisms, perhaps their bodies contained ingested chlorophyll-*a*, which was subsequently detected by the assay.

The increase in chlorophyll-*a* seen during the comparative period did not appear to be related to increased light as solar radiation levels were not significantly different between 2005 and 2006. It is likely that decreased turbidity allowed more solar radiation to penetrate the water.

The electrical conductivity levels seen during the ten-week comparative period were not significantly different from the previous year and were unlikely to be contributory to the changes seen in community structure. Nor did temperature appear to be a factor in the change in community structure.

In the aquatic ecology of the Slough, organic detritus and decomposers are functionally connected, with decomposers breaking down organic matter and creating organic detritus. Both decomposers and organic detritus were always seen in samples in this study, and AI levels appeared to be driven largely by high levels of organic detritus collecting on the sample slides (as well as inorganic particulates). The AI levels showed a dramatic decrease during the comparative period, and in the surface samples, this decrease was significant at $\alpha=0.10$ ($P=0.09$). As lower AI values indicate better water quality, these results provide evidence of improved water quality for the Slough as a result of increased flow.

Finally, the Slough water is visually clearer when RC is connected.

In retrospect, it would have been useful to install a flow meter at the study site sample point to get a more extensive and specific data set for water flow. This sample point is a particularly sluggish area of the Slough, being located next to a culvert, which creates a bottleneck. As noted, flow increased at the inflow in 2005 during the same time period it increased during 2006, so it is unclear whether the connection of RC had any appreciable effect on flow at the sample point, but installation of a flow meter at the culvert might have resolved this question.

In summary, this investigation has demonstrated the use of a comprehensive method to analyze periphyton communities in an urban slough. Further, the study has analyzed and compared the periphyton communities both before and after a local creek was connected, and provided evidence for the improvement of the biological aquatic ecology and water quality in the University Slough as a consequence of connecting Ravenna Creek.

Future Directions and Recommendations

The vast, productive marshland that once existed north of Union Bay is gone and can never be restored. Never-the-less, reweaving some of the historical hydrological threads *is* possible, as has been done between Ravenna Creek and University Slough. Ravenna Creek was reconnected to the Slough in October of 2006 and continues to be connected at this writing (June 2007). The effects on the aquatic ecology downstream will likely be cumulative and only fully realized following several years of the creek-to-slough connection.

Now that a monitoring plan has been initiated for microorganisms living in the University Slough, it is likely that more research will be done to follow changes in the aquatic ecology. Data collected from further field seasons may reveal significant differences in the parameters tested in this study. Predictions include increased biological diversity, particularly of autotrophs, and a further drop in AI values. Expanding the overall study to include more study sites, and installation of flow meters in both reaches of the Slough would be useful, and future projects might also benefit from an expanded and combined study of algae and benthic invertebrates to further understand the trophic interactions at play in the periphyton communities. With more extensive data from more sample points, an Index of Biological Integrity might be constructed. It will be interesting to pay attention to changes in diatoms, cyanobacteria, aquatic worms, and bloodworms, as these taxa are particularly good indicators of changes in water quality.

Future studies could include a Sampling Station that is less prone to vandalism and less likely to add to the shading of samples being collected. As these studies can be valuable opportunities for public education, interpretive exhibits at or near sample points could be useful in deterring vandalism. Vandalism cannot be prevented entirely, but it might be mitigated by engaging the interest of the relevant members of the public.

The UW grounds crew has begun removing invasive vegetation from the area around the Slough. If appropriate plantings are done, the riparian habitat will be enhanced. This, coupled with improved water quality in University Slough, will be one more step toward restoring function to a long-degraded urban ecosystem.

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http://home.earthlink.net/~ravennacreek/

http://www.siue.edu/OSME/river/water&kicknets/characteristics_that_determine_w.htm (downloaded 5/15/2006)

Appendix A - Social and Policy Implications

Fundamental to this study was the daylighting of Ravenna Creek and the history of daylighting Ravenna Creek underscores the radically complex nature of such projects. Stakeholders are typically many - the City of Seattle's Public Utilities and Parks Departments, King County, Ravenna Creek Alliance, local residents, the owner of the University Village Shopping Center, the University of Washington, and several graduate students - to name the major players in this case. When the owners of University Village Shopping Center considered routing Ravenna Creek through their property, costs associated with doing so would have included an underground parking garage to replace parking lost to the new creek bed. As public funds* were used to finance this daylighting project, it did not seem appropriate to use them to build a parking garage, and thus, the daylighting project was stalled for about 12 years until the stakeholders negotiated a compromise plan. Though the vision of an urban creek wandering through the parking lot was attractive to many people, especially those involved in the newly-formed Ravenna Creek Alliance, a different scenario was proposed and eventually accepted by all parties. Once the compromise plan was accepted, several University of Washington departments, including the Regents Office and Environmental Health and Safety, became involved, as the University Slough runs across University property. This means the University could be held legally responsible for any problems created by the connection of the Creek to the Slough.

*Funding Info: This $1.9 million project, funded by the King County Wastewater Treatment Division, by the voter approved Seattle Pro Parks Levy, and the City of Seattle Mayor’s Office of Arts & Cultural Affairs, used public funds. King County also allocated $2.1 million to lay 2,700 lineal feet of pipe, allowing Ravenna Creek to flow to its natural outfall at Union Bay. http://home.earthlink.net/~ravennacreek/index.htm

The issue of erosion of the Slough bed, releasing potentially toxic compounds from the underlying landfill was raised (see Appendix B). The integrity of Clark Road Culvert, which bisects the two "reaches" of the Slough, was questioned, along with its ability to handle increased water flow. Years of meetings and negotiations followed, even after King County laid the trunk line in 2004. However, the daylighting project went forward. Landscape architect Peggy Gaynor designed the new creek bed and associated plantings, artist Mark Brest van Kempen created art installations and the initial connection was made on 22 March 2006. By this time, the plantings surrounding the daylighted portion of the Creek were getting established and the newly-created creek bed accepted the water with grace. It was a triumph, finally, for the Ravenna Creek Alliance and a neighborhood celebration was held on Mother's Day, 13 May 2006.

However, on Memorial Day weekend 2006, a 20-year rain event occurred. University Village merchants experienced flooding into the doorways of their stores. The owner, convinced this flooding was caused by the Creek connection, successfully urged the City to re-route the Creek back into the sewers. This was done on 2 June 2006, just a little over ten weeks after the connection, causing a new flurry of phone calls, letters, and meetings. The flooding was later proved to be unrelated to the RC connection but it was another four months before the Creek ran into the Slough again, on 2 October 2006.

One lesson of such projects is, perhaps, the necessity for sheer determination in the face of all obstacles. There is talk of renaming University Slough. As it is now the mouth of a creek, it may ultimately be called Ravenna Creek.

Appendix B - Hydrological Concerns

There were some initial concerns that the connection of RC to the Slough might cause erosion of the landfill cap, releasing potentially hazardous substances from the underlying sediment, so calculations were done to determine if this was a valid concern. RC water entering the Slough was to be capped at five cubic feet per second (CFS). As a ballpark calculation of what this may mean for the Slough: if the cross section of the Slough averages 30 feet wide by four feet deep (a guess based on visual inspection), then the cross sectional area is 120 square feet. Dividing this cross sectional area by the CFS: 120÷5 = 0.0417 linear feet per second, or 2.5 feet in one minute. It is unlikely that water moving at this maximum flow rate would cause erosion, either from the banks or the bottom of the Slough (Kern Ewing, personal communication, 9 March 2004).

Appendix C - Photo Gallery

The following pages are filled with photomicroscopic images of organisms seen in this study. They are meant to be beautiful and inspiring, and are not intended as a guide to identification. The captions that accompany them are only the best guesses of this amateur algologist. All photos are the property of Julia Helen Tracy, but may be reproduced with permission.

Please enjoy!

Julia Helen Tracy
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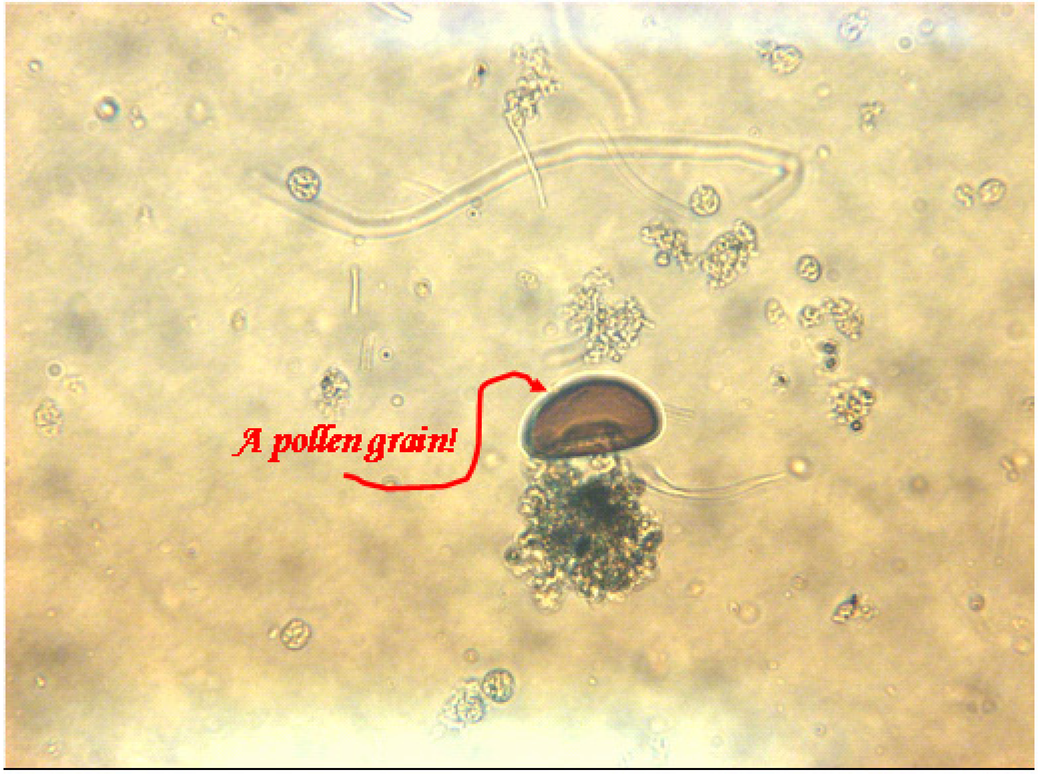
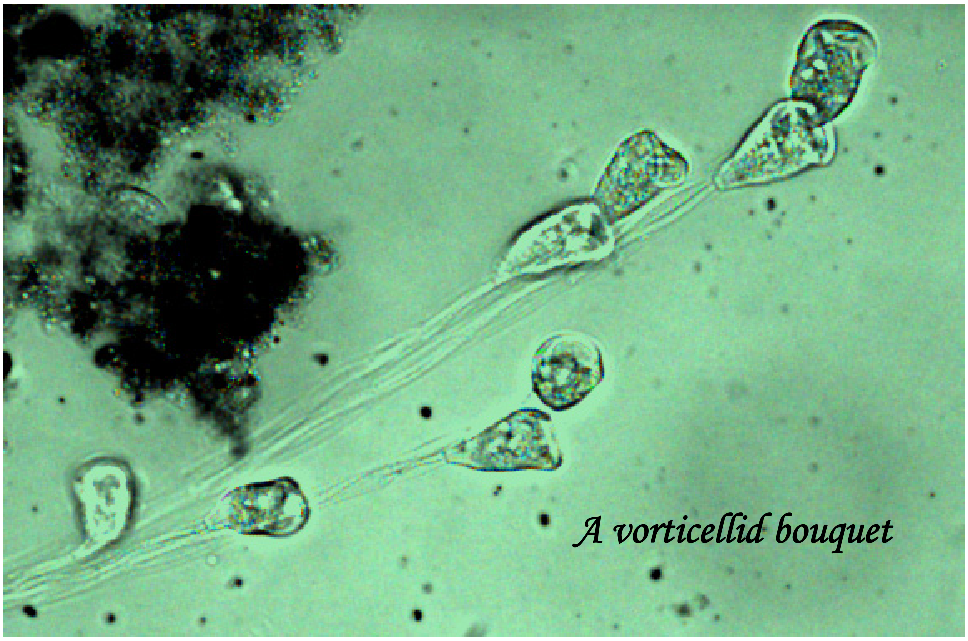
A plethora of diatoms

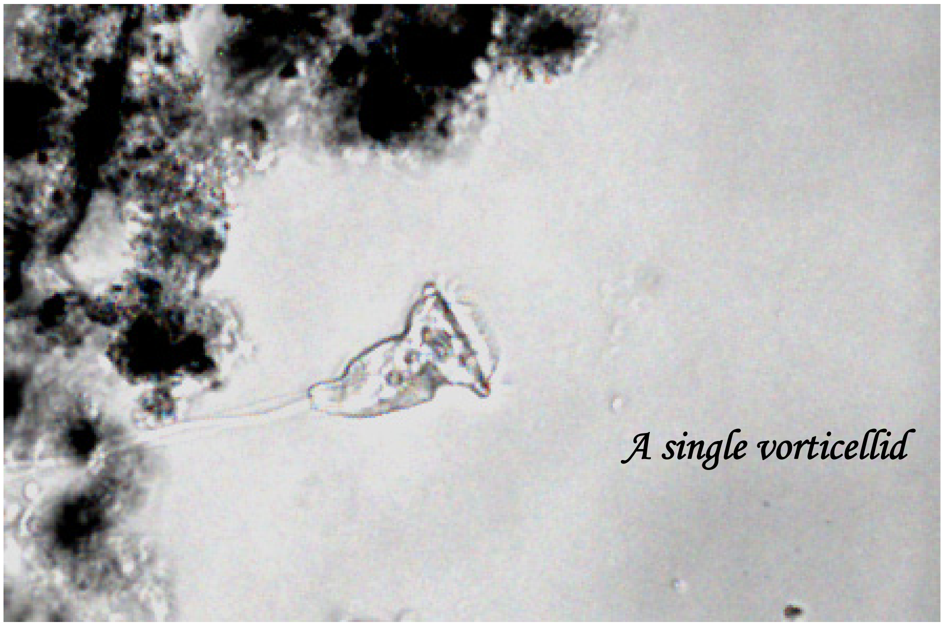

A pollen grain!

Possibly a euglenoid with single flagellum

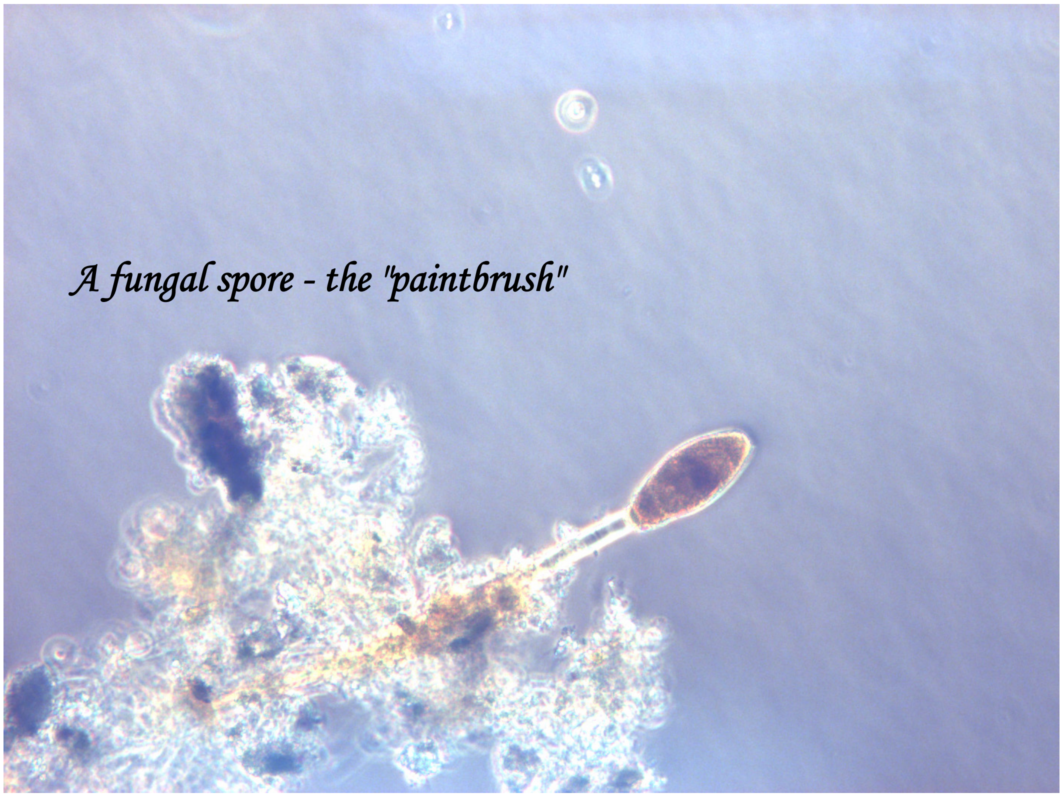
The setae of an aquatic worm, possibly Aeolosoma sp.


A rare green sprig

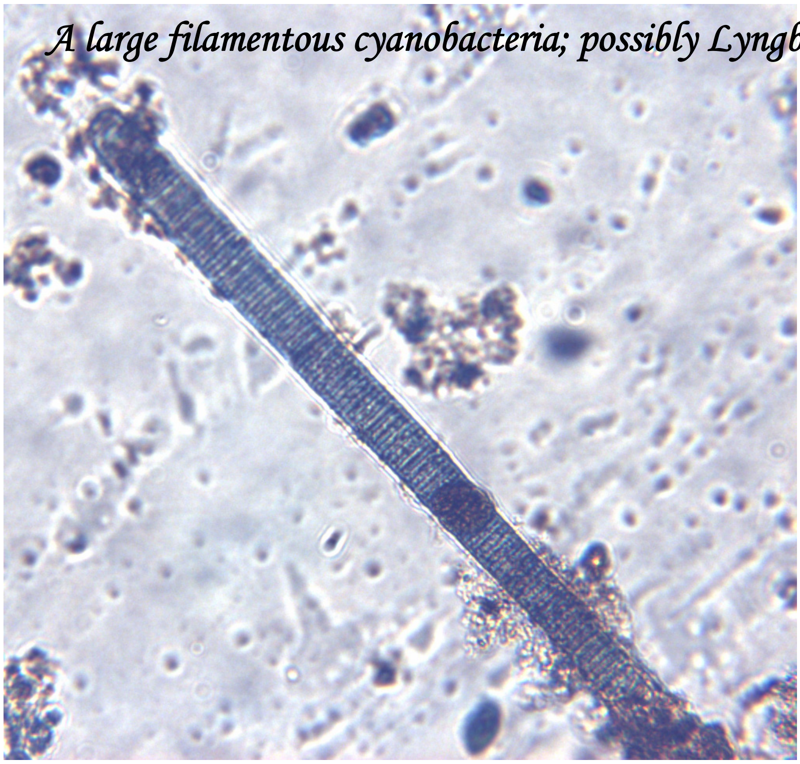

A vorticellid bouquet



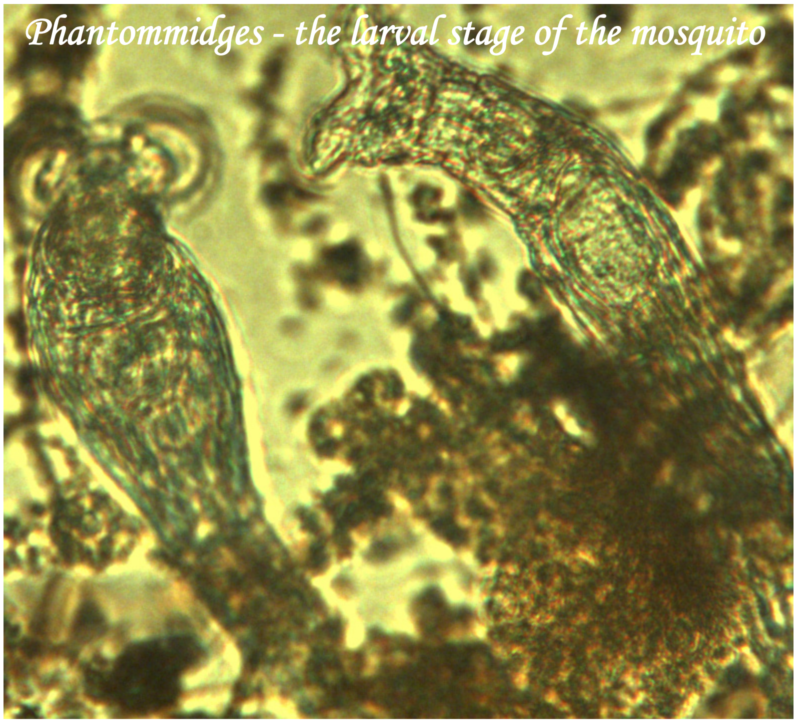
A single vorticellid



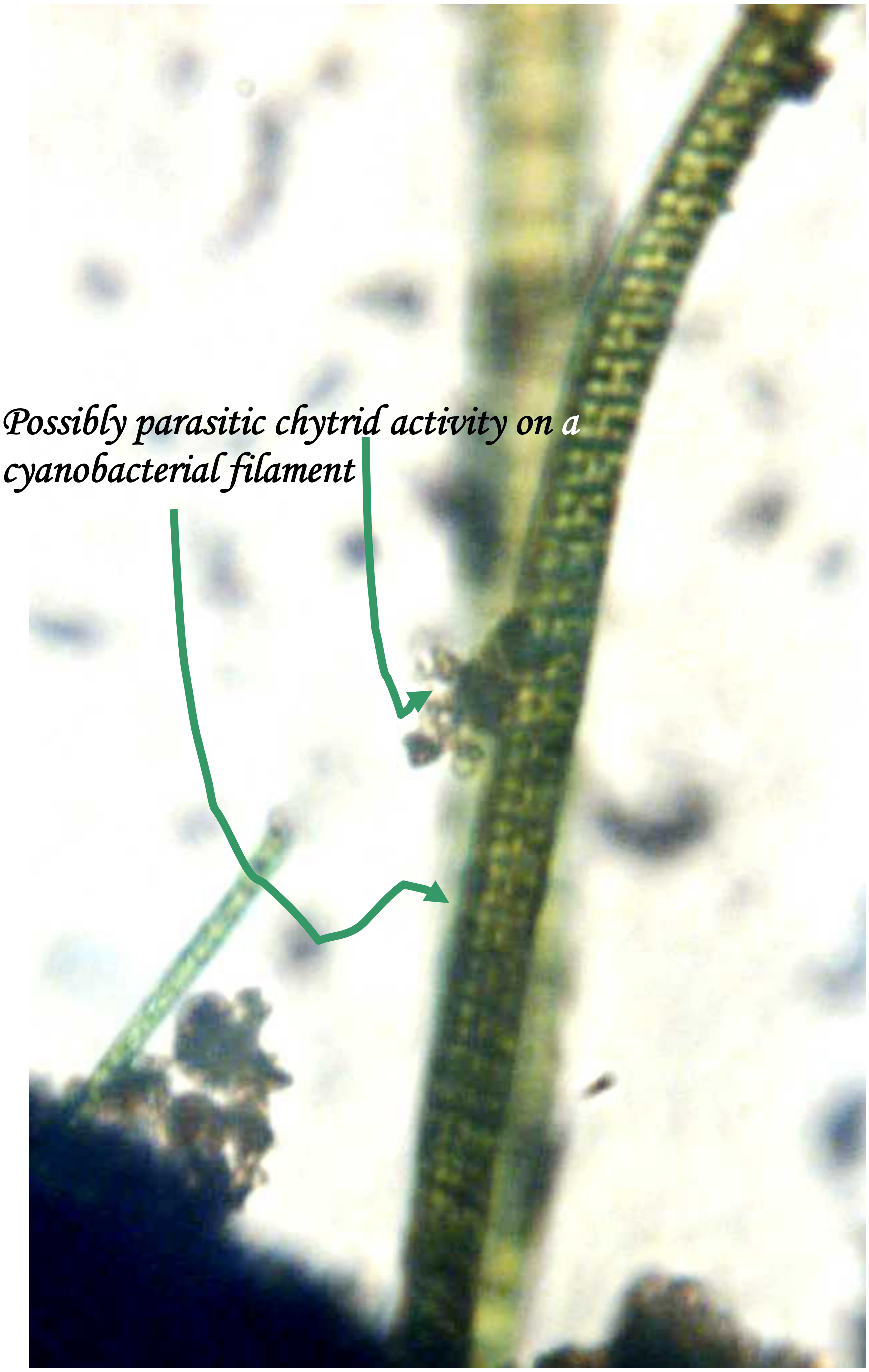
A fungal spore - the "paintbrush"



A large filamentous cyanobacteria; possibly Lyngbya sp.

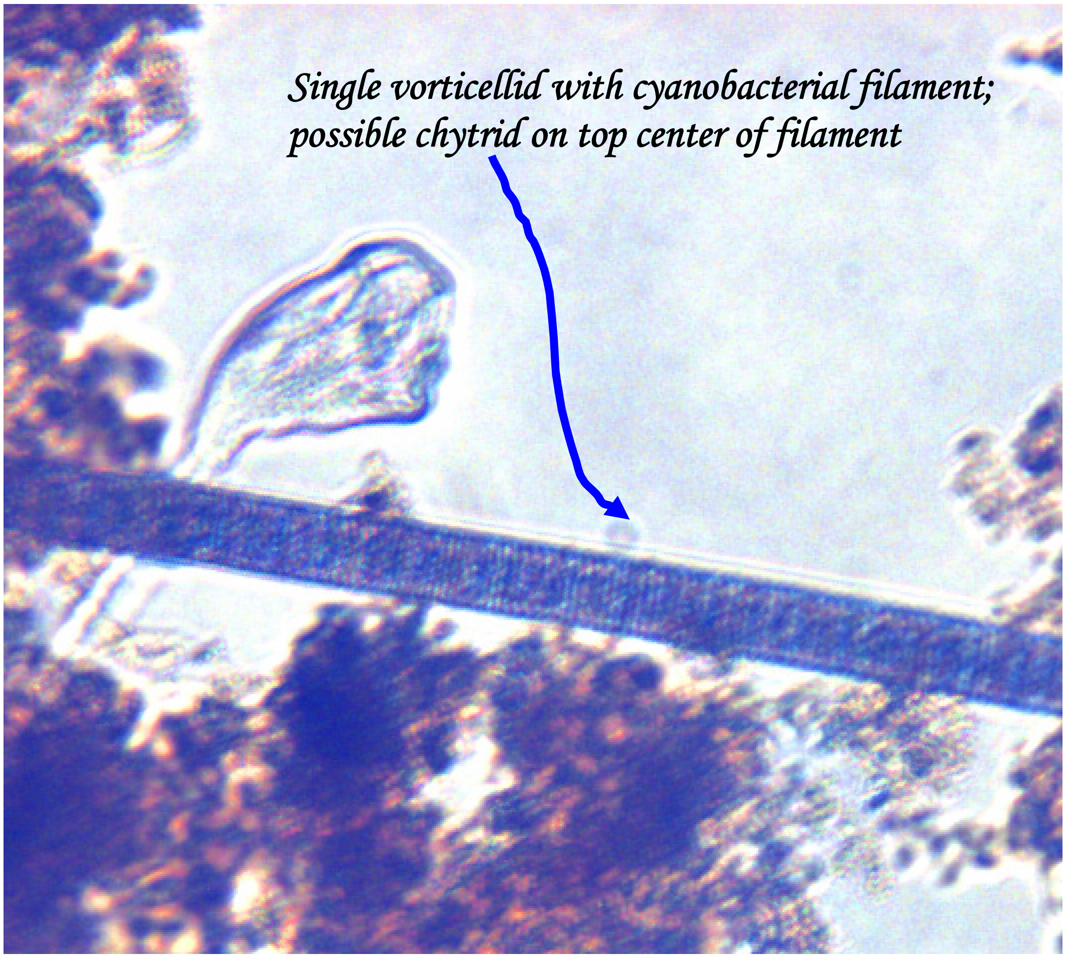


Phantommidges - the larval stage of the mosquito



Possibly parasitic chytrid activity on a cyanobacterial filament

Bosmina (a grazer) with ingested diatoms visible in upper righthand side of animal



Single vorticellid with cyanobacterial filament; possible chytrid on top center of filament

Diatom with baby?
Or just two different species?