Progress Report on the Susquehanna River Algal Turf Scrubber Project

Summer 2008

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Executive Summary

This is a report on the performance of the experimental algal turf scrubber (ATS) system, located at the Muddy Run Hydroelectric Facility, during the summer of 2008. A diverse algal community developed quickly in the ATS and the metabolism of the algae had strong positive effects on water quality. In particular, the data gathered over the summer demonstrated that this ecologically engineered technology removes nutrient pollutants from the water and adds dissolved oxygen to the water at high rates. The ATS system also exhibited high rates of biomass production, which can be used as a feedstock for biofuels. The productivity of the Muddy Run ATS was several times greater than the productivity of natural aquatic ecosystems because of the controlled hydrology and the harvest management of the system. The maximum recorded productivity was greater than 30 grams dry weight/m2/day, which indicates the potential of this technology.

A great deal of design knowledge was developed from the summer operation of the experimental ATS and higher rates of performance are expected as the project continues. A second experimental ATS was constructed in the fall of 2008 and the early indications are that this new system may already be out-performing the original system. The continuing research at Muddy Run holds good prospects for improving the water quality treatment and biomass production capacities of the ATS technology.

Main Findings of the Summer Progress Report

The metabolism of the algal turf community on average raises dissolved oxygen concentration 5.9 mg/l and pH 1.6 units as water moves from the top to the bottom of the scrubber.

Biomass production averaged 18.0 grams dry weight/m2/day with a peak of 24.5 grams dry weight/m2/day on 7/28/08.

The highest productivity measurement was 31.4 grams dry weight/m2/day, recorded on 7/28/08 at the bottom of the scrubber.

Biomass production was composed of the vacuum harvest (80% of the total production), the green water (10% of the total production) and the slough (10% of the total production).

On average total nitrogen concentration decreased by 23% as water moves from the top to the bottom of the scrubber. No data is available on total phosphorus concentration.

Algal biomass averaged about 2.5% nitrogen content and 0.25% phosphorus content.

After the turf had fully developed, nutrient content in the algal biomass declined from the top to the bottom of the system suggesting longitudinal nutrient limitation.

A total of 86 species from five algal phyla were identified from the turf community.

Most of the species (76%) were rare, in the sense of frequency of occurrence.

Species of Melosira, a filamentous diatom genus, and species of Spirogyra, a filamentous green algal genus, were the dominant taxa that give the turf community its structural character.

NARRATIVE

This is the first progress report on the Susquehanna River ATS (algal turf scrubber) project, which introduces the project and reports on data gathered during the summer of 2008. The proposal for the project was submitted in late spring of 2007 and the intention was to have the ATS operational by early spring 2008. The summer of 2007 was spent searching for a suitable site with close proximity to the river, no shading and security. Contact was eventually made with the Exelon Energy Corporation, which operates several power plants on the lower Susquehanna River. The manager of the Conowingo hydroelectric plant became interested in the project and she has assisted in establishing and conducting the project since the first contact. Meetings were held with Exelon administrators during the fall and winter in order to secure corporate permission to operate the ATS on Exelon property. After extensive communications between the Exelon Corporation, the Smithsonian Institute's National Museum of Natural History and the University of Maryland, a suitable agreement was established for the research to be carried out at the Muddy Run hydroelectric power plant in Lancaster County, Pennsylvania. The Hydromentia Corporation of Ocala, Florida fabricated the ATS and had it shipped to the site in late spring of 2008. The system was constructed at Muddy Run with assistance from staff at Exelon and from Living Technologies of Easton, Maryland.

Construction of the ATS was completed on 6/6/08 with water input from the Muddy Run Reservoir. Rocks from the Susquehanna River at Muddy Run were added to the ATS to both provide a seed source for benthic algae and to submerge the ATS screen, which was not physically attached to the trough or bed of the ATS. Wire braces were also installed in order to keep the screen submerged. Benthic algae from Muddy Run Creek, which were placed in bags fashioned from the ATS screen material, was also used to seed the system. Local streams were searched for Cladophora, which was not found at the Muddy Run site. Two nearby streams with Cladophora were located and rocks from these streams were added to the system with the intention of adding this genus to the scrubber community.

An algal community developed relatively rapidly and the system was first harvested on 6/23/08 to initiate the study of biomass production and nutrient dynamics. Measurements of biomass production, or net primary production, began on 6/28/08 and continued throughout the summer approximately every five days. Once the algal community was well established, the rocks and screen bags were removed from the system on 7/3/08. This action unfortunately caused the screen to float more than anticipated, which in turn significantly reduced algal growth. Thus, the rocks were added back into the system on 7/8/08 and the algal growth rate rebounded after several harvests.

METHODS

Basic Water Quality

Water quality parameters were measured before each harvest in the late afternoon in order to quantify the maximum effect of metabolism of the algal community. Measurements were made at the top of the system, where water enters from the Muddy Run reservoir, and at the bottom of the system, as the water flows into the river. The difference between bottom and top values indicates the effect of algal metabolism as water passes over the turf. Water temperature, dissolved oxygen concentration and percent saturation of dissolved oxygen in the water were measured with a YSI meter and pH was measured with an Accumet meter.

Biomass Harvest

Algal biomass was harvested in sample sections along the length of the ATS in order to identify possible longitudinal changes in the community. Several different patterns of harvests were tried initially. The final pattern of harvest was established on 7/28/08 and it has been continued routinely. Biomass is harvested in two adjacent 10' sections of the scrubber near the top of the system (T1 at 50 to 60 feet downstream from the surge box, T2 at 60 to 70 feet), in the middle (M1 at 170 to 180 feet, M2 at 180 to 190) and at the bottom of the system (B1 at 280 to 290 feet and B2 at 290 to 300 feet). This pattern of harvest includes replication of sampling (n=2) at three different locations along the longitudinal gradient of water flow from the input at the top of the system to the output at the bottom of the system. Each individual section has an area of approximately 0.9 m2 (the one foot wide trough x a 10' section between supports on the trough). The total sample area at each harvest is then 5.4 m2 which is 20 % of the total scrubber area (27.6 m2). At the time of harvest the water input to the ATS is turned off at the inflow faucet and the scrubber is allowed to drain for between ½ - 1 hour. Harvesting is done with a wet/dry vacuum. Each sample section of the trough is vacuumed, starting at the top of the system and working sequentially downstream. The entire ATS area (except for the first 10' section below the surge box which has remained an unharvested refuge) is harvested but during the summer only the biomass production samples were retained for measurements. After a sample section is vacuumed, the resulting slurry is dewatered by sieving the harvested material through a 3mm mesh nylon netting (Aquatic Ecosystems, Apopka, FL). The biomass retained in the net is air-dried at 25 degrees C using an electric fan, oven-dried at 70 degrees C for 24 hours and then weighed. Data for biomass production or net primary production are calculated by dividing the oven-dried mass by the number of days between harvest dates.

Two other components of the biomass production of the algal turf community were assessed: algal biomass suspended in the water that was sieved through the nylon netting (termed "green water") and algal biomass that breaks off from the turf between harvests (termed "slough"). For biomass in green water, the volume of sieved water was measured at the time of harvest and a one liter sample was collected and returned to the laboratory. The biomass was allowed to settle out of suspension in the sample bottle creating a dense layer in the bottom of the bottle. The overlying water was removed by

vacuuming and the remaining slurry that contains the biomass was spread out on a tray lined with a plastic film and the water was allowed to evaporate. The biomass remaining after evaporation was oven-dried at 70 degrees C and weighed. Biomass production of the green water component was calculated by dividing the biomass by the area of turf that was harvested and sieved and by the number of days between harvest dates. Routinely, green water was combined for paired samples at the top, middle and bottom of the ATS resulting in three samples for each harvest date after 7/28/08. Biomass that sloughed from the turf between harvest dates was collected in a nylon mesh bag that was attached to the outlet drain pipe at the bottom of the ATS. Material collected in the bag was removed at the time of harvest and it was processed by the same procedure as the biomass harvest collected with the wet/dry vacuum.

Nutrients

Water samples were collected at the inflow and at the outflow of the ATS before harvests. These samples were acidified and stored at 4 degrees C prior to analysis for total Kjeldahl nitrogen (TKN) and nitrate-nitrogen. The water samples were also analyzed for total phosphorus (TP) and ammonium-nitrogen but the resulting values were below detection limits, necessitating less dilution during the analytical procedure. Biomass samples were analyzed for TKN and TP after oven-drying.

Community Structure

Samples of algae from the scrubber were collected periodically and examined with a compound microscope for the purpose of describing the structure of the community. Two or three samples from the turf along with a sample of the green water and a sample of the slough were routinely collected before each harvest and these were examined to rapidly assess the dominant alga taxa and the overall condition of the system. Qualitative notes on these samples were recorded. Samples were collected for a more in-depth assessment of the species composition of the turf on 7/23/08 and 8/1/08. These samples were carefully examined in order to construct a species list of algal taxa found on the scrubber.

RESULTS

Water Quality

Water quality data taken at the time of harvests are listed in Table 1 by date. The important patterns in this data involve differences between the input water at the top of the system and the output water at the bottom. These differences for dissolved oxygen and pH are caused by the metabolism of the turf. The positive increases reflect the net primary productivity of the algae. This net production rate is especially high since there is essentially no herbivory in the system and the net production is the difference between gross production and plant respiration. Summer average increases from top to bottom were as follows: for dissolved oxygen +5.9 mg/l, for percent oxygen saturation +77% and for pH +1.6. These changes in basic water quality of the system are dramatic because the

turnover time of the water in the system is only 6.2 minutes, based on a flow rate of 1.1 liters/sec (18 gallons/minute) and a volume of 411 liters (9144 cm long x 30 cm wide x 1.5 cm deep).

Biomass Production

There are three components of algal biomass production for the ATS based on the methods described above: the biomass harvested with the wet/dry vacuum (vacuum harvest), the biomass contained in the water drained from the vacuum harvest (green water) and the biomass that sloughed off the turf between harvests and that was collected in the net at the bottom of the system (slough). Overall biomass production data are summarized in Table 2 with averages and totals. Total average production for the summer was 18.0 g dry wt./m2/day, while total peak production was 24.5 g dry wt./m2/day on 7/28/08. The highest single measurement for productivity was 31.4 g dry wt./m2/day, which was recorded on 7/28/08 at the bottom of the scrubber.

Vacuum harvest contributed about 80% of the total biomass production during the summer. These samples were dominated by a mixture of filamentous green algae (Spirogyra was dominant) and filamentous diatoms (Melosira sp.) along with pennate diatoms and bluegreen algae (Oscillatoria and Phormidium). There was a tendency for reduced production in the upper most portion of the ATS at the beginning of the study, which is evident in the appendix tables. However, eventually production evened out as the turf fully developed. The highest values of vacuum harvest production occurred in the beginning and end of July at slightly more than 19 g dry wt./m2/day. The disturbance caused by the floating of the screen in the middle of July clearly disrupted the peak production period of the ATS. Vacuum harvest production rates also dropped after 8/6/08, perhaps due to declining nighttime temperature.

Green water biomass production contributed about 10% of the total production. These samples were strongly dominated by fragments of filamentous diatoms and by pennate diatoms, with practically no filamentous green algae.

Slough biomass production contributed about 10% of the total production. These samples were strongly dominated by the filamentous green alga, Spirogyra, though all species from the turf were present in small amounts. This portion of the overall production was the most difficult to measure and more study is required for adequate quantification. There is clearly a dynamic pattern of slough production between harvests with little sloughing immediately after harvest and with high amounts of sloughing immediately before harvest. In part, this pattern which was observed during the summer may be due to the dominance of Spirogyra which seems to easily break off from the turf and float downstream. Less sloughing may be found with other taxa, such as Cladophora, that have specialized holdfast cells.

Nutrients

Total nitrogen (as TKN) and nitrate-nitrogen data are shown in Tables 3 and 4. As with the water quality data, this data is summarized by the differences between inflow water at the top of the ATS and outflow water at the bottom. Differences are presumably due to nutrient uptake by algae on the turf. The average decrease in total nitrogen is 0.20

mg/l, or 23% of the input value and the average decrease in nitrate-nitrogen is 0.12 mg/l, or 18 % of the input value. The uptake values that these differences imply are characteristic of the turf at its maximum productivity, since water samples were collected immediately before harvest when the highest biomass was present. Presumably the differences in concentration between the water inflow and outflow would be much smaller if the water samples were collected immediately after a harvest.

Nutrient contents of algal biomass are summarized in Table 5. The vacuum harvest, which comprises 80% of the total biomass production, has a nitrogen content of about 2.5% and a phosphorus content of 0.25%. Slough biomass has the highest nitrogen and phosphorus content but the N/P ratio is approximately 10/1 for all biomass components. The most significant feature of the nutrient content of the algal biomass is the decline in percentages from top to bottom in the system, which emerged after the turf had fully developed. For example, on 7/28/08 nitrogen content declined from 2.60% at the top to 1.69% at the bottom and phosphorus content declined from 0.36% at the top to 0.13% at the bottom. These patterns of decline in nutrient content of biomass imply some kind of limitation process and they warrant further study.

Community Structure

Detailed information on species composition is given in Table 6 for presence-absence data from 14 samples over two days. The presence-absence data are summarized in Table 6 as frequency of occurrence. A total of 86 species were identified from five algal phyla (Bacillariophyta – 35 species, Chlorophyta – 34 species, Cyanobacteria – 14 species, Euglenophyta – 2 species and Dinophyta – 1 species). Many of the species are rare in the context of frequency of occurrence: 46 species, or 54% of the total community, were found only in one sample (a frequency of 1/14 or 7%) and an additional 19 species, or 22% of the total community, were found only in two samples (a frequency of 2/14 or 14%). Thus, as is typical of any ecological community, most of the species in the algal turf community (76%) are rare.

Three species had the highest frequencies: Melosira varians, a filamentous diatom at 12/14 or 86%, Ulnaria ulna, a pennate diatom at 11/14 or 79%, and Spirogyra sp., a filamentous green alga at 9/14 or 64%. Two of these three frequent taxa along with their congeneric species (Melosira and Spirogyra) are the filamentous algae that form the "canopy" of the turf and give the community its overall structural character. Most of the rest of the community are "understory" species, often epiphytic on the dominant filaments.

Table 1. Comparison of water quality parameters measured at the top and bottom of the MPU.

Parameter	top	bottom	difference
		7/23/08	
Temperature, degrees C	28.9	29.4	+ 0.5
Dissolved oxygen, mg/l	4.4	11.1	+ 6.7
Percent oxygen saturation	57	146	+ 89
pH	7.5	8.8	+ 1.3
		7/28/08	
Temperature, degrees C	28.5	29.3	+ 0.8
Dissolved oxygen, mg/l	4.0	11.1	+ 7.1
Percent oxygen saturation	51	145	+ 94
pH	7.5	9.2	+ 1.7
		8/1/08	
Temperature, degrees C	28.5	30.0	+1.5
Dissolved oxygen, mg/l	4.9	10.6	+ 5.7
Percent oxygen saturation	63	140	+ 77
pH	7.6	9.2	+ 1.6
		8/6/08	
Temperature, degrees C	28.2	29.1	+ 0.9
Dissolved oxygen, mg/l	4.3	11.4	+ 7.1
Percent oxygen saturation	56	150	+ 94
pH	7.6	9.3	+ 1.7

Table 1. Continued

Parameter	top	bottom	difference
		8/11/08	
Temperature, degrees C	26.4	24.4	- 2.0
Dissolved oxygen, mg/l	4.6	8.3	+ 3.7
Percent oxygen saturation	58	99	+ 41
pH	7.2	8.8	+ 1.6
		8/18/08	
Temperature, degrees C	25.8	28.2	+ 2.4
Dissolved oxygen, mg/l	4.5	9.6	+ 5.1
Percent oxygen saturation	55	121	+ 66
pH	7.1	9.0	+ 1.9
		8/25/08	
Temperature, degrees C	26.3	27.7	+ 1.4
Dissolved oxygen, mg/l	---	---	---
Percent oxygen saturation	---	---	---
pH	7.5	9.1	+ 1.6

Table 2. Summary of algal biomass production for different algal components. Units are g dry wt./m2/day. Means shown at the bottom of the table are based on representative summations without those data marked with an asterisk.

Date	vacuum harvest	greenwater	slough
6/28/08	17.4		
7/3/08	19.2		
7/8/08	screen had floated, no biomass measurements taken		
7/13/08	5.1*	8.8*	0.1*
7/18/08	16.2	3.4	0.2*
7/23/08	12.8	---	0.7
7/28/08	19.6	1.7	3.2
8/1/08	17.5	---	---
8/6/08	10.1	2.4	0.3*
8/11/08	8.7	3.0	1.8
8/18/08	10.5	3.0	0.2
8/25/08	10.0	1.0	1.0
Mean	14.2	2.4	1.4

* Problems occurred with these samples and they are not included in the means.

Table 3. TKN nitrogen in water entering the ATS at the top and leaving at the bottom. Data are in units of mg/l.

Date	top	bottom	difference
7/13/08	1.43	0.67	0.76
7/18/08	0.95	0.78	0.17
7/23/08	0.93	0.54	0.39
7/28/08	0.67	0.74	-0.07
8/1/08	0.79	0.89	-0.10
8/6/08	0.91	0.57	0.34
8/11/08	0.62	0.63	-0.01
8/18/08	0.71	0.62	0.09
8/25/08	0.84	0.58	0.26
Average	0.87	0.67	0.20

Table 4. Nitrate nitrogen in water entering the ATS at the top and leaving at the bottom. Data are in units of mg/l.

Date	top	bottom	difference
7/13/08	0.99	0.93	0.06
7/18/08	1.01	0.84	0.17
7/23/08	0.59	0.67	-0.08
7/28/08	0.88	0.64	0.23
8/1/08	0.78	0.62	0.16
8/6/08	0.76	0.62	0.14
8/11/08	0.69	0.50	0.19
8/18/08	0.59	0.50	0.09
8/25/08	0.58	0.48	0.09
Average	0.76	0.64	0.12

Table 5. Summary of nutrient concentrations in algal biomass compartment. Data are in percent.

Biomass compartment	Nitrogen	Phosphorus
Vacuum harvest	2.51	0.24
Green water	2.21	0.25
Slough	3.04	0.32

Table 6. Species composition of the Muddy Run algal turf scrubber, summer 2008. Data are frequency of occurrence. There were 4 samples on 7/23/08 and 10 samples on 8/1/08.

Taxa	7/23/08	8/1/08	total
Chlorophyta:			
Ankistrodesmus convolutus	0	1	1
cf. Botryococcus sp.	1	1	2
cf. Schroederia sp.	0	1	1
Cladophora glomerata	1	1	2
Cladophora sp.	1	0	1
Closteriopsis longissima	0	3	3
Closterium sp.	1	0	1
Cosmarium obsoletum	0	1	1
Cosmarium cf. subturnidum	0	1	1
Cosmarium sp.	2	2	4
Desmodesmus armata	0	1	1
Desmodesmus asymmetricus	0	1	1
Desmodesmus cf. spinosus	0	1	1
Desmodesmus gutwinskii	0	1	1
Desmodesmus quadricauda	0	6	6
Gloeocystis sp.	2	0	2
Monoraphidium contortum	0	4	4
Pediastrum duplex	0	3	3
Pediastrum sp.	2	0	2
Pediastrum tetras	0	2	2
cf. Pseudocharacium sp.	0	1	1
Rhizoclonium hieroglyphicum	0	3	3
Rhizoclonium sp.	2	1	3
Scenedesmus acutus	0	1	1
Scenedesmus brevispina	0	1	1
Scenedesmus cf. balatonicus	0	1	1
Scenedesmus dimorphus	0	1	1
Scenedesmus ecornis	0	1	1
Scenedesmus sp.	4	1	5
Scenedesmus spinosus	0	1	1
Spirogyra cf. pseudofloridana	1	0	1
Spirogyra cf. rivularis	1	1	2
Spirogyra sp.	3	6	9
Uronema elongatum	0	2	2

Table 6. continued. Data are frequency of occurrence.

Taxa	7/23/08	8/1/08	total
Cyanobacteria:			
Bacularia vermicularis	0	1	1
Chroococcus minor	0	2	2
Eucapsis parallelepipedon	0	1	1
Geitlerinema cf. amphibium	0	2	2
Leibleinia epiphytica	0	6	6
Merismopedia tenussima	1	1	2
Oscillatoria sp.	1	0	1
Phormidium autumnale	0	1	1
Phormidium cf. lividum	0	2	2
Phormidium interruptum	0	1	1
Phormidium lividum	0	3	3
Phormidium sp.	1	2	3
Planktolyngbya brevicellularis	0	2	2
Pseudanabaena galeata	1	2	3
Euglenophyta:			
Phacus sp.	1	0	1
Trachelomonas sp.	1	1	2
Dinophyta:			
Sphaerodinium cinctum	0	1	1

Table 6. continued. Data are frequency of occurrence.

Taxa	7/23/08	8/1/08	total
Bacillariophyta: Pennales (Bacillariales)			
cf. Asterionella sp.	1	0	1
Cymbella affinis	0	1	1
Cymbella sp.	1	2	3
Diadesmis sp.	0	1	1
Diatoma sp.	1	0	1
Encyonema prostratum	0	1	1
Frustulia cf. rhomboides	0	1	1
Frustulia cf. vulgaris	0	1	1
Frustulia sp.	0	1	1
Gomphonema sp.	0	4	4
cf. Gomphonema affine	0	1	1
Luticola cf. geoppertiana	0	2	2
Meridion cf. circulare	0	1	1
Navicula angusta	0	1	1
Navicula cf. cryptocephala	0	2	2
Navicula cf. drouetiana	0	2	2
Navicula cf. gregaria	0	2	2
Navicula rostellata	0	1	1
Navicula sp. 1	3	2	5
Navicula sp. 2	0	1	1
Nitzschia cf. clausii	0	1	1
Nitzschia cf. palea	0	1	1
Nitzschia sp. 1	1	3	4
Nitzschia sp. 2	0	1	1
Rhoicosphenia sp.	1	2	3
Surirella cf. tenera	0	1	1
Surirella sp.	0	1	1
Synedra cf. acus	0	1	1
Synedra cf. berolinensis	0	1	1
Tabellaria sp.	1	1	2
Ulnaria ulna	3	8	11
Bacillariophyta: Centrales (Biddulphiales)			
Cyclotella cf. meneghiana	0	2	2
Cyclotella sp.	0	3	3
Melosira cf. dickiei	0	1	1
Melosira varians	4	8	12