ALGAL PRODUCTION STUDIES AT THE PEACH BOTTOM NUCLEAR POWER FACILITY: A STATUS REPORT

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NARRATIVE

The algae production project at the Exelon Corporation's Peach Bottom Nuclear Power Facility began in the spring of 2010, building on an earlier experience at Exelon's Muddy Run Hydroelectric Power Facility. The Peach Bottom facility is located in southeastern Pennsylvania adjacent to the Susquehanna River. Water from the river is used to help cool the nuclear reactor and the heated water is discharged back into the river through a long canal. The overall purpose of the project is to test an algae production system at the nuclear power facility using the heated discharge water as a resource. This kind of algal system has been shown to be effective as a water quality management option that removes nutrients and adds oxygen to polluted waters (Adey 2010, Adey et al. 2011, Anonymous 2011). It is hoped that the heated discharge waters will extend the growing season of algae in temperate climates and lead to increased algal growth and performance. In particular, use of heated discharge water from Peach Bottom may provide a major stimulus to cleaning up the Chesapeake Bay through controlled algal growth, since the majority of nutrients that pollute the Bay enter through the Susquehanna River. Thus, the Peach Bottom Nuclear Power Facility is at a strategic location to positively impact restoration of the entire Chesapeake Bay Estuary.

The algal production system used at Peach Bottom is an experimental raceway that is one foot wide and 300 feet long. The length of the system is important to study longitudinal patterns of algal growth and nutrient removal. The raceway at Peach Bottom is an aluminum trough with a plastic liner, elevated off the ground with a 2% slope from top to bottom. Water is pumped from the heated water discharge canal to the top of the raceway where it flows by gravity to the bottom. Output water at the bottom of the raceway is released into a wetland that drains back into the heated water discharge canal. The system is an Algal Turf Scrubber ™ or ATS in which water is pulsed from a surge box at the top of the system to generate turbulence in the water flow and algae are grown attached to a plastic mesh screen placed in the bottom of the trough.

This particular raceway had been used to study algae production at the Exelon Corporation's Muddy Run Hydroelectric Facility, located across the river from Peach Bottom, from June 2008 to November 2009 with support from the Lewis Foundation through the Smithsonian Institution (Kangas et al. 2010). A license agreement to operate the algae system at Peach Bottom between the Exelon Corporation and the University of Maryland was extended from an earlier agreement for Muddy Run. This agreement was signed in March 2010. After funding ran out from the Smithsonian Institution, the system was disassembled and moved to Peach Bottom from Muddy Run and it was reconstructed under the supervision of Tim Goertemiller of Living Ecosystem LLC of Easton, Maryland. Mark Ross has been the main contact for the project at Peach Bottom with assistance from Chris Crabtree and Kevin Bristol.

The project functionally began when water flow to the system began in July 2010, without external funding support. The system operated routinely until early September when power outages began to occur due to construction activities at the power plant. These outages caused the pump to turn off, which dried out the algae in the system and reduced productivity. The algae production system operated irregularly through the early fall due to the power outages. Eventually by the end of October 2010 power was completely turned off and, therefore, the algae production system was turned off. A newspaper article about the early operation, arranged by David Tillman, Communications Manager at Peach Bottom, was published on the front page of the Baltimore Sun on September 20, 2010 (see Appendix 1).

Through the efforts of Mr. Ross, a solar-powered pump system was purchased for the project with funding from several departments at Peach Bottom. The solar power system was designed and constructed by Smucker's Energy of Kinzer, Pennsylvania. Using this system water flow was reinstated in the algal production system in May of 2011. The system operated for about five weeks until the pumps failed, presumably due to clogging. A new pump is scheduled to be installed in early August 2011 to restart operations, with supervision from Mr. Goertemiller.

GOALS OF THE PROJECT

The main goal of the project has been to test the performance of the algal production system using heated discharge waters from the nuclear power plant. In particular, the hope is that the growing season of the algae can be extended through the winter months, when cold temperatures normally cause the system to be closed down. A special feature of the project is the ability to compare algal production between a site without heated waters (Muddy Run from 2008-2009) with a site with heated waters (Peach Bottom in 2011-2012). Appendix 2 is the original proposal for the project.

An additional goal emerged once the project began in 2010. Mr. Ross recognized the potential utility of the algal production system for cooling the heated discharge waters. Because algae are grown with a shallow sheetflow of water (about 1 inch or 3 cm deep), heat in the thermal discharges readily exchanges with the atmosphere. This heat exchange causes water temperature to decrease from the top to the bottom of the raceway. Mr. Ross coined the term "green cooling tower" for the algae production system because of this potential. Therefore, study of temperature changes has become an important goal of the project.

CONCEPTUAL BASIS OF THE ALGAL PRODUCTION SYSTEM

The algal production system functions as a water quality management tool because algae remove nutrients from and add oxygen to the polluted water passing through the system as they grow. Nutrients are removed from the system when algae are harvested. Thus, harvesting takes place frequently in order to optimize the water quality improvement function of the algal production system.

In the larger context, the algal biomass harvested from the system has value as a byproduct (eg., as a feedstock for biofuel production), but in terms of water quality management the biomass just has to be removed from the system to achieve nutrient reductions The objective of this ecotechnology is then to maximize the growth rate of algae.

METHODS

Algae were harvested from the system usually every 1-2 weeks. Before a harvest, the pump is turned off and water is allowed to drain by gravity for 30 minutes to an hour.

Then algae is physically scrapped off the screen and placed in buckets for processing. Samples of the algal biomass from the top, middle and bottom of the raceway are dried and weighed and productivity is calculated as the increase in biomass between harvest dates.

Before and after harvesting, several water quality measurements are made to help assess the performance of the system, using a YSI hand-held meter. Water temperature, dissolved oxygen concentration and the degree of oxygen saturation are measured at the top and the bottom of the system in order to assess the effects of algal growth. Change in dissolved oxygen concentration and percent oxygen saturation help assess photosynthesis and respiration rates of the algal community on the screens, while change in temperature helps measure the cooling effect (eg., “green cooling tower” effect).

Finally, samples of the algal community were taken for identification of the dominant taxa with light microscopy. This information is qualitative and is described in Appendix 3 in note form.

RESULTS

Algal Production

Productivity data for 2010 at Peach Bottom are shown in Table 1 from late summer. Growth rate of algae increased over several weeks, then averaged nearly 15 grams dry weight/m2/day. This value was higher than for corresponding dates a year earlier at Muddy Run, presumably because the higher temperature water at Peach Bottom caused an increase in algal metabolism.

Productivity data for 2011 are shown in Table 2 for early summer. Productivity was variable but averaged about 13 g dry wt./m2/day. Water flow rates basically declined over the study period and eventually, after the end of June, the pumps stopped functioning.

Dissolved oxygen data reflects the photosynthetic production of the algae by the increases between the top and the bottom of the raceway (Tables 3-5), since algae are adding oxygen to the water as they metabolize. On average photosynthesis by algae increased dissolved oxygen concentration by about 4 mg/l and increased percent saturation by about 55% from the top to the bottom of the raceway for these point measures.

Water Temperature Decreases

Temperature data, taken after harvest, for 2010 are shown in Table 6. During the study period the average decrease in temperature from top to bottom of the raceway was – 1.8 degrees C. This same data from 2011 are shown in Table 7. During this study period the average decrease in temperature from top to bottom of the raceway was – 0.4 degrees C. Interestingly, higher decreases were found for measurements taken before harvest in 2011 (see Tables 3-5). On these three dates in June 2011 the average decrease in temperature from top to bottom of the raceway was – 2.4 degrees C, six times greater than measurements taken after harvest (Table 7). This comparison suggests a direct role in temperature decreases from the algal biomass.

Algal Species Composition

Although studies described in this report only adequately cover the summer season (late summer in 2010 and early summer in 2011), an interesting seasonal succession of algal species seems to occur at Peach Bottom. In 2010 when water temperatures were highest (high 30s and low 40s in degrees C) diversity was severely truncated in the algal community, presumably due to an upper temperature threshold. At this time to a dramatic extent only two species of blue green algae of the family Oscillatoriaceae were found and one of these may be a species new to Science (H. D. Laughinghouse, personal communication). Under these high temperature conditions the algal community in the raceway was similar to that found in a thermal spring ecosystem (Brock 1978). Before and after the highest temperatures occur, filamentous green algae and pennate diatoms increase in relative abundance to join the blue green species as dominants in the community. During these periods of cooler water temperatures, the species composition more closely resembles the composition that was found across the river at Muddy Run during 2008-2009 (Kangas et al. 2010).

Of interest, aquatic fly larvae of the family Chironomidae reached outbreak population densities during the fall of 2010 and during early summer of 2011 (as they did at Muddy Run in 2009). In these outbreaks the fly larvae cause "eatouts" or bare patches of screen due to their grazing on algae. Apparently the fly larvae can not persist at the highest water temperatures during the late summer, but their population can increase and impact algal productivity at other times of the year. Additionally, pulmonate snails of the family Physidae reached high population densities in early summer of 2011 but their grazing did not cause "eatouts" on the screen.

FUTURE PLANS

Immediate goals of the present project are to:

1) Operate the system through the winter months of 2011-2012 in order to measure algal production in heated waters during the cold season,

2) Develop enough data on temperature changes from the top to the bottom of the raceway to quantify the "green cooling tower" effect, and

3) Carry out appropriate taxonomic research to establish the identity of the thermophilic blue green alga that dominated the system in late summer.

We also hope to begin investigations with an in-water algal production system (called the Aquatic Biomass Production System) to test the potential of another design for controlled algal growth with heated discharge waters.

LITERATURE CITED

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™ The Algal Turf Scrubber is a trademark registered to the Hydromentia Company of Ocala, Florida

Table 1. Comparison of late summer 2010 productivity values for the aluminum ATS at Exelon sites on the lower Susquehanna River. Data are in units of grams dry weight/m2/day.

Date	Muddy Run in 2008	Peach Bottom in 2010
Last week of July	17.5	5.5
Week 1 of August	10.1	8.3
Week 2 of August	8.7	14.9
Week 3 of August	10.5	11.3
Week 4 of August	11.0	17.8

Table 2. Productivity and water flow rate at the experimental ATS raceway during early summer 2011. The system was operational on 4/29/11.

Date	productivity, g dry wt./m2/day	water flow rate, gallons/minute
5/6/11	----	12
5/27/11	7.1	----
6/3/11	21.6	13
6/15/11	9.7	9
6/22/11	9.1	9
6/29/11	15.9	8

Table 3. Water quality comparison of inflow and outflow of the experimental ATS raceway before harvest – 6/29/11.

Parameter	top of ATS	bottom of ATS
Temperature, degrees C	34.5	31.2
Dissolved oxygen concentration, mg/l	6.9	11.5
Percent of oxygen saturation, %	86	156

Table 4. Water quality comparison of inflow and outflow of the experimental ATS raceway before harvest – 6/22/11.

Parameter	top of ATS	bottom of ATS
Temperature, degrees C	33.5	32.9
Dissolved oxygen concentration, mg/l	6.1	9.8
Percent of oxygen saturation, %	86	136

Table 5. Water quality comparison of inflow and outflow of the experimental ATS raceway before harvest – 6/15/11.

Parameter	top of ATS	bottom of ATS
Temperature, degrees C	32.7	29.4
Dissolved oxygen concentration, mg/l	6.4	10.4
Percent saturation of oxygen, %	89	137

Table 6. Temperature comparisons of the experimental ATS raceway after harvest in 2010. Data were gathered around mid-day and are in degrees C.

Parameter	Canal	top of ATS	bottom of ATS	River
7/30/10	40.2	40.0	37.6	30.0
8/6/10	40.0	39.8	38.1	29.7
8/12/10	41.1	41.1	40.4	31.0
8/20/10	39.8	39.5	38.4	28.9
8/24/10	37.9	37.5	34.0	26.4
9/9/10	36.2	35.9	31.0	25.7
9/28/10	33.2	33.5	33.1	23.1
10/8/10	22.5	22.3	22.6	15.5
10/20/10	24.4	-----	-----	14.1

Table 7. Temperature comparisons of the experimental ATS raceway after harvest in 2011. Data were gathered around mid-day and are in degrees C.

Parameter	Canal	top of ATS	bottom of ATS	River
5/6/11	25.2	25.0	25.0	14.8
5/27/11	30.4	30.4	30.7	20.9
6/3/11	32.5	32.2	29.9	23.3
6/15/11	34.3	34.0	33.9	25.6
6/22/11	35.5	35.4	36.6	26.2
6/29/11	36.1	35.5	34.0	26.9

APPENDIX 3. Notes on algal species composition.

Microscopy Notes: 2010

7/30/10

Blue green mat that floats – monoculture of very fine Oscillatoriaceae; no diatoms!

Dark blue green "filaments" – actually colonies of the very fine Oscillatoria plus afew larger filaments of Phormidium?

Blue green mat that sinks – lots of detritus and large filaments (Phormidium?) are common – the mat matrix seems like a dense mucilaginous crust

8/12/10

Mat has several kins of protozoans and worms!

Phormidium is either uncommon or common depending on the patch but the "filamentous" blue green algae is dominant

Mat is comprised of thick bundles of very thin Oscillatoria that trail downstream in the current – is this colony-type induced by the high flow rate?

Lots of detritus in the encrusting mat

10/21/10

An explosion of pennate diatoms; Melosira common; green filaments (Mougeotia?) are rare

Lots of detritus – probably because the water was turned off

Phormidium is abundant

Microscopy Notes: 2011

5/11/11

Encrusting mat dominated by Oscillatoria with a very diverse set of pennate diatoms; Phormidium uncommon

Microspora dominates the attached filamentous green algae with lots of pennate diatoms

6/3/11

Green filaments at top of ATS – dominated by Microspora plus Phormidium fragments, pennate diatoms are very common but less so than the previous week? Is rising temperature affecting them? Also a thin green unidentified filament is uncommon

Encrusting mat – Oscillatoria dominates with Pleurococcus-like di-cell alga, pennate diatoms are very common

6/15/11

Top filaments – Microspora common but fine green unidentified filament is dominant – probably Ulothrix, Phormidium fragments rare, pennate diatoms rare

Middle mat – dominated by Phormidium, Oscillatoria rare, pennate diatoms common, Spirogyra rare, green unidentified filaments rare – also other blue green filaments?

Bottom eatout zone – Microspora and Ulothrix dominate, Spirogyra common, pennate diatoms common

6/22/11

Encrusting mat – dominated by very fine Oscillatoria, Phormidium uncommon

Main turf – Phormidium rare, Oscillatoria common, Microspora common, Spirogyra common, pennate diatoms uncommon

Patches of green filaments – dominated by Spirogyra, Ulothrix uncommon, Microspora rare

6/29/11

Patches of green filaments – Microspora dominates, Spirogyra common, Oedogonium rare, pinnate diatoms rare, very fine filaments are uncommon – is this the thermophilic blue green?

Encrusting blue green mat – Oscillatoria dominates, Phormidium rare, Spirogrya and Microspora uncommon – no pennate diatoms