PROGRESS REPORT ON THE BRIDGETOWN ALGAL TURF SCRUBBER: Summer 2011

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First Draft 8/29/11

Introduction

The purpose of the Bridgetown algal turf scrubber (ATS) project is to test the ATS technology for improving the quality of agricultural drainage water on the Maryland Eastern Shore. An additional challenge of this project is to operate the ATS water pumps using solar power, in order to demonstrate how the technology would work off-the-grid in a farm setting. The project began in 2009 and previous reports describe progress up to the beginning of 2011 (Kangas and Mulbry 2009, 2010, 2011). The purpose of this report is to provide preliminary results from the 2011 growing season.

The ATS is about 6 meters wide and 50 meters long. The land was graded to a 2% slope and a pond liner was placed on the ground to contain the sheetflow of water that is pumped from the adjacent agricultural drainage ditch. The water is pumped through 3" PVC pipes from the ditch to the ATS using two 60 gallon per minute (gpm) Gundfos well pumps. These pumps are powered by two solar panel arrays. One pump runs continuously with power from batteries that are charged by a 2 kVsolar panel array. The other pump runs only during daylight hours with power from a 1 kV solar panel array that has no batteries. Water is pulsed onto the raceways at the top of the ATS through aluminum dump buckets to generate turbulent wave action. Water flows by gravity down the raceways to a lined catch basin at the bottom of the ATS. This catch basin is used to collect algal biomass that washes off the raceways and settles out during and between harvests. Water flows out of the catch basin through an 8" stand-pipe to a small ditch that is connected back to the larger drainage ditch. Algae grow attached to a plastic mesh screen that is submerged in the raceways. The surface of the ATS is divided into six raceways, each one meter wide, to facilitate experimentation.

The 1 kV solar panel system without battery storage was completed in early 2010; the 2 kV solar panel system with battery storage was complete in June 2011. Experiments during 2011 have involved comparing flow regimes: continuous flow (24 hours per day) from the pump powered by the solar panel-battery system versus daytime-only flow from the pump powered by solar panels alone. The first experimental hydraulic regime ran continuous flow through raceways # 2 and # 3 and daytime-only flow through raceways # 4 and # 5. This experiment was run from mid-June to July 14 when it was stopped due to low algal productivity. The second experimental hydraulic regime ran continuous flow through raceway # 5 and daytime-only flow through raceway # 3 from mid-July to the end of August 2011 when it was stopped due to disruption of the ATS by Hurricane Irene.

Methods

Algae are harvested once per week by turning off the pumps and allowing the raceways to drain for about one half hour. Algal biomass in the catch basin is collected by pumping the catch basin water into 200 gallon plastic tank using a sump-pump powered by a portable electrical generator. One liter samples of water are collected from the top and the bottom of the tank. Samples from the top contain a low concentration of algal biomass while samples from the bottom contain a high concentration of algal biomass due to rapid settling. These samples are returned to the lab where the overlying water in the bottles is decanted off and the remaining organic slurry is poured into a pan. Water in the organic slurry is evaporated with aid of a fan and the remaining air-dried biomass is weighed. Total biomass collected in the harvests is calculated by assuming 75% of the total water volume from the basin contains algae at the concentration of the top sample and 25% of the total water volume contains algae at the concentration of the bottom sample.

Algae attached to the screens on the main ATS are harvested by scraping the biomass down the length of the raceways with a long-handled push broom. Biomass is pushed on to a screen that is suspended over the catch basin at the bottom of the raceways. This biomass is left on the screen to drain and to dry until the next harvest, when it is collected. The biomass is returned to the lab, air-dried with aid of a fan and weighed.

For algae collected from the screen, productivity is calculated by dividing the biomass from the raceways by the area of the raceways and by the number of days between harvests. For algae estimated to occur in the catch basin, productivity is calculated by dividing the total biomass by the total area of the ATS since the contribution from the different raceways can not be separated. For these calculations all of the area for raceways # 2 - # 5 is included because they are completely covered with water. However, only 50% of the area for raceways # 1 and # 6 is included because they are not completely covered by water due to channelization at the edges of the main ATS.

Before each harvest, water temperature (degrees C), dissolved oxygen concentration (mg/l) and the degree of oxygen saturation of the water (% saturation) were measured using a YSI meter. Measurements were taken in the ditch, at the top of the ATS in one of the dump buckets and at the bottom of the ATS in the catch basin. These measurements are used to assess the effects of heating and cooling on water temperature and the effects of algal community metabolism on oxygen dynamics.

The taxonomic composition of the algal community was assessed periodically in samples collected from the ATS. These samples were examined with light microscopy and dominant taxa were noted.

Results

Water Flow

Data on water flow to the raceways are given in Table 1 for the first experimental hydraulic regime and in Table 2 for the second experimental hydraulic regime. Comparisons are only for the experimental treatments in both cases since the remaining raceways only received a low flow of about 1 gpm. For both experimental regimes, raceways receiving flow from the solar-battery system are stable at any time of the day and under any sky conditions. However, the raceways receiving flow from the solar system alone are much more sensitive to current sky conditions. For example on 8/4/11 at 9:45AM raceway # 3 had 10 times less flow than typical due to the cloudy conditions. Also, on 6/20/11 at 7:00PM raceways # 4 and 5 received no flow because the sun had effectively set, even though daylight continued for more than hour afterwards. On the other hand, the solar-only hydraulic regimes receive higher flow rates compared to the solar-battery hydraulic regime under full sunlight conditions. For example, on 8/18/11 at 1:00PM flow to raceway # 3 was 60 gpm while flow to raceway # 5 was 20 gpm.

An interesting pattern can be seen when comparing flow from the solar-battery system between the first and second experimental hydraulic regimes: average flow to raceways # 2 and 3 is above 30 gpm in the first experiment, but average flow to raceway # 5 is about 20 gpm in the second experiment. It was expected that the flow from the solar-battery system would be constant, however the flow rate has declined over time. This trend of declining flow rates from the pump powered by the batteries is also seen in Table 3, which shows flows calculated from a continuous flow meter within the plumbing of the new solar system. This pattern of declining water flows over the summer suggests that the battery charge from the solar panels is declining, even though the solar panels were scaled during construction to provide sufficient power to fully charge the batteries. Apparently, reduced solar inputs as daylength changes from summer to fall are effecting the solar-battery system.

Biomass harvest

Raw data on weekly biomass harvest from the raceways screens are given in Table 4 and estimated biomass harvest from the catch basin are given in Table 5. In general, more biomass is harvested from the catch basin than from the screens, sometimes 2-3 times more. However, there is uncertainty with the estimated biomass harvest from the catch basin. Conservative assumptions were used to estimate this fraction of the biomass harvest, but more work is needed to reduce uncertainty.

Basic data on biomass harvest are expressed as daily productivity in Table 6. Because the total biomass from the entire ATS is used to calculate productivity, the values given in Table are relatively low, ranging from 3 to 7 grams air-dried wt $m^{-2}.day^{-1}$. Data in Table 6 are not representative of ATS productivity because over most of the study period four of the six raceways (#s 1, 2, 4, and 6) only received a low flow rate to maintain live algae. Table 7 shows productivity data for raceways # 3 and # 5 alone since these raceways received the highest water flow during the second experimental hydraulic regime. Two ways of combining biomass harvest from the raceway screen and from the catch basin are shown in the table. For each raceway the first value combines raceway screen productivity with the average productivity from the catch basin and the second value combines raceway screen productivity with a weighted average productivity from the catch basin. This weighted average was calculated by multiplying the relative contribution of productivity from the raceway as a percentage by the total biomass in the catch basin. This approach assumes that each raceway contributes biomass to the catch basin in proportion to the amount of algae on the screen. Productivity in raceway # 3 was relatively low during most of the summer until 8/18/11 the highest values occurred. In comparison, productivity in raceway # 5 was relatively high during most the summer.

Temperature and Oxygen Changes

Basic data for measurements of temperature and oxygen across the ATS system are given in Appendix Tables A1 to A14. In each case, data are compared along the pathway of the water flow: ditch – top of ATS – bottom of ATS. Differences between the top and the bottom of the ATS are of interest because they reflect processes taking place on the ATS: changes in temperature show relative heating and cooling of water and changes in oxygen show metabolism of the turf community (photosynthesis and respiration with diffusion). Differences between top and bottom of the ATS are shown in Table 8 for measurements made before harvest when the algal turf is intact. All of the differences are positive, thus reflecting relative heating of the water (on average by an increase of 4.0 degrees C) and relative oxygenation of the water through net photosynthesis (on average by an increase of 1.8 mg/l for oxygen concentration and 29% for percent saturation). The differences between the two hydraulic regimes are also of interest, especially for oxygen effects. During the first hydraulic experiment (6/24/11 – 7/14/11) oxygen increased by 0.7 mg/l and percent saturation increased by 18% while during the second hydraulic experiment (7/21/11-8/25/11) oxygen increased by 2.4 mg/l and percent saturation increased by 35%. This comparison between the hydraulic experiments may suggest that focusing the flow in two raceways (second experiment) increased metabolism of the algal turf relative to distributing the flow over four raceways (first experiment).

Discussion

The algal turf community was dominated by filamentous green algae during the summer of 2011 (Appendix B). Important genera were Ulothrix, Microspora and Spirogrya. Blue green algae and diatoms were less common. Grazing by herbivores (Chironomid fly larvae and Physid snails) created bare patches on the screen throughout the summer, mostly in the lower half of the raceways. More studies are needed on the effects of the herbivores since the effects of the two groups seem to differ: fly larvae feed preferentially on filamentous algae while snails feed on single-celled algae and detritus.

Productivity of algae was variable and seemed to be related to water flow rate. The second hydraulic experiment generated more biomass harvest and seemed to stimulate oxygen production. However, the values reported here are lower than have been found in other published studies (Table 9). One limitation may be water flow rate, but other factors also need to be considered.

Nutrient removal can be estimated from the productivity data reported here and from nutrient content data reported in an earlier report. Assuming a productivity of 8 grams dry weight/m2/day (see Table 7), a nitrogen content of 2.5%, and a phosphorus content of 0.2% (Kangas and Mulbry 2011), the nitrogen and phosphorus removal rates would be 0.2 g N/m2/day (1.8 pounds N/acre/day) and 0.016 g P/m2/day (0.1 pounds P/acre/day).

Literature Cited

Kangas, P. and W. Mulbry. 2009. Progress report on “Evaluation of the Algal Turf Scrubber Technology for Treatment of Agricultural Drainage Water”. Report submitted to the Caroline County Soil Conservation District.

Kangas, P. and W. Mulbry. 2010. Progress report on “Evaluation of the Algal Turf Scrubber Technology for Treatment of Agricultural Drainage Water”. Report submitted to the Caroline County Soil Conservation District.

Kangas, P. and W. Mulbry. 2011. Technical Report on "Evaluation of the Algal Turf Scrubber Technology for Treatment of Agricultural Drainage Water". Report submitted to the Caroline County Soil Conservation District.

Table 1. Flow rates during the first hydraulic regime: all of the old solar-powered system (without batteries) through raceways #4 and #5; most of the new solar-powered system (with batteries) through raceways #2 and #3 plus a trickle flow through all of the other raceways. Data are in units of gallons/minute.

Data	conditions	raceways #4&5	raceways #2&3
6/20/11 6:30PM	sunset	21	34
6/20/11 7:00PM	sunset	0	34
6/24/11 10:30AM	full sun	48	34
7/7/11 12:45PM	mostly sunny	50	35
7/14/11 1:15PM	full sun	54	32

Table 2. Flow rates during the second hydraulic regime: all of old solar-powered system (without batteries) through raceway #3; most of the new solar-powered system (with batteries) through raceway #5 plus a trickle flow through all of the other raceways. Data are in units of gallons per minute.

Date	conditions	raceway #3	raceway #5
7/21/11 12:30PM	full sun	40	24
7/28/11 10:00AM	mostly sunny	30	20
7/28/11 1:30PM	mostly sunny	30	20
8/4/11 9:45AM	completely cloudy	3	20
8/4/11 1:30PM	completely cloudy	13	19
8/12/11 11:00AM	full sun	40	19
8/12/11 1:00PM	full sun	40	19
8/18/11 10:30AM	mostly sunny	40	20
8/18/11 1:00PM	full sun	60	20
8/25/11 10:00AM	partly cloudy	30	17
8/25/11 1:00PM	completely cloudy	0	17

Table 3. Data on total water flow for the new solar-powered system (with batteries) as recorded at the flow meter on the inlet pipe. Data was recorded at mid-day. Flow rate was calculated with this data assuming constant flow between data points from the flow meter.

Date	total flow, gallons	calculated flow rate, gallons/minute
6/8/11	3,172,620	
6/24/11	4,267,500	48
6/30/11	4,542,600	32
7/7/11	4,847,520	30
7/14/11	5,154,060	30
7/21/11	5,448,760	29
7/28/11	5,723,478	27
8/4/11	5,987,525	26
8/12/11	6,274,580	25
8/18/11	6,451,720	21
8/25/11	6,717,280	

Table 4. Listing of biomass harvests from the raceways in July 2011. All data are air-dried weights in grams.

Raceway	7/7/11	7/14/11	7/21/11	7/28/11
1	755.8	61.8	178.7	386.5
2	2321.2	51.9	210.8	571.7
3	3726.9	115.3	30.4	259.6
4	1725.0	16.7	90.9	52.6
5	828.6	14.3	229.2	803.0
6	1680.8	411.9	563.2	916.0
Total	11,038.3	671.9	1303.2	2989.4

Table 4 continued. Listing of biomass harvests from the raceways in August 2011. All data are air-dried weights in grams.

Raceway	8/4/11	8/12/11	8/18/11*
1	71.9	95.5	5.3
2	183.9	151.5	50.5
3	296.2	539.5	1165.0
4	49.3	219.8	42.3
5	1708.7	1594.9	1152.6
6	653.1	522.9	362.7
Total	2963.1	3124.1	2778.4

* Some biomass was lost or redistributed among raceways when the lower end of the ATS was flooded in the week before harvest.

Table 5. Listing of biomass concentration samples from the collection tank. Data for samples are in grams air-dried weight/liter of water. Data on total volume of water is in reference to the 200 gallon (760 liter) tank used to collect the water from the holding basin at the bottom of the raceways.

Date of collection	top sample	bottom sample	total volume of water	estimated biomass, grams air-dried weight
7/7/11	0.5	31.4	1520 L (2 full tanks)	12,502
7/14/11	1.6	42.5	1011 L (1 full tank plus 1/3 tank)	11,966
7/21/11	0.1	29.4	912 L (1 full tank plus 1/5 tank)	6,771
7/28/11	0.2	24.7	836 L (1 full tank plus 1/10 tank)	5,287
8/4/11	0.2	7.3	1011 L (1 full tank plus 1/3 tank)	1,999
8/12/11	0.2	16.8	836 L (1 full tank plus 1/10 tank)	3,636
8/18/11	0.2	30.2	836 L (1 full tank plus 1/10 tank)	6,437

Table 6. Comparison of productivity components across the wetted ATS area (250 m2). Data are in units of grams air-dried weight/m2/day.

Sample date	screen productivity	catch basin productivity	total
7/14/11	0.4	6.8	7.2
7/21/11	0.8	3.9	4.7
7/28/11	1.7	3.0	4.7
8/4/11	1.7	1.1	2.8
8/12/11	1.6	1.8	3.2
8/18/11	1.9	4.3	6.2

Table 7. Comparison of daily productivity (grams air-dried weight/m2/day) for raceway #3 (solar power only) and #5 (solar powered batteries) during the second hydraulic experiment. Data are combined productivity from the raceway screen plus from the catchbasin. Two catchbasin contributions are shown: unweighted (from Table 5) and weighted by percentage of the raceway total.

Date	**raceway #3**		**raceway #5**	
	raceway + unweighted catch basin	raceway + weighted catch basin	raceway + unweighted catch basin	raceway + weighted catch basin
7/28/11	3.7	2.1	5.3	6.4
8/4/11	2.0	1.5	6.0	8.2
8/12/11	3.2	2.1	5.8	8.6
8/18/11	8.2	12.9	8.1	12.6

Table 8. Differences for temperature and oxygen data between the bottom and the top of the ATS. In each case the top parameter value is subtracted from the bottom parameter value.

Date	temperature	dissolved oxygen	percent oxygen saturation
	Degrees C	mg/l	%
6/24/11	5.7	0	12
7/7/11	5.9	0.1	13
7/14/11	3.6	1.9	28
7/21/11	4.0	0.2	11
7/28/11	3.6	2.2	33
8/4/11	1.2	2.5	32
8/12/11	3.6	1.0	17
8/18/11	4.5	4.3	61
8/25/11	3.7	4.0	54
Average Difference			

Table 9. Comparison of biomass production values for algal turf scrubbers.

System	productivity (g dry wt./m2/day)	reference
South Florida Agricultural drainage water		Adey et al. 1993
Floway system	21.2	
Serial system	33.5	
Industrial wastewater		Adey et al. 1996
Phases 1 and 2	13.9	
Phase 3	7.5	
California domestic sewage		Craggs et al. 1996
Mean	23.8	
Summer maximum	60.9	
Winter minimum	4.2	
Maryland dairy wastewater		Mulbry et al. 2008
Highest loading rate	25.0	
Lowest loading rate	2.5	
Patuxent River, Maryland		Mulbry et al. 2010
Maximum (May-June)	21.4	
Minimum (December-February)	1.2	
Susquehanna River,		Kangas et al. unpublished

Southeastern Pennsylvania		(in Adey 2010)
Mean, aluminum testbed	14.0	
Mean, wooden testbed	11.7	
Northwestern Arkansas		(in Adey 2010)
Mean	25.3	
Lower York River, Virginia		Duffey et al. unpublished (in Blackrock Energy Corporation 2010)
Maximum (late spring/early summer)	40-50	
Minimum (January)	<5	
Wicomico River, Virginia		Adey unpublished
Mean		

References for Table 9

Adey, W. H. 2010. Algal Turf Scrubber (ATS) Algae to Energy Project, Cleaning Rivers while Producing Biofuels and Agricultural and Health Products. Report to the Lewis Foundation, Cleveland, OH..

Adey, W., C. Luckett and K. Jensen. 1993. Phosphorus removal from natural waters using controlled algal production. Restoration Ecology 1:29-39.

Adey, W., C. Luckett and M. Smith. 1996. Purification of industrially contaminated groundwaters using controlled ecosystems. Ecological Engineering 7:191-212.

Blackrock Energy Corporation. 2010. An Interim Report on Research Progress (February 1 – June 30, 2010): Chesapeake Algae Project. Report to the Statoil Corporation.

Craggs, R., W. Adey, B. Jessup and W. Oswald. 1996. A controlled stream mesocosm for tertiary treatment of sewage. Ecological Engineering 6:149-169.

Mulbry, W., S. Kondrad, C. Pizarro and E. Kebede-Westhead. 2008. Treatment of dairy manure effluent using freshwater algae: Algal productivity and recovery of manure nutrients using pilot-scale algal turf scrubbers. Bioresource Technology 99:8137-8142.

Mulbry, W., P. Kangas and S. Kondrad. 2010. Toward scrubbing the bay: Nutrient removal using small algal turf scrubbers on Chesapeake Bay tributaries. Ecological

Table A1. Temperature and dissolved oxygen data from the Bridgetown ATS on 6/20/11 at 6:45PM.

Sample location	temperature	oxygen concentration	% saturation
Ditch	23.2	8.8	103
Top of ATS	23.5	9.1	107
Bottom of ATS	24.2	8.7	104

Table A2. Temperature and dissolved oxygen data from the Bridgetown ATS on 6/20/11 at 8:15PM.

Sample location	temperature	oxygen concentration	% saturation
Ditch	22.8	8.0	93
Top of ATS	22.9	8.5	99
Bottom of ATS	21.7	8.0	91

Table A3. Temperature and dissolved oxygen data from the Bridgetown ATS on 6/24/11 at 10:15AM.

Sample location	temperature	oxygen concentration	% saturation
Ditch	22.5	8.4	97
Top of ATS	22.6	8.2	95
Bottom of ATS	28.9	8.2	107

Table A4. Temperature and dissolved oxygen data from the Bridgetown ATS on 7/7/11 at 5:45AM.

Sample location	temperature	oxygen concentration	% saturation
Ditch	21.7	3.2	36
Top of ATS	21.9	4.8	54
Bottom of ATS	20.9	7.1	79

Table A5. Temperature and dissolved oxygen data from the Bridgetown ATS on 7/7/11 at 10:15AM.

Sample location	temperature	oxygen concentration	% saturation
Ditch	22.5	7.7	90
Top of ATS	22.7	8.4	97
Bottom of ATS	28.6	8.5	110

Table A6. Temperature and dissolved oxygen data from the Bridgetown ATS on 7/14/11 at 9:30AM.

Sample location	temperature	oxygen concentration	% saturation
Ditch	20.9	6.0	66
Top of ATS	21.0	7.2	81
Bottom of ATS	24.6	9.1	109

Table A7. Temperature and dissolved oxygen data from the Bridgetown ATS on 7/14/11 at 1:00PM after harvest.

Sample location	temperature	oxygen concentration	% saturation
Ditch	24.0	11.0	131
Top of ATS	24.2	10.9	131
Bottom of ATS	27.8	8.4	107

Table A8. Temperature and dissolved oxygen data from the Bridgetown ATS on 7/21/11 at 10:15AM.

Sample location	temperature	oxygen concentration	% saturation
Ditch	24.6	6.6	80
Top of ATS	25.1	7.6	92
Bottom of ATS	29.1	7.8	103

Table A9. Temperature and dissolved oxygen data from the Bridgetown ATS on 7/28/11 at 9:45AM.

Sample location	temperature	oxygen concentration	% saturation
Ditch	22.8	5.1	59
Top of ATS	22.8	6.5	75
Bottom of ATS	26.4	8.7	108

Table A10. Temperature and dissolved oxygen data from the Bridgetown ATS on 8/4/11 at 9:30AM.

Sample location	temperature	oxygen concentration	% saturation
Ditch	21.9	4.3	50
Top of ATS	22.0	5.9	67
Bottom of ATS	23.2	8.4	99

Table A11. Temperature and dissolved oxygen data from the Bridgetown ATS on 8/12/11 at 10:15AM.

Sample location	temperature	oxygen concentration	% saturation
Ditch	20.0	6.5	71
Top of ATS	20.3	8.1	90
Bottom of ATS	23.9	9.1	107

Table A12. Temperature and dissolved oxygen data from the Bridgetown ATS on 8/18/11 at 10:15AM.

Sample location	temperature	oxygen concentration	% saturation
Ditch	21.3	4.6	52
Top of ATS	21.3	6.0	67
Bottom of ATS	25.8	10.3	128

Table A13. Temperature and dissolved oxygen data from the Bridgetown ATS on 8/18/11 at 1:00PM after harvest.

Sample location	temperature	oxygen concentration	% saturation
Ditch	23.7	5.2	62
Top of ATS	23.6	6.2	74
Bottom of ATS	28.6	8.9	115

Table A14. Temperature and dissolved oxygen data from the Bridgetown ATS on 8/25/11 at 10:00AM.

Sample location	temperature	oxygen concentration	% saturation
Ditch	21.2	5.3	59
Top of ATS	21.1	6.4	72
Bottom of ATS	24.8	10.4	126

APPENDIX B: Microscopy Notes: 2011

4/6/11

Very fine, parietal chloroplasts, green filament – Ulothrix – dominates as a near monoculture at the top of the raceways – strongly attached to screen; Microspora rare

Further down the raceways Ulothrix mixes with Tetraspora (small ovoid cells in a mucilaginous matrix forming a heterogeneous "colony"

No diatoms seen!

Brown patches further down the raceways have more detritus in the turf but Ulothrix is still dominant; Spirogyra rare

6/20/11

Ulothrix is dominant in green patches at the top of the system; crust growth is common further down the raceways with Oscillatoria – is it resistant to chironomid grazing?

7/7/11

Brownish turf – Microspora with dominant pennate diatoms – lots of both free swimming and epiphytic species; Ulothrix uncommon

Green patches of Spirogyra are rare

7/14/11

Green patches with high current energy are dominated by Ulothrix at very top of raceways

Green patches on main turf are dominated by Microspora with rare pennate diatom epiphytes; brown patches are detritus with Oscillatoria and abundant pennate diatoms with common Microspora

7/28/11

Main turf is dominated by Spirogyra; Ulothrix is uncommon as are pennate diatoms; Melosira is rare along with Phormidium, Microspora is common

In patches among the chironomid eatouts, Microspora and pennate diatoms dominate with detritus

8/18/11

Top zone – Microspora dominant; Ulothrix common; Spirogyra rare; pennate diatoms common; Phormidium rare – high turbulence removes detritus here

Lower zone – Microspora dominant; Ulothrix common; Melosira abundant, pennate diatoms common; Phormidium and Spirogyra are rare – much more detritus than in top zone