Report on the Baltimore Inner Harbor Algal Turf Scrubber Project

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INTRODUCTION

As part of a continuing effort to evaluate the algal turf scrubber (ATS) technology™ as a best management practice for water quality improvement in the Chesapeake Bay watershed, an experimental ATS was studied on the Baltimore Inner Harbor from December 2011 through December 2012. The site was on the Honeywell property near Fells Point in Baltimore. The system was 1’ wide and 300’ long with a 1% slope and it was constructed out of wood with fiberglass coating by the firm of Living Ecosystems from Easton, Maryland. Algae were grown on a plastic screen placed in the bottom of the system with a mesh size of 0.25 cm2. Water was pumped from a canal at the Living Classrooms Foundation marina to the system with a Flotec submersible pump. Water flow rate through the system averaged 28.9 gallons/minute over the study period (Appendix 1). The ATS was operated over an annual cycle to examine season differences in biomass production and nutrient removal rates. Water temperature data over the annual cycle are given in Figure 1. Salinity at the site was brackish (Figure 2).

METHODS

Basic Water Quality

Water quality parameters were measured before each harvest in the late morning or 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 Inner Harbor, and at the bottom of the system, as the water flows back into the harbor. The difference between bottom and top values indicates the effect of algal metabolism as water passes over the turf. Water temperature, salinity, dissolved oxygen concentration, percent saturation of dissolved oxygen in the water and conductivity were measured with a YSI meter and pH was measured with an Accumet meter. On two dates, water quality parameters were measured over a diurnal cycle in order to assess ecosystem metabolism of the turf communities.

Biomass Harvest

Algal biomass was harvested in three sections along the length of the ATS (top 100’, middle 100’ and bottom 100’) in order to examine possible longitudinal changes in productivity and nutrient uptake. At the time of harvest the water input to the ATS was turned off at the inflow and the scrubber was allowed to drain for about ½ hour. Harvesting was done by scraping biomass into a mesh bag at the bottom of the raceway. Biomass from each section of the raceway was collected, air dried and weighed. Data for biomass production or net primary production were calculated by dividing the dried mass by the number of days between harvest dates and by the area of the harvest.

Another component of the biomass production of the algal turf community, termed greenwater, was assessed for four sample dates at the end of the study period. The green water contains algal biomass that is suspended in the water sieved through the mesh bag at the bottom of the system during harvest. 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 decanting and the remaining slurry that contained the biomass was spread out on a tray lined with a plastic film in which the water was allowed to evaporate. The biomass remaining after evaporation was air dried 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.

Nutrients in Algal Biomass

Subsamples of biomass were oven-dried, digested in sulfuric acid and peroxide and analyzed for nutrient content with a Hach Co. DR 2800 spectrophotometer. Total nitrogen content was measured with the Kjeldahl method and total phosphorus was measured with the Ascorbic acid method.

Algal 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 at the time of harvest. Two or three samples from the algal turf were collected periodically and these were examined to identify the dominant alga taxa of the system (Appendix 2). Field observations of the condition of the turf were also made periodically before harvest (Appendix 3).

RESULTS

Water Quality

At one seasonal extreme, during the summer, input dissolved oxygen concentration was low at around 0.5-3 mg/l with about 10-20 % saturation. At the other seasonal extreme, during the winter, input dissolved oxygen concentration was high at around 10-12 mg/l with about 90-100 % saturation. pH of input waters ranged from 7.0 to 7.5. Passage of the input water through the ATS increases dissolved oxygen concentration, percent oxygen saturation and pH in proportion to ecosystem metabolism of the ATS. During mid-day these increases between the top and bottom of the ATS in dissolved oxygen concentration, percent saturation and pH were dramatic (see Figures 2 and 3 for oxygen increase data relative to water temperature). These increases are especially noteworthy given that the turnover time of water in the systems was less than 10 minutes.

Biomass Production

Data on algal biomass production from the routine harvesting are given in Appendix 4 and a seasonal summary is given in Table 1. This table shows three possible scenarios of harvest according to the 100’ sections of the raceway. The far right hand column gives the production of all three sections combined, the middle column gives the production of the top and middle sections combined, and the far left hand column gives production of the top section only. Data are presented in this way so that the longitudinal pattern of production can be assessed. The highest production was found when the top and middle 100’ sections were combined, suggesting some type of limitation in the lower 100’ section. This kind of analysis can be used to design the length of an ATS for optimal production.

Total production of the three potential harvest scenarios was similar, ranging from a low of 7.1 g/m2/day to a high of 7.7 g/m2/day over the annual cycle. Ash content was measured to be 59% of biomass.

A small sample of greenwater biomass data is given in Table 2. Relatively, greenwater biomass productivity was high on 10/11/12 during a polychaete eat-out, but low after the eat-out in November and early December.

Nutrient Content in Algal Biomass

Nutrient data for algal biomass is given in Table 3 for three sample dates during the annual cycle of data collection. Nitrogen content averaged 3.20% and phosphorus content averaged 0.05% of the algal biomass.

Nutrient Uptake Rates

Nutrient uptake by the ATS was found by multiplying the biomass production rate (g dry weight/m2/day) by the nutrient contents of the biomass (%). Using a biomass production rate of 7.7 g/m2/day from Table 1 (and assuming a 7% water content of air dried biomass based on past experience) and an average nitrogen content of 3.2% from Table 3, the total annual uptake rate for nitrogen would be:

(7.7 g/m2/day)(0.93 dry g/air dried g)(0.032 gN/g)(4047 m2/acre)(365 days/year)(1 kg/1000g)(2.2 lbs./kg) = 745 lbs N/acre/year.

The same calculation using an average phosphorus content of 0.05% from Table 3, yields 12 lbs P/acre/year.

Table 1. Comparison of seasonal productivities longitudinally calculated along the raceway for three scenarios. All data are in units of g air-dried weight/m2/day. Calendar months are given in parentheses under the seasons.

Season	top only	top + middle	top+middle+bottom
Winter (12-2)	4.6	4.6	4.8
Spring (3-5)	6.0	7.0	6.5
Summer (6-8)	14.2	14.4	12.2
Fall (9-11)	5.5	4.6	4.9
Annual Average	7.6	7.7	7.1

Table 2. Comparison of “greenwater” biomass production on selected dates at the end of the growing season.

Date	top (grams)	middle (grams)	bottom (grams)	total (grams)	productivity (grams/m2/day)
10/11/12	378.4	592.8	724.5	1695.7	4.3
11/1/12	*	78.1	94.0	-------	----
11/14/12	79.4	41.3	27.8	148.5	0.4
12/6/12	72.7	93.0	203.0	368.7	0.6

*No sample

Table 3. Nutrient content of algal biomass. Data are means of three replicate subsamples, from harvests taken from the three sections of the ATS: top 100’, middle 100’, bottom 100’.

Sample date		% nitrogen	% phosphorus
5/31/12	Top	4.36	0.03
	Middle	3.60	0.06
	Bottom	3.60	0.06
7/10/12	Top	2.92	0.05
	Middle	3.38	0.05
	Bottom	3.08	0.06
9/27/12	Top	2.58	0.04
	Middle	2.53	0.05
	Bottom	2.71	0.03

Appendix 1. Flow rates at the Baltimore Inner Harbor ATS. Data are averages of three measurements on each date.

Date	flow rate (gallons/minute)
1/28/12 (4PM)	35.0
1/28/12 (6:30PM)	35.3
1/28/12 (9PM)	36.1
2/14/12	31.5
3/13/12	33.6
5/25/12	29.1
5/30/12	28.0
6/26/12	29.0
7/3/12	31.5
7/10/12	31.1
7/18/12	28.3
7/27/12	27.7
8/17/12	26.3
8/24/12	26.3
9/4/12	25.2
9/6/12	23.3
9/27/12	21.8
10/18/12	26.5
11/1/12	26.0
12/6/12	25.5

Appendix 2. Microscopy notes from the Baltimore Inner Harbor ATS.

12/22/11 Super dominant – Melosira, rare green filaments (thin Ulothrix and a nice Vaucheria), very rare pennate diatoms epiphytes

1/17/12 Melosira and Fragillaria-like pennate dominant; rare to abundant blue green filament (Phormidium?)

1/31/12 Main turf – dominated by Melosira with lots of epiphytic pennate diatoms, Fragillaria common, a very thin Ulothrix is uncommon

Some very thin green filaments attached to side of raceway near top? A small amount of it is the Ulothrix but most is something else non-descript

2/28/12 Melosira dominate with lots of pennate diatoms – some epiphytic and some free-living

Very thin green filament attaches to the side of the ATS especially at the top where turbulence is high – Ulothrix

Diversity seems low

4/25/12 Melosira (barrel-shaped higher salinity species) dominant with lots of epiphytes diatoms, Phormidium rare; Vaucheria (coenocytic branching filaments) common

5/18/12 Melosira (barrel-shaped species) dominant with lots of epiphytic pinnate diatoms, Phormidium rare

Blue green mats dominated by an Oscillatoria with abundant Melosira and common pennate diatoms- smelled like sewage

Enteromorpha is common near the top of the ATS and dominates patches – it had been planted by Peter May

6/12/12 Enteromorpha dominates with common pennate diatoms, Melosira uncommon, very thin filamentous blue-green rare

Enteromorpha is dominant at the upper 100'; below 100' it remains dominant but diatoms (pennate epiphytes and Melosira) become more important

6/26/12 Same as 6/12/12 but Melosira is increasing in dominance

July sample – look in field notes for observations taken when Brazilians visited

Appendix 2 continued.

8/17/12 turf dominated by two species of Melosira plus abundant pennate diatoms as epiphytes and free living

In the lower portion of the ATS, Enteromorpha is rare with very thin blue green filaments common too

Sewage smell is apparent in the sample from the top of the raceway

8/24/12 brown turf – Melosira dominant and Enteromorpha common – very thin blue green (an Oscillatoria) also common, plus pennate diatoms are common

Green turf at the very top – still dominated by Enteromorpha

9/27/12 brown turf – Melosira dominant – 2 species – plus abundant pennate diatoms

Deep spot in the ATS – Melosira dominant with Enteromorpha, lots of pennate diatoms, an Oscillatoria rare

Green turf at the top(it is short – about 30') – Enteromorpha dominates – with some pennate diatoms common

10/11/12 In eat out areas - lots of detritus, Melosira (both species) common pennate diatoms common, a thin blue green filament very rare

In turf – Melosira (both species) are abundant as are pennate diatoms – Enteromorpha common – less detritus

11/1/12 top section of ATS – Enteromorpha monoculture

In the rest of the turf – understory is dominated by Melosira (both species) and detritus, pennate diatoms are common; the overstory is dominated by Melosira with rare pennate diatoms

12/27/12 top section (20') is an Enteromorpha monoculture

From 20' to 200' – both species of Melosira co-dominant, pennate diatoms are common, a very fine green filament is rare

From 200' to 300' – Melosira dominant with common pennate diatoms

Appendix 3. Fields notes from the Baltimore Inner Harbor ATS.

12/22/11 Coverage of algae on the screen was less than 1%; screen was running one week - just a few tufts of filaments – maximum of 1 cm in length – mostly near the lower end and at bumps on the screen where material catches from the current.

1/17/12 Coverage almost 100%; Screen covered with thick filamentous algae up to 15 cm in length

5/18/12 greens mixed in with pale brown filaments in top three sections; brown filaments look like they've been stressed – amazing white flocks on tips of filaments throughout!; blue green felt-like mat mixes in with brown filaments starting at about 50'; some dead (bleached) spots make up about 5% coverage; white flecks (fungi?) less abundant; smells like sewage at inlet

Lots of amphipods

5/25/12 many blue crabs by outfall!

Beautiful brown filaments throughout – up to 15 cm in length; lots of bubbles caught in the mat formed by filaments; lots of slough flowing down the raceway; can see about 5 – 10 % bare screen with the biofilm – the rest is made up of thick filaments; flecks of sewage fungi (?) caught in the filaments in the top half of the ATS but very little; greens obvious only in the top 3 sections (25') and only "common" not "abundant"; no sign of stress like last time; there was a sewage smell but not as strong as last week

5/30/12 Enteromorpha dominant over first 3 ½ sections – it has spread! Melosira filaments dominate the rest of the ATS; very little "bare screen" – only 5% of the bottom sections; Melosira filaments 5 – 10 cm in length; lots of slough flowing down the raceway relatively; lots of air bubbles caught in the filamentous turf; can see some invertebrate tubes

6/12/12 thick, well-attached greens dominate at the top – only a little white organisms on the tips; brown filaments mix in the middle with some felt-like blue green crust; Enteromorpha picks up down the length of the raceway; hard rain

6/18/12 Green filaments dominate at the top; brown filaments increase after about 50'; very light rain

6/26/12 Top 50' has long green filaments mixed with brown filaments; the rest of the length is brown filaments with an "understory" of blue green crust; only the top 10' or so has a few flecks of white fungi (?), only a slight sewage smell but water looked cloudy (like soap)

Appendix 3 continued.

It is amazing that Enteromorpha has decrease at the bottom – it is still strong in the top with high biomass and strong attachment

Lots of polychaetes (tube dwellers) Nereis-type, saw one chironomid fly larvae

7/3/12 much less Enteromorpha even at the top – beautiful bed of Melosira with 15 cm long filaments; large bubbles caught in the turf; light green filaments apparent with a browner understory; patches of brown mat occupy the lower 50'; geese are eating in the lower sections where they can walk in the raceway – saw 20 geese around the lower section – this could be a problem for a large-scale ATS on the ground

Saw lots of polychaetes – especially in the top 100'

7/10/12 throughout the raceway - dark green filaments about 10 cm long – darker green crust understory with three dimensional structure where the water is deep; the top two sections have more Enteromorpha but it is not dominant; lots of mussels in the top sections – Chris Streb saw barnacles

Lots of polychaetes

7/18/12 pump stopped at 11:30AM just as we arrived; top section has thin coverage with Enteromorpha co-dominant with brown filaments; the whole turf is thin

Nereis density can be seen through the thin turf; density is a maximum of 5/100 cm2 – they can be seen crawling through the turf --- the top section looks like an eat-out

Lots of mussels evident in the top sections

7/27/12 Melosira dominates throughout with pennate diatoms abundant

Floating mat appears in the lower 50'

Enteromorpha is very rare – especially at the top

Very high density of false dark mussels especially at the top

8/17/12 weird brown filaments at the lower 50' with light brown carpet underneath – Melosira-like filaments 10 cm in length throughout most of the system; only a tiny bit of green filaments evident; lots of bubbles in the turf; Enteromorpha still dominates in the top 20'

8/24/12 bottom sections have a crust with scattered filaments and bubble patches – filaments are short 5-10 cm in length; crust dominates with lots of polychaetes; deep

Appendix 3 continued.

sections are different with three dimensional structure with longer filaments; lots of bubbles throughout caught in crust; Enteromorpha dominant in the top three sections

Lots of polychaetes

9/4/12 not much algae – mostly brown turf with short filaments and lots of detritus; major eat-out is apparent ; polychaete eat-out seems different from a chironomid fly eat-out with the screen bare at the top not the bottom – can see bare screen grid and green algae more common at the top – do they eat diatoms preferentially? Maybe they need low oxygen which occurs at the top? Should do a longitudinal survey of worm density – can see about 5+ individuals per 25cm2 – they range in length from 1-3 cm; Is the eat-out triggered by higher salinity? Due to summer drought?

9/27/12 top 40' dominated by green Enteromorpha, then brown filaments take over with a benthic crust that traps oxygen bubbles; turf looks good, filaments of greens and browns are up to 20 cm in length with 100% coverage and no sign of polychaetes; brown filaments are shorter in the lower half of the raceway at 5 – 10 cm in length, can see a lighter brown crust in places beneath the filaments

10/11/12 very little algae in the upper 80' of the raceway, scattered short brown filaments start at 80' then increase in coverage; brown filaments are only up to 5 cm in length; light brown crust (blue greens?) begins at about 120', then continues to the bottom; coverage is 100% from 150' down to the bottom, 80-90% coverage from 100'-150'; Enteromorpha nearly gone from top –just scattered filaments – was this because the water pulse was removed when the dump bucket broke – dump bucket fell off but flow continued for 3-5 days, bucket was fixed 10/8/12

Lots of hydroids in the top sections

Lots of polychaetes throughout, the eat-out continues…

10/18/12 water has been on for 5 days since cleaning for eat-out; basically no algae visible on screen, scattered brown filaments can be seen on the bottom portion of the ATS – is this regrowth?

11/1/12 Enteromorpha dominates top three sections then gives way to a green-brown mix of filaments which are up to 20 cm long, the brown green filament extends as dominant all the way to the bottom with only occasional openings covered with a dark brown film as crust; system looks great; only saw 2 polychaetes all day – eat-out over

12/27/12 Enteromorpha dominant in top 30', then it mixes with brown diatom filaments which are 20+ cm in length; diatom filaments dominate the rest of the scrubber with bubbles caught in the turf in spots; filaments shorter in the lower 100' with a few bare spots but there is still 95% coverage in the bottom

Appendix 4. Biomass production of the Baltimore Inner Harbor ATS. Biomass and productivity data are air-dried weights for algae collected in mesh bags (no "greenwater" is included). Duration is the number of days between harvests. The total area of the raceway is about 28 m2. To calculate productivity for a date, sum the biomass from top, middle and bottom and divide by 28 m2 and by the duration. The system was started in mid-December 2011.

Harvest date	top (grams)	middle (grams)	bottom (grams)	duration (days)	productivity (grams/m2/day)
1/17/12	312	380	1614	30	2.7
1/31/12	243	335	633	14	3.1
2/14/12	855	1048	810	14	6.9
2/28/12	948	1085	799	14	7.2
3/13/12	1069	1155	1143	14	8.6
--pump off due to plumbing repair -------------------------					
5/18/12	452	120	221	24	1.2
5/25/12	491	891	427	7	9.2
5/31/12	351	480	310	6	6.8
6/5/12	396	585	442	5	10.2
6/12/12	955	1118	531	7	13.3
6/18/12	807	773	282	6	11.1
6/26/12	1606	1704	191	8	15.6
7/3/12	1253	1311	406	7	15.2
7/10/12	1214	947	638	7	14.3

Appendix 4. Continued.

Harvest date	top (grams)	middle (grams)	bottom (grams)	duration (days)	productivity (grams/m2/day)
7/18/12	936	1417	782	8	14.0
7/27/12	828	546	1137	9	10.0
--pump broke (water off 4 days)-----------------------------					
8/17/12	1180	1542	754	12	10.3
8/24/12	741	359	409	7	7.7
9/6/12	209	111	158	13	1.3
--pump off to control eat-out (water off 4 days)-----------					
9/27/12	1389	1113	1118	18	7.2
10/11/12	205	224	178	14	1.5
--pump off to control eat-out (water off 2 days)-----------					
11/1/12	1091	716	624	19	4.6
11/14/12	1185	571	627	13	9.8
12/6/12	1229	589	766	22	4.2

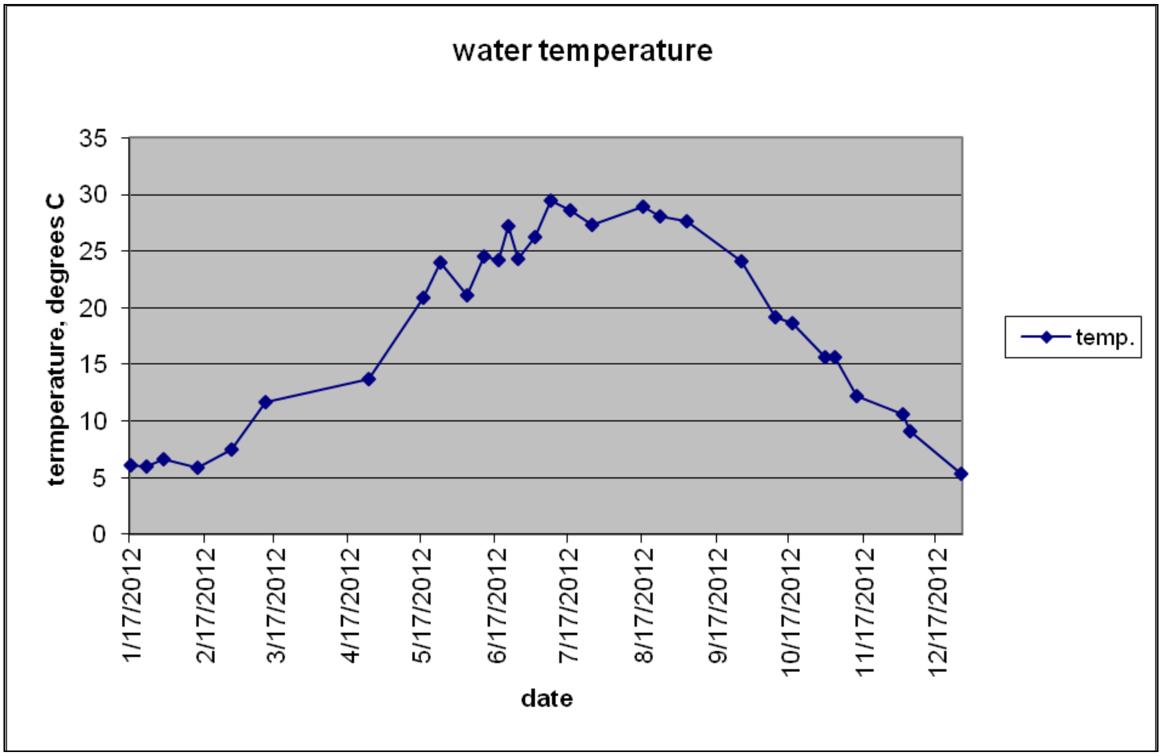

Figure 1. Incoming water temperature data during the study period.

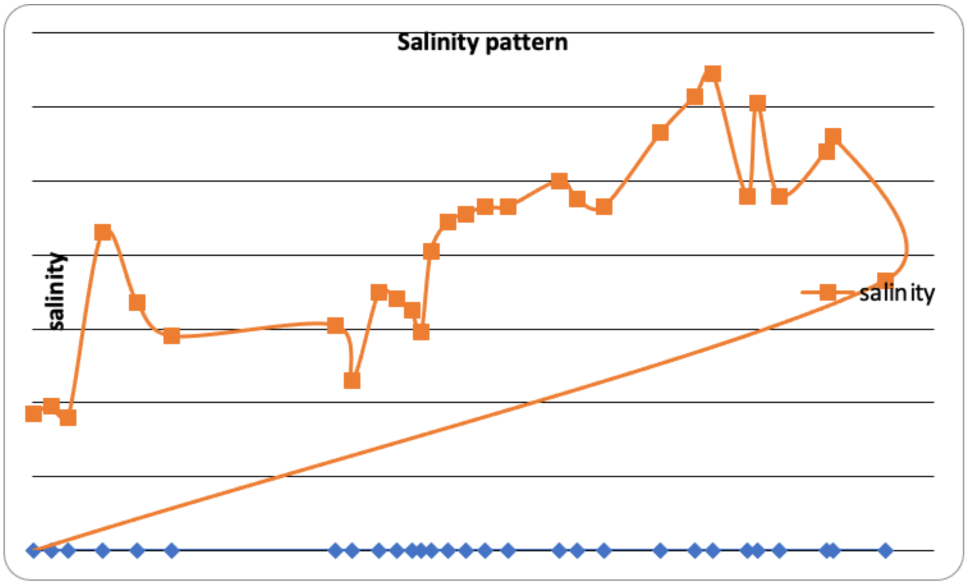

Figure 2. Incoming salinity data during the study period.

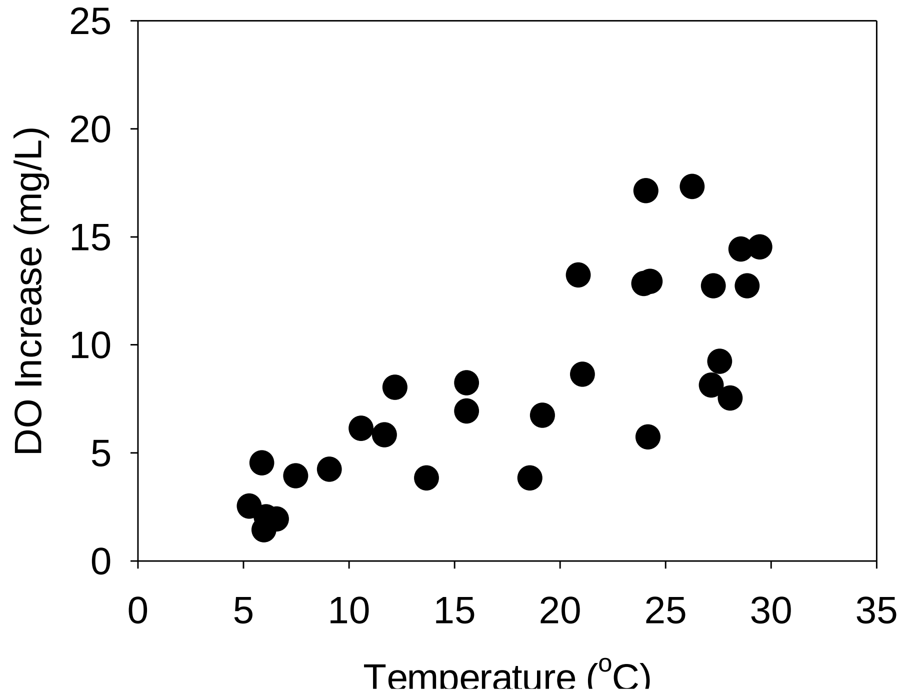

Figure 3: The increase of DO (mg/L) after water flowing through ATS varied with water temperature.

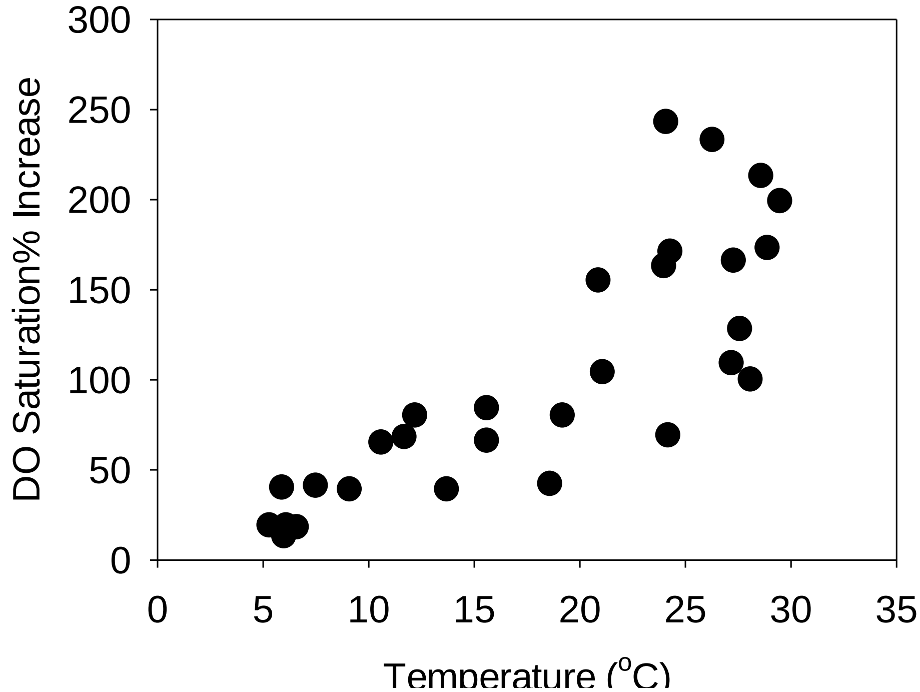

Figure 4: The increase of DO Saturation (%) after water flowing through ATS varied with water temperature.