# The Effect of Temperature Change and Grazing on Algal Primary Production and Nutrient Uptake

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## Abstract:

Two species of algae (*Ulva sp.* and *Gracilaria sp.*) were placed in a growth chamber set to a different temperature to measure GPP and nutrient uptake of algae in different treatments under different temperatures stresses. The treatments were algae with/without the presence of grazers and the dark/light treatment. Although there was a weak correlation between the rate of GPP and the rate of nutrient uptake, the Ulva resulted in having a higher rate of nutrient uptake at higher temperatures. This suggests that Ulva has the potential to become more dominant in the aquatic ecosystem during the warmer seasons since it can take up nutrients rapidly.

## Key Words:

Temperature, Nutrient uptake, Macroalgae, Ulva, Gracilaria, Palaemonetes,

## Introduction:

Temperature, although it varies between seasons, are an important environmental factor, which can become a stress for primary producers when it fluctuates, disrupting growth, nutrient uptake and other vital activities. By observing the effects of temperature on aquatic primary production, such as algae, it is possible to understand the important relationship between temperature, growth and nutrient uptake. The algal growth and temperature relationship reveals a model which suggests an exponential increase of the growth rate as the temperature increases (Goldman et al, 1974). The nutrient availability also greatly affects the growth of algae, since nutrient limitation can inhibit the growth. All of these environmental conditions can affect the algae, thus altering the conditions for algal grazers.

Macroalgae are not only food for grazers, but also provides structure, habitat, safety and food for organisms. Yet it is greatly affected by nutrient inputs, often resulting in massive increases and domination of systems by "macroalgae blooms" as a result of anthropogenic nutrient inputs (Valiela et al., 1997). As much as macroalgaes are great competitors, grazers will benefit greatly through temperature increases, since metabolic rates are greatly affected by temperature (Valiela, 1995)

In specific, two species of macroalgae (Ulva and Gracilaria) were chosen specifically from West Falmouth Harbor to be placed under seasonal and above average temperature stresses with and without grazing *Palaemonetes* (grass shrimp) to observe changes in nutrient fluxes, rate of photosynthesis. Although grass shrimp is often referred to as an opportunistic omnivore, they consume algae and are ideal grazers because of their abundance (Quinones-Rivera et al., 2005).

As global temperature change becomes a daunting reality, such experiments under laboratory conditions will provide useful insights to understand predator-prey relations and its ability to adapt to temperature stresses, as well as recognizing which species will be in an advantage from this change.

## Methods:

The two kinds of macro algae (*Ulva* and *Glacilaria*) and the grazer (*Palaemonetes*, commonly know as grass shrimp) were collected at the West Falmouth Harbor using nets and clam rakes. These algae were blot dried and weighed (average of ~1.8g) to be placed into 1L jars with sea water from Vineyard Sound. There were a total of six treatments including the Ulva, Ulva with grazer, Glacilaria, Glacilaria with grazer, sea water and just grazers at two different temperstuers (20C and 30C). There was one replicate for each jar with macroalgae. Each jar with grazers were placed five *Palaemonetes* in each jar. To determine the amount of grazer appropriate for each jar of algae a preliminary experiment was conducted by randomly picking out algae with a dip net and removing the grazers form the algae. By recording the amount of grazers found per gram wet weight of algae, I was able to determine the natural abundance of grazers.

The jars were placed under the growth chamber, which was set at either the 20C or 30C treatment and were under the 12/12 hour day-night cycle for at least 24 hours for algae and grazers to acclimate to the temperature conditions. The individual jars were submerged under acclimated and oxygen stripped sea water to prevent air bubble formation. Nutrients were given to the individual jars and sampled were taken every 30 minutes. This additional nutrient was a 10ml sea water based nutrient mixture that had the concentration of 80uM N and 5 uM P, which was made using 3000 uM $NH_4NO_3$ and 375 uM P.  Dissolved oxygen was measured every 15 minutes using the oxygen-probe (Oxi-probe 340i) that was attached to the lid of the jar. Each jar was observed for a total of 1.5 hours. The jars were left over night under the same conditions to be placed under a cover to measure the concentration of dissolved oxygen over time the following day in the dark. Nitrogen (ammonium and nitrate) and phosphate concentrations were measured following the laboratory techniques and using the Shimadzu 1601 (for ammonium and phosphate) and Lachat (for nitrate).

## Results:

To determine the amount of grazer appropriate for each jar of algae a preliminary experiment was done, resulting in an average of 5 grazers per approximately 2 grams of algae (figure 1). This data was used as the natural standard of grazer to algae ratio for this experiment.

For both dissolved oxygen concentration and nutrient (ammonium, nitrate and phosphate) uptake, the Ulva was a more responsive algae compared to Gracilaria. The raw data points of DO and nutrient change over time was plotted on a graph and a linear regression was fit to the points (figure 2). The rate of change for D.O. and nutrients were taken from the equation of the regression line, which was averaged, scaled (to per gram wet weight of algae) and graphed for each treatment for comparison (figure 3).

The increase of oxygen concentration was detected for both algae treatments (algae and algae with grazer) in the light condition and decreased in the dark condition (figure 4). The rate of net photosynthesis was calculated by subtracting the respiration from the gross photosynthesis. The results showed that Ulva had a higher rate of gross and net photosynthesis and respiration at the lower temperature (20C) for both treatments (algae and algae with grazers). The patterns for Gracilaria is harder to distinguish, since the difference is small compared to the Ulva (figure 5). The treatment with grazers at 20 degrees Celsius had the most rapid respiration out of the four Glacilaria treatments. The sea water and grazer only controls detected small changes in the rate of net photosynthesis and respiration. However, there was no gross photosynthesis for three treatments and a small amount of gross photosynthesis for the only grazer treatment at 20 degrees Celsius. Over all, the rate of gross primary production for the Ulva was higher at lower temperature treatment, while the Gracilaria shows no clear trend with a slightly higher rate of GPP in the only algae treatment at 30C and in the algae with grazer treatment at 20C.

The rate of ammonium uptake was the highest for the Ulva with the grazer treatment at 30C (figure 6). In general, the Ulva at the higher temperature had a more rapid uptake of ammonium. While this was not true in the case of the Gracilaria, the trend is difficult to determine since the control was contaminated and in some cases the control has a larger rate of ammonium uptake compared to the Gracilaria.

Nitrate uptakes were detected to be highest in 30C treatments for Ulva and 20C treatments for Glacilaria (figure 7). Interestingly, the highest rate of nitrate uptake was measured in the algae with grazer treatment at 30C for Ulva and the only algae treatment at 20C for Gracilaria. Additionally, there was a release of nitrates in the Ulva with grazer treatment at 20C. This nutrient release was also detected for the control seawater with grazer treatment at 20C.

The rate of phosphate uptake was drastically different between the Ulva and the Gracilaria (figure 8). The uptake of phosphate was greater at higher temperature for Ulva. This pattern was also observed in the Gracilaria, however, the high contamination in the control treatments makes the result questionable. The highest uptake of phosphate was measured for the Ulva treatment with grazers at 30C. A nutrient release was also measured in the Gracilaria with grazer at 20C treatment, which was also observed in the control. In general, the Ulva showed a clearer trend that warmer temperature induce higher nutrient uptakes compared to lower temperatures.

## Discussion:

Interestingly, the respiration rate for Ulva was higher without grazers at the temperature treatment of 20 degrees Celsius, suggesting that the treatment is the optimal condition for Ulva. This is also supported by the GPP data, which shows that the Ulva with the no grazer and 20C treatment has the highest rate of GPP out of all the treatments (figure 5).

The highest rate of ammonium uptake was observed at higher temperatures for the Ulva, suggesting that the Ulva are more able to take in the nutrient at higher temperatures (figure 6). If this was true, it would imply that that the Ulva can take up more nutrients in the warmer season, which could be another reason why there are algae blooms during the spring and summer. This is unfortunately not a strong argument since the standard error is high and the controls detected an ammonium uptake, suggesting interference by other organisms. The differences in the rate of ammonium uptake for the Gracilaria treatments are smaller than the difference in rate between the different controls, suggesting a contamination or a presence of another organism in the sea water. The positive rate of ammonium uptake in the control was unexpected, since logically the expectation was to find a correlation between the rate of GPP and rate of nutrient uptakes, since nutrients are a necessity for growth. Since the experiment was conducted and monitored over a short period of time, this result could be a result of a short term response. Additionally, the control shows a high rate of ammonium uptake, which could be causing the disruptions in the data.

The rate of nitrate uptake, unlike the ammonium has a cleaner control data, making the result more reliable (figure 7). The standard error for the Ulva, however, is high relative to the rate, suggesting variability in the Ulva data. Glacilaria resulted in the exact opposite trend with the higher uptake by the lower temperature treatments. This suggests that the Ulva favors higher temperature and that Gracilaria favors the cooler temperature. The release of nitrate in the Ulva with grazer treatment and sea water with grazer treatment at 20C suggests that the sea water or the grazer releases nutrients at the 20C condition. However, the rate of nitrate release occurring in with the presence of Ulva is much greater than the control; thus, the control is unable to explain for all of the release of nitrate.

The phosphate uptake was unlike the other nitrogen data resulting in a considerably different uptake between the Ulva and Gracilaria, ranging from 0.64 to 0.14 uM for Ulva and 0.09 to -0.13 uM for Gracilaria (figure 8). Similarly to the ammonium uptake data, the control was detected to have a nutrient change ranging from 0.25 to -0.13 uM which makes the Gracilaria results difficult to validate any conclusions. Additionally, the nutrient release was also detected in the treatment with grazers at 20C, except in the case of phosphate uptake, the algae was Gracilaria. This releasing trend was observed in the control as well. Since in the case of phosphate the rate of phosphate exceeds the rate of phosphate for all Gracilaria treatments, it is possible that the nutrient release is actually not the response of the algae, but something associated with the grazers or sea water.

To synthesize the all of the data from the measurements, the GPP over the rate of nutrients were plotted on the chart (figure 9). A regression was placed on the graphs; however, the results did not show a high correlation. Because GPP is connected with nutrient uptake, the assumption was to find a rise in rate of GPP as the nutrient uptake rate increased. Other research supports this idea, since algae with fast growth are known to have a more rapid nitrogen uptake (Pedersen et al, 1997). However, other research suggests that maybe nitrogen is not the limiting factor for GPP and the addition on dissolved inorganic carbon would enhance the algal growth (Rivers et al, 1995). A repetition of the experiment over a longer segment of time would be ideal to plot this data. In general, the loose trend for both algae and algae with grazer treatment for nitrate is a decrease and for phosphate it is an increase of nutrient uptake as the GPP increases.

Interestingly, the release of nutrient happens to be only with the algae with grazer at 20C treatment and the control with only grazer at 20C. Although it is possible for the algae to respond to the condition by releasing nutrients, because the release was measured in the control simultaneously, it is hard to identify the cause of this particular response in nitrate and phosphate.

Part of the explanation for why the Ulva was more responsive to treatment changes could be a result of more surface area, which can make nutrients and carbon dioxide more available compared to Gracilaria. Previous research confirms that macroalgal uptake of nutrients and surface area to volume ratio is correlated. (Hein et al, 1995) This pattern was also observed between oak and pine leaves in previous laboratory experiments during the first ten weeks of SES.

The rate of nutrient uptake in the control was especially a concern in the ammonium and phosphorus data, since the control showed a larger change between treatments than the Gracilaria. It is suspected that there was a contamination in the laboratory material or a presence of another organism. This was unexpected, since the GPP data for the control suggested that there was no presence of a photosynthesizing organism. It is probable that there were some bacteria or other forms of micro-organisms that are not primary producers that was present on the sea water.

## Conclusion:

Over all, Ulva with grazers at 30C had the highest rate of nutrient uptake, which was consistently seen in all three nutrient data. The uptake of nutrients for Ulva increased as the temperature increase and with the presence of grazers. However, the highest GPP was at recorded for the Ulva with the lower temperature treatment without the presence of grazers. The algae only treatment at 20C has the highest ammonium and nitrate uptake amongst all the Gracilaria treatments. Further experimentation is necessary to find a convincing result, since there were contaminations in the control as well as the limitation of time.

## Acknowledgments:

Ken Foreman, Greg Henkes, Rich McHorney, Clara Funk, Laura Wittman and Beth Bernhardt.

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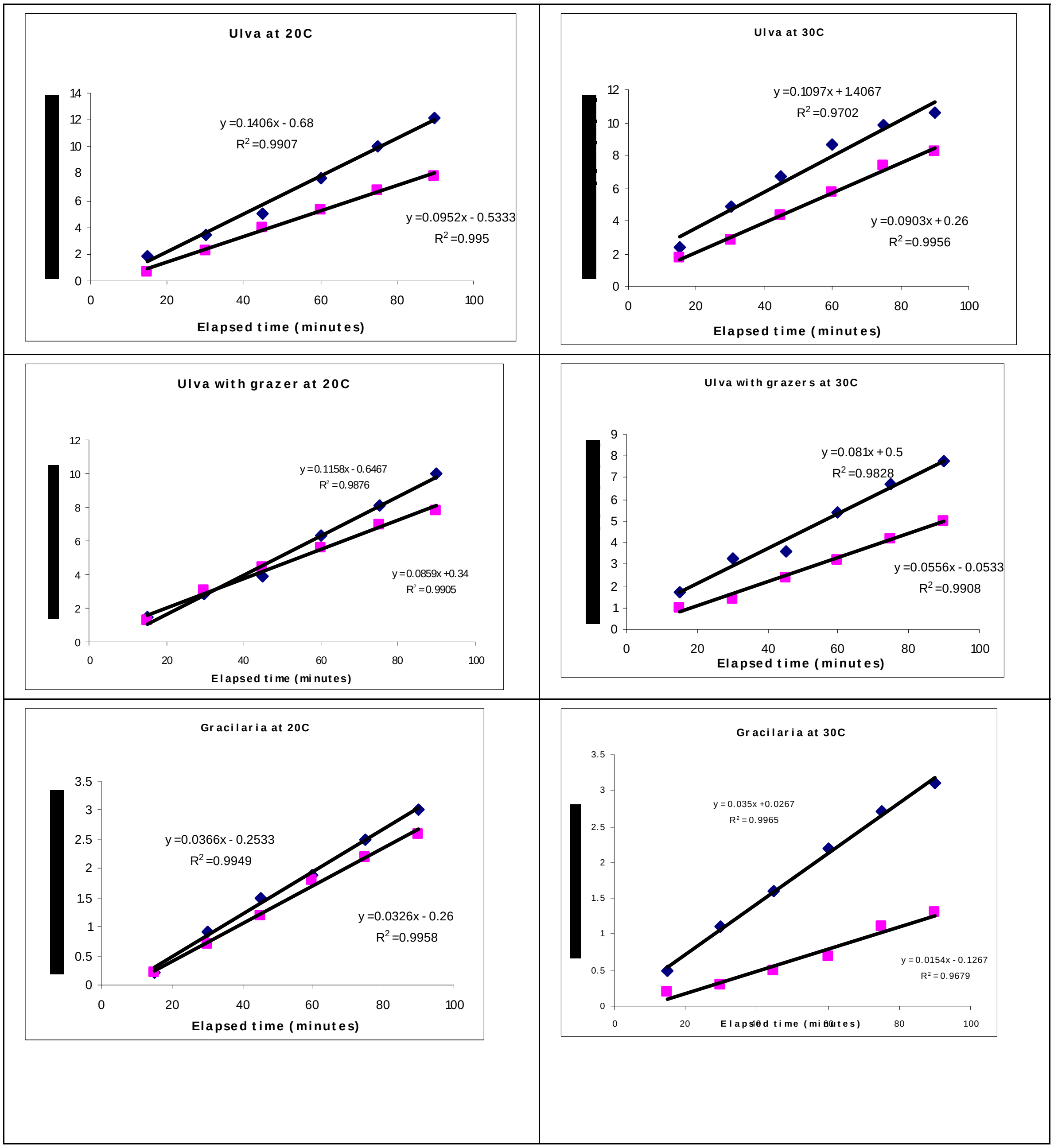
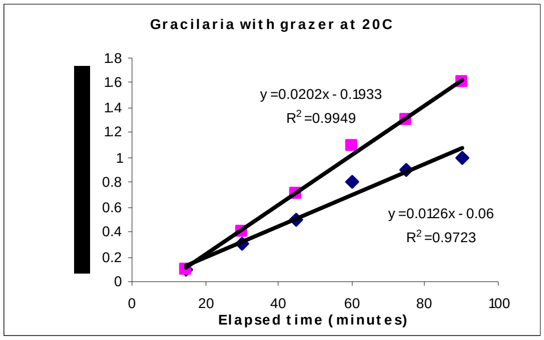
-753.

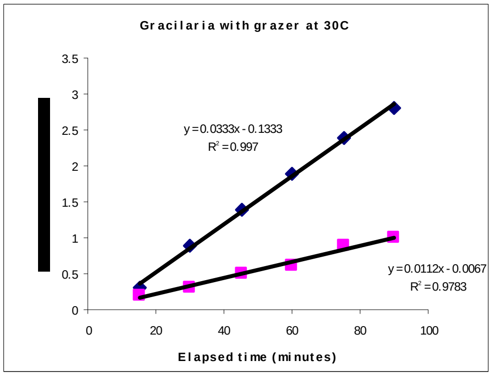
Figure 1
The natural abundance of grazers

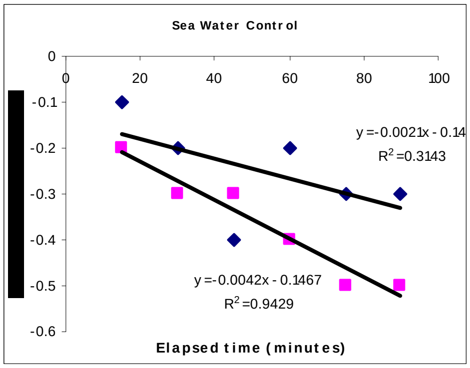
| | Ulva | | Gracilaria | |
|---|---|---|---|---|
| | wet weight (g) | # of grazers | wet weight (g) | # of grazers |
| | 1.67 | 4 | 2.40 | 7 |
| | 2.08 | 4 | 1.83 | 4 |
| | 3.44 | 7 | 1.02 | 4 |
| | 1.53 | 3 | 3.62 | 5 |
| | 1.98 | 5 | 2.54 | 4 |
| | 2.00 | 5 | 1.89 | 2 |
| | 2.71 | 5 | 2.21 | 6 |
| | 1.22 | 4 | 2.37 | 5 |
| | 2.60 | 3 | | |
| | 3.14 | 6 | | |
| Average | 2.237 | 4.6 | 2.235 | 4.625 |

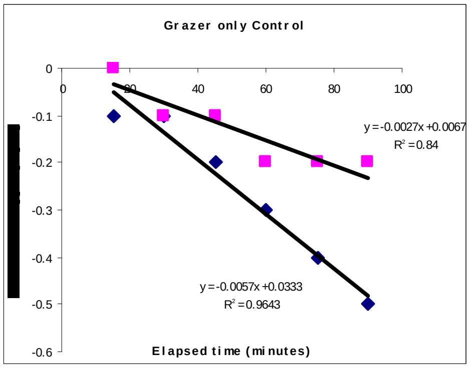
Figure 2
The change in dissolved oxygen content over time and the regression line in the light condition.

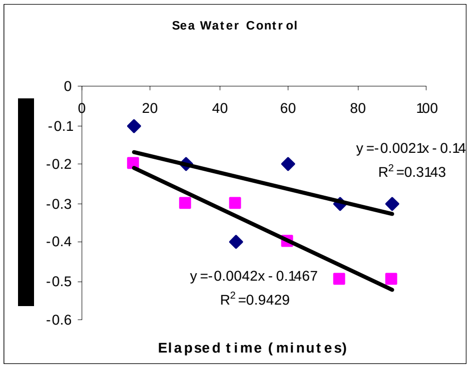


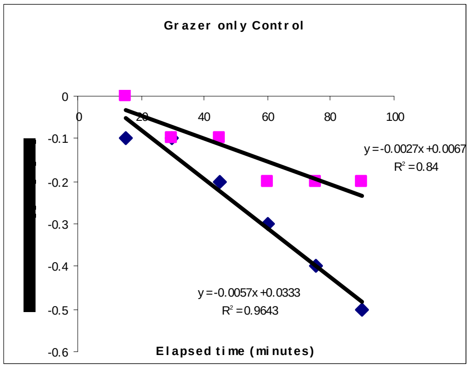




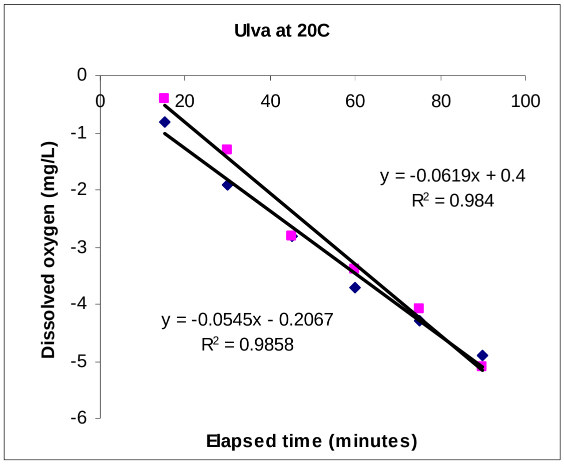


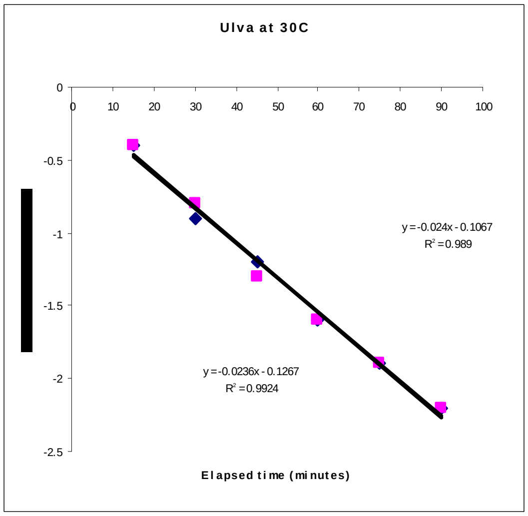


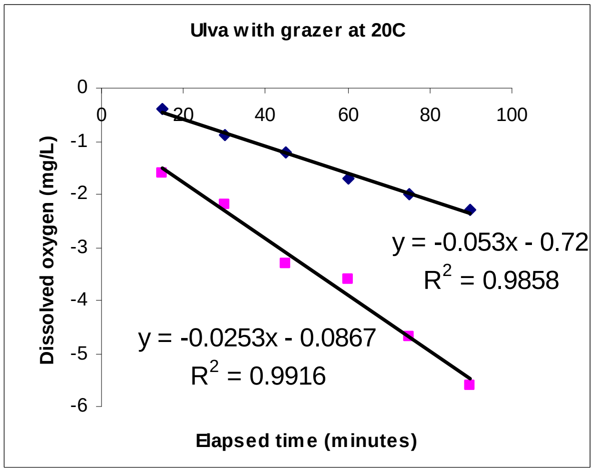


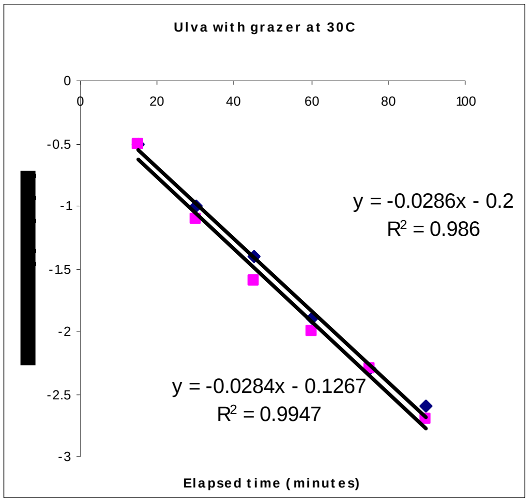


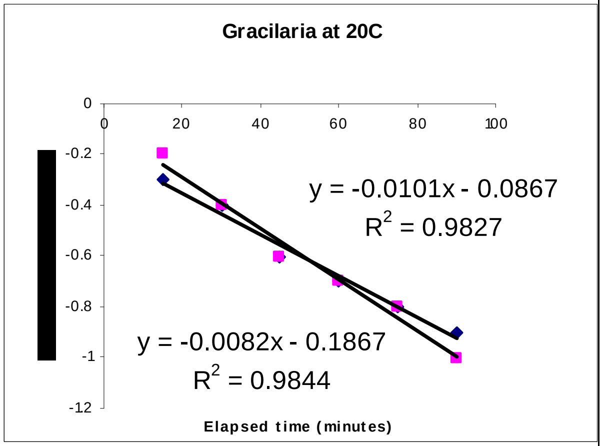
The change in dissolved oxygen content over time and the regression line in the dark condition.

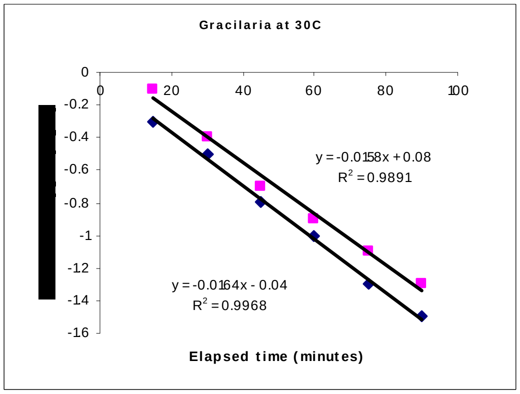

Ulva at 20C
Dissolved oxygen (mg/L)
0
-1
-2
-3
-4
-5
-6
0
20
40
60
80
100
y = -0.0619x + 0.4
$R^2$ = 0.984
y = -0.0545x - 0.2067
$R^2$ = 0.9858
Elapsed time (minutes)

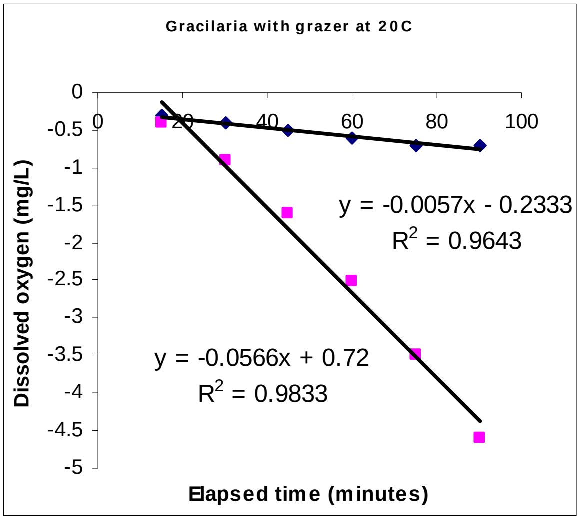

Ulva at 30C
[redacted]
0
-0.5
-1
-1.5
-2
-2.5
0
10
20
30
40
50
60
70
80
90
100
y = -0.024x - 0.1067
$R^2$ = 0.989
y = -0.0236x - 0.1267
$R^2$ = 0.9924
Elapsed time (minutes)


Ulva with grazer at 20C
Dissolved oxygen (mg/L)
0
-1
-2
-3
-4
-5
-6
0
20
40
60
80
100
y = -0.053x - 0.72
$R^2$ = 0.9858
y = -0.0253x - 0.0867
$R^2$ = 0.9916
Elapsed time (minutes)

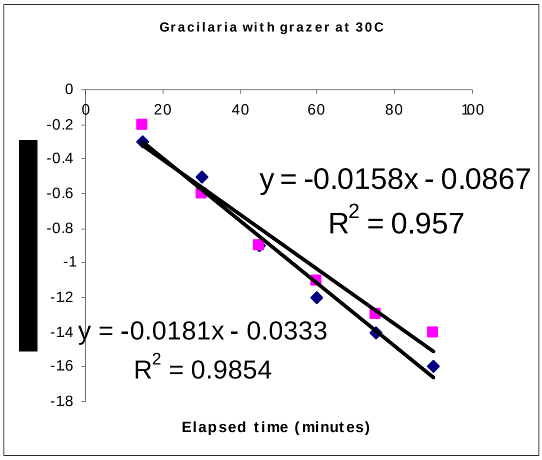

Ulva with grazer at 30C
[redacted]
0
-0.5
-1
-1.5
-2
-2.5
-3
0
20
40
60
80
100
y = -0.0286x - 0.2
$R^2$ = 0.986
y = -0.0284x - 0.1267
$R^2$ = 0.9947
Elapsed time (minutes)


Gracilaria at 20C
[redacted]
0
-0.2
-0.4
-0.6
-0.8
-1
-12
0
20
40
60
80
100
y = -0.0101x - 0.0867
$R^2$ = 0.9827
y = -0.0082x - 0.1867
$R^2$ = 0.9844
Elapsed time (minutes)

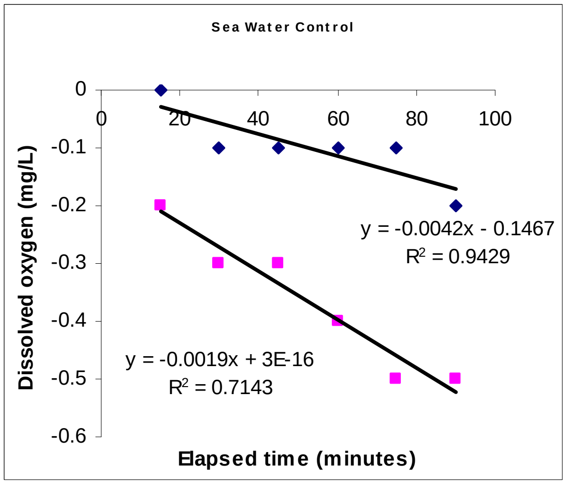

Gracilaria at 30C
[redacted]
0
-0.2
-0.4
-0.6
-0.8
-1
-12
-14
-16
0
20
40
60
80
100
y = -0.0158x + 0.08
$R^2$ = 0.9891
y = -0.0164x - 0.04
$R^2$ = 0.9968
Elapsed time (minutes)



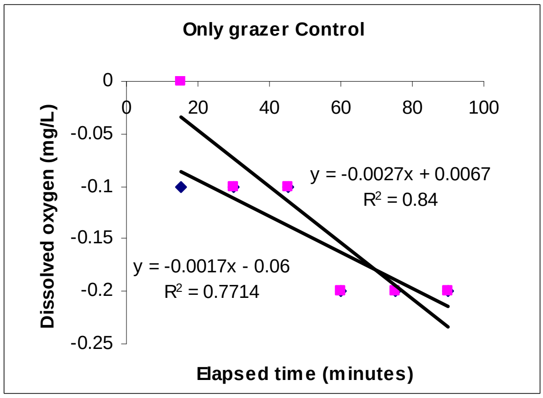
Gracilaria with grazer at 20C



Gracilaria with grazer at 30C



Sea Water Control



Only grazer Control

Figure 3
Scaled rate of gross photosynthesis and nutrient uptake

| Jar # | Algae | Grazer treatment | Temperature treatment | wet weight of algae (g) | rate of change O2 (Pg) | rate of change NH4 | rate of change NO3 | rate of change PO4 |
|---|---|---|---|---|---|---|---|---|
| 1 | U | no grazer | 20 | 2.403 | 0.084 | 1.07 | -0.18 | 0.25 |
| 2 | U | no grazer | 20 | 2.333 | 0.064 | 2.59 | 0.34 | 0.04 |
| 3 | U | grazer | 20 | 2.321 | 0.073 | -1.29 | -0.43 | 0.09 |
| 4 | U | grazer | 20 | 2.272 | 0.049 | 1.23 | -1.07 | 0.32 |
| 7 | G | no grazer | 20 | 2.060 | 0.023 | 2.76 | 0.15 | -0.09 |
| 8 | G | no grazer | 20 | 2.111 | 0.019 | 3.27 | 1.82 | 0.13 |
| 9 | G | grazer | 20 | 2.106 | 0.012 | 1.88 | 0.36 | -0.25 |
| 10 | G | grazer | 20 | 2.144 | 0.032 | 1.26 | 0.66 | 0.17 |
| SW | - | no grazer | 20 | | | | | |
| Gr | - | grazer | 20 | | | | | |
| 1 | U | no grazer | 30 | 2.305 | 0.058 | 6.26 | 0.85 | 0.29 |
| 2 | U | no grazer | 30 | 1.864 | 0.061 | 2.79 | 0.14 | 0.48 |
| 3 | U | grazer | 30 | 2.038 | 0.054 | 13.29 | 1.57 | 0.68 |
| 4 | U | grazer | 30 | 1.897 | 0.044 | 6.82 | 5.83 | 1.95 |
| 7 | G | no grazer | 30 | 1.844 | 0.028 | -12.86 | 0.31 | -0.10 |
| 8 | G | no grazer | 30 | 1.739 | 0.018 | 0.99 | 0.67 | 0.16 |
| 9 | G | grazer | 30 | 2.058 | 0.024 | 1.86 | 0.57 | 0.06 |
| 10 | G | grazer | 30 | 2.096 | 0.014 | 2.07 | 0.22 | 0.12 |
| SW | - | no grazer | 30 | | | | | |
| Grazer | - | grazer | 30 | | | | | |

Figure 4: The rate of Gross Photosynthesis, Net Photosynthesis and Respiration

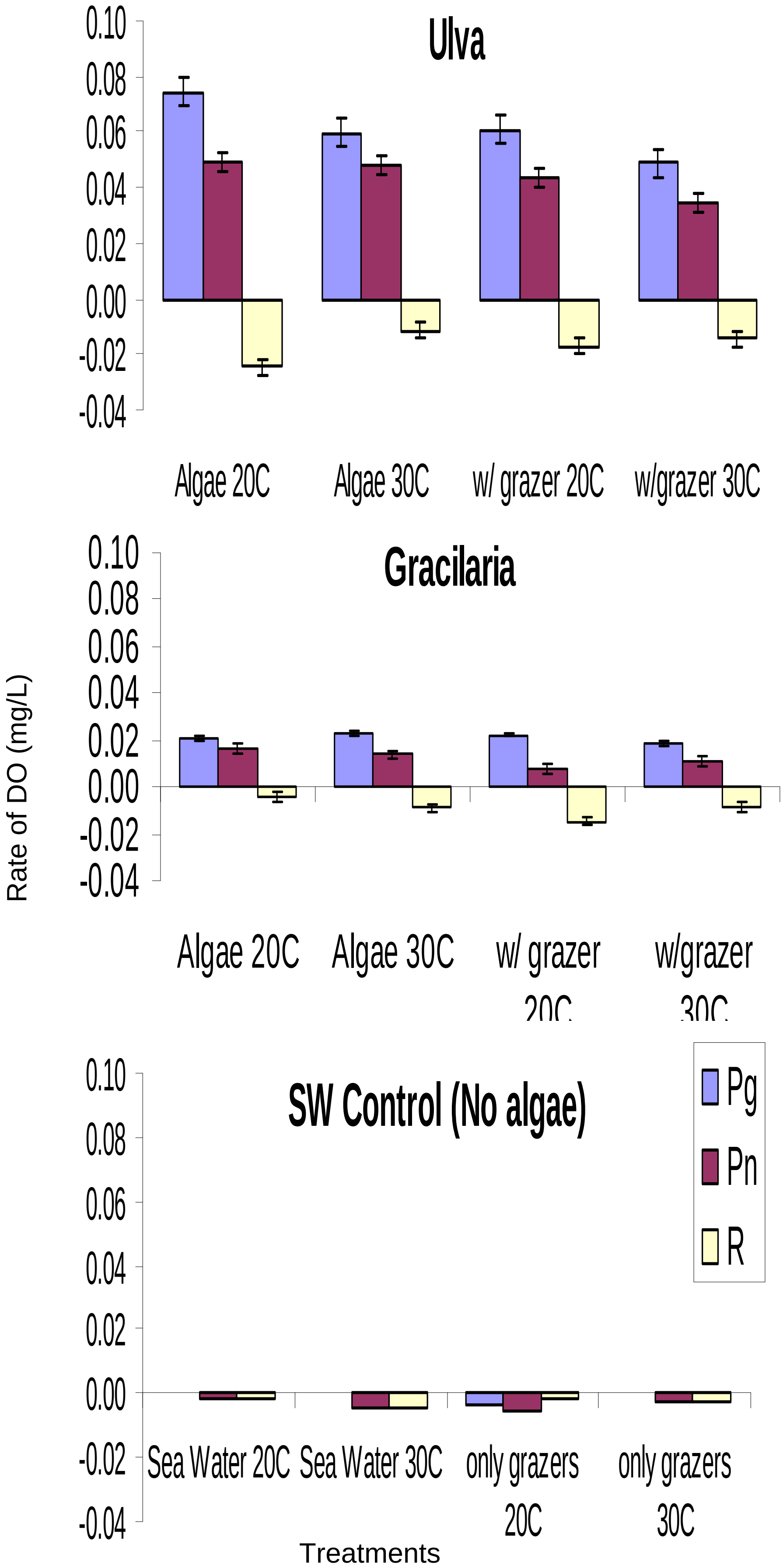


Figure 5: The rate of GPP
(mg O2* $L^{-1}$* $minute^{-1}$* gram wet wt. of $algae^{-1}$)

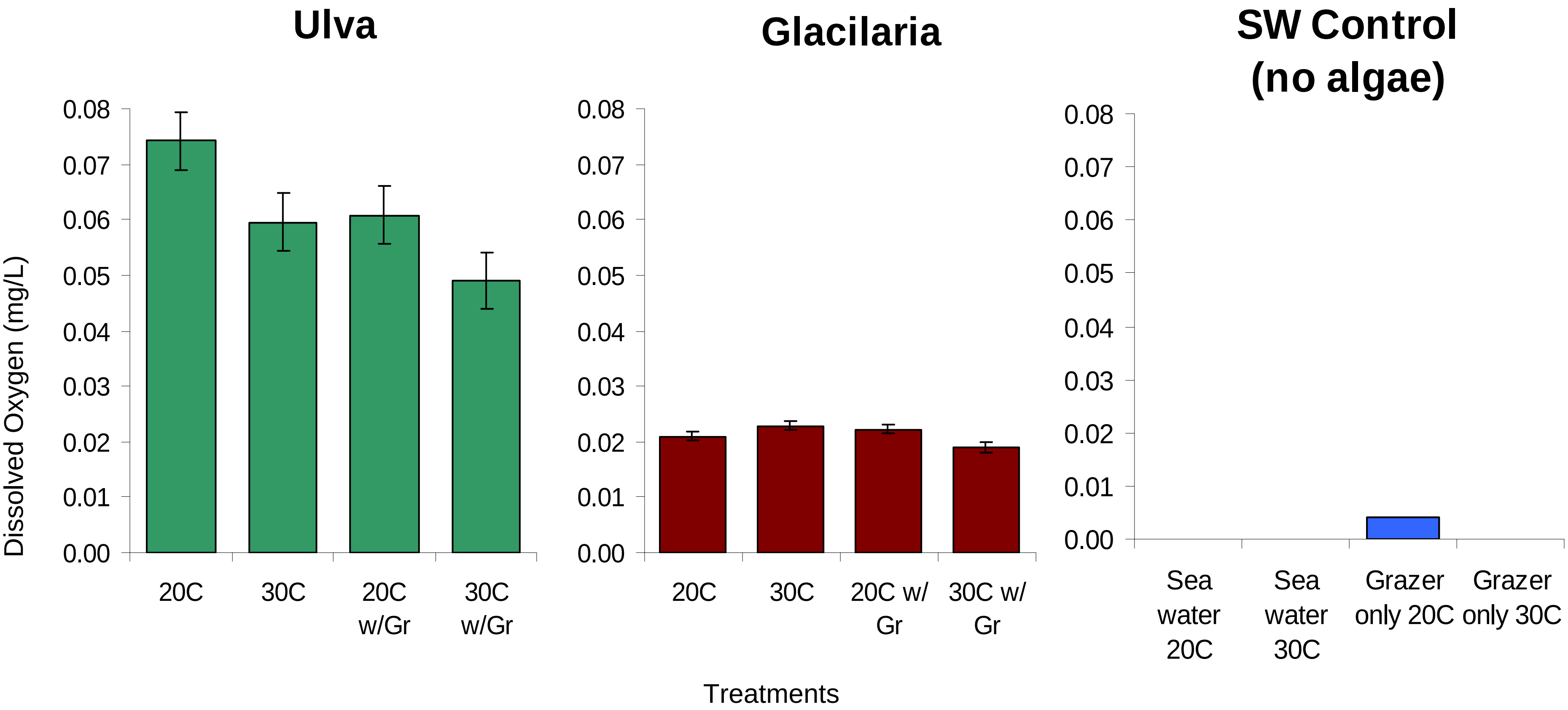


Figure 6: The rate of ammonium uptake
(uM* L$^{-1}$* minute$^{-1}$* gram wet wt. of algae$^{-1}$)

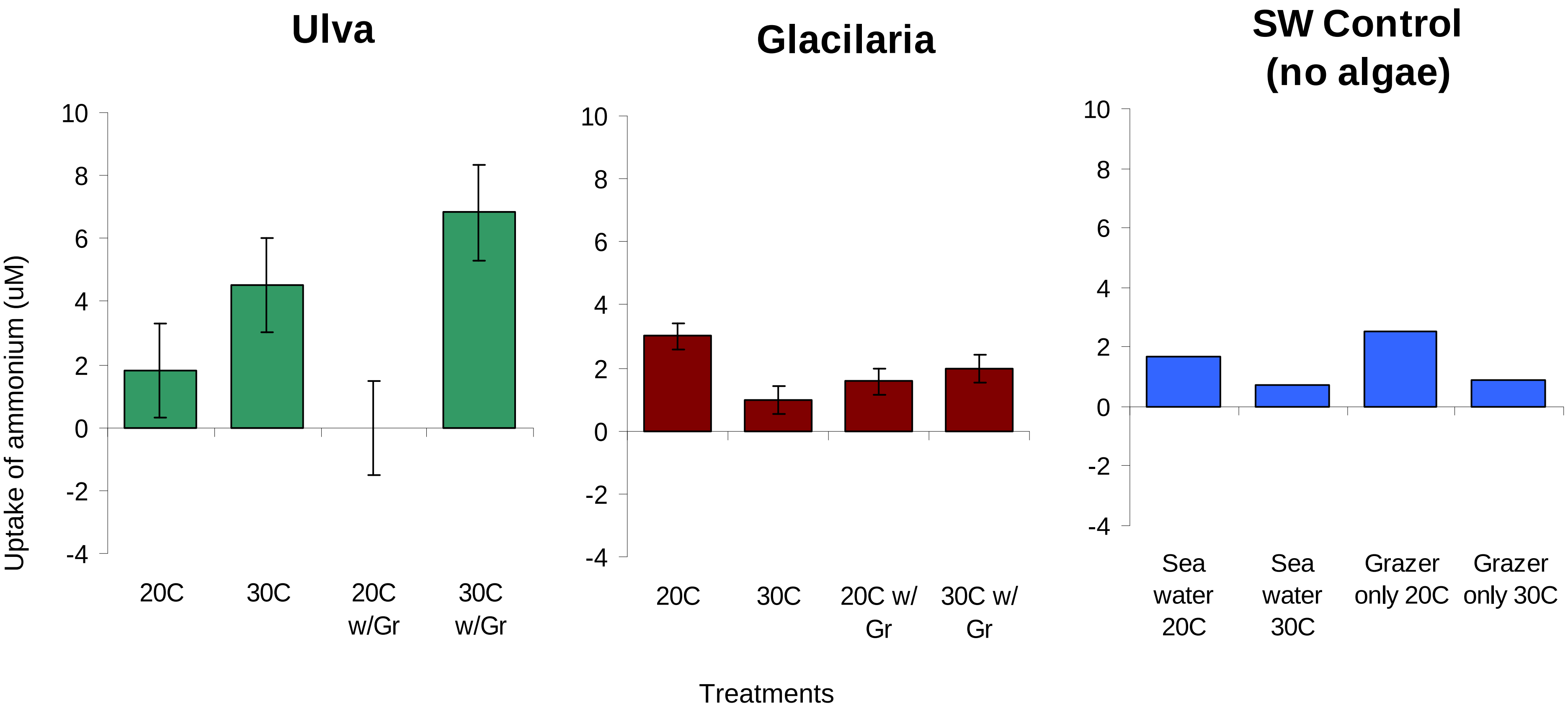


Figure 7: The rate of nitrate uptake
(uM* L$^{-1}$* minute$^{-1}$* gram wet wt. of algae$^{-1}$)

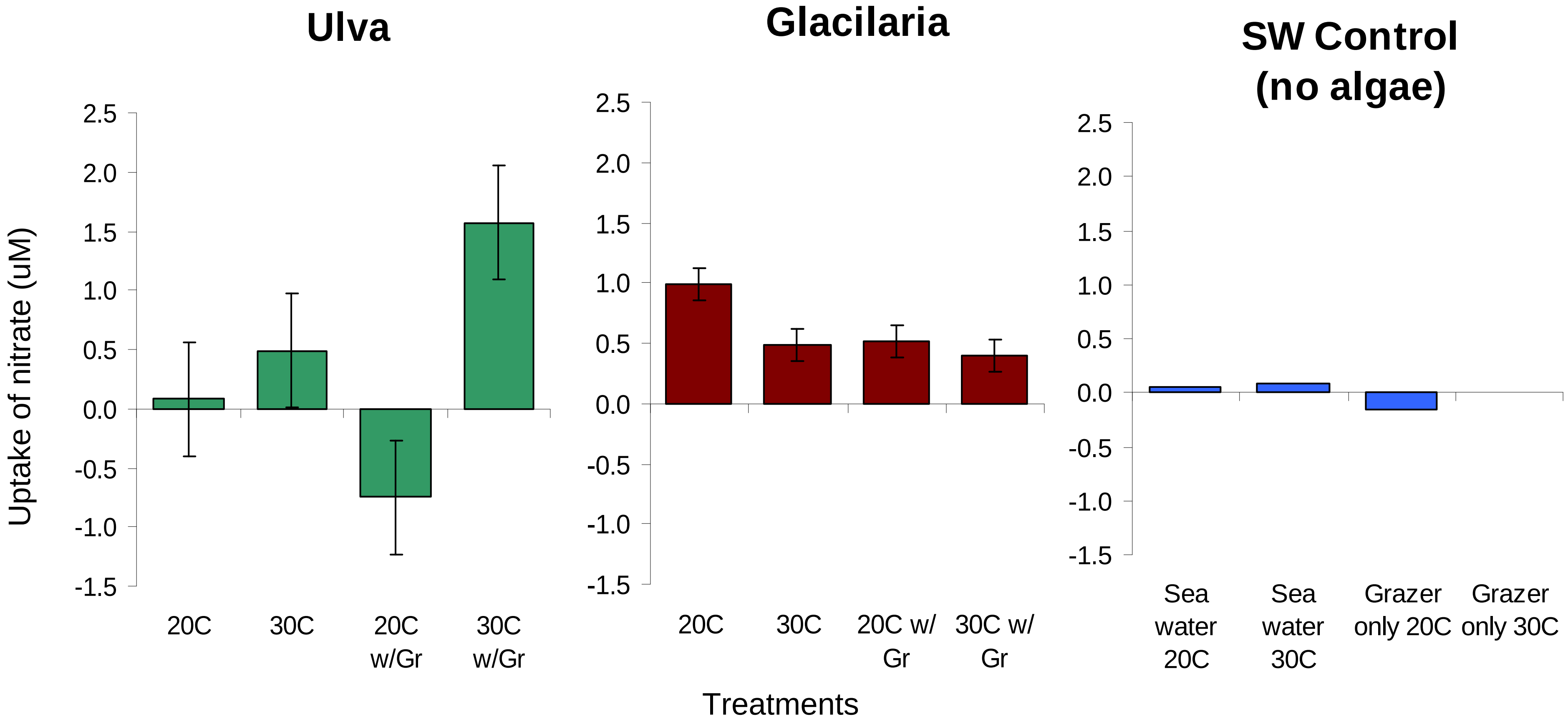


Figure 8: The rate of phosphate uptake
(uM* L$^{-1}$* minute$^{-1}$* gram wet wt. of algae$^{-1}$)

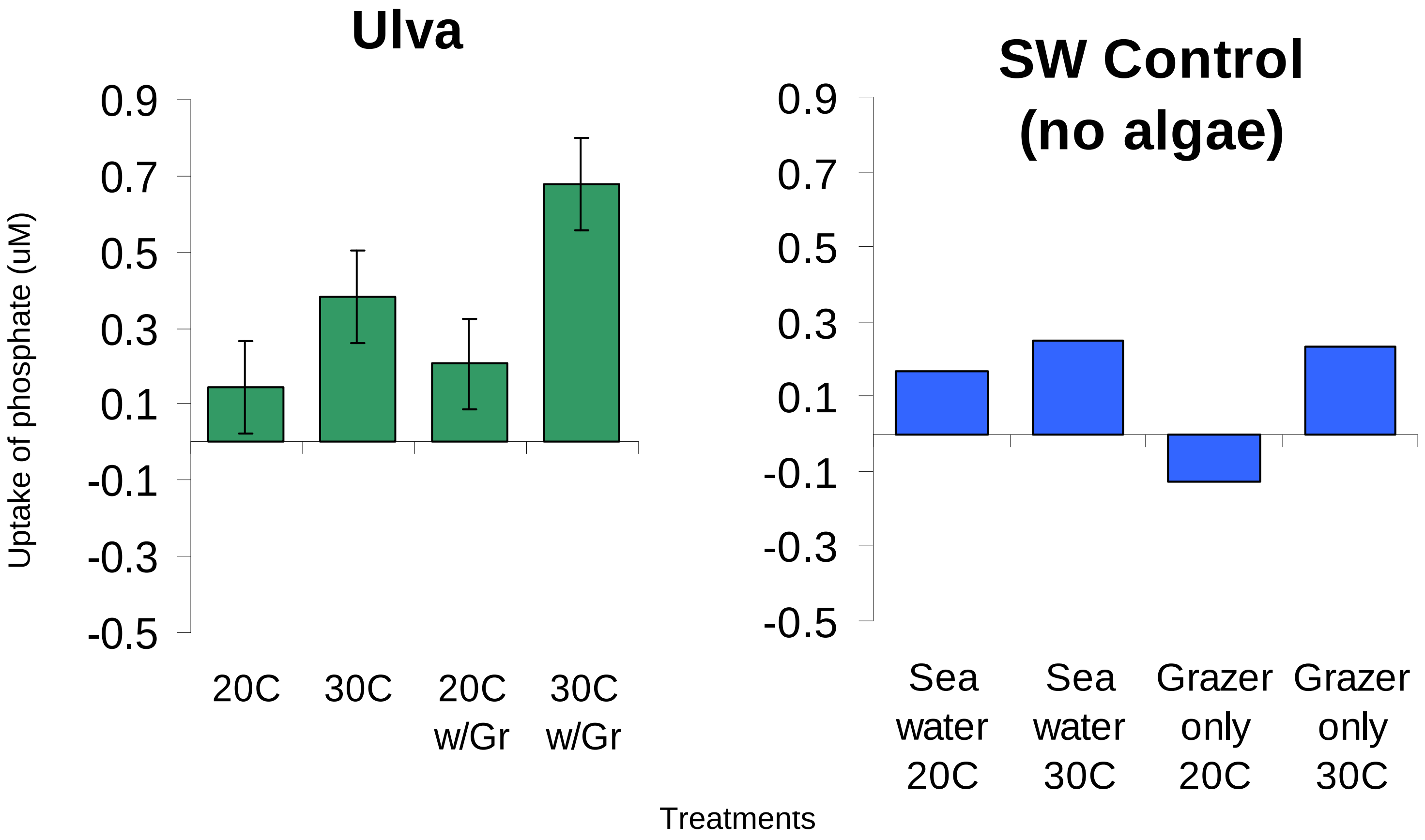


Figure 8: The rate of phosphate uptake
(uM* $L^{-1}$* $minute^{-1}$* gram wet wt. of $algae^{-1}$)

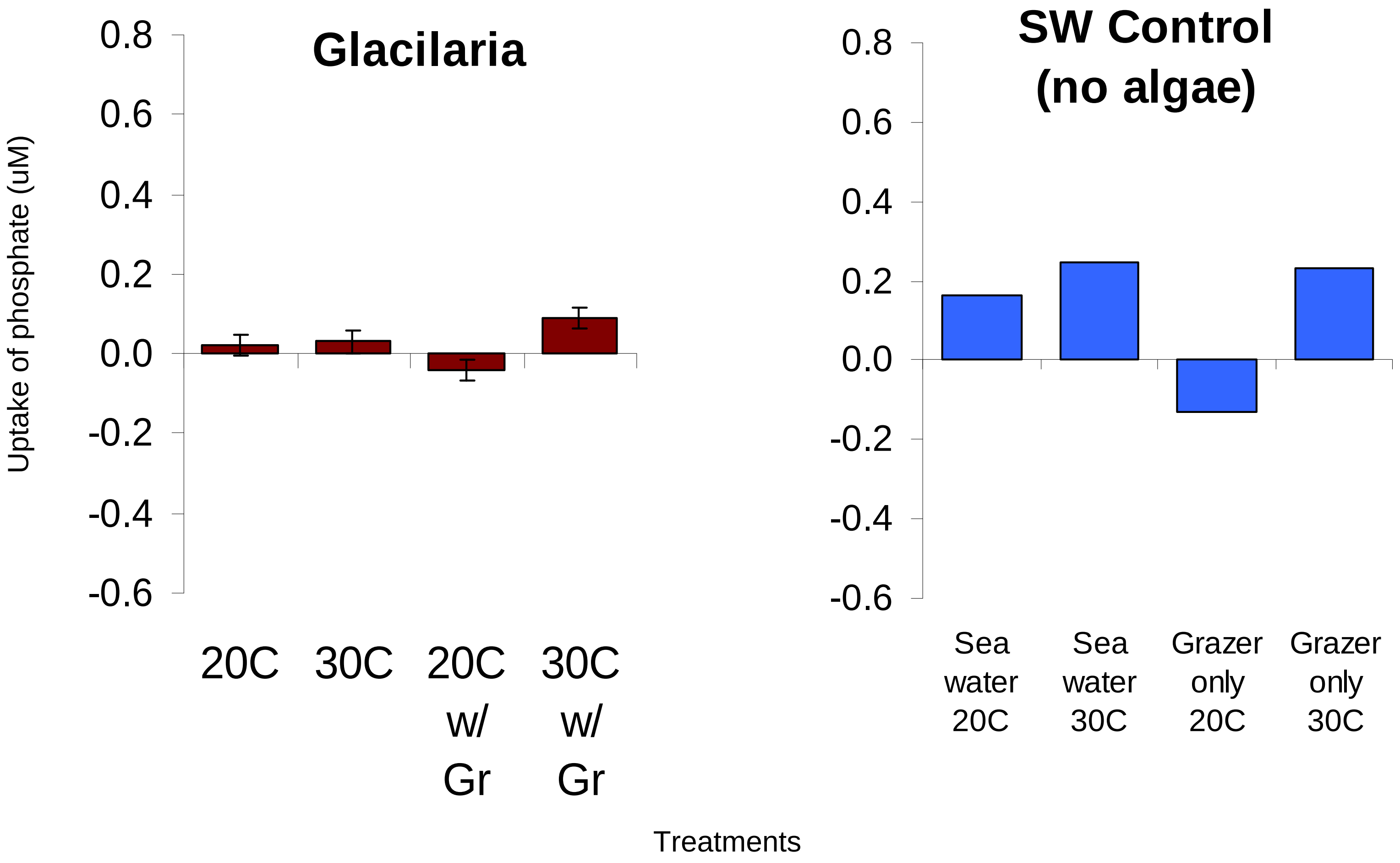
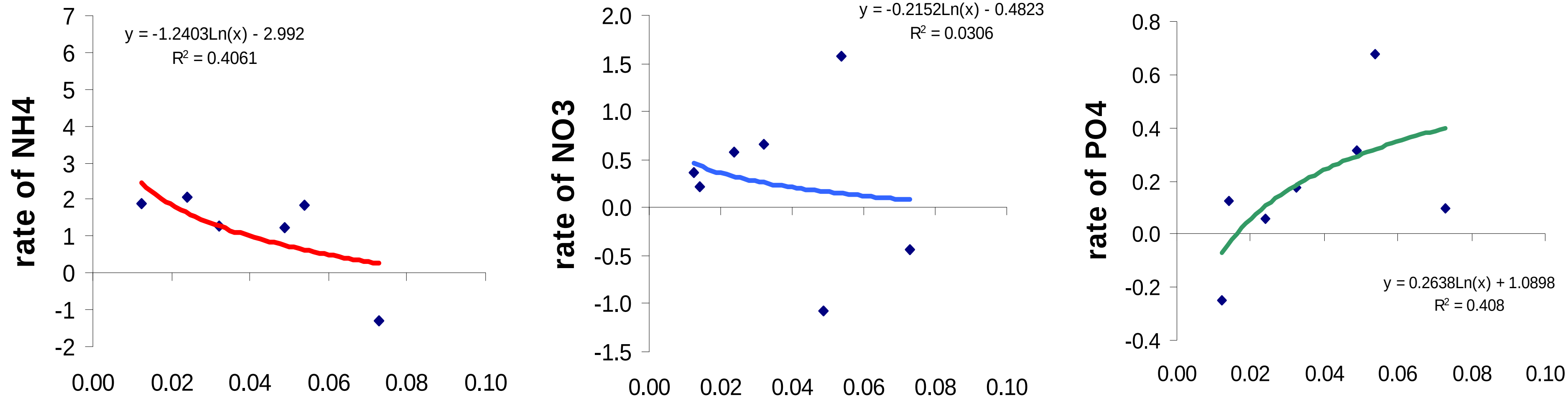


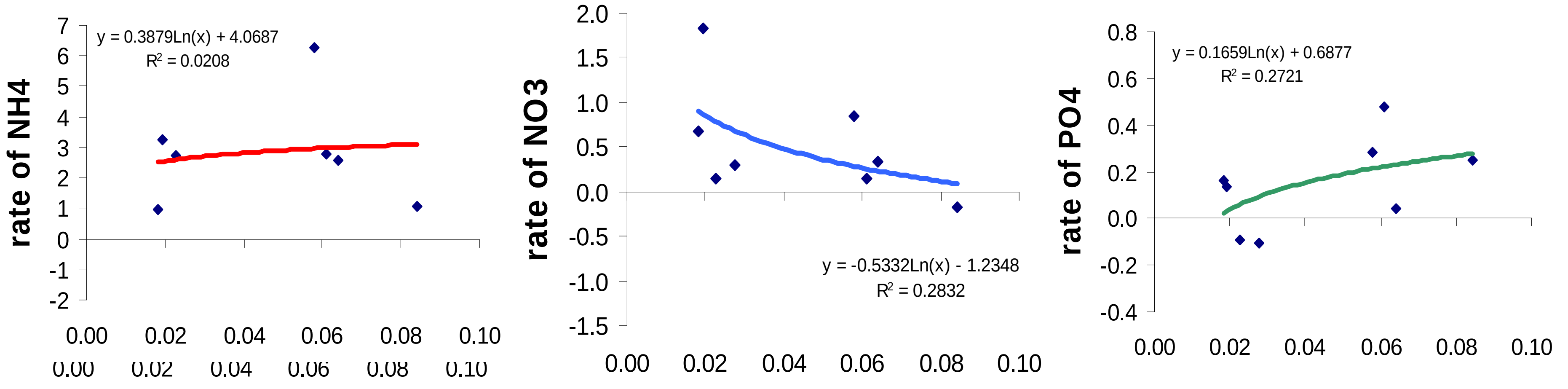
Figure 9: Rate of nutrient (uM) over rate of GPP (mg/L)

Algae



(uM)

Algae with grazers



Rate of GPP (mg/L)