GrowthResponses in the Marine Picocyanobacteria *Synechococcus*: A Multi Stressor Approach

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Background

- **Marine picocyanobacteria** are the most widely distributed group of photosynthetic prokaryotes on Earth, and contribute up to 50% of fixed C in the open ocean[1].
- **It is currently unknown how global change such as ocean acidification will impact picocyanobacteria on a global scale**.
- **Carbon dioxide (CO_2)** is one of the principal drivers of global change[2].
- While CO_2 concentration in the atmosphere is estimated to be about 270 ppm before the industrial revolution, it has currently increased to about **415 ppm** and is expected to reach **800–1000 ppm** by the end of this century according to the "business as usual" CO_2 emission scenario[3].
- Marine ecosystems are a major sink for atmospheric CO_2, currently accounting for the removal of one-quarter to one-third of anthropogenic CO_2 emissions from the atmosphere[4].
- The dissolution of anthropogenic CO_2 in the ocean and the subsequent formation of carbonic acid has already resulted in a 30% (0.1 pH unit) increase in seawater [H+] and will continue to lower pH by an additional 0.2-0.3 pH units by the end of the century. This decline in ocean pH is referred to as **ocean acidification**[5].
- At the same time, warming will increase the mean surface temperatures by an average of 3 °C, leading to longer periods of **stratification** with fewer deep mixing events[3] (Fig. 1).
- To date, most ocean acidification studies have focused on large-celled, bloom forming phytoplankton such as diatoms and coccolithopores, and there are **very few reports on picocyanobacteria**[6].

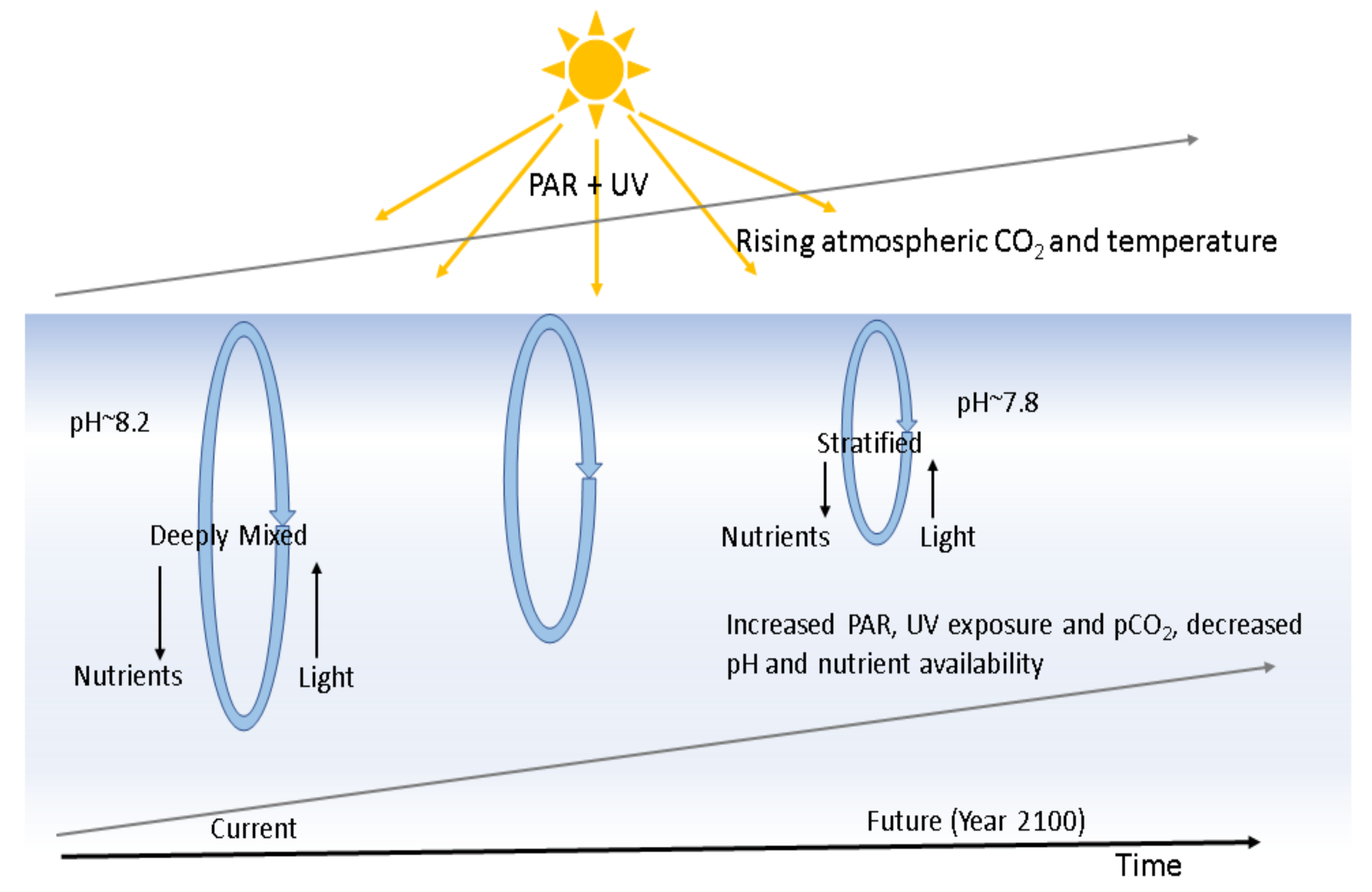


Figure 1. Global change effects on the surface ocean: By the year 2100, pH of the ocean will decline to 7.8 due to increased uptake of atmospheric CO_2. Concomitantly, increased thermal stratification will trap phytoplankton in the surface ocean, resulting in increased light exposure and lower nutrient availability to the cells[3].

Methods

- The *Synechococcus* strain **WH 8109** (previously isolated from northwestern Atlantic Ocean slope water) was used in this study.
- Cultures of WH 8109 were maintained in dilute, semi-continuous batch culture in a temperature controlled growth chamber (22 °C) under continuous white light.
- The culture media consisted of 75% coastal seawater and 25% MilliQ water with SN nutrient amendments[7].
- Cultures were grown at three different temperatures (**22 °C**, **24 °C** and **26 °C**) and three CO_2 levels (**400 ppm**, **600 pp**m and **800 ppm**) simultaneously (Fig. 2a).
- A constant light intensity of 20 µE m^{-2} s^{-1} was maintained during the experiments.
- Growth was monitored via measurement of **raw fluorescence** on the Turner fluorometer (**Turner Designs Trilogy**).
- Specific growth rates μ (d^{-1}) were calculated using two time points from within the exponential phase of the growth curve using the following equation:

$$\mu = \frac{\ln(X_1/X_0)}{t_1 - t_0}$$

(Where X_1 and X_0 are the fluorescence values obtained on the days t_1 and t_0 respectively).

- The photochemical efficiency of PS II in the dark adapted state (F_v/F_m) and the functional absorption cross section of PSII in the dark adapted state (σ_{PSII}) were monitored on a FIRe fluorometer.
- The daily changes in the medium pH were also monitored.

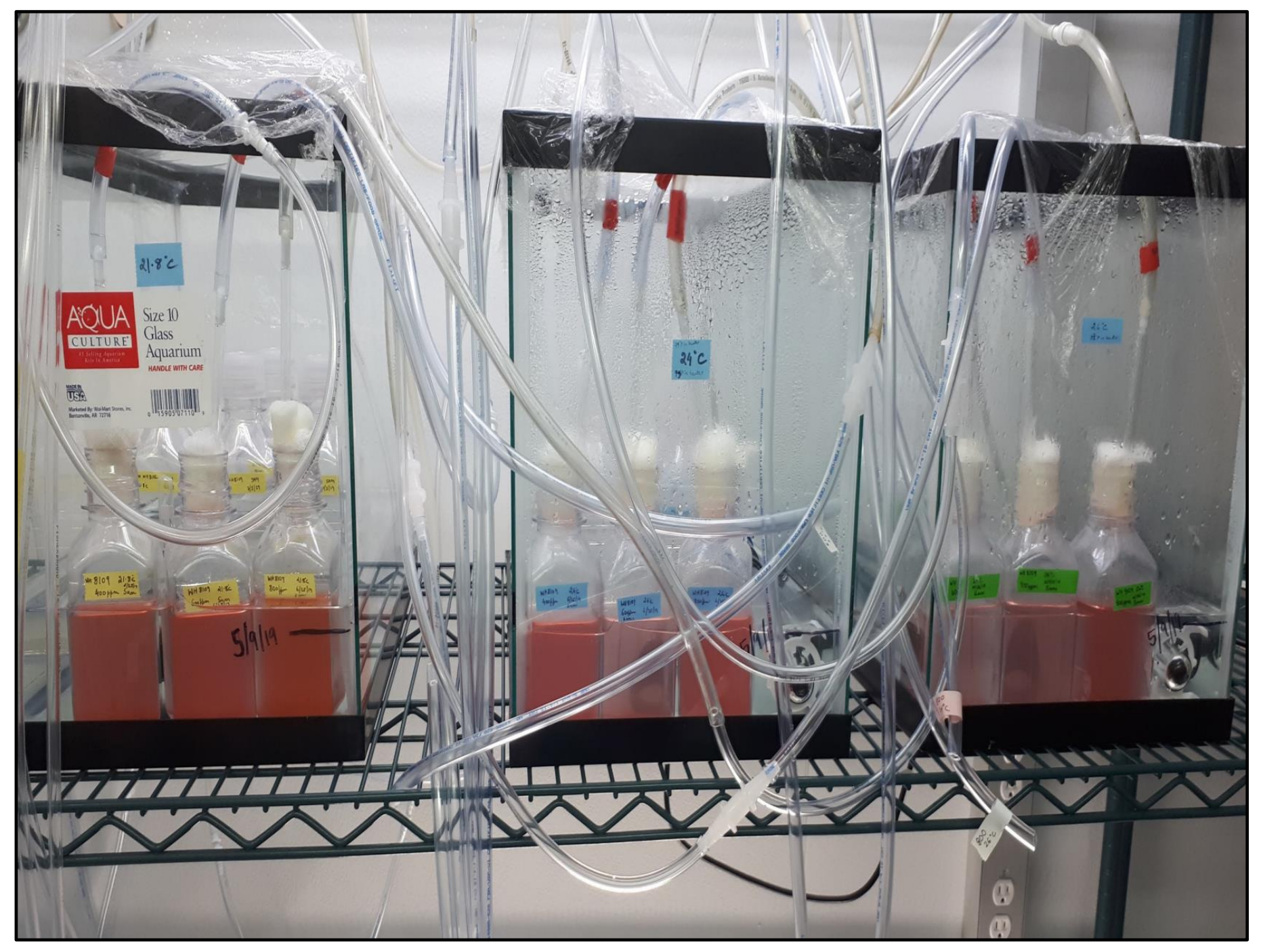


Figure 2a. Experimental set up consisting of 3 glass tanks with temperature controlled water for culturing *Synechococcus* WH8109 under 3 different temperature and CO_2 levels.

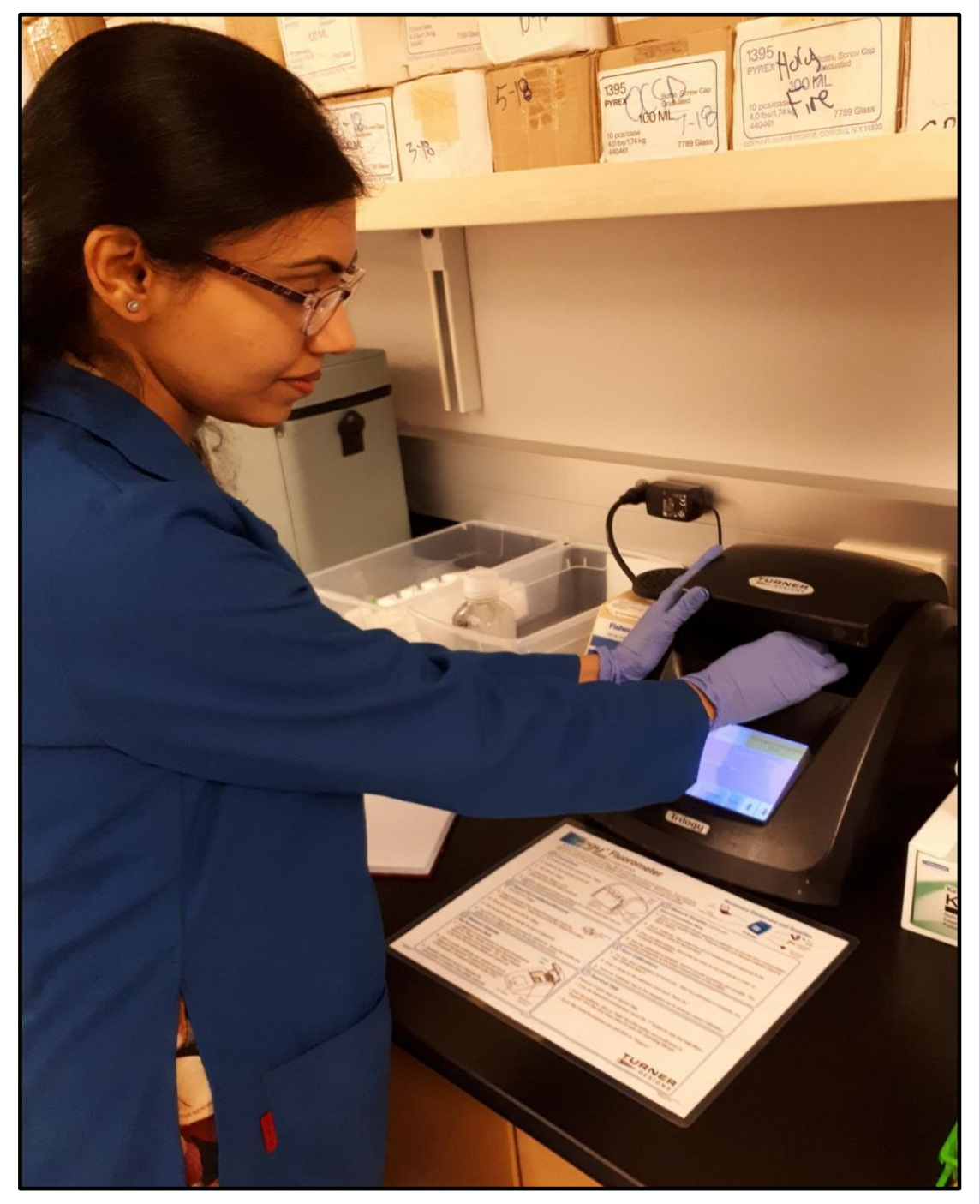


Figure 2b. Raw fluorescence measurement conducted on Turner Designs Trilogy Laboratory Fluorometer.

Results

Fig. 3a

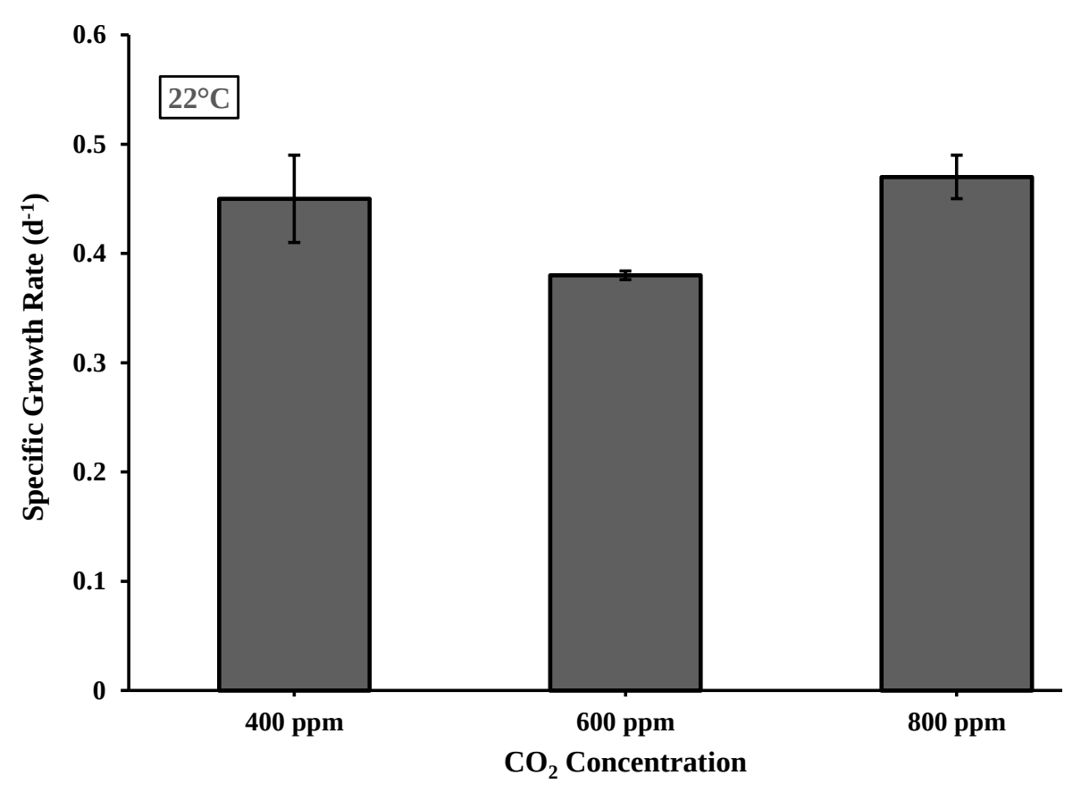


Fig. 3b

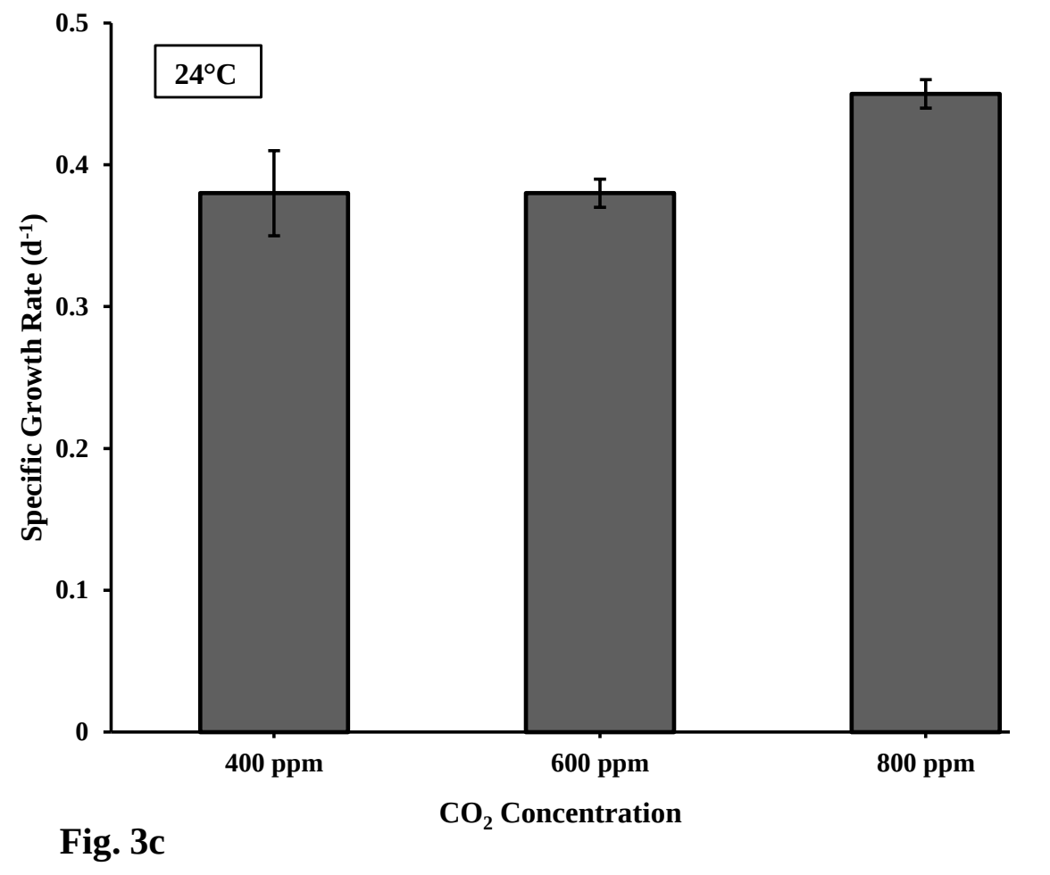
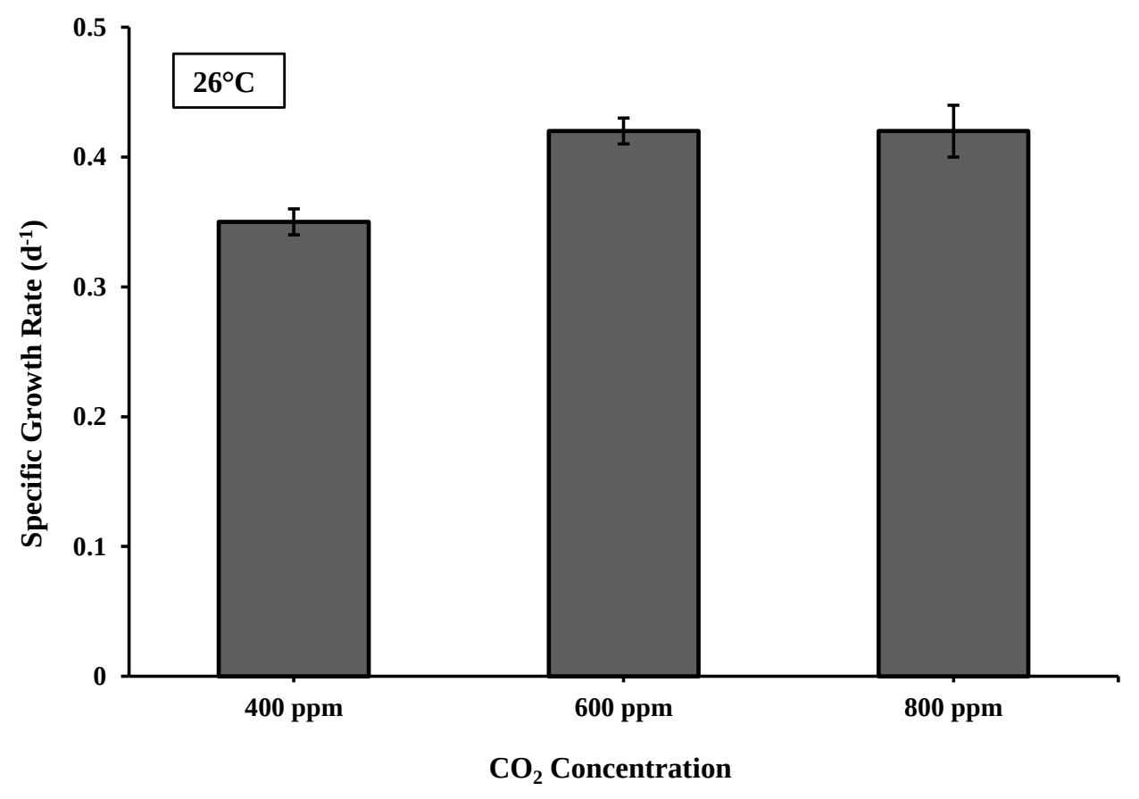


Fig. 3c



Specific growth rates of *Synechococcus* WH8109 incubated at 22 °C (Fig. 3a), 24 °C (Fig. 3b) and 26 °C (Fig. 3c) under varying CO_2 concentrations.

Fig. 4a

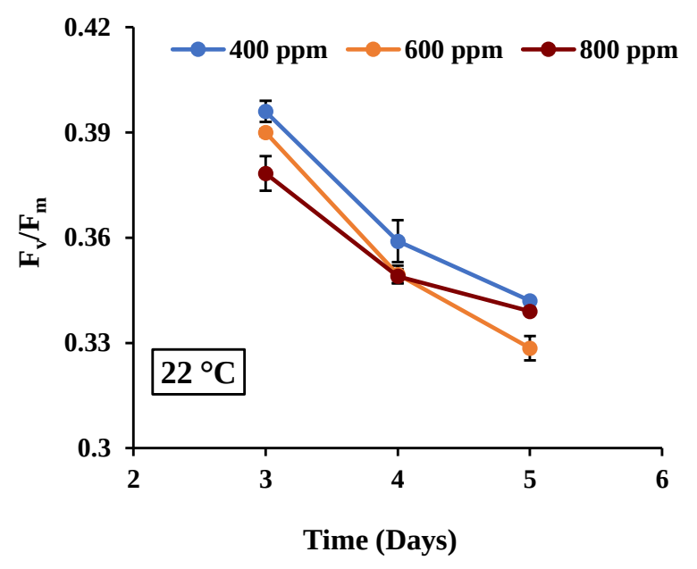


Fig. 4b

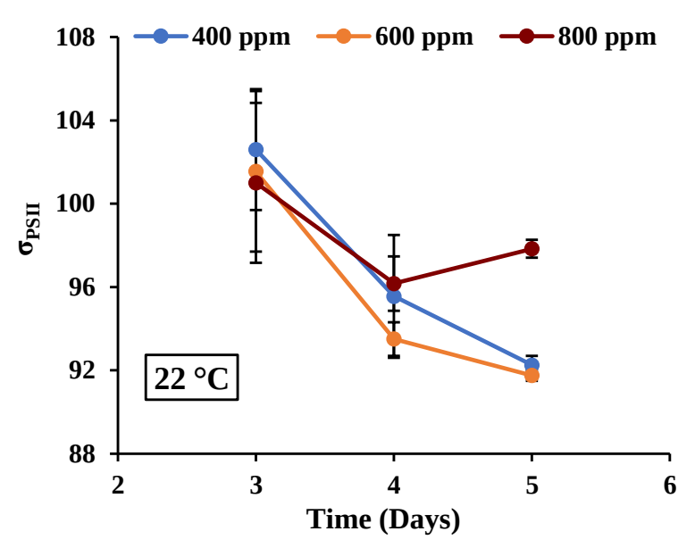


Fig. 5a

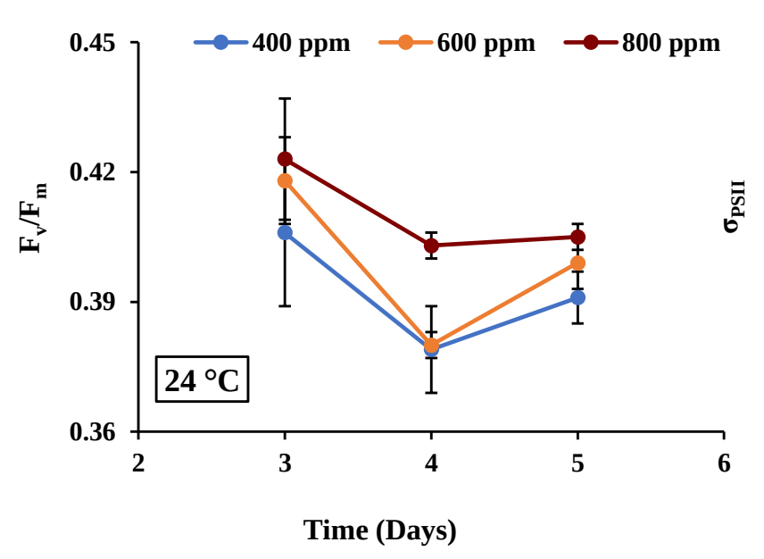


Fig. 5b

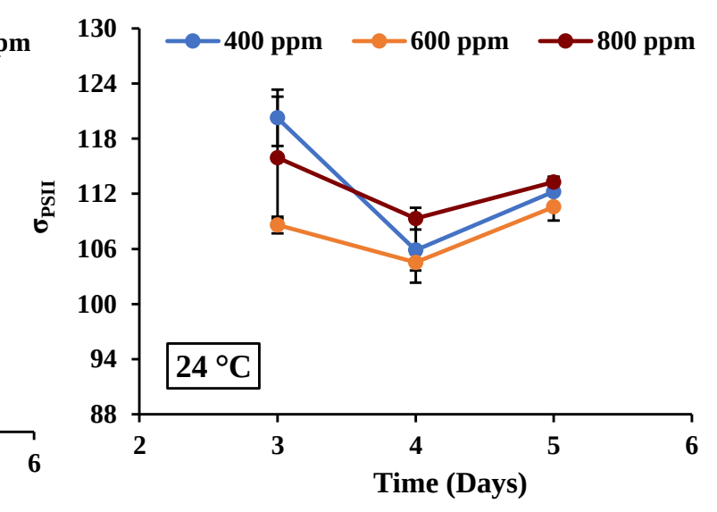


Fig. 6a

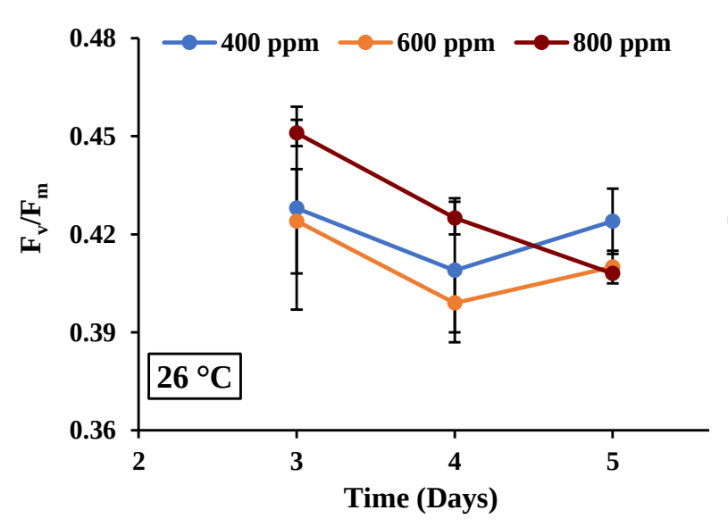
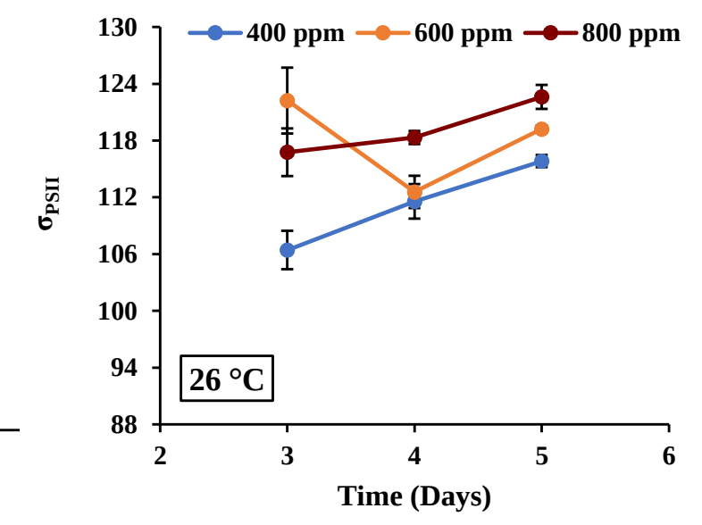


Fig. 6b



F_v/F_m values of *Synechococcus* WH8109 incubated at 22 °C (Fig. 4a), 24 °C (Fig. 5a) and 26 °C (Fig. 6a) under varying CO_2 concentrations, and **σ_{PSII}** values of *Synechococcus* WH8109 incubated at 22 °C (Fig. 4b), 24 °C (Fig. 5b) and 26 °C (Fig. 6b) under varying CO_2 concentrations.

Conclusions

- The highest specific growth rate of 0.47 d^{-1} was observed at 22 °C and 800 ppm CO_2 concentration.
- Doubled CO_2 concentration of 800 ppm resulted in higher specific growth rates in *Synechococcus* strain WH 8109 under all the three temperature treatments.
- The values of photochemical efficiency of PS II in the dark adapted state (F_v/F_m) for *Synechococcus* strain WH 8109 remained at or near maximal levels at 26 °C.
- Therefore, increased CO_2 availability combined with higher temperatures may benefit the picocyanobacteria *Synechococcus*, resulting in their dominance in the future ocean.
- However, because individual picocyanobacteria strains may respond differently to future CO_2 and temperature increases, further investigation with additional strains is required prior to generalizing their responses to global change.

Acknowledgements

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References

1. Fu, F. X., Warner, M. E., Zhang, Y., Feng, Y., & Hutchins, D. A. Effects of Increased temperature and CO_2 on photosynthesis, growth, and elemental ratios in marine *Synechococcus* and *Prochlorococcus* (cyanobacteria). Journal of Phycology **2007**, 43(3), 485-496.
2. Lam, M.K.; Lee, K.T.; Mohamed, A.R. Current status and challenges on microalgae-based carbon capture. International Journal of Greenhouse Gas Control **2012**, 10, 456–469.
3. Basu, S.; Mackey, K. R. M. Phytoplankton as key mediators of the biological carbon pump: Their responses to a changing climate. Sustainability **2018**, 10, 869.
4. Li,W.; Gao, K.S.; Beardall, J. Interactive effects of ocean acidification and nitrogen-limitation on the diatom *Phaeodactylum tricornutum*. PLoS ONE **2012**, 7, e51590.
5. Bhadury, P. Effects of ocean acidification on marine invertebrates-a review. Indian Journal of Geo-Marine Sciences **2015**, 44(4), 1-11.
6. Mackey, K. R., Morris, J. J., Morel, F. M., & Kranz, S. A. Response of photosynthesis to ocean acidification. Oceanography **2015**, 28(2), 74-91.
7. Waterbury, J.B., Watson, S.W., Valois, F.W., and Franks, D.G. Biological and ecological characterization of the marine unicellular cyanobacterium *Synechococcus*. Can Bull Fish Aquat Sci **1986**, 214: 120.