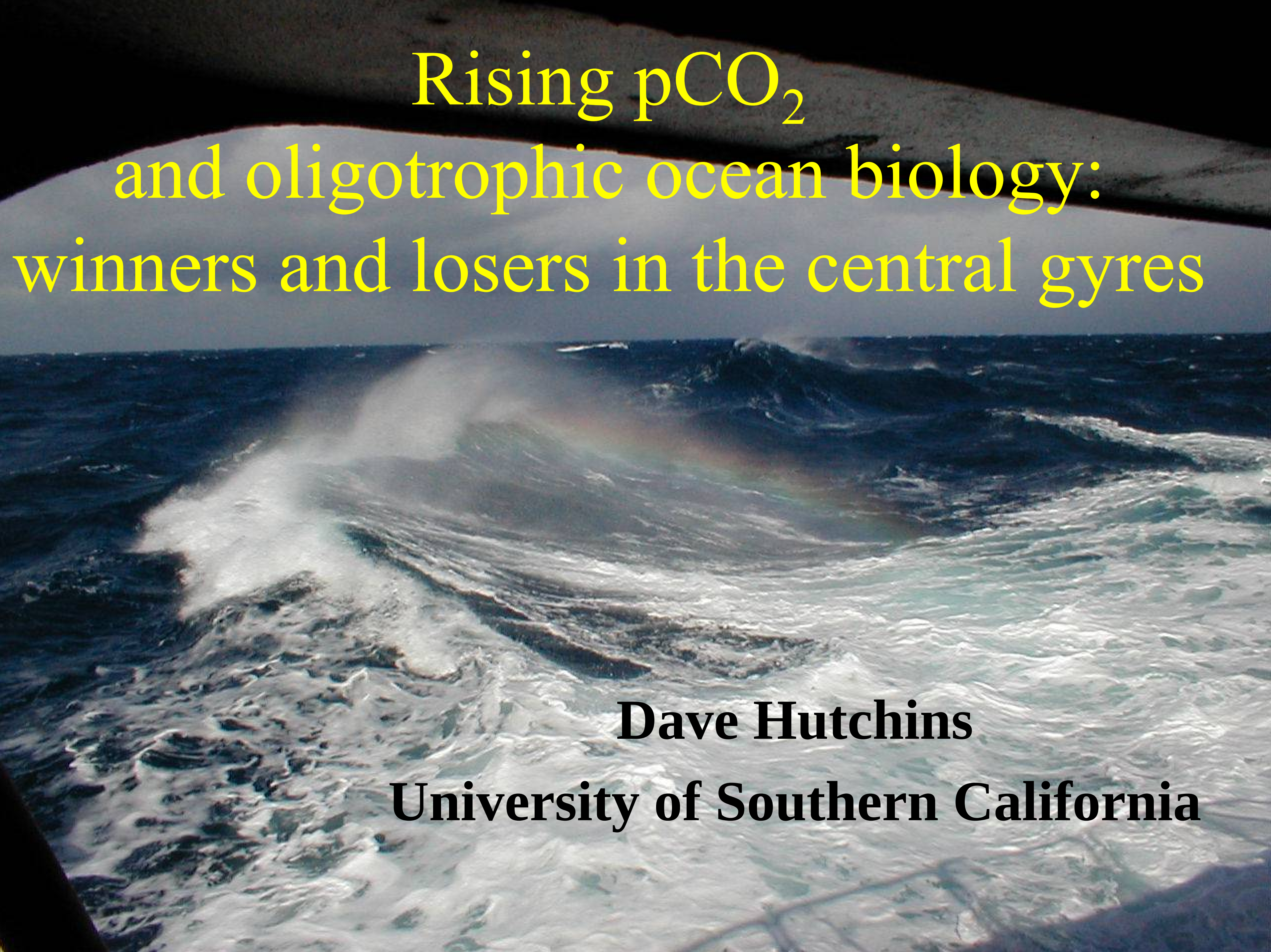
Rising pCO_2 and oligotrophic ocean biology: winners and losers in the central gyres



Dave Hutchins

University of Southern California

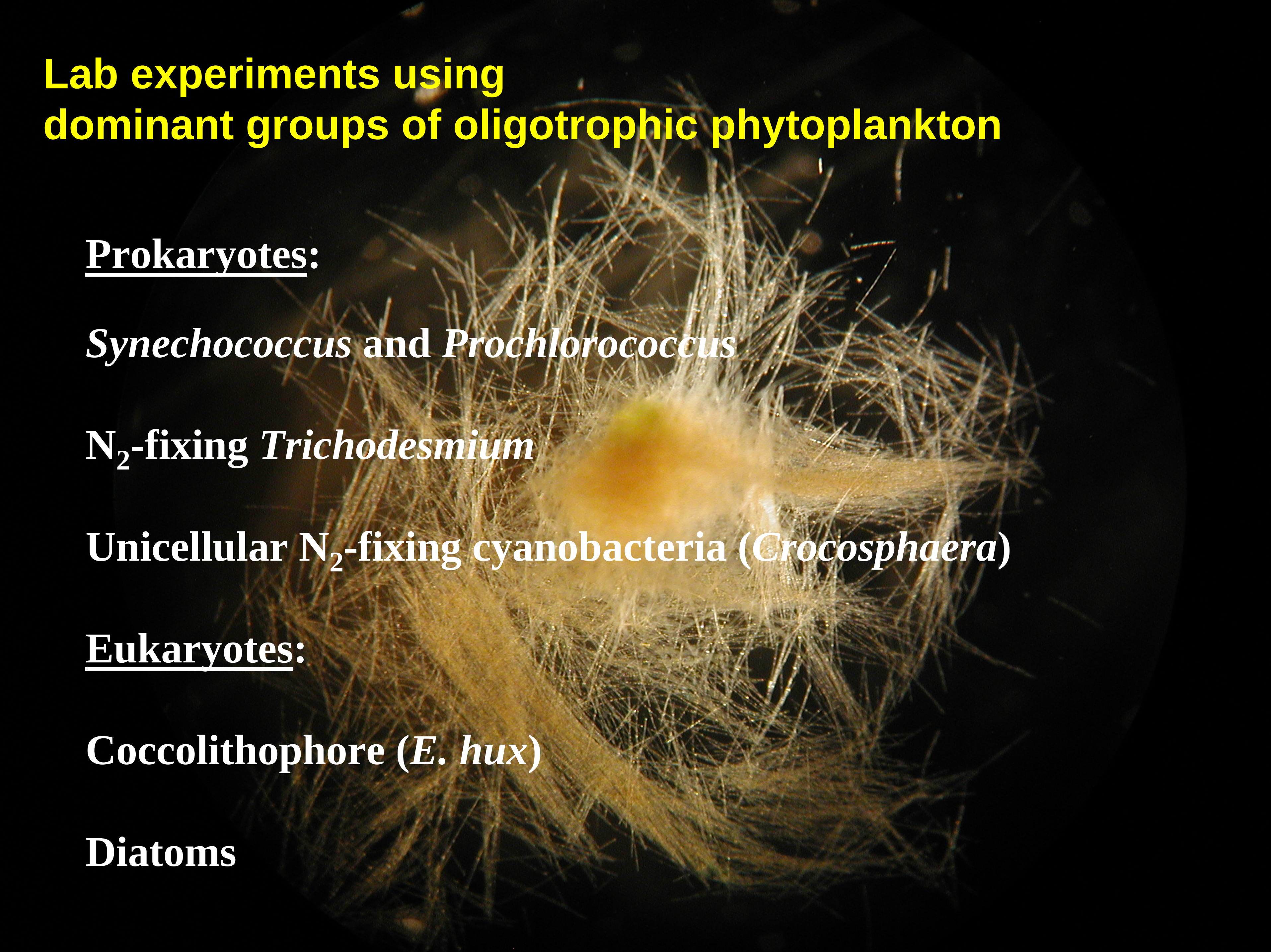
Approaches to understanding rising pCO_2 impacts on ocean biology

1. **Laboratory experiments using cultures of major algal functional groups**

2. **Shipboard continuous culture experiments using natural phytoplankton communities in the North Atlantic spring bloom, the Bering Sea, and the Ross Sea.**

3. **Interactions between changing pCO_2 and other global change co-variables, including temperature, nutrients, light, and Fe.**

Lab experiments using dominant groups of oligotrophic phytoplankton



Prokaryotes:

Synechococcus and *Prochlorococcus*

N_2-fixing *Trichodesmium*

Unicellular N_2-fixing cyanobacteria (*Crocosphaera*)

Eukaryotes:

Coccolithophore (*E. hux*)

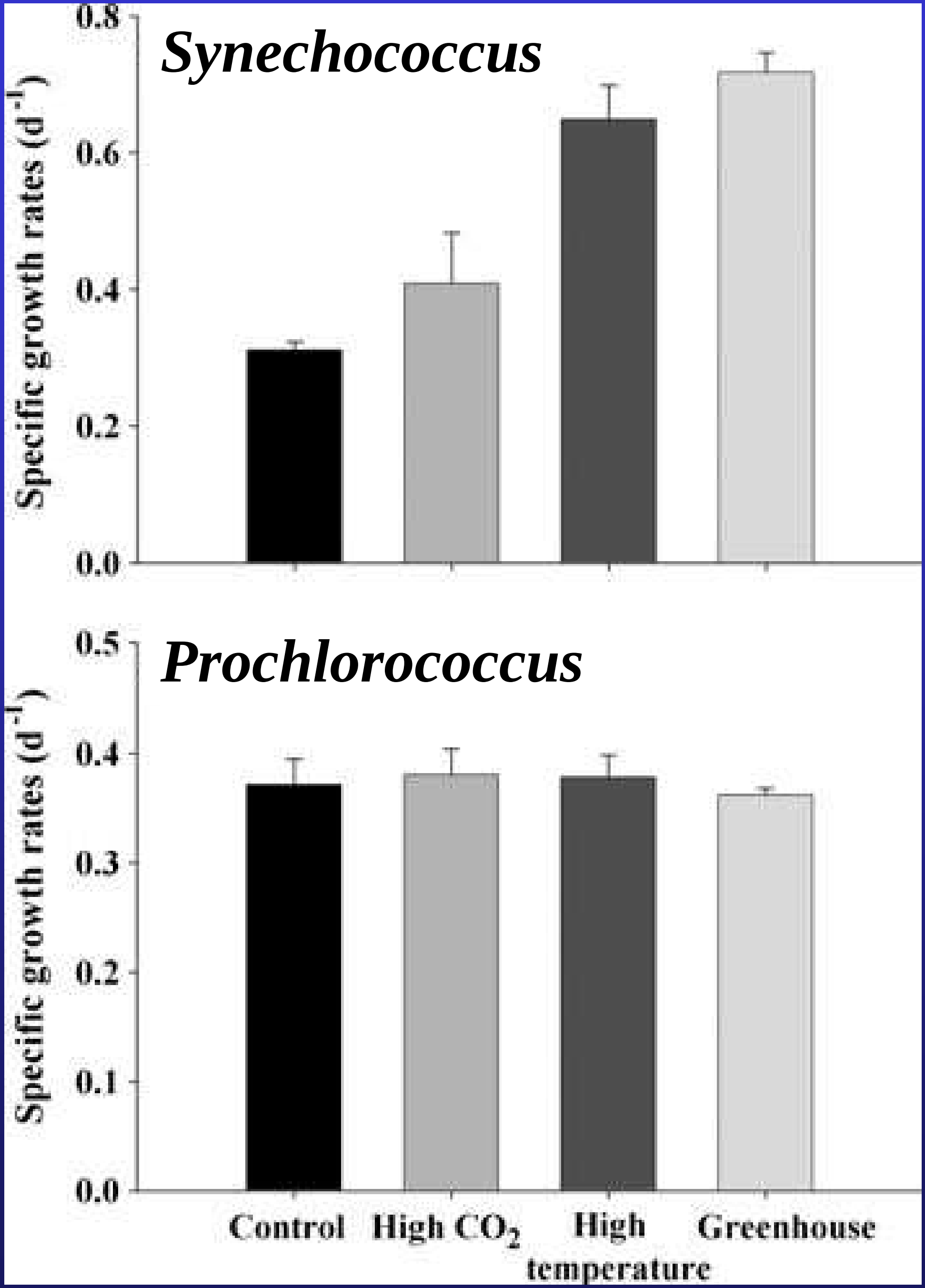
Diatoms

Interactions between CO_2 and temperature: A factorial experimental design

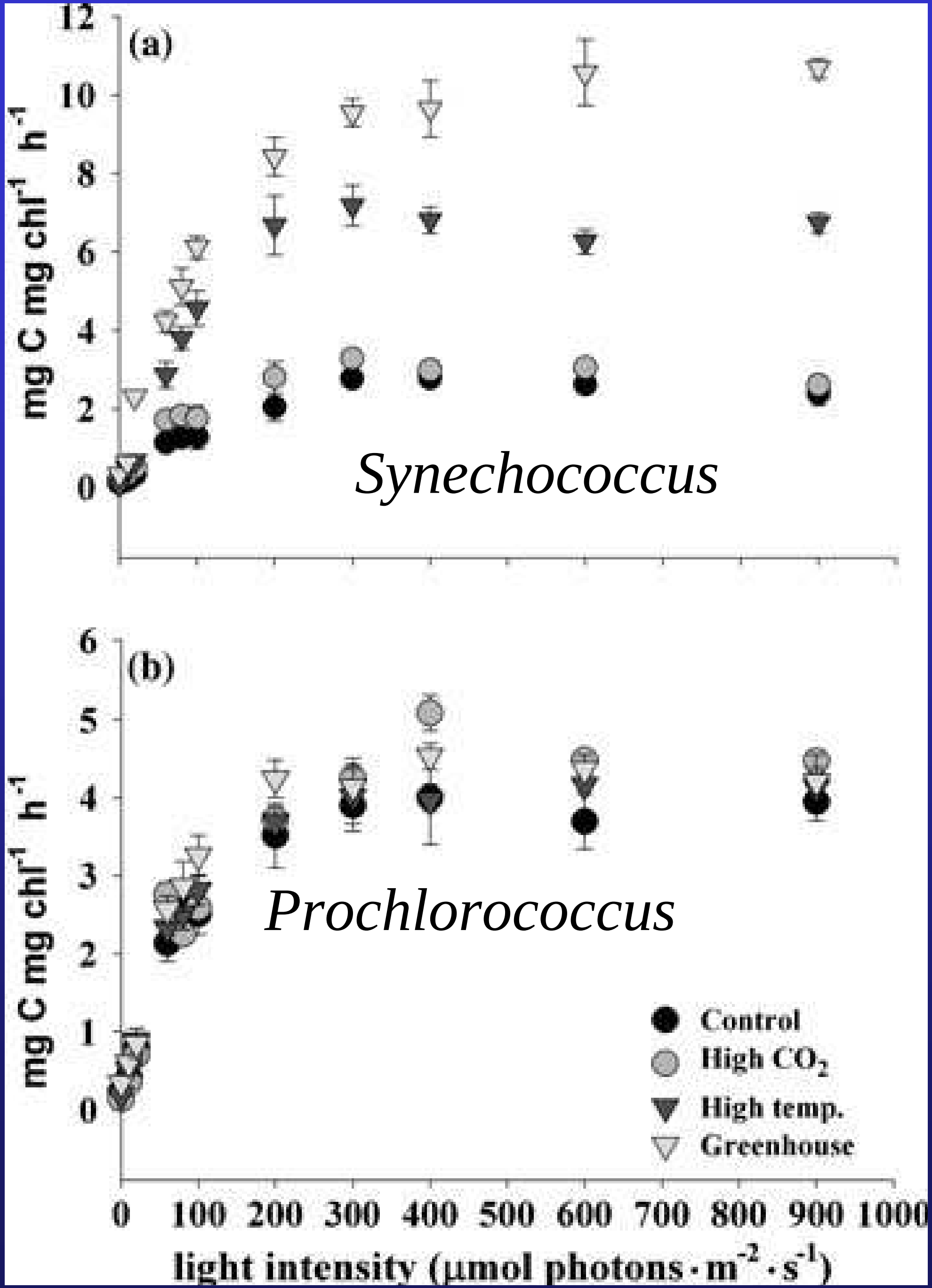
- **Control:** **Present day temperature and pCO_2**
- **High pCO_2:** **Present day temperature and 750 ppm CO_2**
- **High Temperature:** **+3-5^{o}C and present day pCO_2**
- **Greenhouse:** **+3-5^{o}C and 750 ppm CO_2**

Combined pCO_2 and temperature effects on growth rates of picocyanobacteria

(Fu et al. 2007, J. Phycol. 43)



Photosynthesis versus irradiance curves: Different responses of *Synechococcus* and *Prochlorococcus* to elevated pCO_2 and temperature (Fu et al. 2007, J. Phycol. 43)

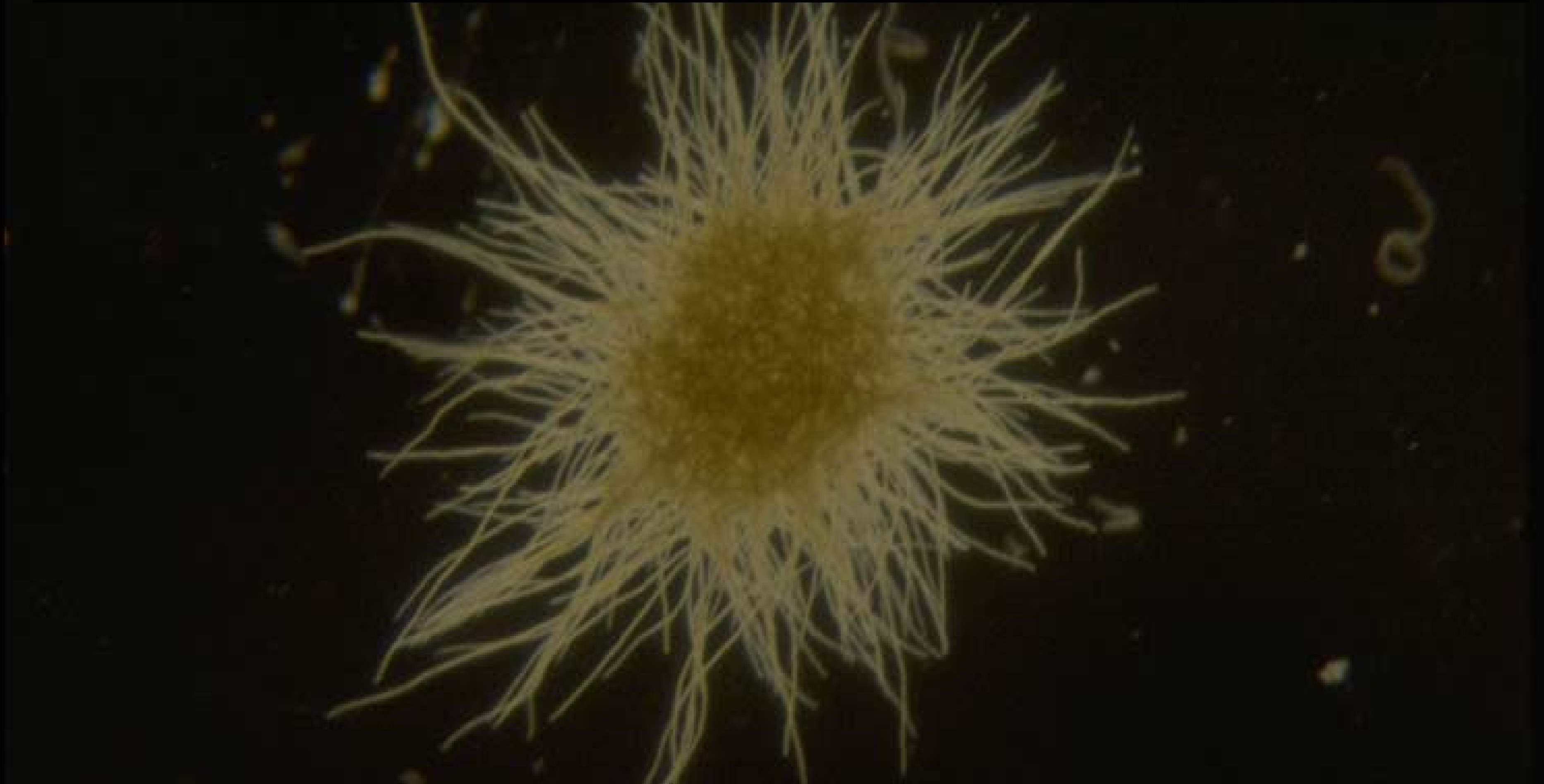


-- *Synechococcus* CCMP1334 photosynthesis, growth and elemental ratios are all responsive to changing pCO_2 and temperature

--*Prochlorococcus* CCMP1986 physiology is relatively unaffected by these variables

Individual picocyanobacteria groups will respond in very different ways to increasing pCO_2 and temperature- beware of overgeneralizing!

How does *Trichodesmium* growth and nitrogen fixation respond to changing pCO_2?



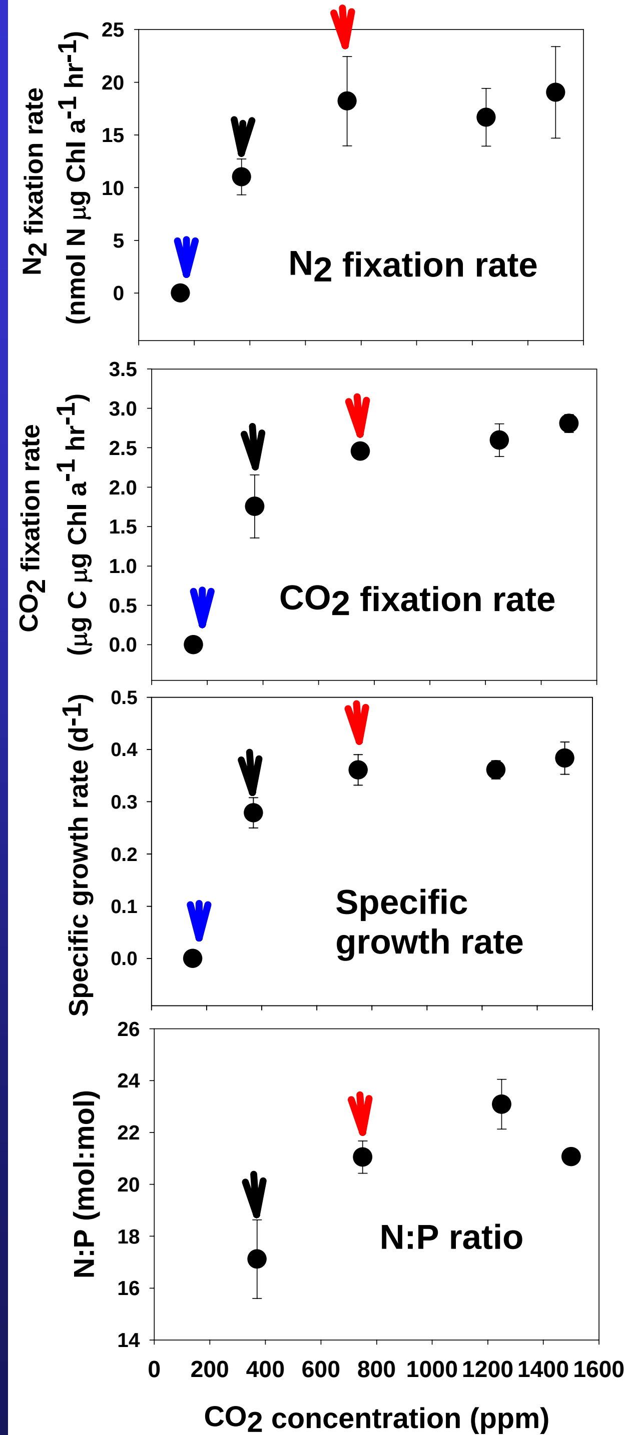
***Trichodesmium erythraeum* strain GBR cultured at a range of pCO_2 : 150, 380, 750, 1250 and 1500 ppm**

CO_2 limitation of *Trichodesmium*

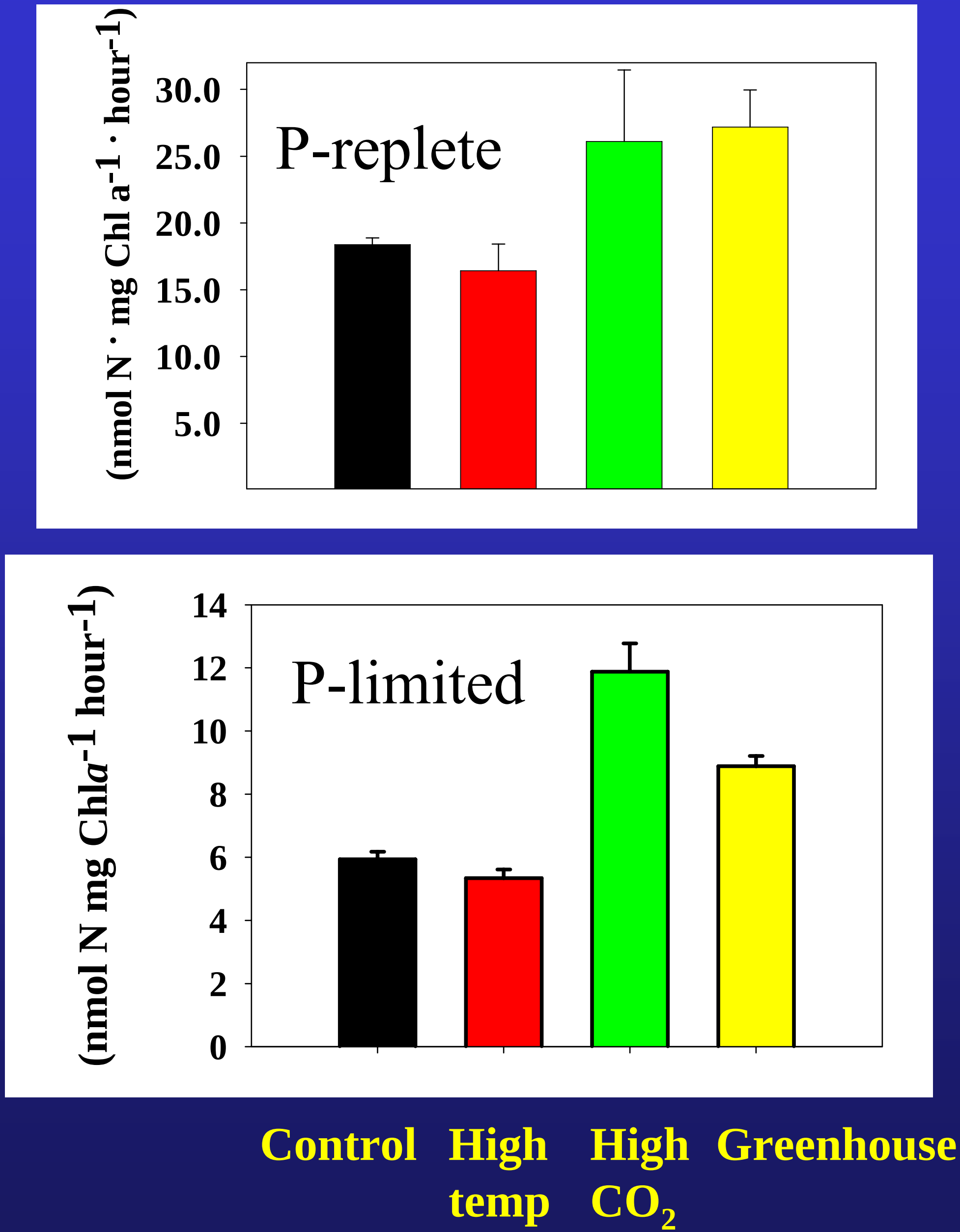
- Last glacial maximum pCO_2 (~190 ppm)
- Present day pCO_2 (380 ppm)
- Year 2100 pCO_2 (~750 ppm)

1. N_2 fixation rates increase by 63% between 380 and 750 ppm pCO_2
2. CO_2 fixation rates increase by 54% between 380 and 750 ppm pCO_2
3. Specific growth rates increase by 37% between 380 and 750 ppm pCO_2
4. *Trichodesmium* was unable to grow at all at a pCO_2 of 150 ppm
5. N:P (and C:P) ratios increase by 35% between 380 ppm and 1250 ppm CO_2

(Hutchins et al. 2007, L&O 52(4): 1293- 1304)



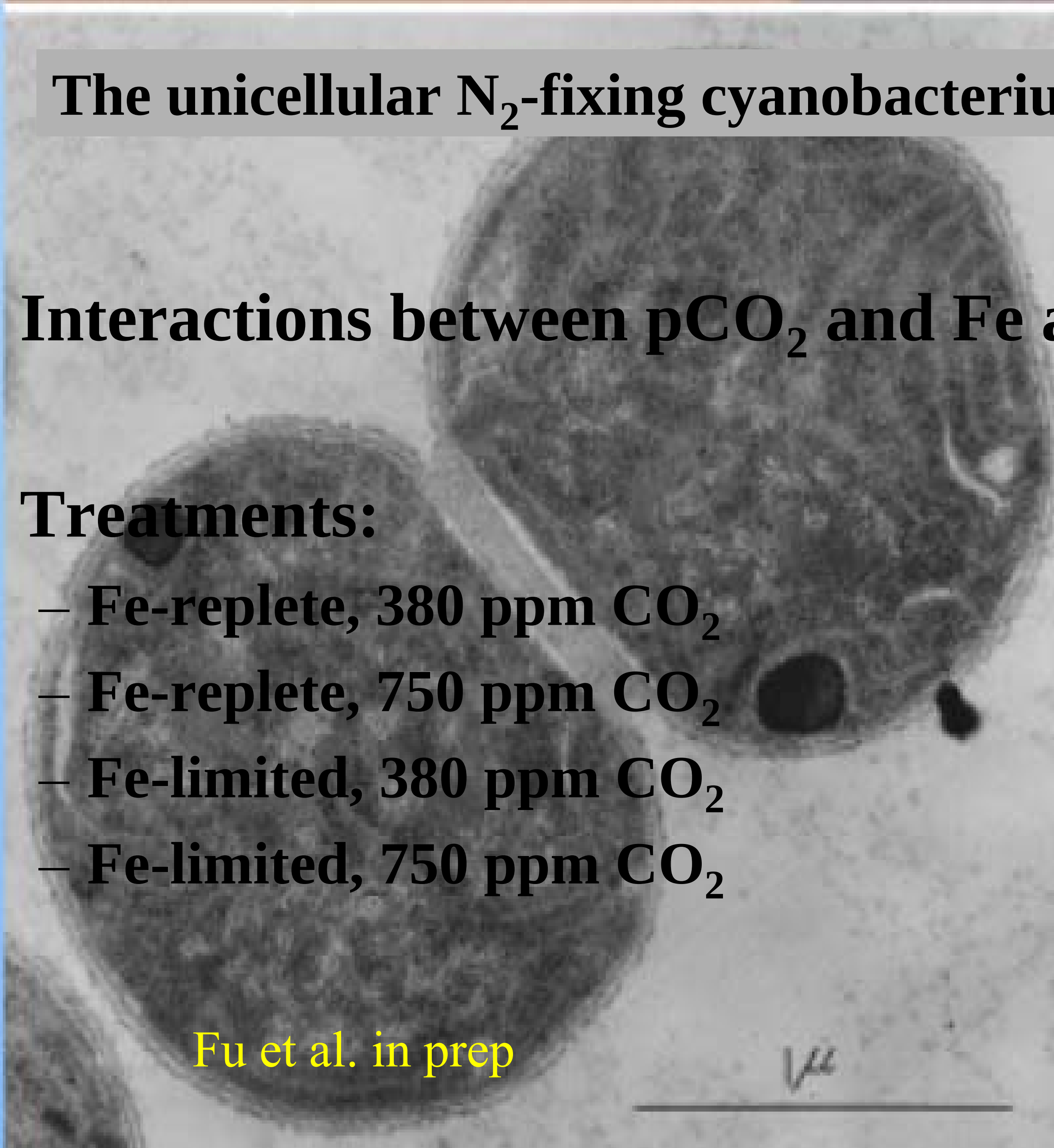
pCO_2 and P co-limitation of *Trichodesmium* N_2 fixation

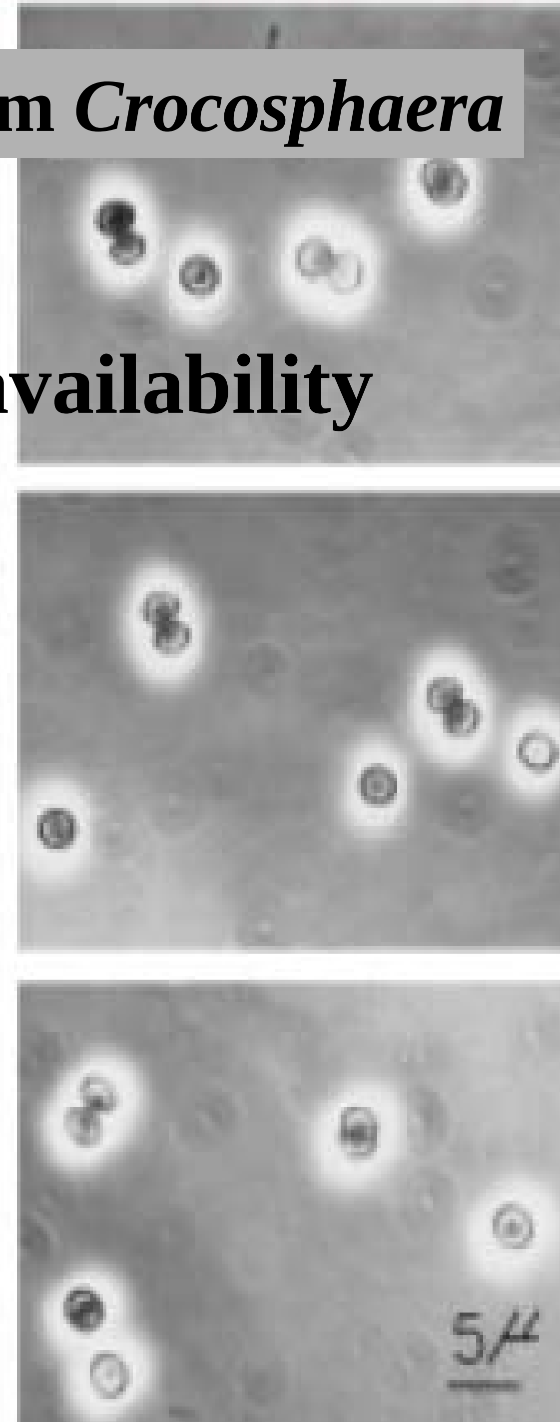


Adding <u>either</u> P or CO_2 increases N_2 fixation and growth rates of P-limited cultures at present day pCO_2

(Hutchins et al. 2007, L&O 52)

The unicellular N_2-fixing cyanobacterium *Crocosphaera*





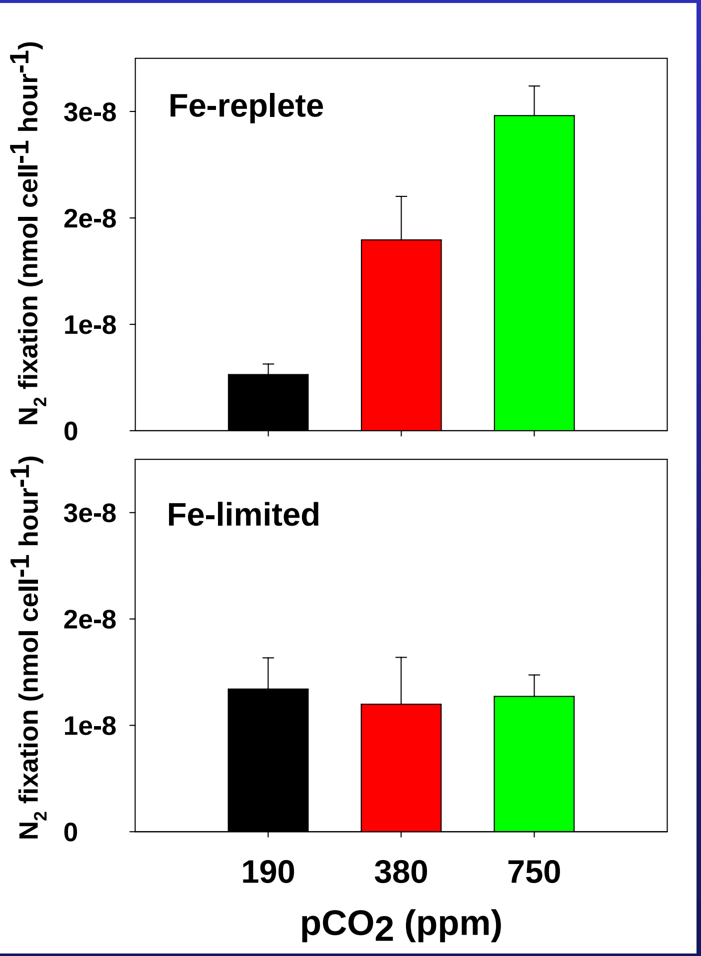
Interactions between pCO_2 and Fe availability

Treatments:

- Fe-replete, 380 ppm CO_2
- Fe-replete, 750 ppm CO_2
- Fe-limited, 380 ppm CO_2
- Fe-limited, 750 ppm CO_2

Fu et al. in prep

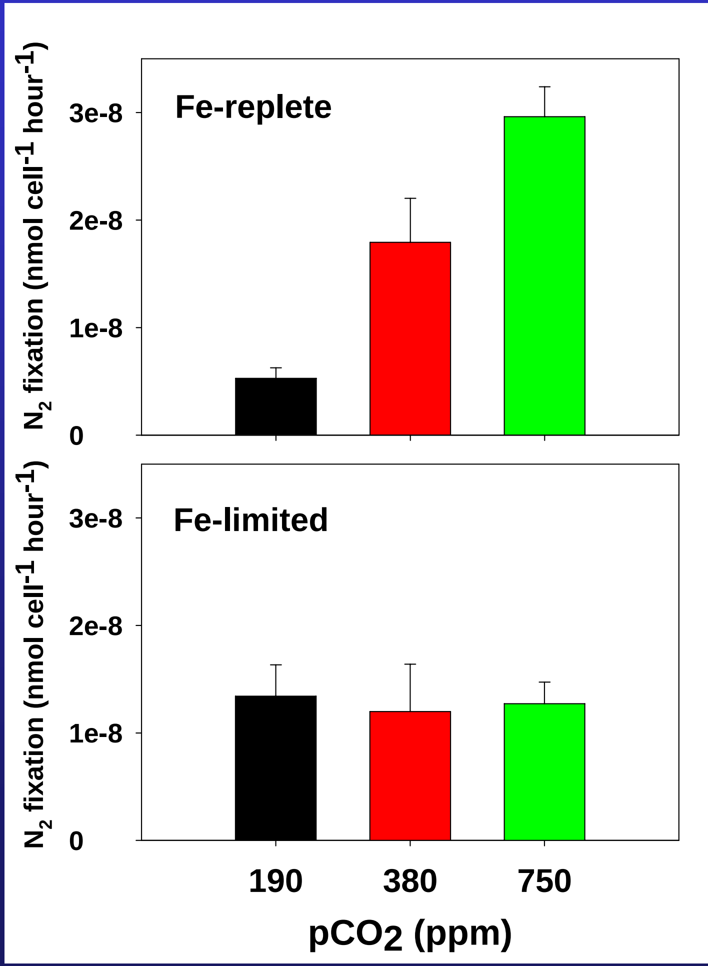
pCO_2 effects on N_2 fixation rates of Fe-replete and Fe-limited *Crocosphaera*



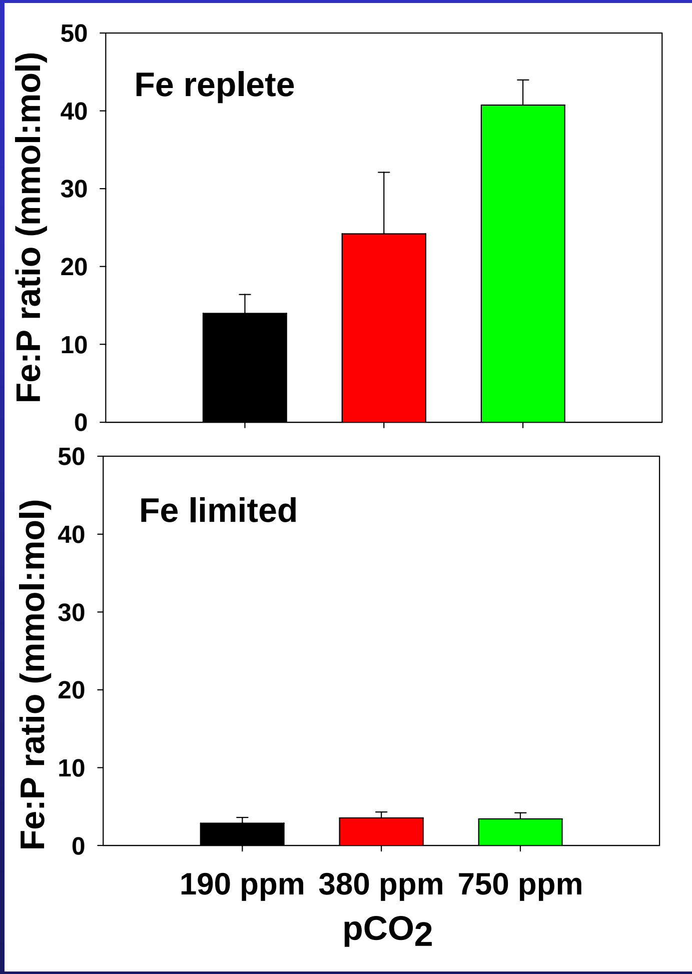
Fu et al. in prep

Crocosphaera

N_2 fixation rates



Cellular Fe quota



Fu et al. in prep

Crocosphaera:

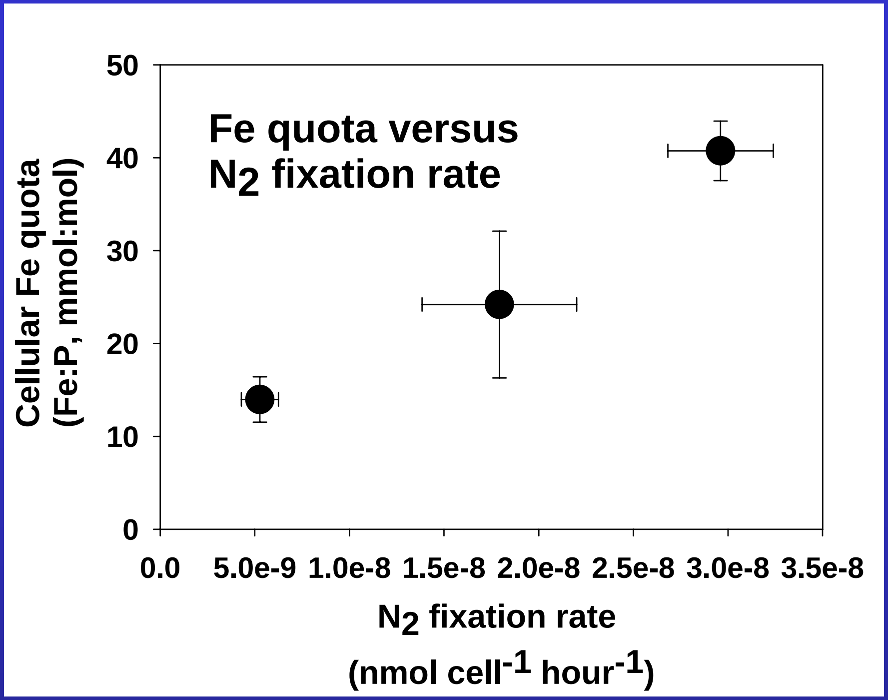
pCO_2

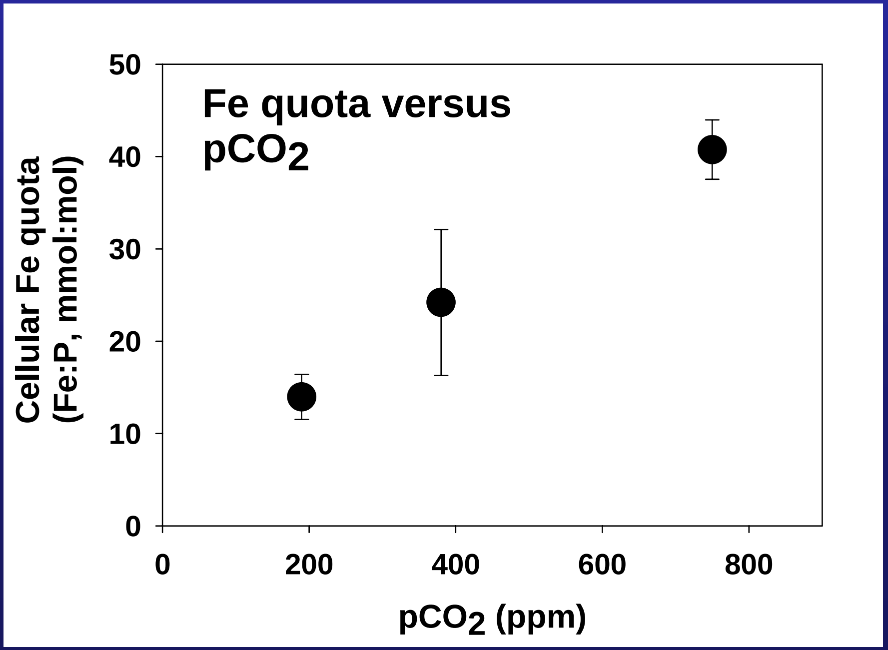
↓

N_2 fixation

↓

Fe quota

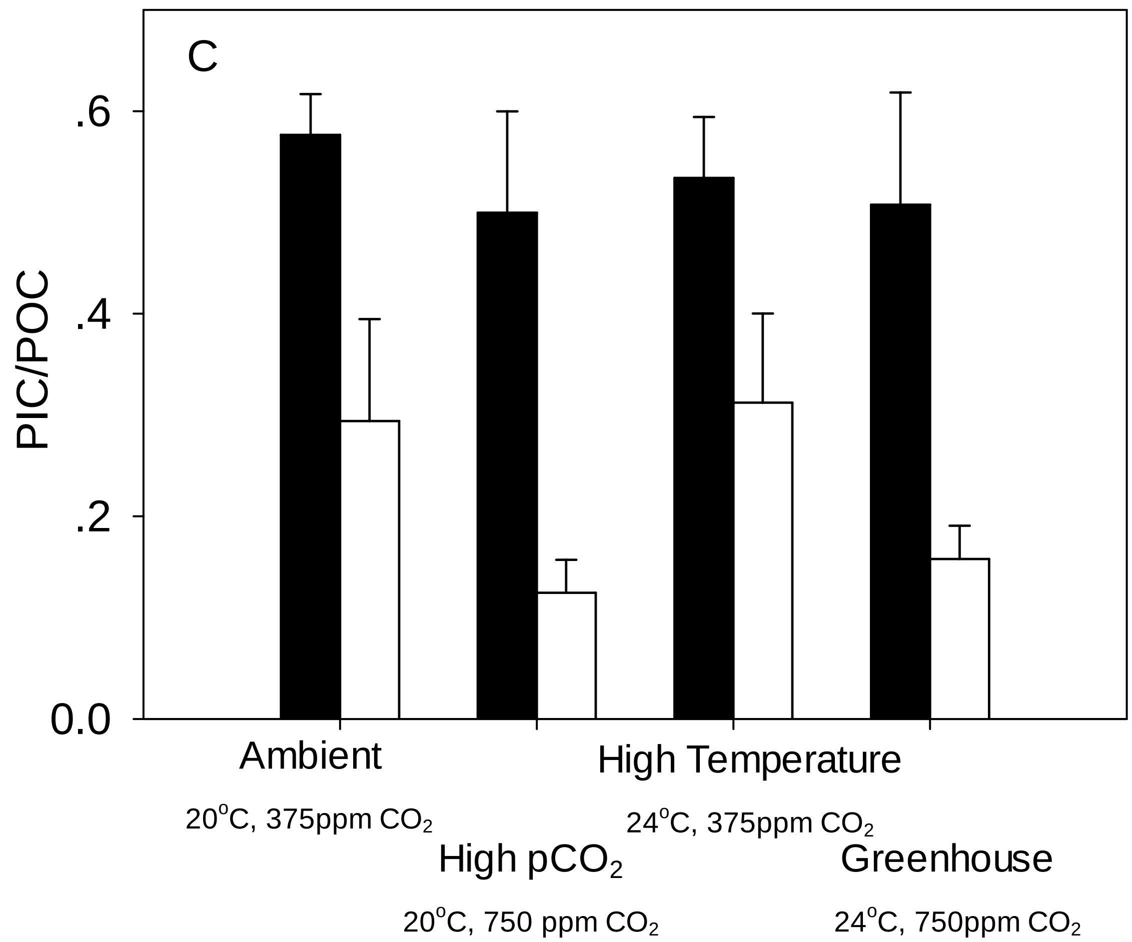




Biogeochemical Implications

- Global marine N_2 fixation could increase dramatically (~50%?) with doubled pCO_2 over the next 100 years.
- CO_2-mediated increases in N:P ratios may drive oligotrophic regimes further towards P limitation. Elevated Fe requirements may drive diazotrophs further towards Fe limitation as well.
- Rising CO_2 thus directly impacts the N cycle by increasing new N supply from N_2 fixation, and thereby also indirectly controls both P and Fe biogeochemistry.

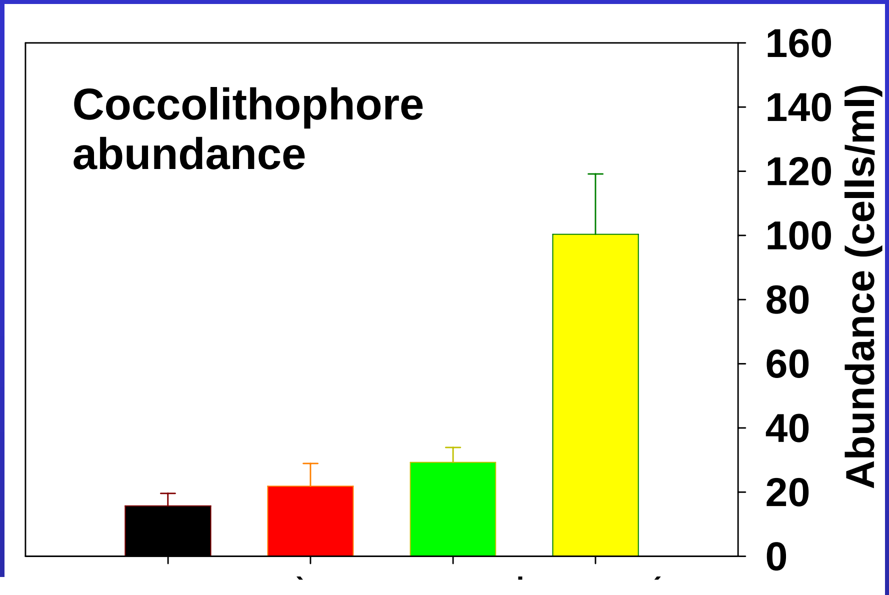
Interactive effects of light, temperature and pCO_2 on calcification by a Sargasso Sea *E. hux*. isolate

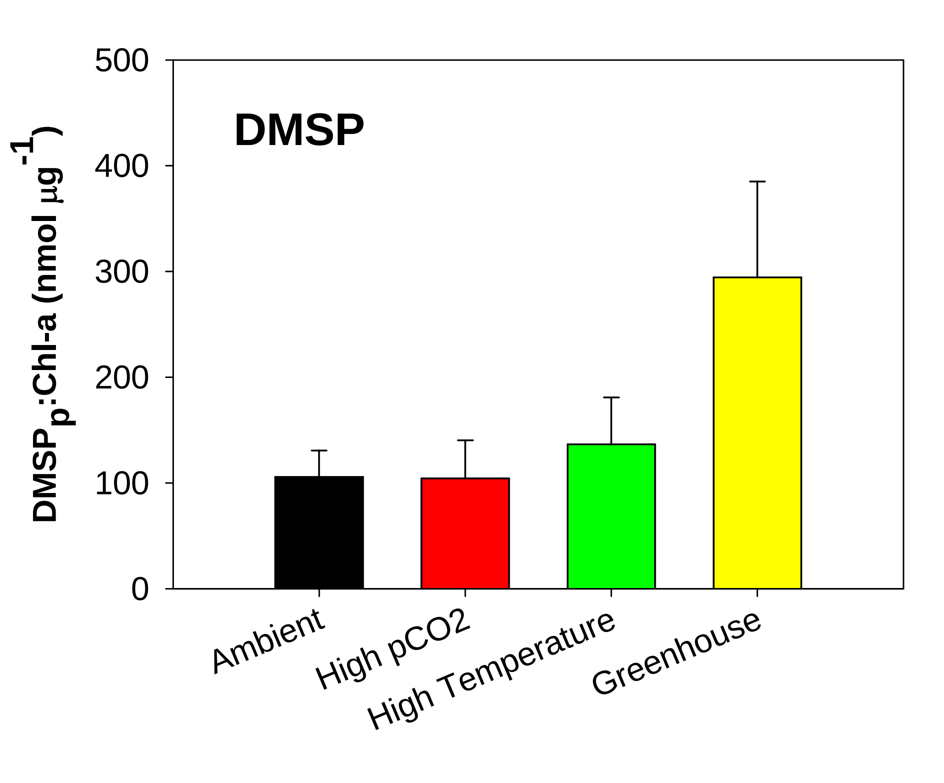


Feng et al. in press, European Journal of Phycology

The primary control on calcification in this strain is light intensity- pCO_2 exerts a secondary effect, but only under saturating light conditions

North Atlantic Spring Bloom CO_2/temperature experiment: coccolithophores and DMSP

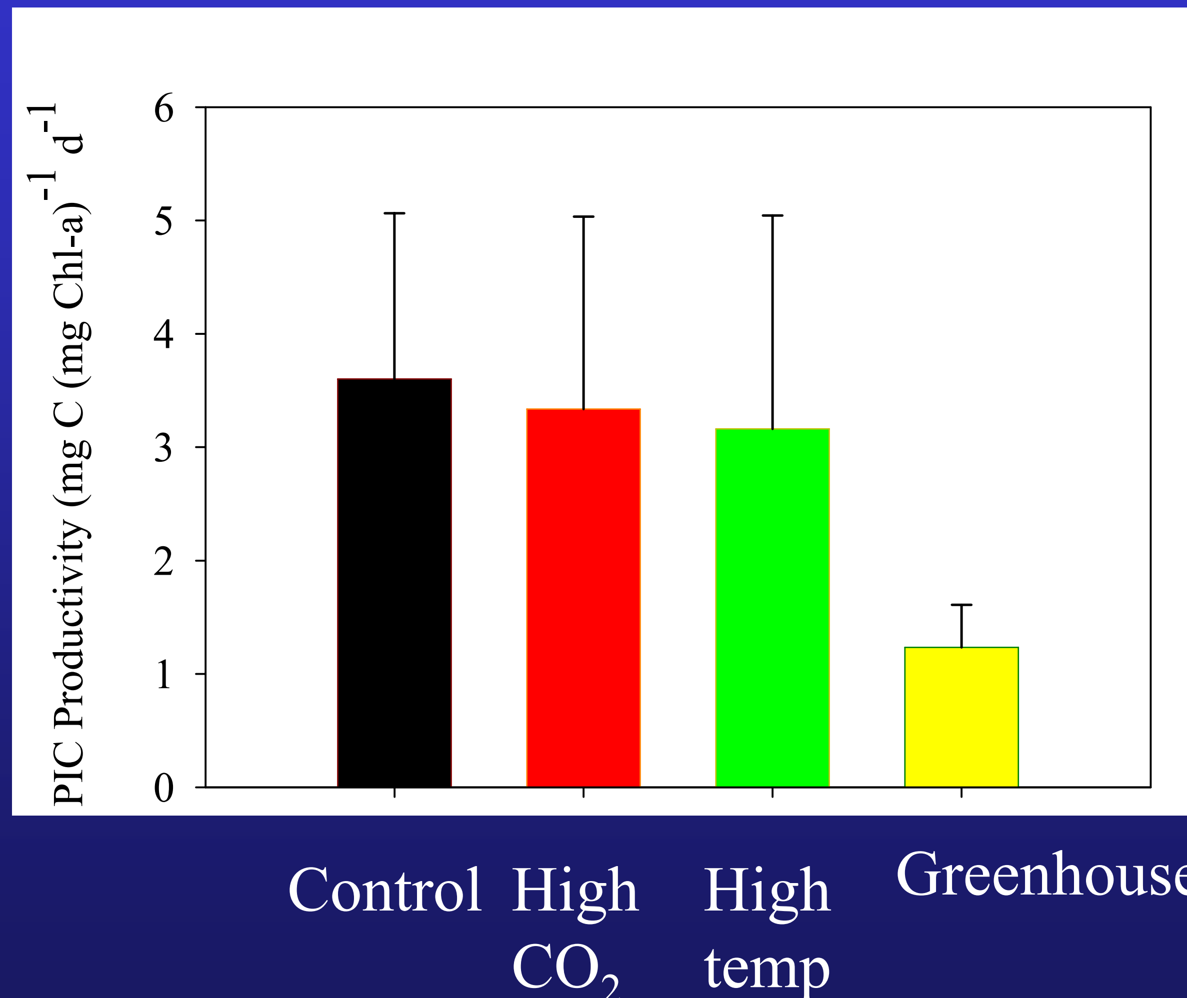




Feng et al. in prep.

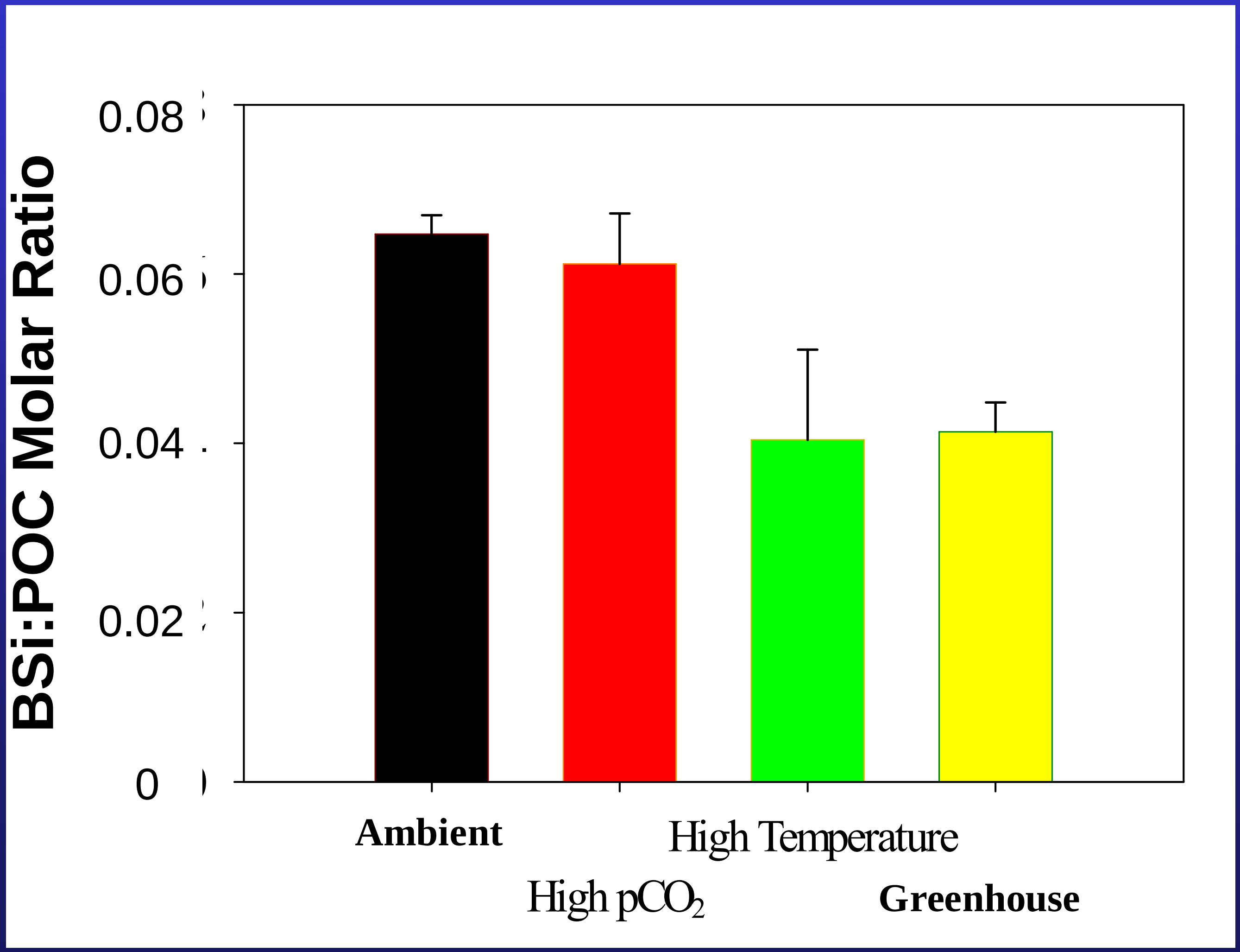
North Atlantic Bloom CO_2/ temperature experiment: PIC production

PIC production rates

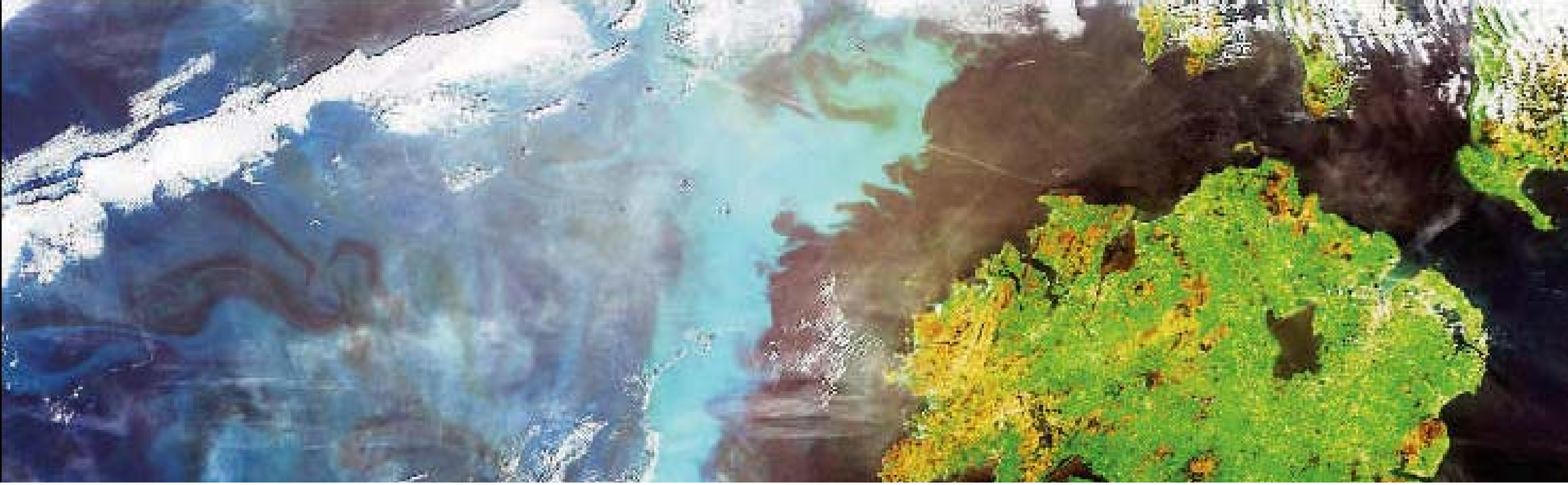


Feng et al. in prep.

Biogenic silica:POC ratio: Warmer temperatures shift communities away from diatoms in the North Atlantic Spring Bloom



Feng and Hutchins in prep.



"Greenhouse" conditions preferentially stimulate the growth of coccolithophores, while paradoxically greatly reducing calcification

Light and temperature interactive effects can be at least as important as rising pCO_2 alone for coccolithophore dominance and calcification

Acknowledgements

Collaborators

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J. DiTullio, P. Lee, U. Passow, I. Benner

Students and postdocs

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Ocean Carbon & Biogeochemistry

Proposal for a Workshop on Environmental Change and Biological Adaptation in the Ocean

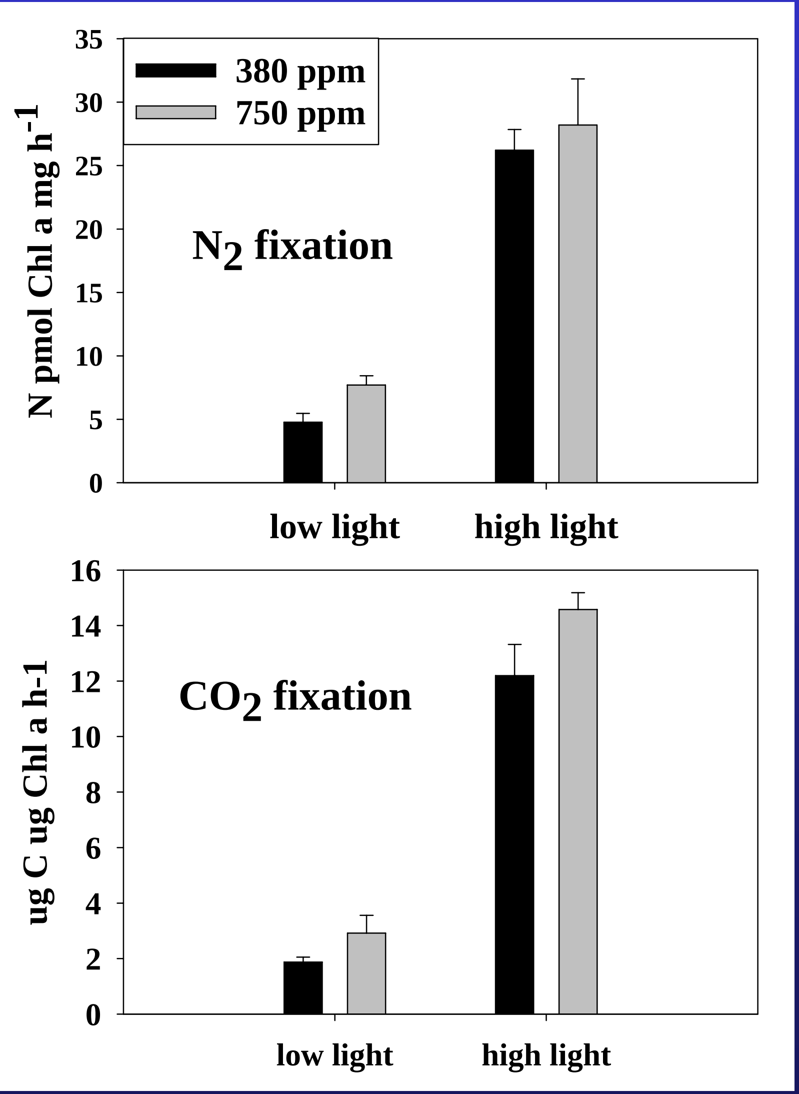
Dave Hutchins
Donal Manahan

- What questions are best addressed by an integrative approach combining oceanography and evolutionary biology to address biological responses to rapid environmental change in the ocean?

- How can studies of present-day organisms and communities be used to predict long-term adaptations and biological responses to rapid regime shifts?

- Can accurate models be developed to predict future effects of multiple environmental changes on organismal, population, and ecosystem-level adaptations?

Light/CO_2 interactions in *Trichodesmium*

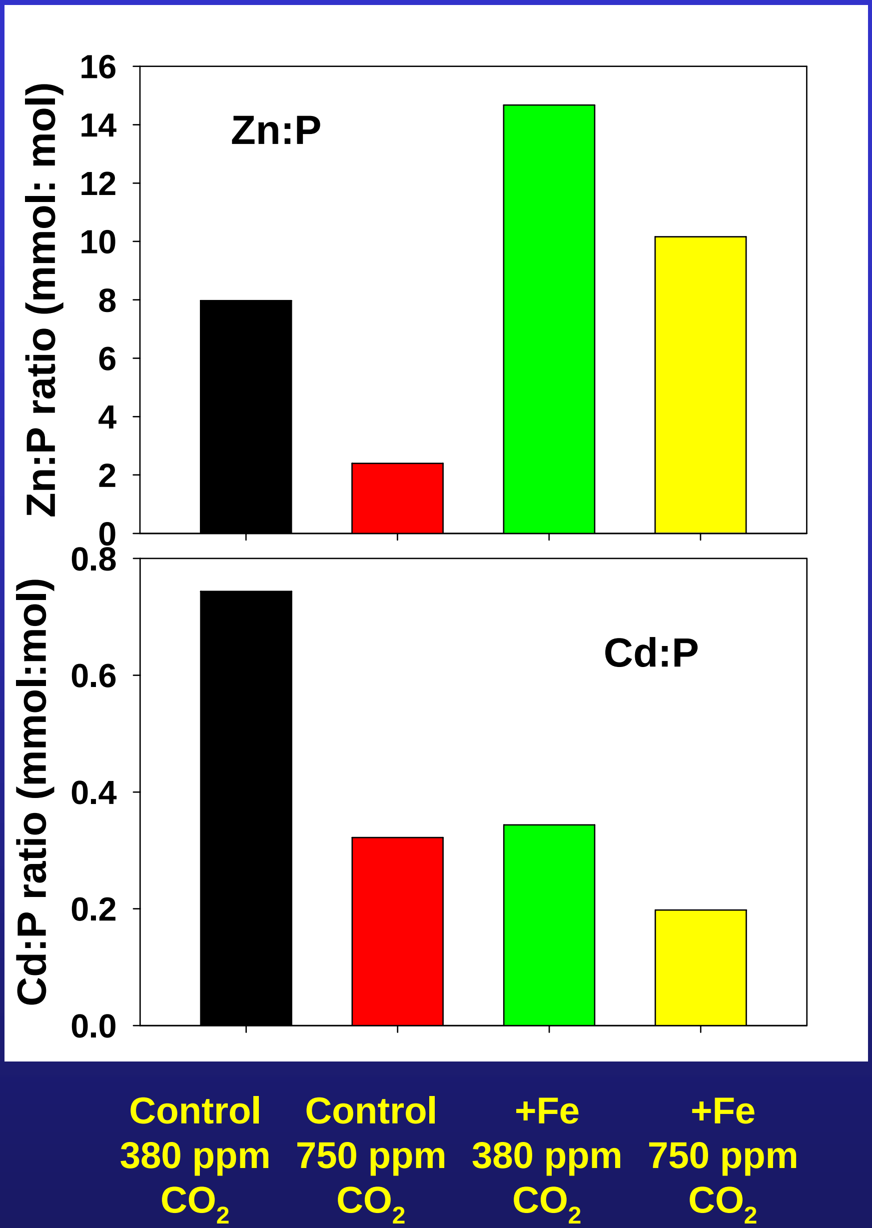


Ross Sea

Phaeocystis antarctica

CO_2/Fe experiment:

Higher Zn and Cd quotas at lower pCO_2

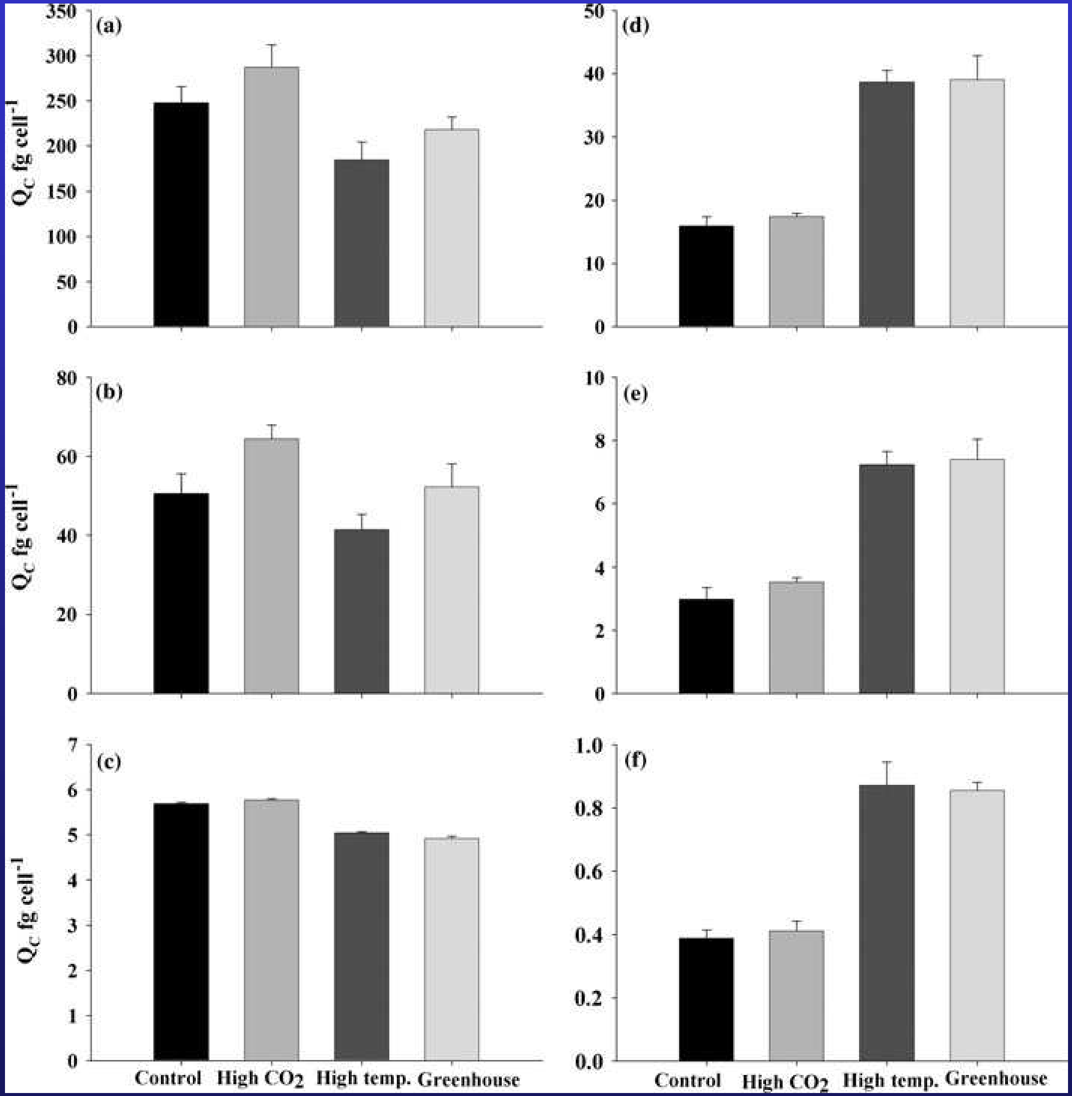


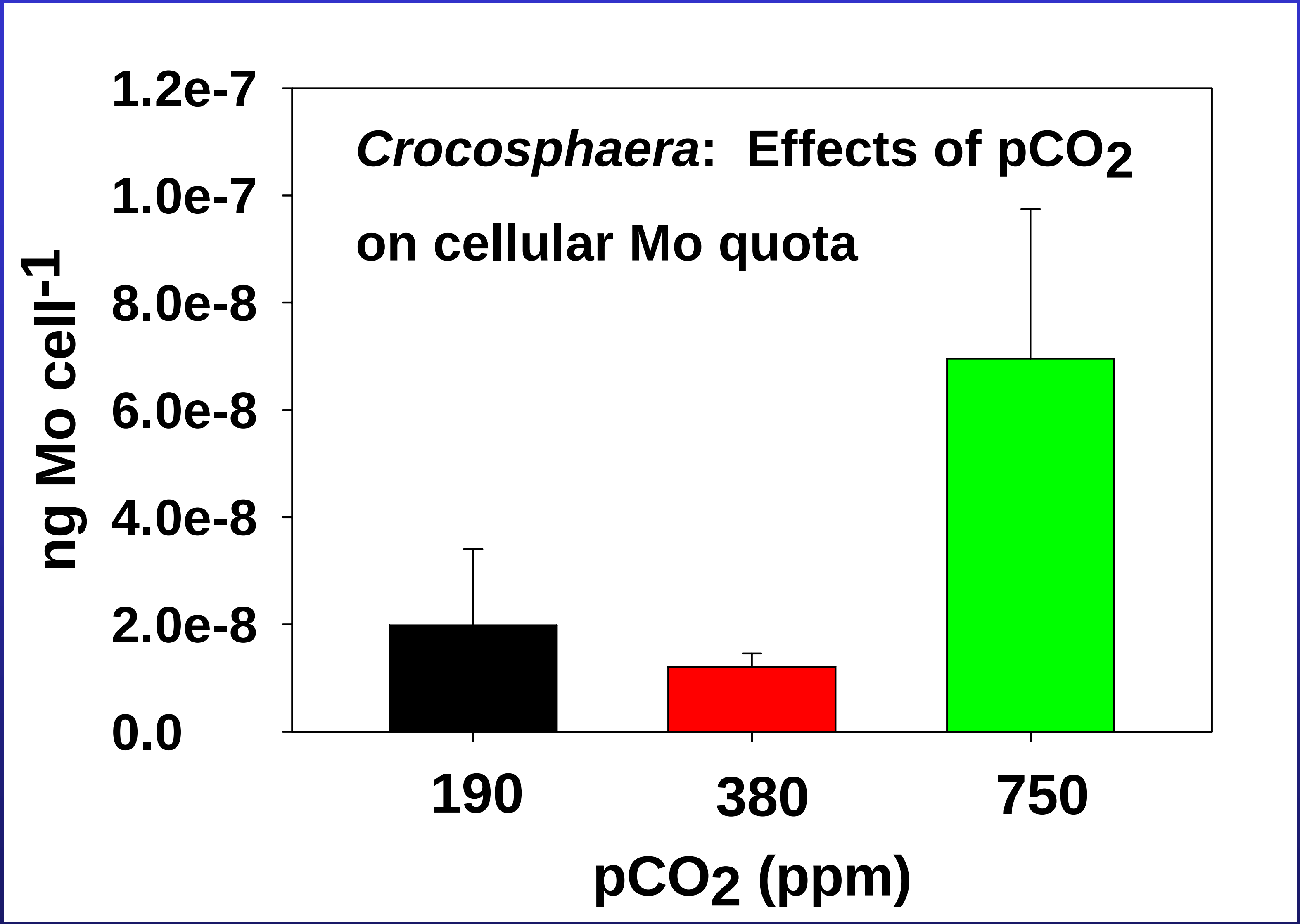
Synechococcus *Prochlorococcus*

Carbon quota ($fg\ cell^{-1}$)

Nitrogen quota ($fg\ cell^{-1}$)

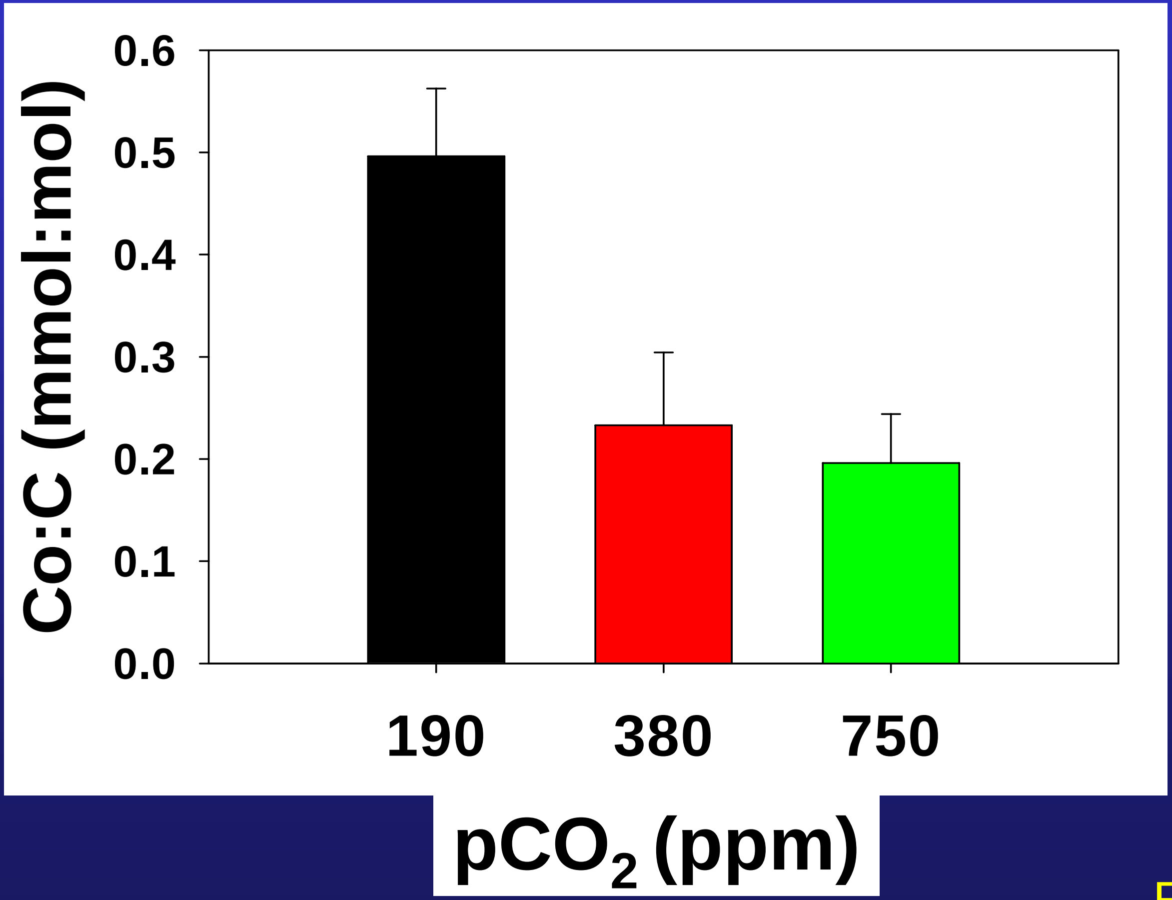
Phosphorus quota ($fg\ cell^{-1}$)





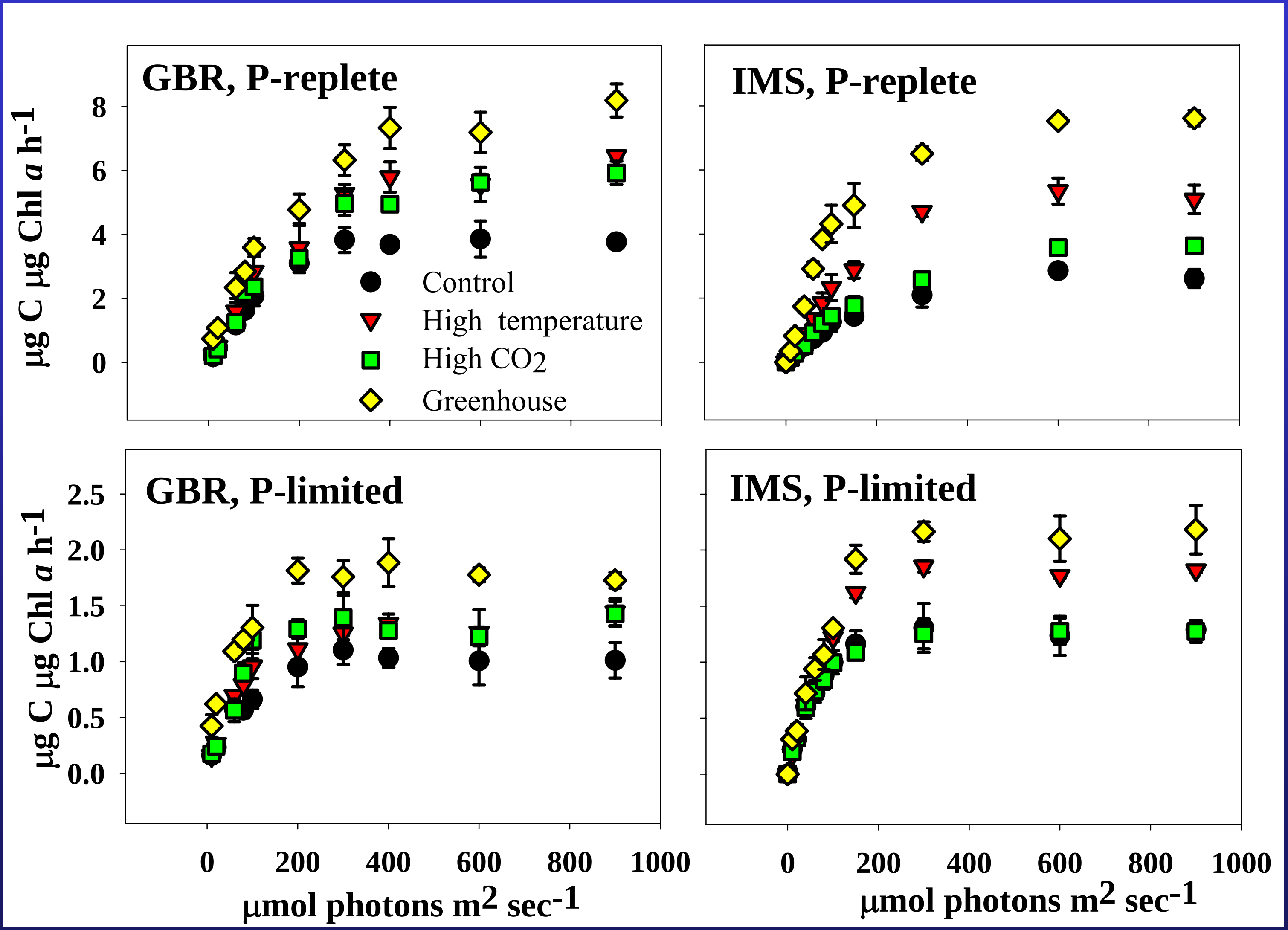
Fu et al in prep

Effects of changing pCO_2 on the Co quota of the unicellular N_2-fixing cyanobacterium *Crocosphaera*



Fu et al in prep

CO_2 fixation versus light, P-replete and P-limited GBR and IMS cultures



Hutchins et al. 2007, L&O