Competition, Trade, and the Economics of Changing Marine Microbial Ecosystems

2018 OCB Workshop

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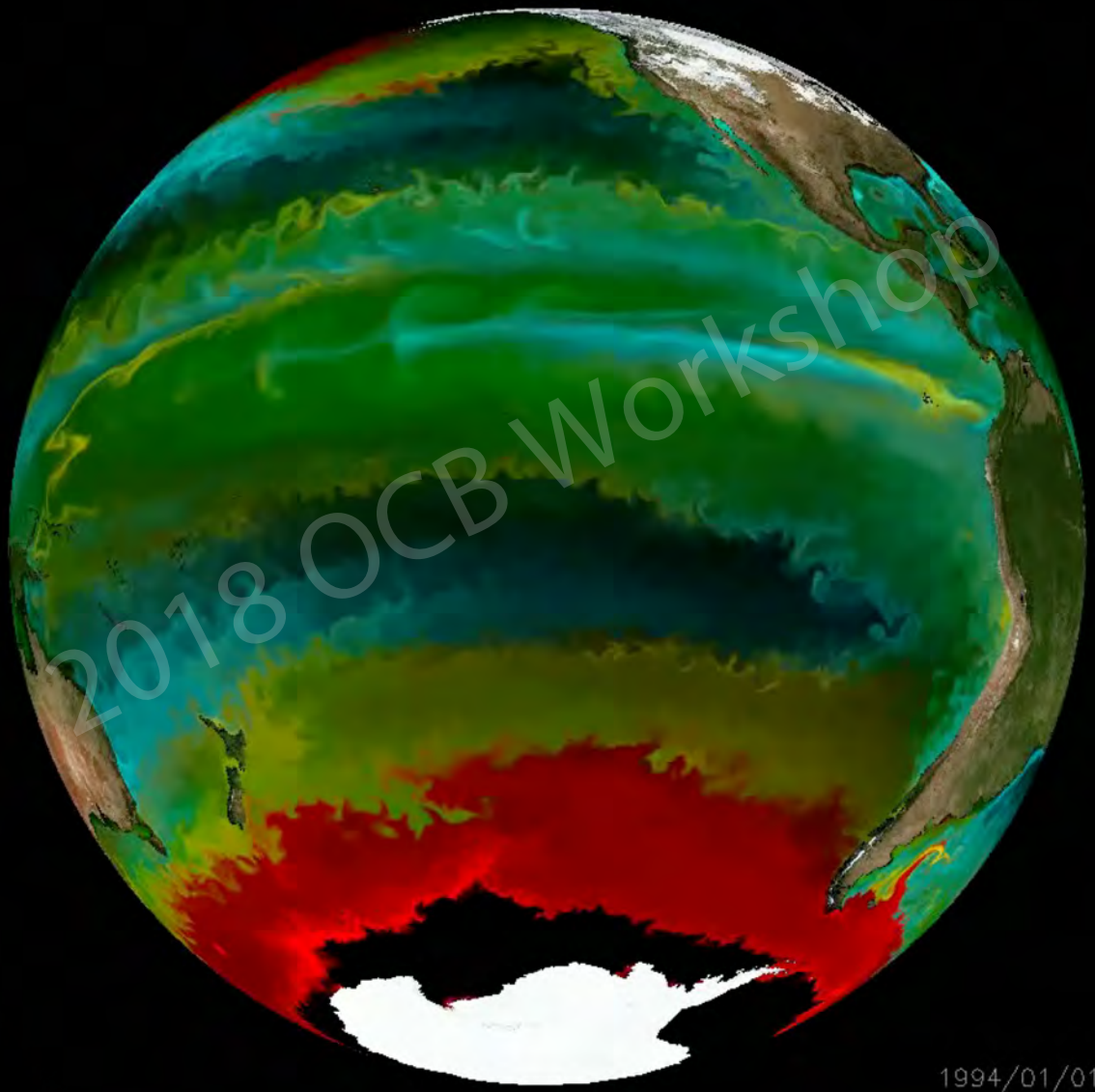
Biogeochemical Models are Our Friends



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(Possible) Pitfalls of biogeochemical Modeling

1. Interactions are strictly negative: competition/exploitation
2. Organisms are modeled as functional groups
3. No evolution

Does this ever matter?

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Do Positive Interspecies Interactions Matter for Models?

1. YES THEY DO (2 examples)
2. How evolution creates positive interactions in the plankton
3. A look ahead: how we are studying the interplay of species interactions and contemporary phytoplankton evolution

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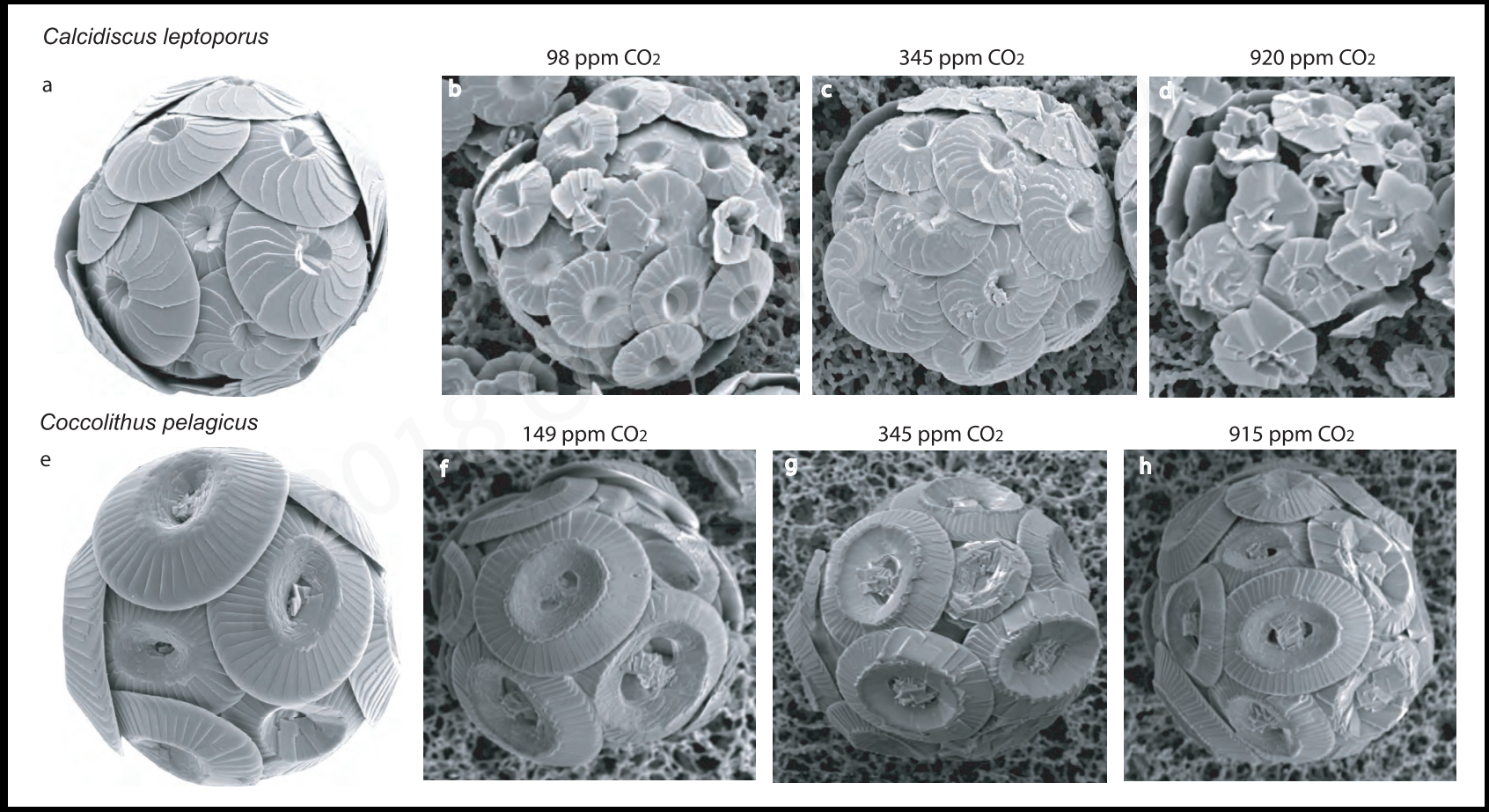
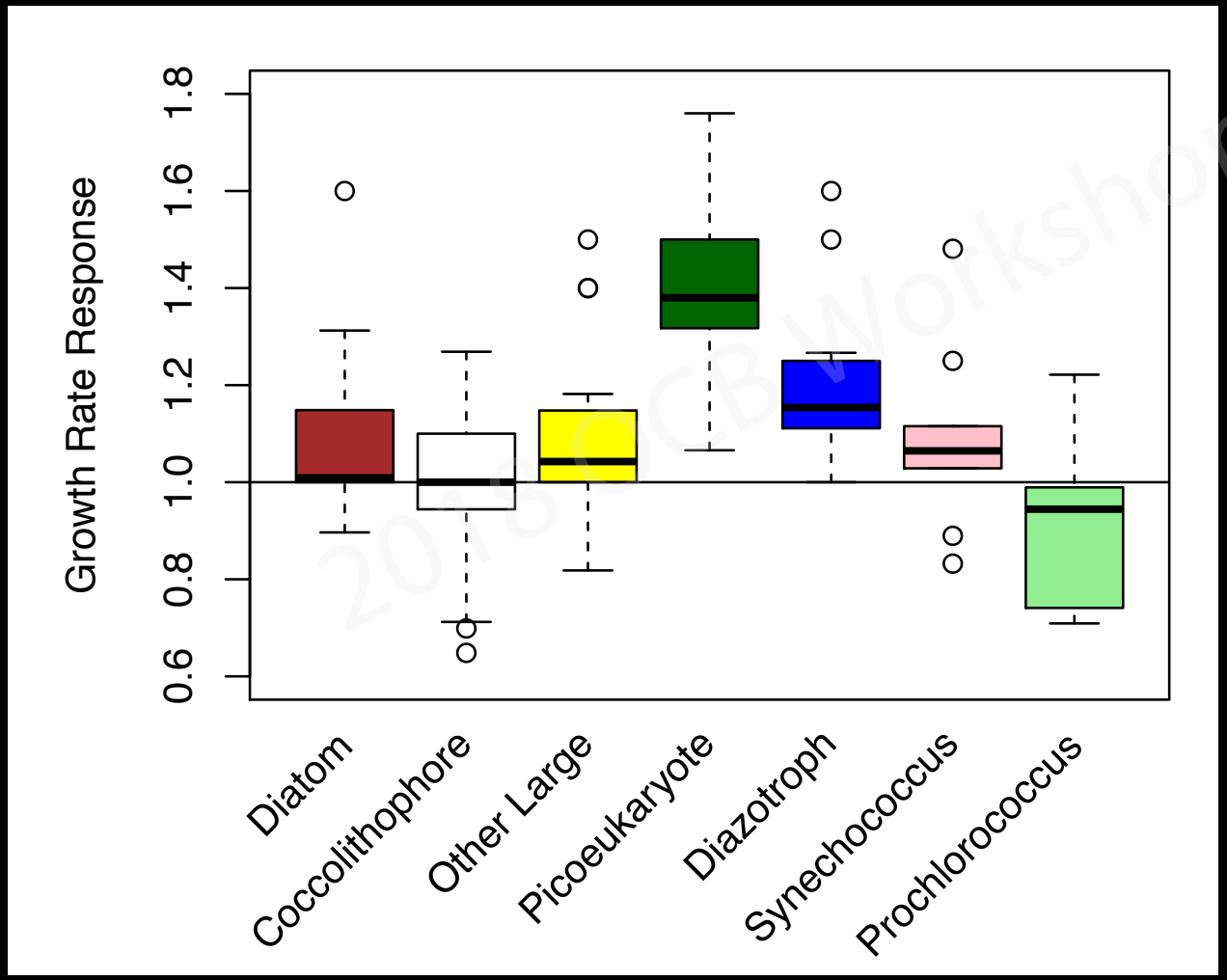
Ocean Acidification vs. Phytoplankton



Langer et al 2006, G3

CO_2 enhances growth rate for cultures of most* small phytoplankton



*(Except for *Prochlorococcus*)

EXAMPLE 1: *Pro* vs. *Syn*

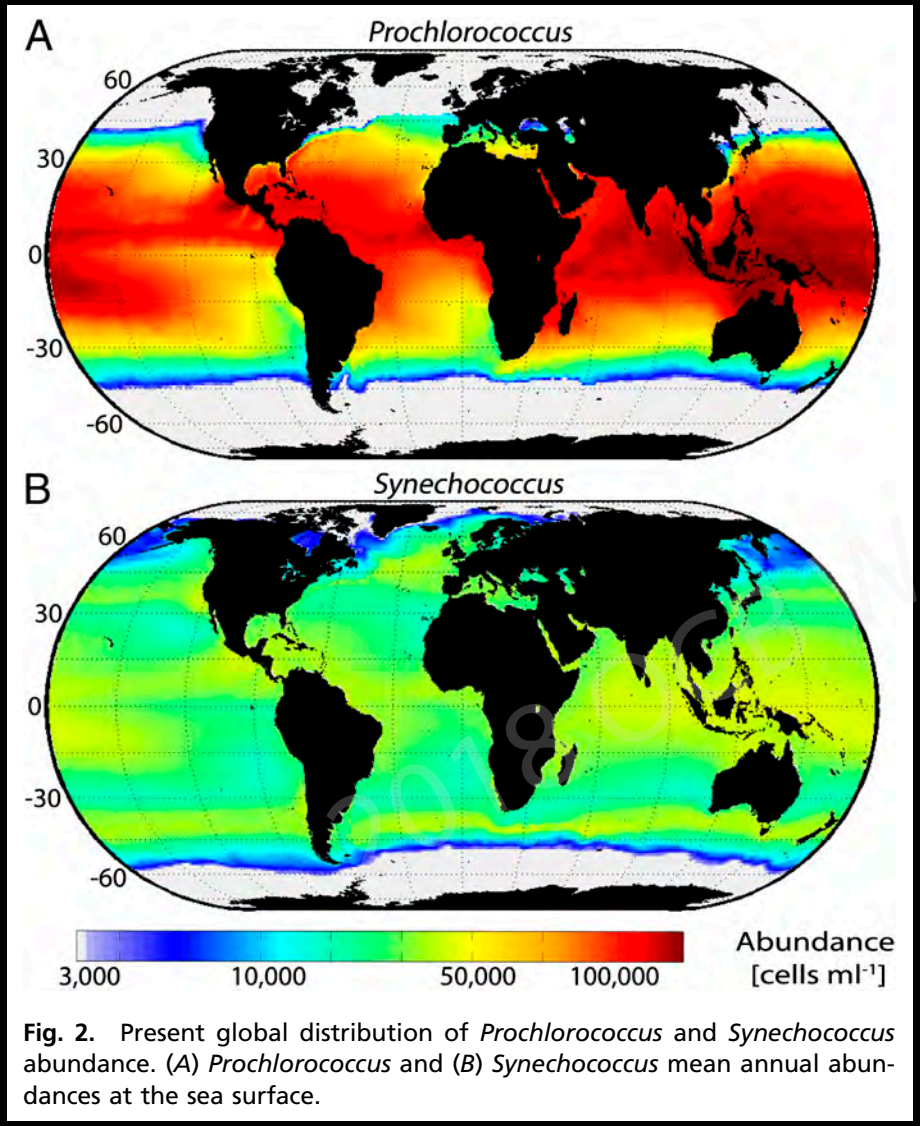


Fig. 2. Present global distribution of *Prochlorococcus* and *Synechococcus* abundance. (*A*) *Prochlorococcus* and (*B*) *Synechococcus* mean annual abundances at the sea surface.

Flombaum et al. 2013, PNAS

Pro and *Syn* coexist throughout the temperate and tropical ocean

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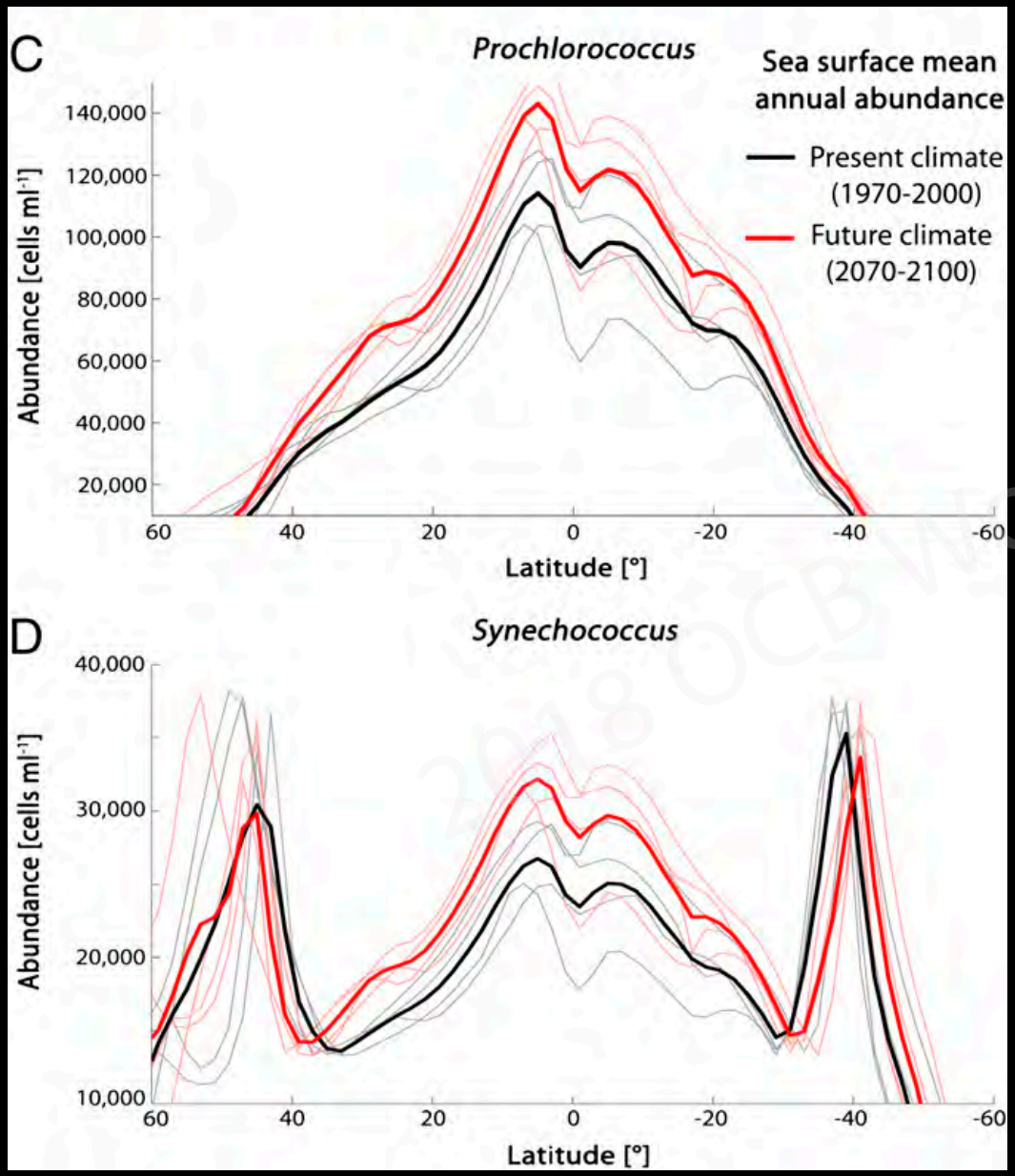
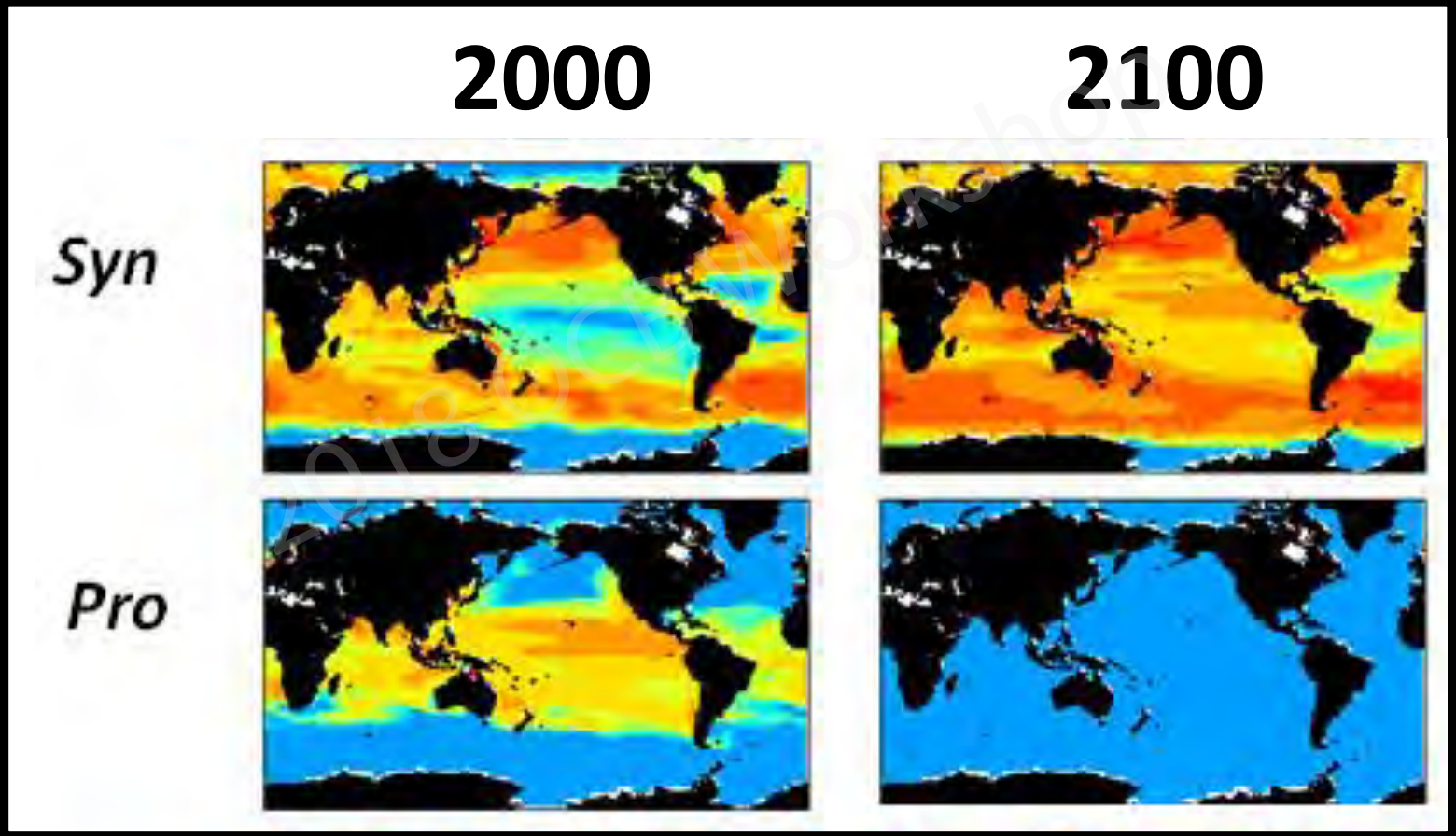


Only considering global warming, both *Syn* and *Pro* are expected to increase in abundance globally

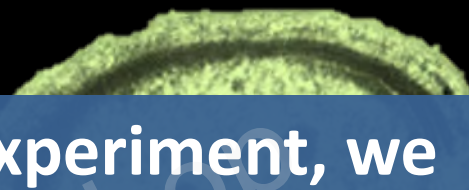
Flombaum et al. 2013, PNAS

In a model that incorporated the CO_2 growth response, *Syn* still increases in abundance, but *Pro* disappears from the model



Dutkiewicz et al. 2015, Nature Climate Change

“Ground truthing” the model



In a direct competition experiment, we measure the change in ratio of the two competitors. If one becomes more relatively abundant over time, it has higher *fitness*.

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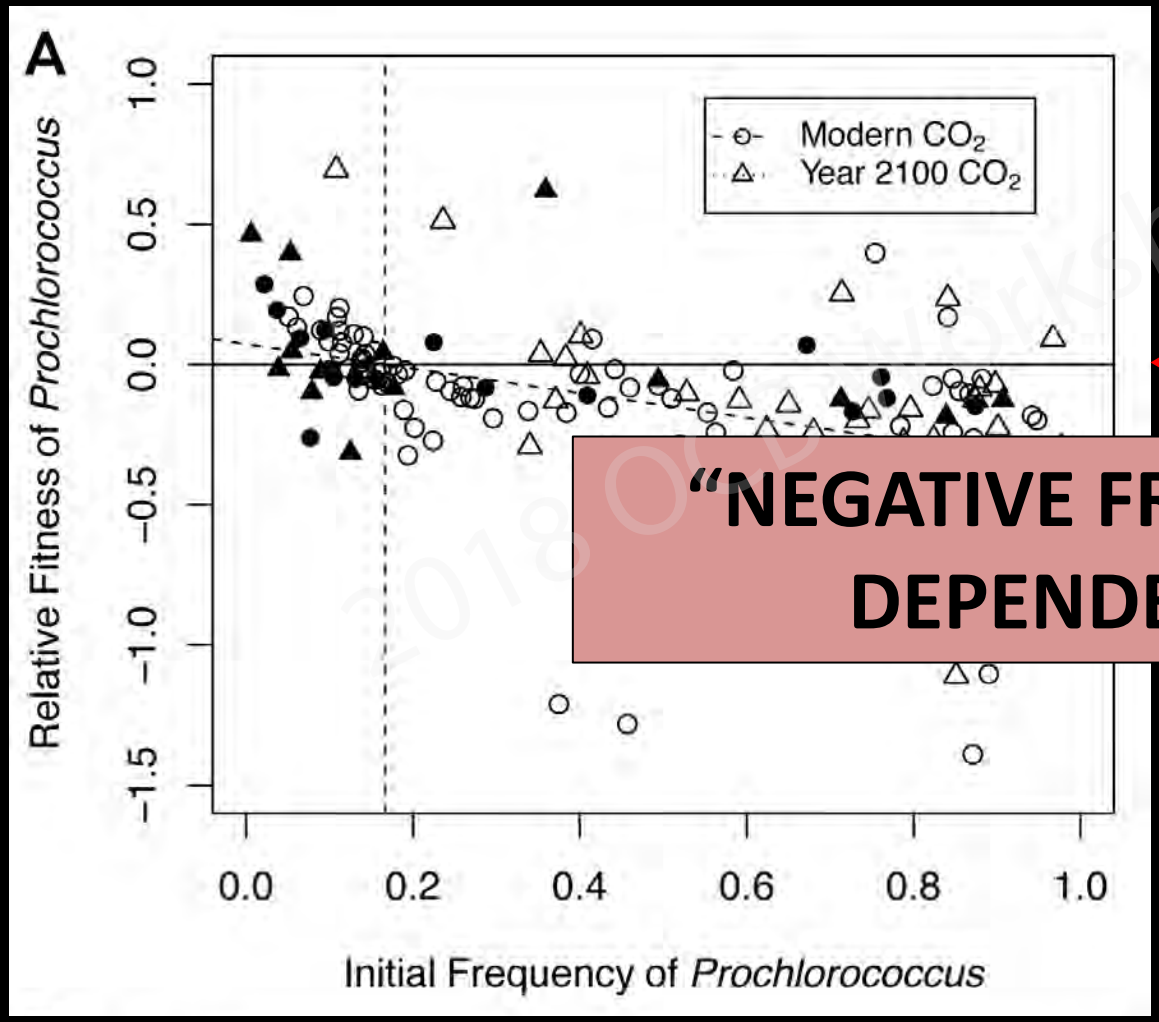
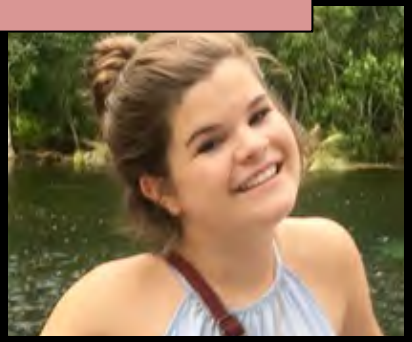
The ratio of *Pro* vs. *Syn* determined their relative fitness under both CO_2 treatments



Equal Fitness

"NEGATIVE FREQUENCY DEPENDENCE"



Maggie Knight
ASFA

Knight and Morris 2018, BioRxiv

Example 2: *Pro* and *Alteromonas*

Heterotrophic bacteria remove reactive oxygen species from the culture media

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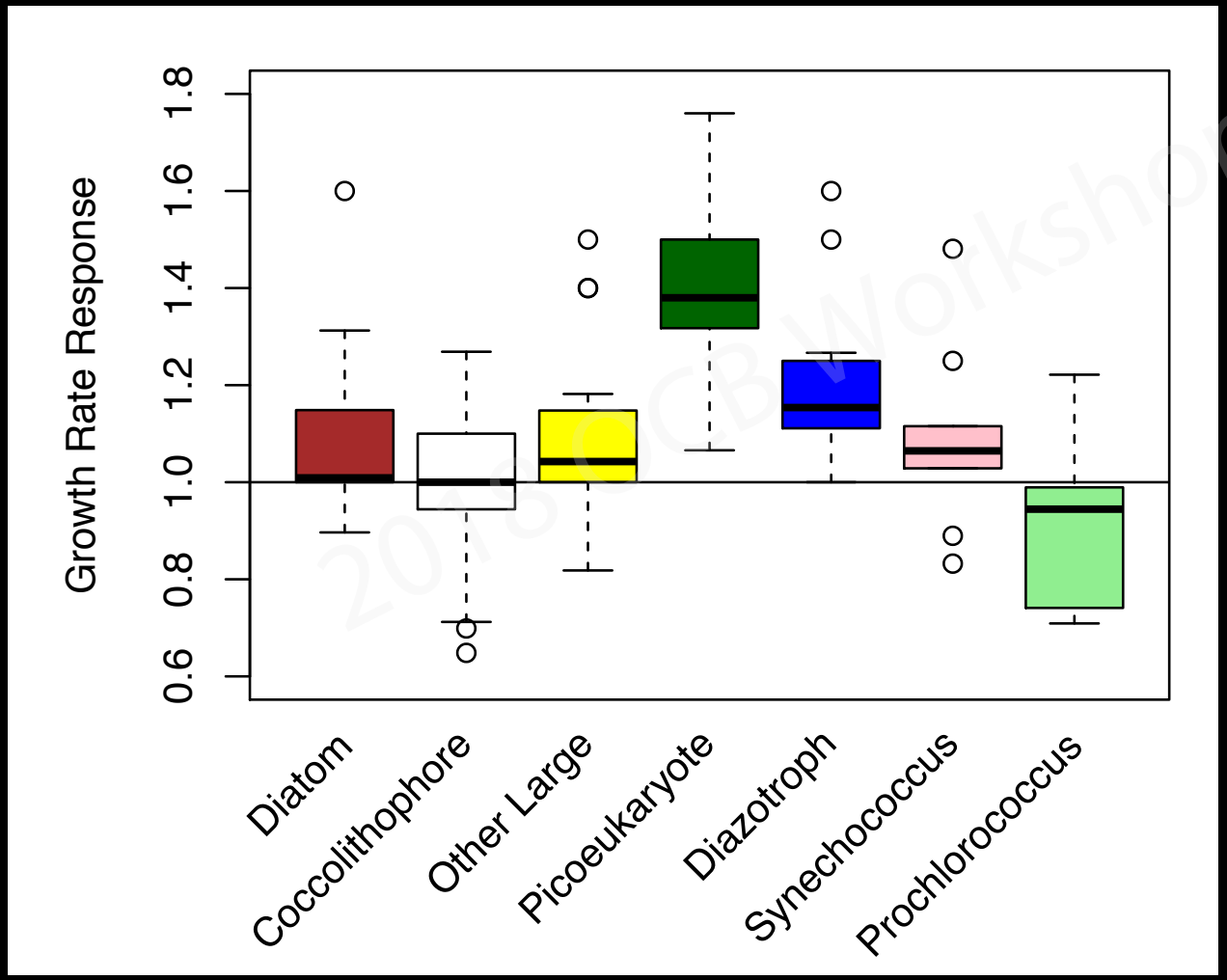
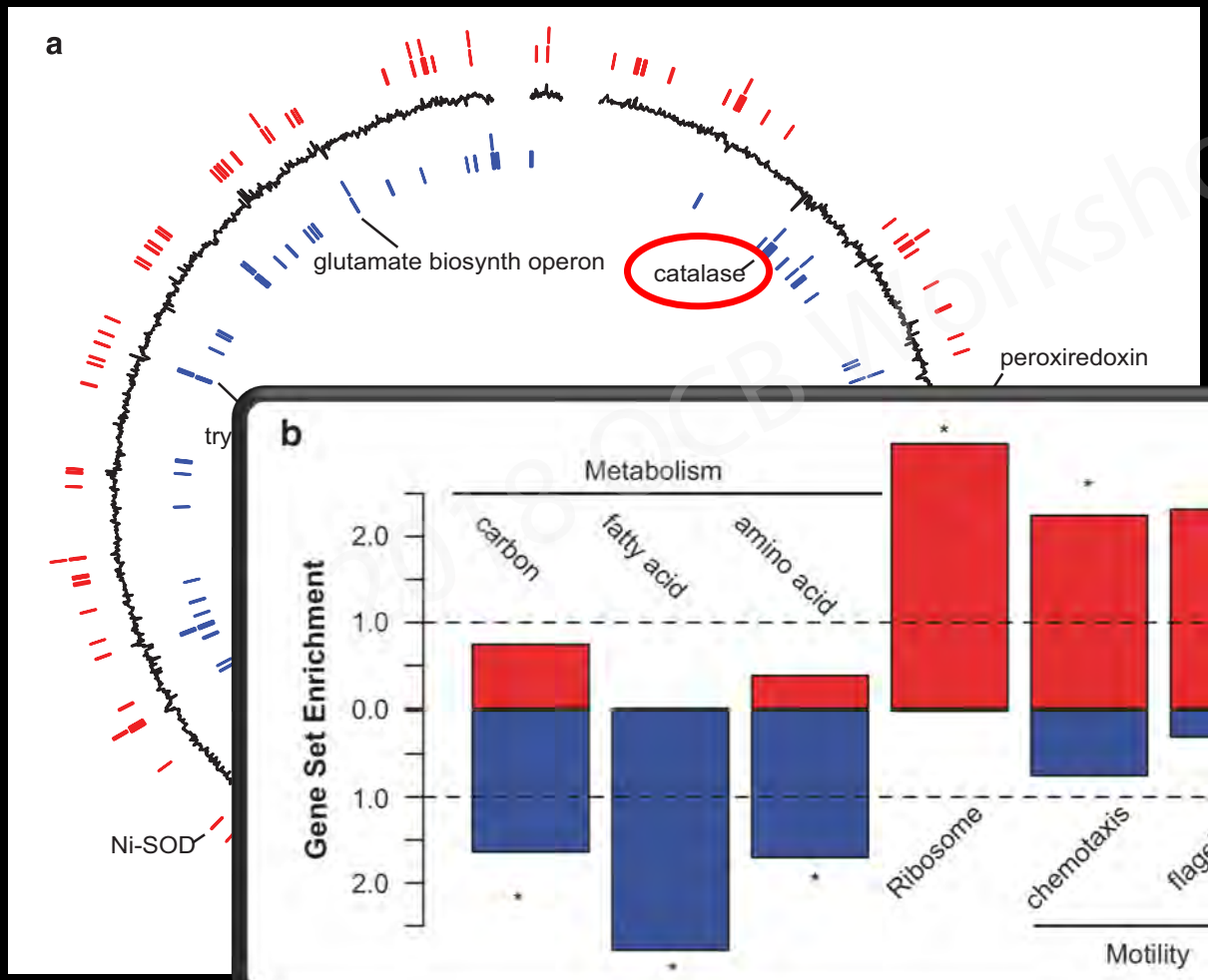
Prochlorococcus needs "helpers" to grow at "ecologically relevant" cell densities in the lab

…Many phytoplankton cultures are not *axenic*



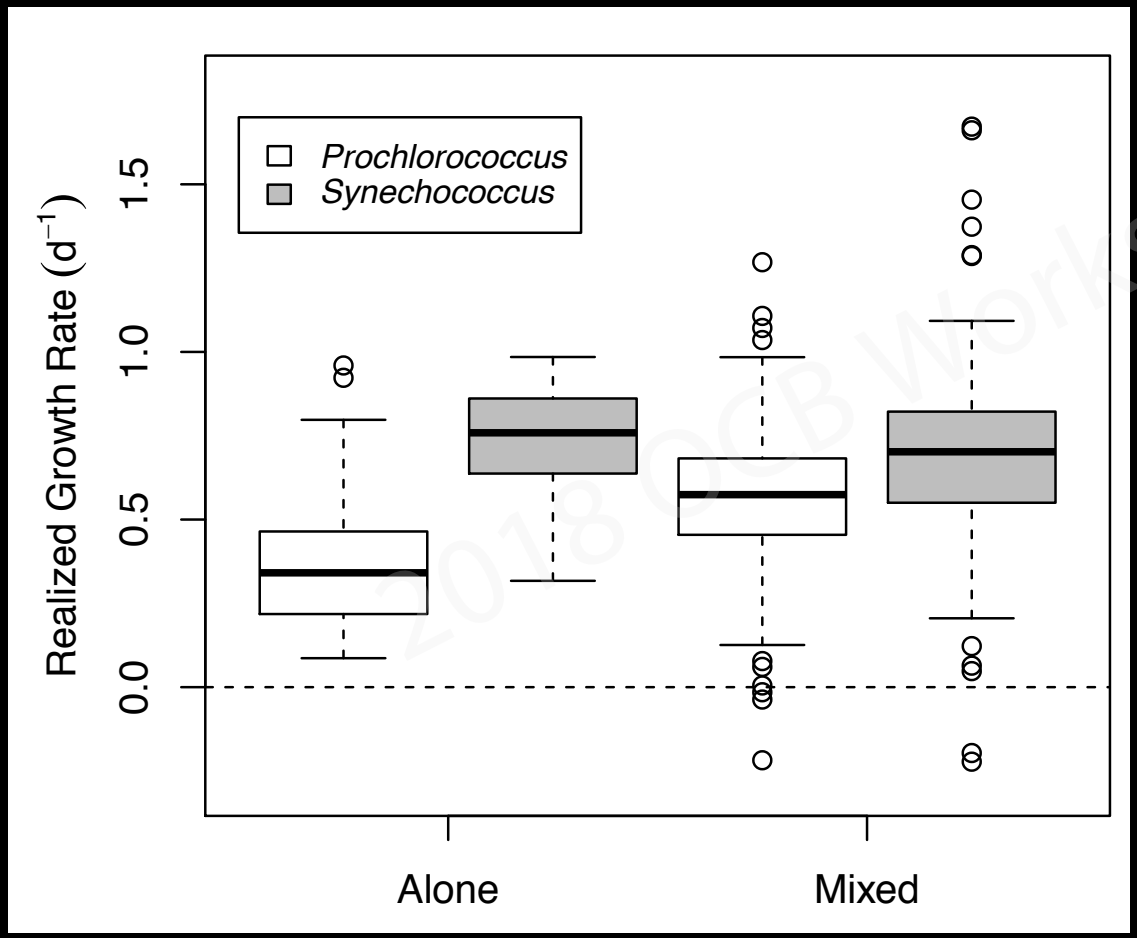
Prochlorococcus + "helper" *Alteromonas*

At 800 ppm CO_2, *Alteromonas* stops helping *Pro*



Hennon et al 2017, ISME J

But *Syn* appears to make up for *Alteromonas*' stinginess at 800 ppm CO_2



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Knight and Morris 2018, BioRxiv

Non-competitive Interactions Dominate this Simple Ecosystem

1. *Pro* and *Syn* should be strict competitors, but also have positive interactions
2. *Pro*'s response to CO_2 is entirely governed by the community context in which it is measured

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Why are these bacteria so “friendly”?

- Natural selection favors non-cooperating *“cheaters”*

Cooperation evolves best in structured populations

Vibrio fischeri and Hawaiian bobtail squid

THIS IS ~ IMPOSSIBLE FOR PHYTOPLANKTON

Corals and symbiotic algae

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- Spatial structure prevents intraspecies “cheating” by close relatives
- Vertical transmission cements interspecies bonds (like between animal hosts and symbionts)

The Economics of Community Evolution

- Every biological function has a cost
- The products/services of these functions have a value set by supply vs. demand
- When the cost is greater than the value, natural selection favors organisms that don't perform the function

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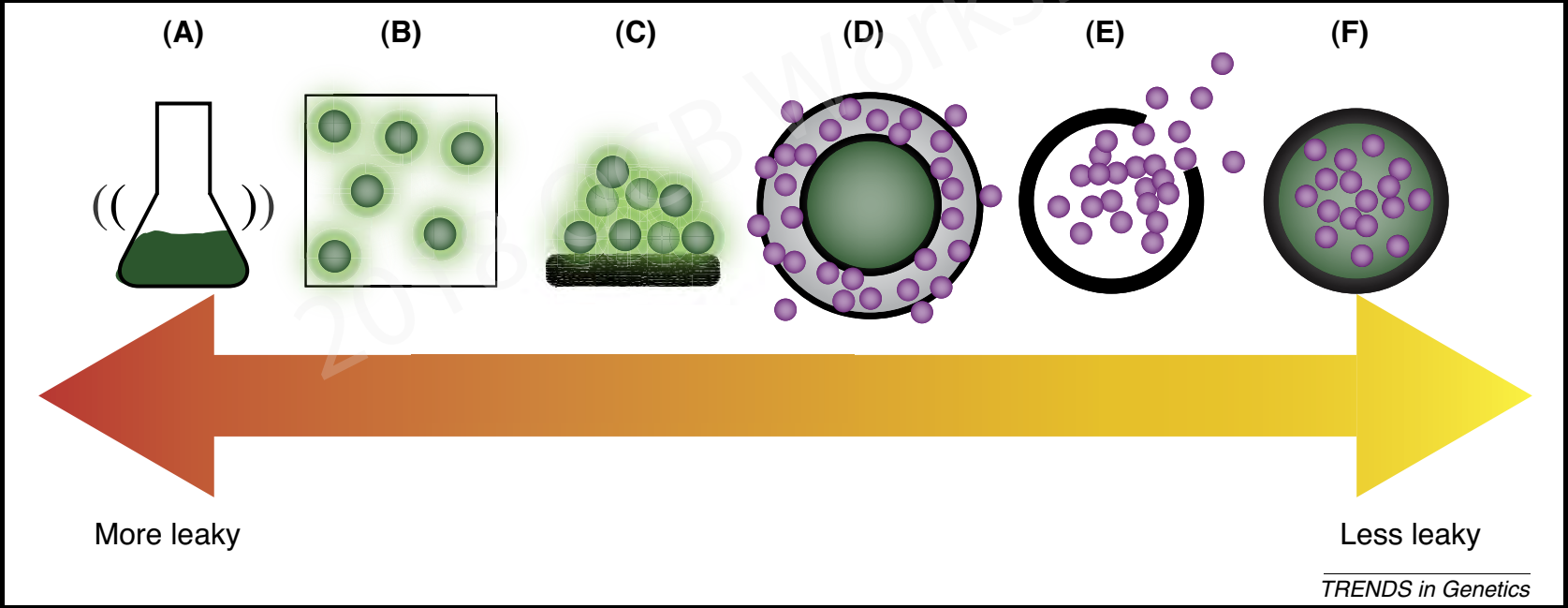
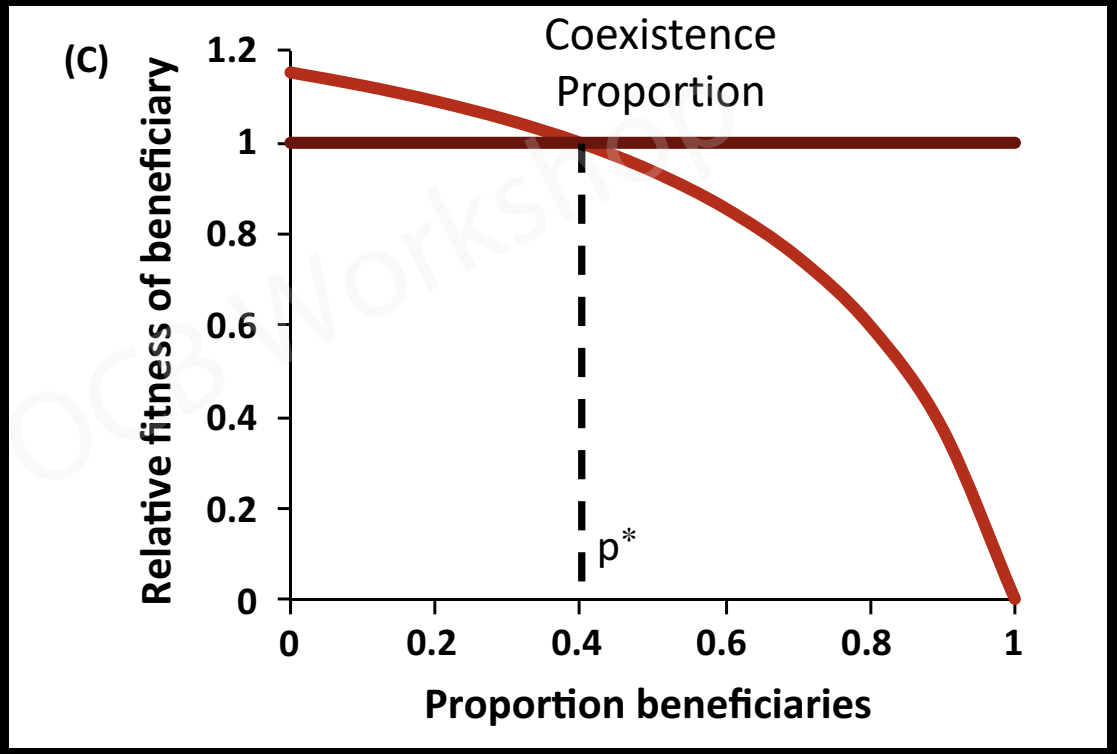
“Leakiness”

Many functions yield goods/services that are unavoidably “leaked” into the environment



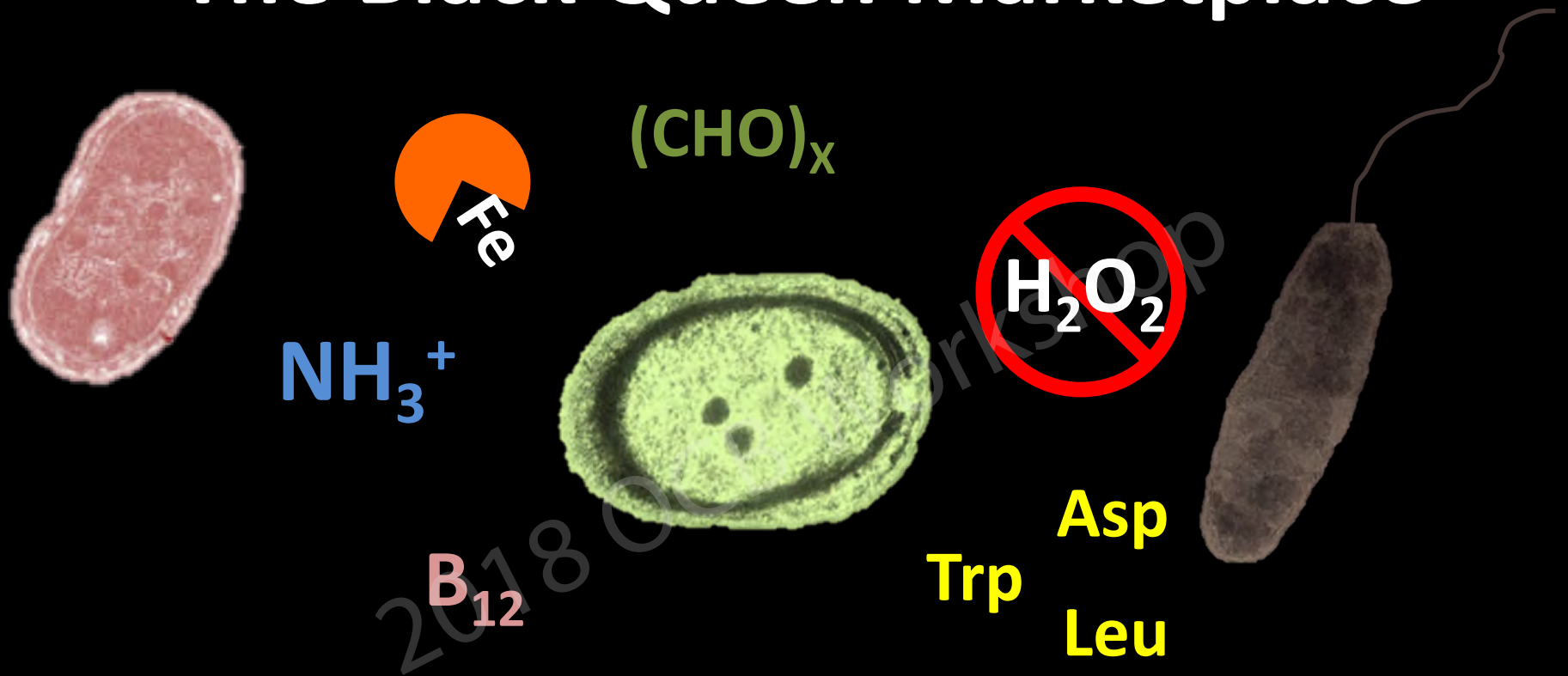
Morris 2015, Trends in Genetics

The Black Queen Hypothesis (Morris et al 2012, mBio)



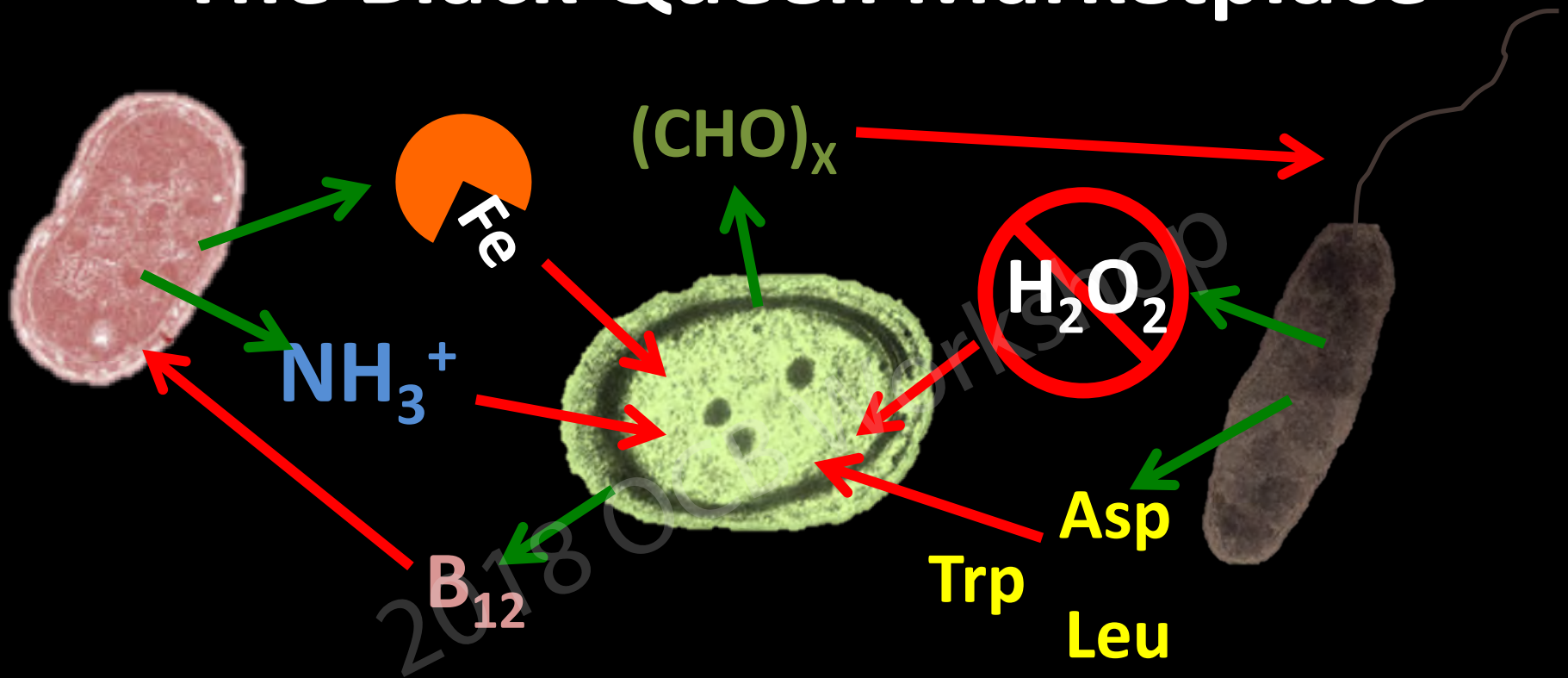
Evolution driven by the economics of leaky functions produces negative frequency dependence

The Black Queen Marketplace



- Planktonic cells are suspended in a metabolic marketplace of leaked products from Black Queen functions

The Black Queen Marketplace



- Evolution leads to complex webs of interdependency

How do communities structured by Black Queen functions evolve?

IMPORTANT: Black Queen “mutualisms” are fundamentally less stable than “true” mutualisms

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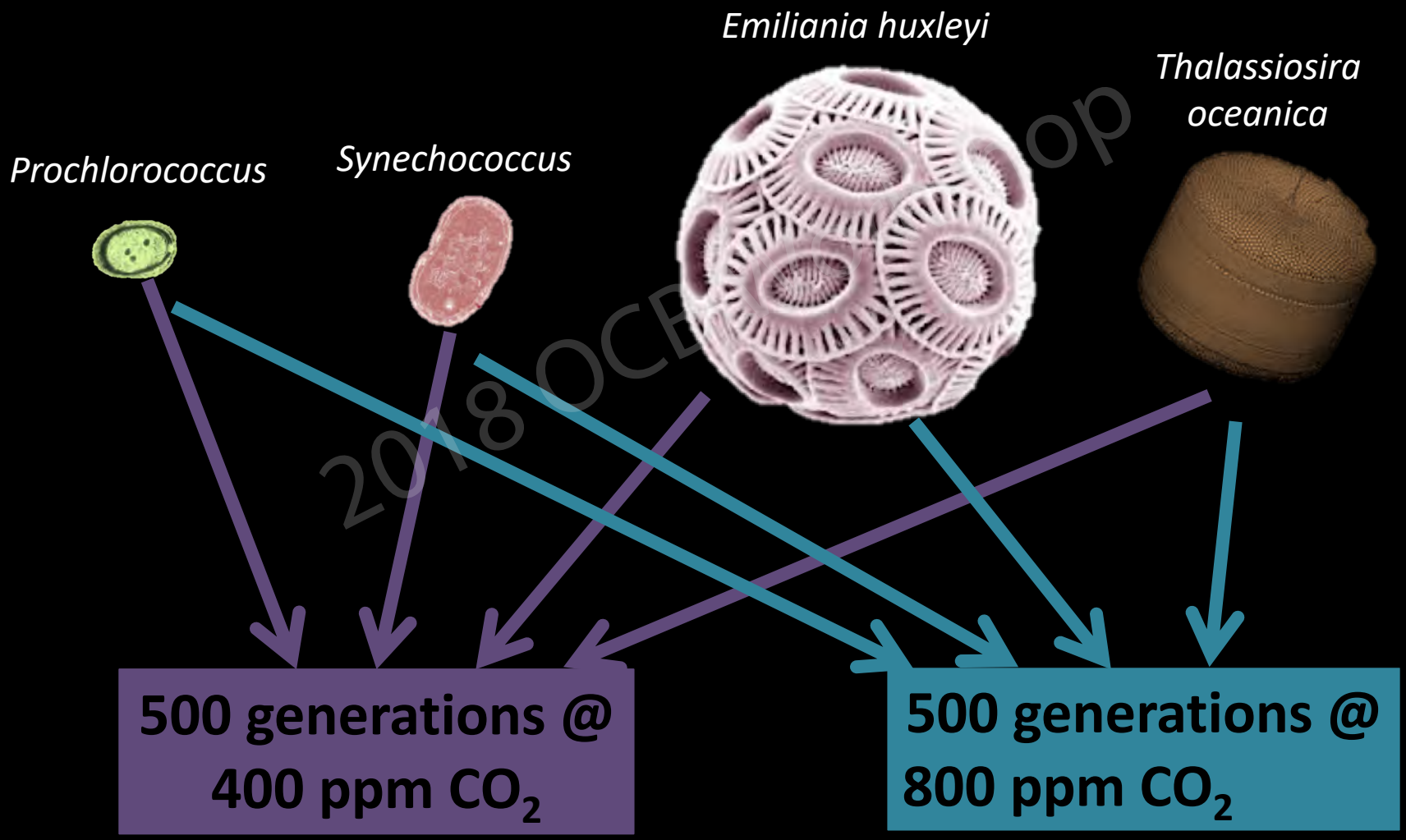
The Long-Term Phytoplankton Evolution (LTPE) Experiment



The Long-Term Phytoplankton Evolution (LTPE) Experiment

Emiliania huxleyi

Thalassiosira oceanica

Prochlorococcus

Synechococcus

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Alteromonas maceleodii

- All 48 populations were evolved alongside the same *Alteromonas* species
- We can mix-and-match strains in competition experiments

Out-standing Questions

1. Does rapid evolution in response to environmental change alter key Black Queen relationships?

2. Do phytoplankton and *Alteromonas* evolve specific mutualism-enforcing traits during long-term co-culture?

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