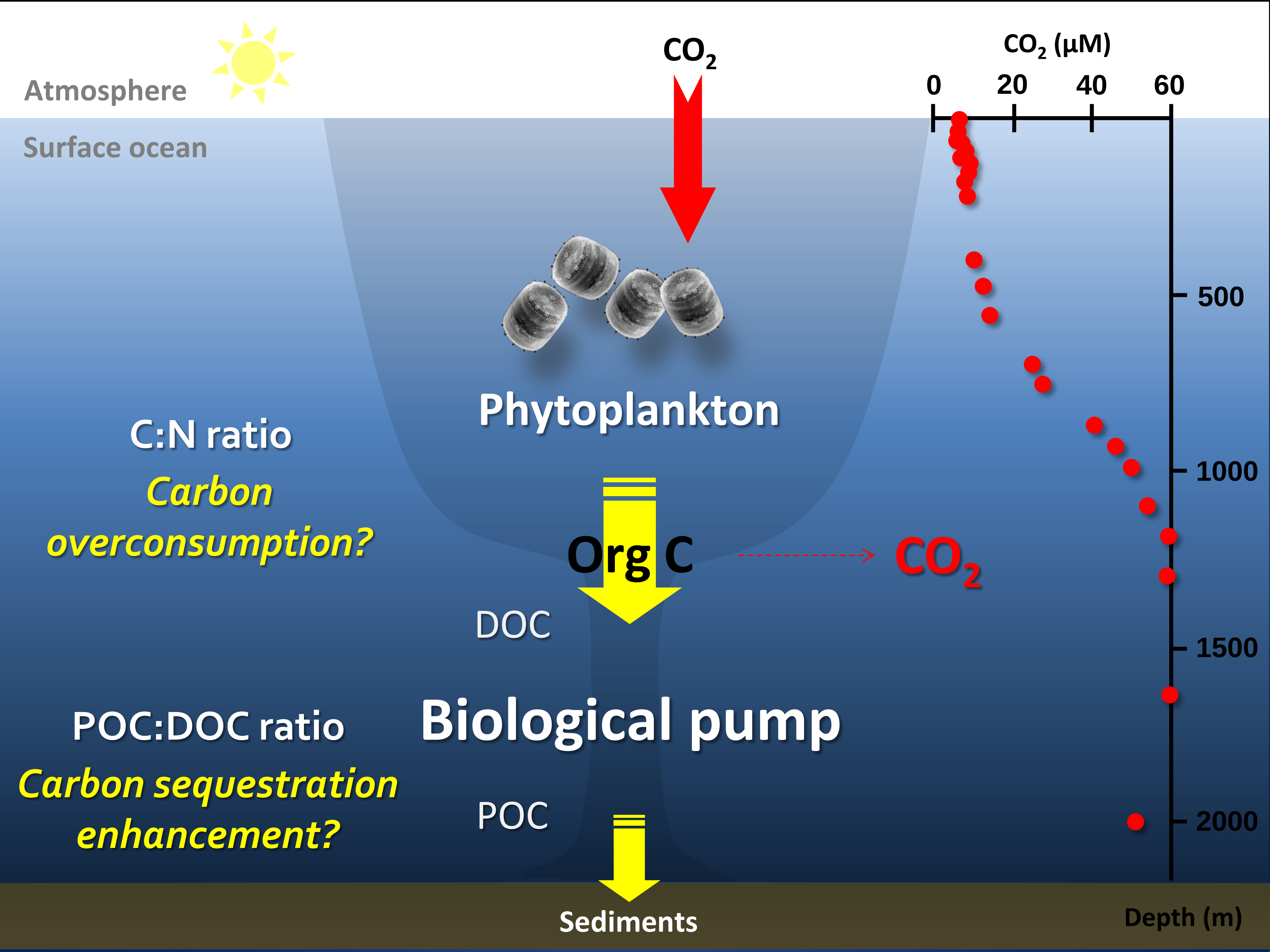
Effects of ocean acidification & warming on organic matter production

: Possible changes in biological carbon pump efficiency

POSTECH

Ja-Myung Kim

PICES 2015 Annual Meeting · October 14-25 · Qingdao · China



Atmosphere

Surface ocean

CO$_2$

Phytoplankton

C:N ratio

Carbon overconsumption?

Org C

CO$_2$

DOC

Biological pump

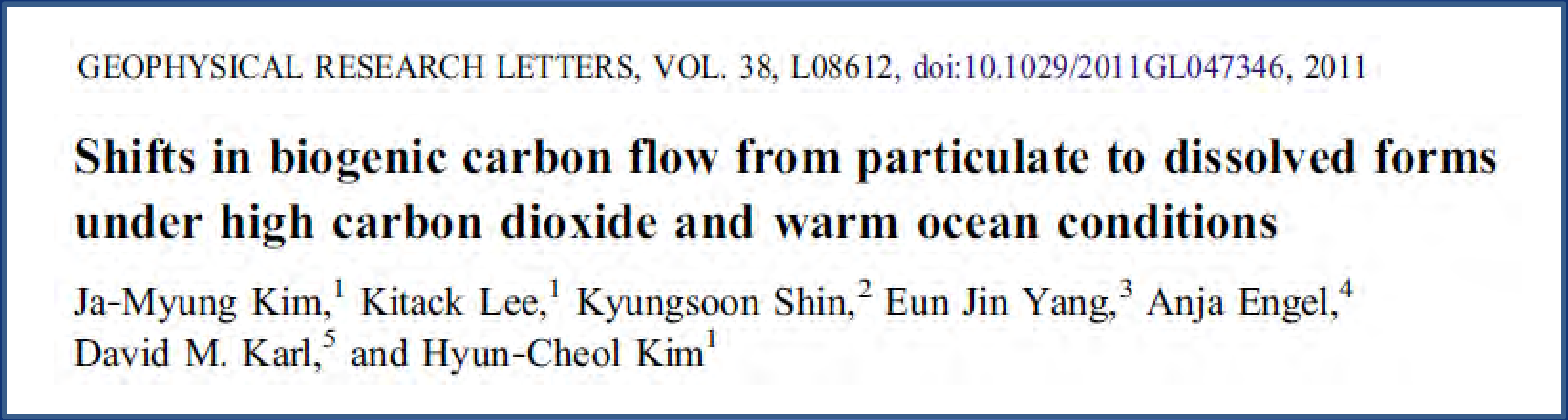
POC:DOC ratio

Carbon sequestration enhancement?

POC

Sediments

Controlled in-situ mesocosm experiment

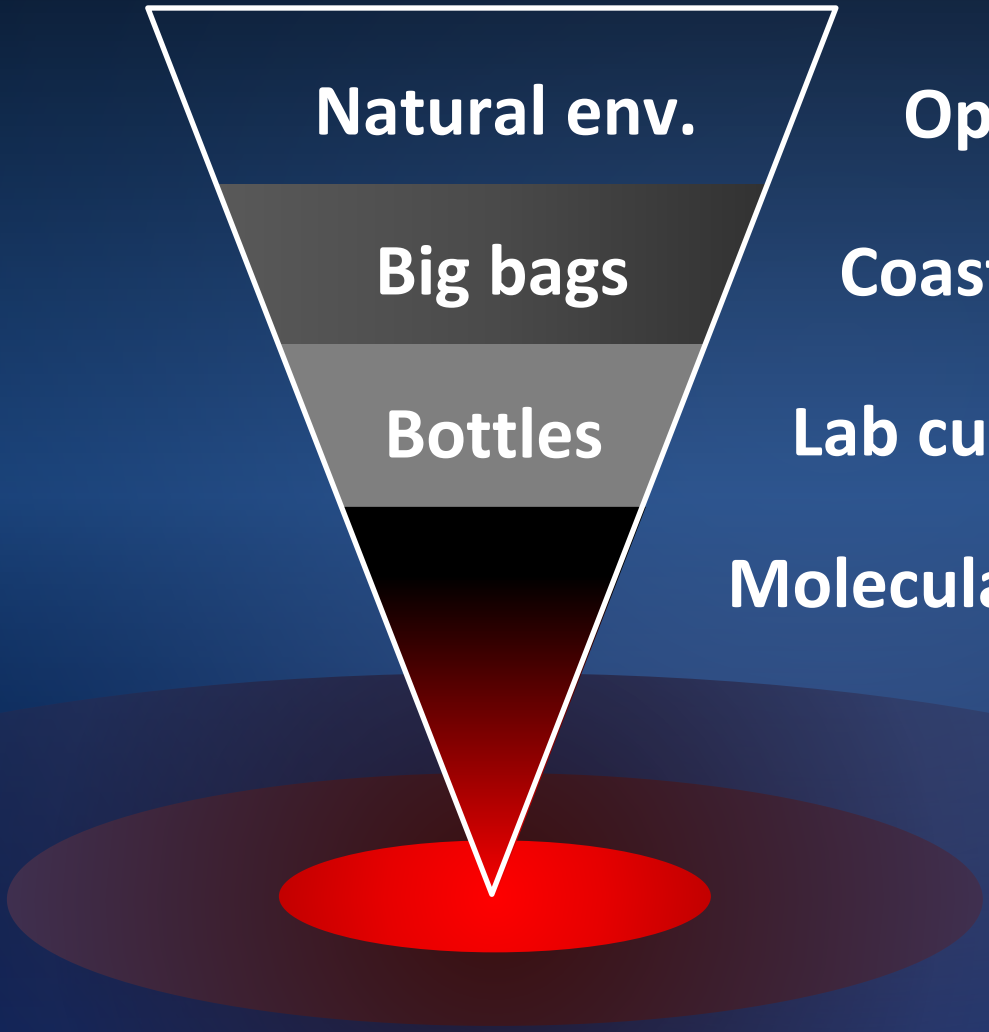


GEOPHYSICAL RESEARCH LETTERS, VOL. 38, L08612, doi:10.1029/2011GL047346, 2011

Shifts in biogenic carbon flow from particulate to dissolved forms under high carbon dioxide and warm ocean conditions

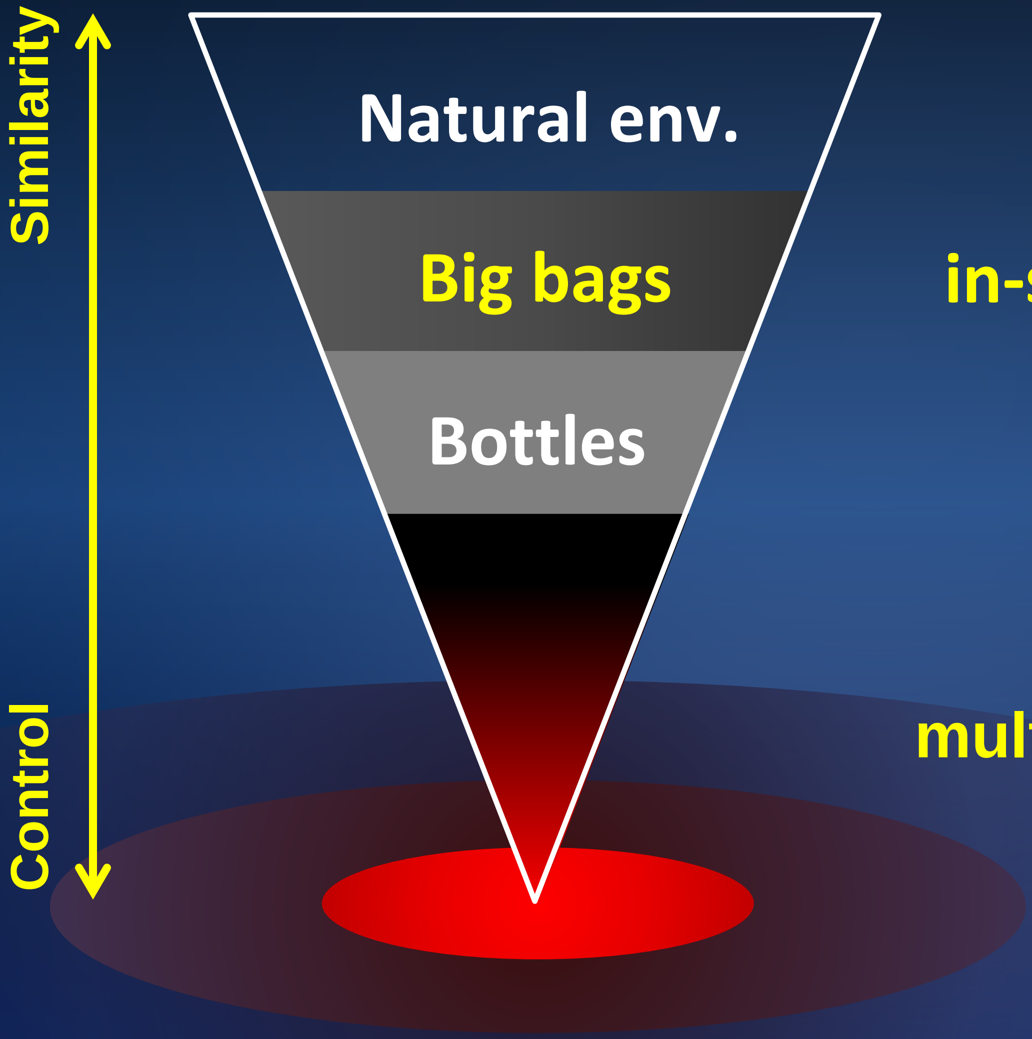
Ja-Myung Kim,[1] Kitack Lee,[1] Kyungsoon Shin,[2] Eun Jin Yang,[3] Anja Engel,[4]
David M. Karl,[5] and Hyun-Cheol Kim[1]

Experimental approaches



Natural env.	Open ocean monitoring
Big bags	Coastal in-situ perturbation
Bottles	Lab cultures
	Molecular mechanisms

Experimental approaches



Similarity

Control

Natural env.

Big bags

Bottles

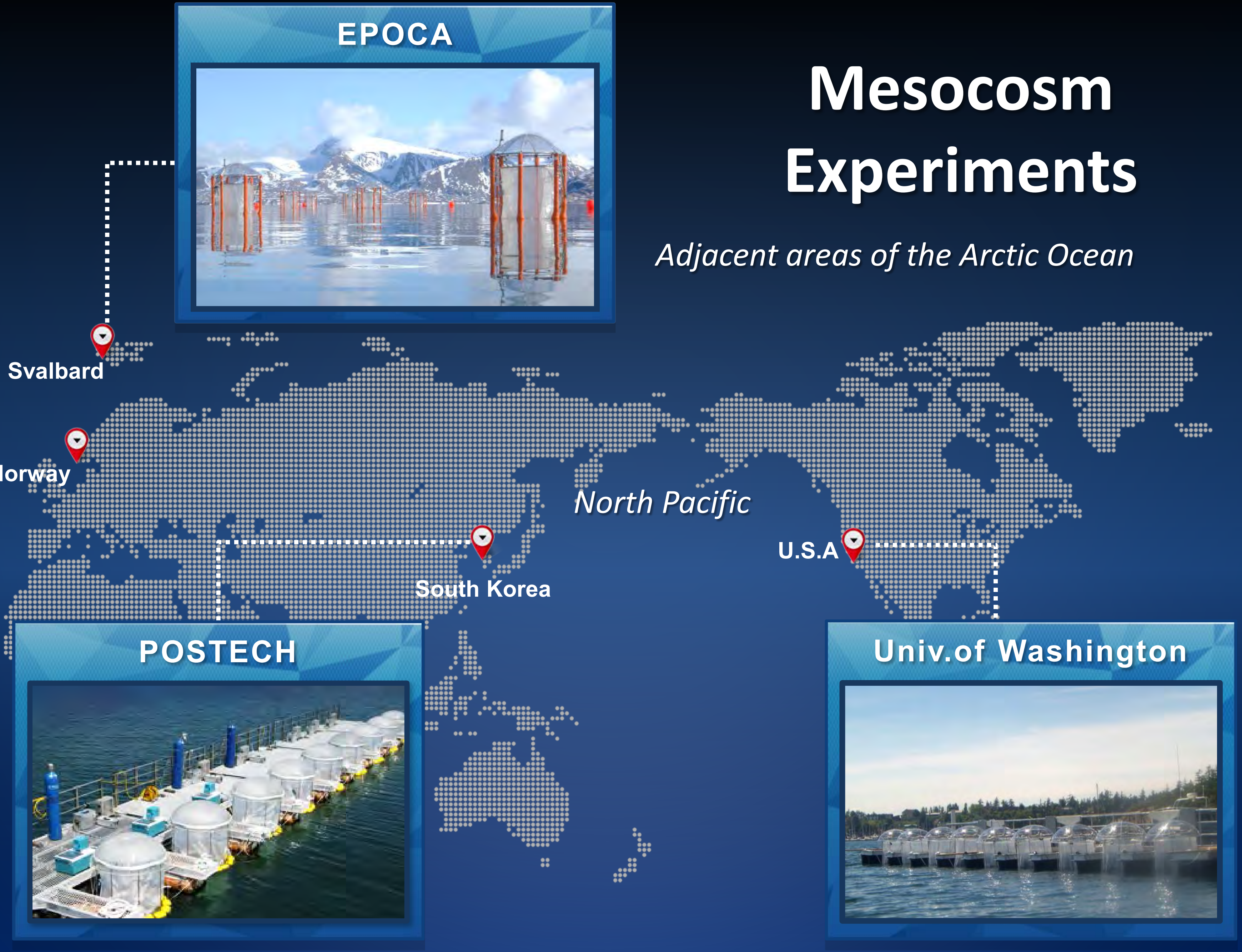
in-situ perturbation expt.

Mesocosm

Observation on
multidisciplinary parameters

Mesocosm Experiments

Adjacent areas of the Arctic Ocean



Mesocosm System

Jangmok, Geoje island, Korea

Experimental conditions

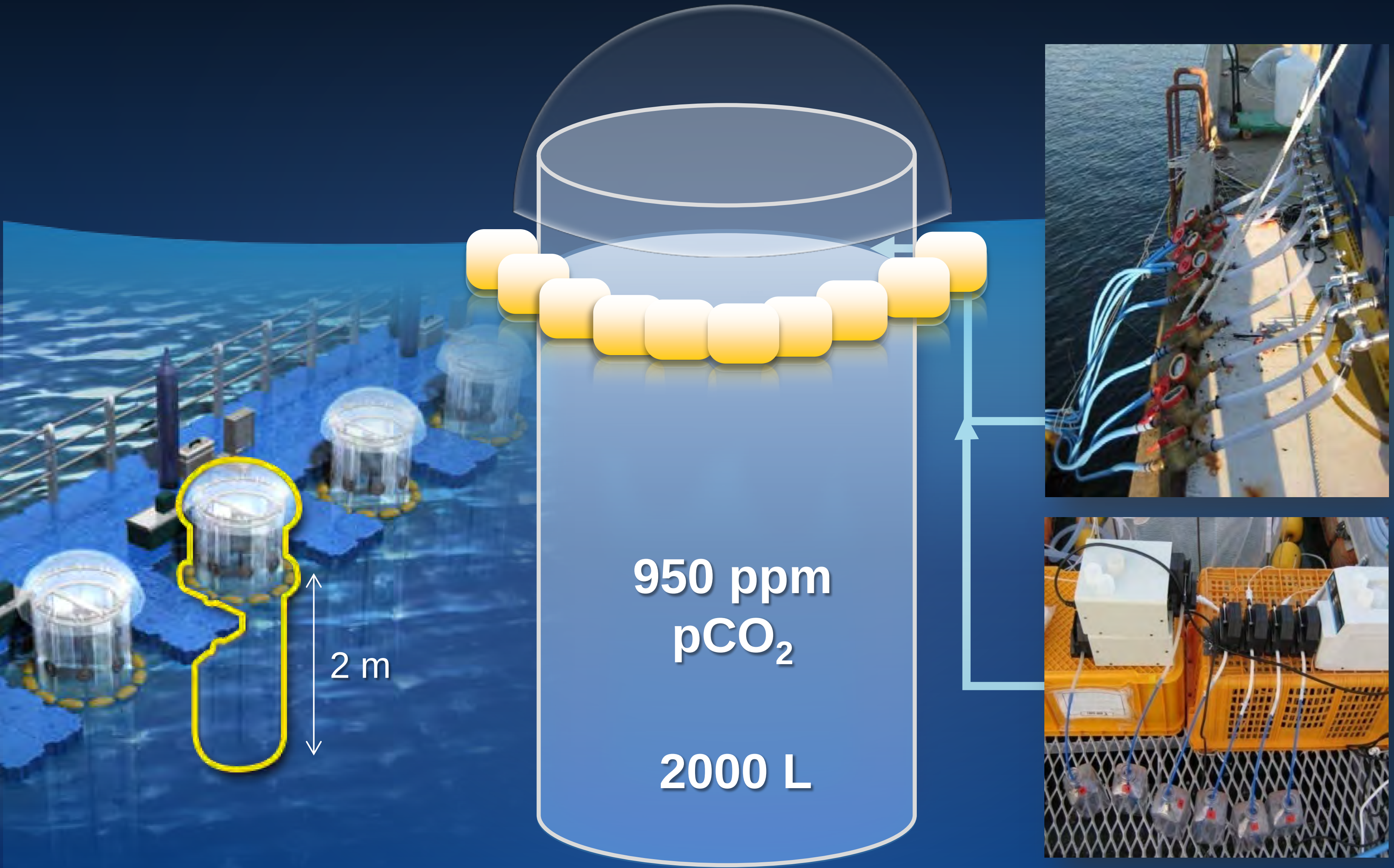
CLIMATE CHANGE 2007

THE PHYSICAL SCIENCE BASIS

Combined effects of seawater pCO_2 concentration & temperature

400 ppm **Ambient temp.**	**950 ppm** **Ambient temp.**	**950 ppm** **3°C higher temp.**
Control	**Acidification**	**Greenhouse**

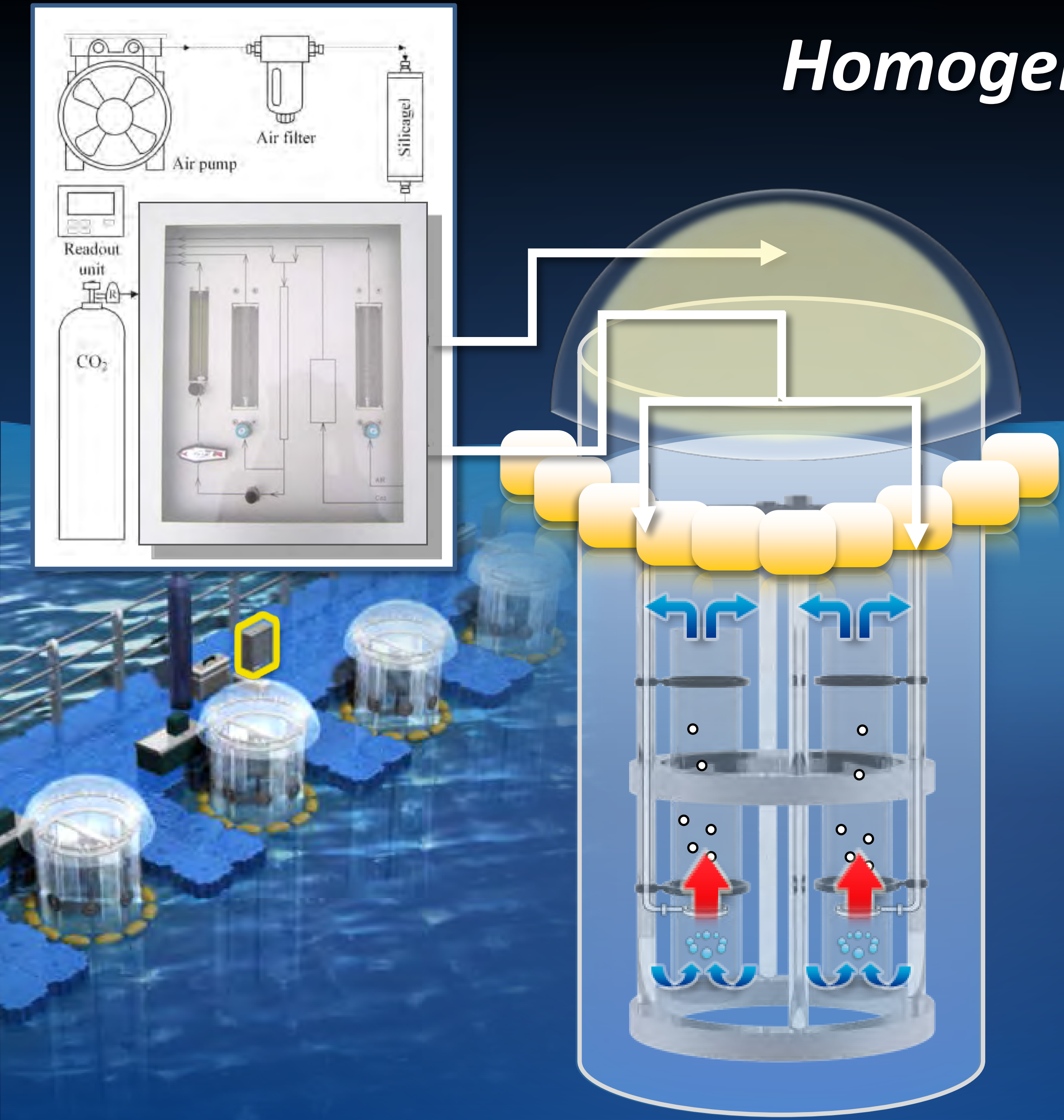
Experimental set up: *pCO_2 adjustment*

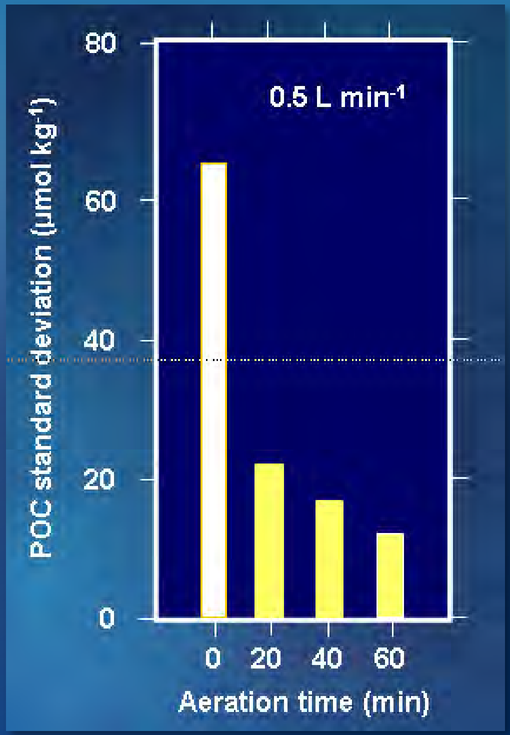


950 ppm pCO_2

2000 L

Homogeneous mixing

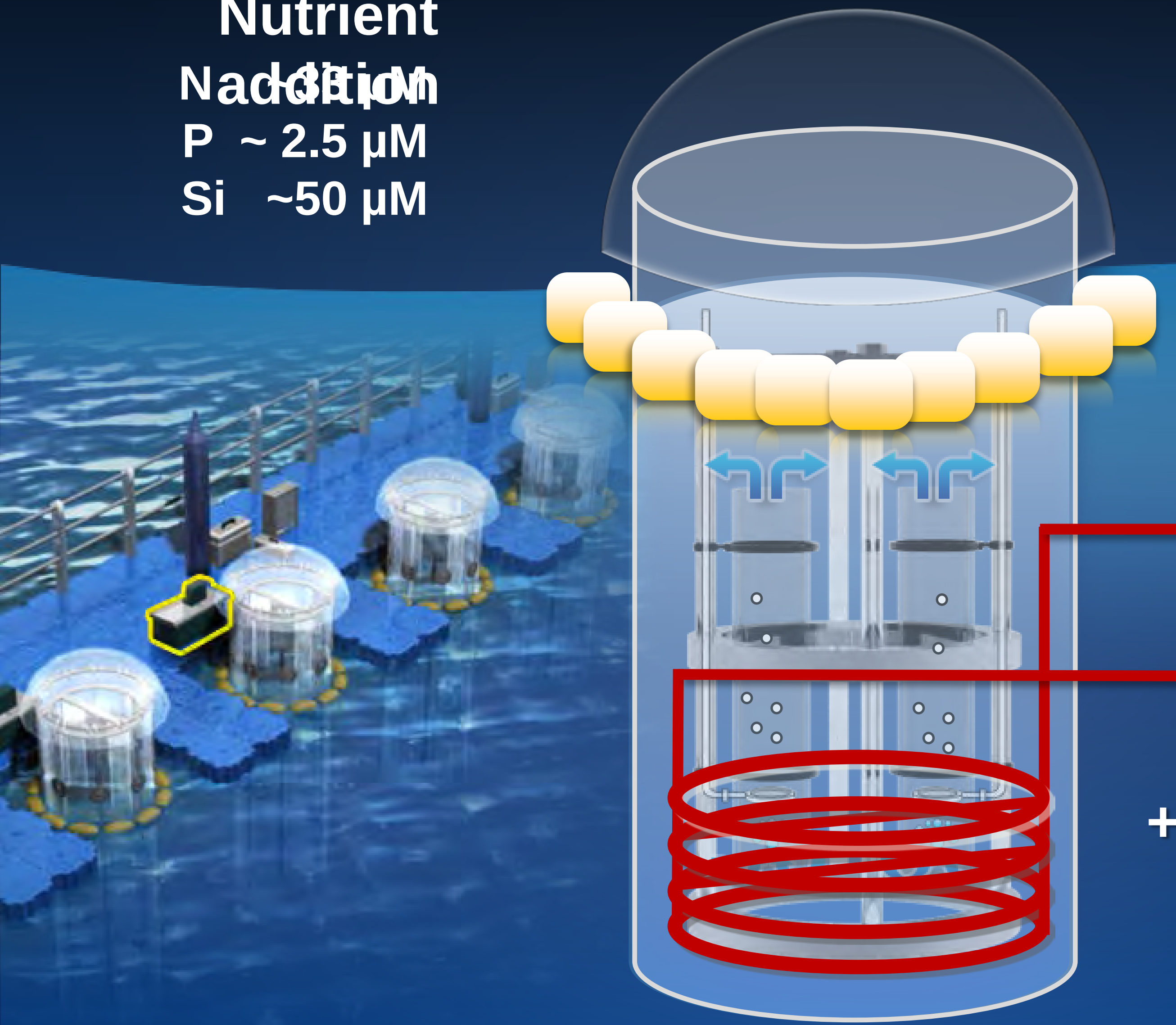


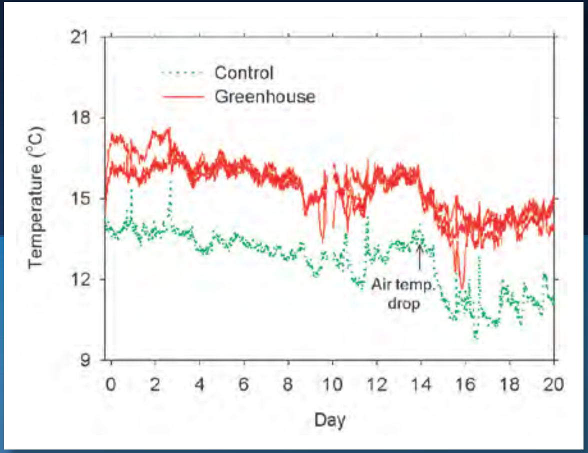


Temperature adjustment

Nutrient addition

N ~33 µM
P ~ 2.5 µM
Si ~50 µM

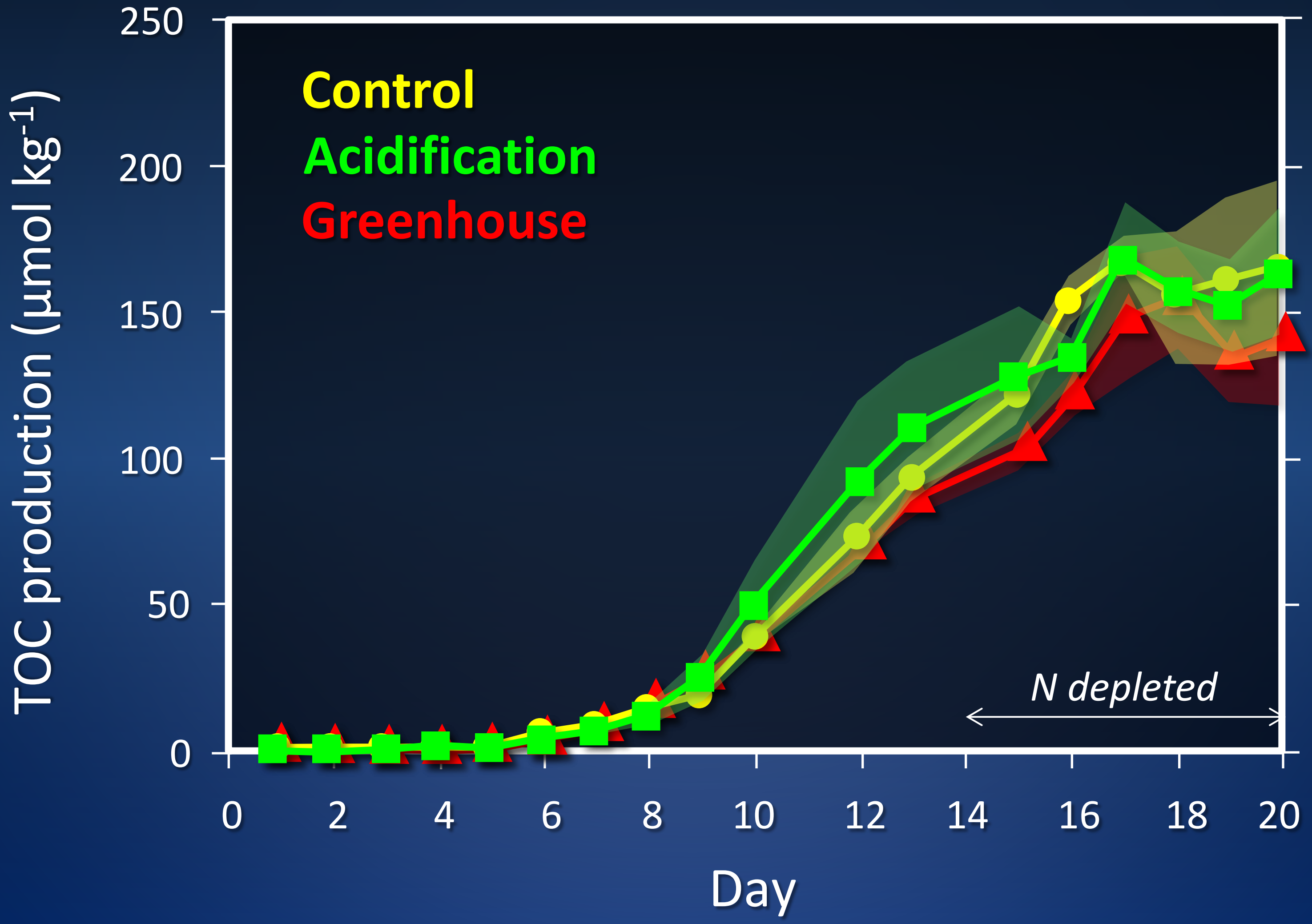




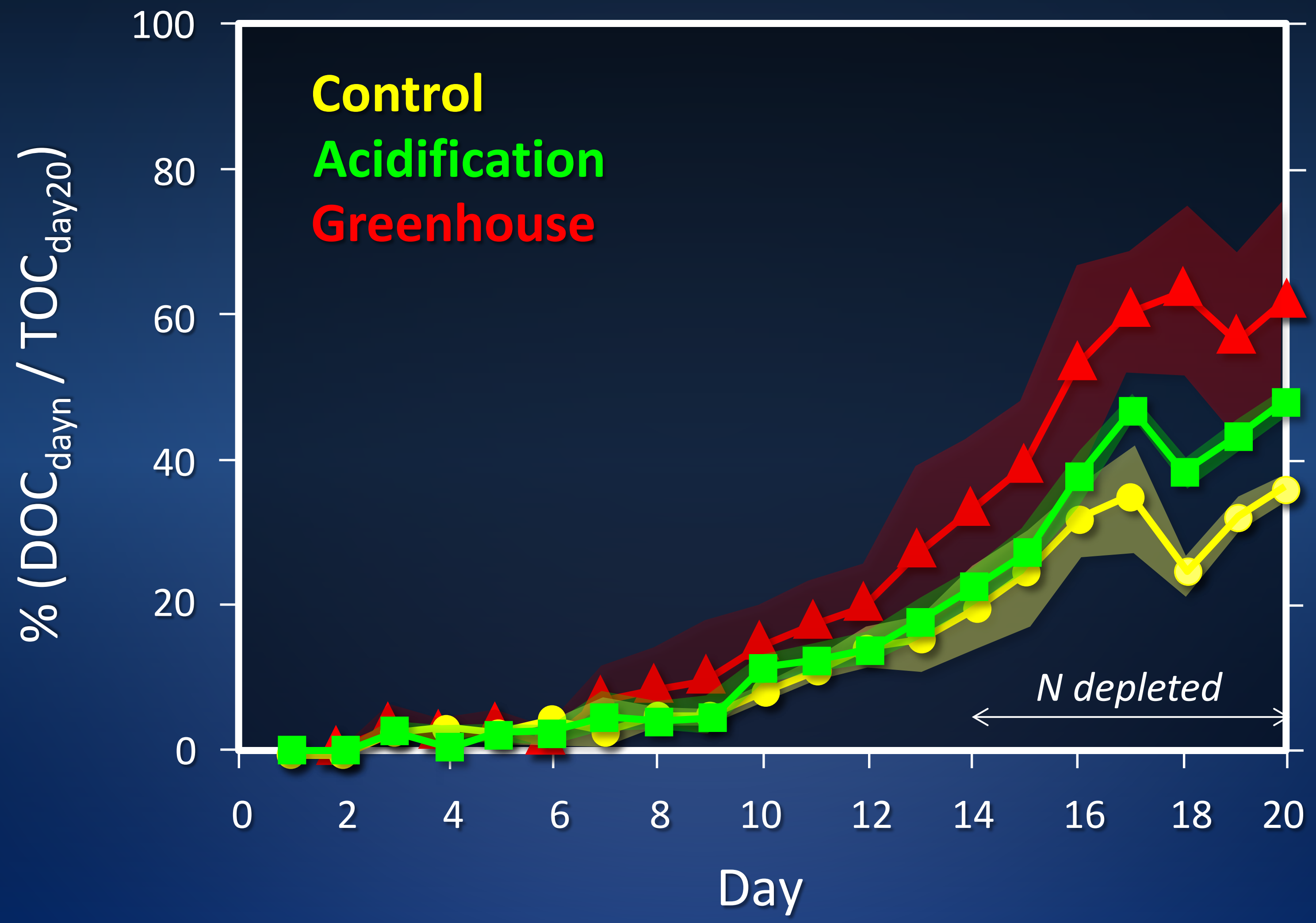
Water bath

+ 3°C

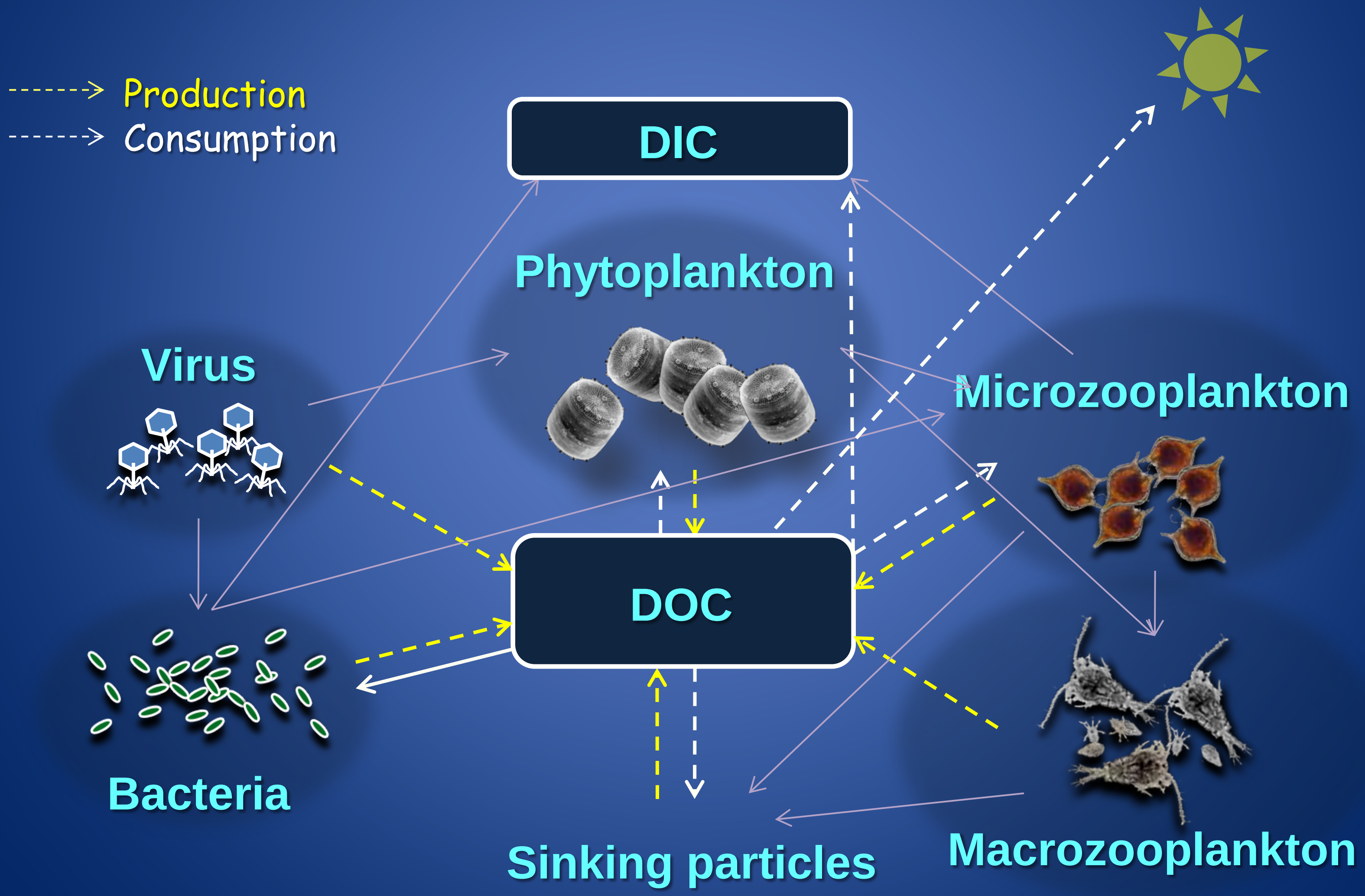
Total organic carbon production



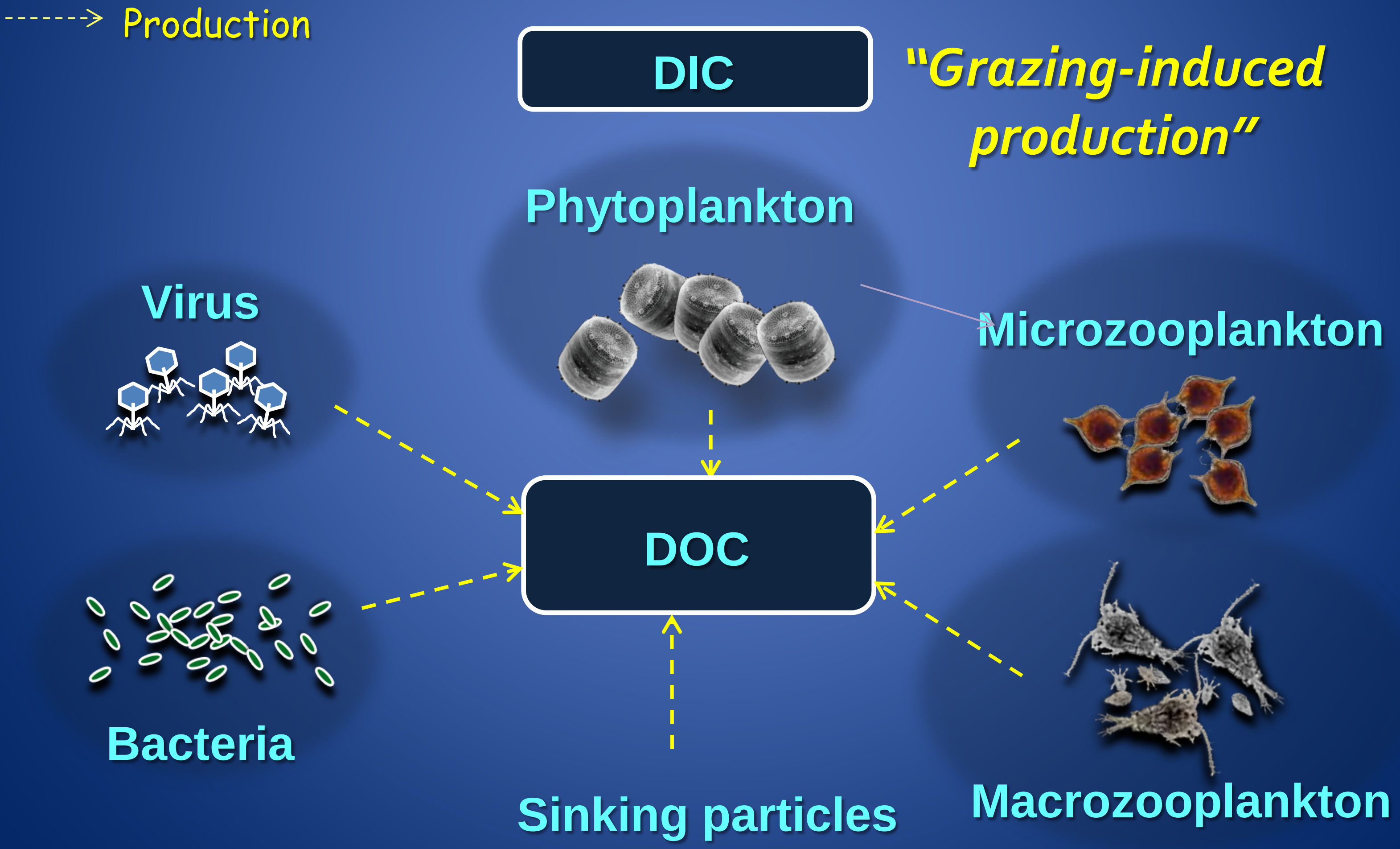
% ratio of DOC to TOC production



DOC production process in marine system



The most likely mechanism of enhanced DOC production



-------> Production

DIC

"Grazing-induced production"

Phytoplankton

Virus

Microzooplankton

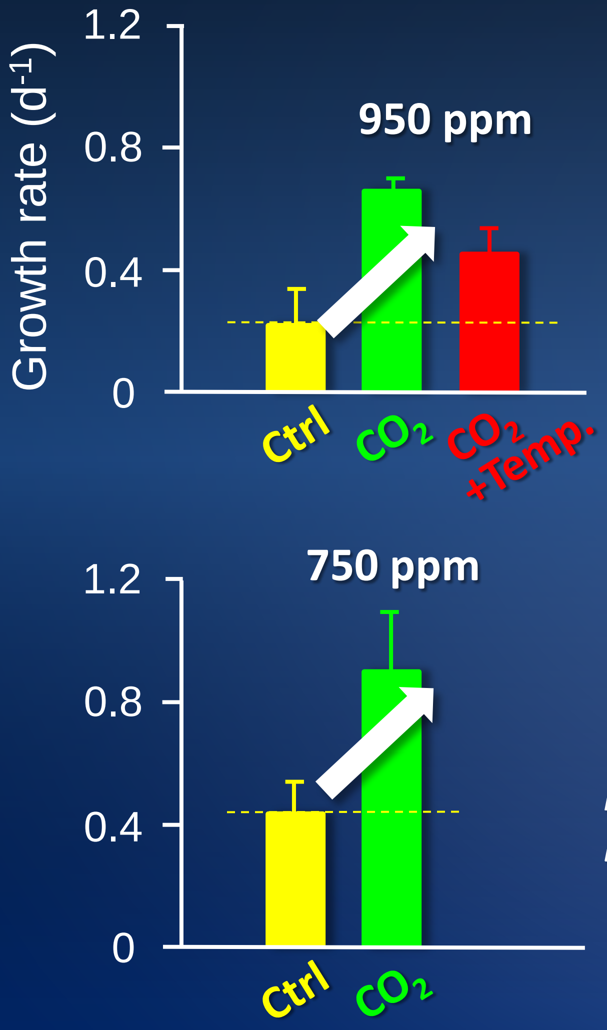
DOC

Bacteria

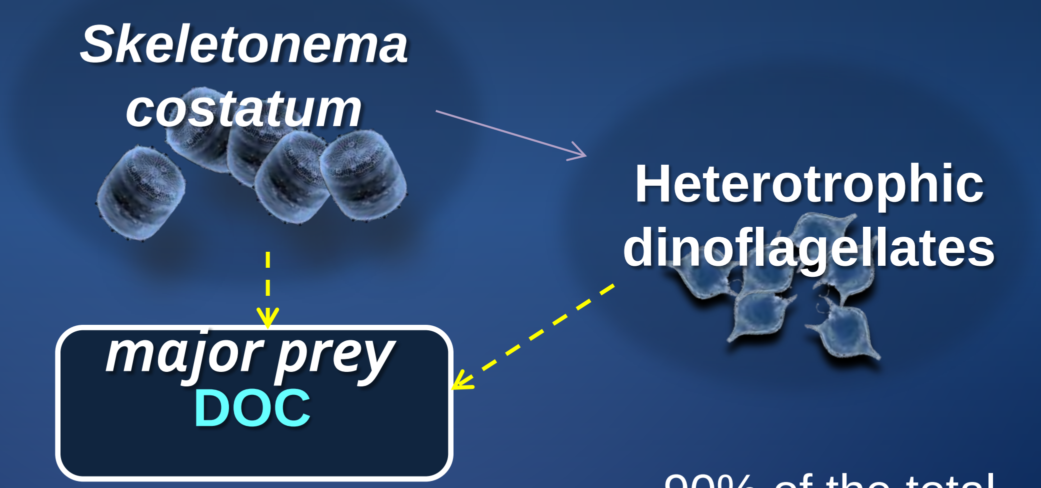
Sinking particles

Macrozooplankton

The most likely mechanism of enhanced DOC production



"Grazing-induced production"



Skeletonema costatum

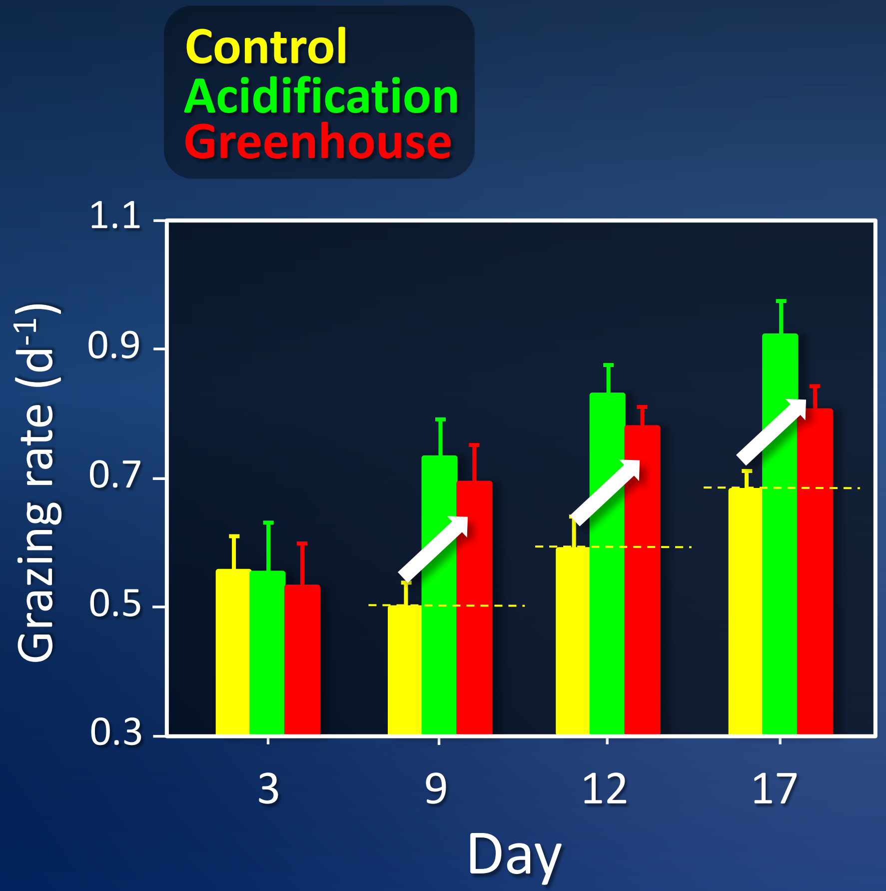
Heterotrophic dinoflagellates

major prey
DOC

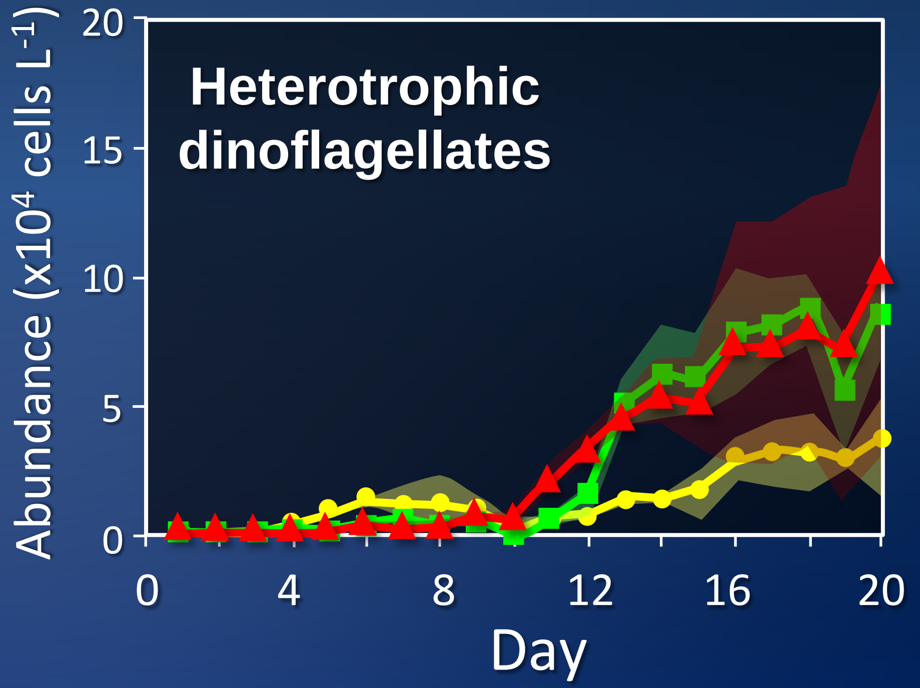
Kim et al. 2006
Limnol. Oceanogr.

~ 90% of the total carbon biomass of microzooplankton

The most likely mechanism of enhanced DOC production

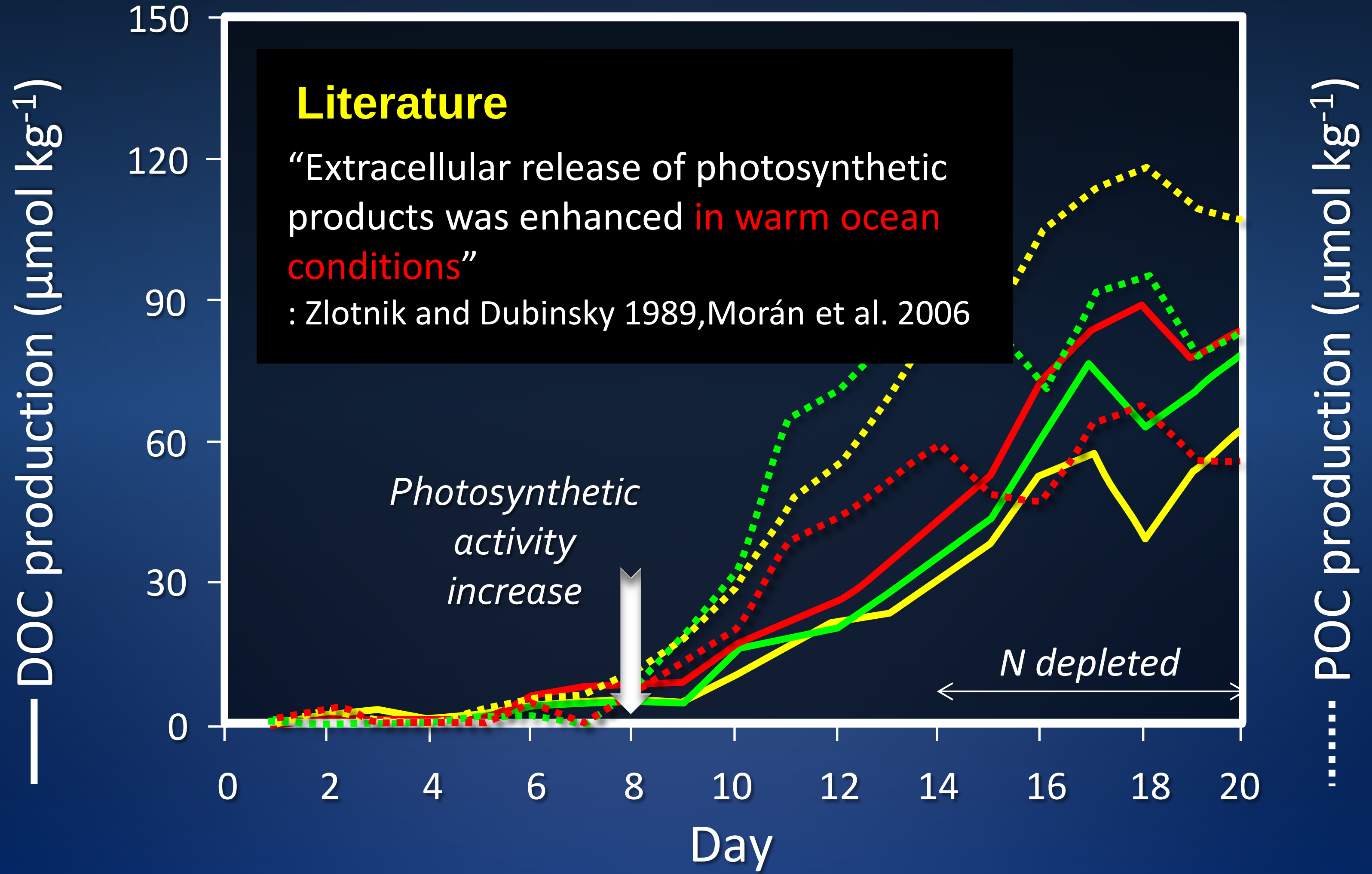


"Grazing-induced production"



Another possible mechanism…

"Extracellular DOC release"



Literature

"Extracellular release of photosynthetic products was enhanced in warm ocean conditions"

: Zlotnik and Dubinsky 1989,Morán et al. 2006

Enhanced DOC production under warm ocean condition

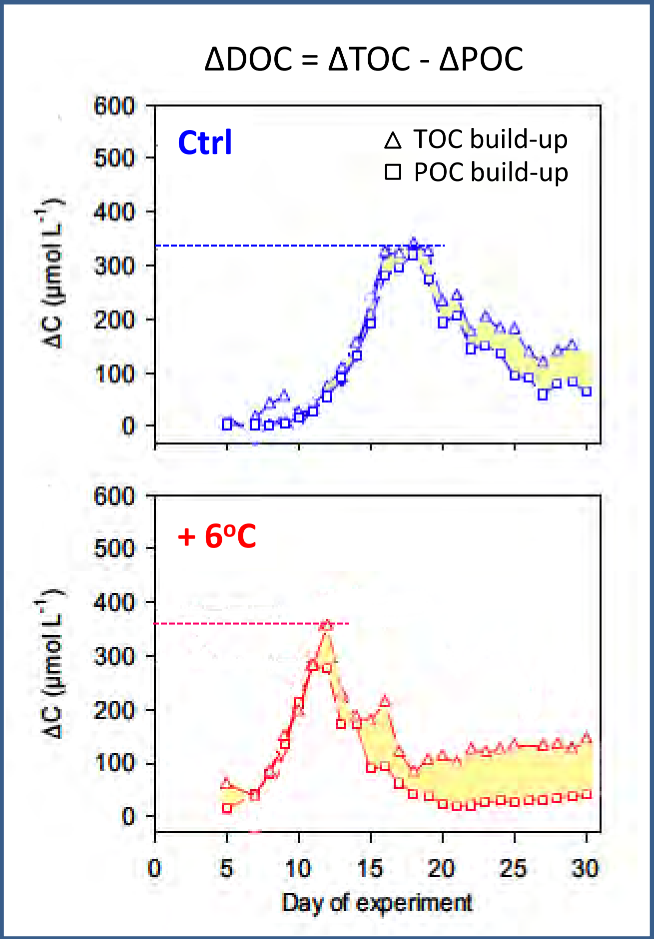
Wohlers et al. 2009

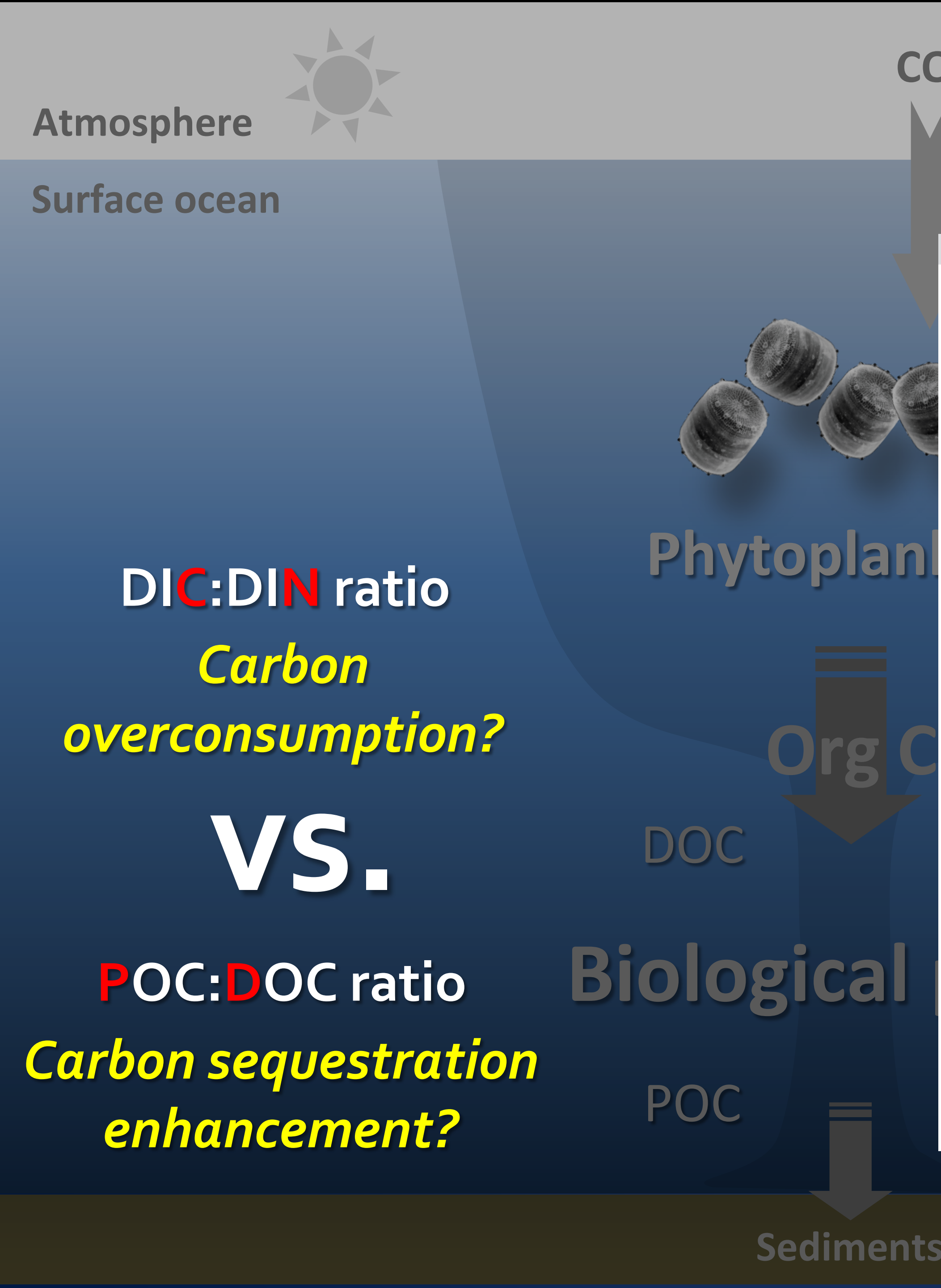
- Indoor-mesocosm
- Baltic seawater (winter/spring)
- Diatom (*S. costatum*) dominated

Net build-up of TOC was NOT markedly affected by changes in temperature.
Yet, after the biomass peak, an enhanced accumulation of DOC occurred at high Temp.

*** Underlying Mechanism**

High respiratory consumption of organic C relative to autotrophic production





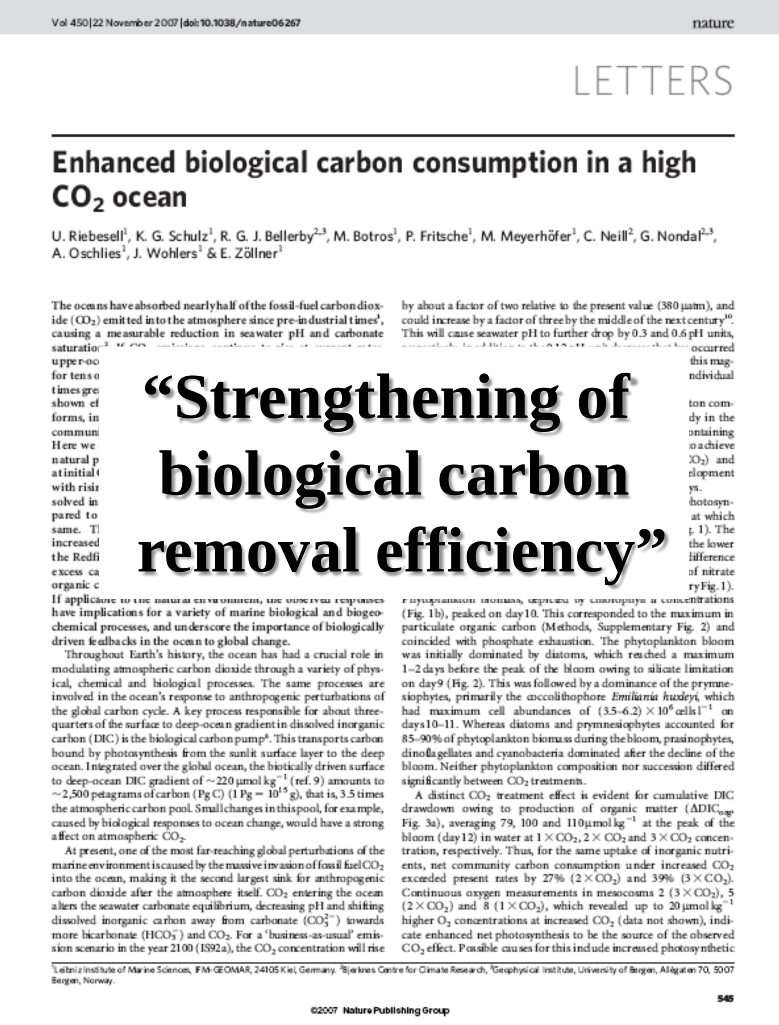
DIC:DIN ratio

Carbon overconsumption?

VS.

POC:DOC ratio

Carbon sequestration enhancement?



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nature

LETTERS

Enhanced biological carbon consumption in a high CO_2 ocean

U. Riebesell[1], K. G. Schulz[1], R. G. J. Bellerby[2,3], M. Botros[1], P. Fritsche[1], M. Meyerhöfer[1], C. Neill[2], G. Nondal[2,3], A. Oschlies[1], J. Wohlers[1] & E. Zöllner[1]

> “Strengthening of biological carbon removal efficiency”

The oceans have absorbed nearly half of the fossil-fuel carbon dioxide (CO_2) emitted into the atmosphere since pre-industrial times[1], causing a measurable reduction in seawater pH and carbonate saturation

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have implications for a variety of marine biological and biogeochemical processes, and underscore the importance of biologically driven feedbacks in the ocean to global change.

Throughout Earth's history, the ocean has had a crucial role in modulating atmospheric carbon dioxide through a variety of physical, chemical and biological processes. The same processes are involved in the ocean's response to anthropogenic perturbations of the global carbon cycle. A key process responsible for about three-quarters of the surface to deep-ocean gradient in dissolved inorganic carbon (DIC) is the biological carbon pump[8]. This transports carbon bound by photosynthesis from the sunlit surface layer to the deep ocean. Integrated over the global ocean, the biotically driven surface to deep-ocean DIC gradient of ~220 μmol kg^{-1} (ref. 9) amounts to ~2,500 petagrams of carbon (Pg C) (1 Pg = 10^{15} g), that is, 3.5 times the atmospheric carbon pool. Small changes in this pool, for example, caused by biological responses to ocean change, would have a strong affect on atmospheric CO_2.

At present, one of the most far-reaching global perturbations of the marine environment is caused by the massive invasion of fossil fuel CO_2 into the ocean, making it the second largest sink for anthropogenic carbon dioxide after the atmosphere itself. CO_2 entering the ocean alters the seawater carbonate equilibrium, decreasing pH and shifting dissolved inorganic carbon away from carbonate (CO_3^{2-}) towards more bicarbonate (HCO_3^-) and CO_2. For a 'business-as-usual' emission scenario in the year 2100 (IS92a), the CO_2 concentration will rise by about a factor of two relative to the present value (380 μatm), and could increase by a factor of three by the middle of the next century[10]. This will cause seawater pH to further drop by 0.3 and 0.6 pH units,

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(Fig. 1b), peaked on day 10. This corresponded to the maximum in particulate organic carbon (Methods, Supplementary Fig. 2) and coincided with phosphate exhaustion. The phytoplankton bloom was initially dominated by diatoms, which reached a maximum 1–2 days before the peak of the bloom owing to silicate limitation on day 9 (Fig. 2). This was followed by a dominance of the prymnesiophytes, primarily the coccolithophore *Emiliania huxleyi*, which had maximum cell abundances of (3.5–6.2) × 10^6 cells l^{-1} on days 10–11. Whereas diatoms and prymnesiophytes accounted for 85–90% of phytoplankton biomass during the bloom, prasinophytes, dinoflagellates and cyanobacteria dominated after the decline of the bloom. Neither phytoplankton composition nor succession differed significantly between CO_2 treatments.

A distinct CO_2 treatment effect is evident for cumulative DIC drawdown owing to production of organic matter (ΔDIC_{org}, Fig. 3a), averaging 79, 100 and 110 μmol kg^{-1} at the peak of the bloom (day 12) in water at 1 × CO_2, 2 × CO_2 and 3 × CO_2 concentration, respectively. Thus, for the same uptake of inorganic nutrients, net community carbon consumption under increased CO_2 exceeded present rates by 27% (2 × CO_2) and 39% (3 × CO_2). Continuous oxygen measurements in mesocosms 2 (3 × CO_2), 5 (2 × CO_2) and 8 (1 × CO_2), which revealed up to 20 μmol kg^{-1} higher O_2 concentrations at increased CO_2 (data not shown), indicate enhanced net photosynthesis to be the source of the observed CO_2 effect. Possible causes for this include increased photosynthetic

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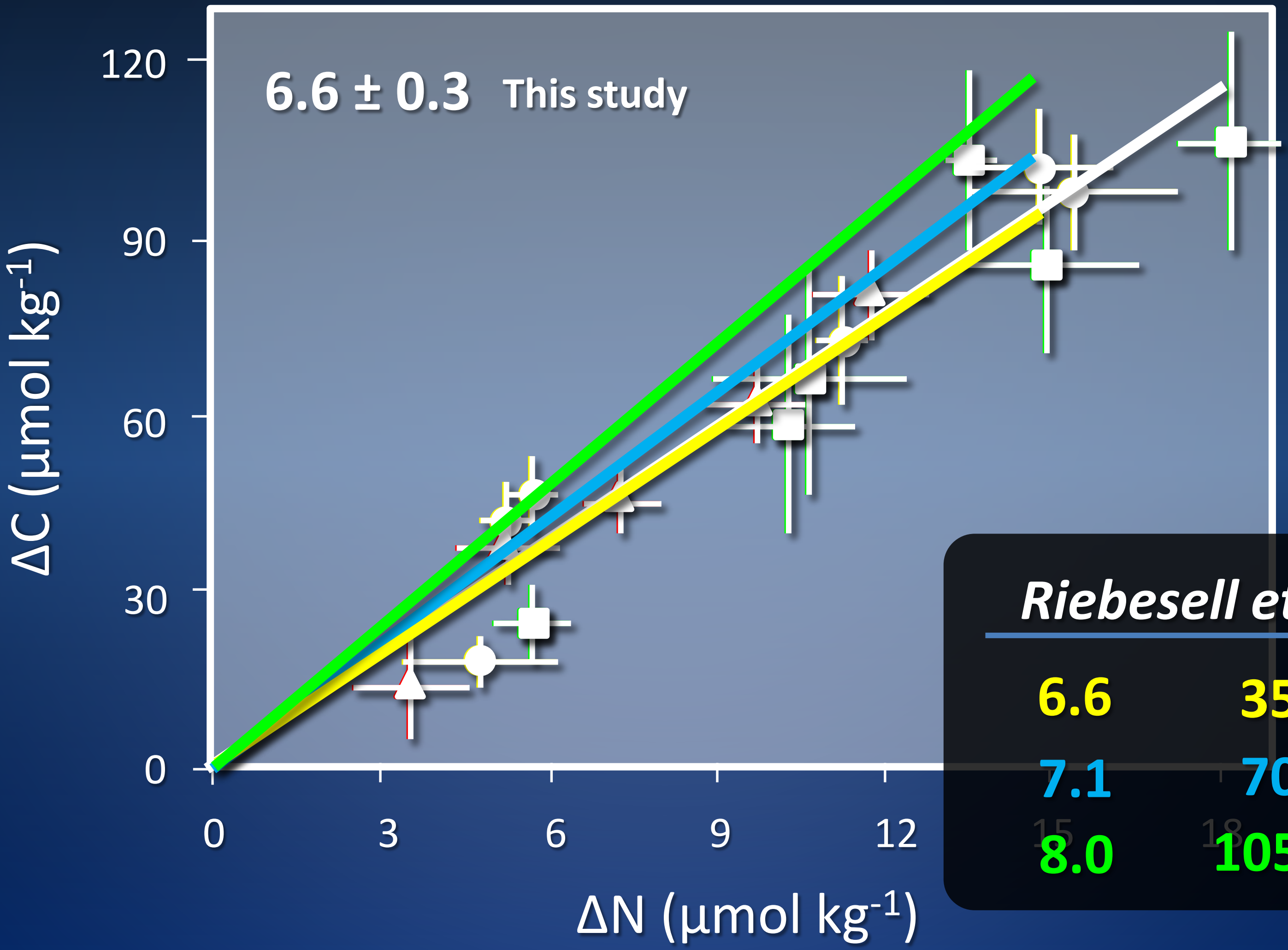
The molar ratio of C to N

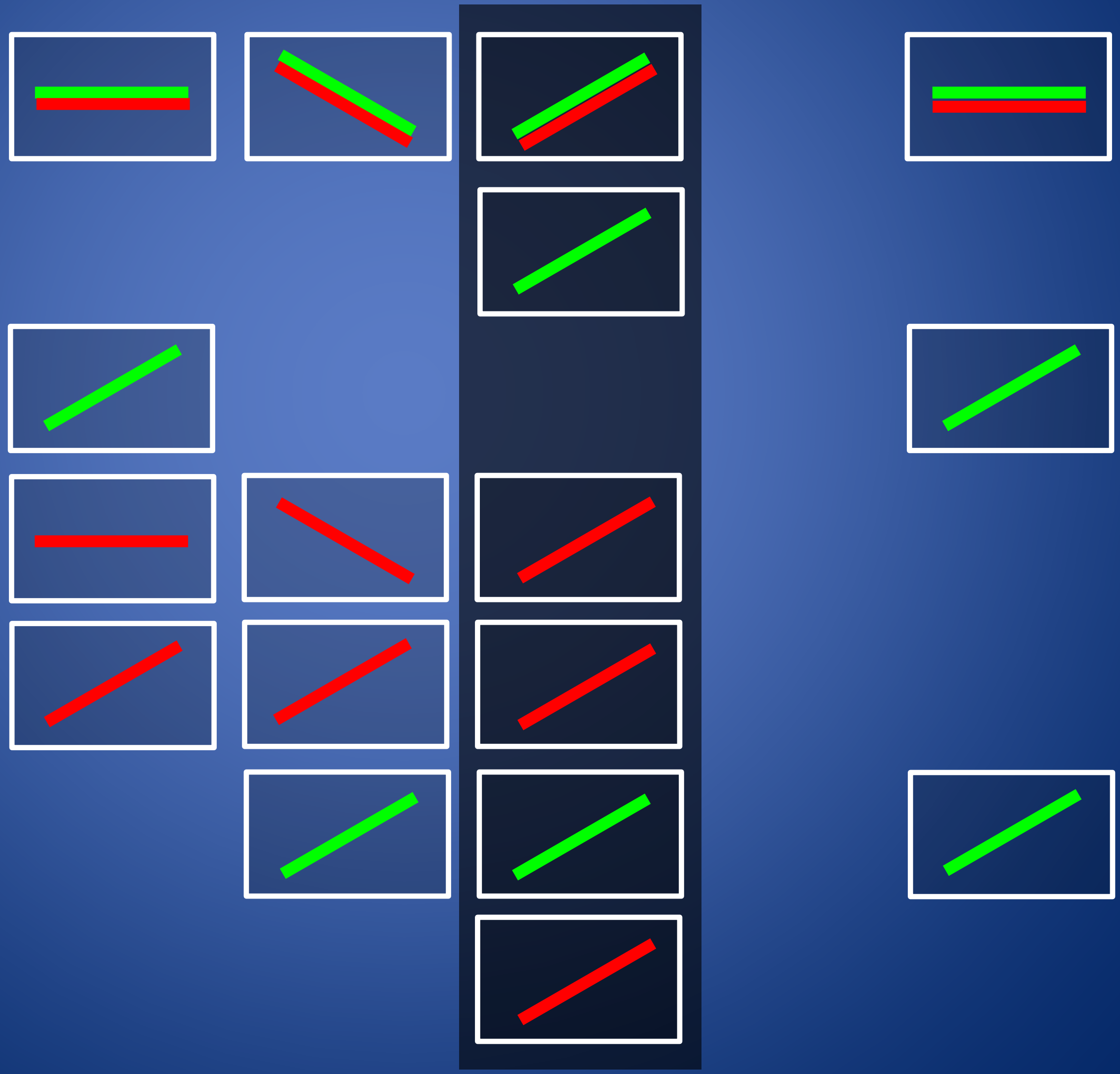


Riebesell et al. 2007

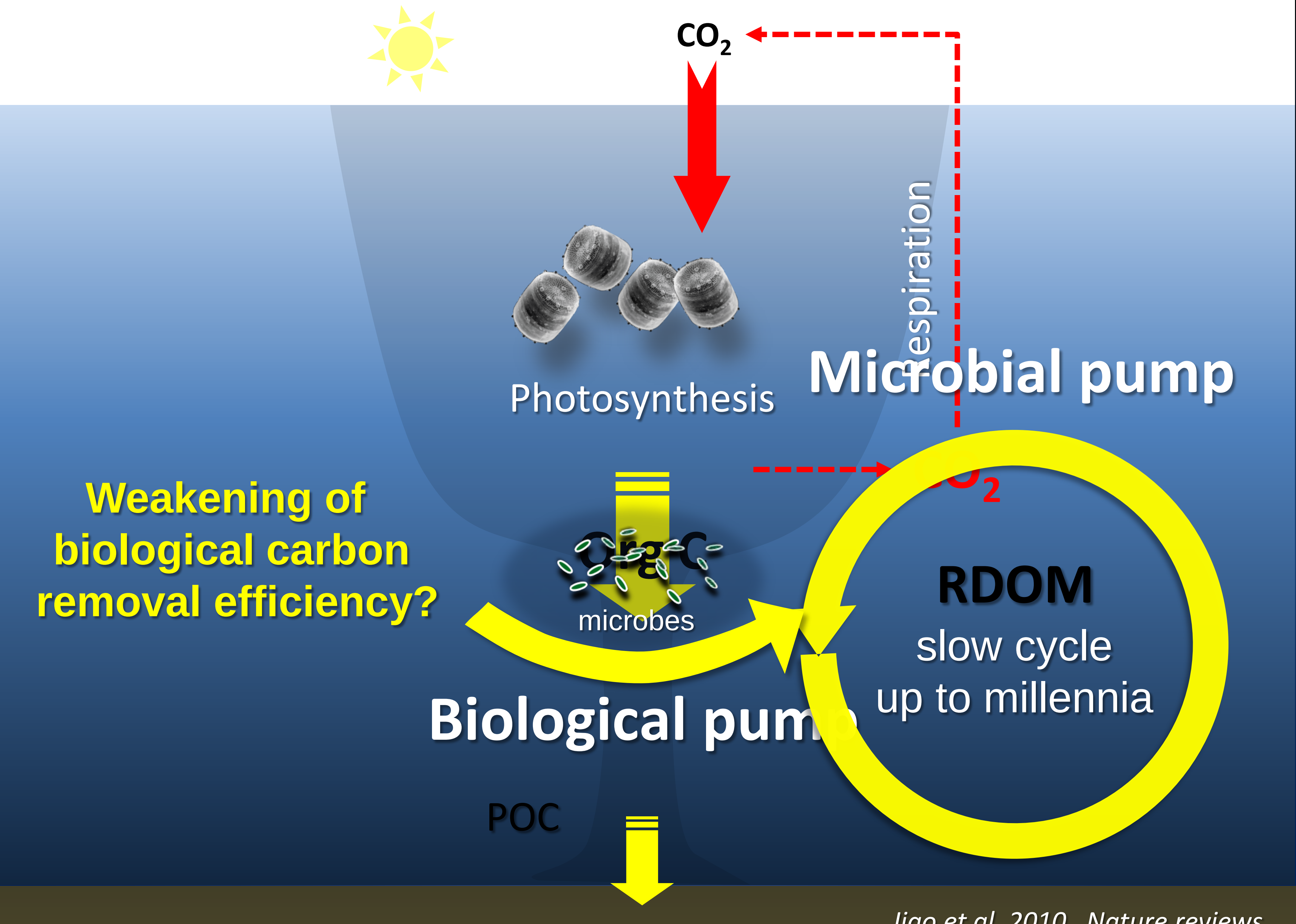
6.6	350 ppmv
7.1	700 ppmv
8.0	1050 ppmv

CO_2 effect

Temp. effect



	Partitioning			Elemental ratio
	ΔTOC (or ΔDIC)	ΔPOC	ΔDOC	ΔTOC:N (or ΔDIC:N)
This study	🟩→ 🟥→	🟩↘ 🟥↘	🟩↗ 🟥↗	🟩→ 🟥→
Engel et al. 2004			🟩↗	
Riebesell et al. 2007	🟩↗			🟩↗
Wohlers et al. 2009	🟥→	🟥↘	🟥↗	
Taucher et al. 2012	🟥↗	🟥↗	🟥↗	
Engel/Czerny et al. 2013		🟩↗	🟩↗	🟩↗
Biermann et al. 2015			🟥↗	



CO_2

Respiration

Photosynthesis

Microbial pump

Weakening of biological carbon removal efficiency?

CO_2

Org C

microbes

RDOM

slow cycle
up to millennia

Biological pump

POC

Jiao et al. 2010 Nature reviews

Conclusion

1. Elevated seawater pCO_2 concentration and temperature stimulated two main processes responsible for enhancing DOC production (release by grazers and the extracellular release by phytoplankton).

2. An increase in the DOC:POC production ratio implies a shift in the organic carbon flow from particulate to dissolved forms under future ocean condition.

3. Excess DOC production may act as a positive feed back to increase the atmospheric CO_2 (if the produced DOC is labile and rapidly transformed into inorganic carbon by microbial degradation).