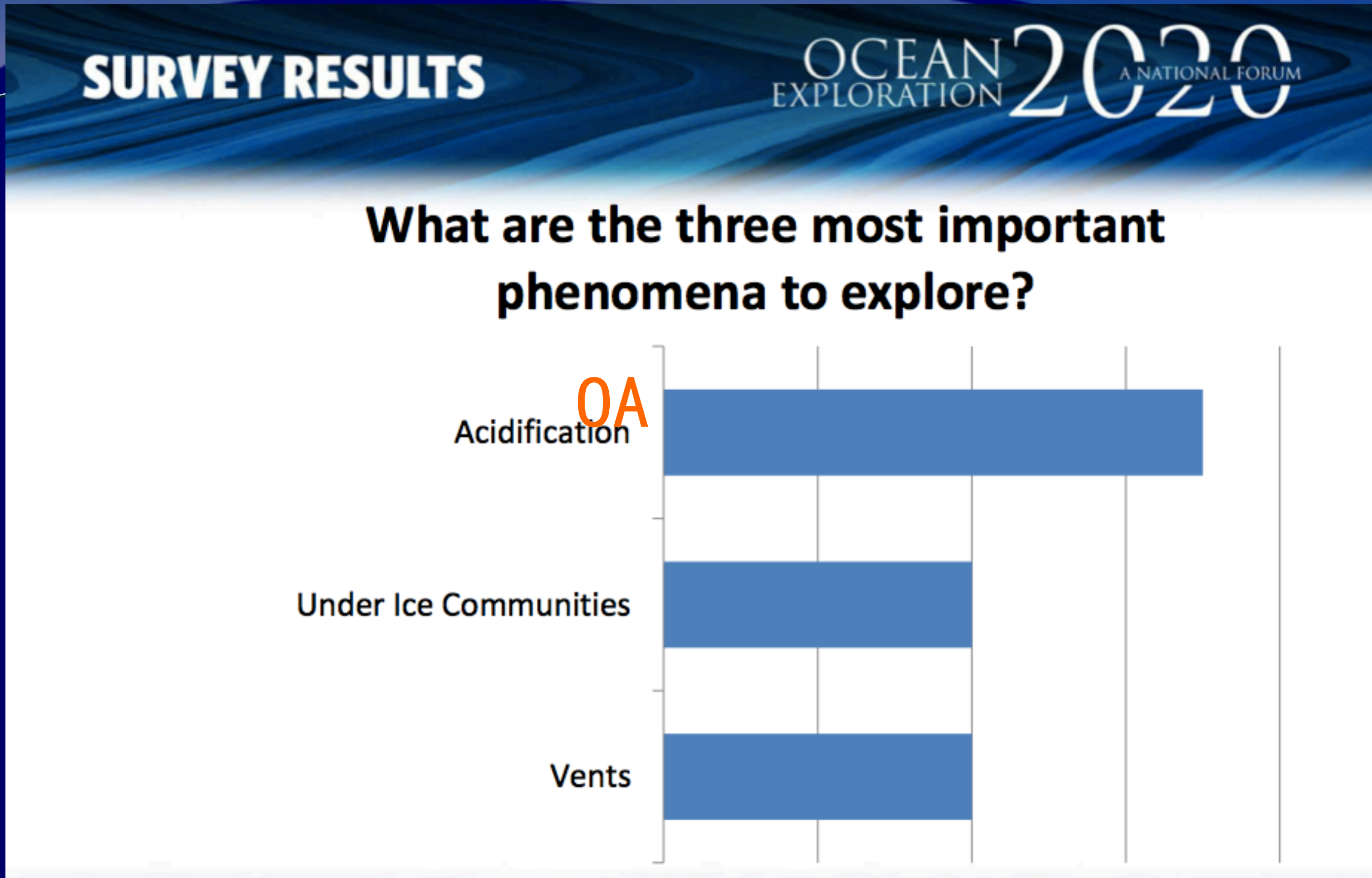
Effects of Ocean Acidification on Marine Primary Producers

Kunshan Gao et al.

PICES, Qingdao, 2015

MEL
State Key Laboratory of Marine Environmental Science

State Key Laboratory of Marine Environmental Science (Xiamen Univ.)



Google Search（<1 s）

2009年 “海洋酸化”/ocean acidification: 70/700 K

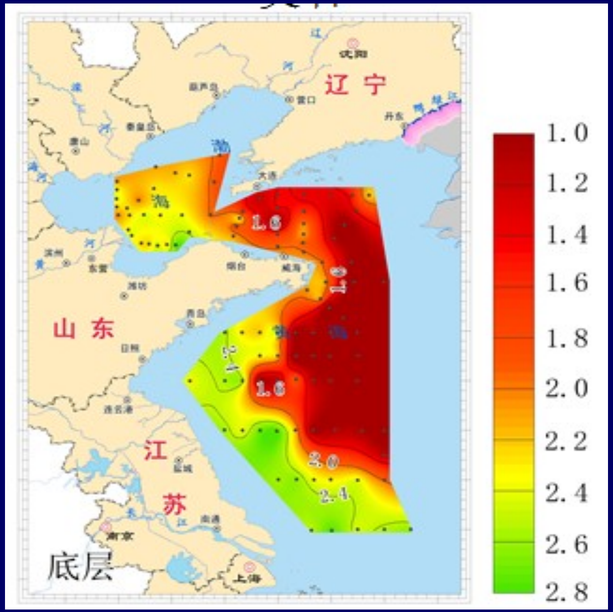
2013年 “海洋酸化”/ocean acidification: 2.58/2.59 M

“Chinese OA awareness index”

Documented low pH in the Chinese coastal waters

Regions	Low pH
The Bohai Sea (***Chinese Science Bulletin 2012)***	7.64 H^+ rise by 220%
The Yellow Sea（***Biogeosciences 2014***）	7.80
The East China Sea (***Biogeosciences 2013)***	7.80
The Northern South China Sea（*JGR 2011*）	7. 9

Ocean acidification is occurring in the Chinese waters.



“中国海洋环境公报 2012”

Seawater Carbonate System Changes

CO_2 CO_2 CO_2

Doubled pCO_2

$CO_2\ (g) \rightarrow CO_2\ (aq)$ ↑ 100%

$CO_2\ (aq) + H_2O \rightarrow H_2CO_3$

$H_2CO_3 \rightarrow HCO_3^- + H^+$

$CO_3^{2-} + H^+ \rightarrow HCO_3^-$

0.3-0.4, 40%, 10%

pH ↓ CO_3^{2-} ↓ HCO_3^- ↑

$\Omega = [CO_3^{2-}]_{MEAS} / [CO_3^{2-}]_{CAL}$ ↓ 40%

- Briefing Ecological Effects of OA
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- Summary

G Caramnna

SEA CHANGE WITH PLYMOUTH UNIVERSITY

MedSeA
MEDITERRANEAN SEA ACIDIFICATION UNDER CHANGING CLIMATE

UK Ocean Acidification Research Programme

save our seas FOUNDATION

Effects on Ecosystems

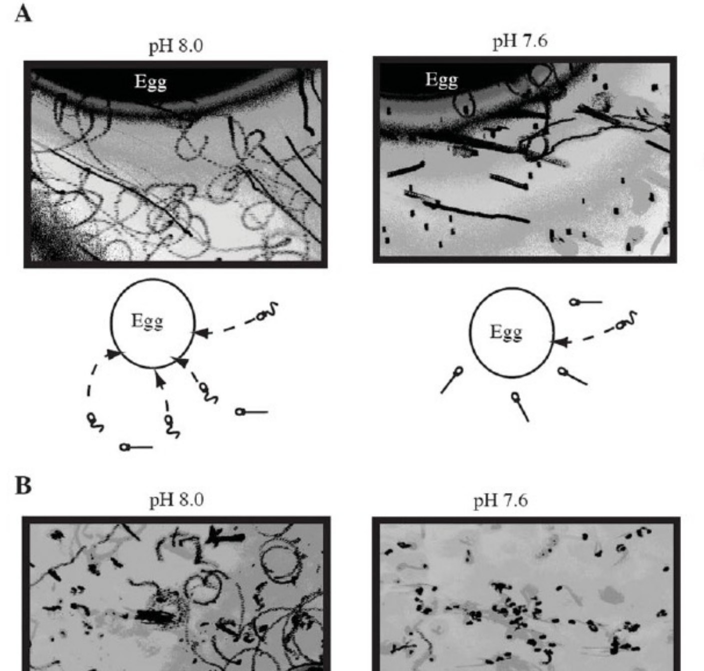
A window into the future of coral reefs?

pH 8.05: Today **pH 7.95: ~ year 2050** **pH 7.8: ~ year 2100**

Fabricius et al. (2010) *Nat Clim Change*

Inoue et al. 2013 *Nat Clim Change*

Munday et al. 2009



Reduce the sperm flagella motility of reef invertebrates (Morita et al.2009)

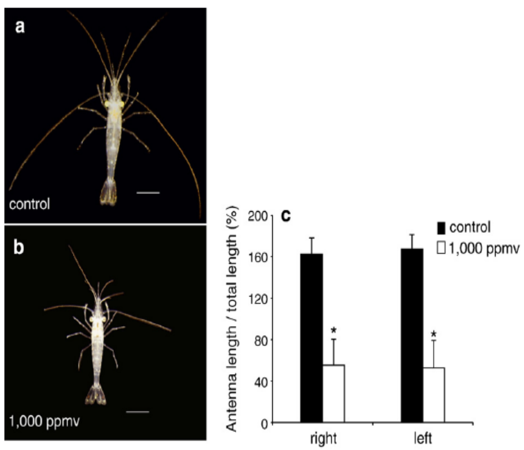
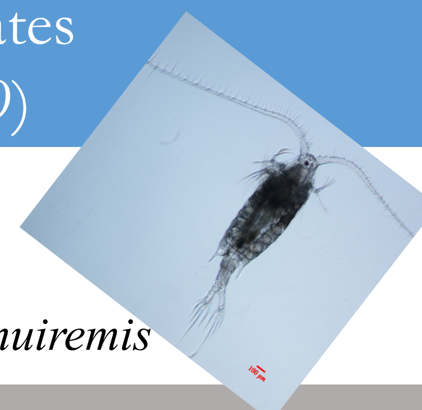


Fig. 6. Effects of 30-week exposure to 1,000 ppmv CO_2 on the antenna length of the marine shrimp *Palaemon pacificus* (**a** control, **b** experimental). The ratio of antenna/total length was significantly smaller in experimental shrimps (54.0±21.9%, n=9, 2 individuals not measured) than in controls (164.9±14.2%, n=18, *t*-test, $p<0.001$, **c**). Bar=1 cm.

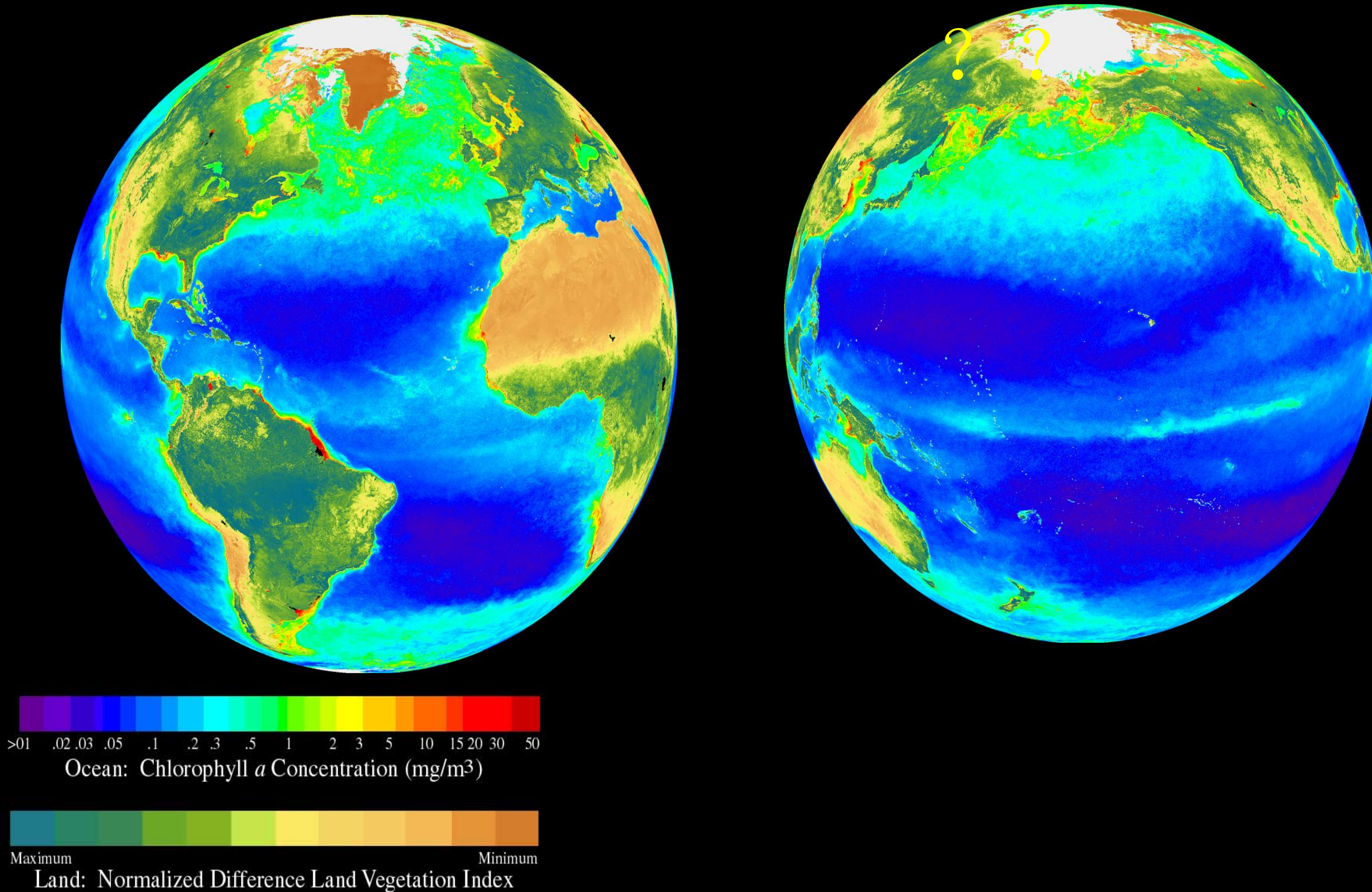


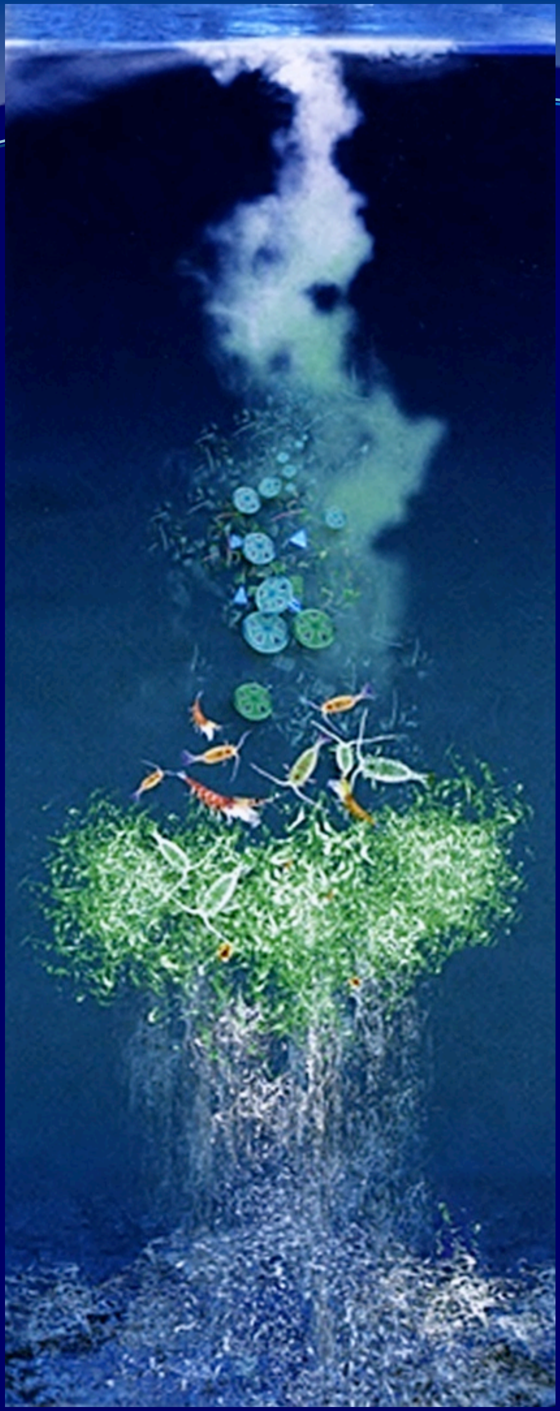
Centropages tenuiremis

Shorter antennae
Kurihara et al.2008

A marine secondary producer respires and feeds more in a high CO_2 ocean
Li & Gao 2012

Phytoplankton communities will change due to climatically-driven ocean changes (*Falkowski et al.2007)*. Are marine PP going to sustain by 50%





Photosynthesis-driven biological CO_2 pump would lead to more or less CO_2 dissolution into the oceans ?

?

- Briefing Ecological Effects of OA
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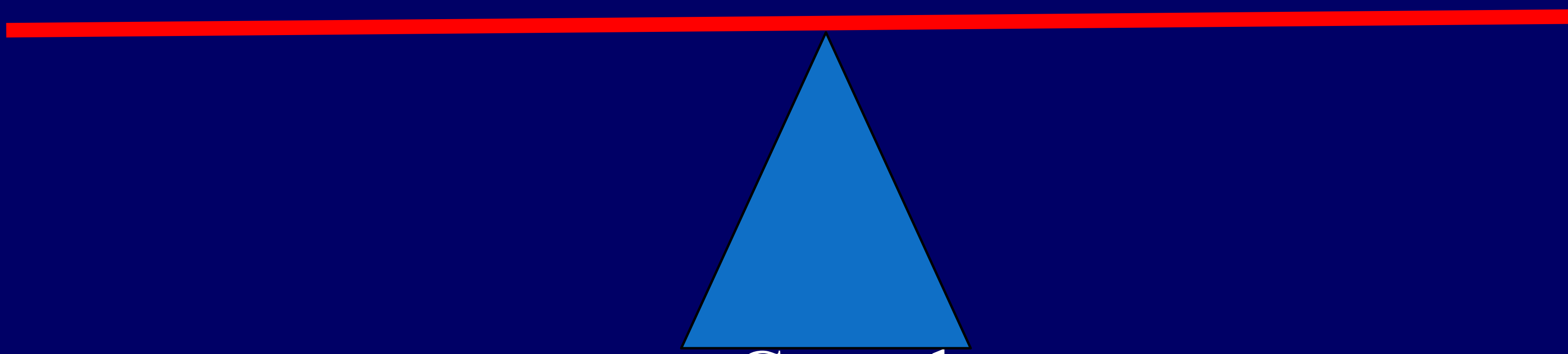
About 451 papers on phytoplankton and 282 macro algae's response to OA till Jul. 13, 2015 (OA-ICC bibliographic database)

Nature 1997,
Science 2008…….

Nature 2000, 2011;
Nat Clim Change 2012
……...

- Stimulating Neutral Inhibitive

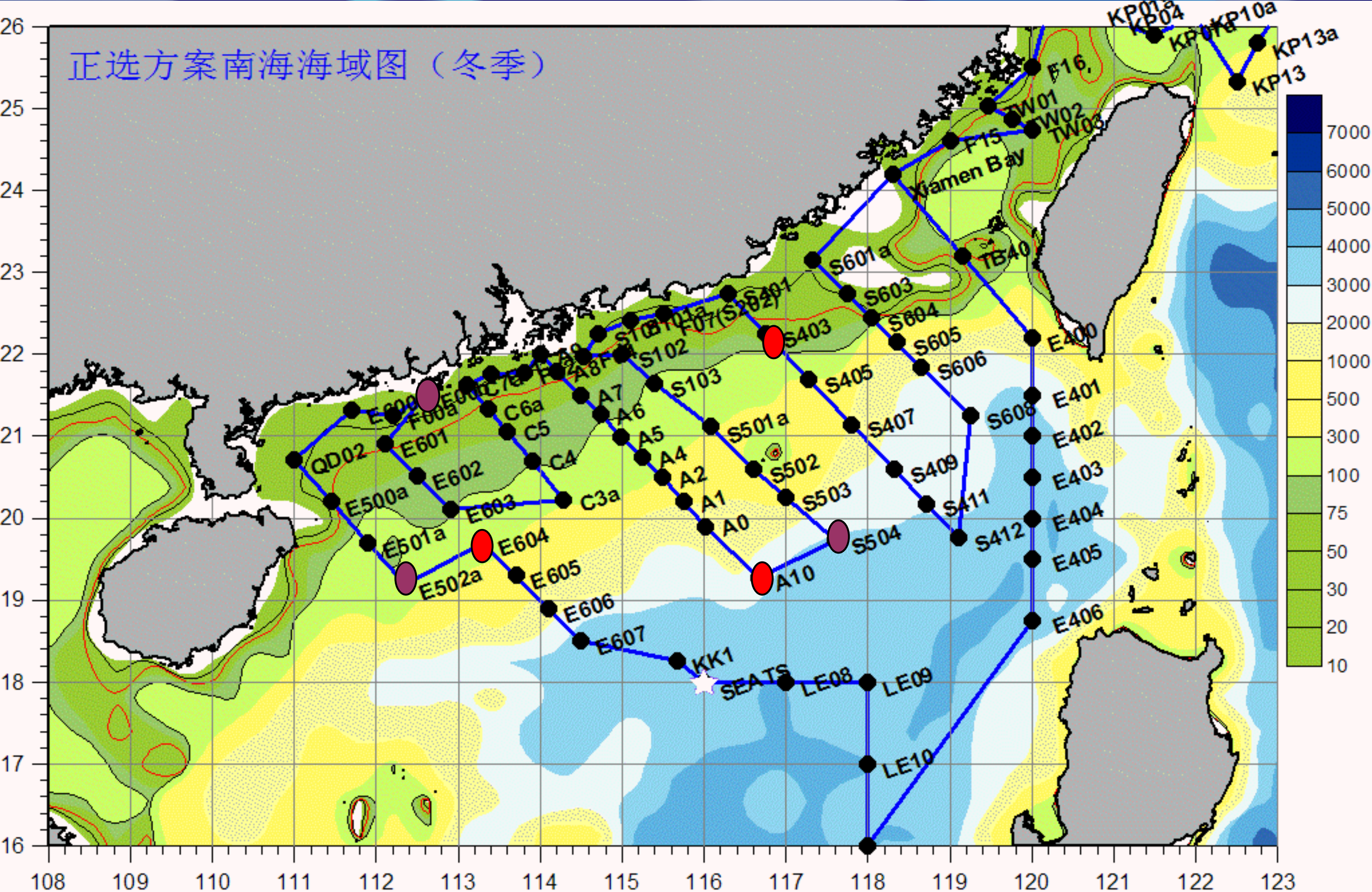


Growth

Photosynthesis

Respiration

Calcification


正选方案南海海域图（冬季）
Xiamen Bay
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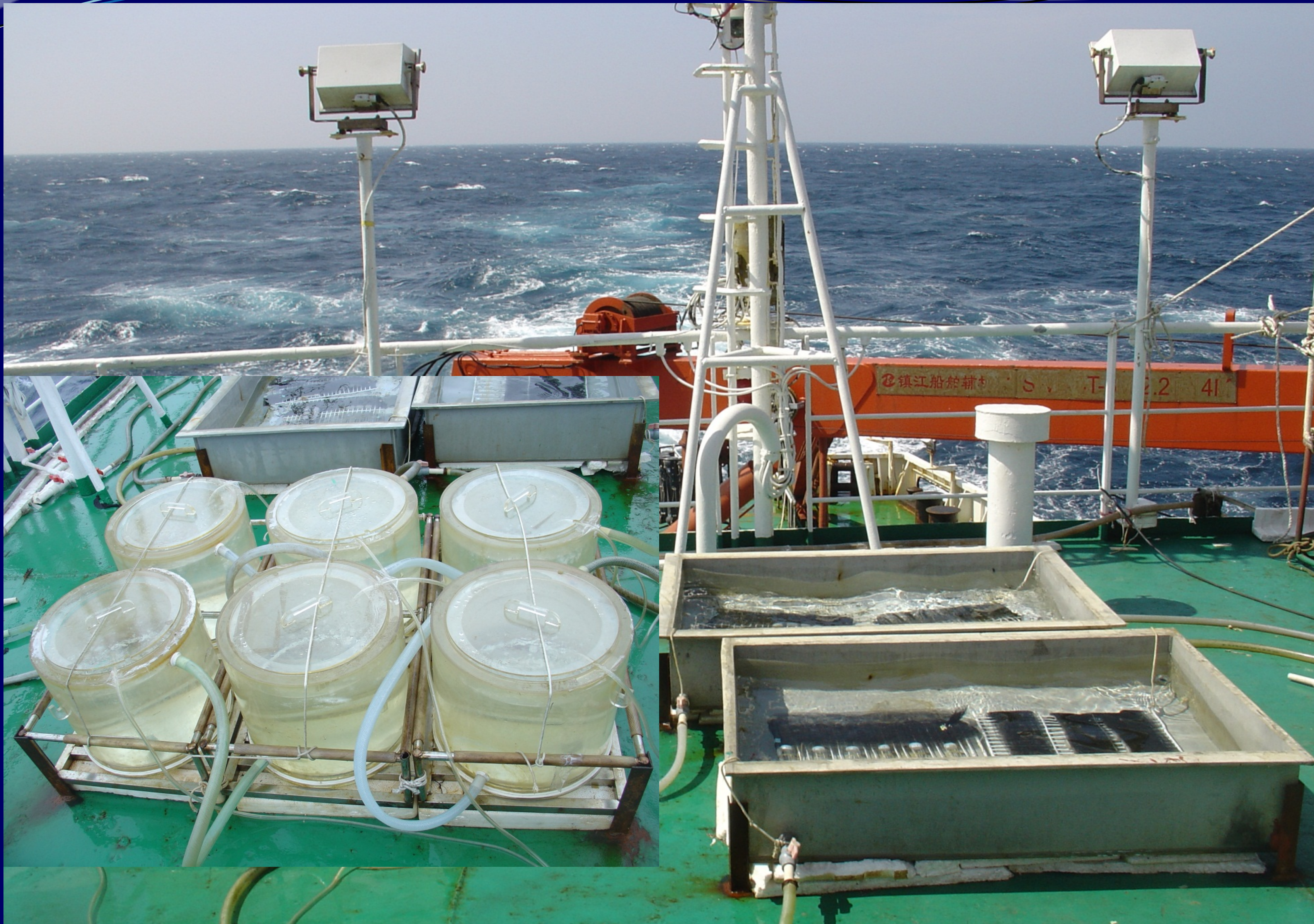
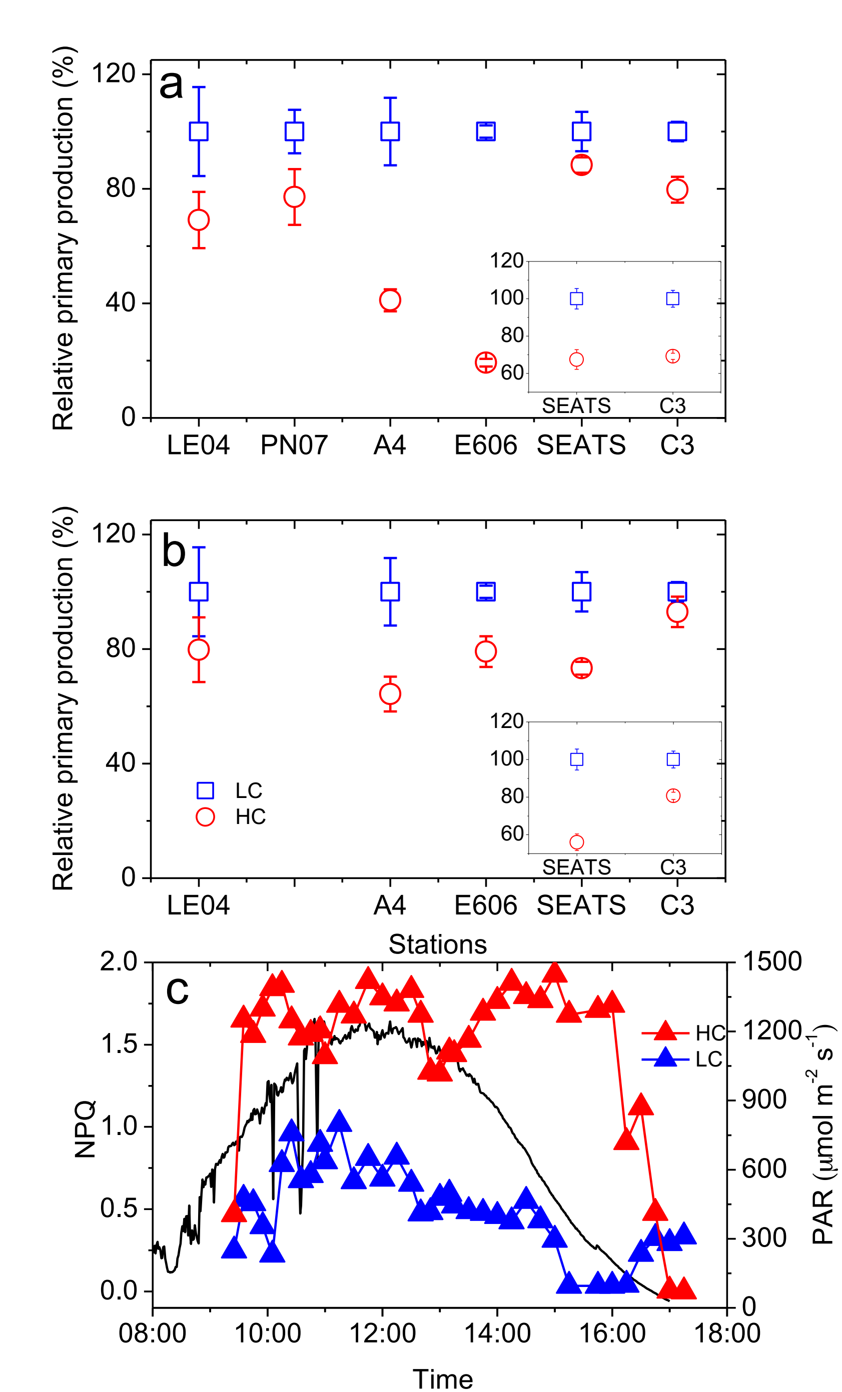
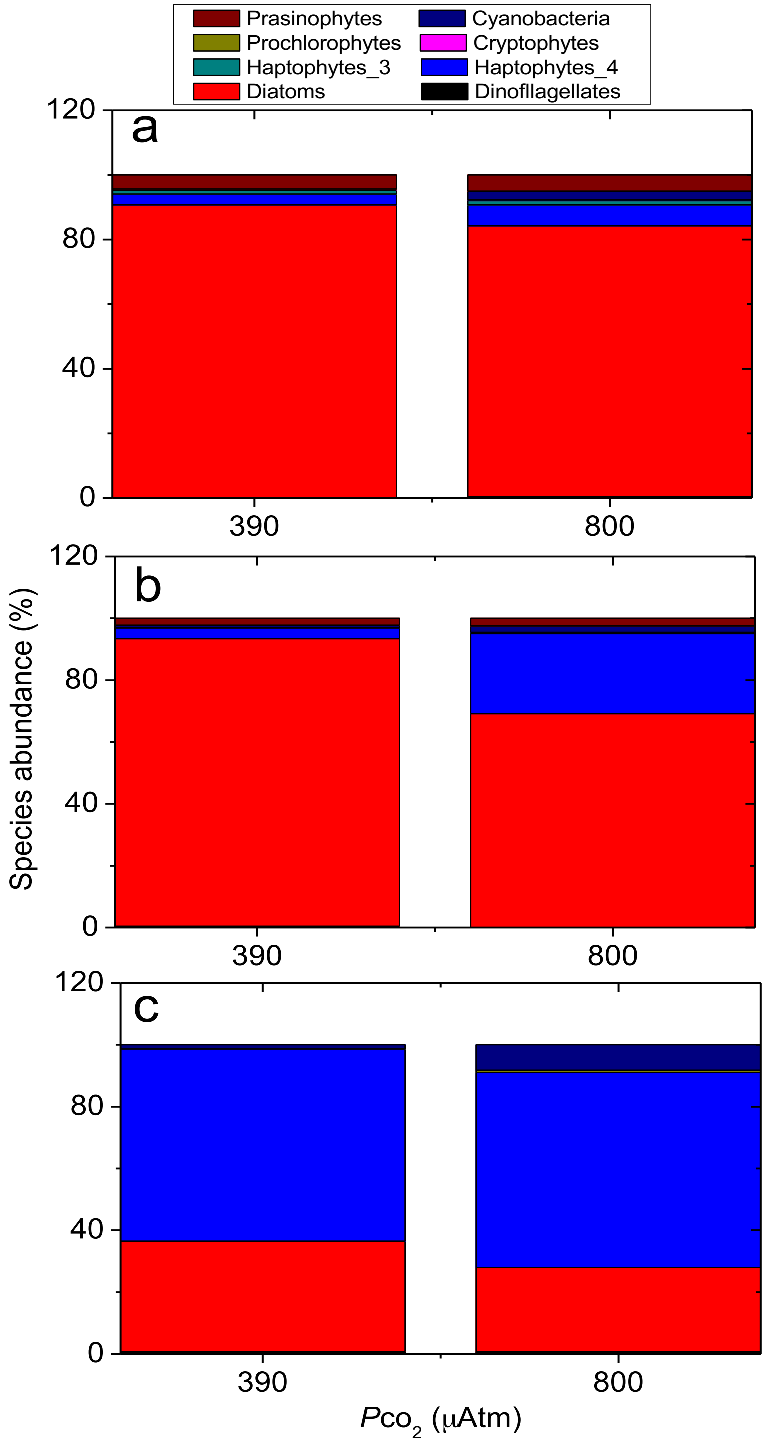




Growth at the high pCO_2 level thus significantly (P values are given in Supplementary Table 3) reduced primary productivity by 12-81% per volume of seawater (Fig. 1a) and by 7-36% per amount of chl. *a* (Fig. 1b) based on the daytime 6 or 12 h ^{14}C-traced incubations.

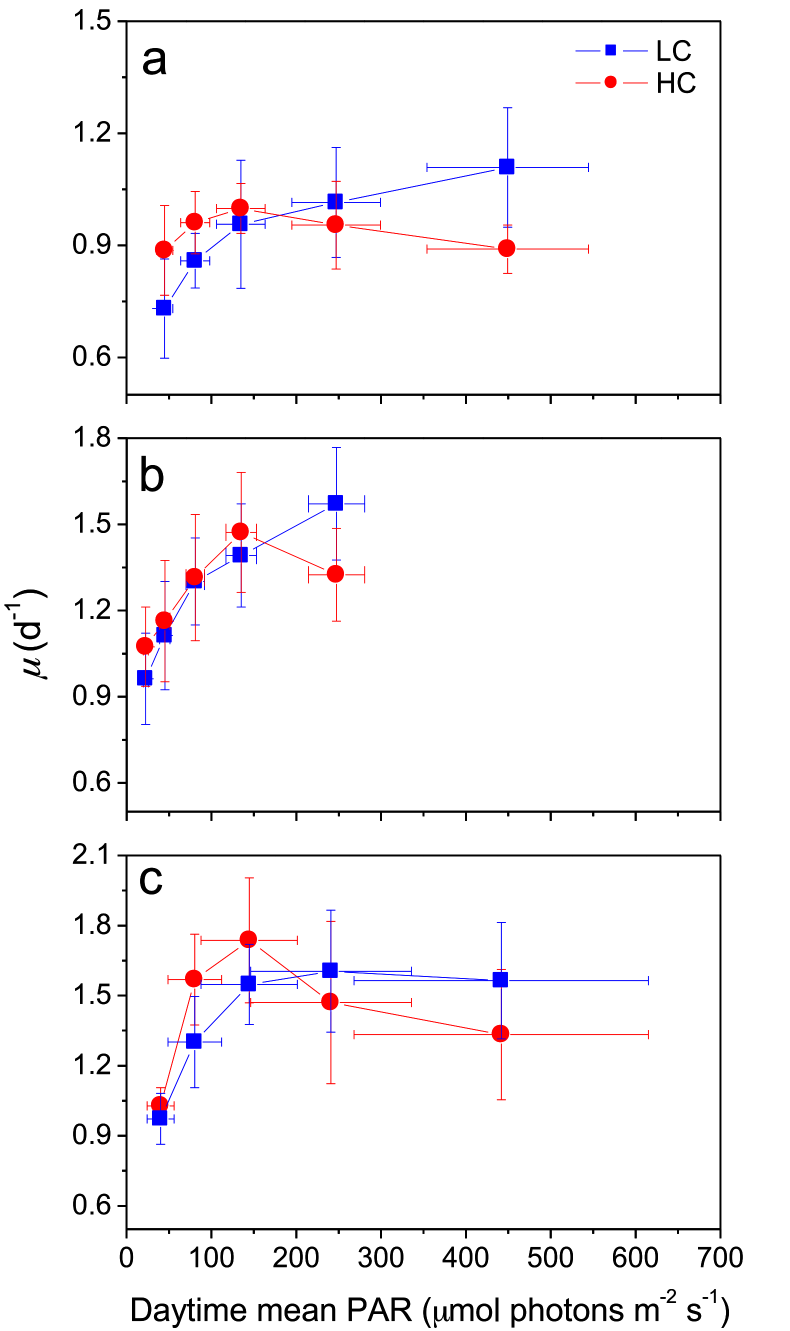
Primary production in CO_2 perturbed microcosms by phytoplankton assemblages collected in the South China Sea and East China Sea (station PN07). a) per volume of seawater (μg C $L^{-1}h^{-1}$); b) per chlorophyll a (μg C $chla^{-1}h^{-1}$); Chl *a* concentration at PN07 was not measured. For the high pCO_2 (*HC, 800 μatm for all stations except SEATS and C3, where 1000 μatm pCO_2 was applied*) and low CO_2 (*LC, 385 μatm*) experiments, triplicate microcosms (32 L) were used for each pCO_2 level (seawater carbonate system parameters are given in Supplementary Table 1). The phytoplankton assemblages in all microcosms were equally exposed to 91% incident solar visible radiation. Detailed information for the stations and related physicochemical and biological features are given in Supplementary Table 2. Inset: additional 24 h-incubations carried out at the two stations. Error bars represent standard deviations of triplicate incubations of samples from triplicate microcosms. Details about the statistical comparisons among the treatments are given in Supplementary Table 3. Note, higher photosynthetic carbon fixation rates were found under low CO_2 … nching (NPQ) … E606 grown … gle) and high … ocosms on day 6. NPQ in other stations showed similar patterns (Supplementary Fig.2). The black line represents the visible light intensity of that day. Note, higher NPQs

Gao et al. 2012
Nature Climate Change



Composition of phytoplankton assemblages grown under LC (pCO_2 385 μatm) and HC (pCO_2 800 μatm) levels. a. Station A4, January 2010, 7-day CO_2 pre-conditioning; b. Station of A4, November 2010, 7-day CO_2 pre-conditioning; c. Station E606, November 2010, 6-day CO_2 pre-conditioning.

Gao et al. 2012 Nature Climate Change

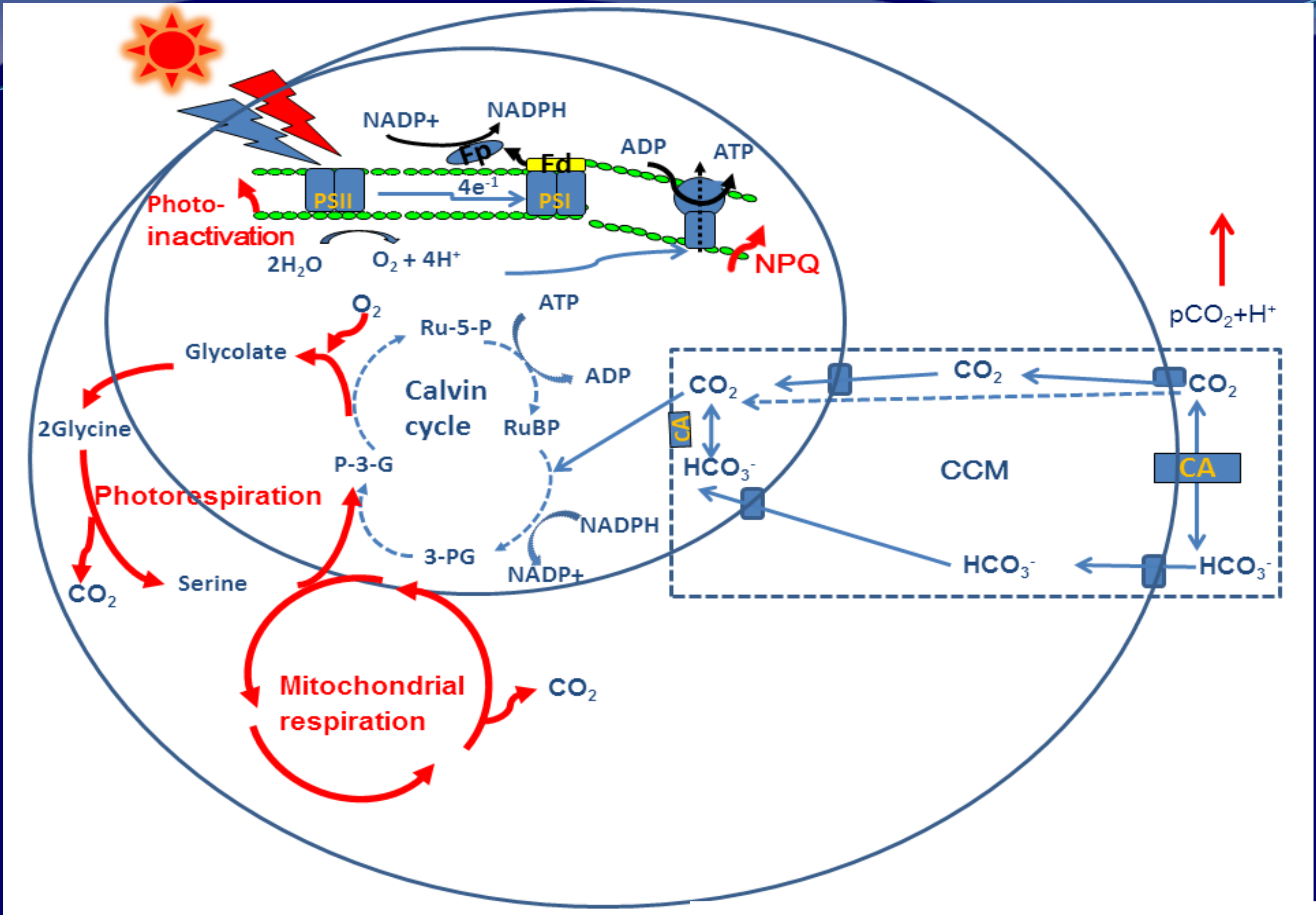


Growth rate reversed at higher PAR levels, with the PAR thresholds (daytime mean PAR levels) at the reversion points being about 160, 125 and 178 µmol photons m^{-2} s^{-1} for *P. tricornutum*, *T. pseudonana* and *S. costatum*, respectively.

These light levels correspond to 22-36 % of incident surface solar PAR levels and are equivalent to PAR levels at 26-39 m depth in the South China Sea

Gao et al. Nature Climate Change 2012

Red： up-regulated

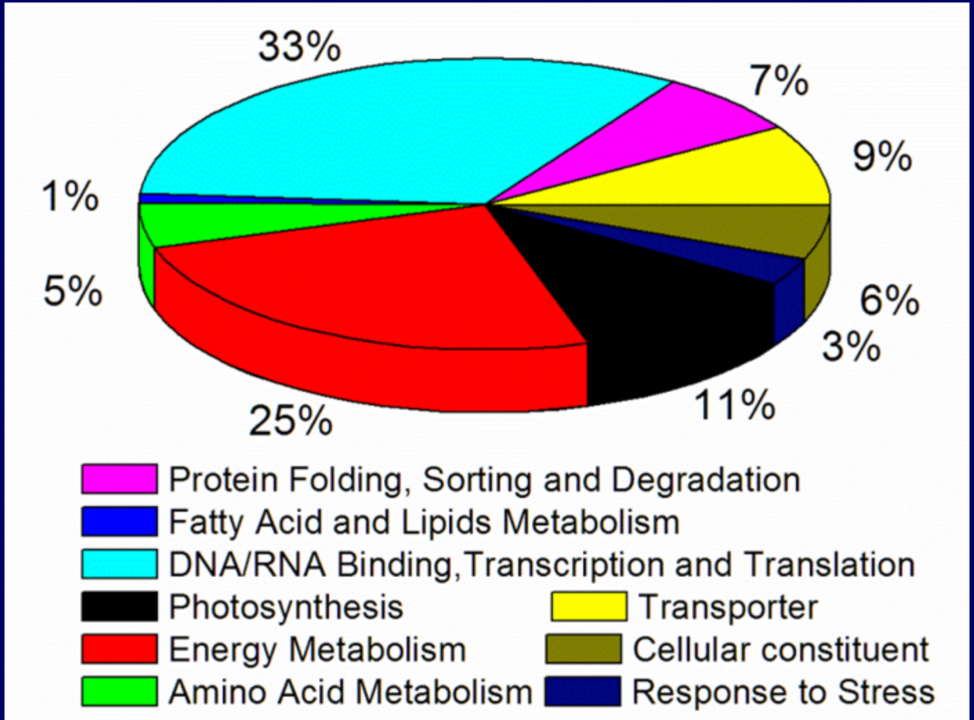


Down-regulated CCM
saving by 20% energy demand
Hopkinson *et al*. 2011

Gao et al. 2012
Gao & Campbell 2014

Genetic responses to OA

Phaeodactylum tricornutum



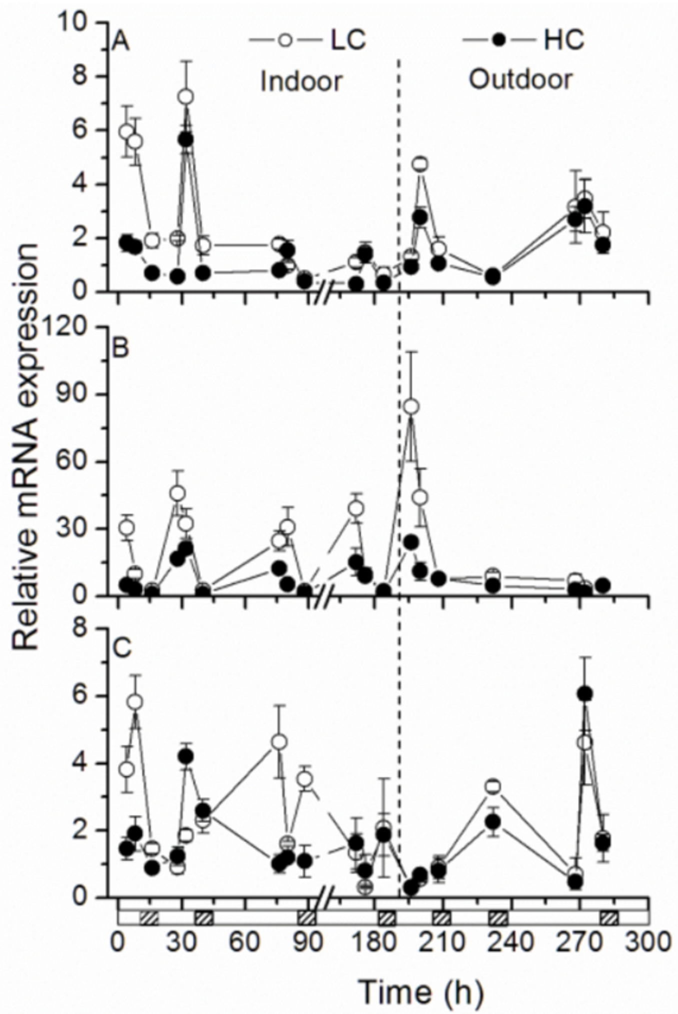


Fig.5 Time series of the relative abundances of fucoxanthin chlorophyll a/c protein, lhcf type (FCP; A), carbonic anhydrase (CA; B), ribulose-1, 5-bisphosphate carboxylase/oxygenase large subunit gene (RbcL; C) by quantitative real-time PCR (qPCR) of *P. tricornutum* cells grown in ambient (390 μatm) and elevated CO_2 (1000 μatm) conditions under constant light (indoor) and fluctuating sunlight levels (outdoor). Data are presented as means ± SD, n = 3 (triplicate cultures).

FCP

CA

RbcL

Li et al. 2015

Biogeosciences-discuss

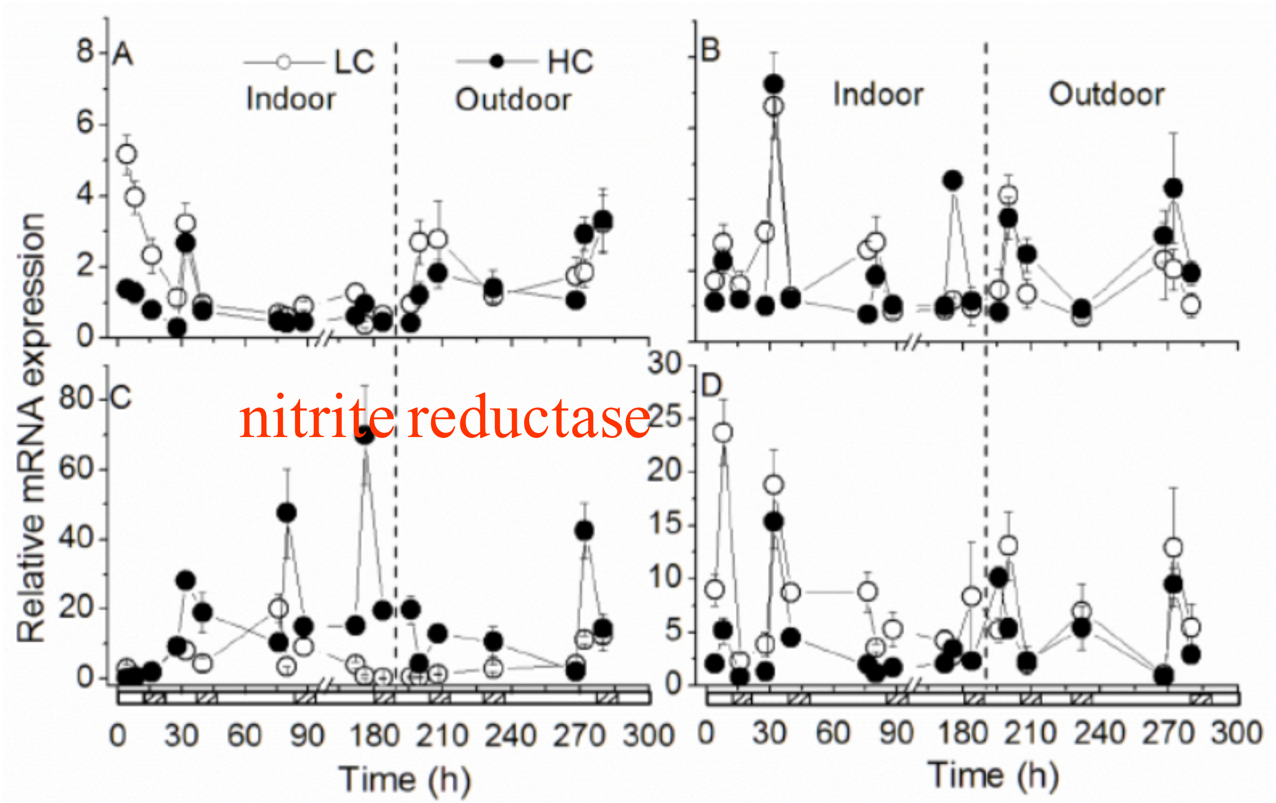
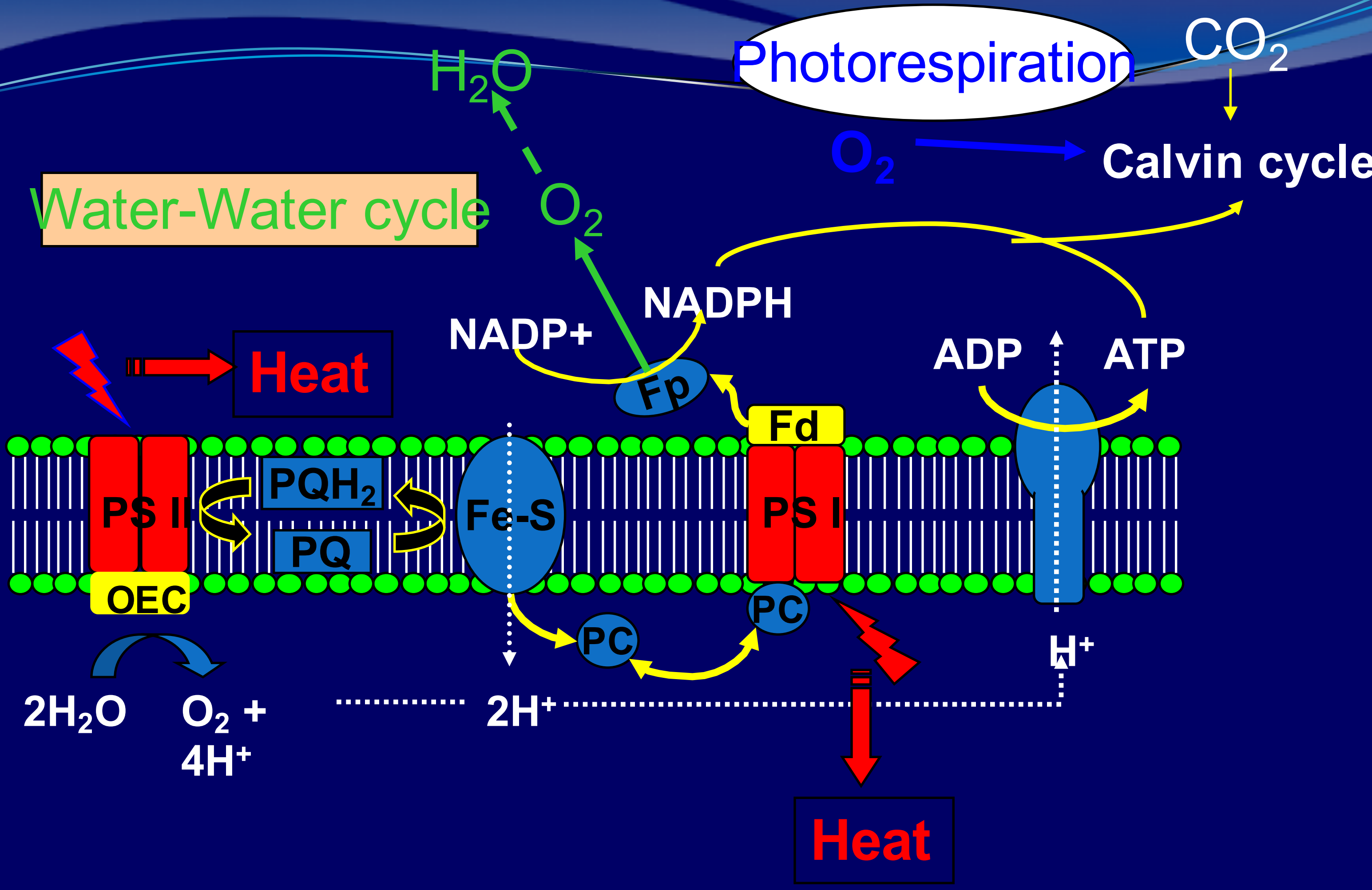


Fig.6 The time series of the relative abundances of mitochondrial ATP synthase (mtATP; A), peroxisomal membrane protein-related (PMP; B), nitrite reductase (NiR; C) and NADH dehydrogenase subunit 2 (Ndh2; D) by quantitative real-time PCR (qPCR) of *P. tricornutum* cells grown in ambient (390 μatm) and elevated CO_2 (1000 μatm) conditions under constant light (indoor) and fluctuating sunlight levels (outdoor). Data are presented as means ± S (triplicate cultures).

Li et al. 2015
Biogeosciences-discuss



OA exacerbates high-light stress, stimulate photorespiration and mitocondrial respiration（diatoms, a green alga, a coccolithorpore）

Wu et al. 2010 Biogeosciences;
Gao et al.2012a,b MEPS, Nat Clim Change;
Xu and Gao 2013 Plant Physiol.
Jin et al. 2015 Nat. Comm.

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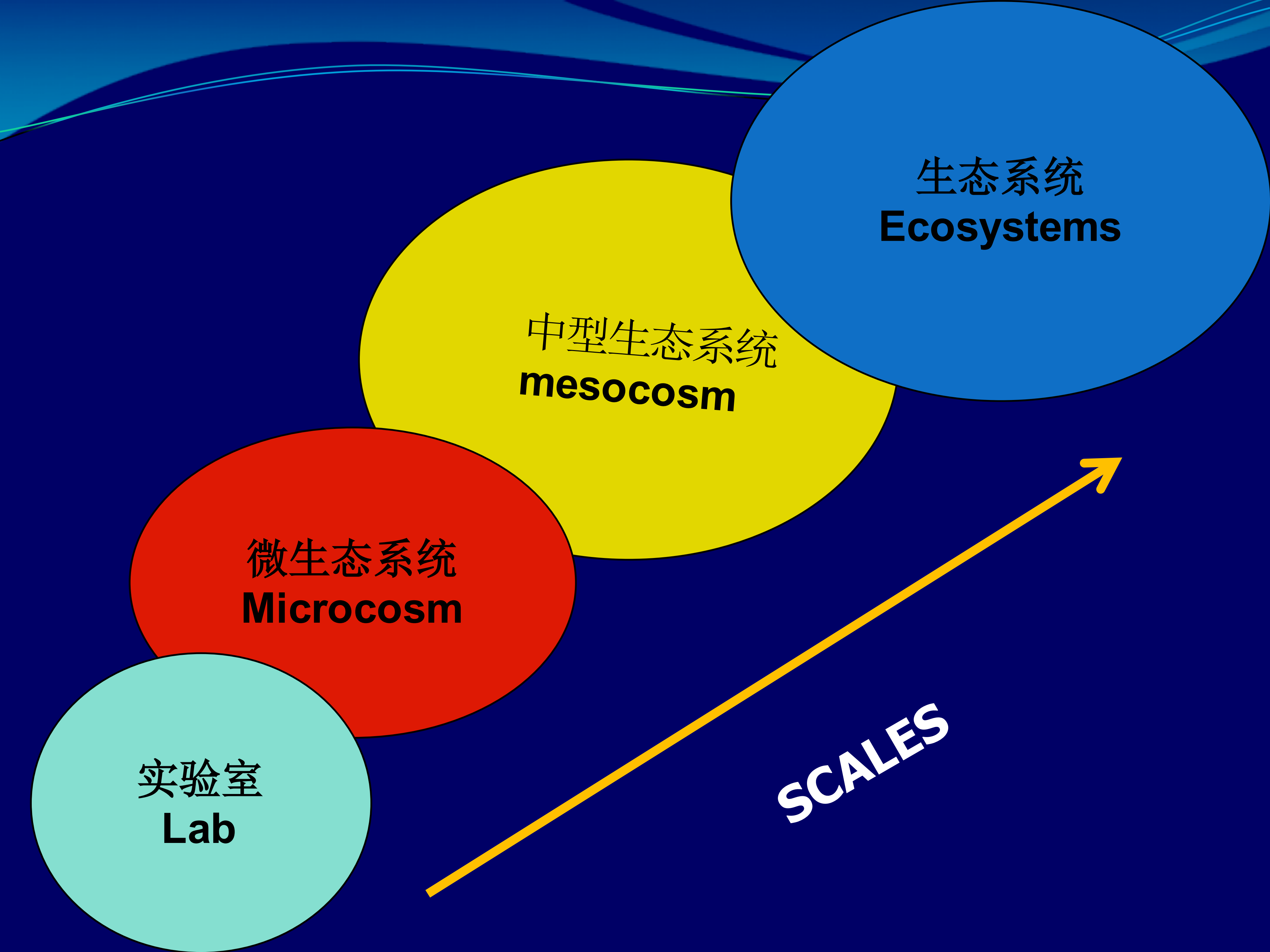
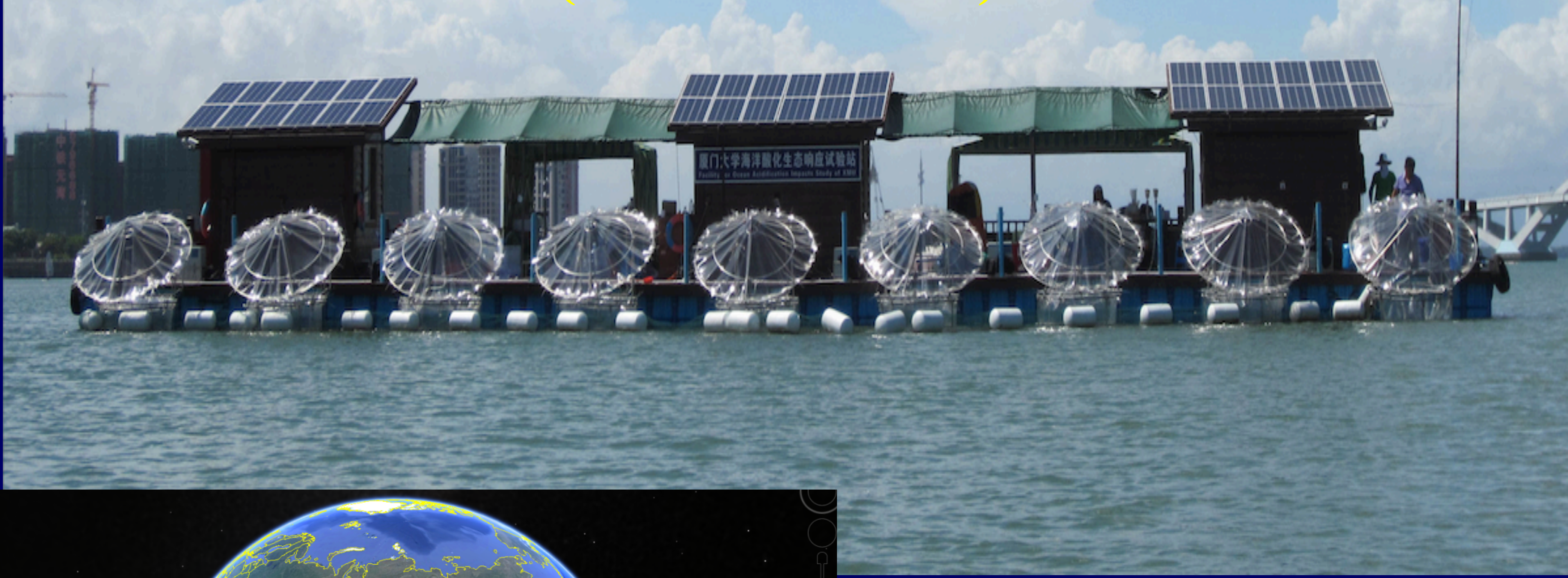
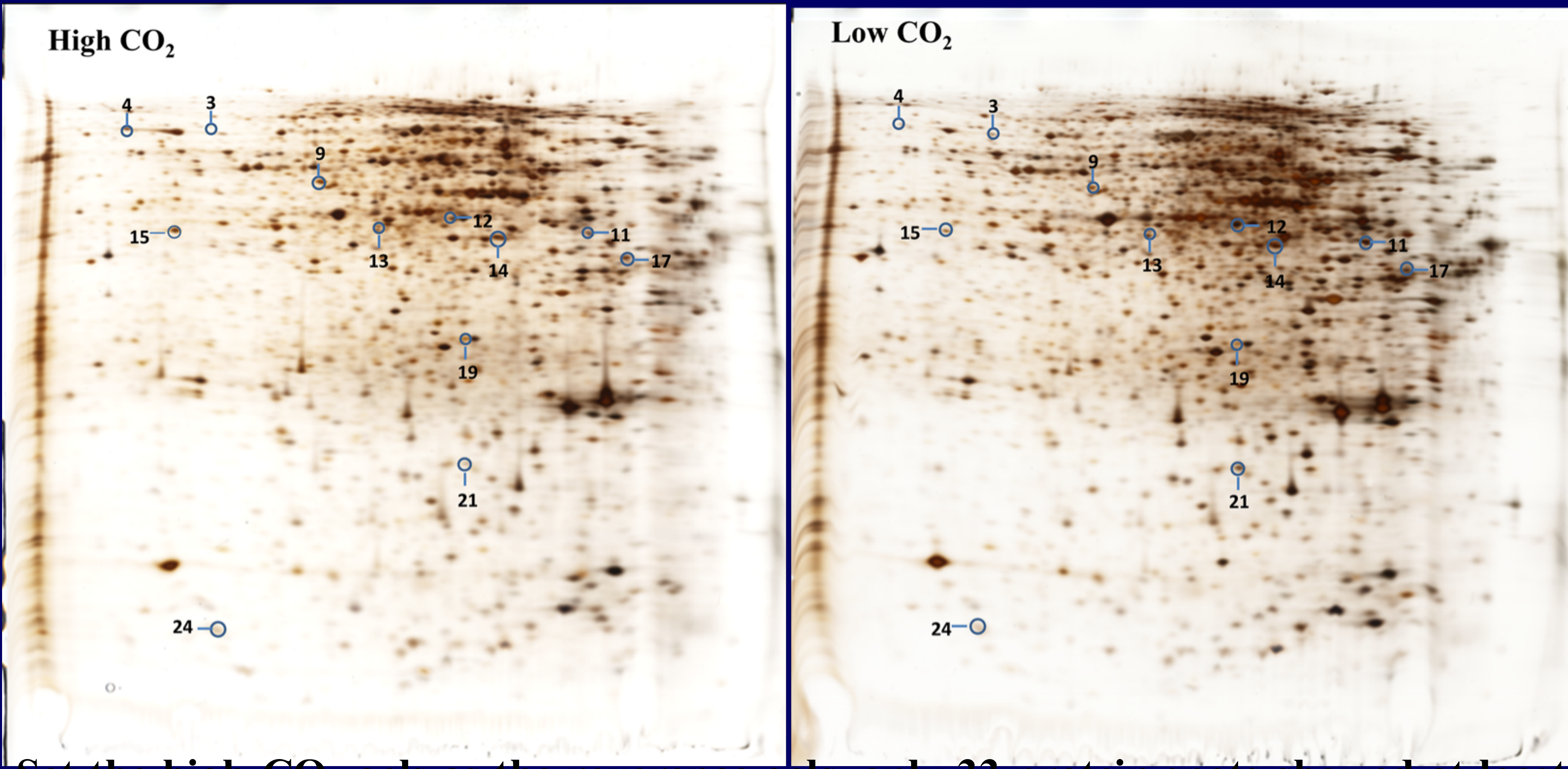

生态系统
Ecosystems
中型生态系统
mesocosm
微生态系统
Microcosm
实验室
Lab
SCALES

Mesocosm Facility for Ocean Acidification Impact Study (FOANIC-XMU)



FOANIC-XMU
(N24° 31′48″, E118° 10′47″)

Proteomics responses, *Emiliania huxleyi* CCMP 1516

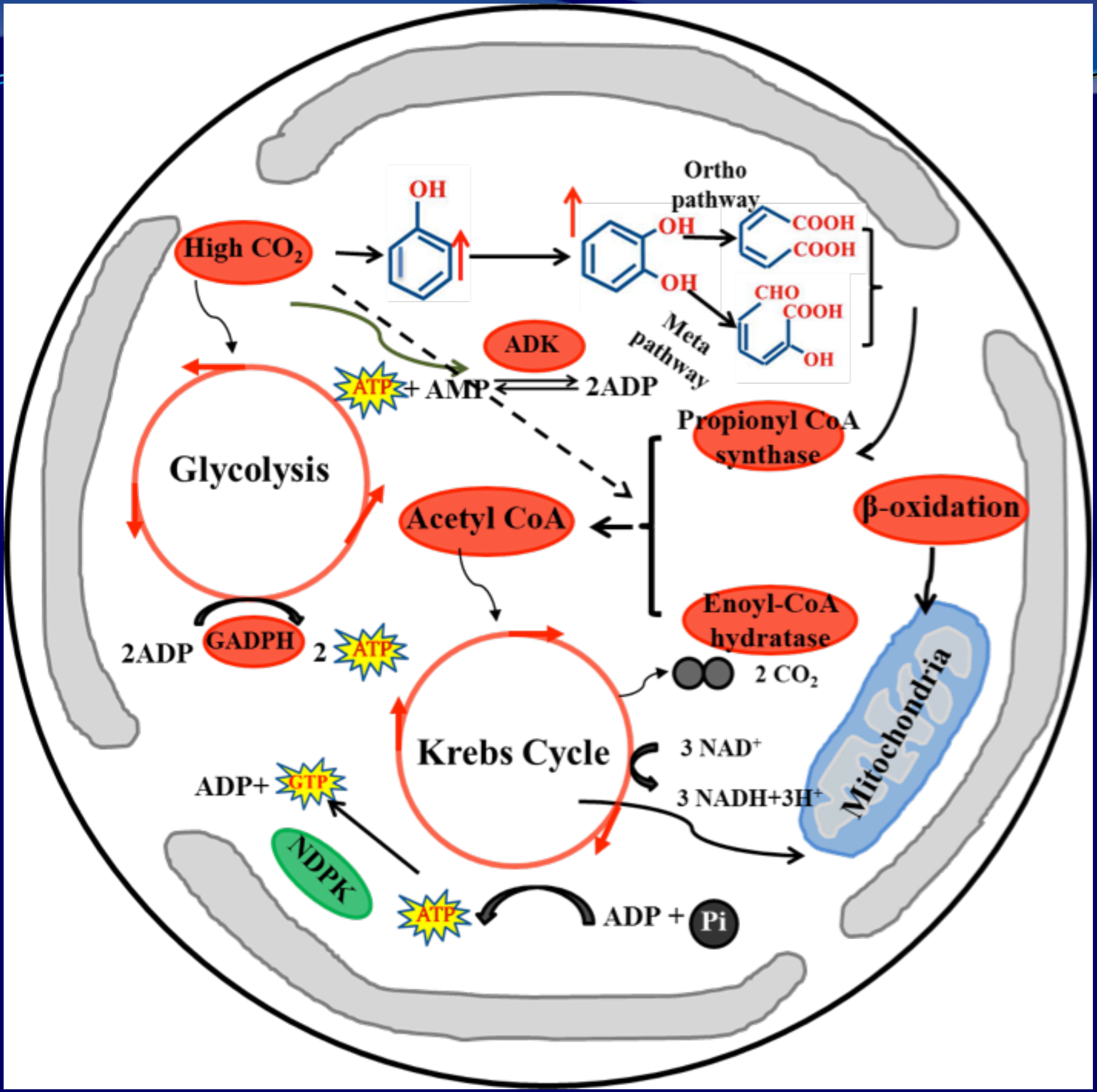


Set the high-CO_2 gels as the reverence gels, only 33 protein spots showed at least 2-fold differences in expression level of the low-CO_2 gels. All the different protein spots are observed in the gels of different experiment conditions.

Jin et al. 2015 Nat. Comm.

Various proteins, that showed statistically significant alterations in abundance greater than 2-fold, in HC and LC treatments

Spot Id.	Protein identity	GI number	Protein score C.I. (%)	Total Ion C. I. %	Protein score (peptides)	MW/pI	Fold change		Function
							High CO_2	Low CO_2	
3	Propionyl CoA synthase	239994558	100	100	357(14)	69708.5/5.51	2.33	1.00	β-oxidation
4	Serine protein kinase	239995429	100	99.946	177(15)	74347.3/5.31	2.82	1.00	Protein kinase, signal transduction
9	Hypothetical protein AmacA_2	223994739	100	100	805(22)	51069.6/5.61	2.01	1.00	Unknown
11	Hypothetical protein MDMS009_211	254489880	100	100	440(11)	447891.1/4.87	1.00	4.34	Unknown
12	Methane/ phenol/ toluene hydroxylase	148260382	100	100	238(5)	39315.7/5.76	3.40	1.00	Phenol biodegradation
13	Acyl-CoA dehydrogenase family protein	83943662	100	100	438(18)	44108.4/5.55	1.00	2.66	β-oxidation
14	Chloroplast glyceraldehyde-3-phosphate dehydrogenase	77024139	100	100	336(7)	44096.1/5.2	2.92	1.00	Glycolysis
15	Conserved hypothetical protein (bacterium S5)	288797257	100	99.996	166(7)	21306.1/4.87	2.50	1.00	Unknown



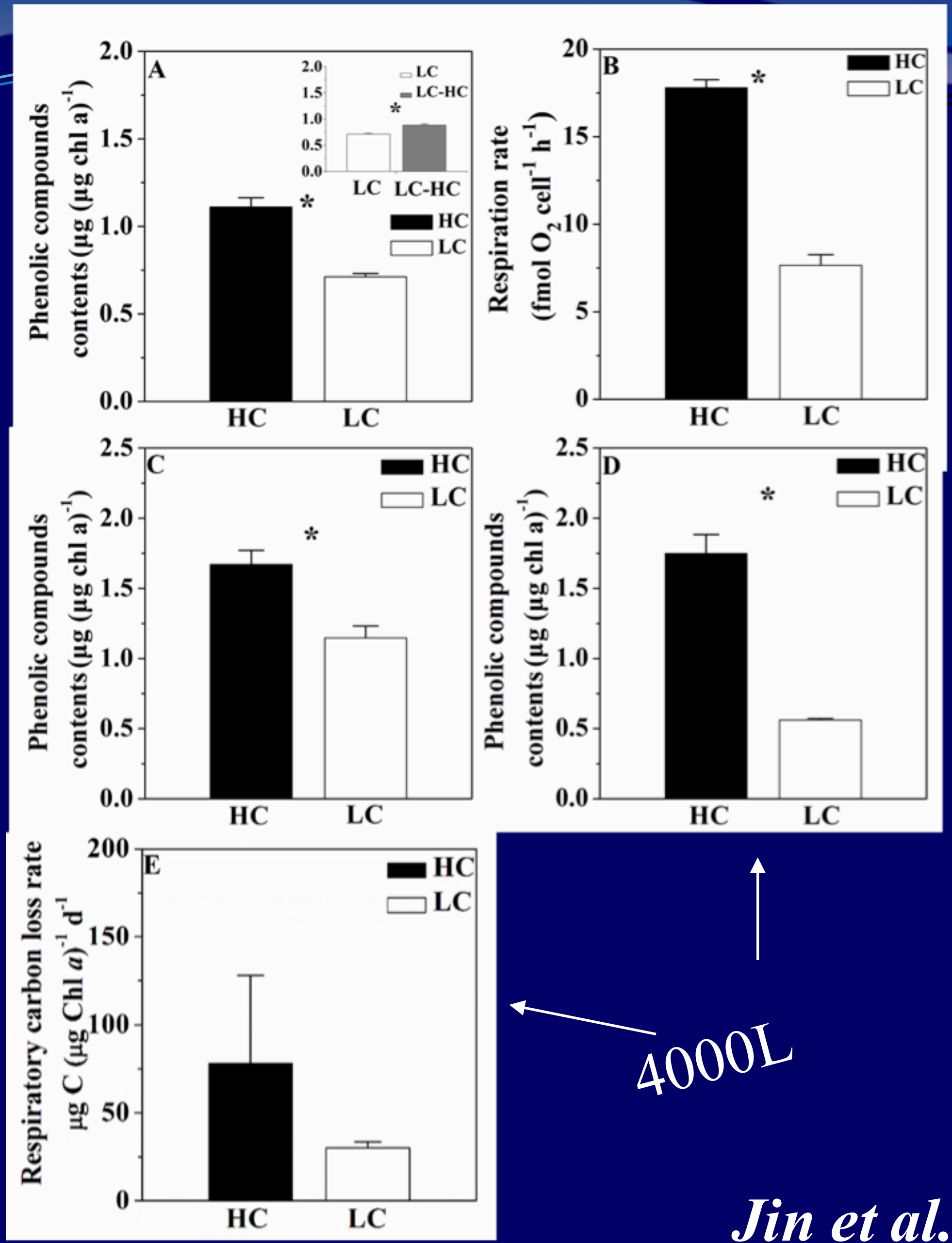
Red: up-regulated

Metabolic pathways in the coccolithophorid Emiliania huxleyi altered under ocean acidification (HC, CO2 1,000 matm; pHNBS 7.81) basedon proteomic, physiological and biochemical analyses.

Jin et al. Nature Comm. 2015

Lab

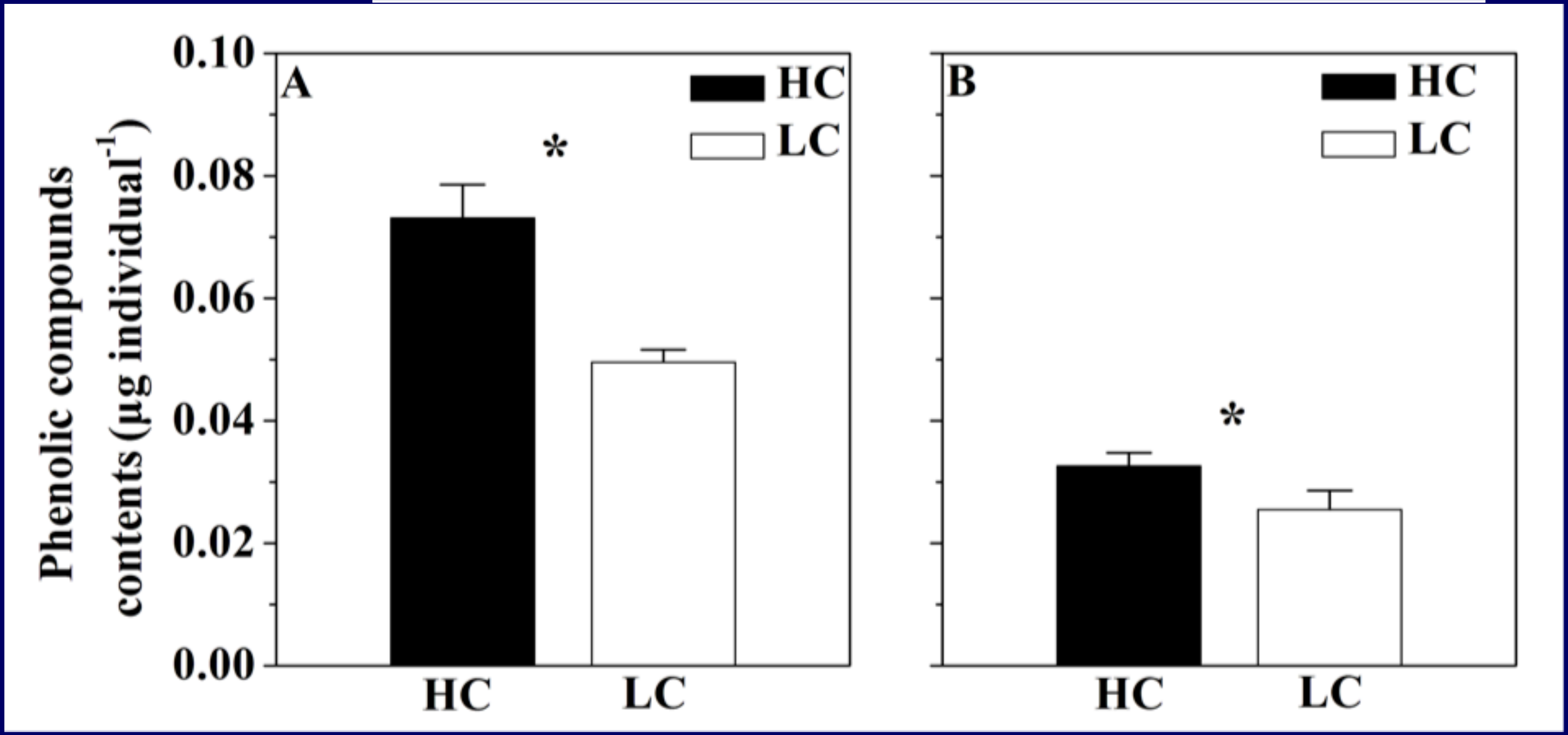
30L



4000L

Jin et al. Nature Comm. 2015

30 L 4000 L



Content of phenolic compounds (mg per individual) in zooplankton assemblages (body size >112 mm)

Jin et al. Nature Comm. 2015

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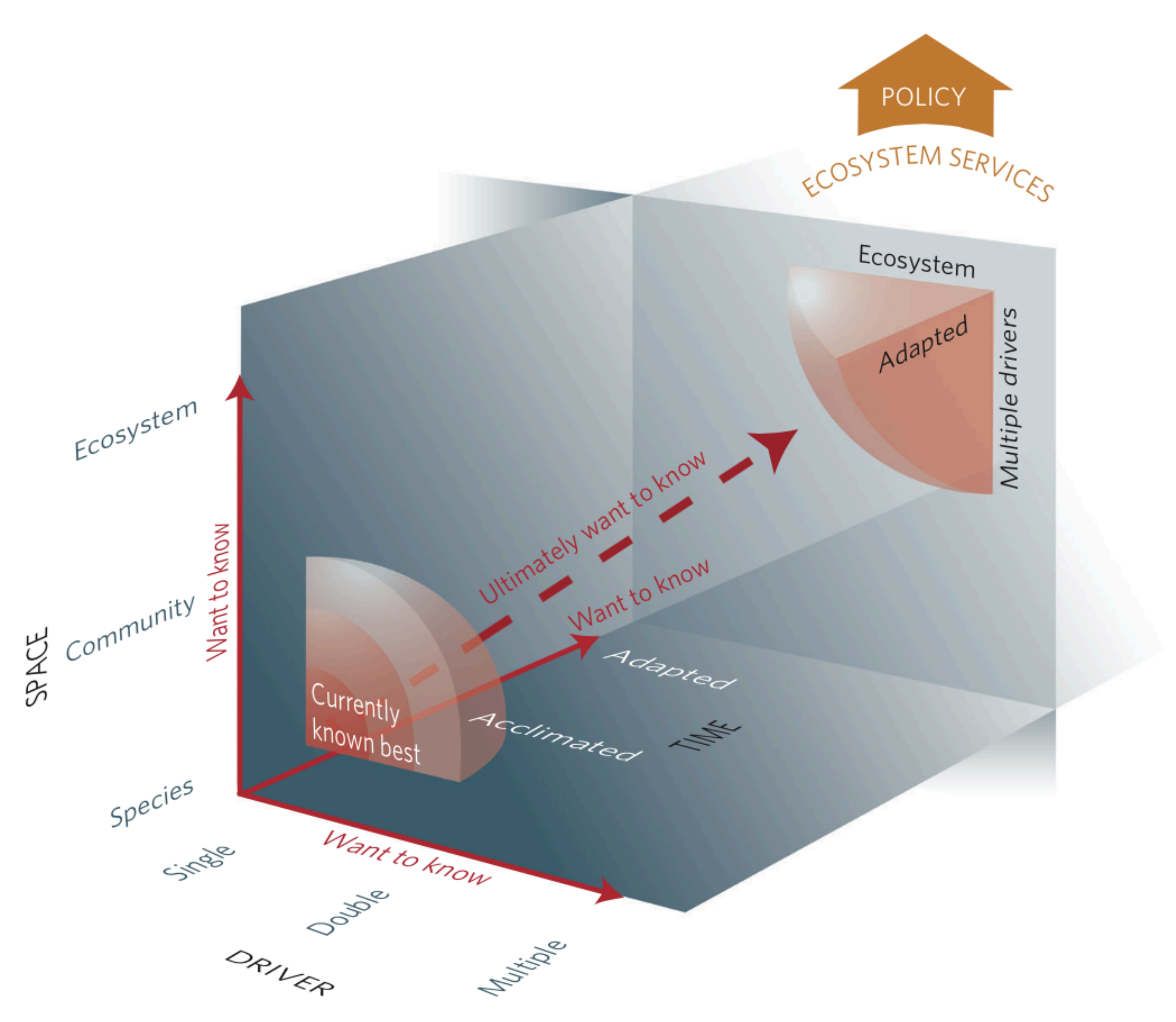
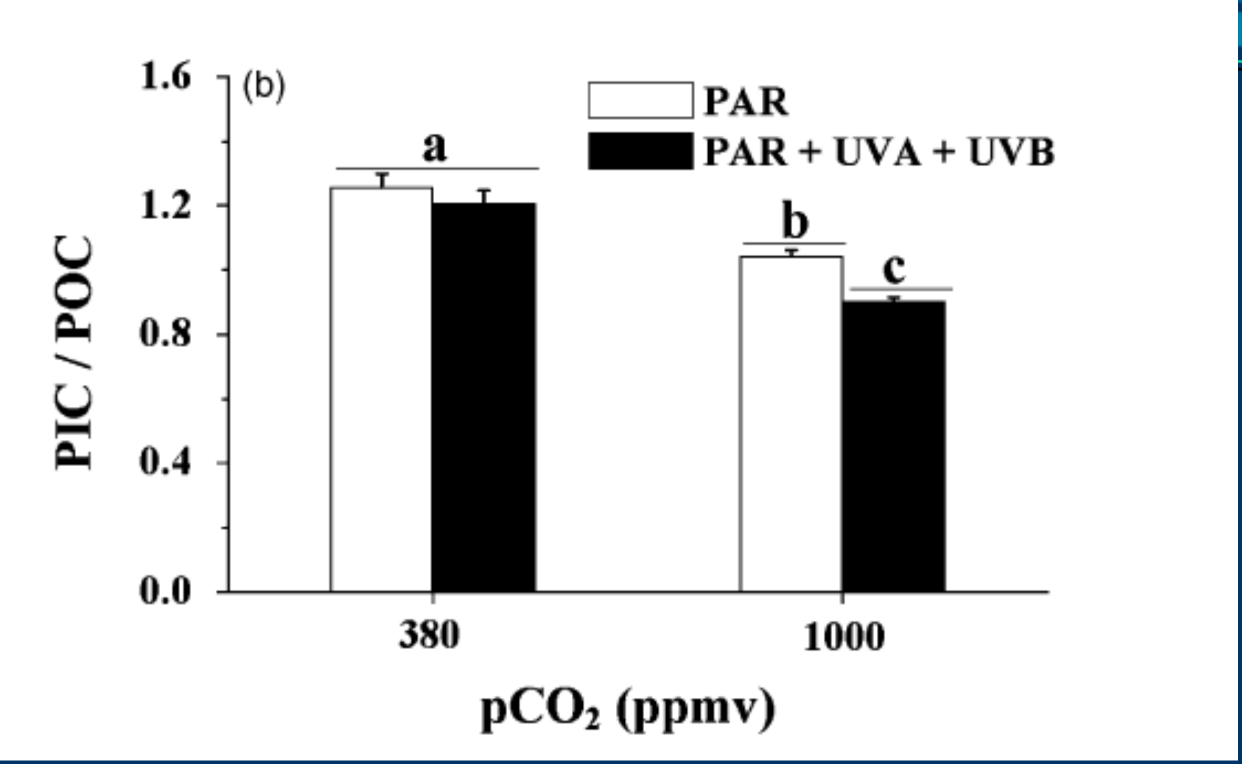
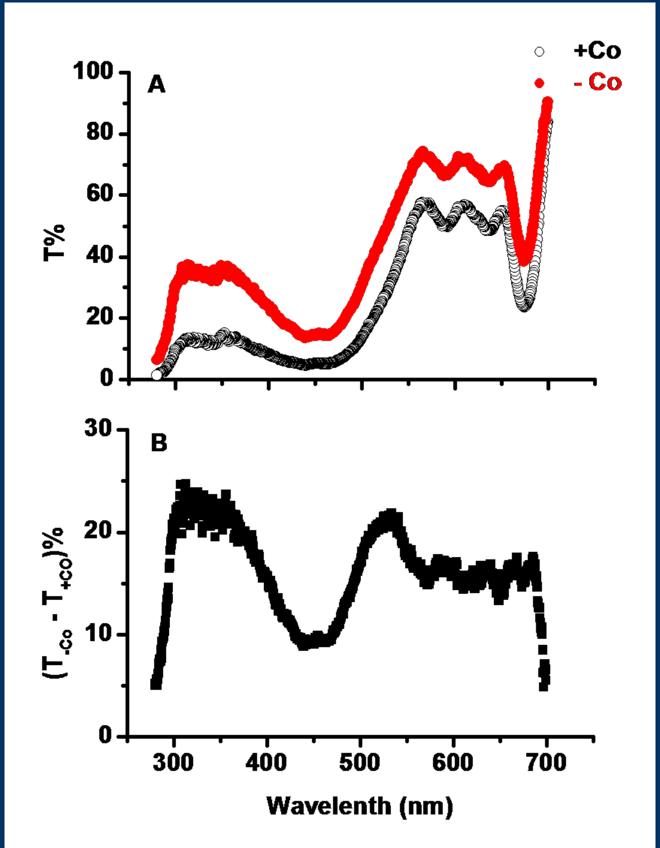


Riebesell and Gattuso (2015)

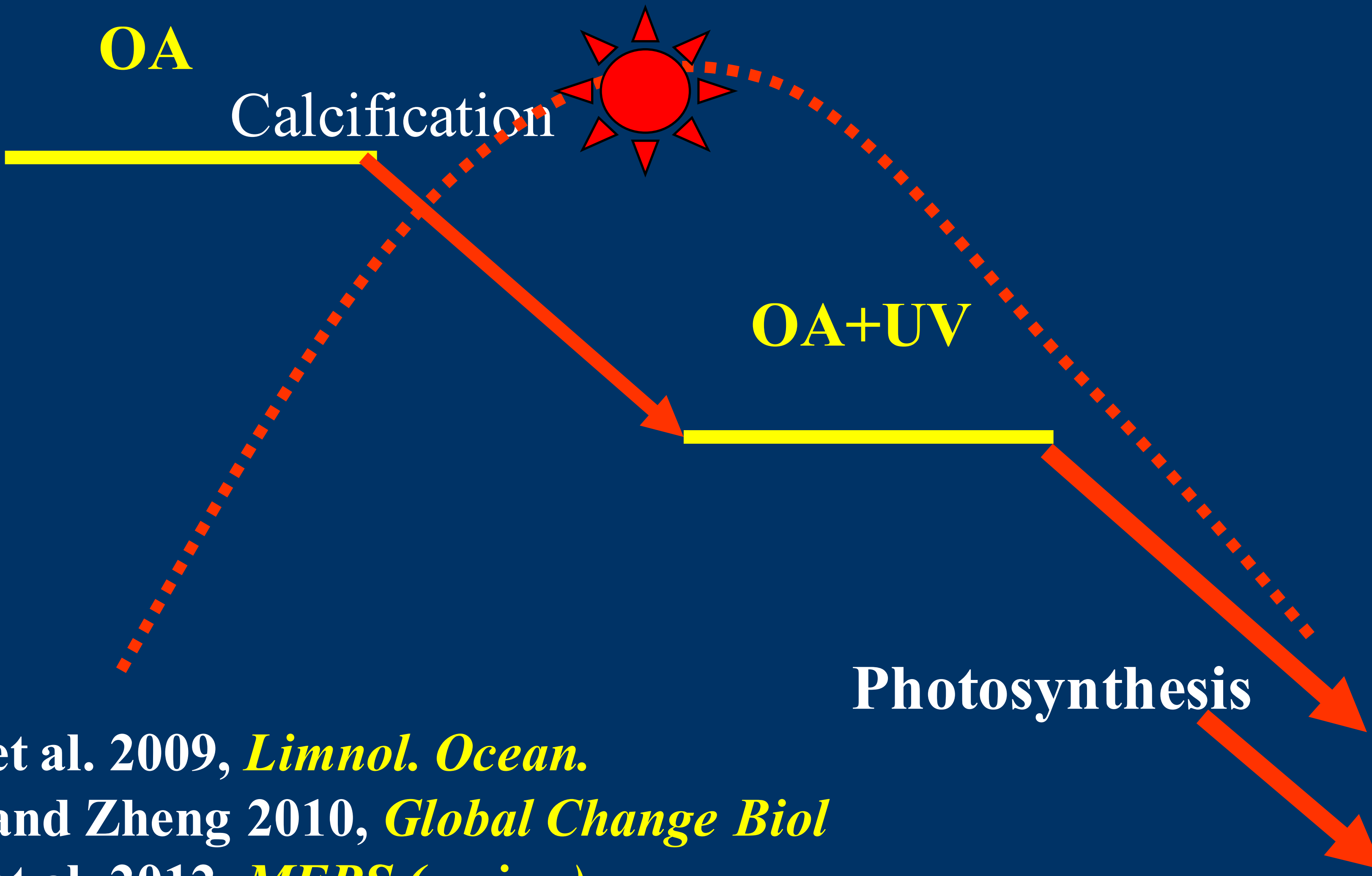
Coraline algae





E .hux

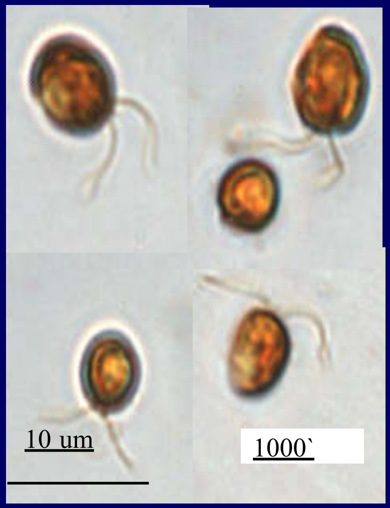
Synergistic impacts of OA and UV on calcifying algae

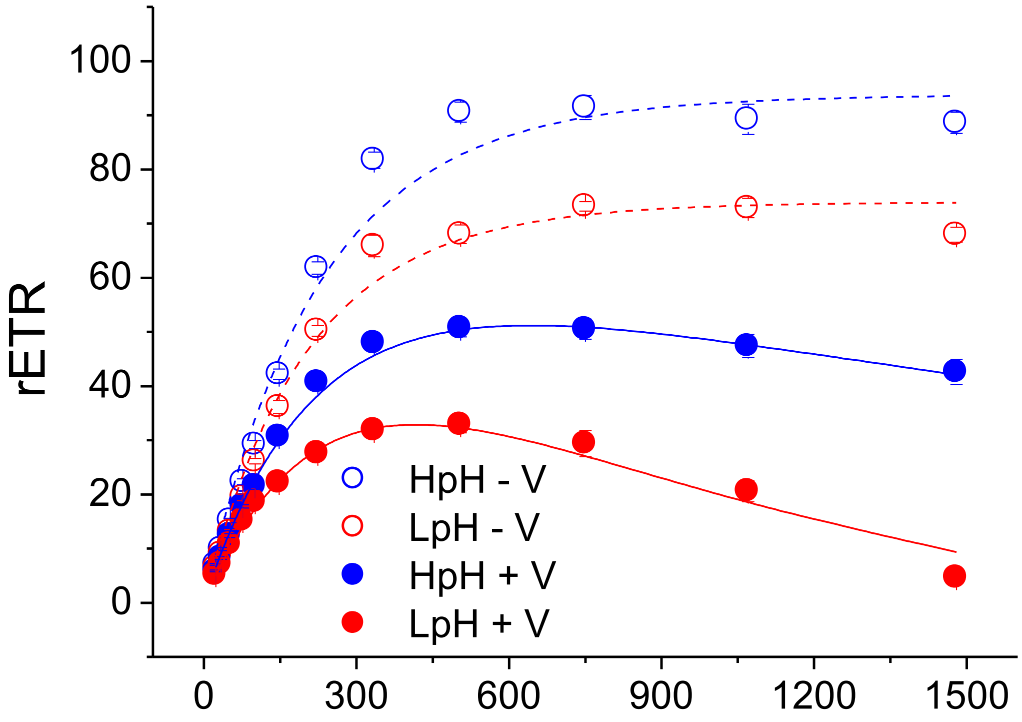


Gao et al. 2009, *Limnol. Ocean.*
Gao and Zheng 2010, *Global Change Biol*
Gao et al. 2012 *MEPS (review)*

Virus as a bio-stressor

Ocean acidification influences the effects of viral infection on a bloom-forming alga





赤潮藻（棕囊藻）病毒恶化该藻受酸化的影响

Global Change Biology

Viral attack exacerbates the susceptibility of a bloom-forming alga to ocean acidification

SHANWEN CHEN[1], KUNSHAN GAO[2] and JOHN BEARDALL[3]

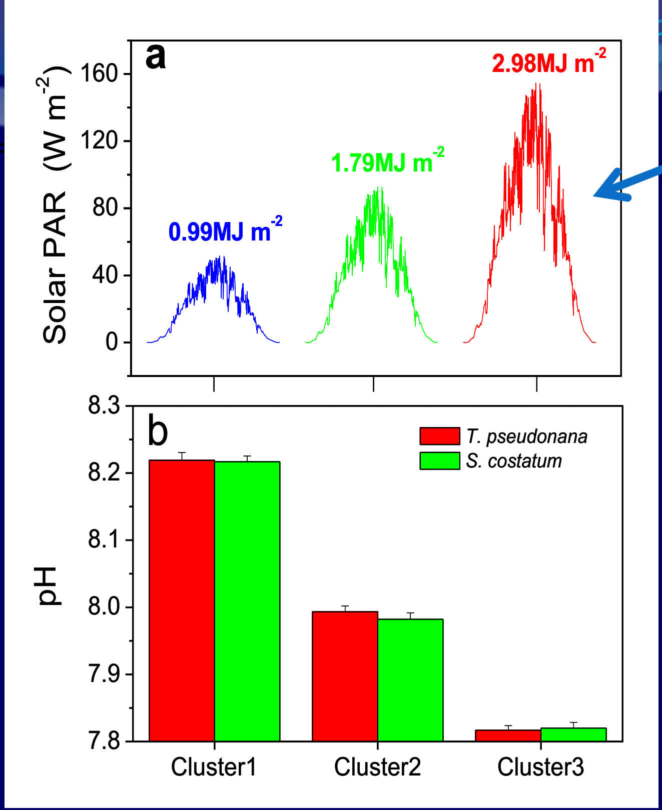
2014

Enhanced Stratification

Less nutrients

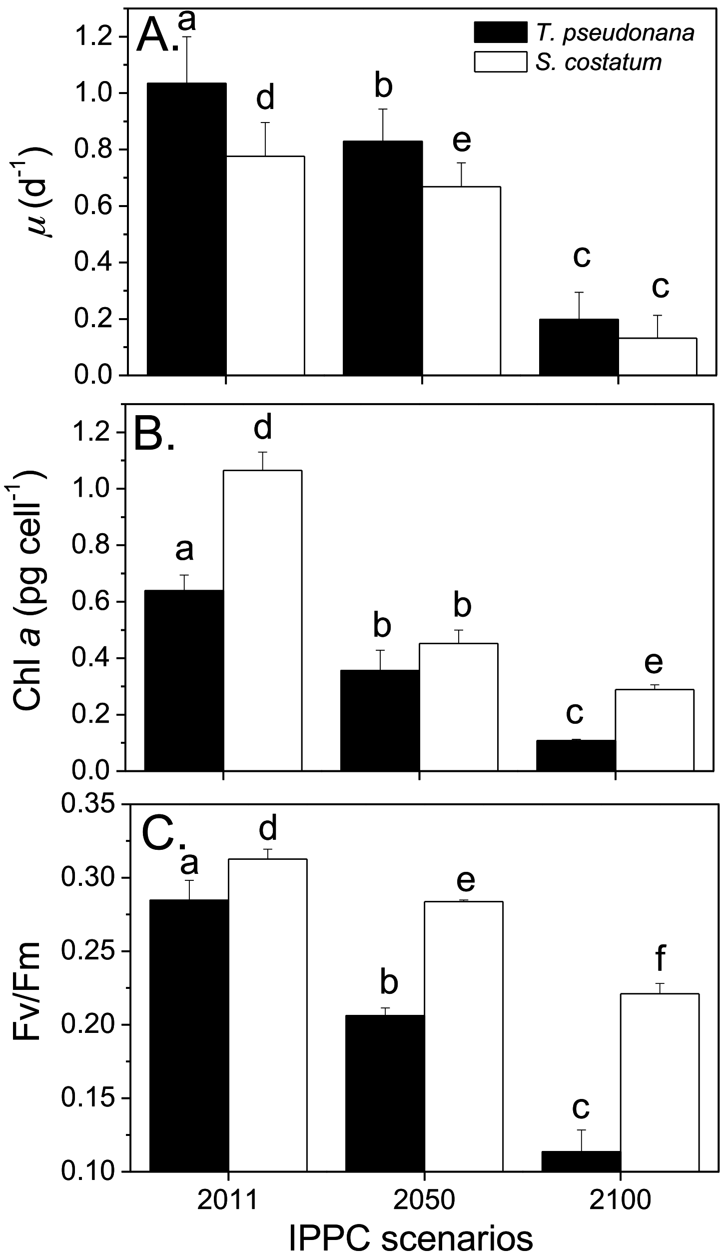
Increased light exposures

Ocean acidification



2011 2050 2100

Scenarios	Light (% of surface)	CO_2 (µatm)	pH	NO_3^-(µM)	PO_4^{3-}(µM)	Si (µM)
2011	10%	390	8.18	20	2	20
2050	18%	700	7.96	10	1	10
2100	30%	1000	7.82	5	0.5	5

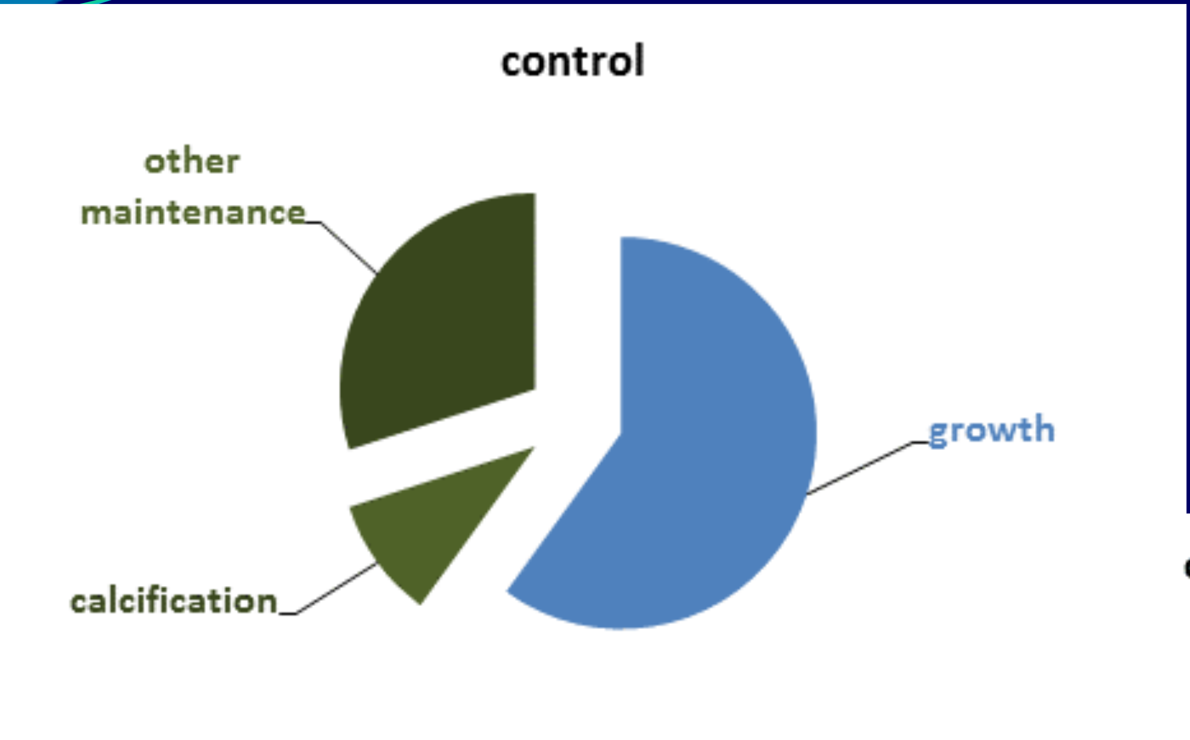


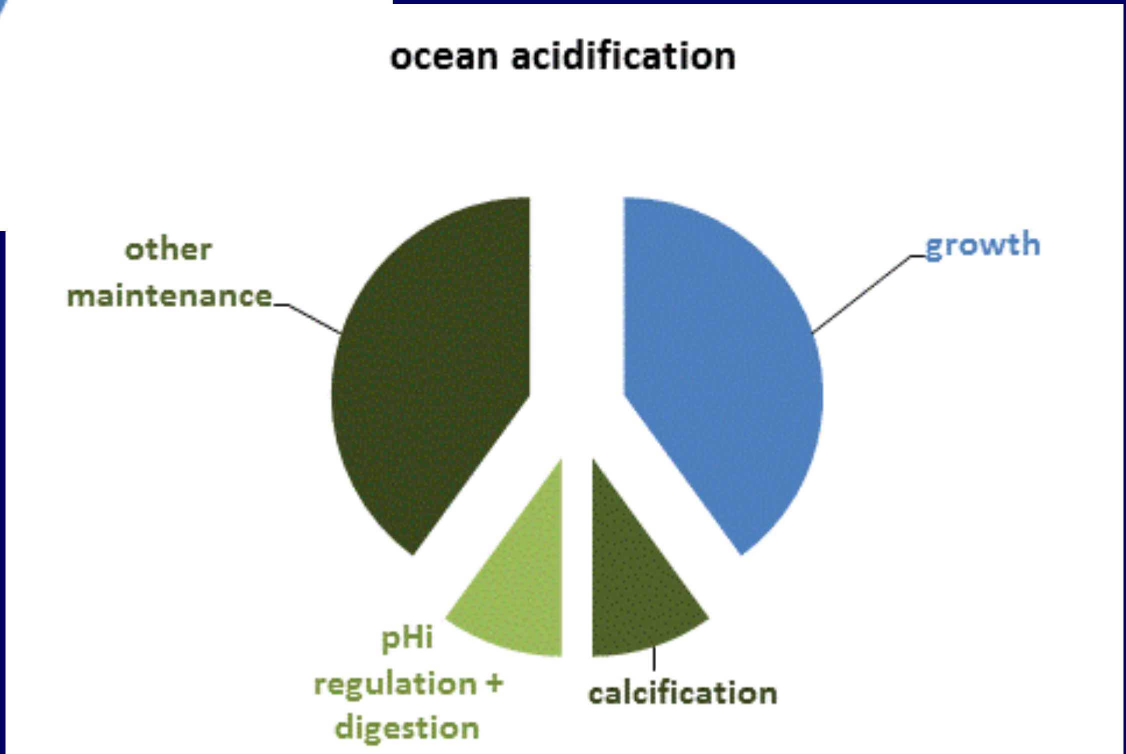
Time

Growth, Chl a, Fv/Fm

Xu et al. 2014 MEPS

Shift in energy budget





Summary

- **+/- effects of OA depends on light or solar radiation levels**

- **Ocean acidification increases levels of phenolic compounds in phytoplankton and zooplankton, implying a food chain impact.**

- **UV radiation and OA interact synergistically to reduce algal calcification and photosynthetic C fixation**

- **Virus infection to primary producers would be worse under OA**

OA and taste of shrimps
Dupont et al. 2014

Thank you for your attention

Funded by

NSF-C
MOST
SOA