Harmful Algal Blooms & Ocean Climate Change: Progress on tackling a Formidable Predictive Challenge

Gustaaf M. Hallegraeff

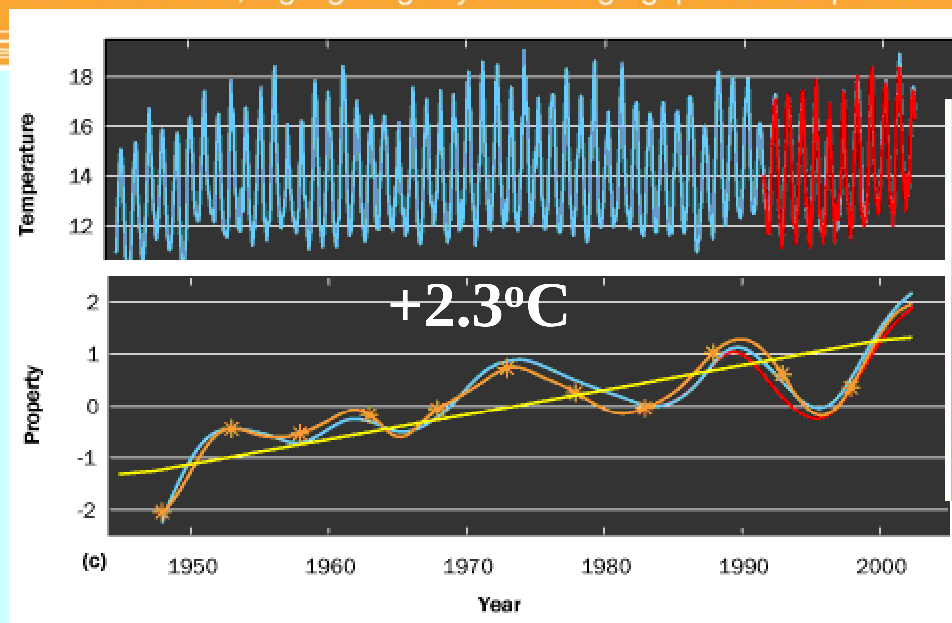
PICES

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer
ICES CIEM

UNESCO
United Nations Educational, Scientific and Cultural Organization
Intergovernmental Oceanographic Commission

IMAS
INSTITUTE FOR MARINE AND ANTARCTIC STUDIES

WINNERS



LOSERS

EXTREME EVENTS

Increased Bush Fires

IPCC
INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
WMO UNEP

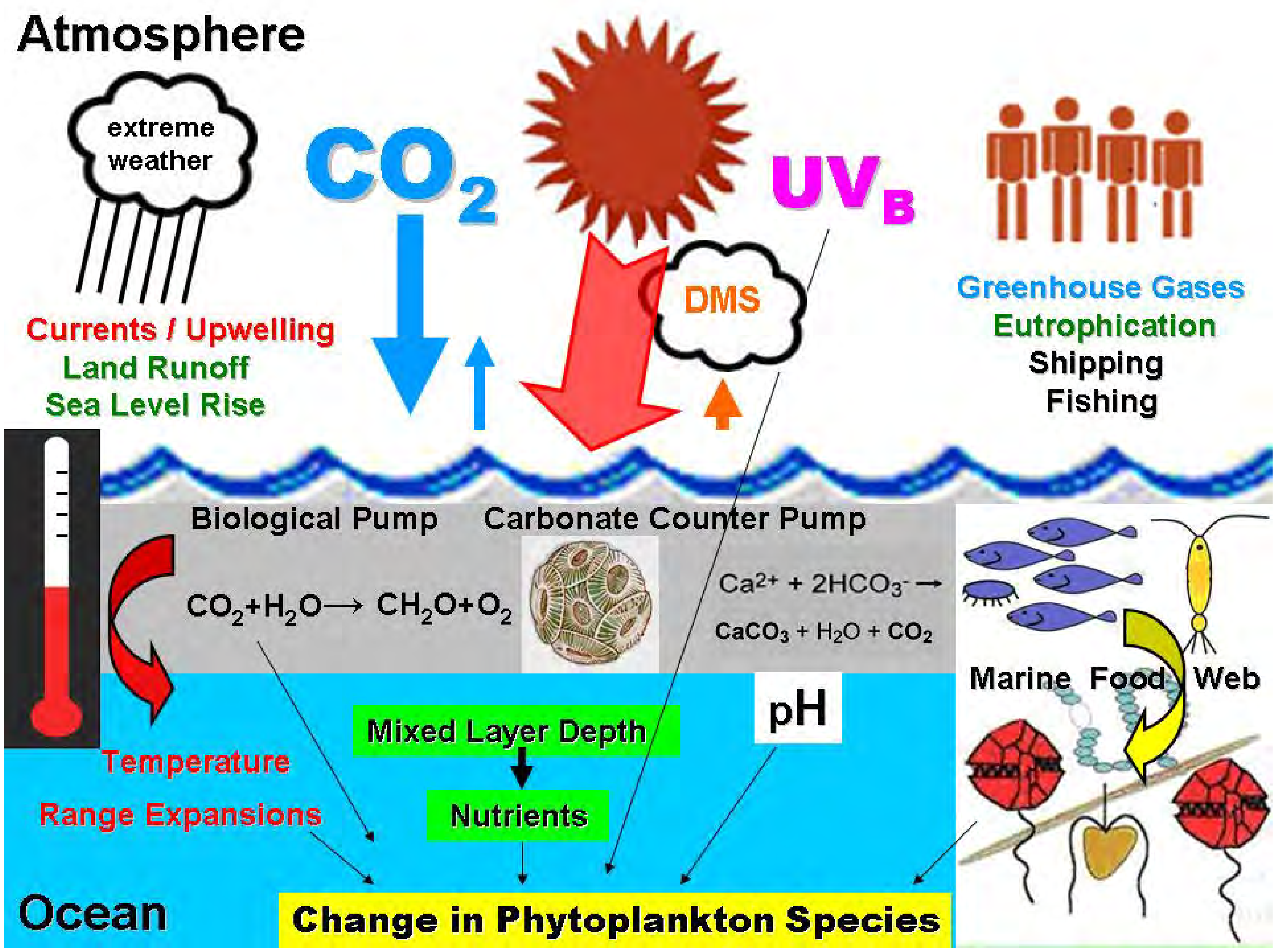
WGII AR5
Ch 6 & 30

Sydney Dust Storm

Brisbane 1:100 yr flood

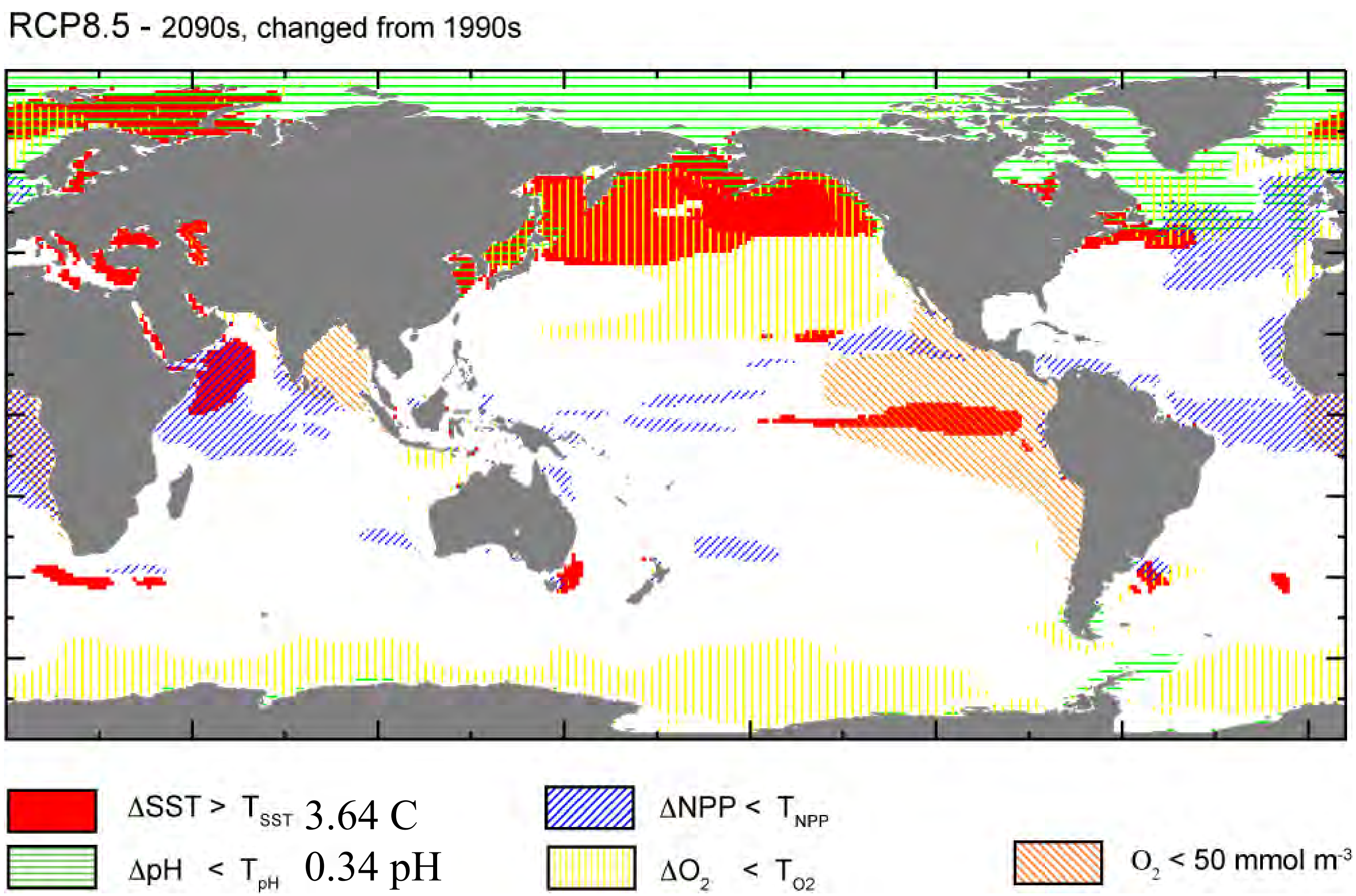
California 1:100 yr drought

Climate Change is Multifactorial: Warming, Stratification, Light, Nutrients, Ocean Acidification, Grazing



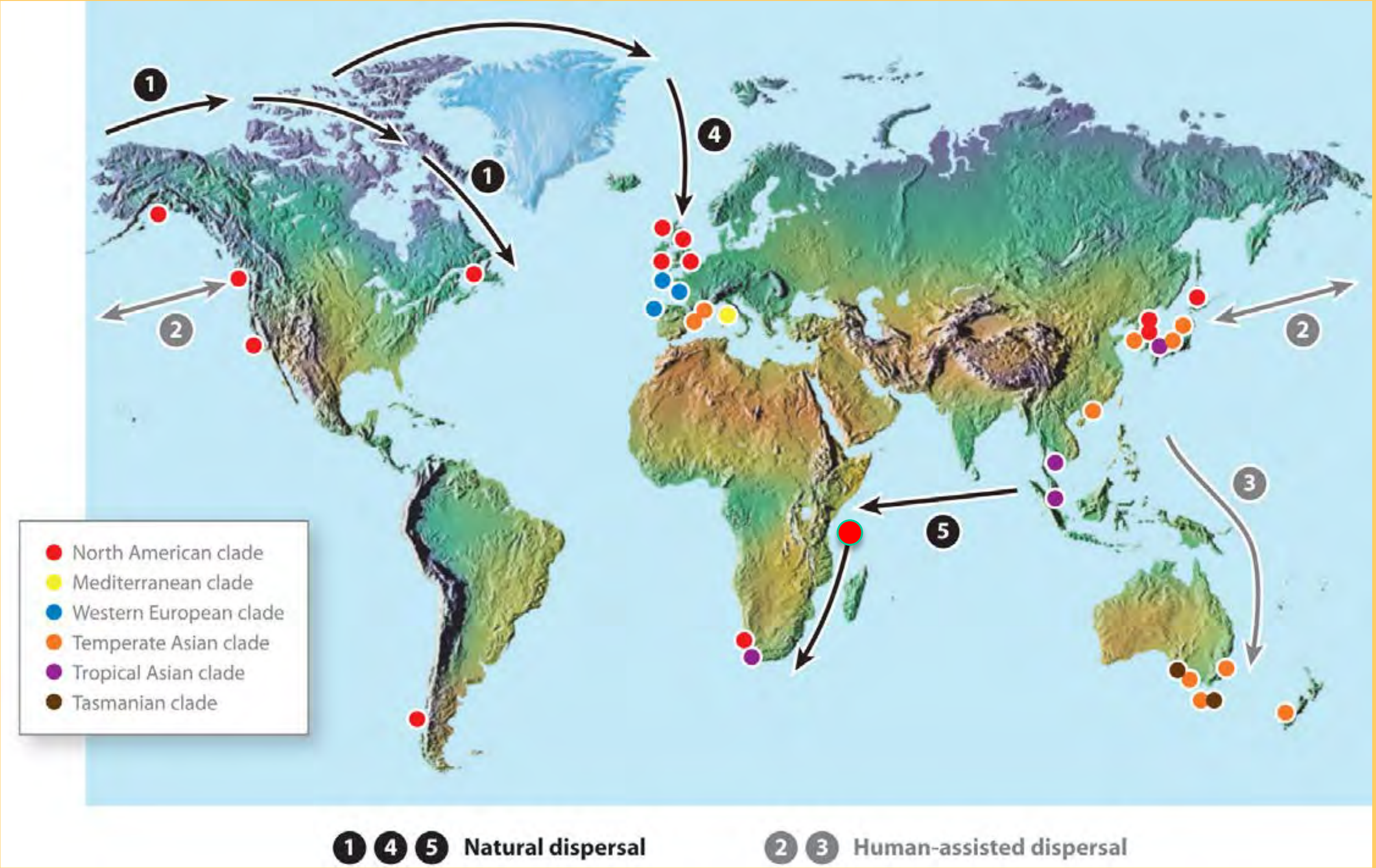
Different ocean regions change at different rates

Boyd. *Nature Clim. Ch*. **5**, 71–79 (2015); Bopp. *Biogeosc. Disc*.10, 6225-45 (2013)



We need consensus on agreed observer hotspots for pH, T, N,P, O_2

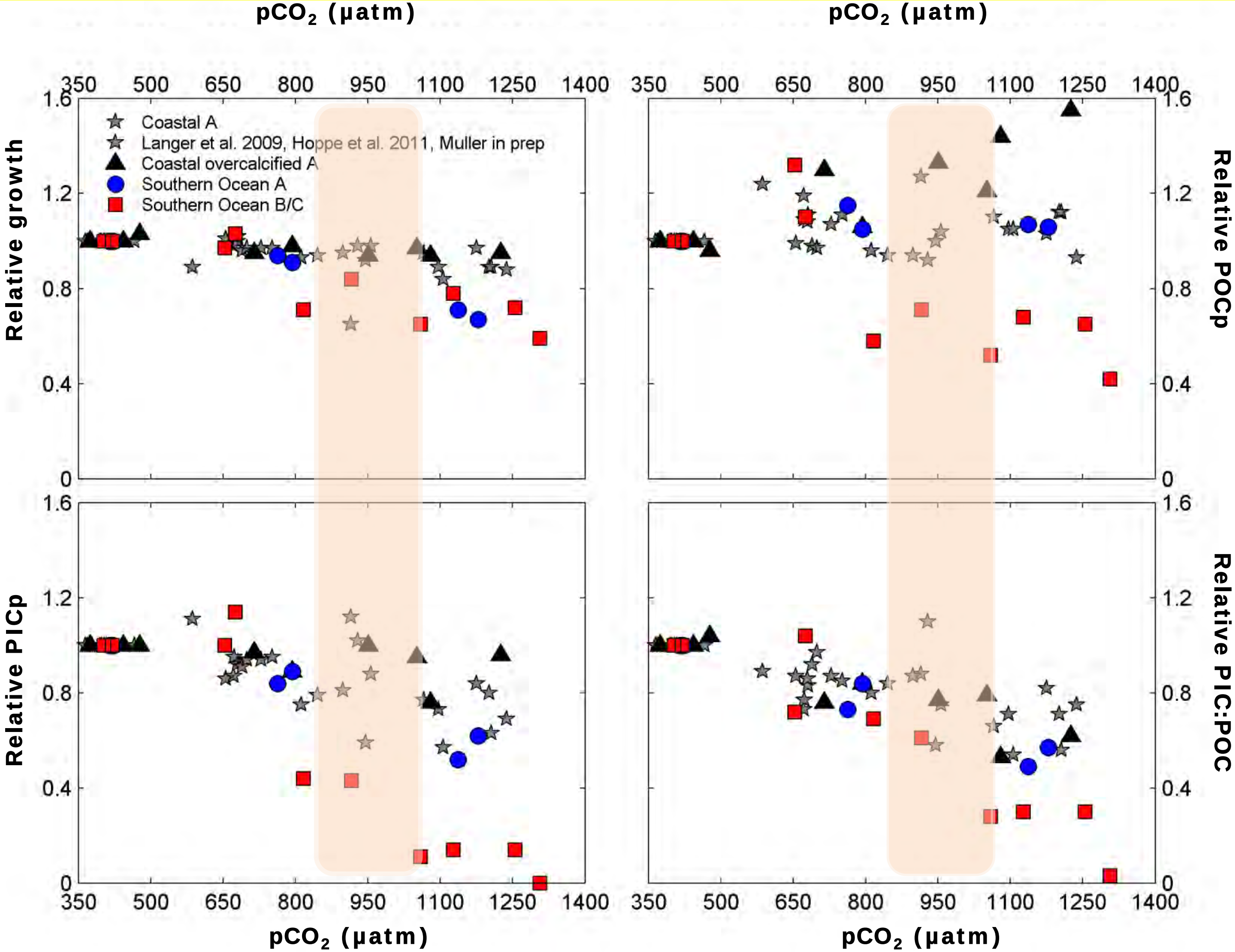
A single culture strain is NOT representative of global population!

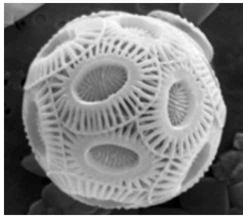


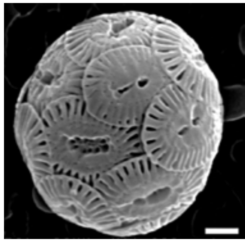
Alexandrium tamarense-species complex

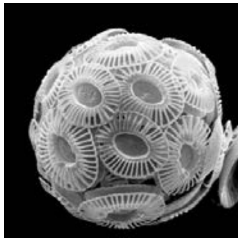
We need to work on agreed keystone species & well-defined strains

Differing responses of 3 Southern Ocean *Emiliania huxleyi* ecotypes to ocean acidification



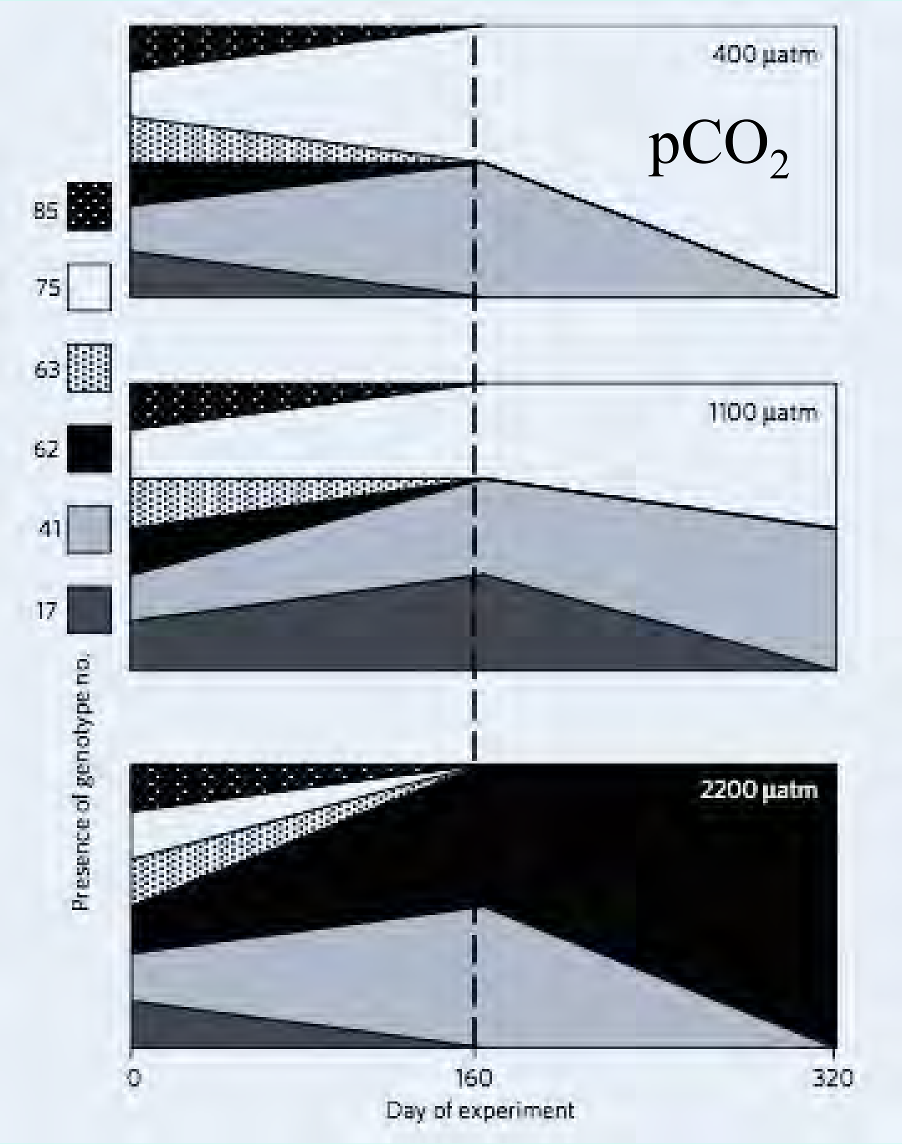


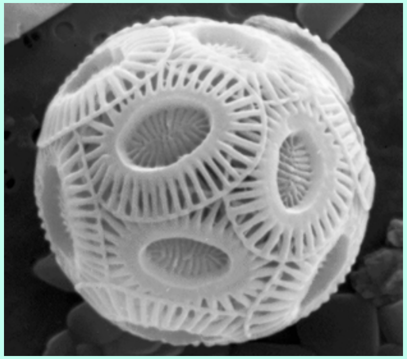




Műller, Trull & Hallegraeff, MEPS 2015, in press

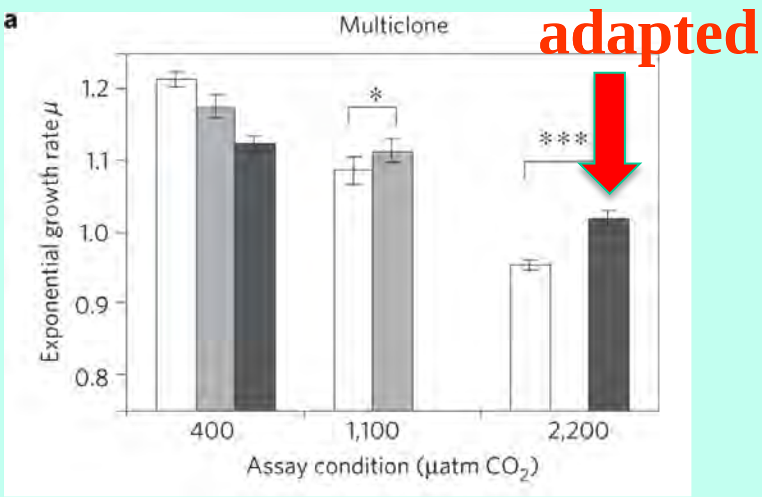
Multiclonal culture (6 genotypes)





Genetic shifts in multiclonal cultures over 500 generations

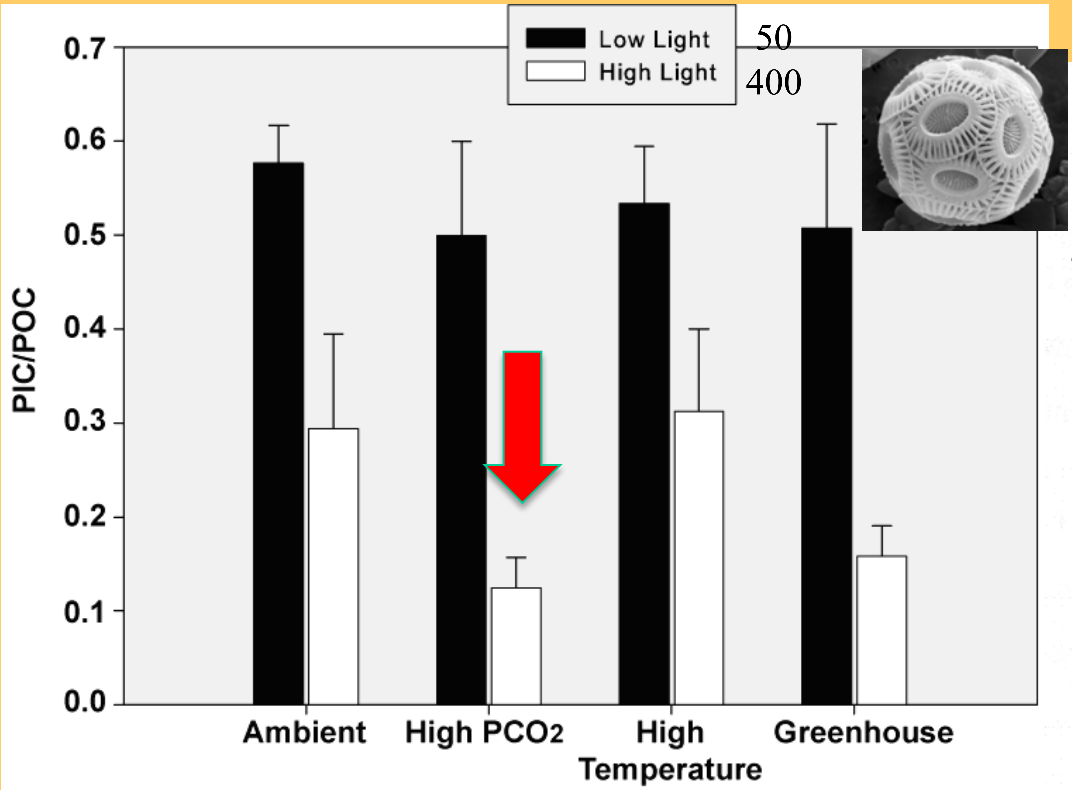
Lohbeck, Riebesell, Reusch. 2012



Microorganisms with short generation times may be able to respond to environmental alterations through adaptive evolution

FACTOR INTERACTIONS *Emiliania huxleyi* x pCO_2

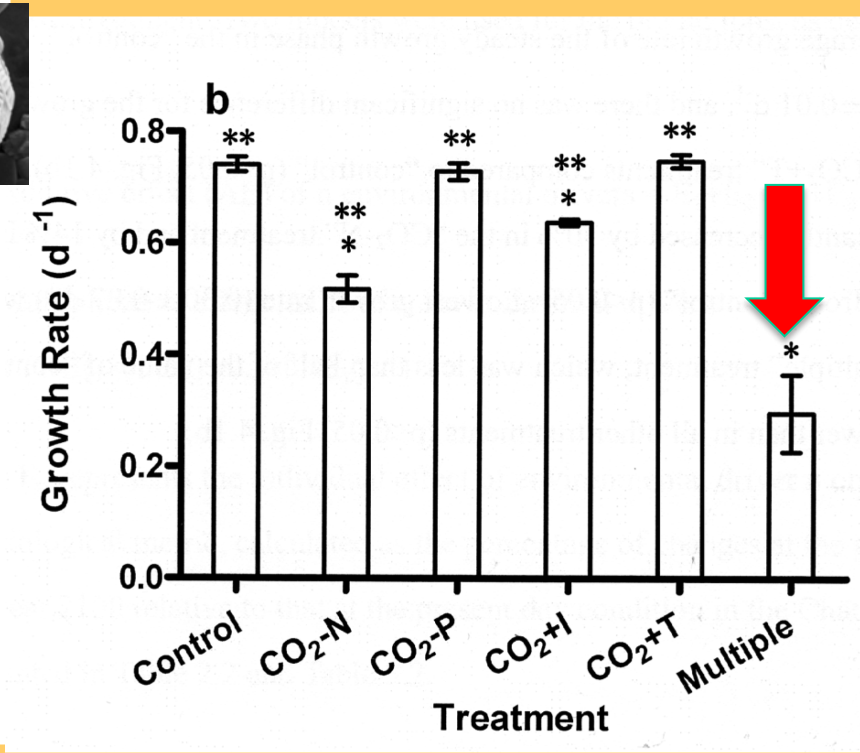
CO_2 ; Temp x light interaction



20C;375ppm 20;750 24; 375 24; 750

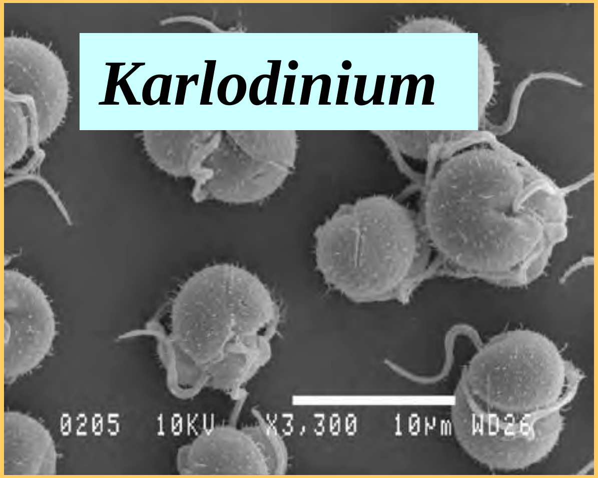
Yuanyan Feng et al. 2008. Eur. J. Phycol. 43:87–98.

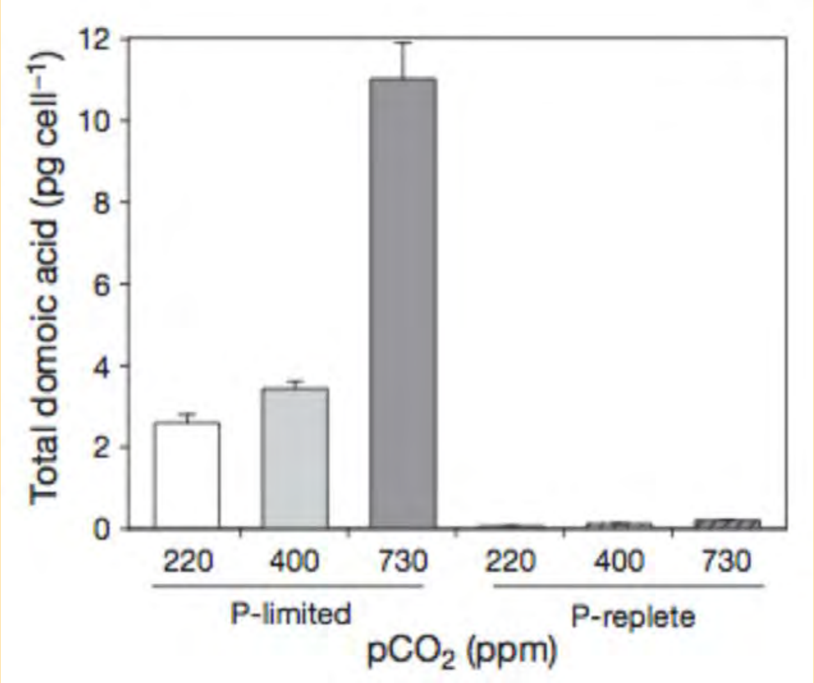
Lowest growth when changing **Multiple Drivers (N-,P-, I+,T+,CO_2+)**



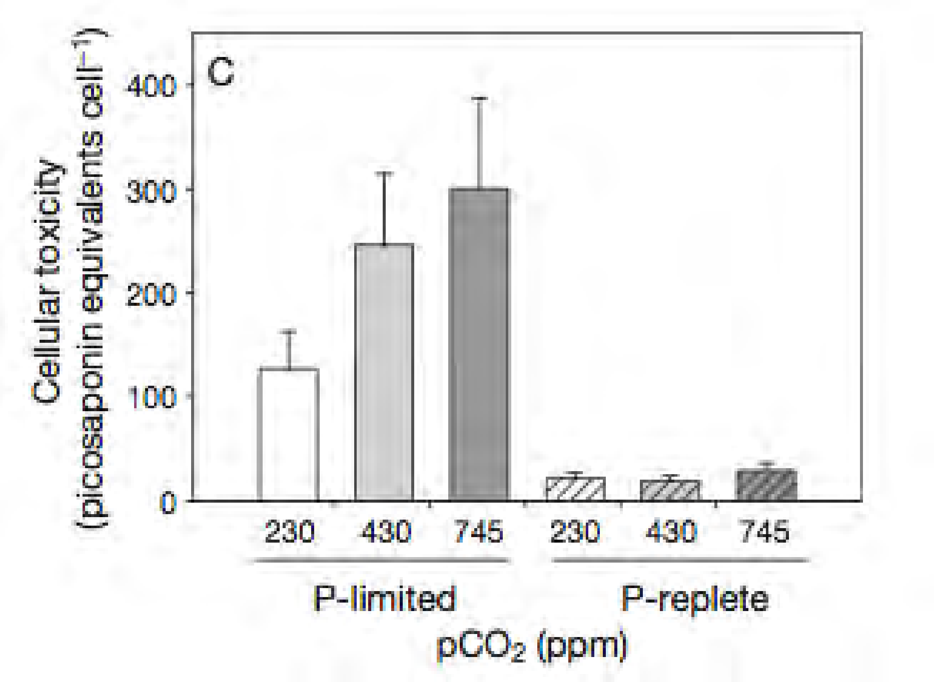
Feng 2015 Unpubl. PhD thesis

Ocean Acidification + P limitation can alter Toxicity



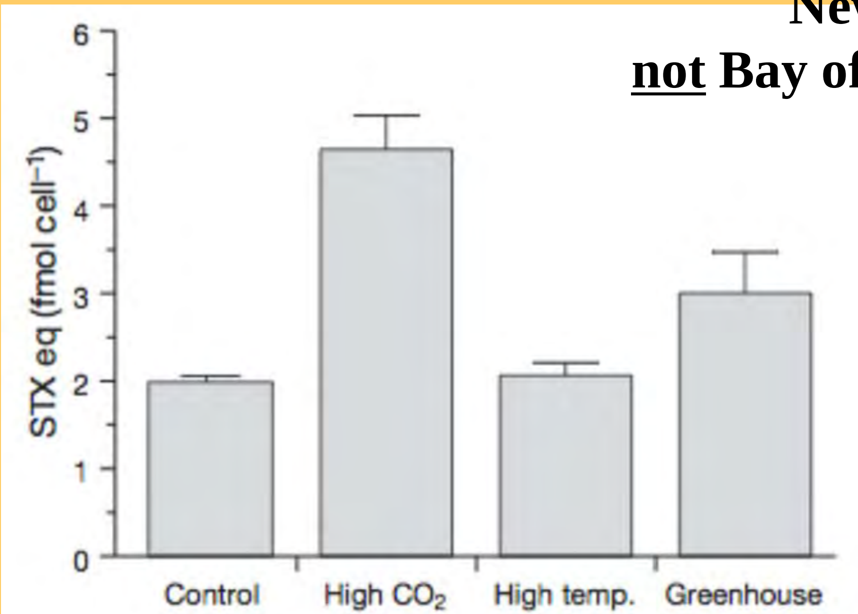


Sun et al. 2011. Limnol.Oceanogr.56:829-840



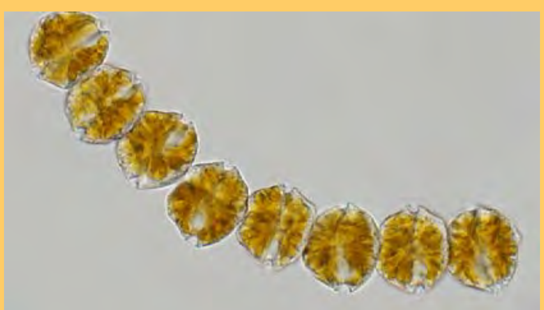
Fu et al. 2010. Aquat.Microb.Ecol.59:55-65

Alexandrium : more PST California strain
New York strain
<u>not</u> Bay of Fundy strain

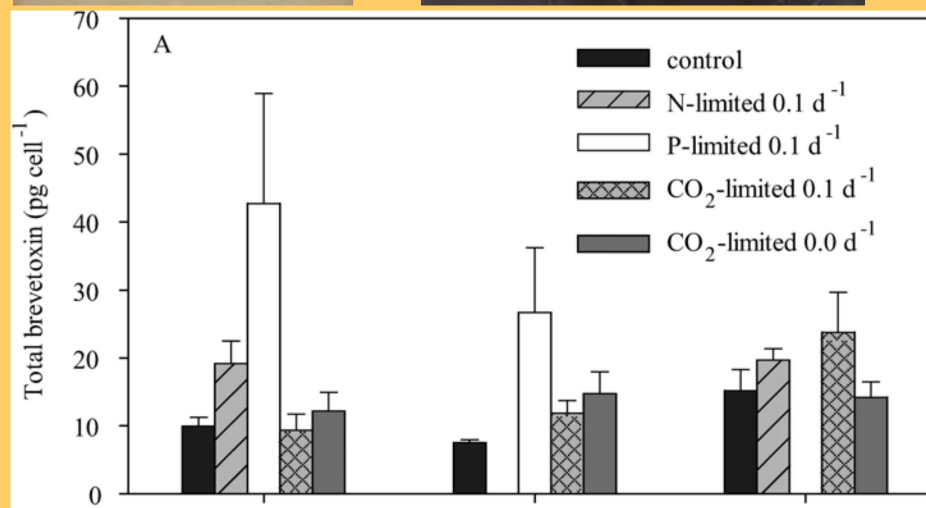


800 ppm; 15C

Tatters et al. 2013
Hattenrath-Lehmann 2014

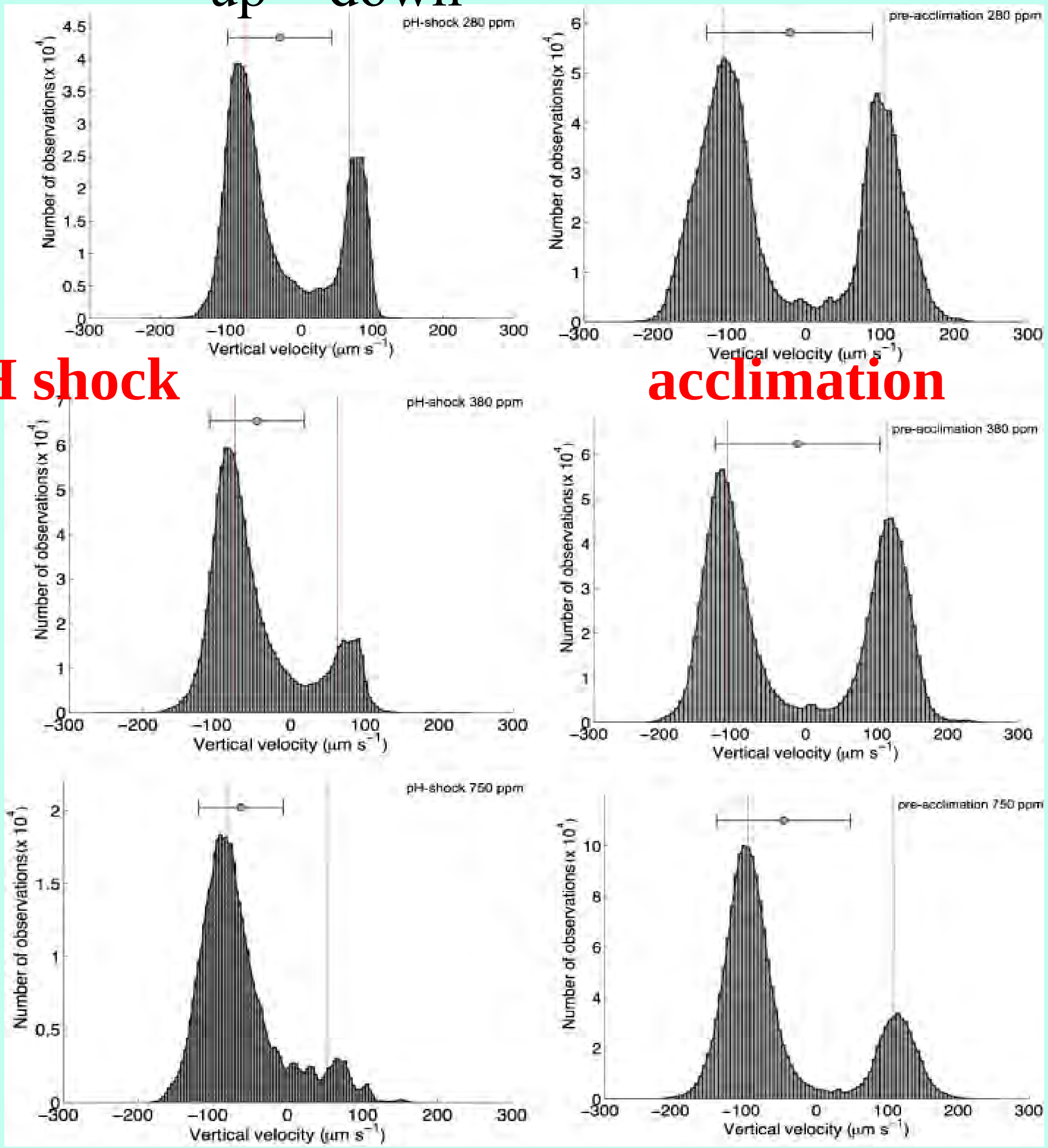


Karenia brevis



P deficiency strongest driver BTX

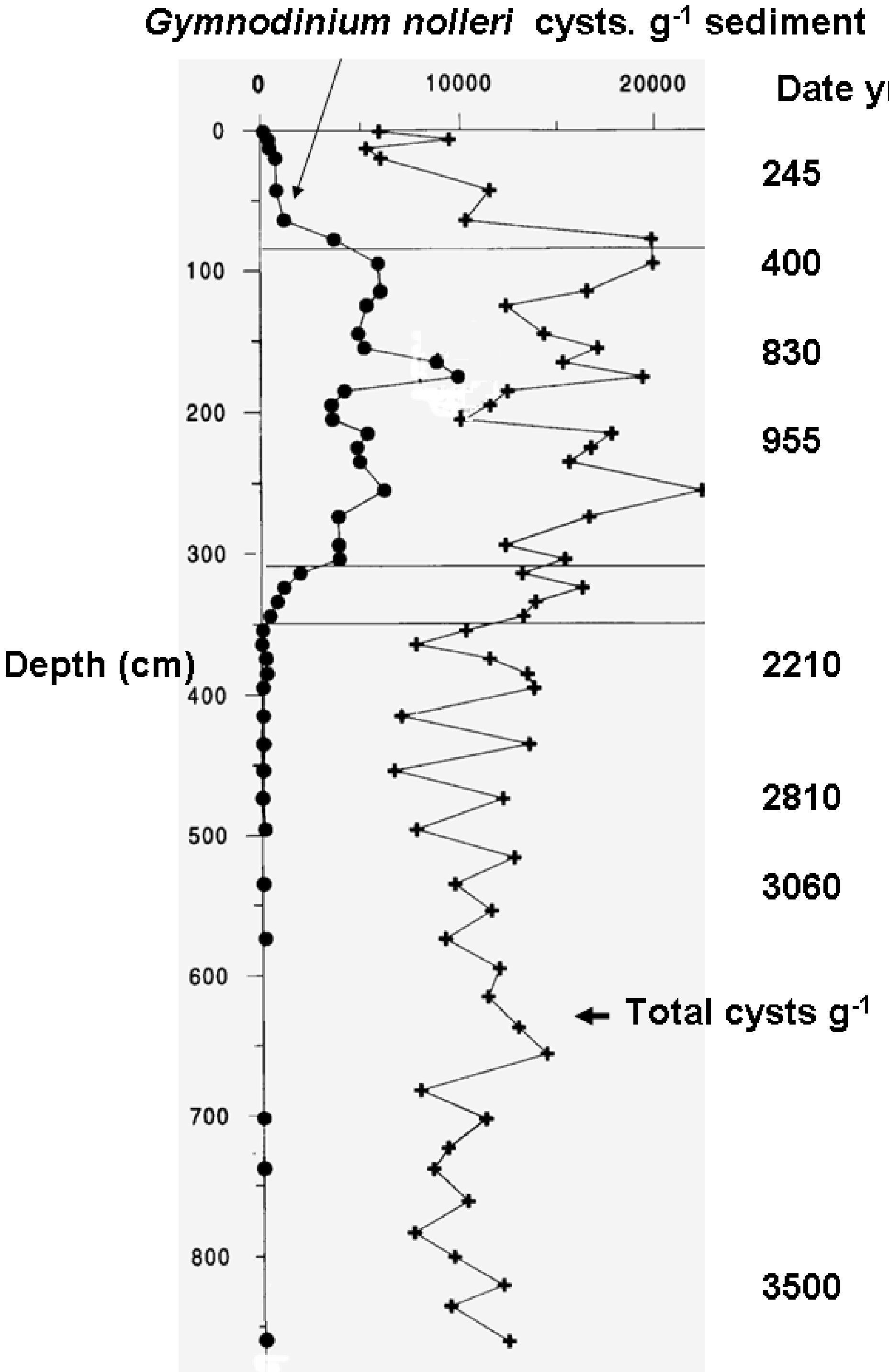
Hardison 2014

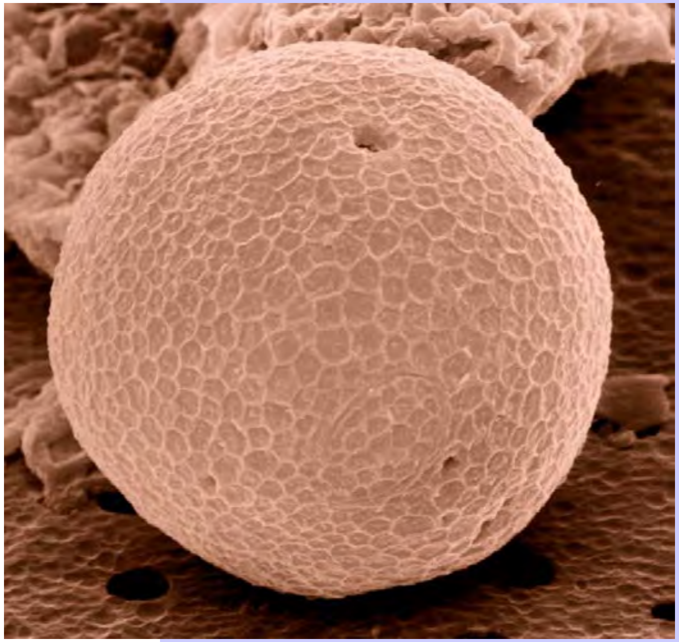


pH alters swimming behaviour of *Heterosigma* .

Kim et al. HARALG 2013

Kattegat

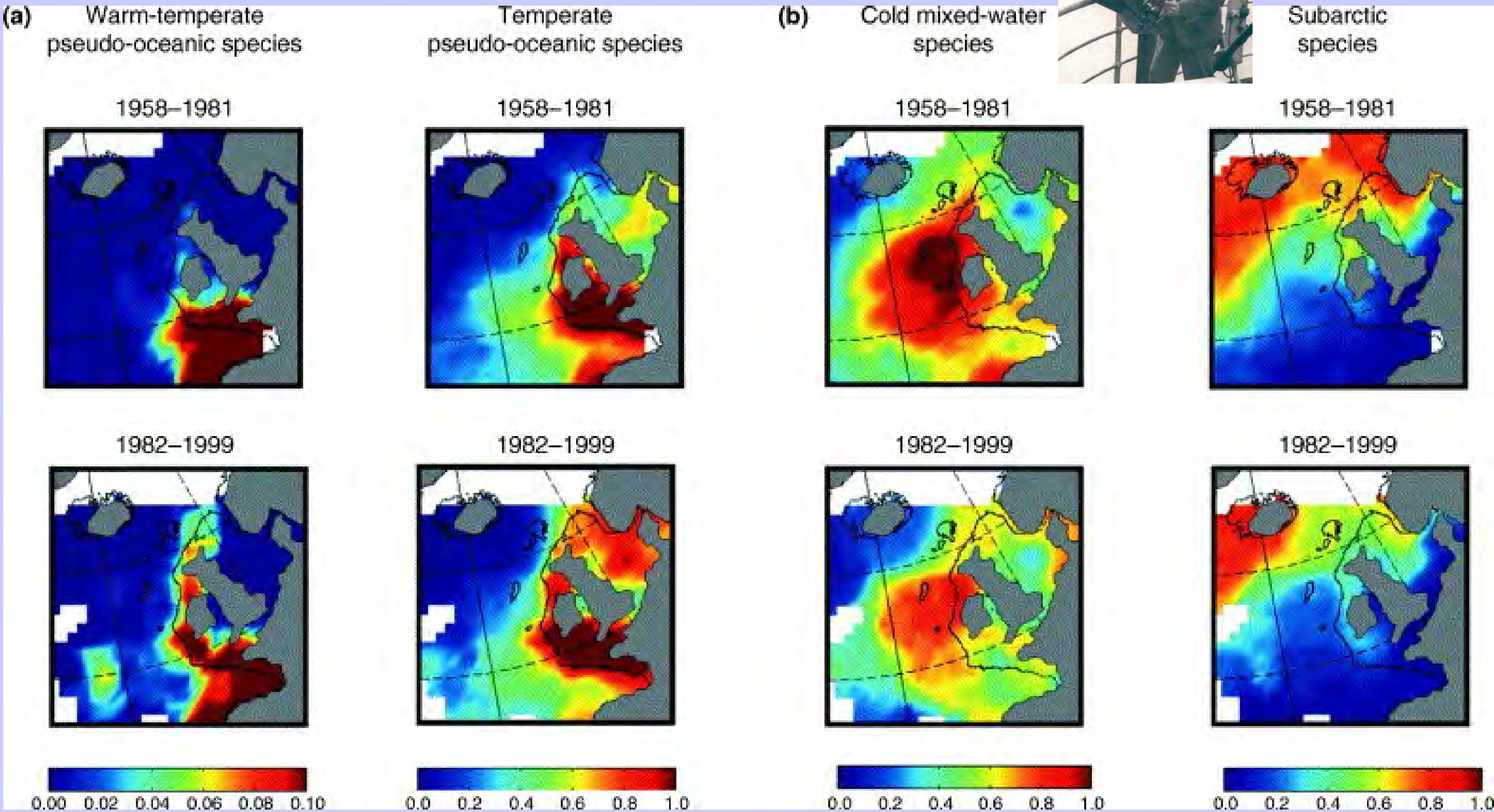




We can learn from the dinoflagellate cyst record

Improve via palaeogenetics?

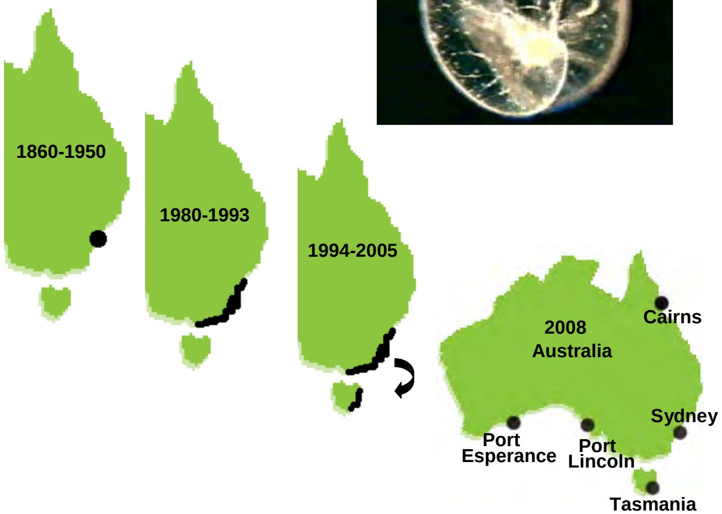
We need long-term (>30 yrs) Plankton Records

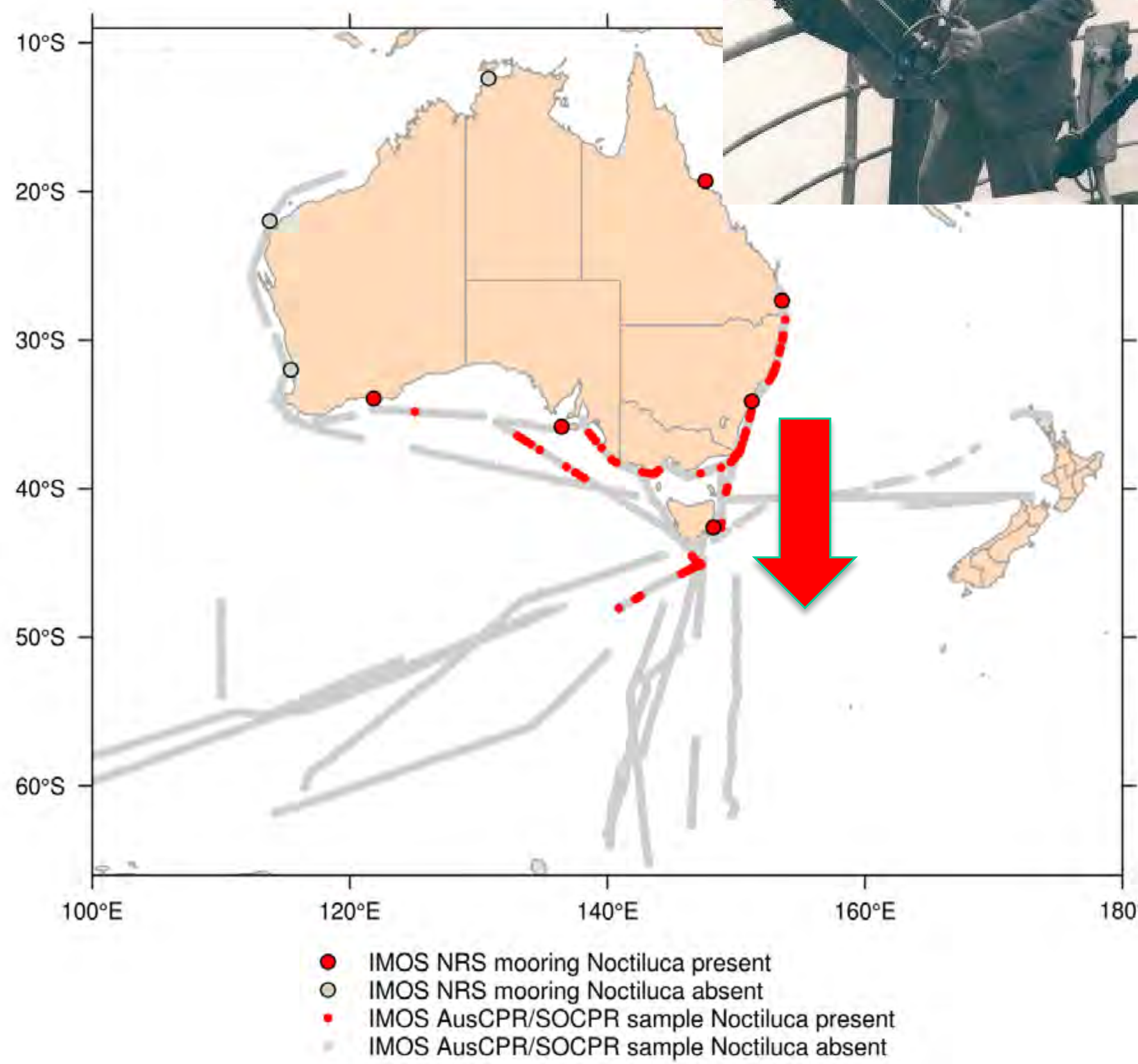


North Atlantic Zooplankton (CPR)

Pole-ward shift warm-water species; Cold-water species contract

Range Expansion Red-tide Dinoflagellate *Noctiluca*





Grazing impact?

• Mediterranean and Eastern Atlantic

Is *Gambierdiscus* expanding to new areas

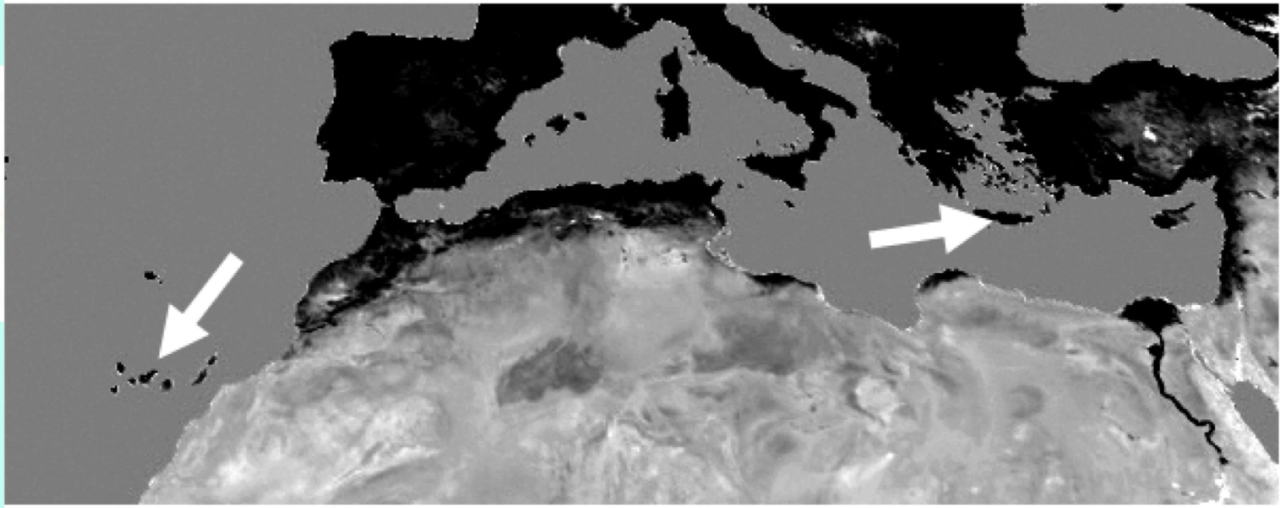
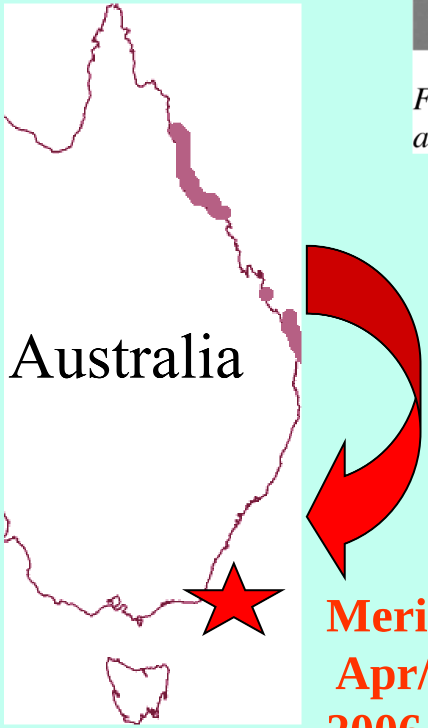
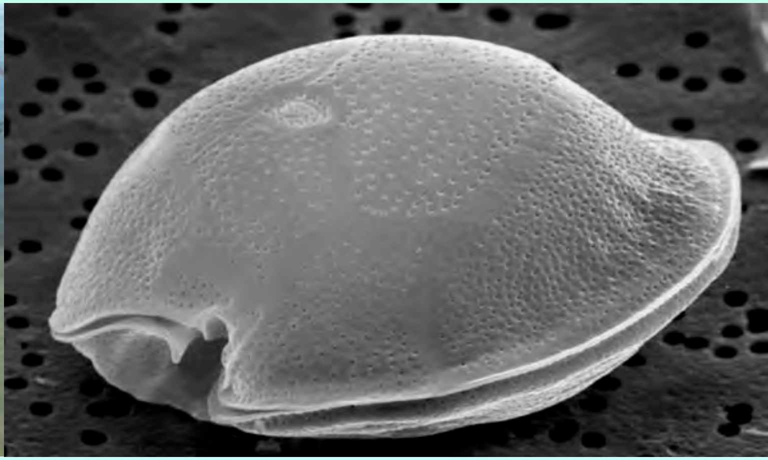


Fig. 1. Map indicating (arrows) the locations of Gambierdiscus *sp. records (Canary Islands, Spain and Crete, Greece).*

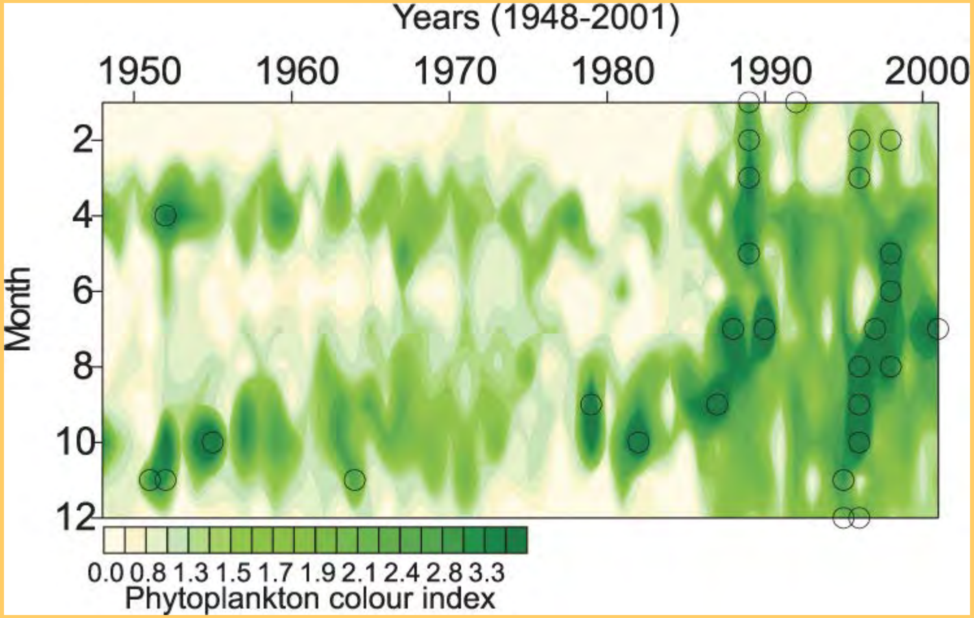


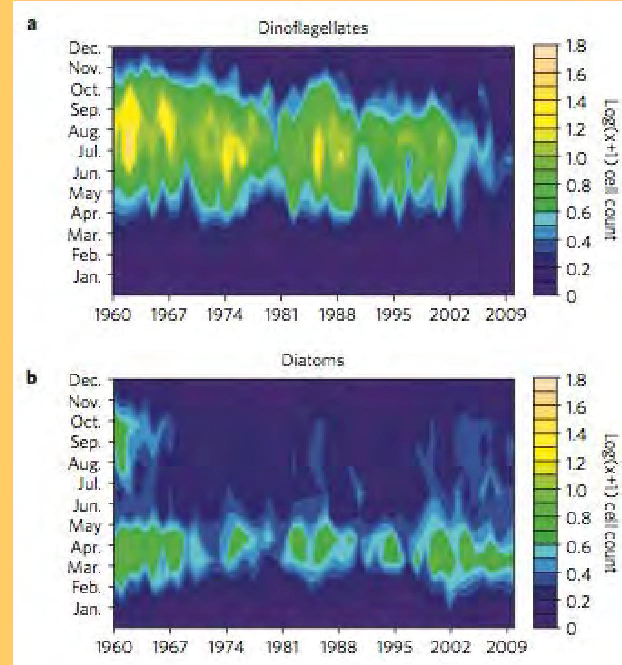
Merimbula, Apr/May 2006-2013



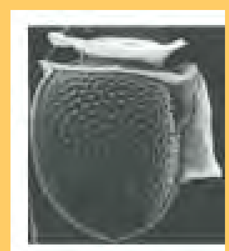
new coastal fisheries unexpectedly at risk

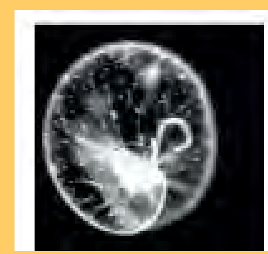
Earlier spring /autumn phytoplankton blooms in North Sea

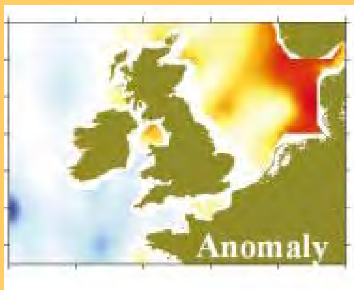


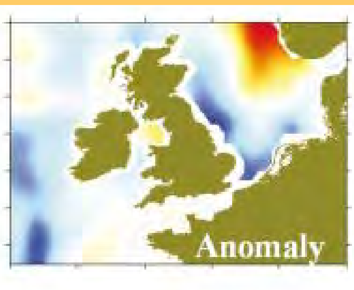


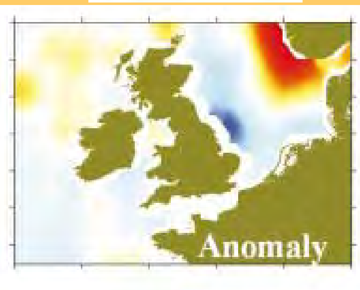
Shifts in selected HAB species in North Atlantic

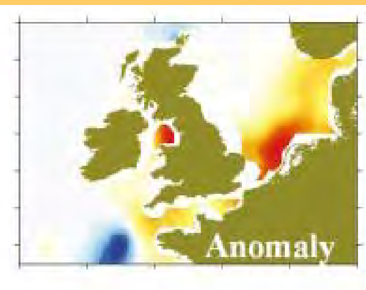




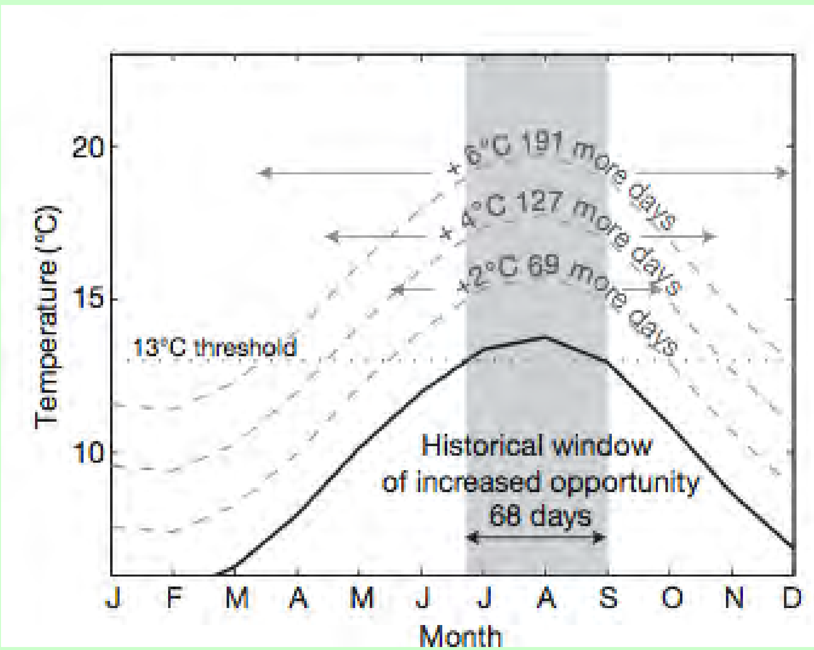








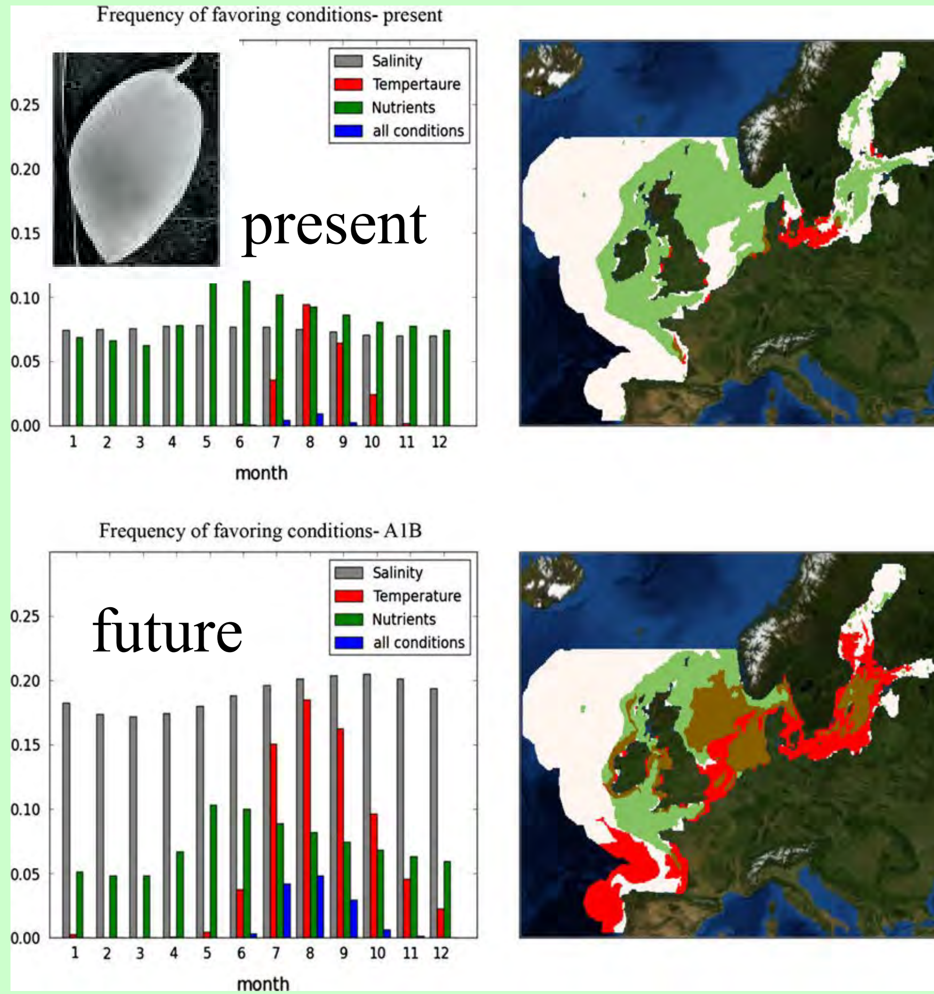
1960-1989
vs
1990-2002



Moore et al. 2010

Wider Bloom Window

Prorocentrum, Europe



Glibert et al. Global Change Biology 2014

We can expect

- Range expansion of warm-water at expense of cold-water species

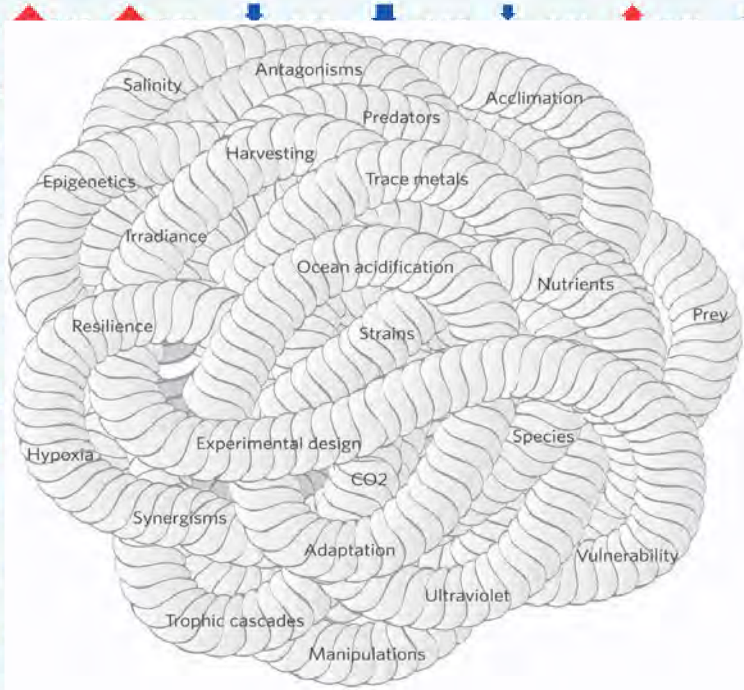
•Changes in abundance & seasonal window of growth

•Knock-on effects for marine foodwebs when individual zooplankton/fish are differentially impacted (match/mismatch)

•Ocean acidification combined with nutrient limitation or temperature changes may increase toxicity of HABs

•Increased vigilance for unexpected species invasions & food web alterations

	Physical variables							Biogeochemical variables				CO_2- system			
	Temp. (°C)	Salinity (psu)	Ice fraction –	Log_{10} MLD (cm)	PAR ($W m^{-2}$)	Windstress ($dyn cm^{-2}$)	Pot. density ($kg m^{-3}$)	Log_{10} SiO_3 ($mmol m^{-3}$)	Log_{10} PO_4 ($mmol m^{-3}$)	Log_{10} Fe ($mmol m^{-3}$)	Log_{10} NO_3 ($mmol m^{-3}$)	Alkalinity ($meq m^{-3}$)	CO_3^{2-} ($\mu mol kg^{-1}$)	pH –	p_{CO_2} (ppmv)
Global mean	↑ 2.50	↓ −0.10	↓ −0.03	↓ −0.02	↑ 0.43	↓ 0.00	↓ −0.73	↓ −0.13	↓ −0.31	↑ 0.07	↓ −0.25	↓ −6.52	↓ −82.5	↓ −0.33	↑ 486
SSO	↑ 1.51	↓ −0.30	↓ −0.19	↓ −0.03	↑	↑	↓	↓	↓	↑	↓ −0.01	↓ −2.7	↓ −51.3	↓ −0.3	↑ 440
NSO	↑ 2.96	↑ 0.02	↓ 0.00	↓ −0.03							↓ −0.18	↓ −4.1	↓ −73.8	↓ −0.3	↑ 493
SSPO	↑ 2.41	↓ −0.02	↓ 0.00	↓ −0.01							↓ −0.44	↓ −6.8	↓ −96.2	↓ −0.3	↑ 488
WEPO	↑ 2.53	↓ −0.48	↓ 0.00	↓ −0.03							↓ −0.65	↓ −9.1	↓ −98.7	↓ −0.3	↑ 482
EEPO	↑ 2.80	↓ −0.16	↓ 0.00	↓ −0.04							↓ −0.36	↓ −7.2	↓ −73.1	↓ −0.3	↑ 447
NSPO	↑ 2.44	↓ −0.17	↓ 0.00	↓ 0.00							↓ −0.46	↓ −7.8	↓ −96.6	↓ −0.3	↑ 493
NPO	↑ 3.22	↓ −0.45	↓ 0.00	↓ −0.03							↓ −0.11	↓ −7.3	↓ −66.2	↓ −0.3	↑ 491
SIO	↑ 2.62	↓ −0.20	↓ 0.00	↑ 0.01							↓ −0.25	↓ −4.7	↓ −96.1	↓ −0.3	↑ 494
NIO	↑ 2.70	↓ −0.19	↓ 0.00	↑ 0.00							↓ −0.19	↓ −7.8	↓ −96.6	↓ −0.3	↑ 483
SAO	↑ 2.38	↑ 0.08	↓ 0.00	↓ −0.01							↓ −0.27	↓ −6.9	↓ −93.3	↓ −0.3	↑ 482
NSAO	↑ 2.37	↑ 0.55	↓ 0.00	↑ 0.00							↓ −0.19	↓ −5.18	↓ −96.0	↓ −0.3	↑ 494
NAO	↑ 1.94	↓ −0.19	↓ −0.04	↓ −0.08	↑ 1.49	↓ −0.06	↓ −0.57	↓ −0.16	↓ −0.20	↑ 0.05	↓ −0.16	↓ −12.0	↓ −81.9	↓ −0.4	↑ 495
AO	↑ 1.51	↓ −0.30	↓ −0.19	↓ −0.03	↑ 3.67	↑ 0.18	↓ −0.35	↓ −0.08	↓ −0.01	↑ 0.01	↓ −0.01	↓ −16.3	↓ −48.8	↓ −0.3	↑ 440



Red arrows denote an increase, and blue arrows denote a decrease in an ocean property. The arrows are scaled according to the regional deviation from the global mean; larger arrows indicate a stronger regional anomaly relative to the global mean anomaly, and smaller arrows a weaker regional anomaly. Together, these regional deviations, across ocean properties, drive distinctive patterns in multi-stressors. The acronyms for the regions are defined in Fig. 2 and Supplementary Fig. 1.

Regional anomalies

Largest regional anomaly	Global mean	Smallest regional anomaly
↑ ↓	↑ ↓	↑ ↓

Major Departure from current HAB approaches

LAB

- Study multiple strains
- Best practices experimental techniques (adaptation)
- Multifactorial experiments should be norm
- Hypotheses why OA etc impact on cellular toxicity
- Global extrapolations via mathematical modelling

FIELD

- High quality long-term time series (CPR, micropaleontology)
- Recommended hot spot observer sites
- Study HABs as part of total phytoplankton
- We need to better collaborate & partition this formidable task!