Harmful algal blooms and ocean acidification in Santa Monica Bay, CA

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SANTA MONICA BAY OBSERVATORY

Mooring

First deployment: June 2001
Latest deployment ended May 2010

Instruments on the mooring:
- Surface CTD, fluorometer, transmissometer
- Meteorological station
- Surface CO_2 and O_2 analyzer
- Downward looking ADCP (~ 100m)
- Temperature-salinity string (~ 100m)
- Packet radio: www.smbayobservatory.org

Shipboard measurements

~bi-weekly since January 2003
> 170 cruises

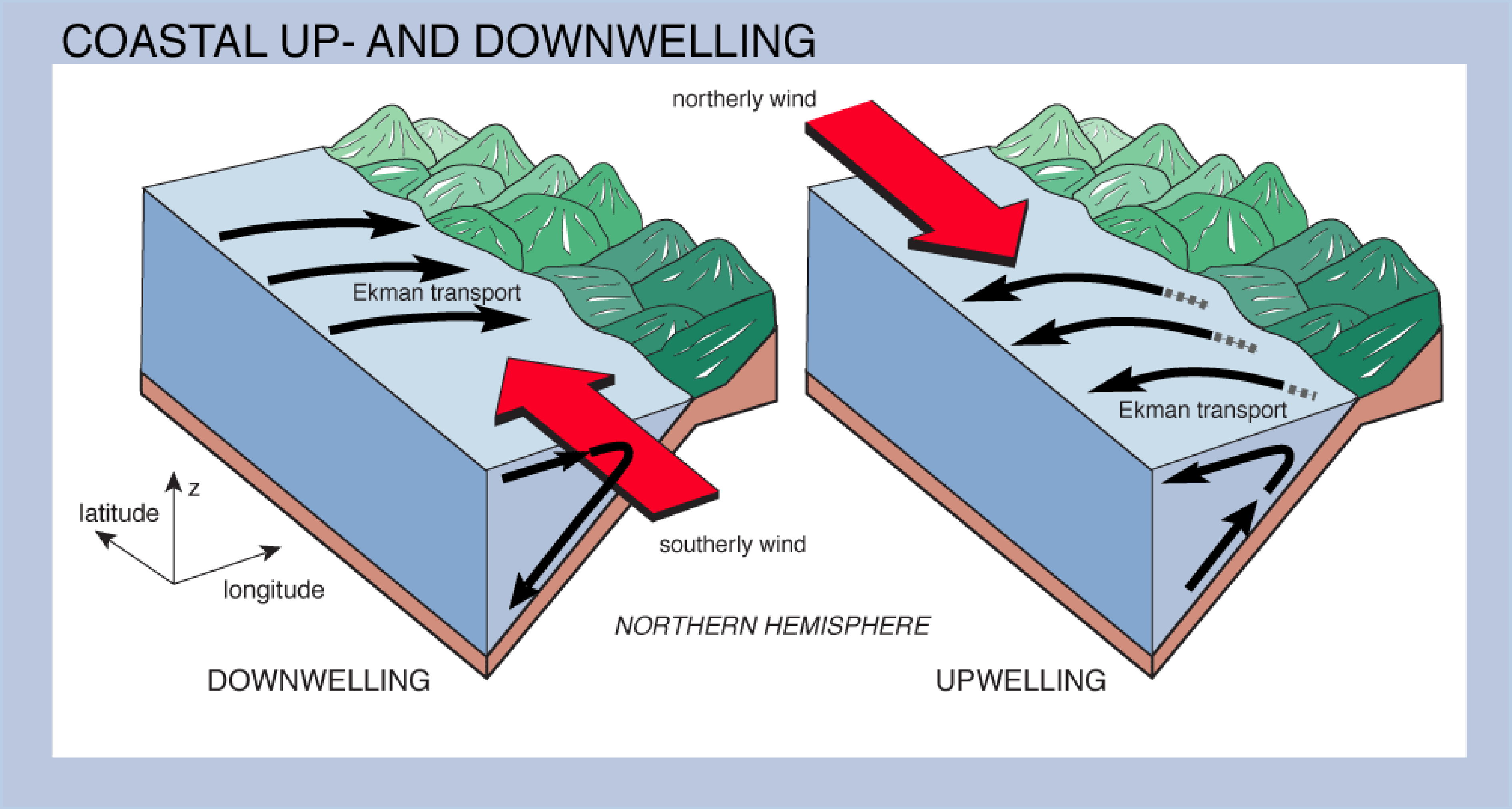
Discrete water samples to *300m:*
- Dissolved inorganic carbon
- Alkalinity
- Nutrients
- Phytoplankton community
- Chlorophyll a
- Biological and mineral opal

+CTD measurements

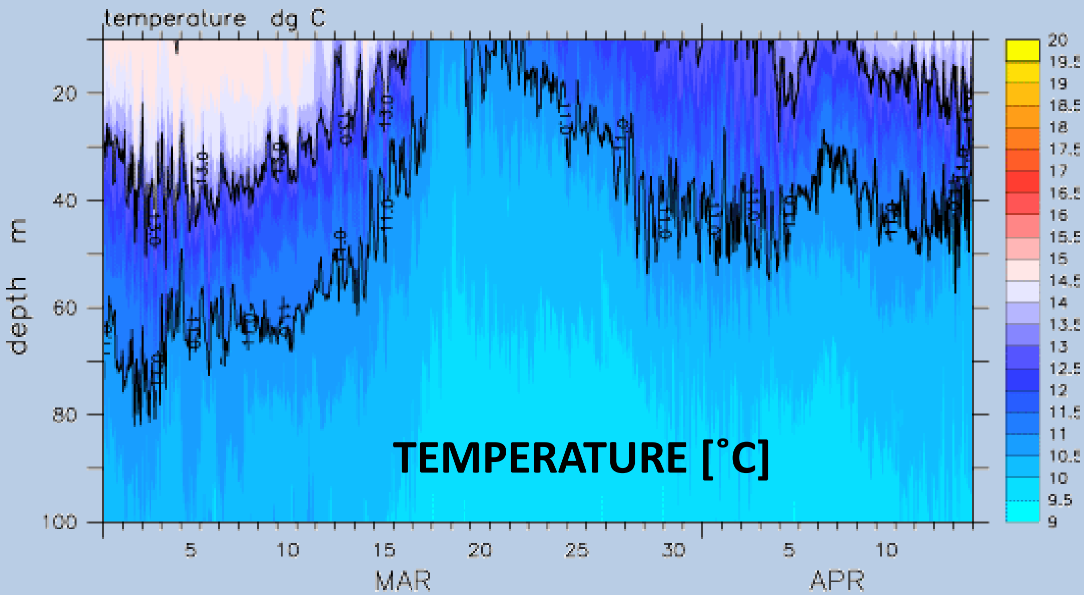
Periods of:
- Trace metals (Fe,Mn)
- N_2 fixation, PP rates

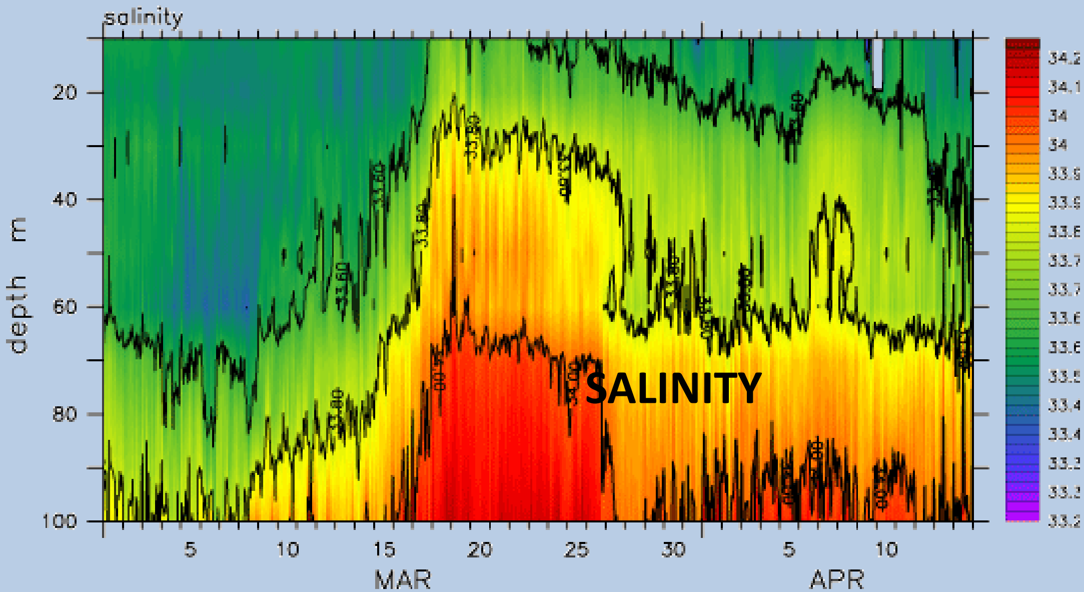
Working off a commercial dive boat!

What happens during upwelling?



March 2002 event: Oceanic response

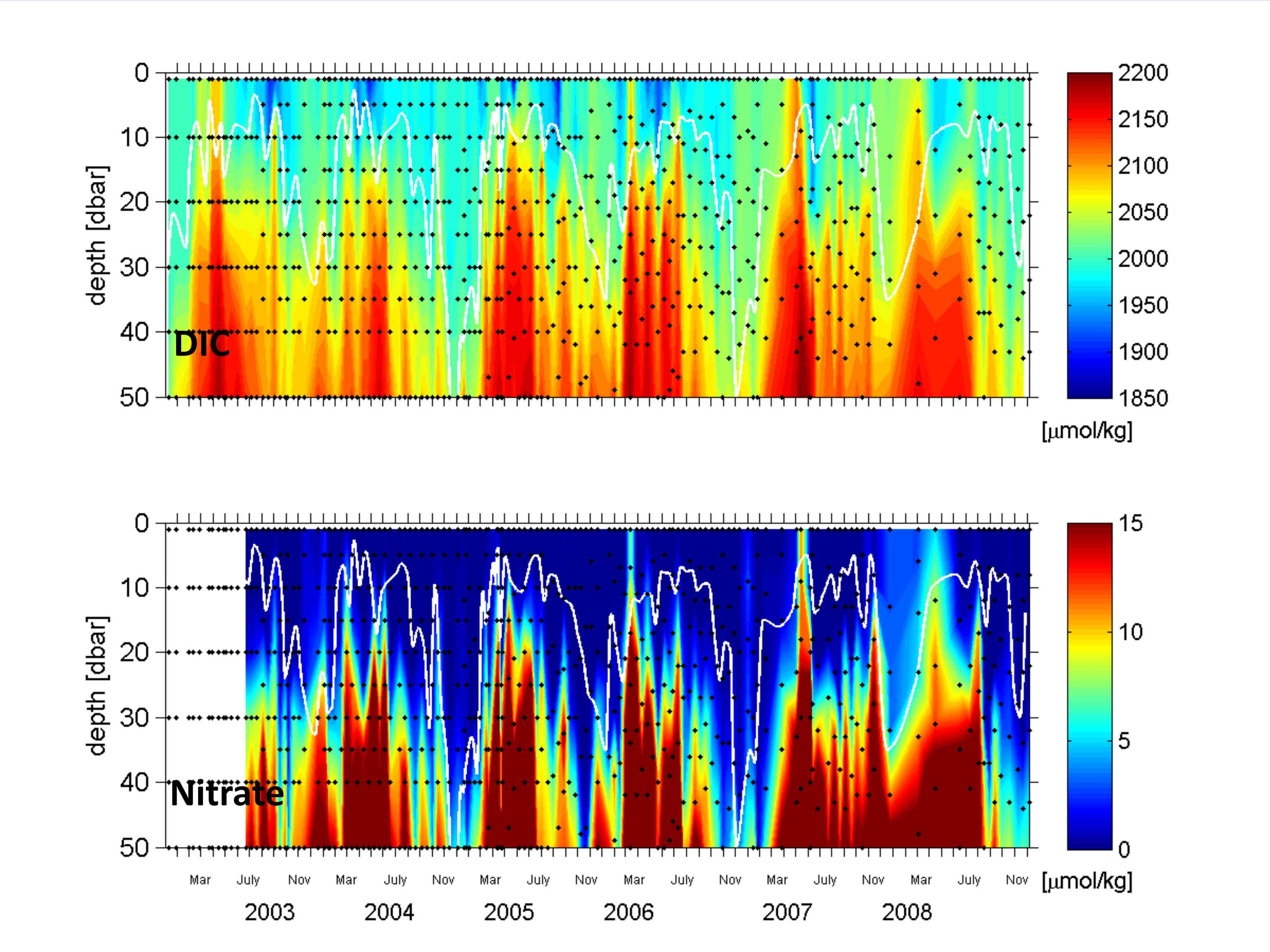




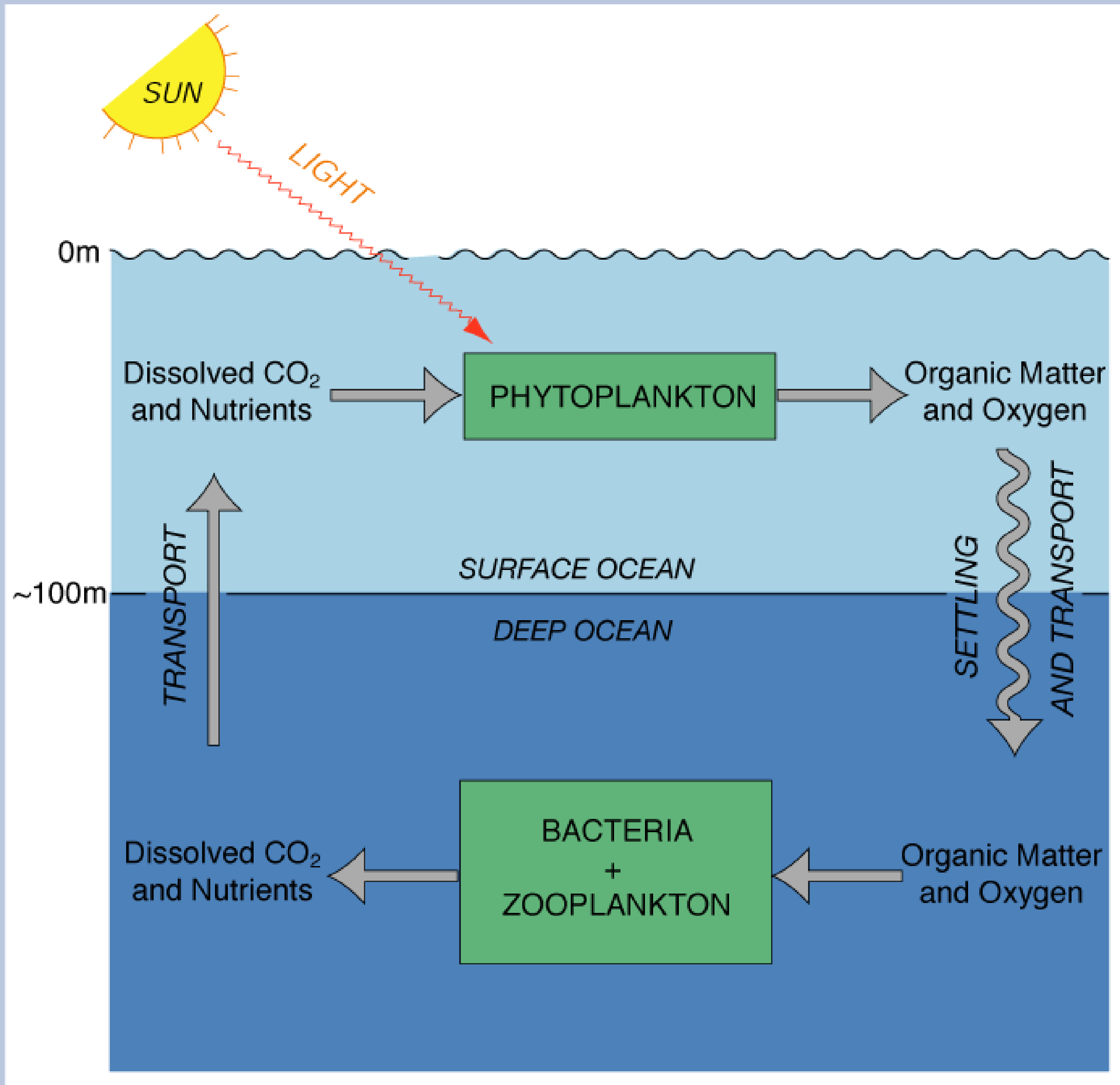
Strong uplifting of isopycnals, leading to outcrop of very cold water

SMBO data, Gruber et al., in prep

Nutrient response to upwelling



THE GREAT BIOGEOCHEMICAL LOOP



Photosynthesis and Respiration

The processes of life

Photosynthesis by phytoplankton sets the bgc loop in the ocean in motion

$$106\ CO_2 + 16\ HNO_3 + H_3PO_4 + 122\ H_2O + \text{light}$$
$$= \underbrace{(CH_2O)_{106}(NH_3)_{16}(H_3PO_4)}_{\text{Organic matter, I.e phytoplankton biomass}} + 138\ O_2$$

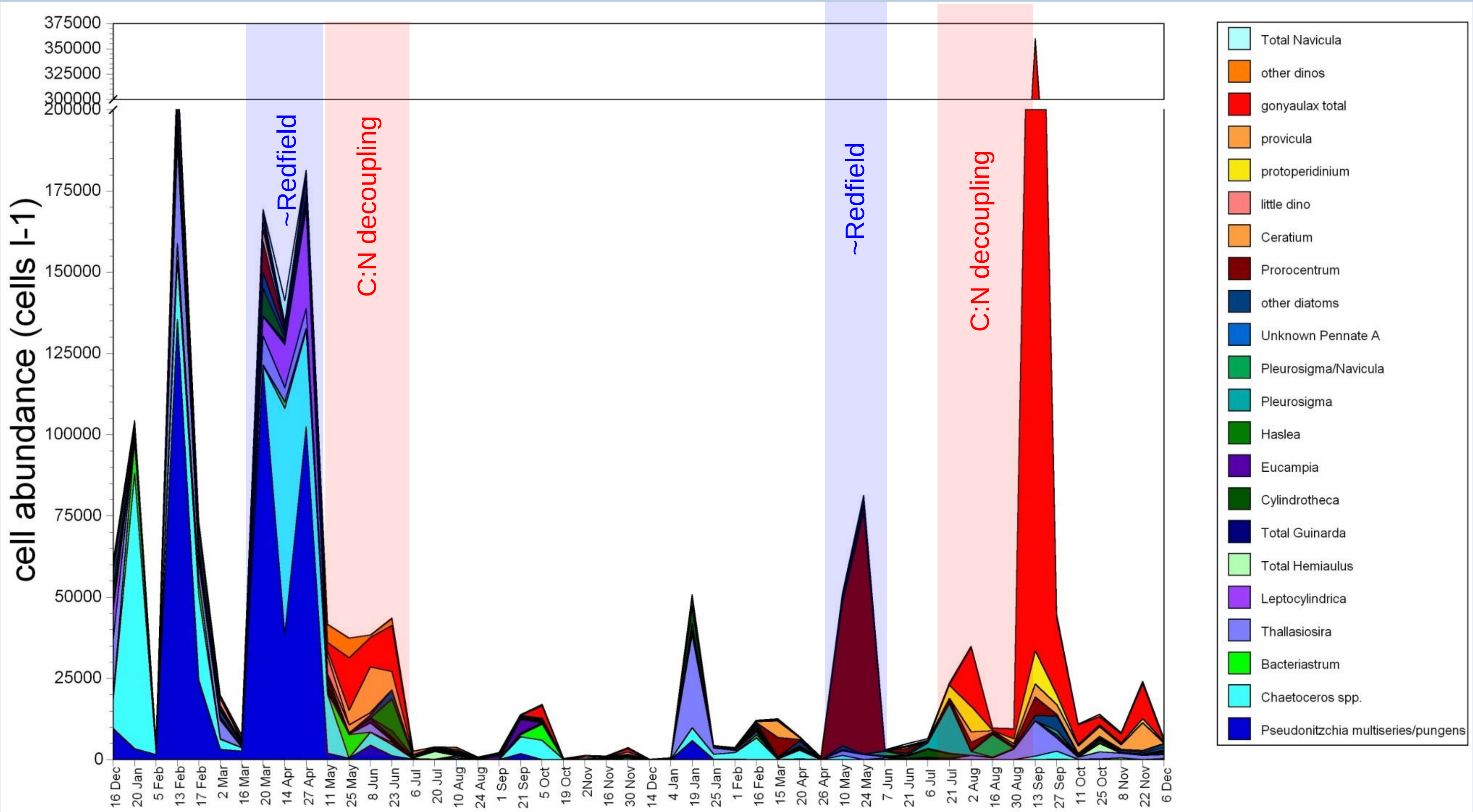
Limiting factors:

Light

Nutrients (nitrate, phosphate, micronutrients)

Grazing (by zooplankton)

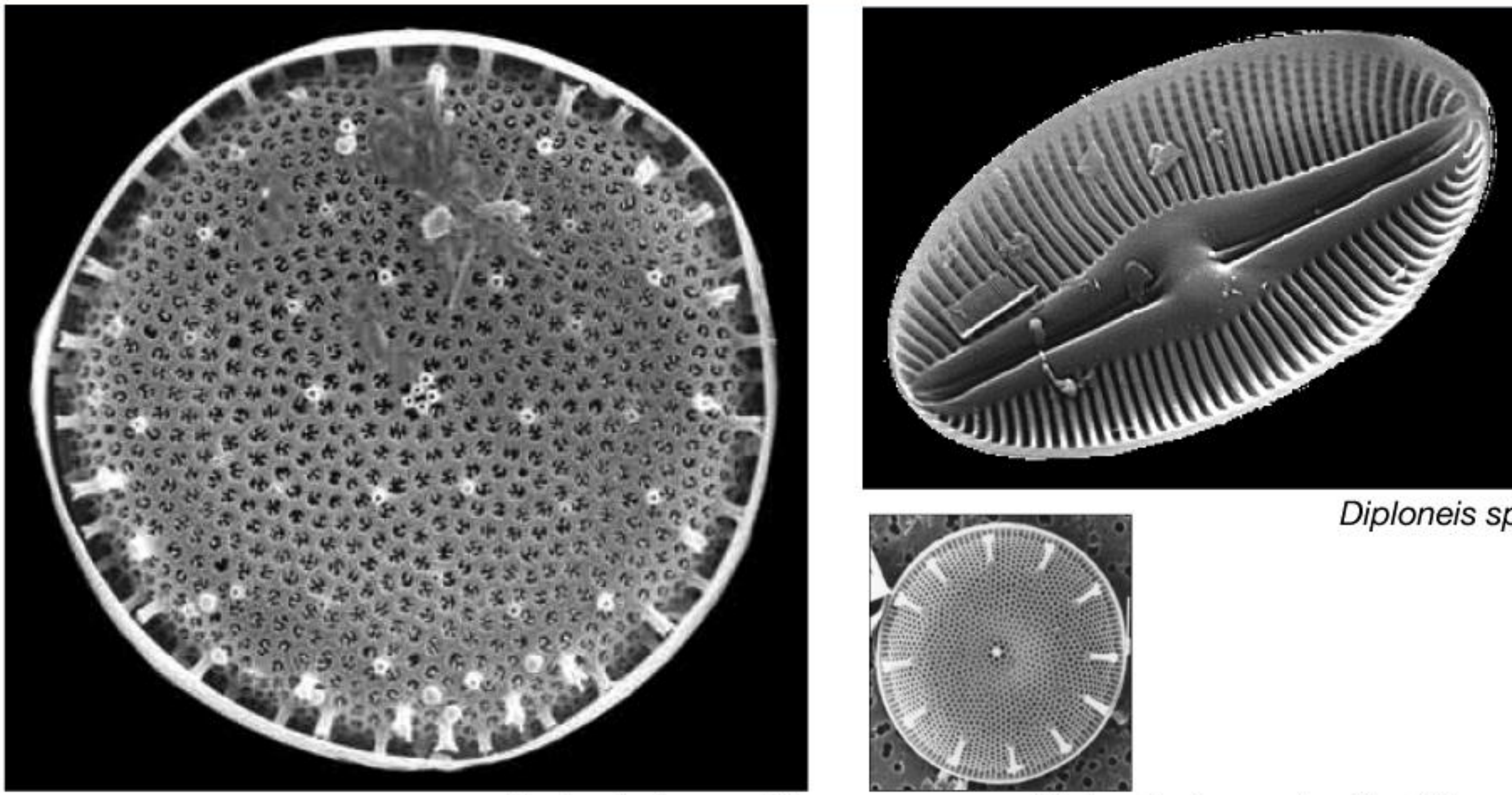
SMBO Phytoplankton Succession



2004 | 2005

R. Shipe

MARINE DIATOMS



Diploneis sp.

Thalassiosira gravida *Thalassiosira nordenskioeldii*

Usually dominant during spring bloom

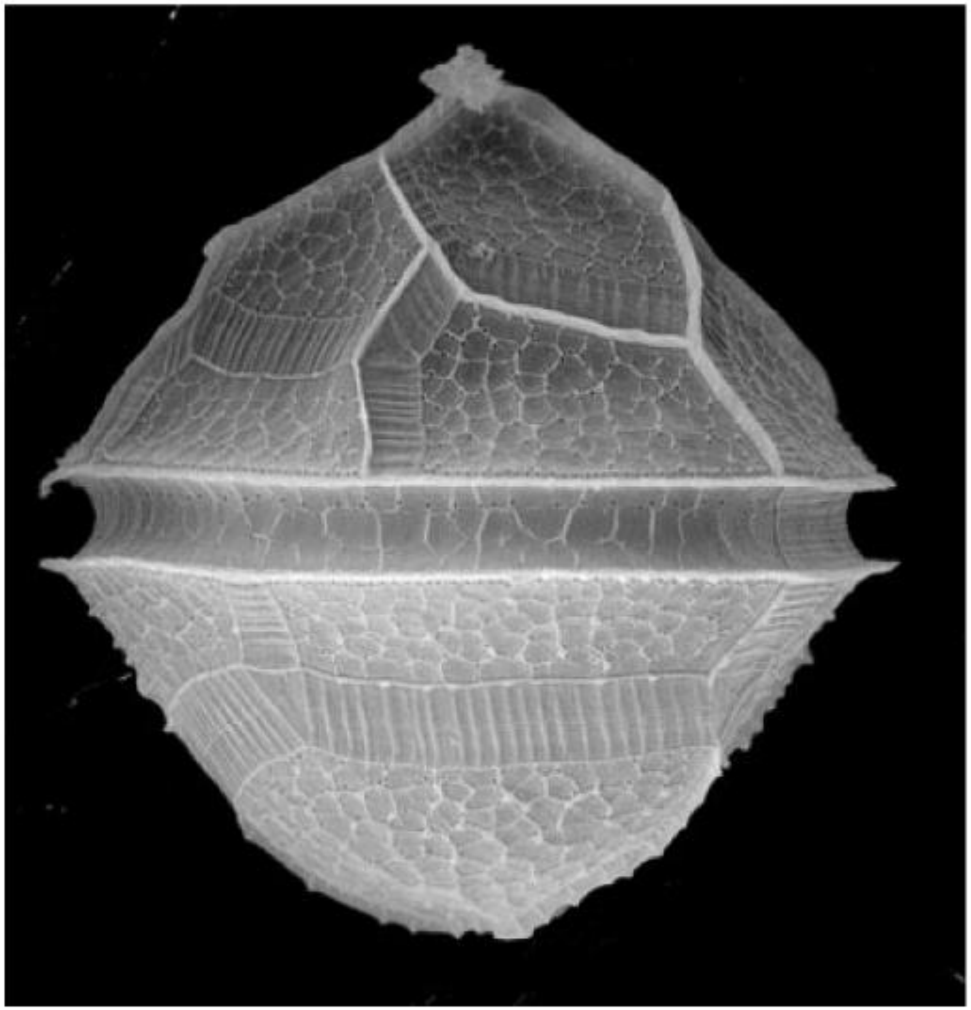
Diatoms

- size: 2µm to 2000 µm
- thousands of species
- silicon cell wall

Pseudonitzchia blooms

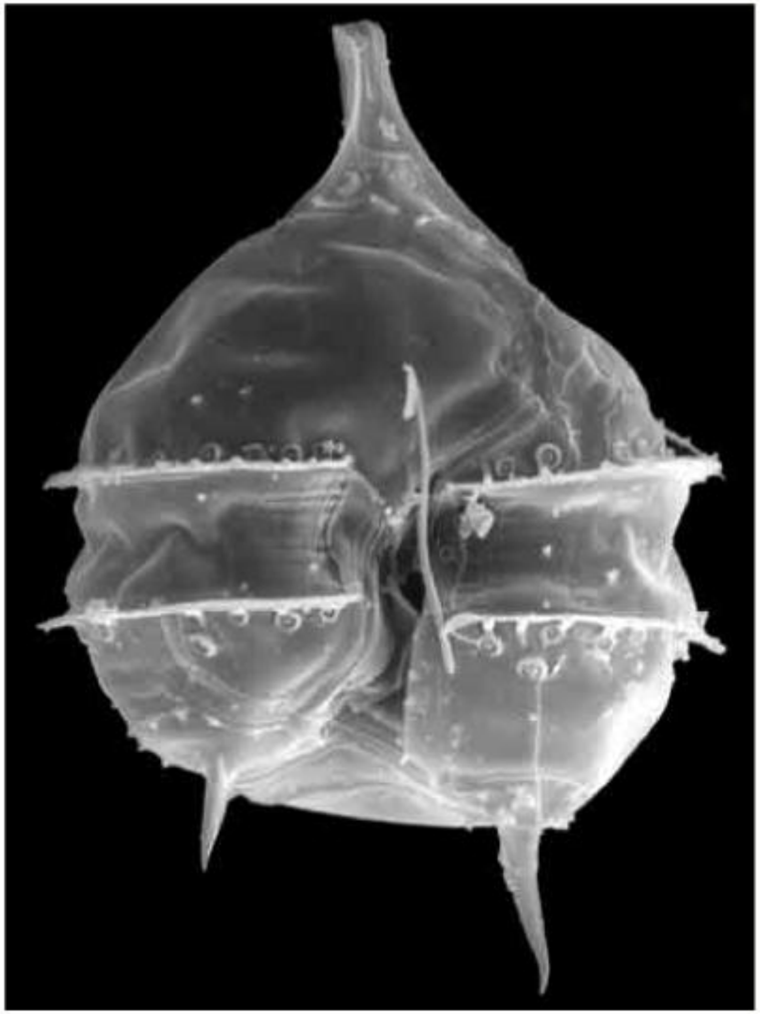
- Can produce neurotoxin domoic acid
- Harmful to birds, marine mammals, humans

MARINE DINOFLAGELLATES



L

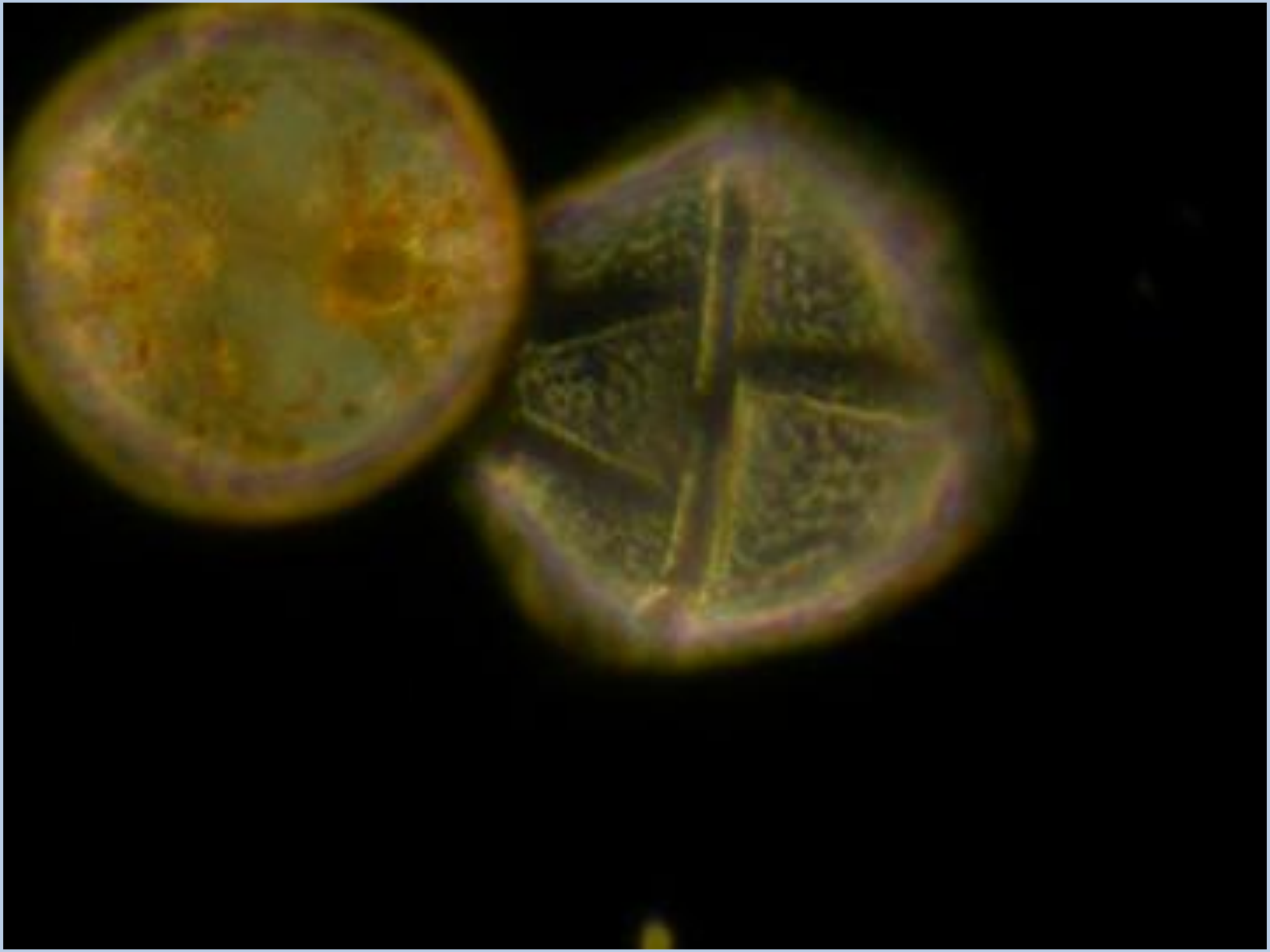
Protoperidinium latistriatum



Protoperidinium defectum

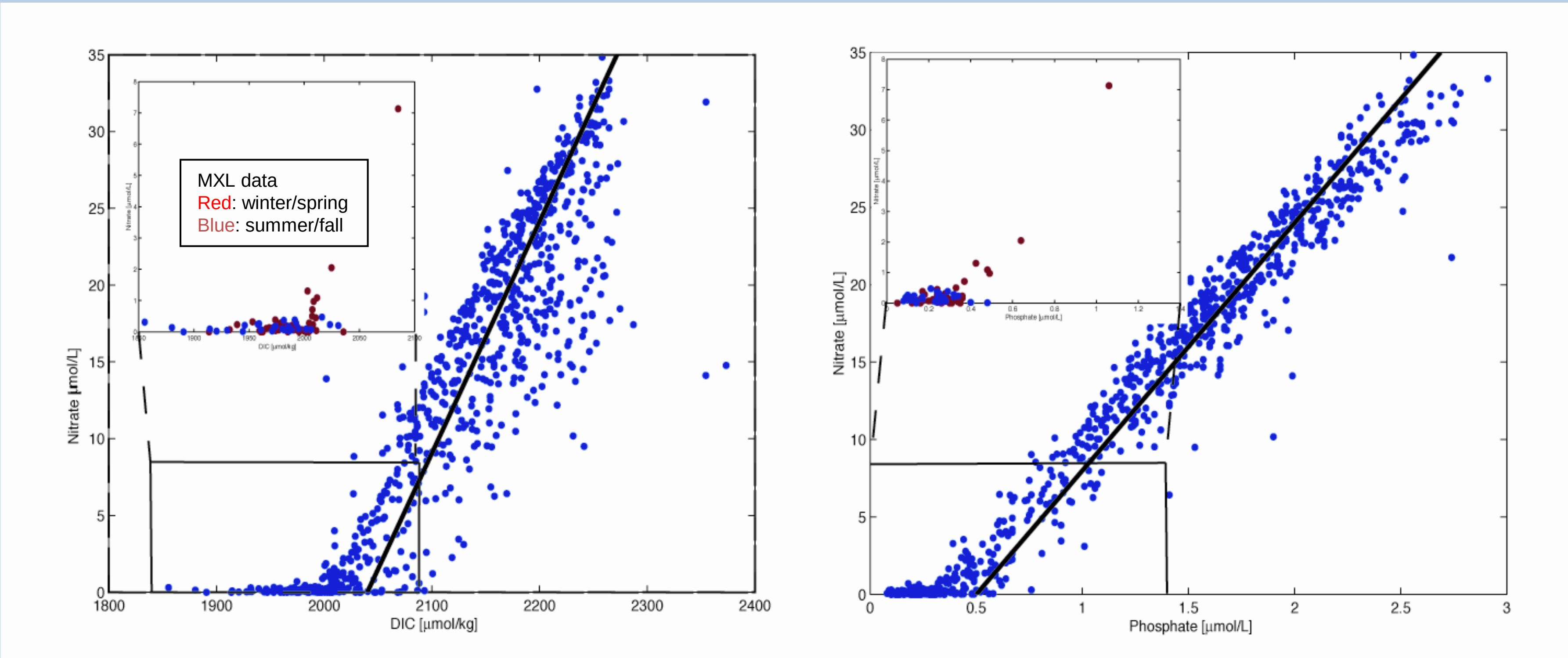
Usually dominant during summer

Lingulodinium polyedrum



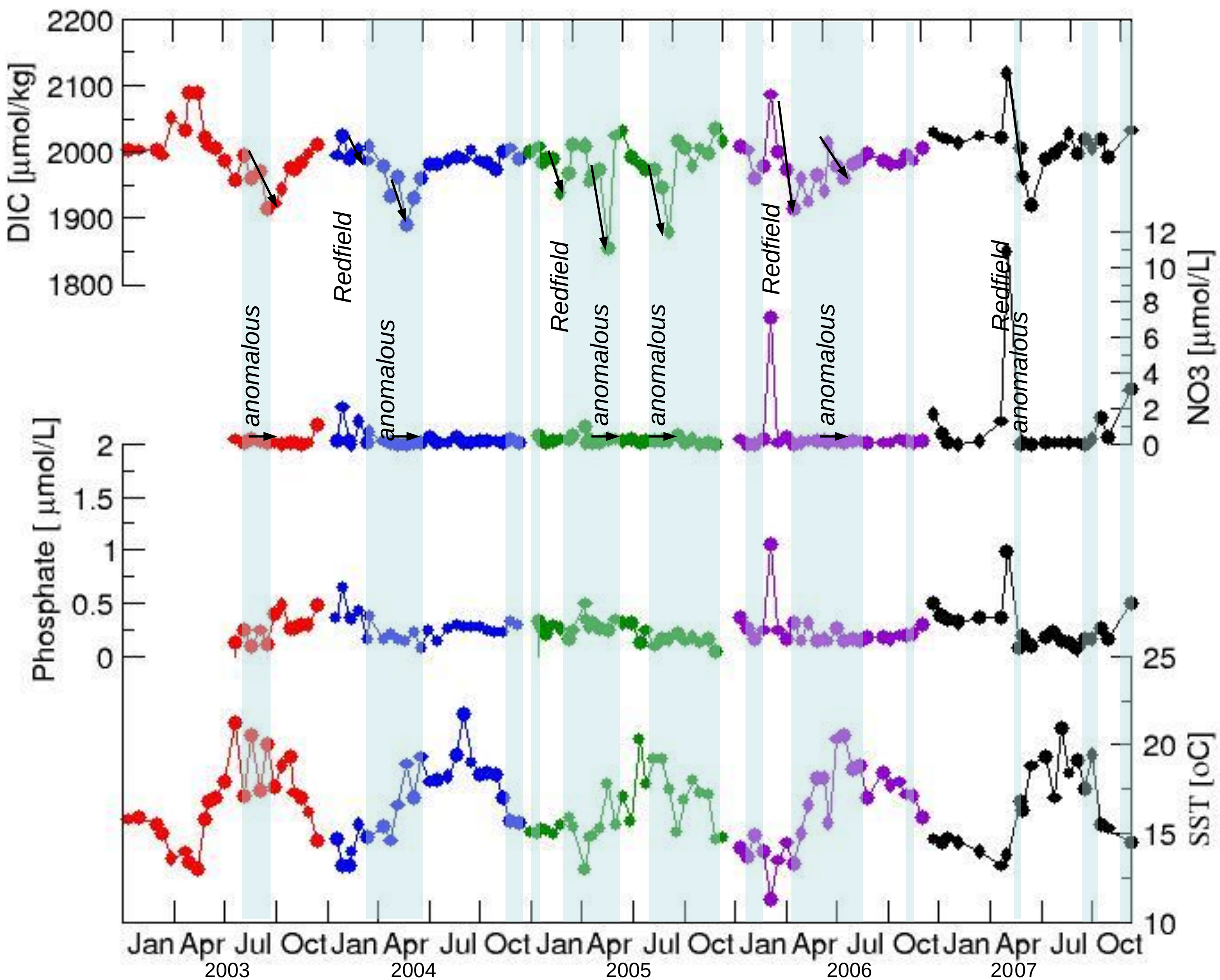

@ PJS Franks

SMBO: RELATIONSHIP BETWEEN DIC AND MACRONUTRIENTS



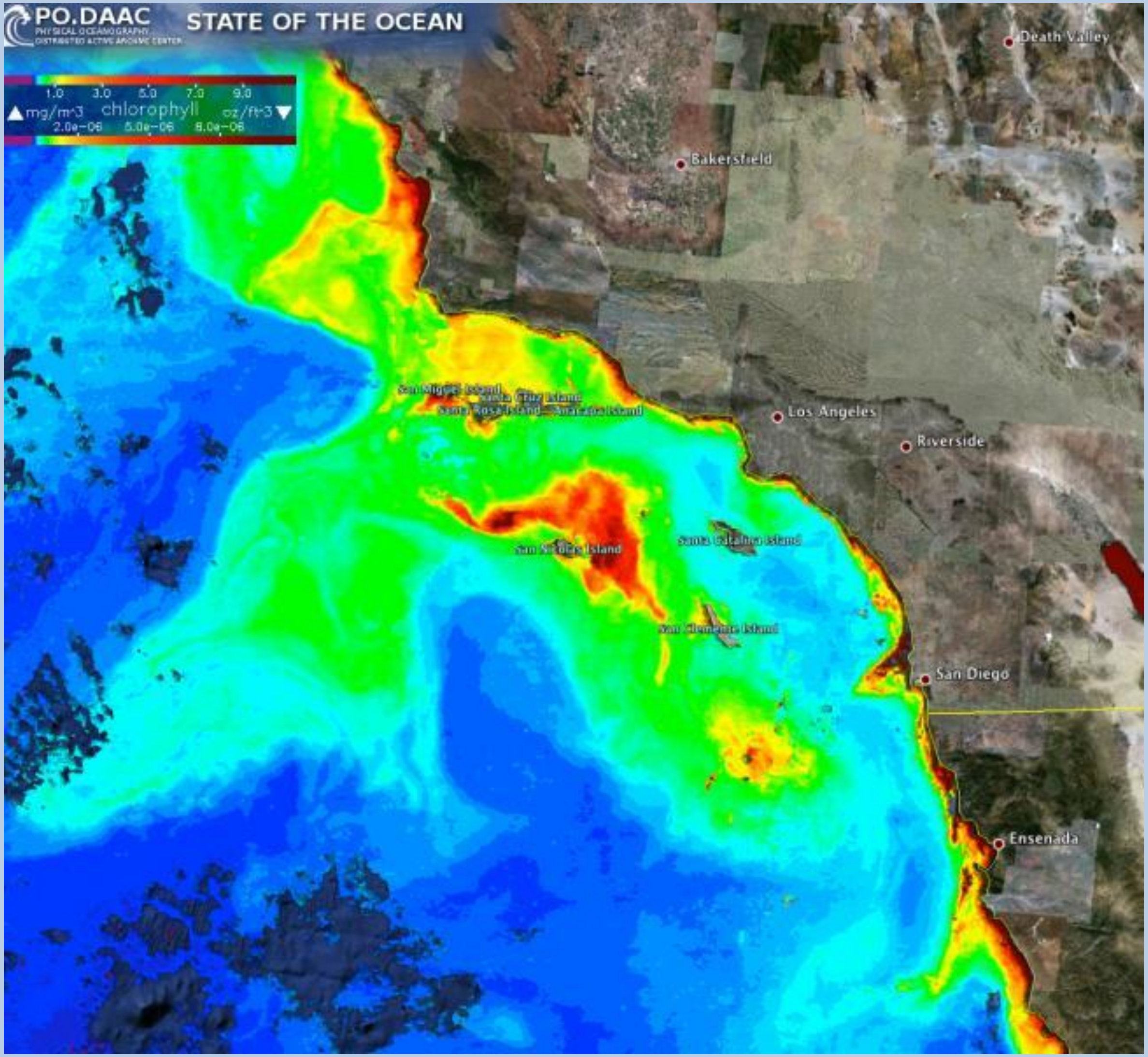
Upper thermocline: tends to follow Redfield ratio 106C:16N:1P

Surface ocean: C and N decoupling

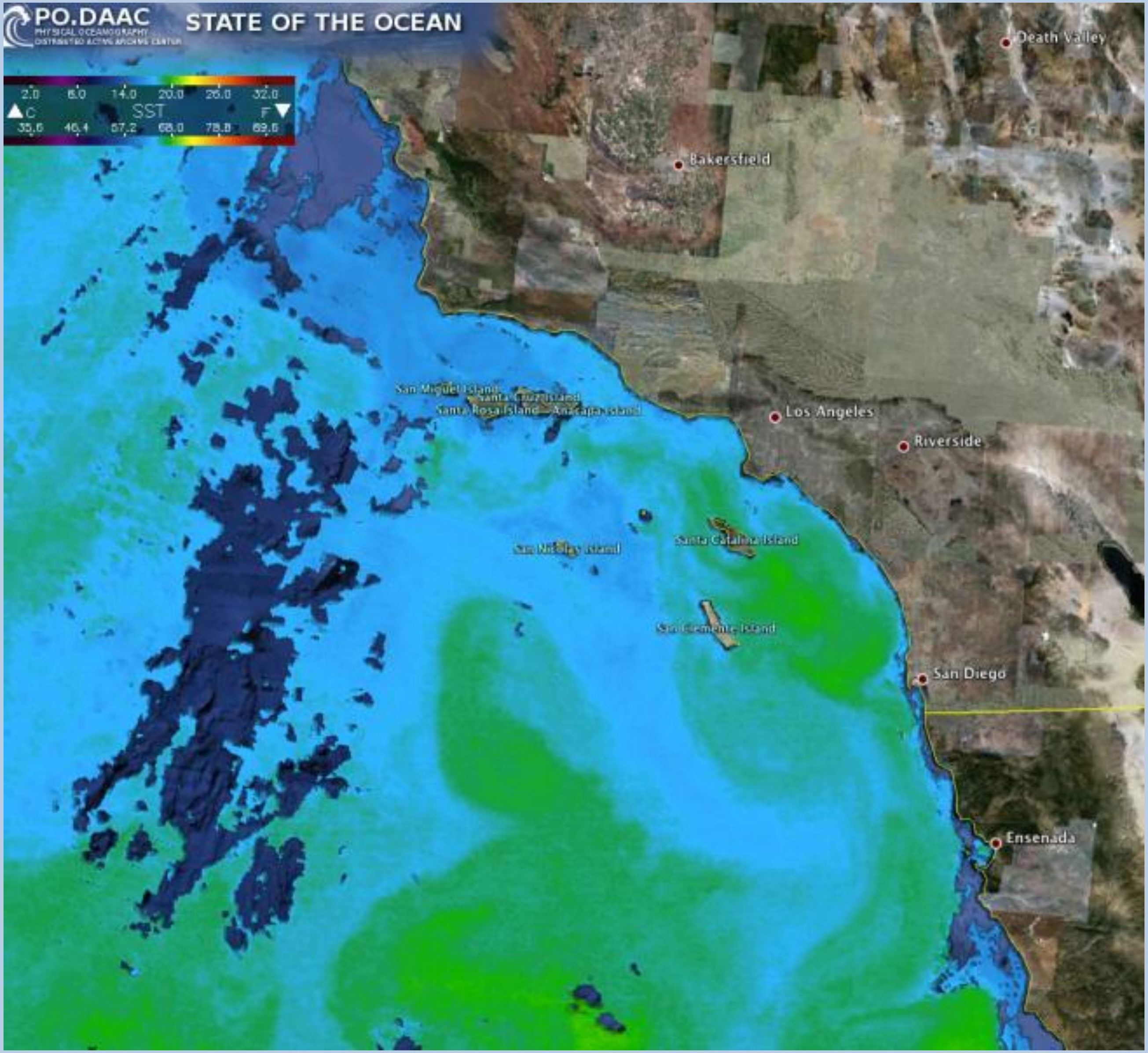

DIC [µmol/kg]
2200
2100
2000
1900
1800
Redfield
anomalous
NO3 [µmol/L]
12
10
8
6
4
2
0
Phosphate [µmol/L]
2
1.5
1
0.5
0
SST [oC]
25
20
15
10
Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct
2003
2004
2005
2006
2007

Red Tide in Southern California
End of September/October 2011

NASA MODIS - Chlorophyll



NASA MODIS - Sea Surface Temperature



CARBON CHEMISTRY:

CHANGE DUE TO OCEAN ACIDIFICATION

The pH Scale

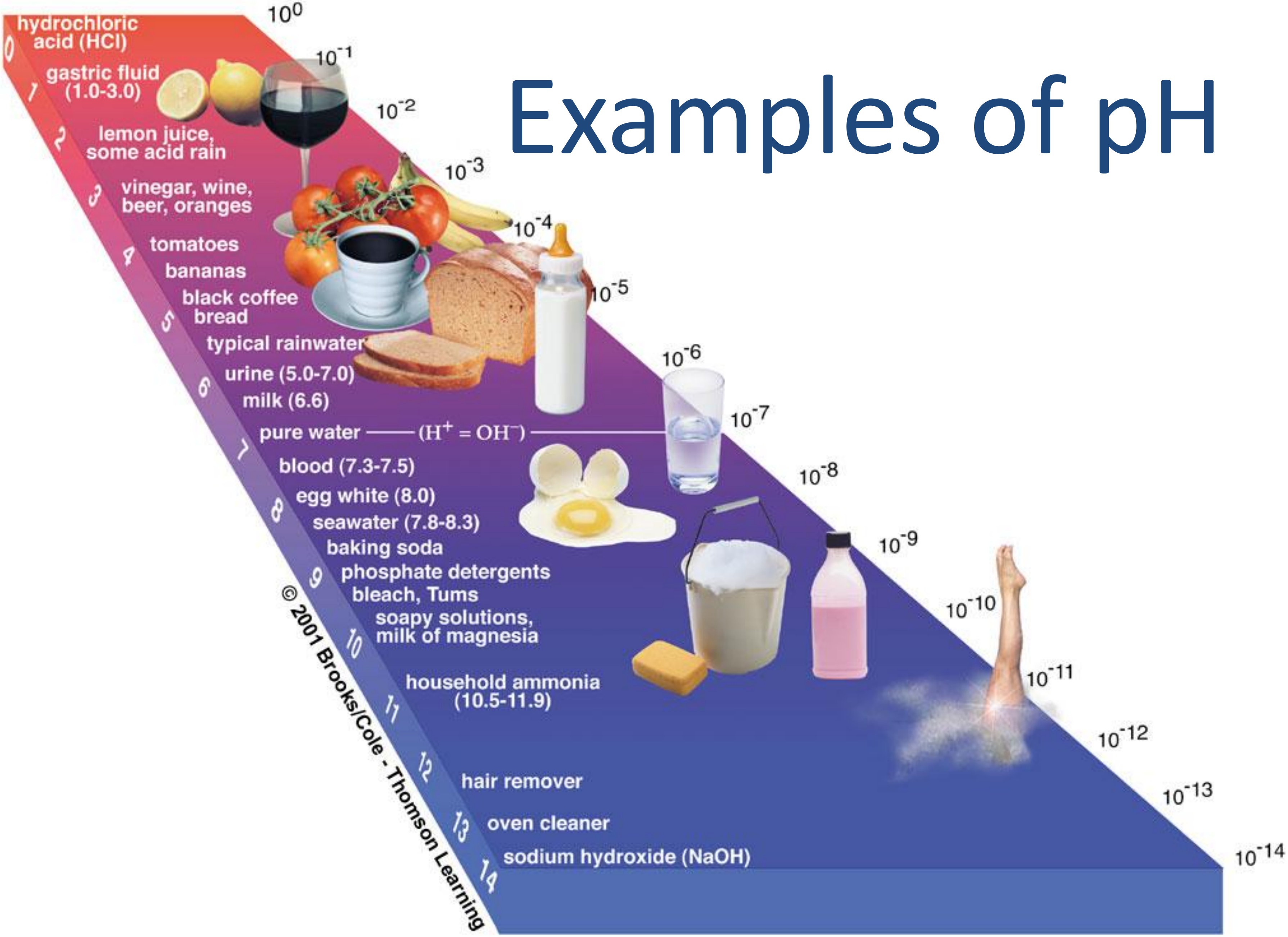
- Measures H^+ concentration of fluid
- Change of 1 on scale means 10X change in H^+ concentration

Highest H^+ Lowest H^+

0--------------------7------------------14

Acidic Neutral Basic

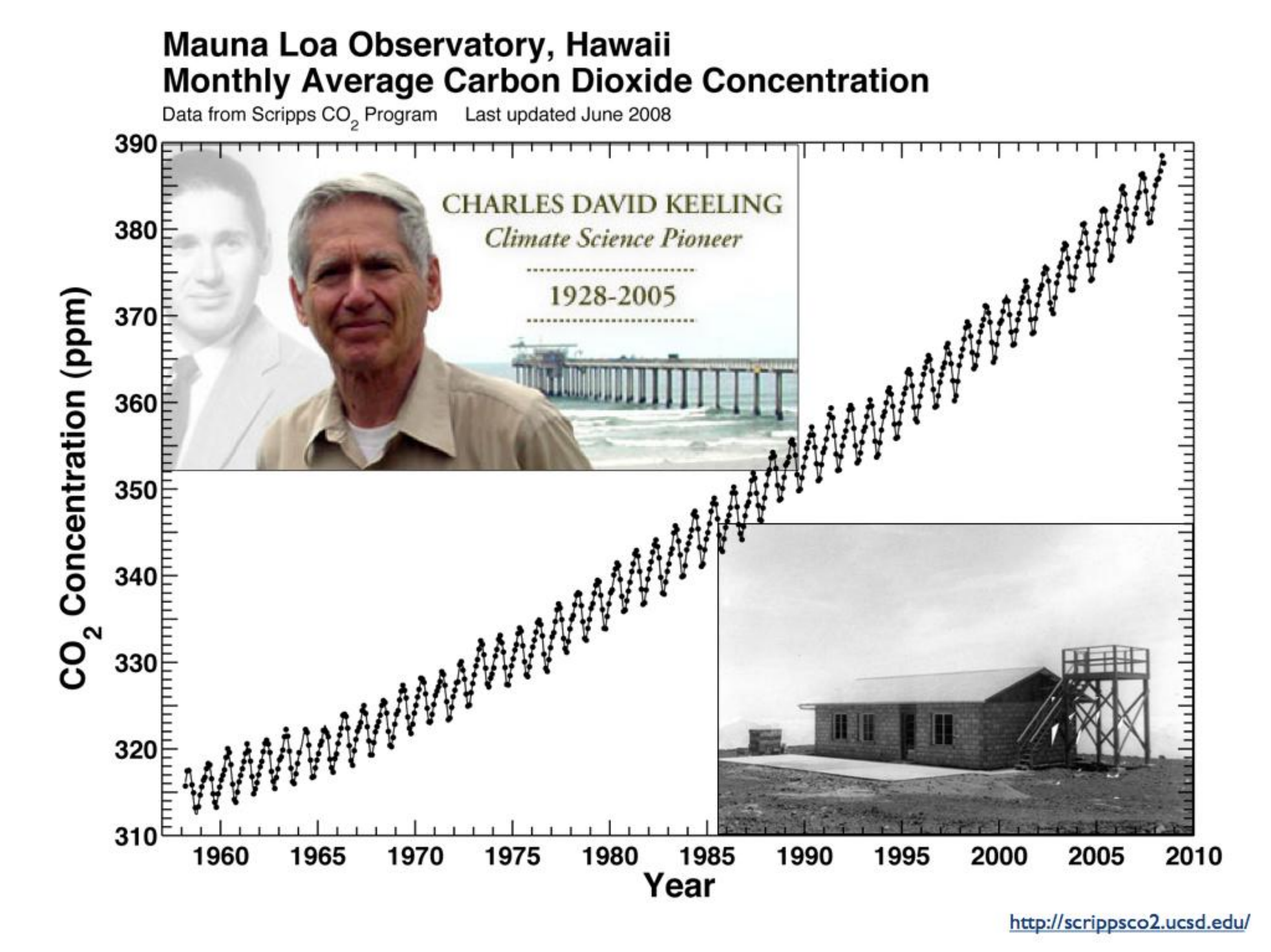
Examples of pH



CO_2

- Like all gases, carbon dioxide (CO_2) is soluble in seawater, depends on Temp. and Salinity.
- Unlike other gases, CO_2 reacts with water so only a small fraction of dissolved inorganic carbon (DIC) stays as CO_2.
- Without this reactivity, several percent of the atmosphere would be CO_2! (instead of <1%)

THE FAMOUS MAUNA LOA CURVE



Atmospheric CO_2 concentration is now higher than it has been for at least 650,000 years.

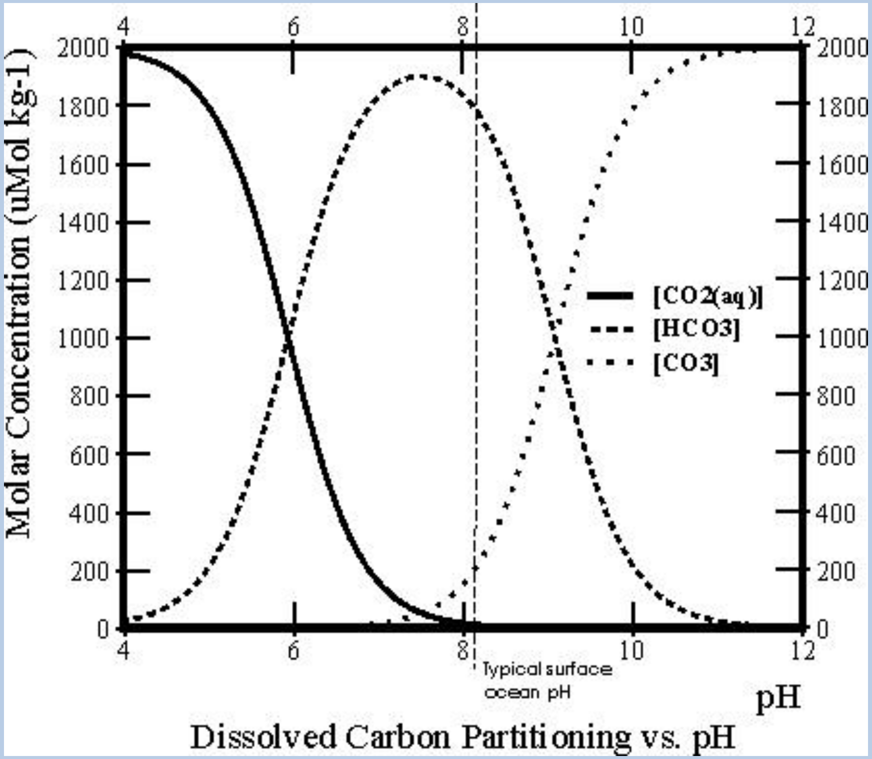
Uptake of anthropogenic CO_2 changes seawater chemistry

$$[CO_2] + [H_2O] \Rightarrow [H_2CO_3]$$

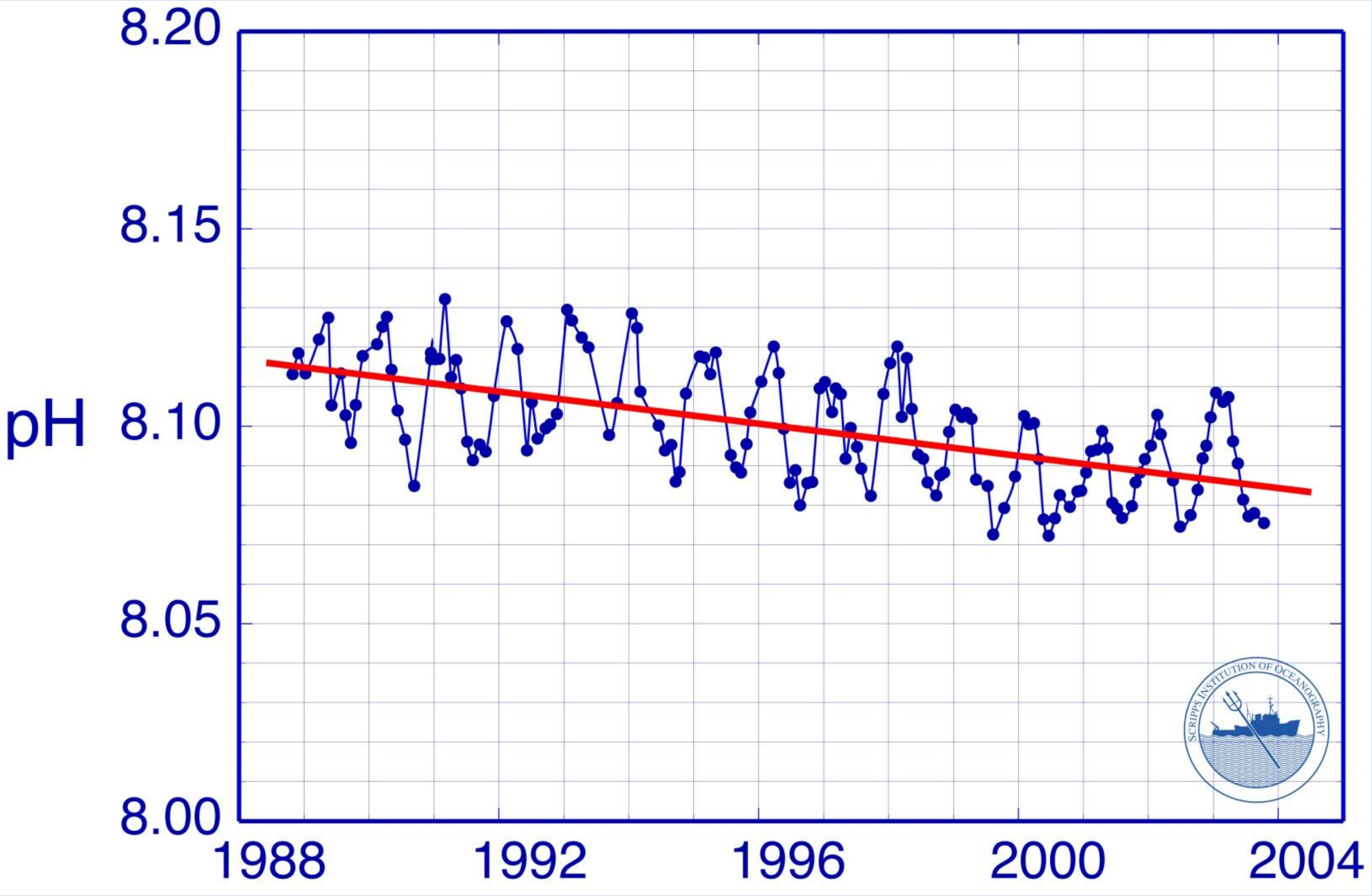
$$[H_2CO_3] \Rightarrow [H+] + [HCO_3^-]$$

$$[H+] + [CO_3^{2-}] \Rightarrow [HCO_3^-]$$

Net effect: increase H^+, H_2CO_3 and HCO_3^-, decrease CO_3^{2-}.



SURFACE OCEAN pH AT HOT



(Andrew Dickson, SCRIPPS, calculated from unpublished data)

The pH has dropped about 0.1 units since the beginning of the industrial revolution (a change of about 30% in hydrogen ion concentration), and is expected to reduce pH by up to another 0.3 units by the end of this century (Caldeira & Wickett, 2005, Orr *et al.*, 2005).

CALCIUM CARBONATE SATURATION HORIZON

Formation and dissolution of carbonate minerals

$$\begin{gathered}\leftarrow \text{mineral formation} \\ CaCO_3 \Leftrightarrow [Ca^{2+}] + [CO_3^{2-}] \\ \text{dissolution} \rightarrow\end{gathered}$$

Saturation horizon: depth, where critical carbonate ion concentration has been reached. Below this depth, $CaCO_3$ tends to dissolute.

The $CaCO_3$ mineral calcite is less soluble than aragonite.

POSSIBLE CONSEQUENCES

Sound absorption

Ocean acidification will result in significant decreases in ocean sound absorption for frequencies lower than about 10 kHz (Hester *et al.*, 2008).

Marine ecosystems

Growth rates for phytoplankton (e.g. Riebesell *et al.*, 2007), nitrogen fixing bacteria (Hutchins et al, 2007), and sea grass (e.g. Hall-Spencer *et al.*, 2008) seem to be neutral or enhanced under elevated CO_2.

Small changes in pH could effect species growth rate, abundances, and succession in coastal phytoplankton community (Hinga, 2002)

Elevated pCO_2 will effect the physiology of fish (Portner *et al.*, 2004).

POSSIBLE CONSEQUENCES

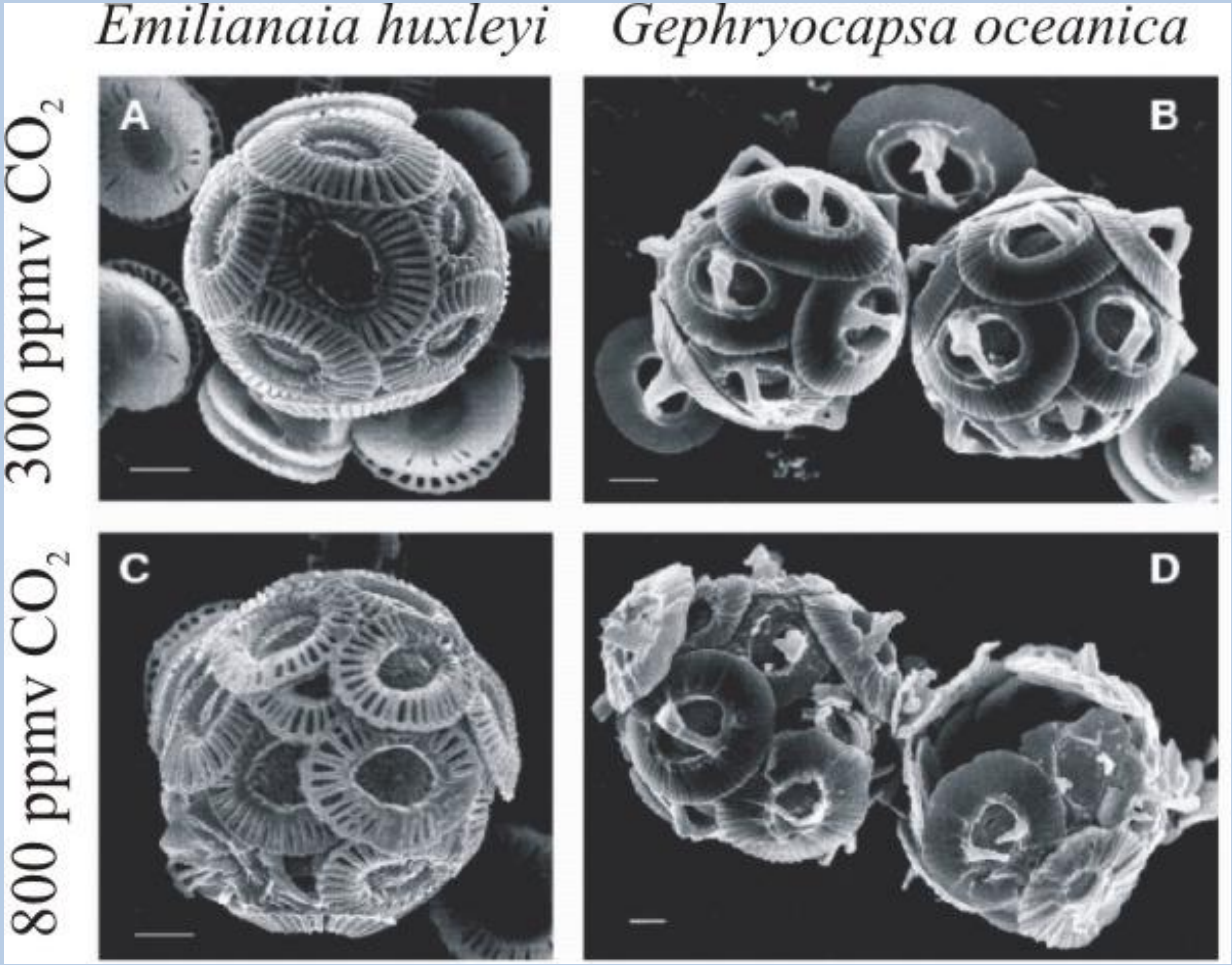
Marine ecosystems

Negative effects due to the reduction in the saturation state of calcite and aragonite are likely to be felt on biological processes such as calcification
(e.g. *Orr et al.*, 2005; *Kleypas et al.*, 2006)

Major planktonic producers of $CaCO_3$ are coccolithophores, foraminifers, and pteropods (planktonic snails).

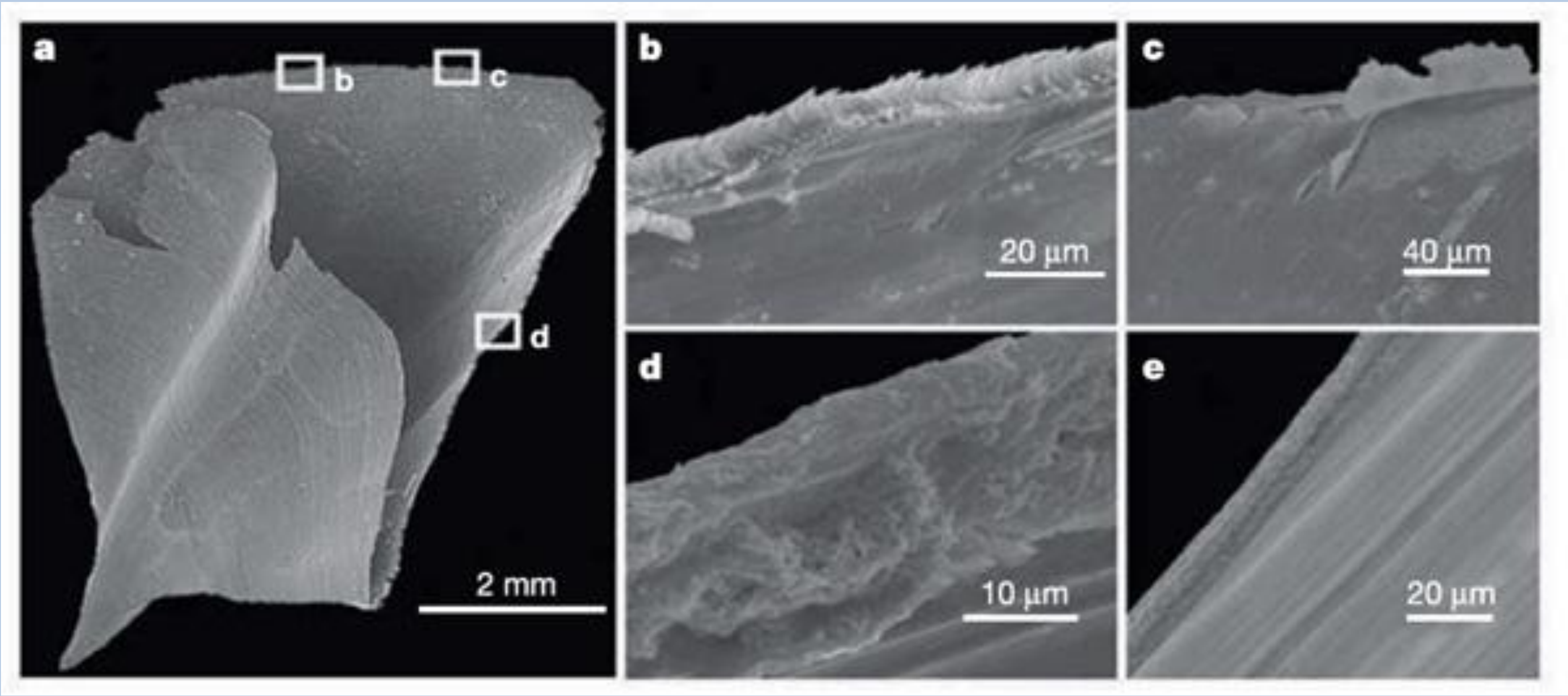
Lab and mesocosm experiments in many species point toward reduced calcification rates in response to elevated CO_2 levels (e.g. Guinotte & Fabry, 2008).

LABORATORY EXPERIMENTS FOR COCCOLITHOPHORES



(Riebesell *et al.*, 2000)

LABORATORY EXPERIMENTS FOR PTEROPODS (PLANKTONIC SNAIL)



(Orr *et al.*, 2005)

The pteropod was placed in a tank of water undersaturated with respect to aragonite. *Sub-images b, c, and d* show degradation of the snail's shell, and *sub-image e* shows a the surface of a normal pteropod shell.

All studies thus far on the impacts of ocean acidification on calcareous plankton have been short-term experiments (hours to weeks).

“Ray of hope”: ~ 145-65 million years ago (Cretaceous), sediment cores show that coccolithophores survived a high CO_2 climate (Toby Tyrell)

Some lab experiments for *Emiliania huxleyi,* show elevated calcification and net primary production under high *p*CO2 (Iglesias-Rodriguez *et al.*, 2008)

HOWEVER

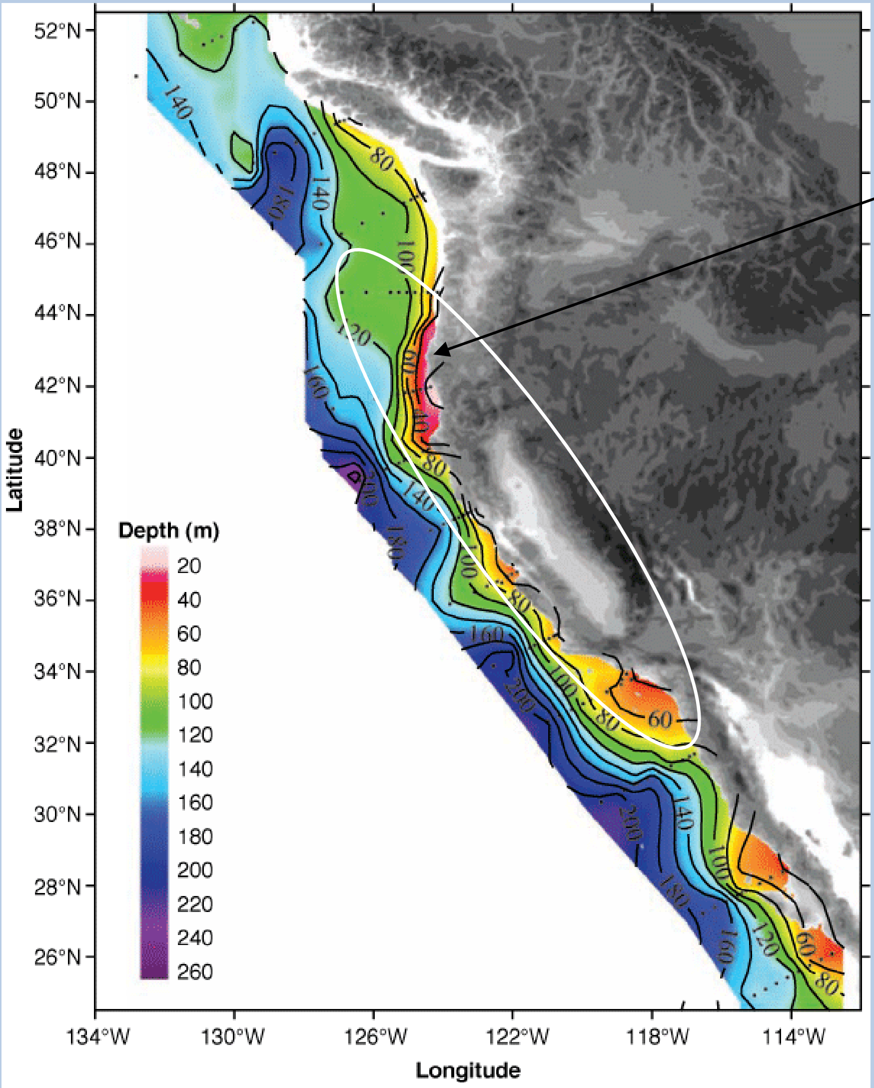
At this time, almost nothing is known about the long-term ecosystem effects or the ability of organisms to adapt to these changes (e.g. Guinotte & Fabry, 2008)

Regions most prone to ocean acidification

- Polar regions
- Eastern Boundary Upwelling Systems (EBUS)

ARAGONITE SATURATION HORIZON

ALONG THE NORTH AMERICAN WEST COAST



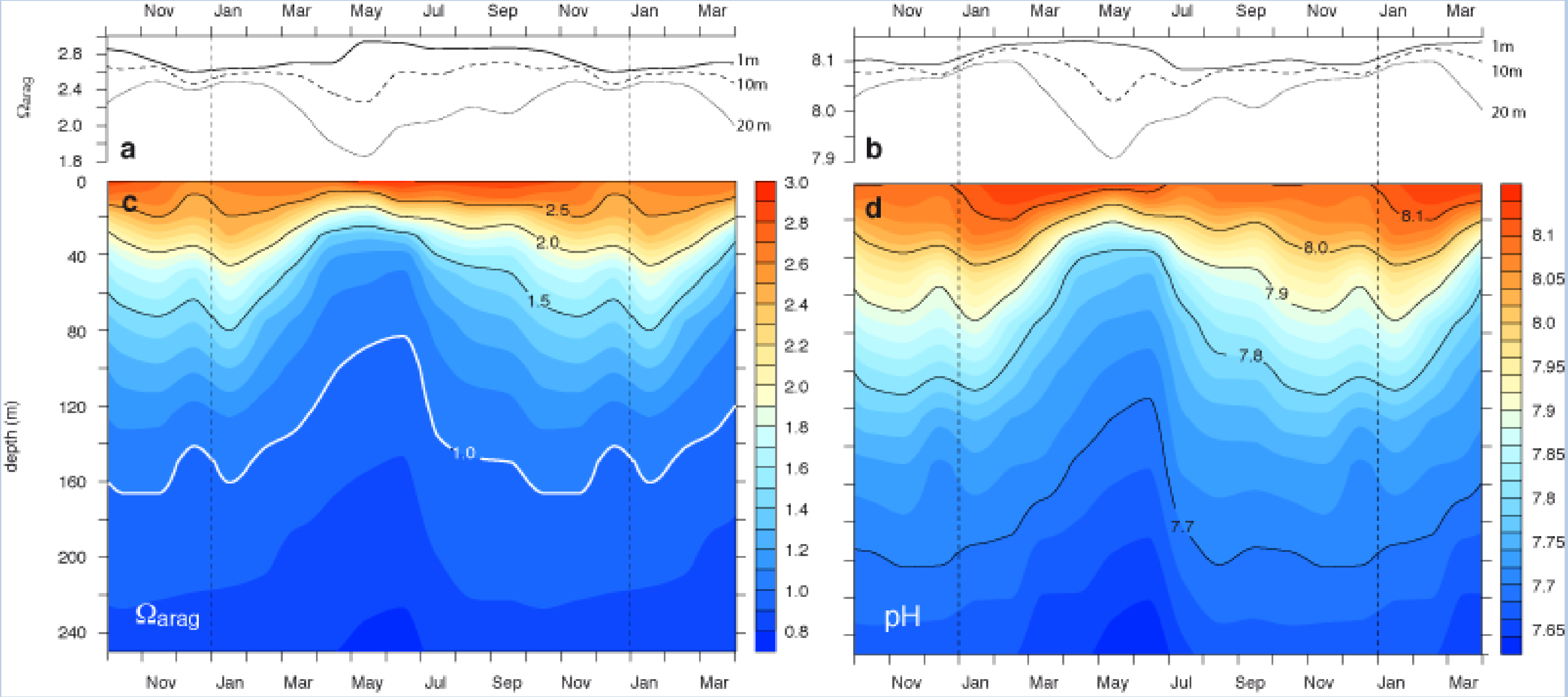
(Feely et al., 2008)

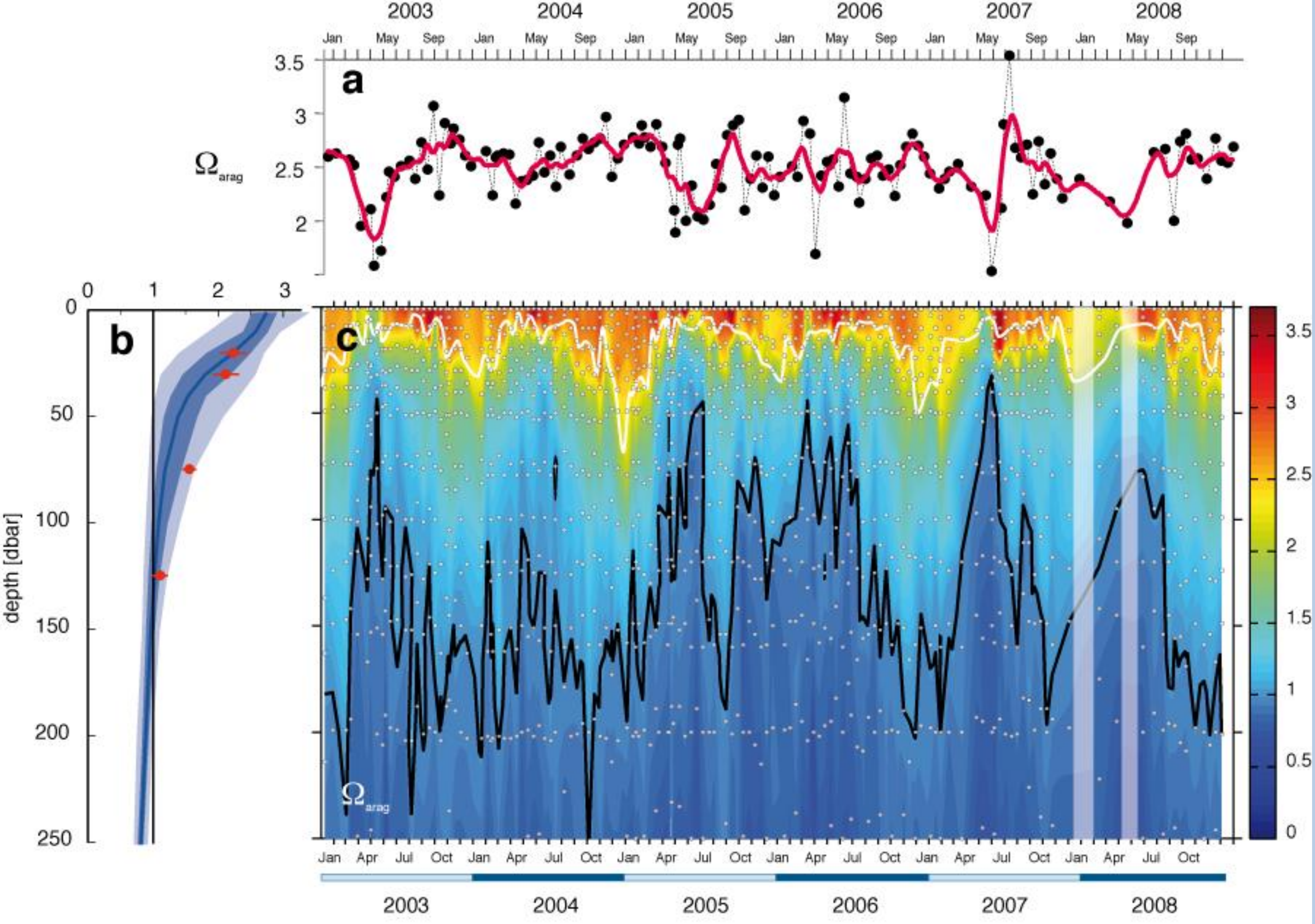
In the northeastern Pacific, due to the uptake of anthropogenic CO2, corrosive water shoals into the euphotic zone already today during upwelling!

Without this anthropogenic signal, the aragonite saturation horizon would be about 50m deeper (Feely *et al.*, 2008)

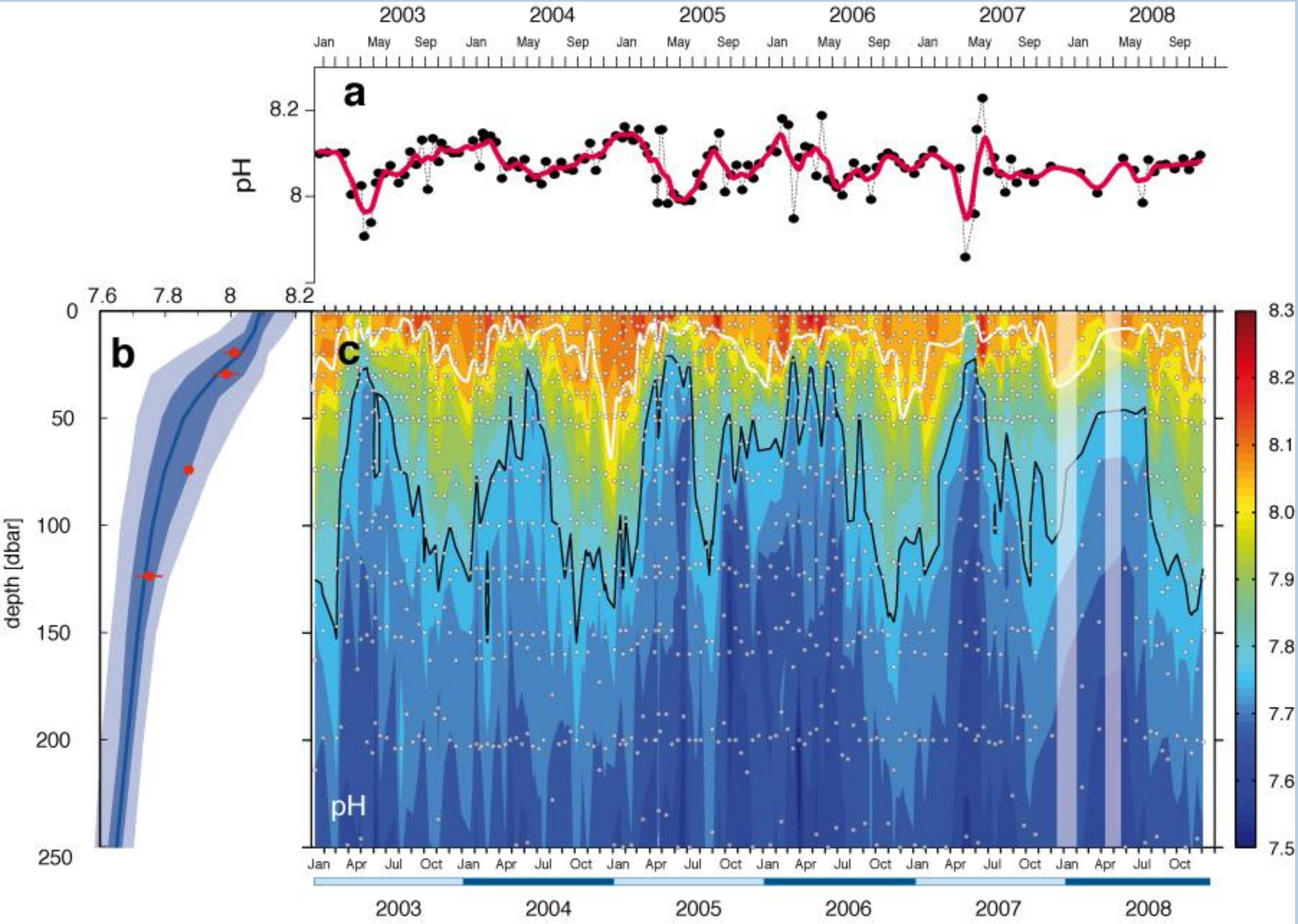
Ocean acidification in Santa Monica Bay

Climatology for aragonite saturation and pH





2003
2004
2005
2006
2007
2008
Jan
May
Sep
3.5
3
2.5
2
a
Ω arag
b
0
1
2
3
0
50
100
150
200
250
depth [dbar]
c
Ω arag
0.5
1
1.5
2
2.5
3
3.5
Jan
Apr
Jul
Oct

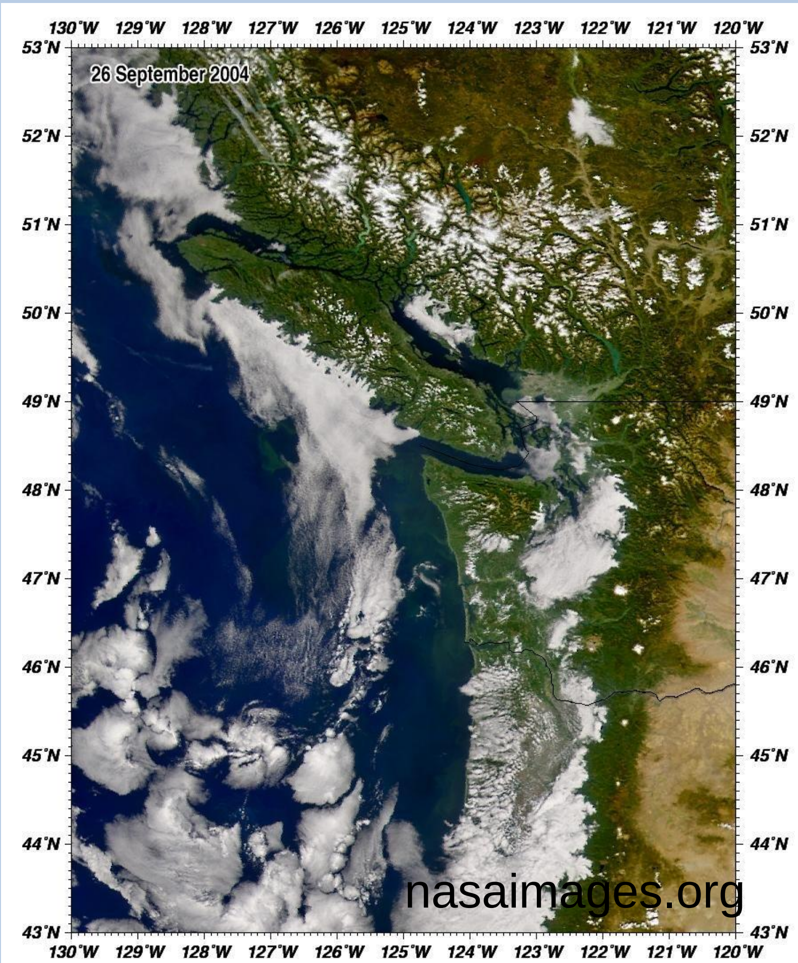


a
pH
b
c
pH
depth [dbar]
2003
2004
2005
2006
2007
2008

What are possible consequences for Harmful Algal Blooms due to ocean acidification?

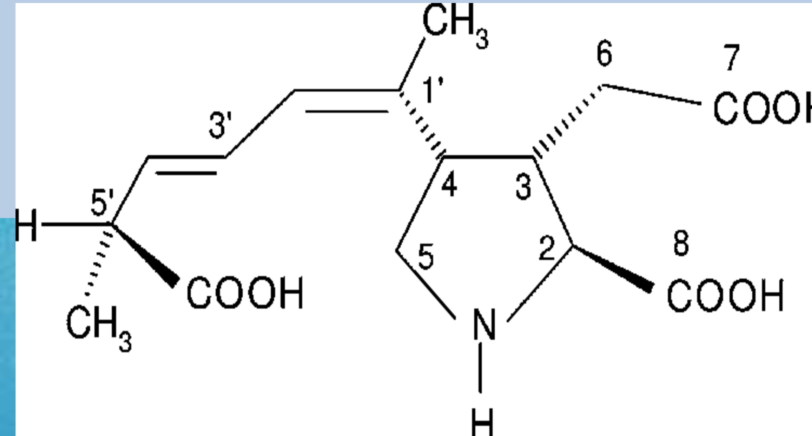
- observations in the past three years did not repeat previous observations for C/N decoupling
- HAB containing dinoflagellate bloom in 2011 caused by upwelling, not vertical migration
- Although meteorological conditions seemed ideal in 2012, we did not see C/N decoupling events happening and no dinoflagellates in the water – but DIATOMS!

Pseudo-nitzschia blooms

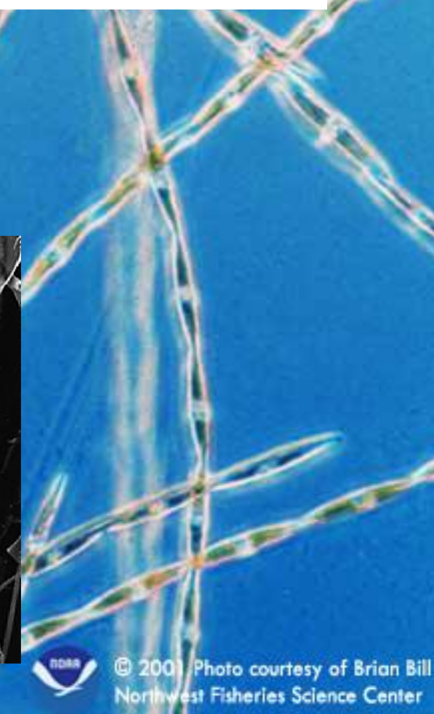


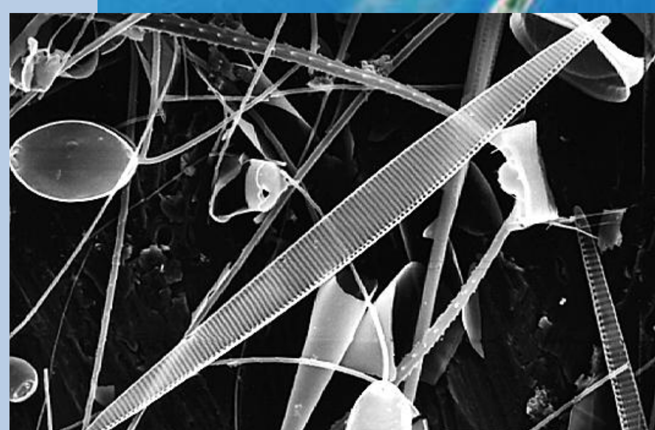
Pseudo-nitzschia bloom,
Juan de Fuca eddy

Courtesy of Dave Hutchins, USC



Domoic Acid



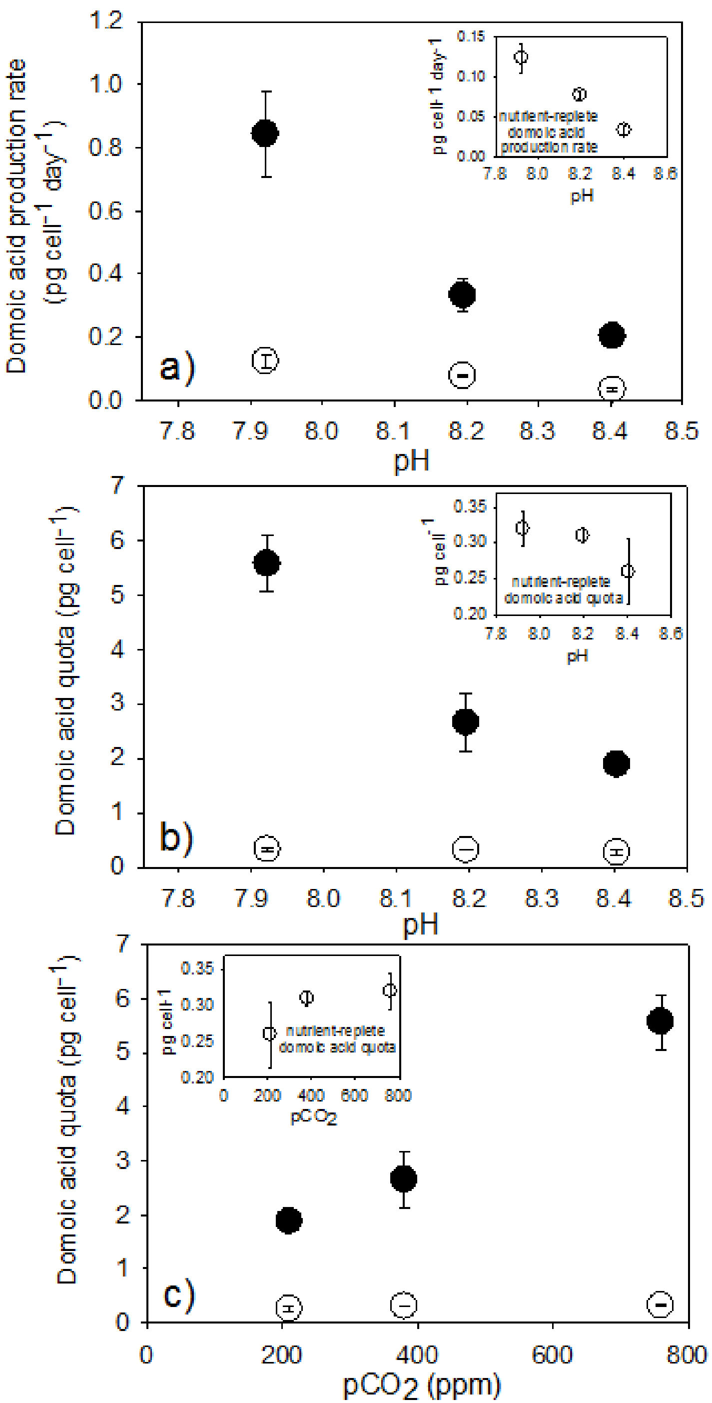


www.whoi.edu/redtide/

Domoic acid production increases dramatically at lower pH (higher pCO_2), especially during Si-limited growth

o Si-replete

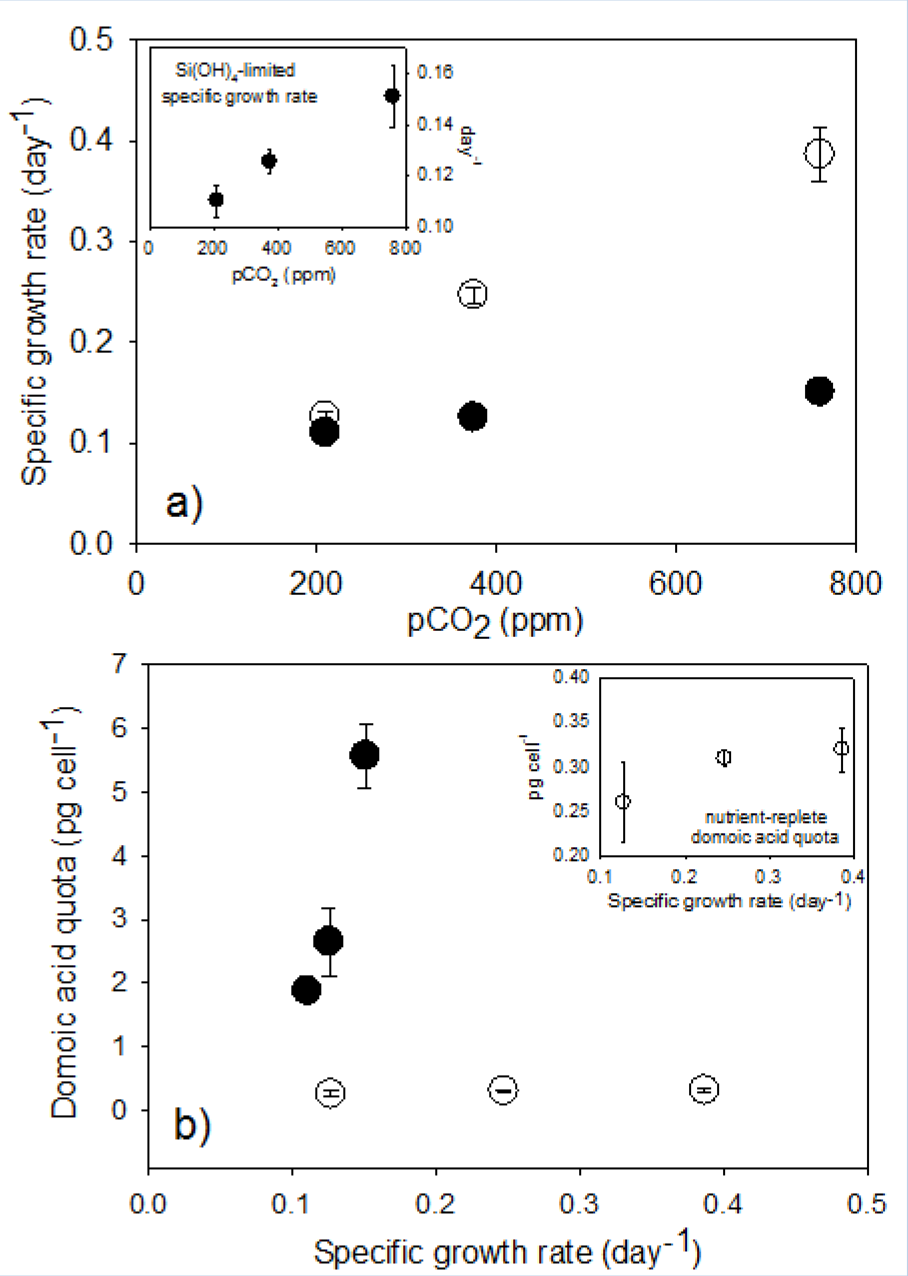
● Si-limited



Tatters, Fu and Hutchins

2012 PLoS ONE

Growth rate
is positively
correlated with
toxin production
in both Si-limited
and Si-replete
diatom cultures



O **Si-replete**

● **Si-limited**

Tatters, Fu and Hutchins

2012 PLoS ONE

Summary and outlook

- Eastern boundary upwelling regions (particularly those of the Pacific) are among those with the *lowest pH* and will be among the first regions to *experience undersaturation* with regard to aragonite
- Observations at SMBO show shallow saturation level with respect to aragonite as well large temporal variations
- High spatial and temporal variability exposes organisms to a *large range* of pH and saturation conditions.
- These upwelling systems could represent ideal testbeds for studying the impact of ocean acidification on organisms and their possible adaptive strategies