Effects of Elevated *p*CO_2 on Calcareous Plankton

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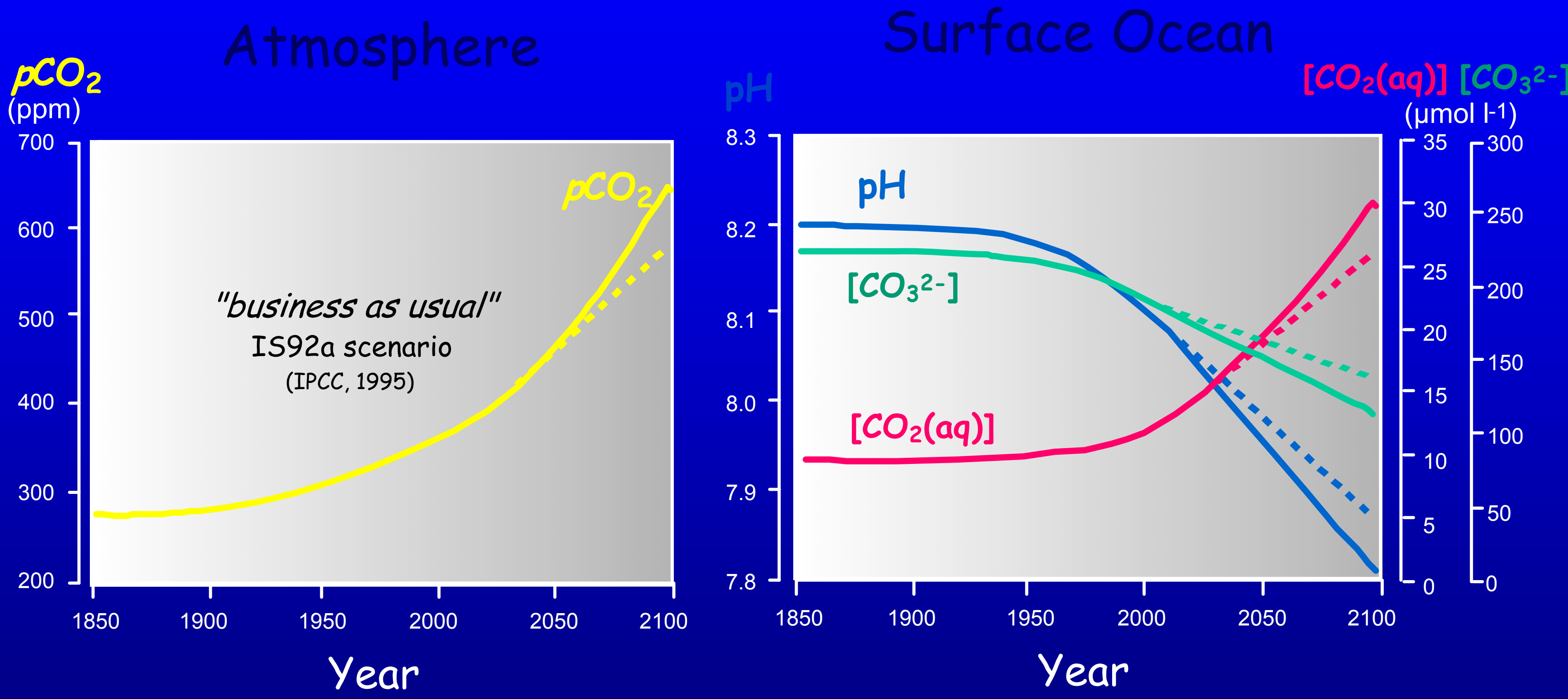
Changes in carbonate chemistry from atmospheric CO_2 increase



Rate of change is probably 100 times greater than that which occurred at end of recent ice ages

Wolf-Gladrow et al., 1999

Changes in seawater CO_2 chemistry and impacts to biota

The Ocean in a High CO_2 World

UNESCO, May 2004

Workshop on the Impacts of Increased CO_2 on Marine Calcifiers

NSF/NOAA/USGS, April 2005

Ocean Acidification Due to Increasing Carbon Dioxide,

Report of The Royal Society, released June 2005

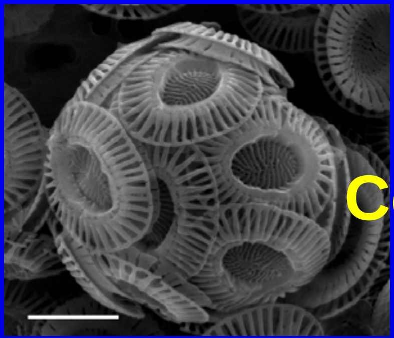
<u>Emerging consensus</u>

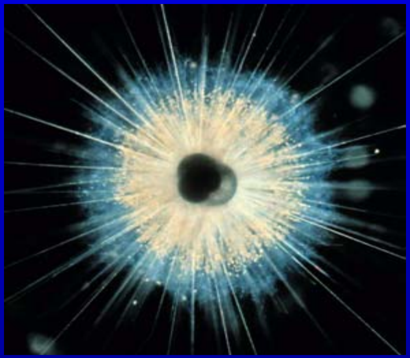
- For many calcifying organisms investigated, calcification progressively decreases as the seawater becomes more acidified (i.e., $p\mathrm{CO_2}$ increases, $[\mathrm{CO_3^{2-}}]$ and $\mathrm{CaCO_3}$ saturation state decrease)

- The "adverse effect on calcification is one of the most obvious and <u>**possibly most serious**</u> of the likely environmental impacts of ocean acidification."

-Raven et al., 2005. The Royal Society

Major planktonic calcifiers



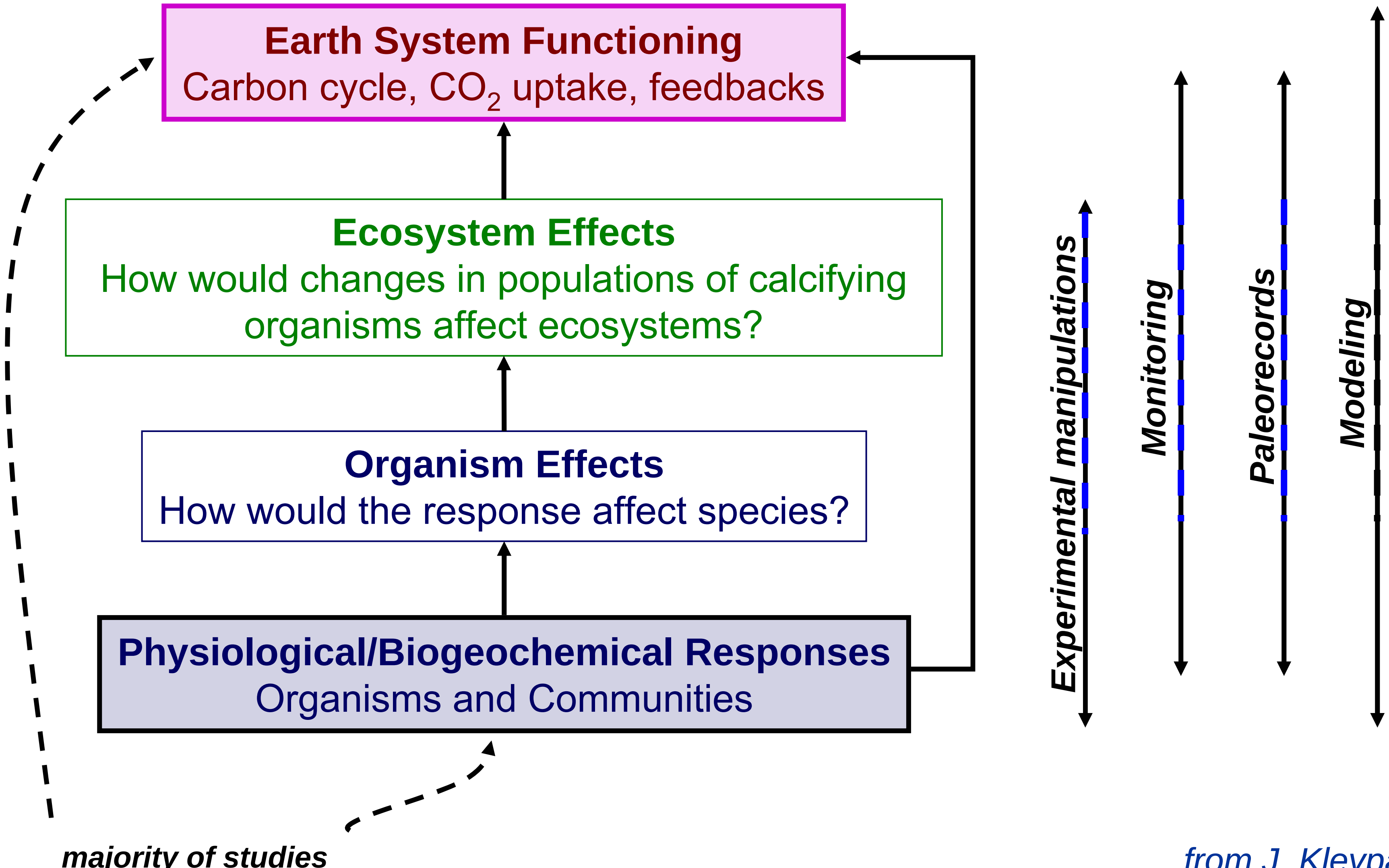


H. Spero

B. Seibel

	# Extant species	Mineral form	Generation time
Coccolithophores (autotrophs)	~ 200	calcite*	days
Foraminifera (heterotrophs)	~ 30	calcite	weeks
Pteropods (heterotrophs)	~ 32	aragonite	months to year?

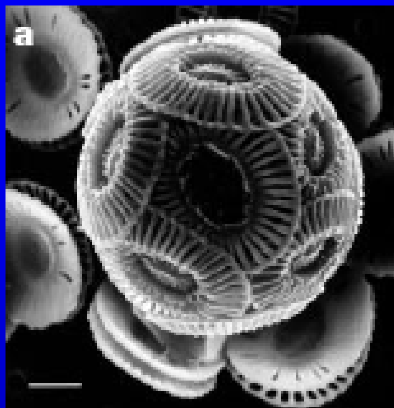
Changing carbonate chemistry can impact different temporal and spatial scales



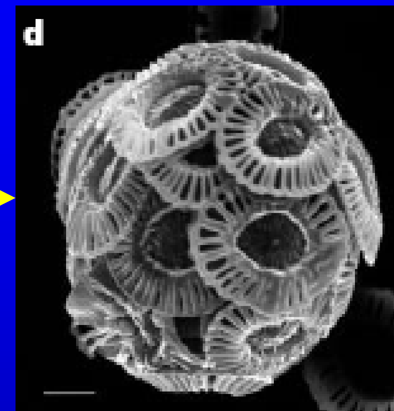
from J. Kleypas

Coccolithophores

***p*CO_2 280-380 ppmv** | ***p*CO_2 780-850 ppmv**



Emiliania huxleyi



Calcification decreased

- 9 to 18%

Gephyrocapsa oceanica

- 45%

Manipulation of CO_2 system by addition of HCl or NaOH

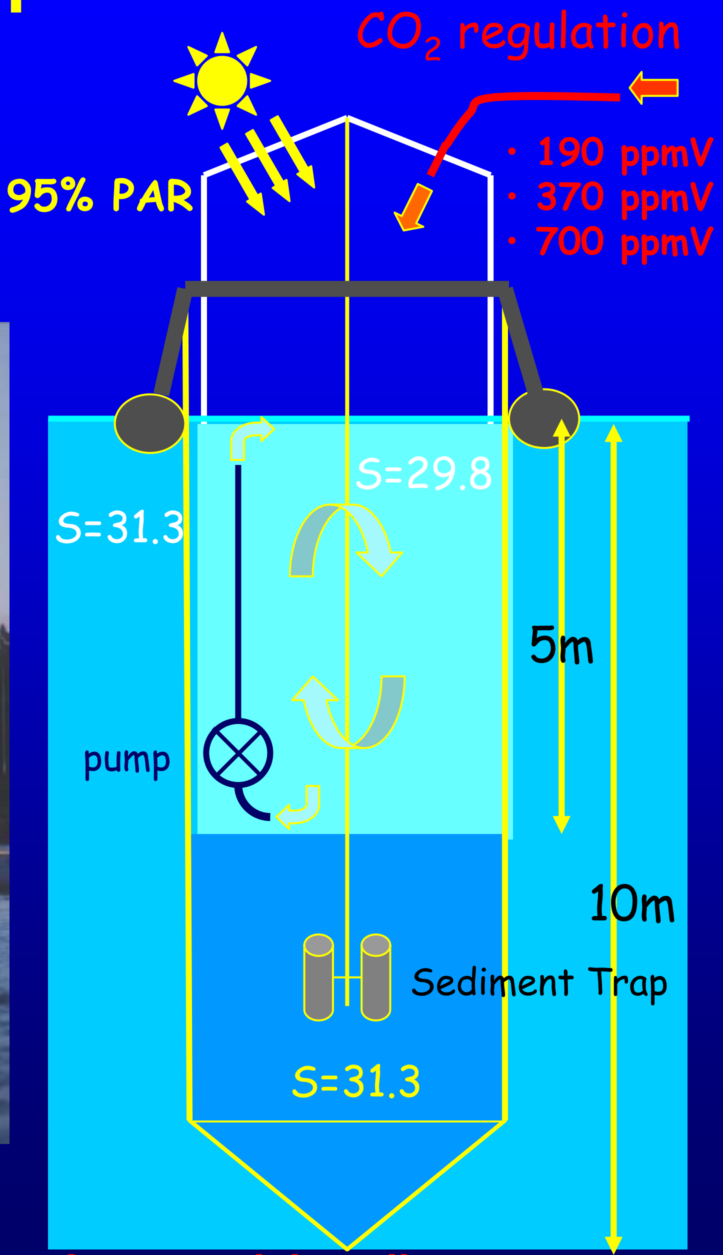
Riebesell et al.(2000); Zondervan et al.(2001).

Mesocosm experiment, Bergen

Pelagic Ecosystem CO_2 Enrichment Study

Three pCO_2 treatments representing: Glacial, Present, and Year 2100

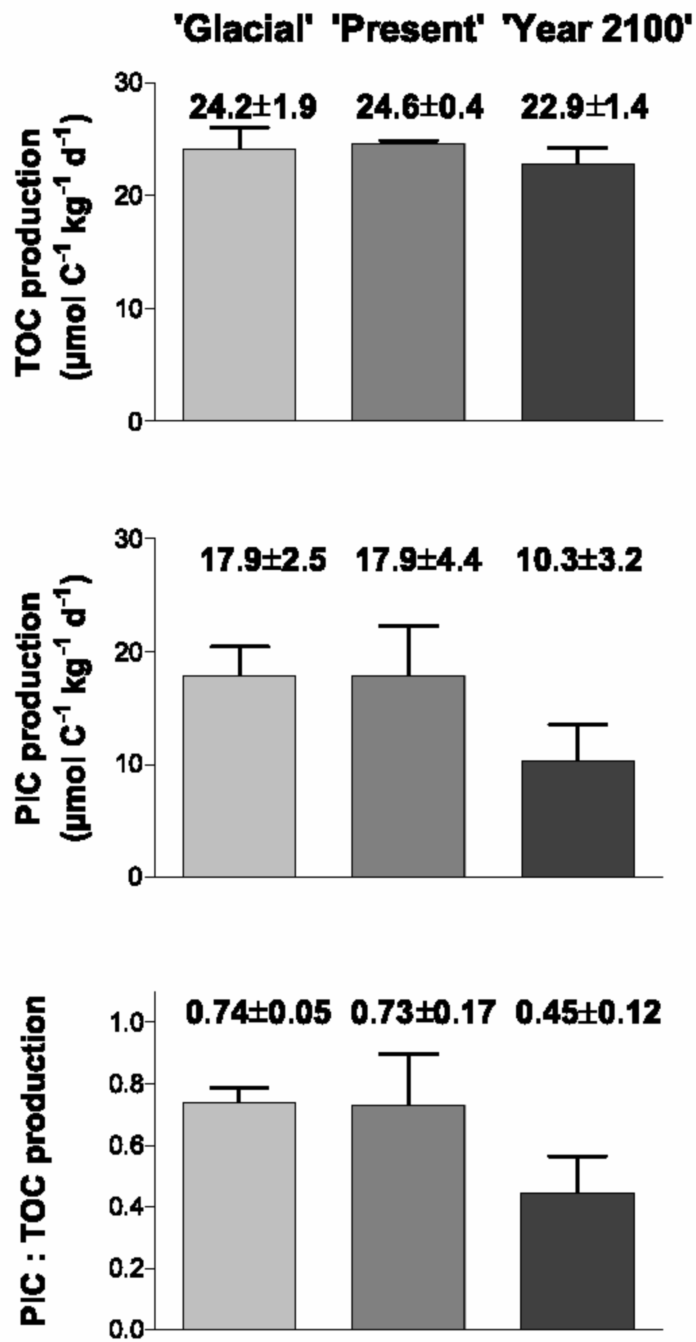
Large Scale Mesocosm Facility, University of Bergen, Norway



from U. Riebesell & B. Rost

Mesocosm study
Bergen 2000

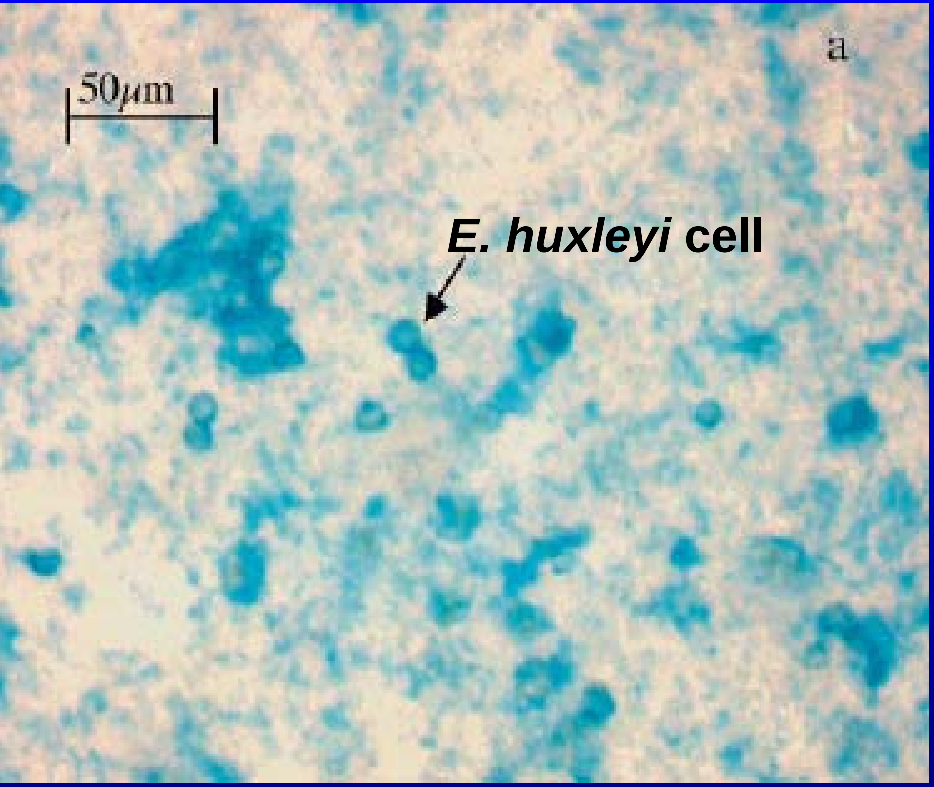
- Total organic carbon (TOC) production: No difference between pCO_2 treatments
- Particulate inorganic carbon (PIC) production: declined in high pCO_2 treatment
- Ratio of PIC/TOC: Lower in high pCO_2 treatment



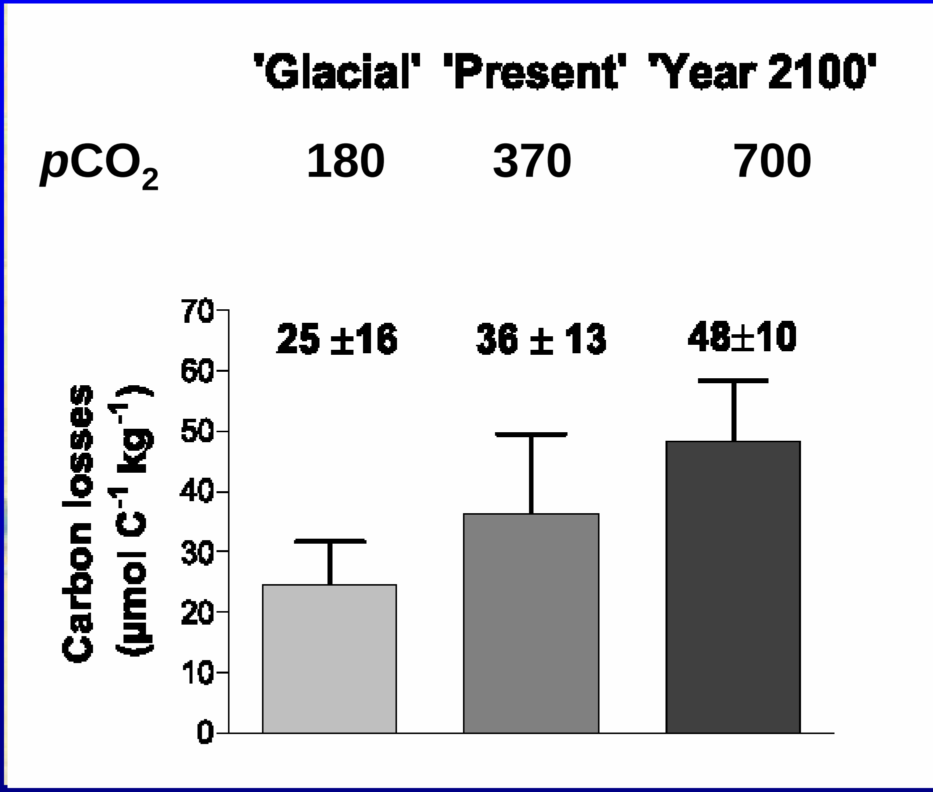
Delille et al. (2005)

Enhanced formation of transparent exopolymer particles (TEP) with elevated pCO_2

During bloom



Later in bloom



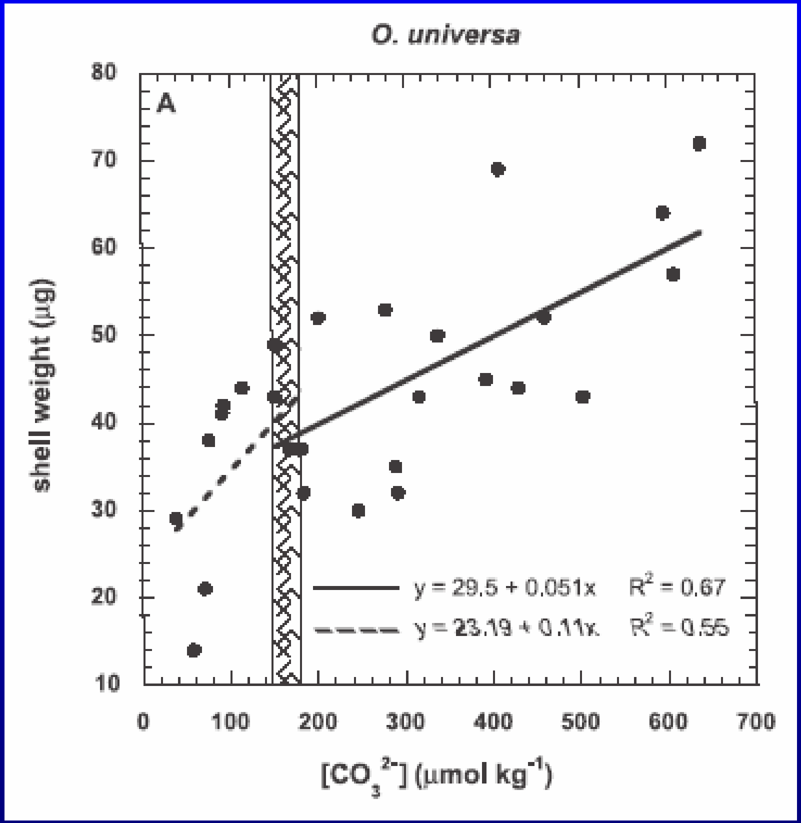
Higher carbon export through TEP production, even though calcification was reduced at pCO_2 700 ppmv

Engel et al. (2004); Delille et al. (2005)

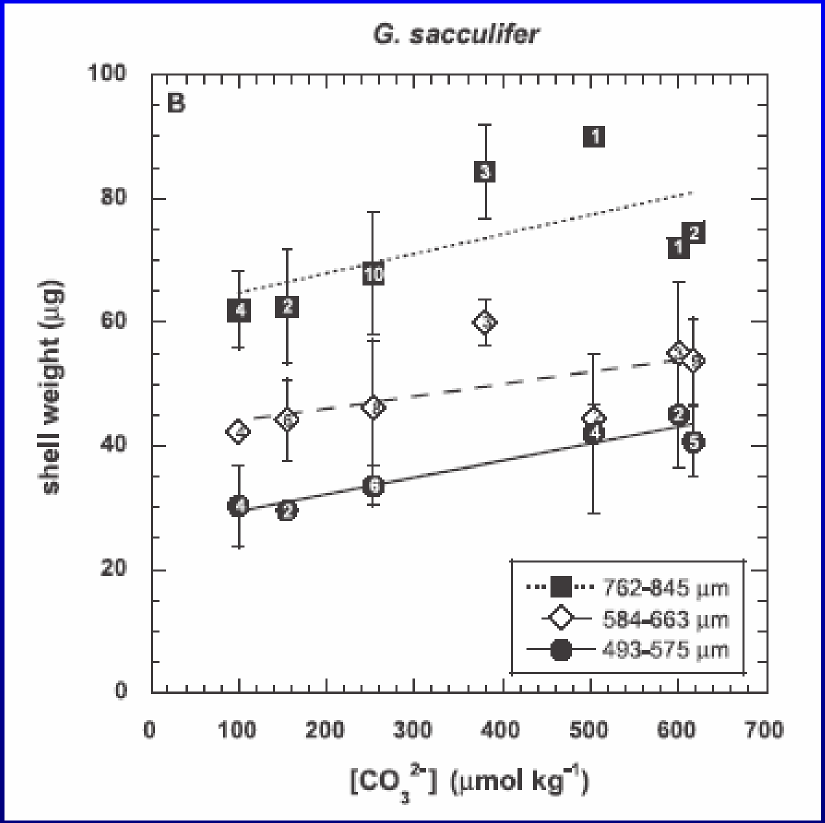
Foraminifera

Shell mass is positively correlated with $[CO_3^{2-}]$

Orbulina universa



Globigerinoides sacculifer



Manipulation of CO_2 system by addition of Na_2CO_3 and/or HCl or NaOH

Bijma et al. (2002)

Foraminifera

Shell mass is positively correlated with $[CO_3^{2-}]$

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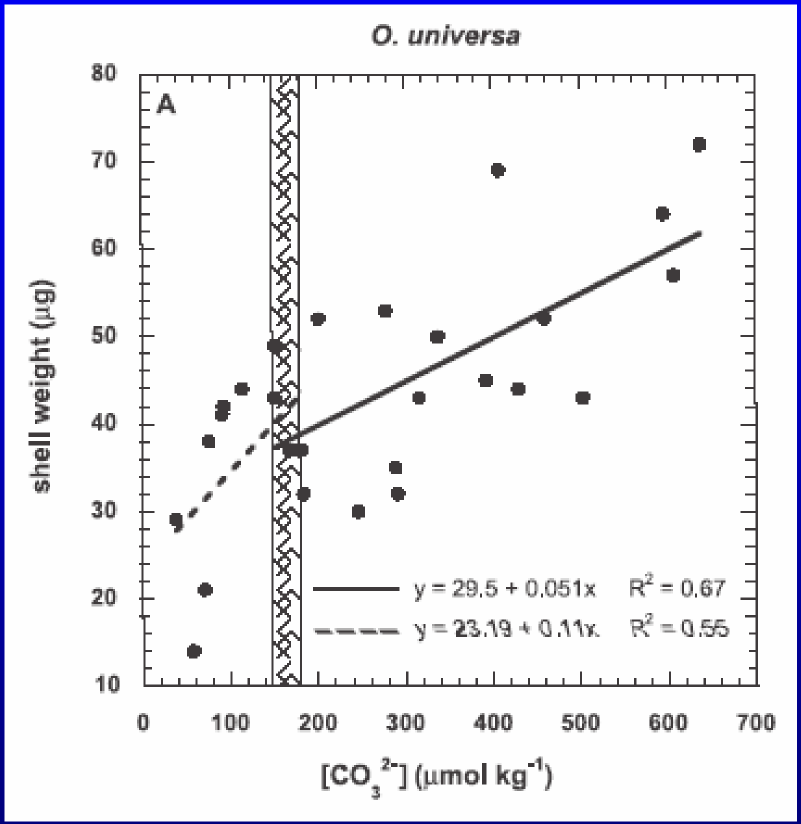

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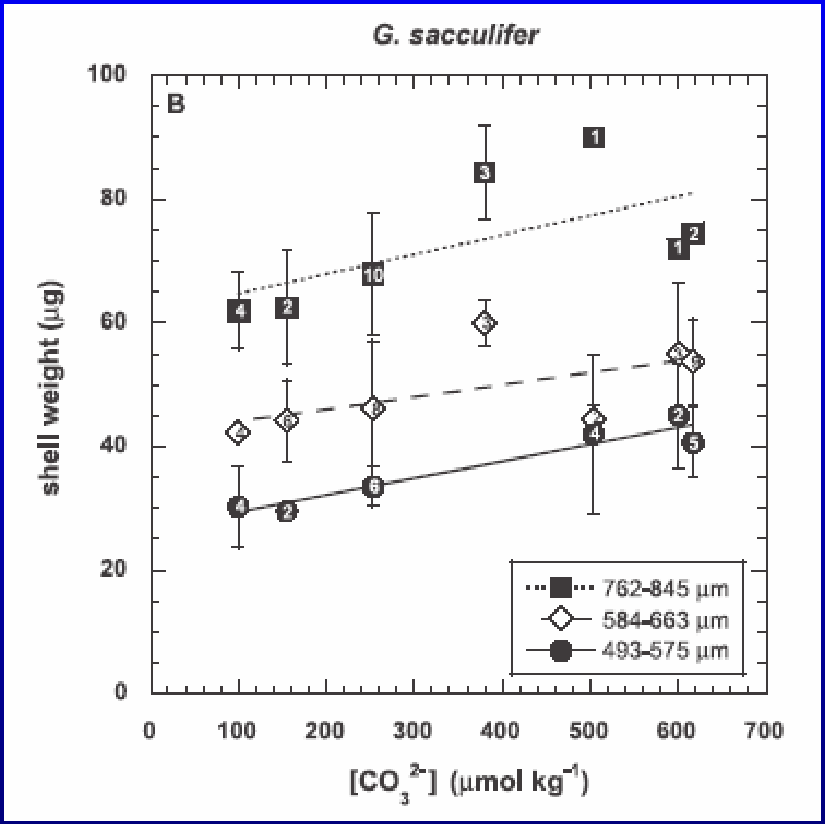


-4 to -8% decline in calcification at $2xCO_2$

-6 to -14% decline in calcification at $3xCO_2$

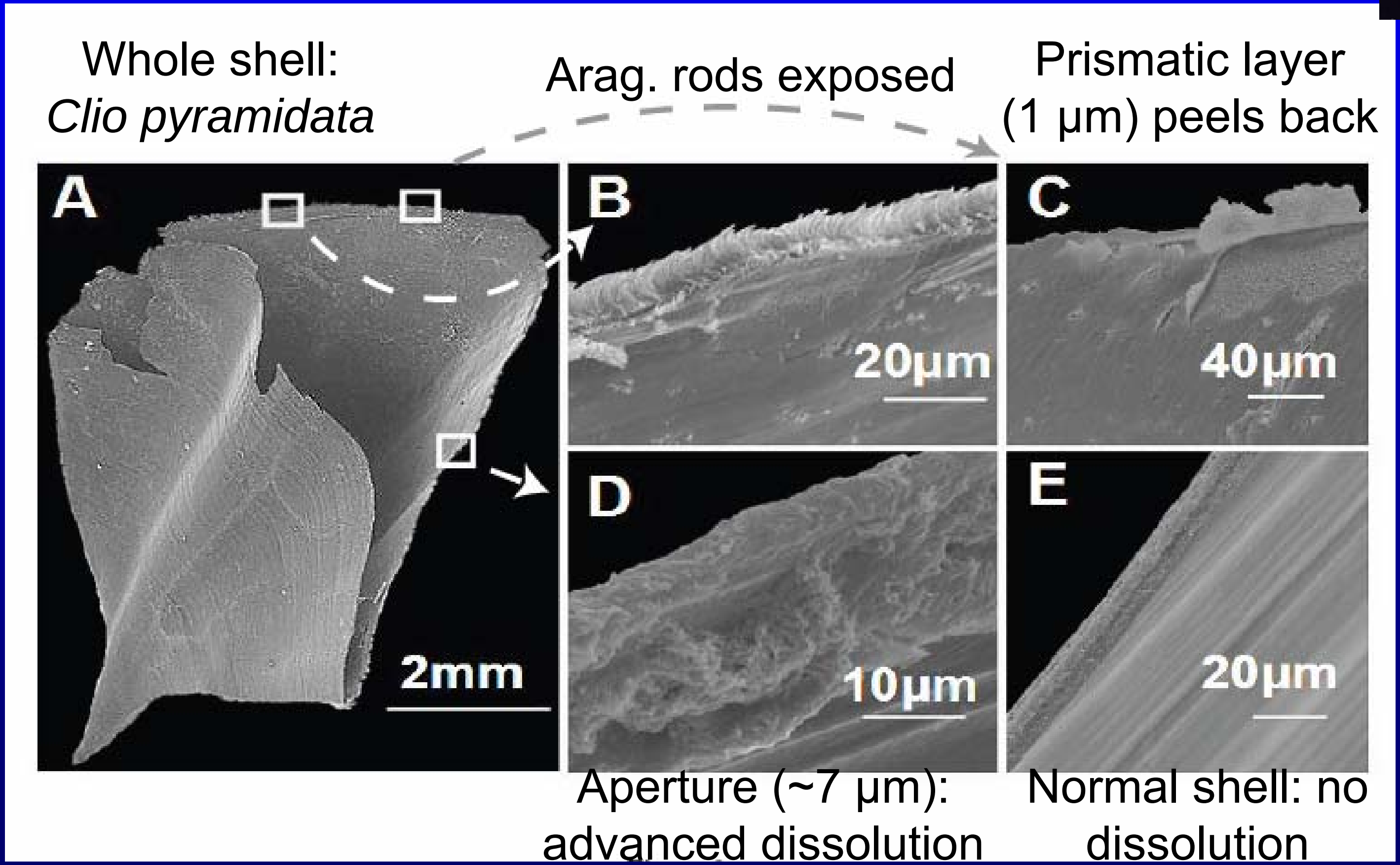
Bijma et al. (2002)

Pteropods

Collected in subarctic Pacific

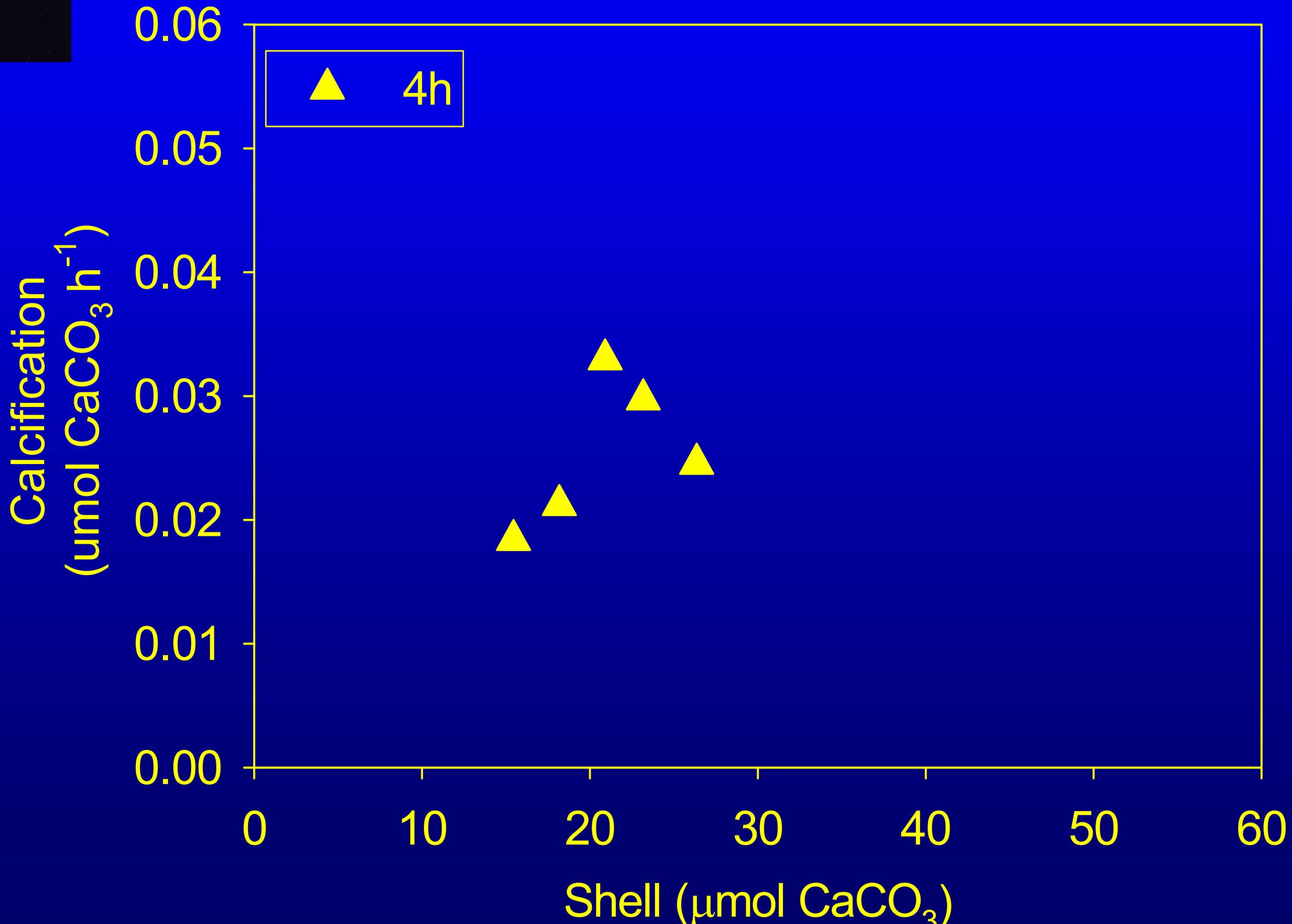
Respiratory CO_2 forced Ω_A <1

Shells of live animals start to dissolve within 48 h



Orr et al., in press

^{45}Ca uptake experiments show reduced calcification rates as respiratory CO_2 progressively decreased the aragonite saturation state



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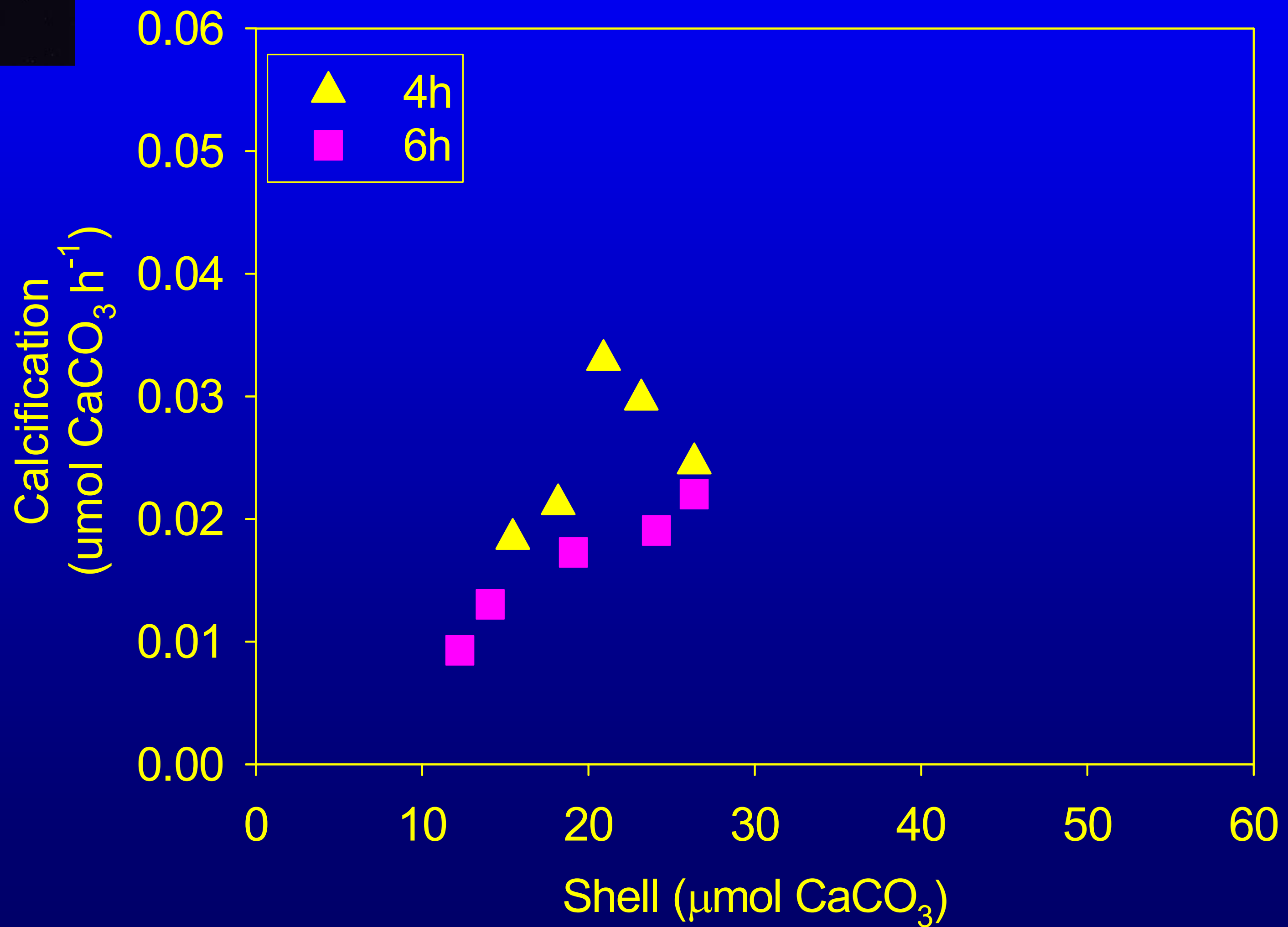

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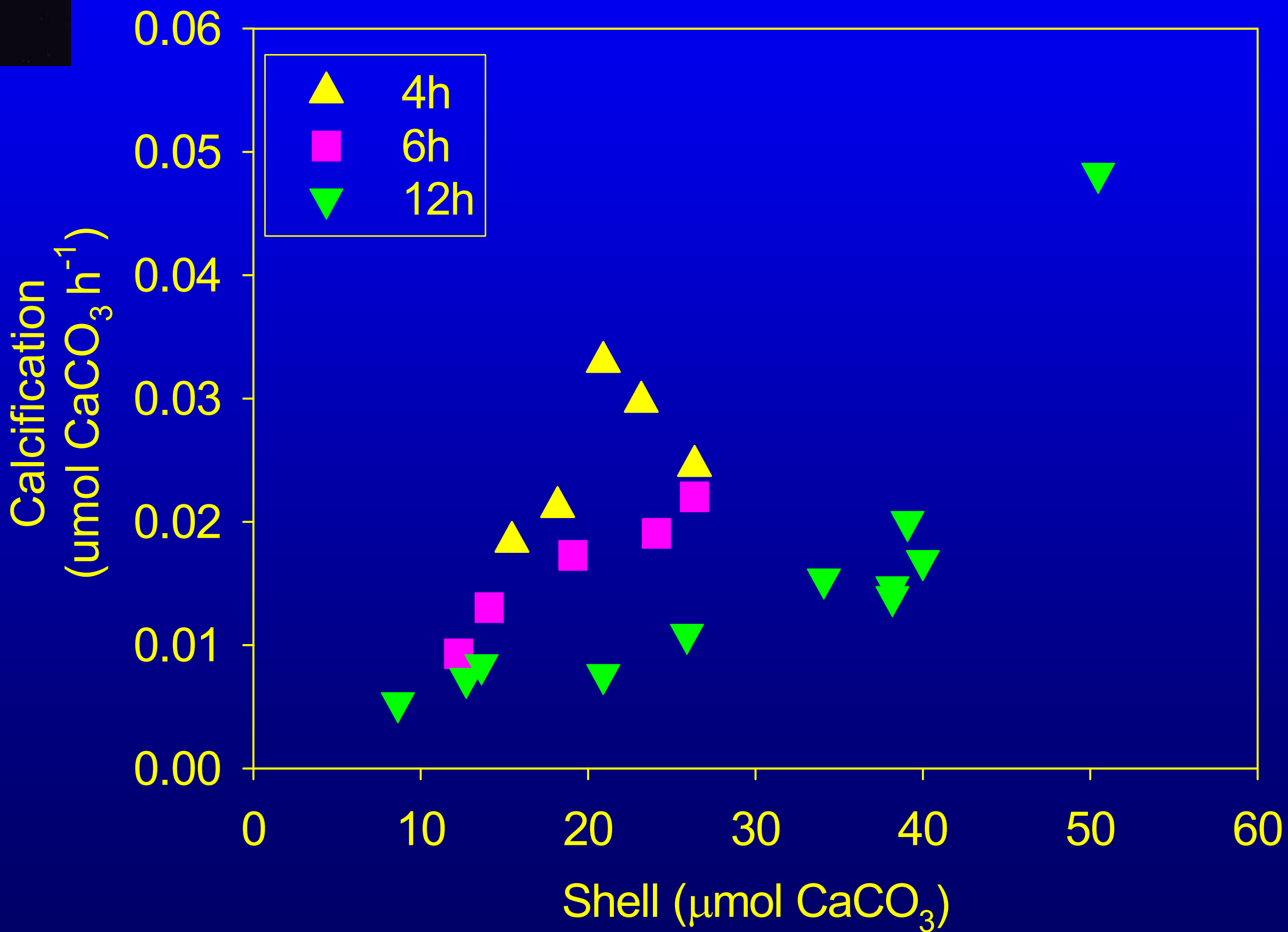

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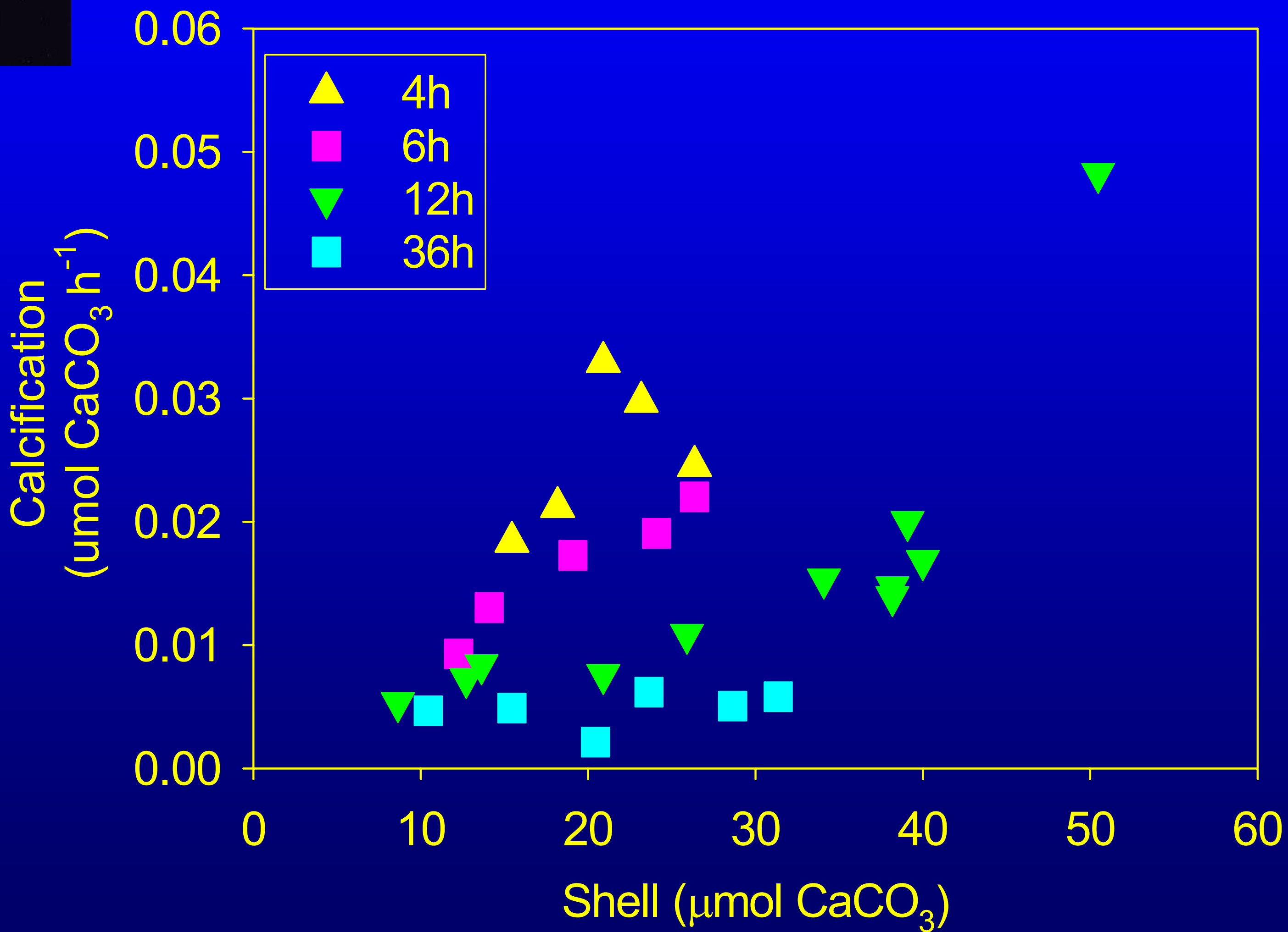

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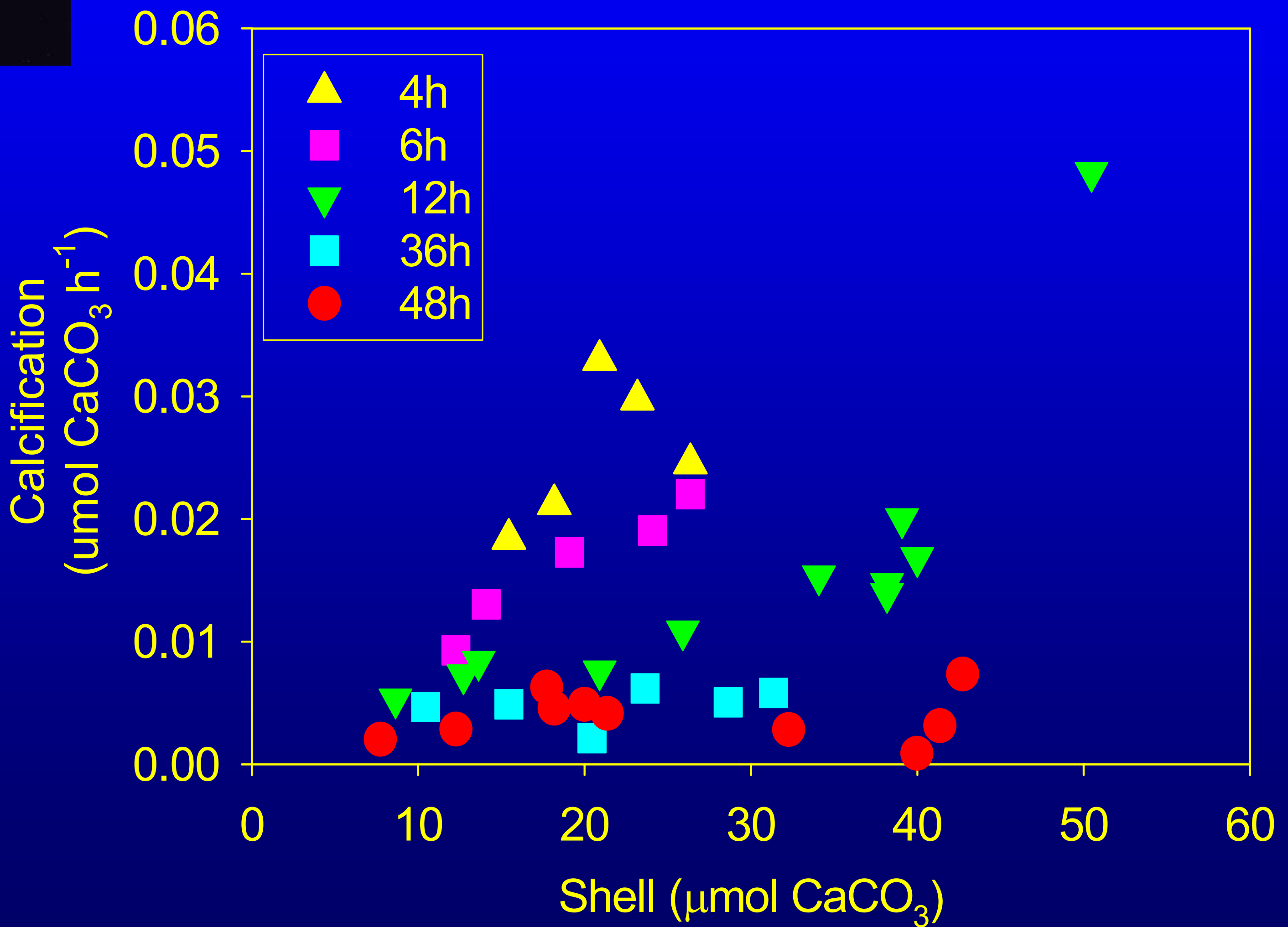


What we know

- **Direct measurements of the short-term calcification response in 4 coccolithophorid species (out of 200 spp)**
  - **Interactions of nutrients with elevated *p*CO_2 in *Emiliania huxleyi***

- **Measured response of 2 foraminifera species (out of ~35 species), using shell mass as a proxy for calcification.**

- **Information on the qualitative response of 1 pteropod species (out of ~ 32 species) when aragonite saturation state < 1**

Critical Research Needs

Calcification Response

- **Measure calcification responses of multiple taxa**
  - **Additional coccolithophore species**
  - **Foraminifera and pteropods**
  - **Other calcareous plankton (e.g., ostracods, larvae of benthic molluscs and echinoderms)**

- **Examine interactions of multiple controls on calcification (e.g., pCO_2, temperature, nutrients, light)**

- **Mechanistic understanding of calcification process**

- **Capacity of calcifiers to adapt to elevated pCO_2**

- **Impacts of elevated pCO_2 on species surviorship and fitness**

Critical Research Needs

Ecosystem Response

- **Shifts in relative abundance and distribution of calcifying species**
  - **Non-calcifying species may outcompete calcifiers**
  - **Geographical ranges of calcifying species may shift**
  - **Vertical distributions of calcifying species may shoal with decreasing $CaCO_3$ saturation state**

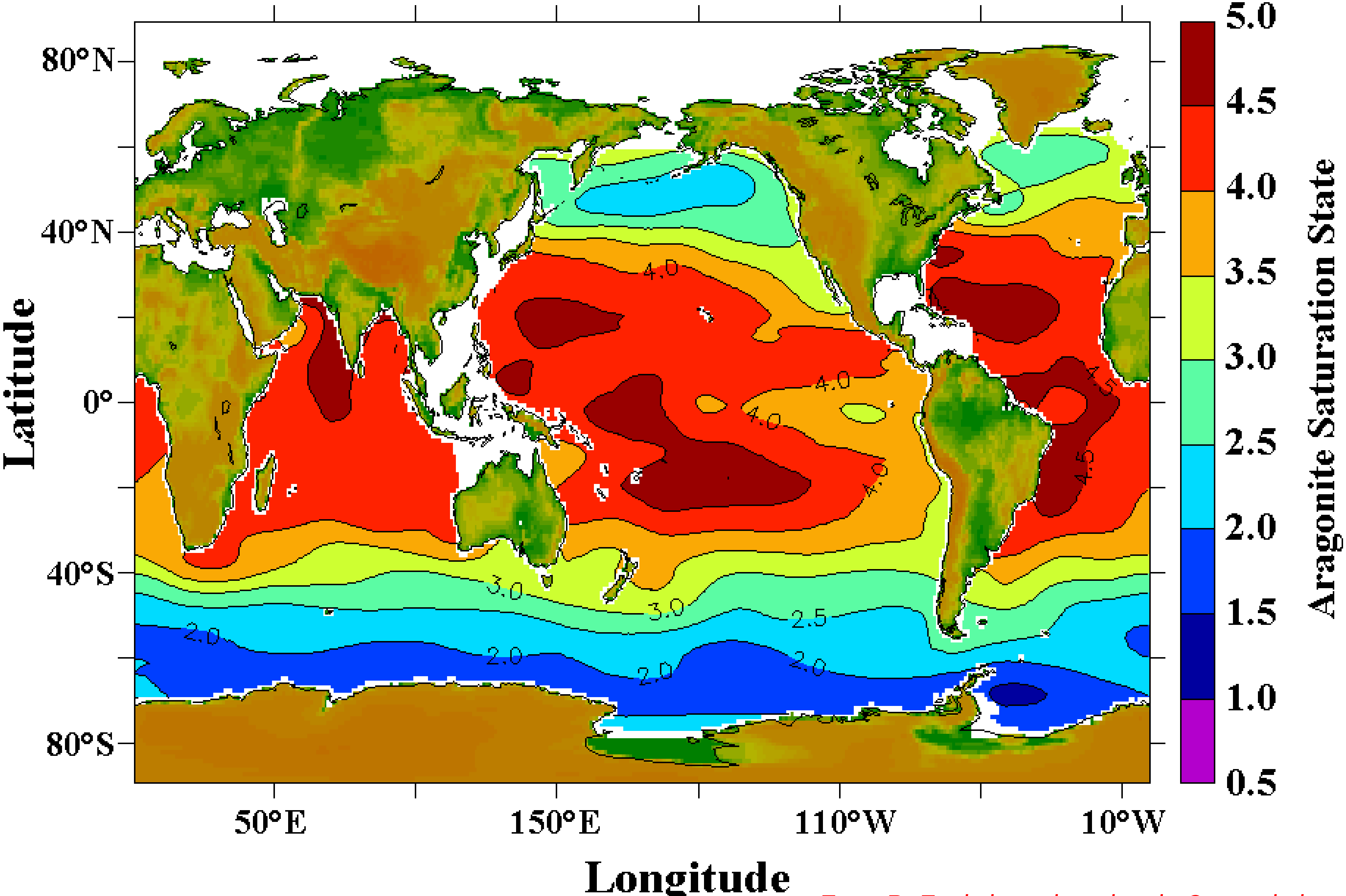
- **Changes in food webs and other species interactions**

- **Biogeochemical cycles**
  - **Shoaling of aragonite and calcite saturation horizons in several oceanic regions will lead to increased $CaCO_3$ dissolution within water column**
  - **Changes in export of organic C and $CaCO_3$**

Investigation of ecosystem impacts requires field process studies in multiple oceanic regions

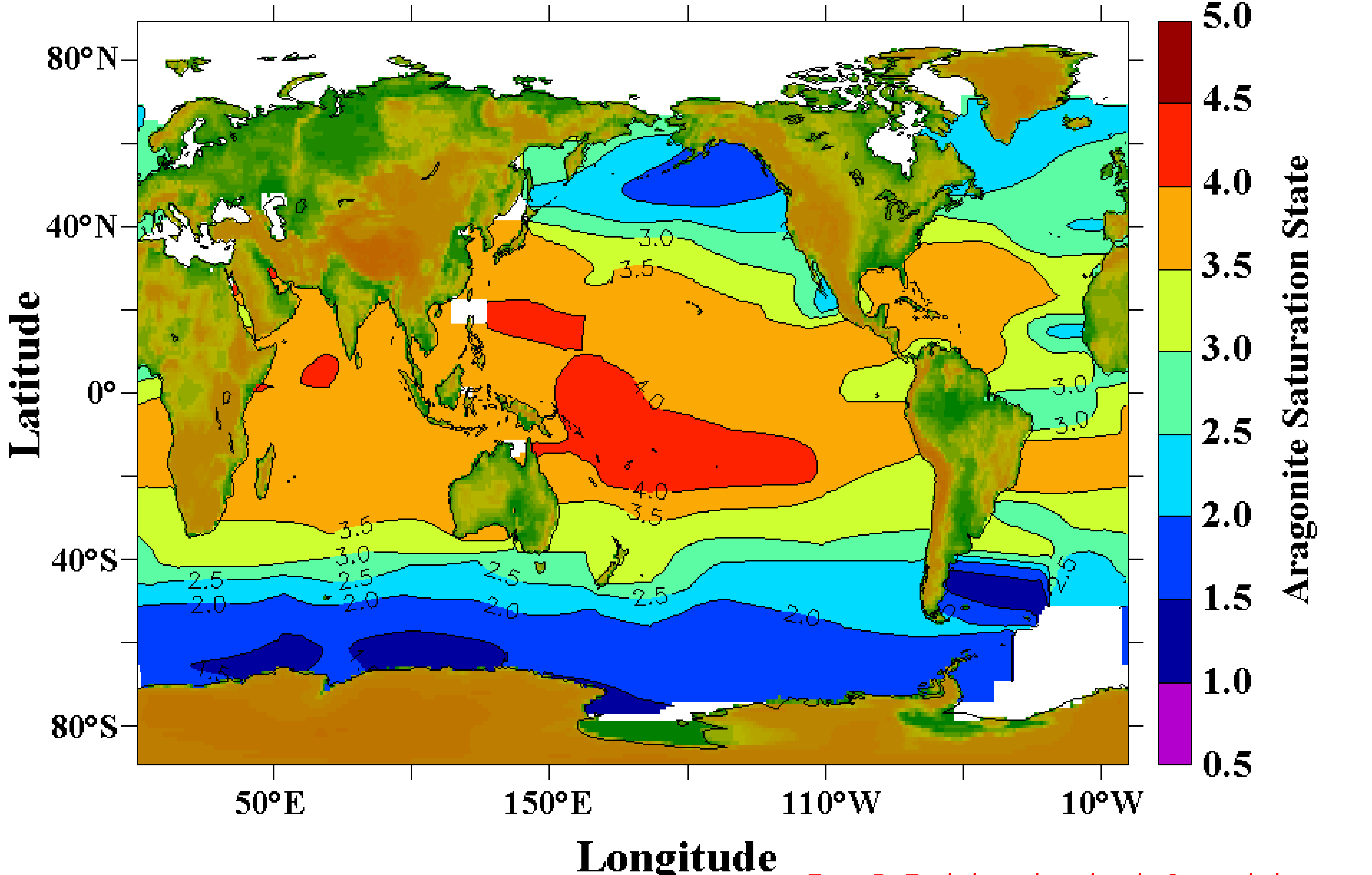
Which pelagic ecosystems are most at risk?

Aragonite Saturation Levels in 1765



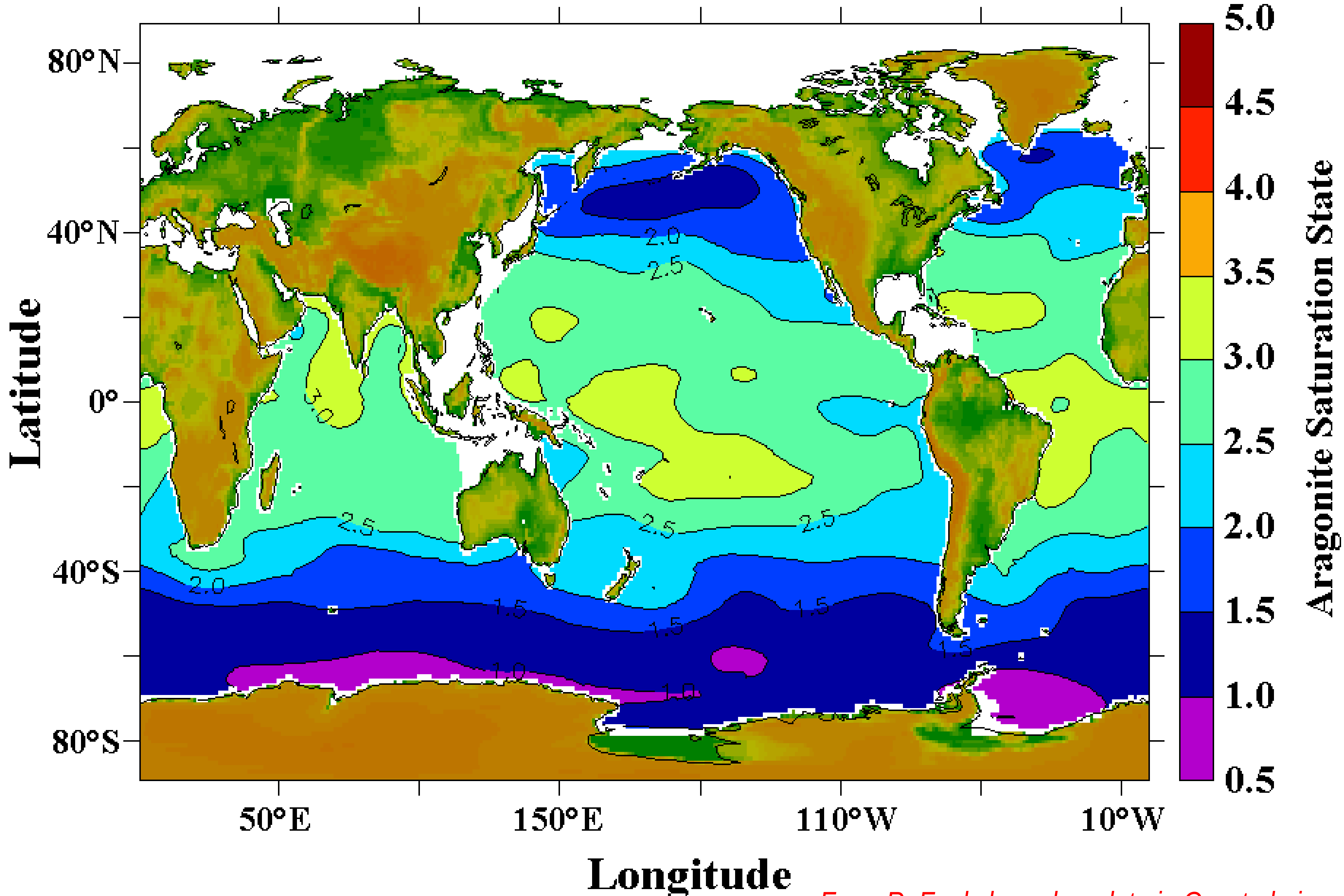
From R. Feely based on data in Orr et al., in press

Aragonite Saturation Levels in 1994



From R. Feely based on data in Orr et al., in press

Aragonite Saturation Levels in 2060



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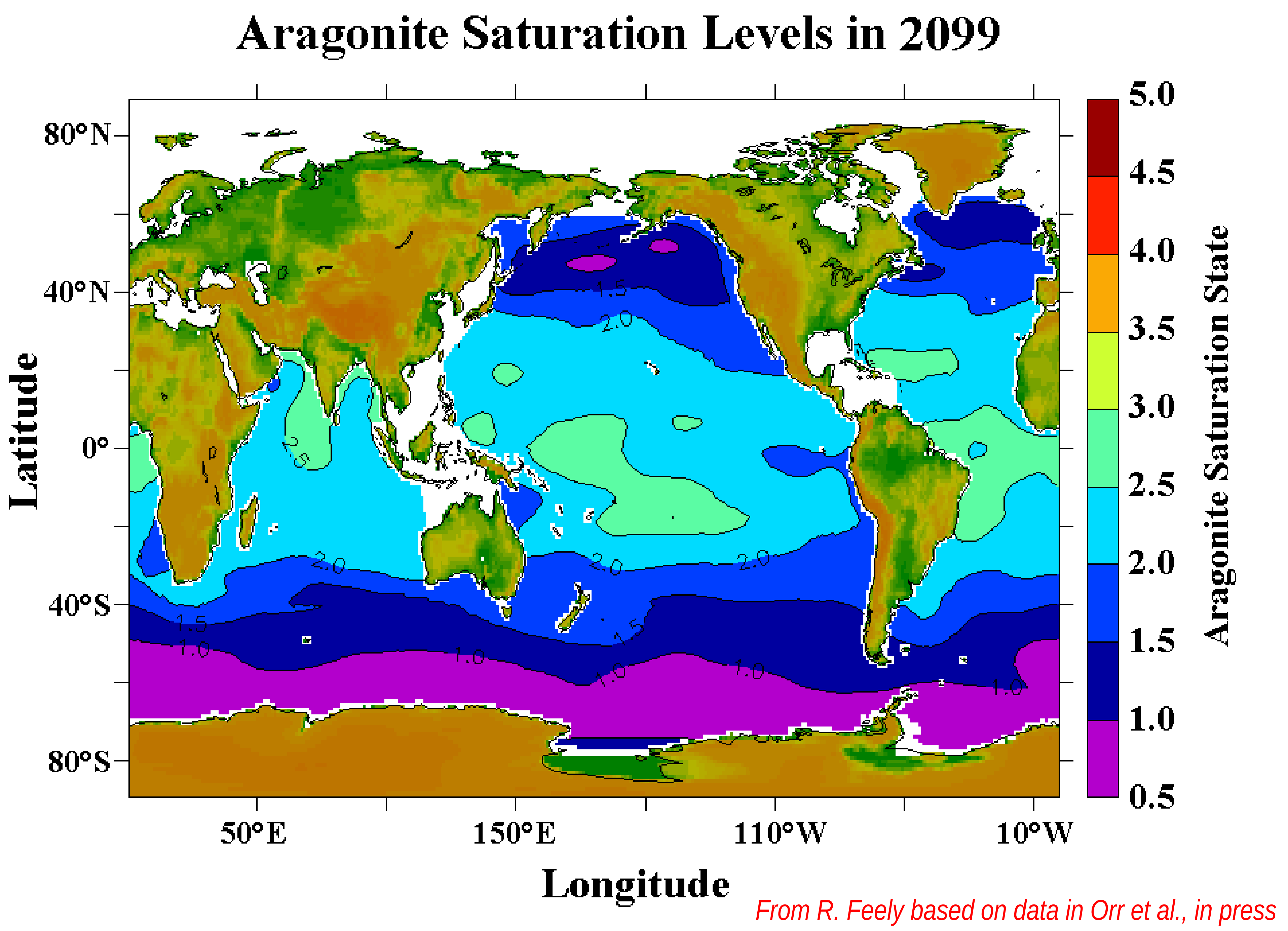
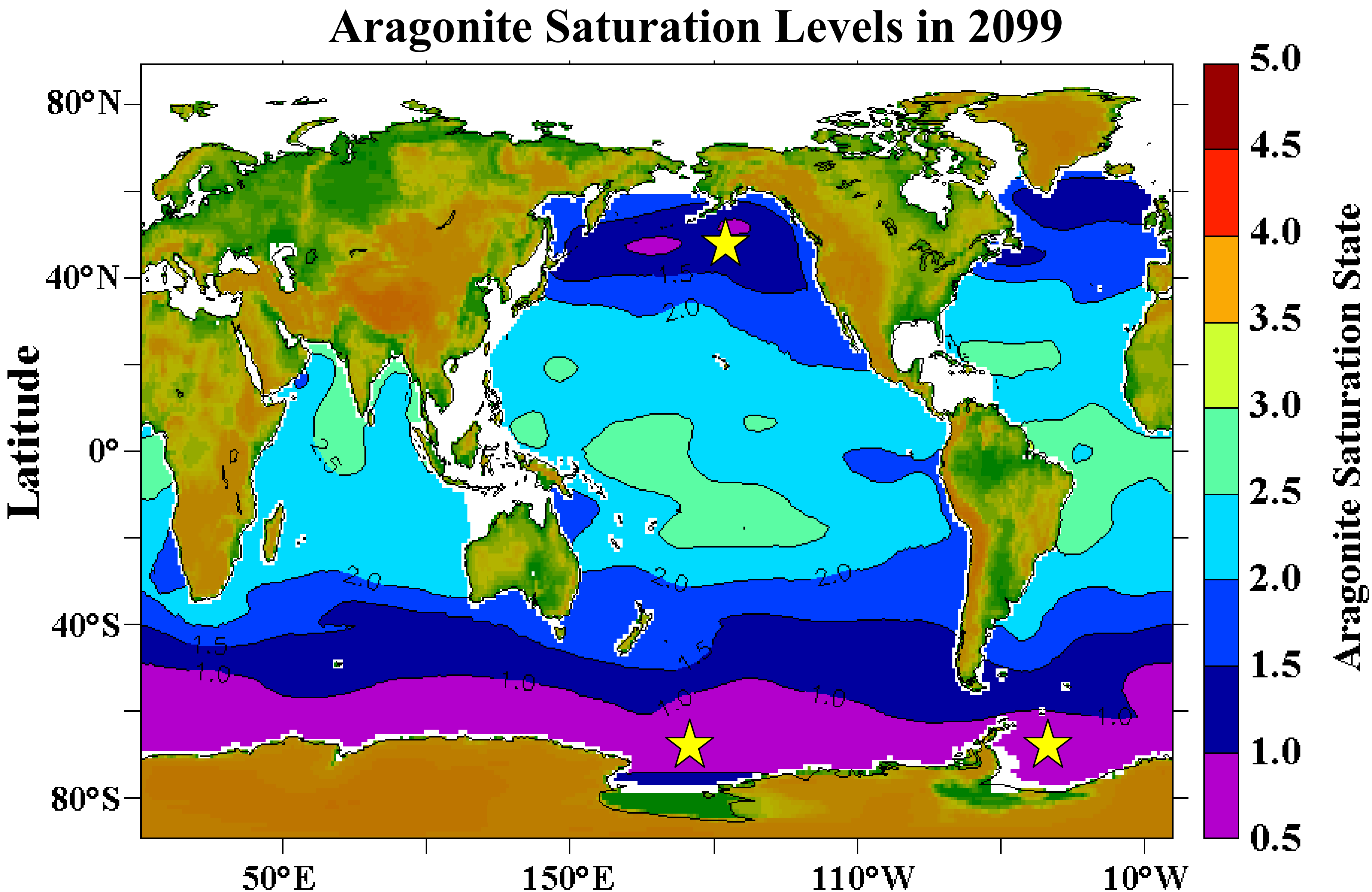


Aragonite Saturation Levels in 2099
80°N
40°N
0°
40°S
80°S
Latitude
50°E
150°E
110°W
10°W
Longitude
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
Aragonite Saturation State
From R. Feely based on data in Orr et al., in press

Which pelagic ecosystems are most at risk?

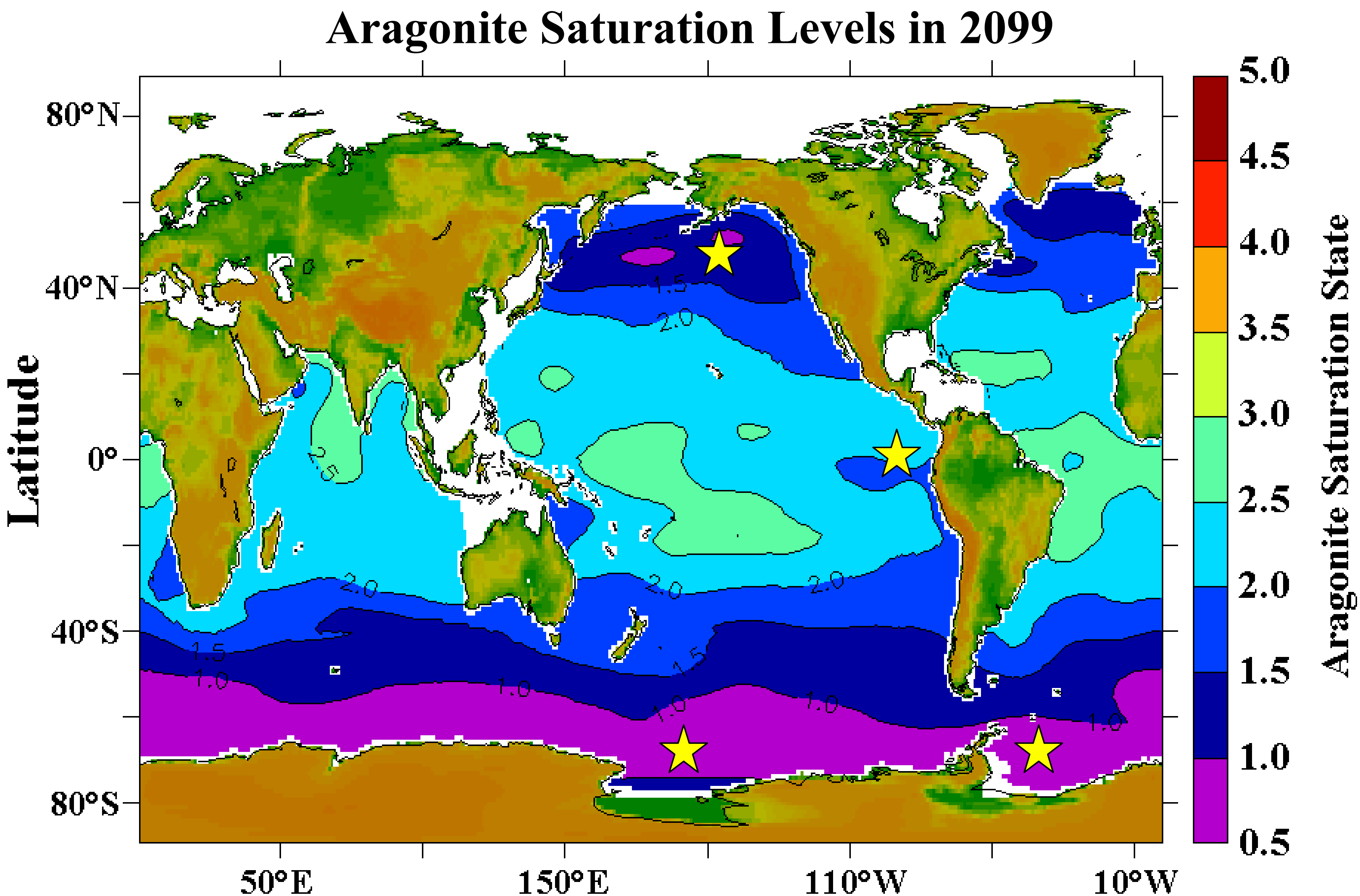
- Regions where aragonite saturation states are predicted to shoal to surface or near-surface by year 2100
  - **High latitudes, particularly the Southern Ocean and subarctic Pacific**
- Ecosystems in which aragonite-producers are important components
  - **Pteropods in the Southern Ocean and subarctic Pacific**

Where should process studies be conducted?



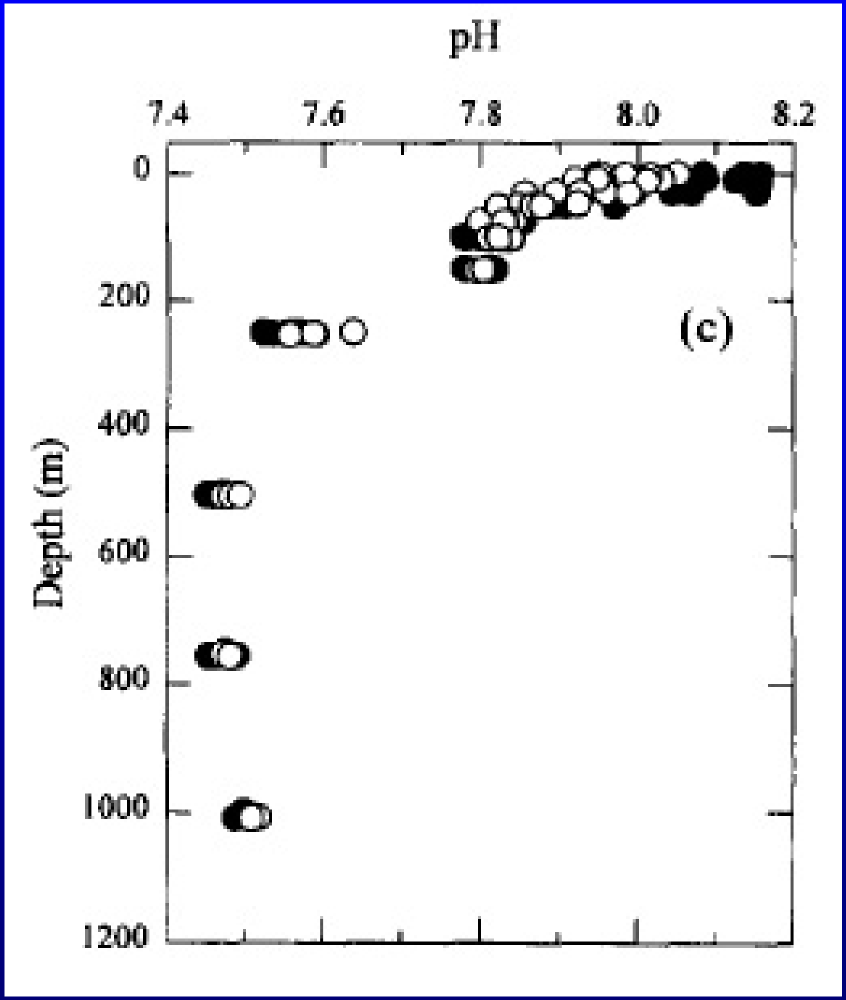
High latitude locations for pelagic calcification studies

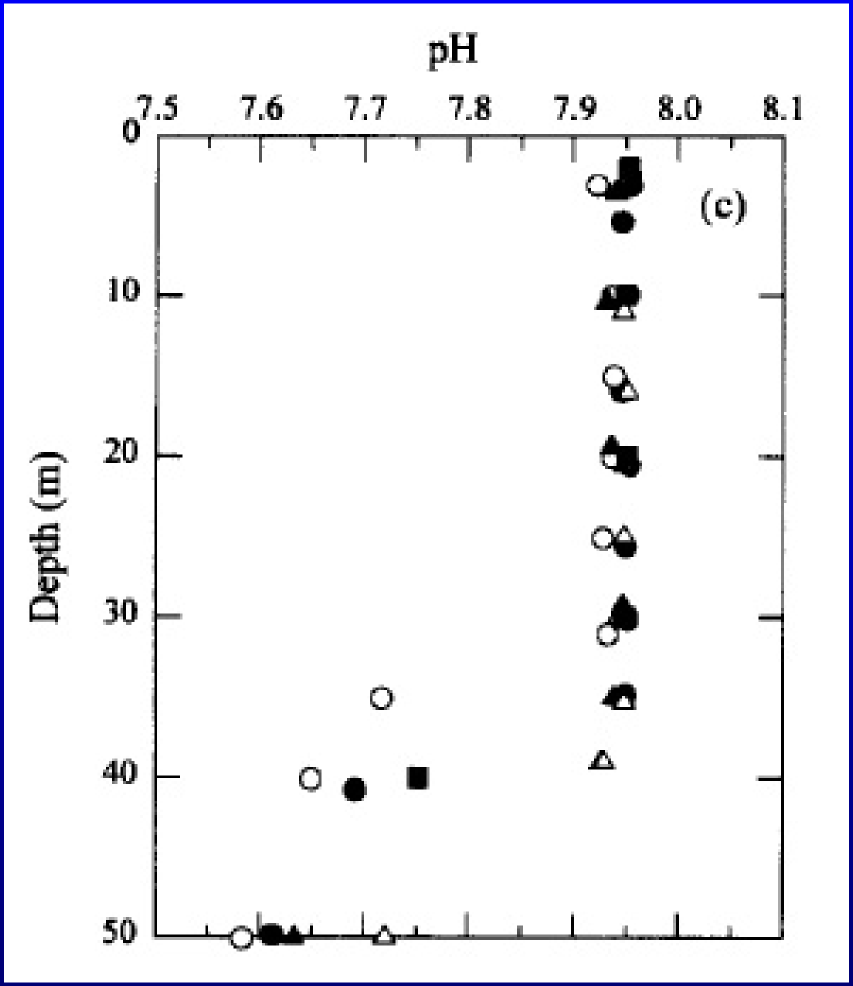
Where should process studies be conducted?



Galapagos region - strong vertical and horizontal pH gradients

Galapagos region: Strong pH gradient with depth





MIllero et al. (1998)