Climate Change in the Ocean: Carbon Dioxide Acidification

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Ocean Acidification -

Where Does it Come From?

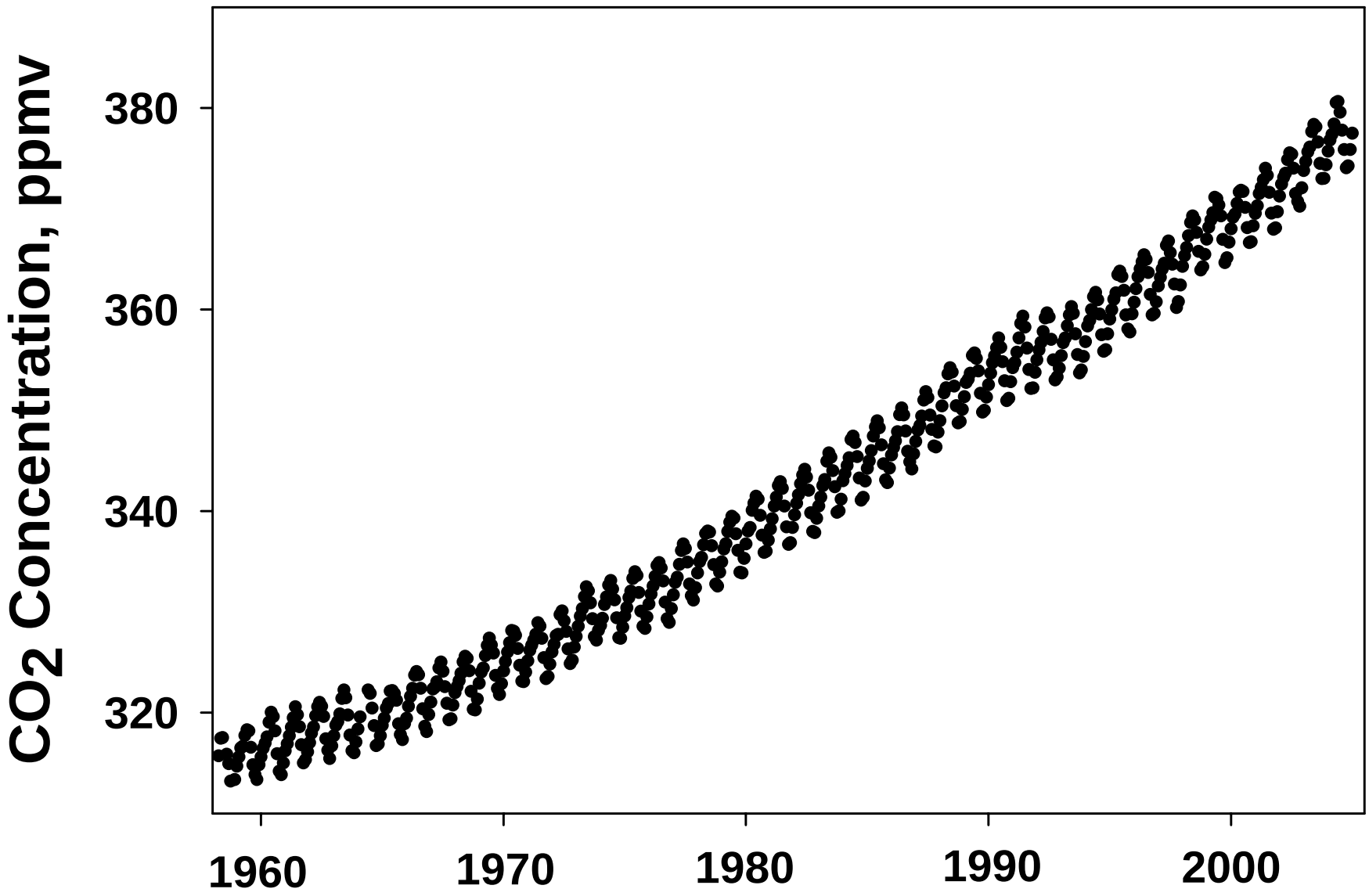
How Does it Work?

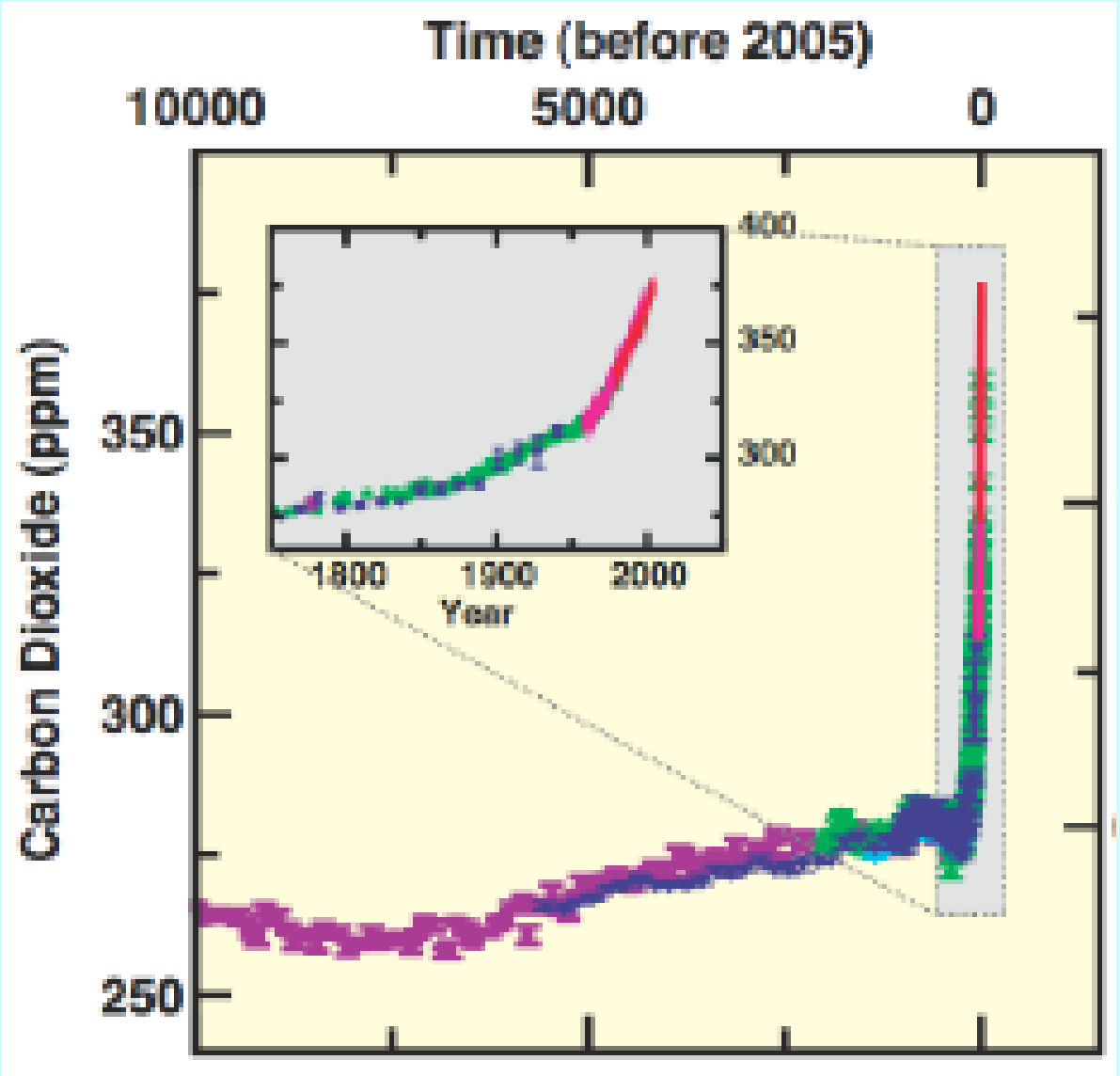
What Oceans are Most Vulnerable?

What Alaskan Organisms are Most at Risk?

How Fast is it Changing?

The Keeling Curve





Orr et al. (2005) Nature 437:681

Ocean Acidification -

Where Does it Come From?

How Does it Work?

Atmospheric Composition:

Nitrogen (N_2)	-	78%
Oxygen (O_2)	-	21%
Carbon Dioxide (CO_2)	-	0.038%

Seawater Concentrations (34‰ Salinity)

	20°C	6°C
N_2	7.3	10.3
O_2	11.7	15.7
CO_2	0.54	0.85
	(mg/L)	

Net Result:

$$H_2O + CO_2 + CO_3^{-2} \rightleftharpoons 2HCO_3^-$$

$CO_2(atm)$

$CO_2(aq)$ + H_2O $\rightleftharpoons$ H_2CO_3 $\rightleftharpoons$ $H^+ + HCO_3^-$

Carbonic Acid

Bicarbonate ion

Carbonate ion

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

Three Factors Increase Ocean Acidification Effects in Alaska:

Cold Temperatures *Increase* CO_2 Solubility

Upwelling Seawater Enriched in CO_2

Low Surface Salinity = Low Calcium

Calcium Carbonate Solubility and Saturation

$K_{sp} = [Ca^{+2}][CO_3^{-2}] = 4.16 \times 10^{-8}$ M (calcite, 34‰, 6°C)

$K_{sp} = [Ca^{+2}][CO_3^{-2}] = 6.60 \times 10^{-8}$ M (aragonite)

$$\Omega = [Ca^{+2}][CO_3^{-2}]_{measured}/K_{sp}$$

So, when $\Omega < 1$, seawater is undersaturated, $CaCO_3$ dissolves

when $\Omega = 1$, seawater is saturated, and

when $\Omega > 1$, seawater is supersaturated, $CaCO_3$ precipitates

Currently, surface seawater is supersaturated worldwide

But not for much longer....

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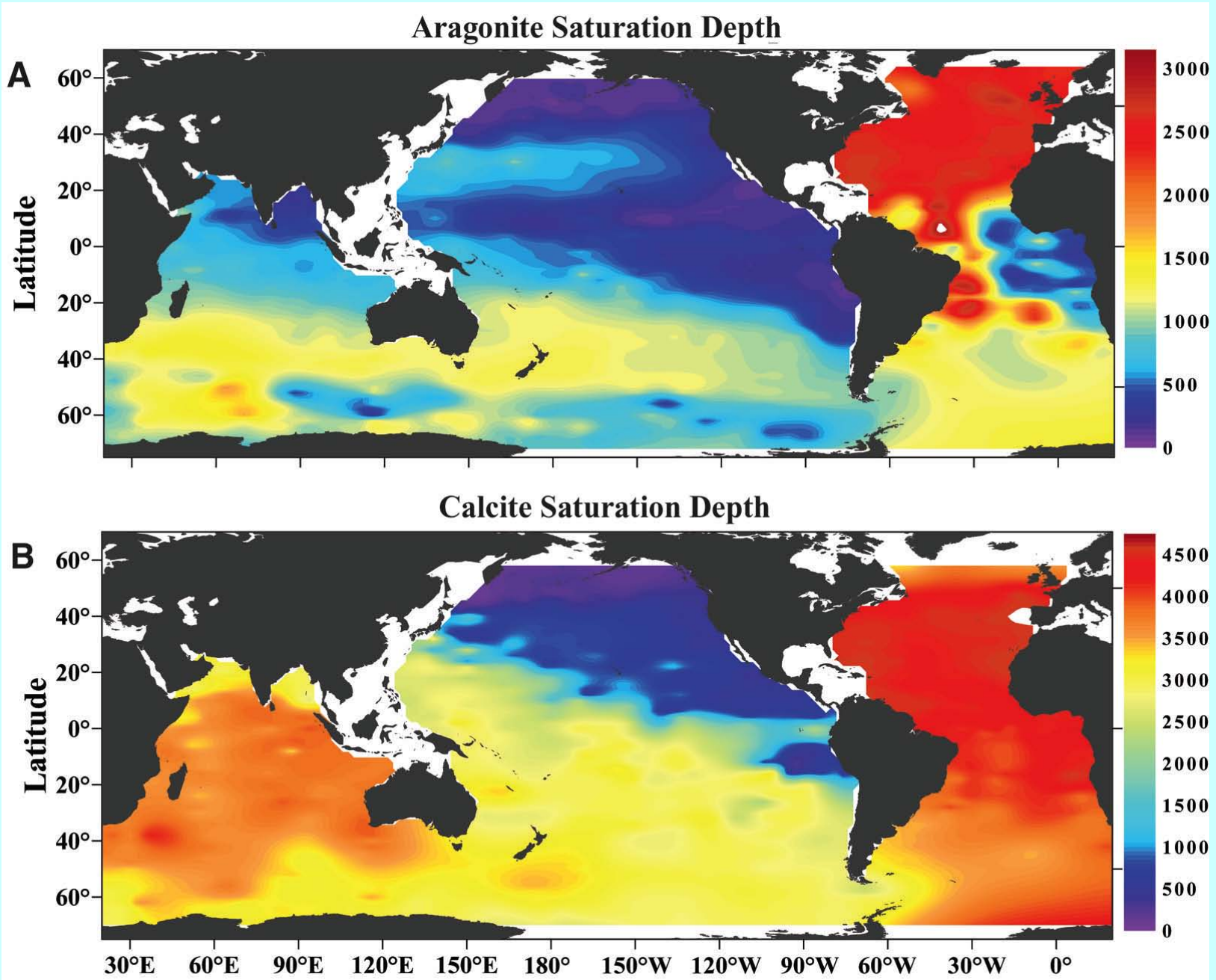
Aragonite and Calcite Saturation Depths in the Global Oceans



Feely et al. (2004) Science 305:362

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Calcifying organisms play multiple pivotal roles in marine ecosystems

Many are harvested commercially

Ocean Acidification - Calcareous plankton

Pteropods (snail)

Coccolithophores (phytoplankton)

Foraminifera (protist)

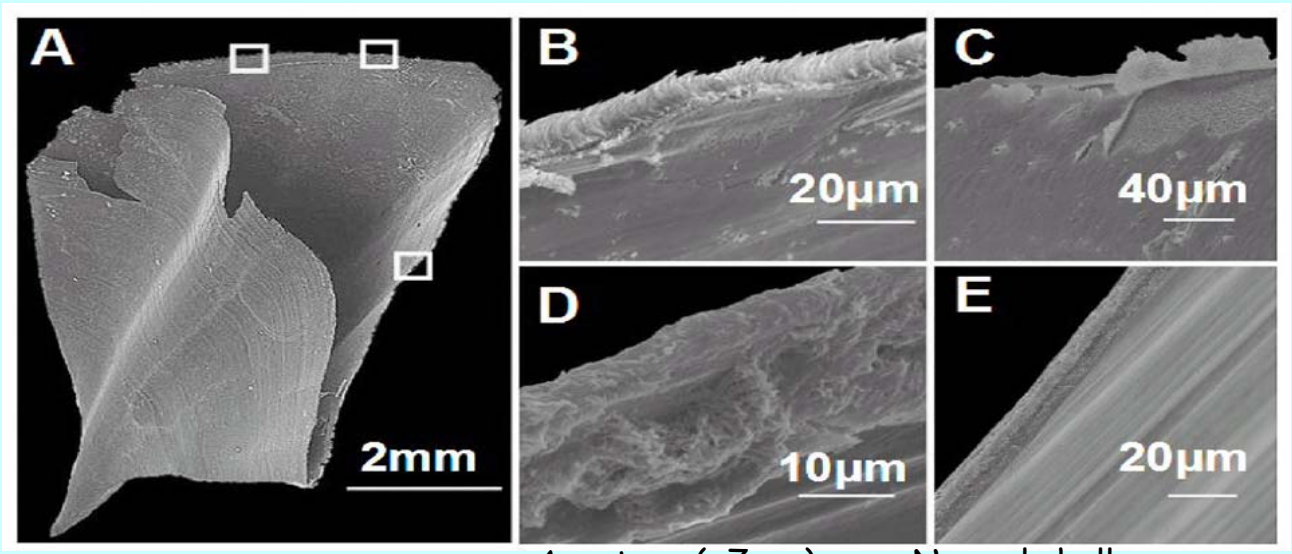
What we know
about the biological impacts of ocean acidification
…on marine zooplankton

Dissolution of pteropods

Whole shell:
Clio pyramidata

Arag. rods exposed

Prismatic layer
(1 μm) peels back



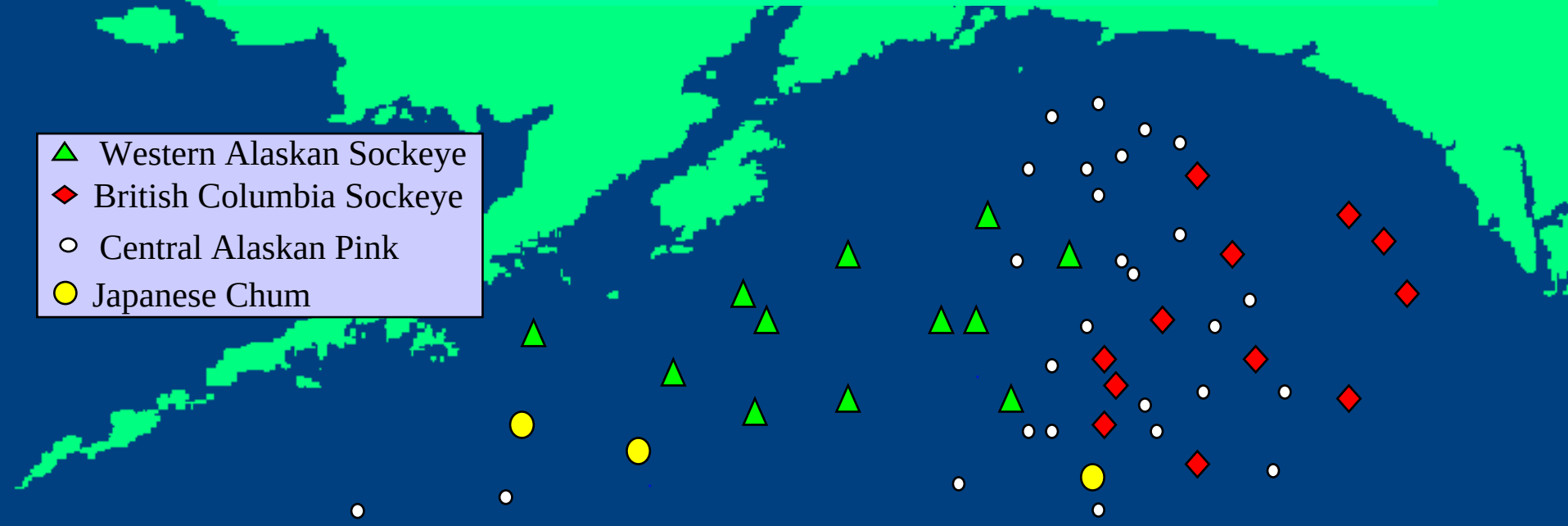
Orr et al., (2005)

Aperture (~7 μm):
advanced dissolution

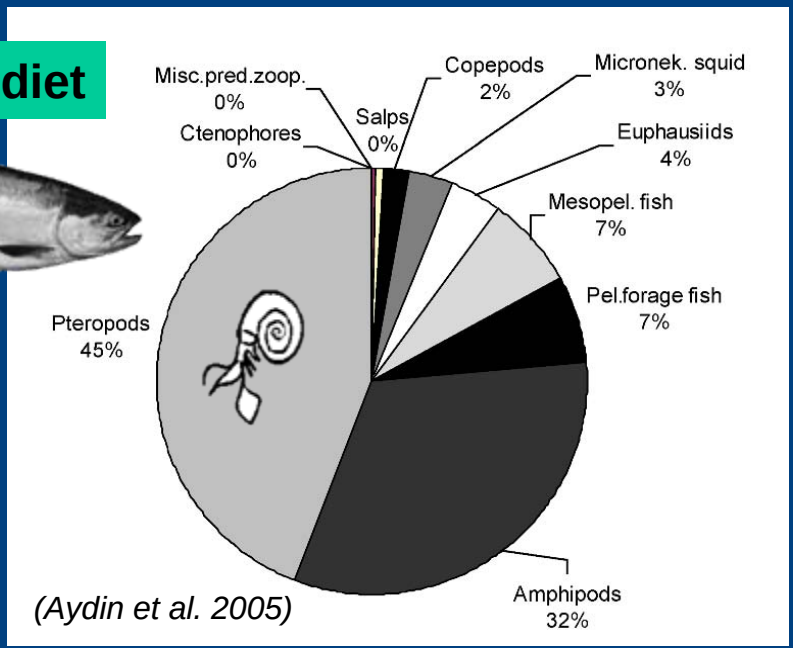
Normal shell: unexposed
to undersaturated water

Courtesy of Dr. Richard Feely

Modeling Trophic Consequences of Ocean Acidification



Pink salmon diet



(Aydin et al. 2005)

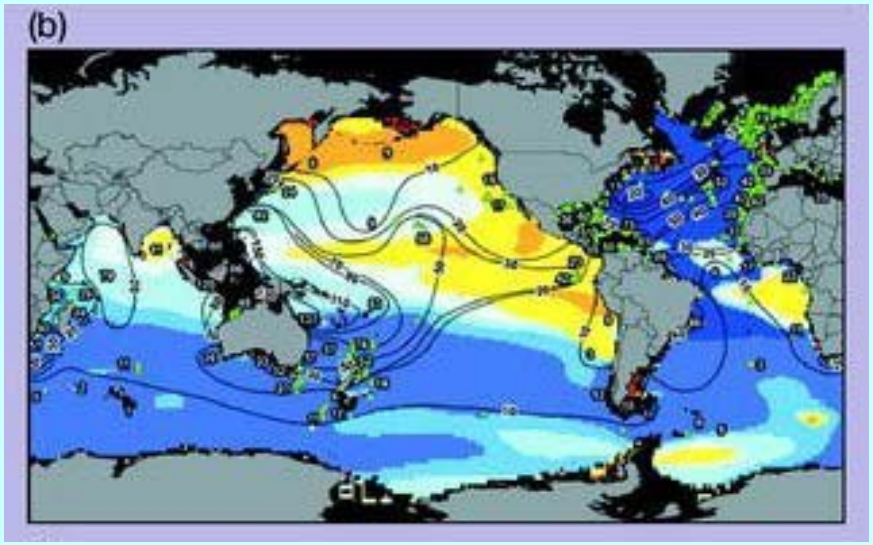
Predicted effect of climate change on pink salmon growth:

- 10% increase in water temperature leads to 3% drop in mature salmon body weight (physiological effect).

- 10% decrease in pteropod production leads to 20% drop in mature salmon body weight (prey limitation).

Ocean Acidification - Corals

Deep-sea bioherm forming corals



Guinotte, JM, J. Orr, S. Cairns, A. Freiwald, L. Morgan, and R. George. 2006. Will human-induced changes in seawater chemistry alter the distribution of deep-sea scleractinian corals? Front. Ecol. Environm. 4:141-146. Green triangles are locations of deep-sea bioherm forming corals.

Depth distribution of Aleutian corals.

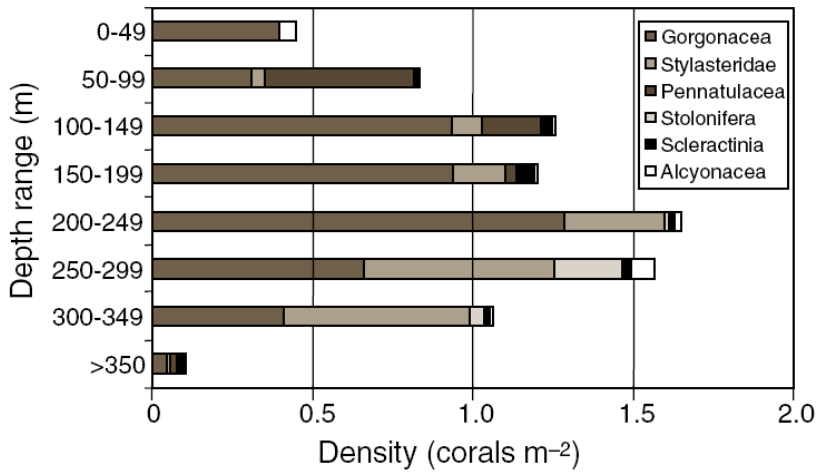


Fig. 3 Density of corals observed in 50-m depth zones with the submersible '*Delta*'

Stone, R. P. 2006. Coral habitat in the Aleutian Islands off Alaska: Depth distribution, fine-scale species associations, and fisheries interactions. Coral Reefs 25:229-238.

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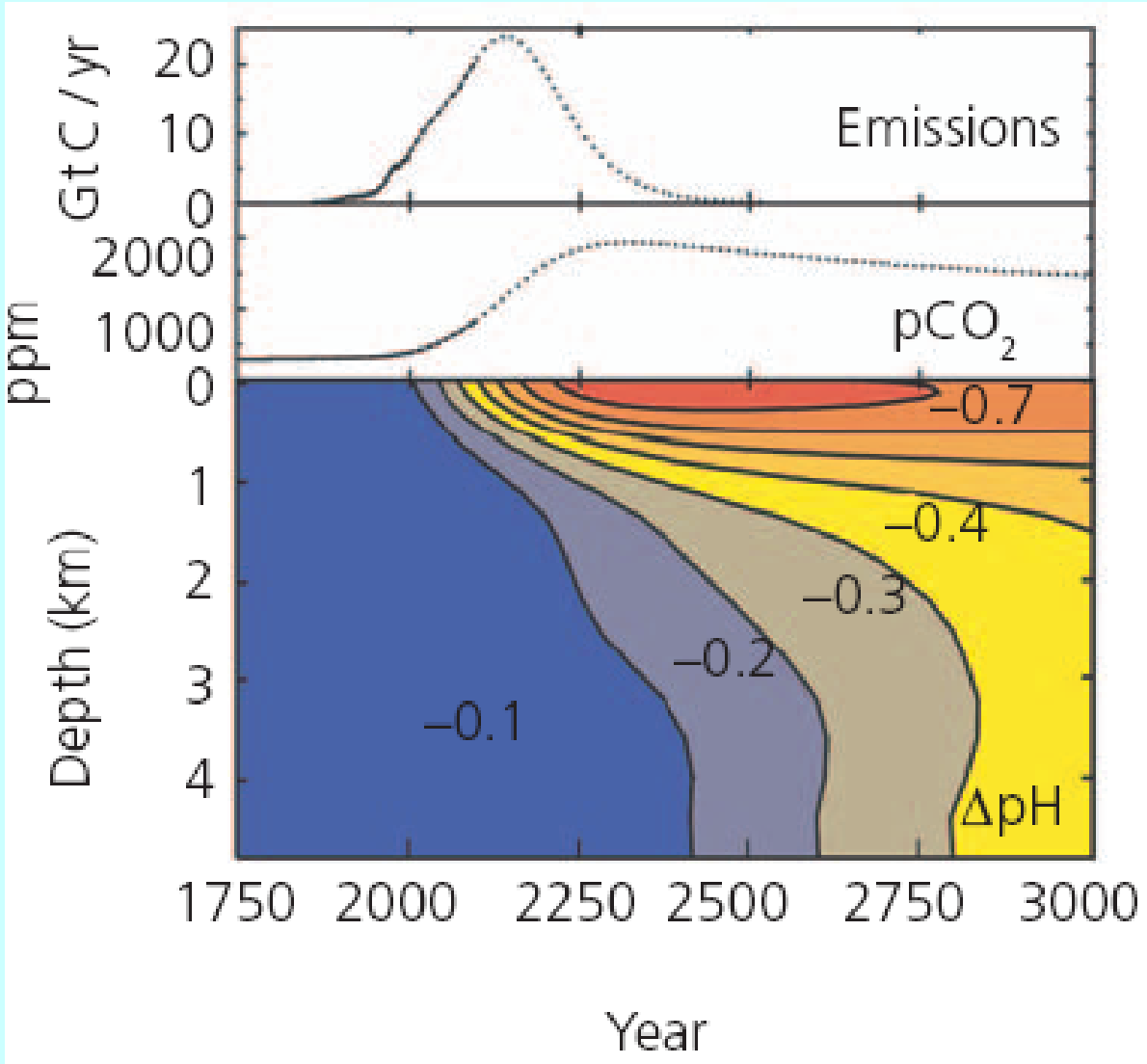
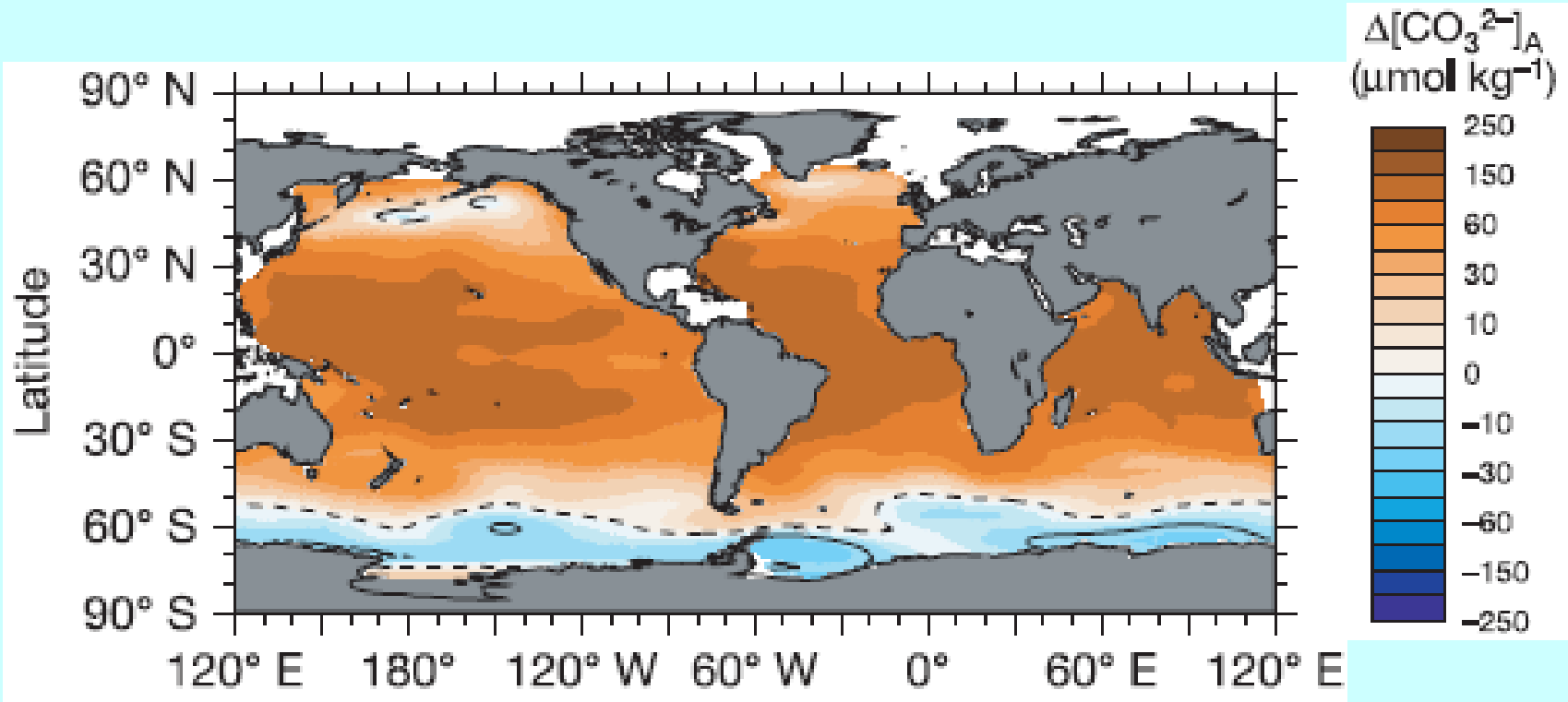


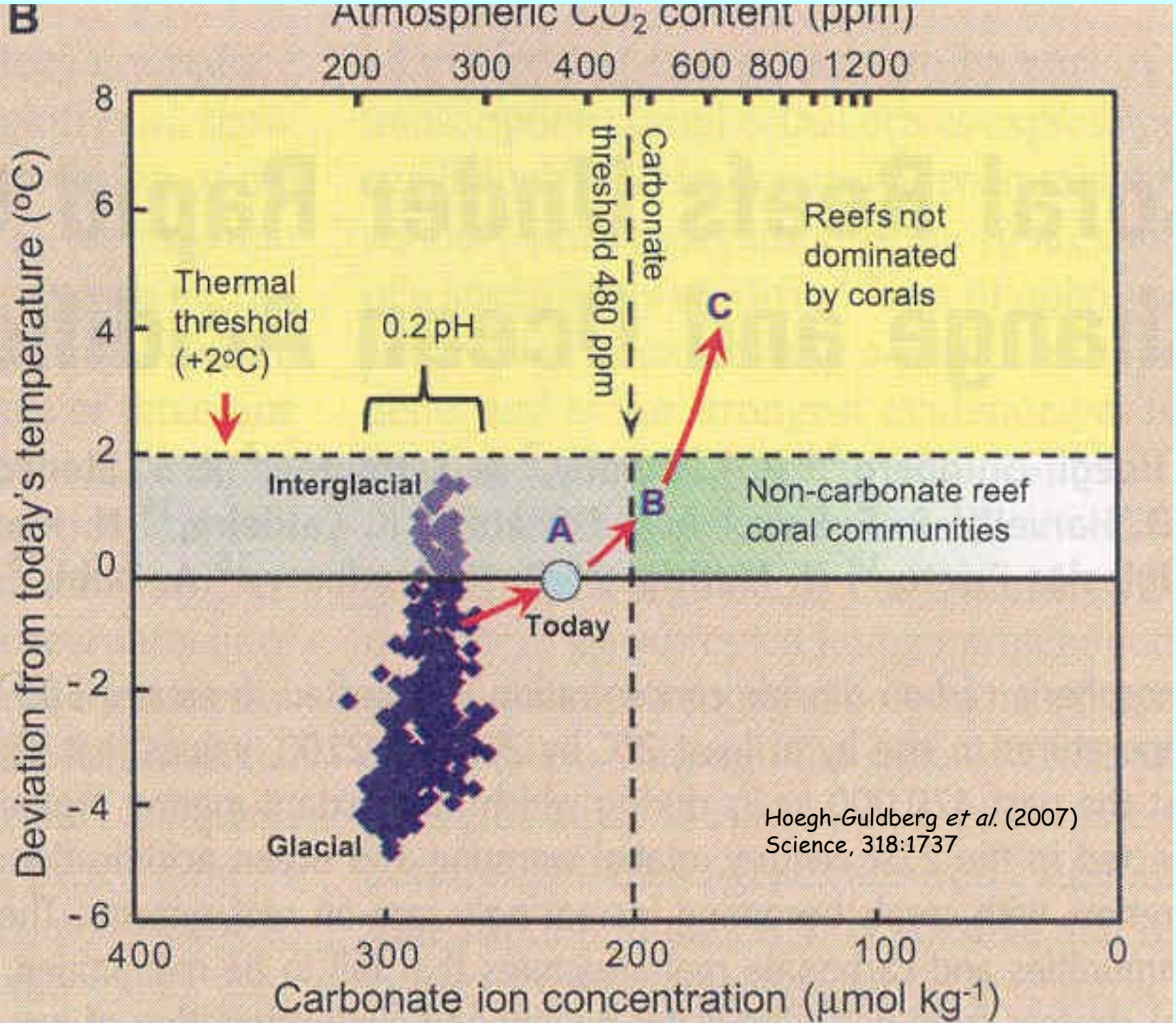
Δ pH = - 0.5 means $[H^+]$ *Triples,* & much of the subpolar ocean surface becomes undersaturated

Caldeira & Wickett, Nature, 2003

Projected Aragonite Surface Saturation, 2100 (IS92a)



Orr et al. Science 2005



Hoegh-Guldberg *et al.* (2007) Science, 318:1737

Thanks for Your Attention!

For more Information, Contact:

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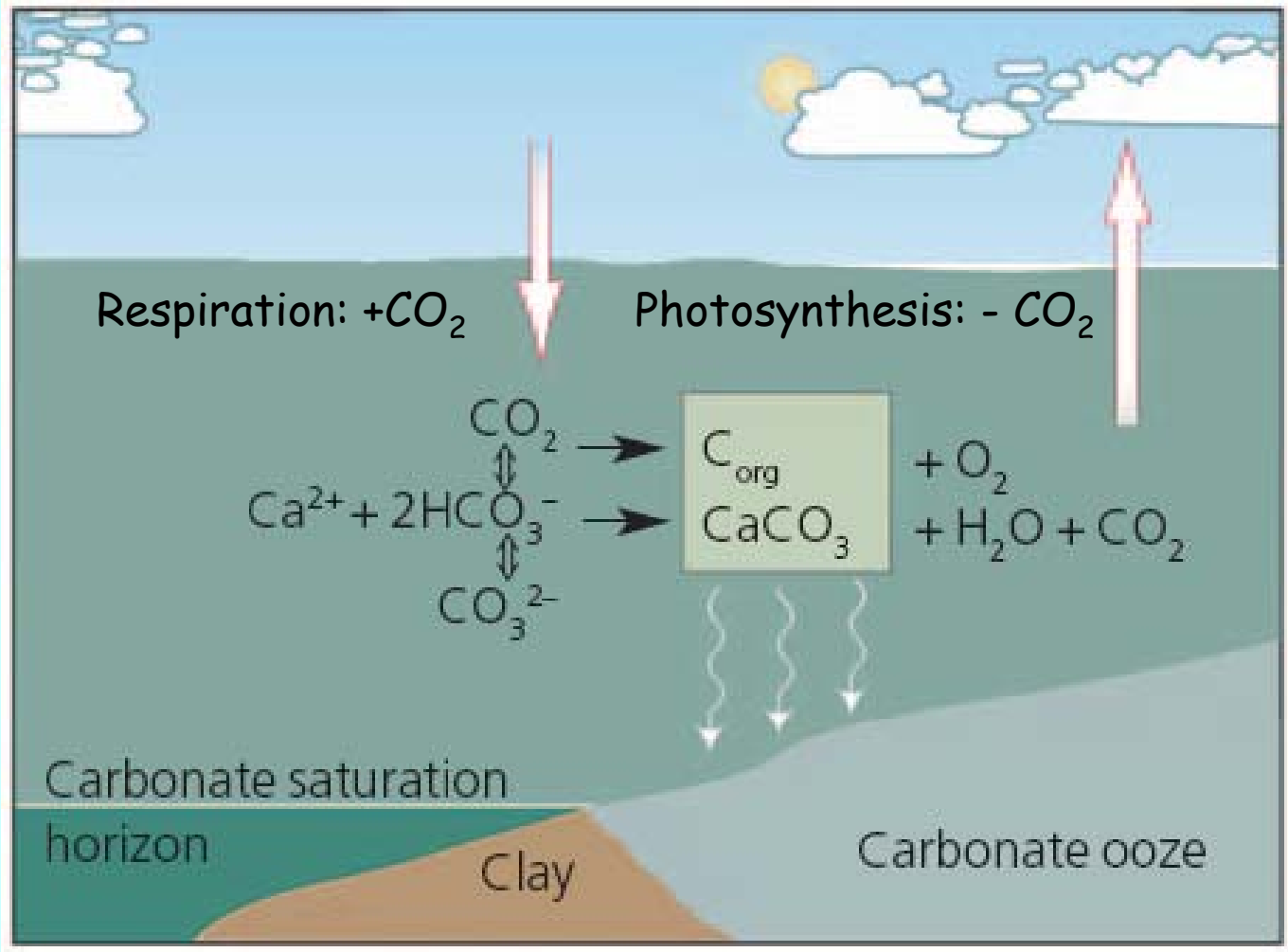
The "Biological Pump"

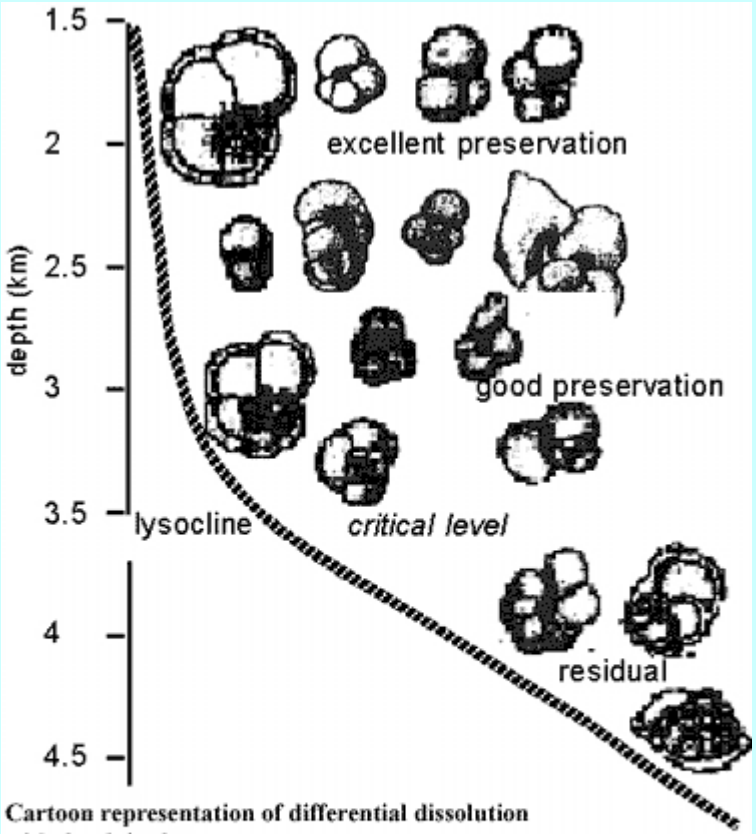


Royal Society UK 2005

$CaCO_3$ Stability vs Seawater Depth

$CaCO_3$ Begins to Dissolve at the "lysocline", about 3 – 4 km deep

$CaCO_3$ is always dissolved below the "Compensation Depth"



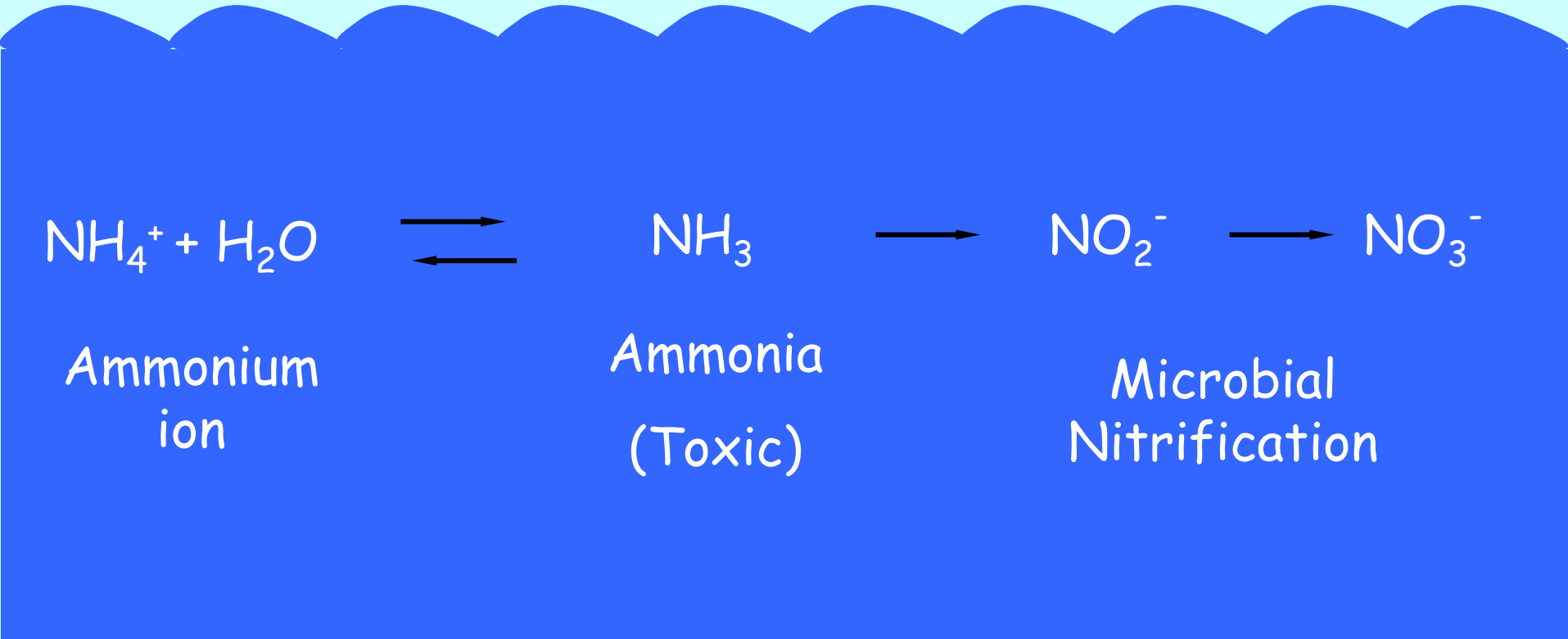
Cartoon representation of differential dissolution with depth in the ocean. At shallower depths, usually <3000 m, planktonic foraminiferal tests are well preserved in the sediment. Below the lysocline, preservation rapidly deteriorates with depth. Below the CCD, tests are not preserved.

U. Puerto Rico - Mayaguez

Altered Nutrient Cycling:

At pH 8.1, $[NH_3]/[NH_4^+] = 0.072$

At pH 7.8, $[NH_3]/[NH_4^+] = 0.036$



Food Web Disruption

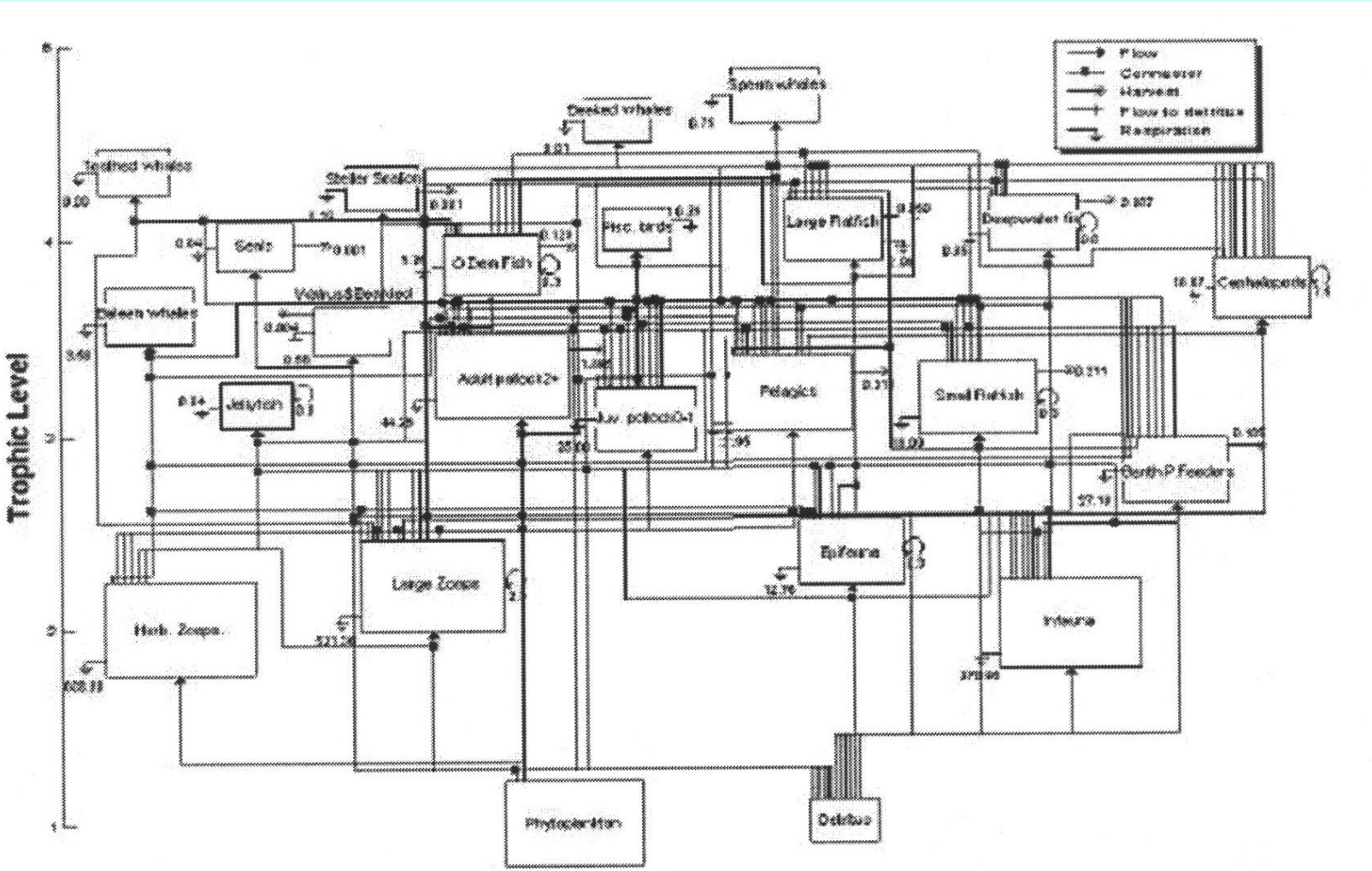


Fig. 2. Flowchart of trophic interactions in the eastern Bering Sea during the 1980s. All flows are in t•km^{-2} year^{-1}. Minor flows are omitted as are all backflows to the detritus. The size of each box is roughly proportional to the biomass therein.