ECOSYSTEMS BIOLOGY – GLOBAL ISSUES

DKN

How have microbes impacted large scale biogeochemical cycles?

How does microbial metabolism change the game so dramatically?

How could microbes impact future global climate change?

*Break – short movie*

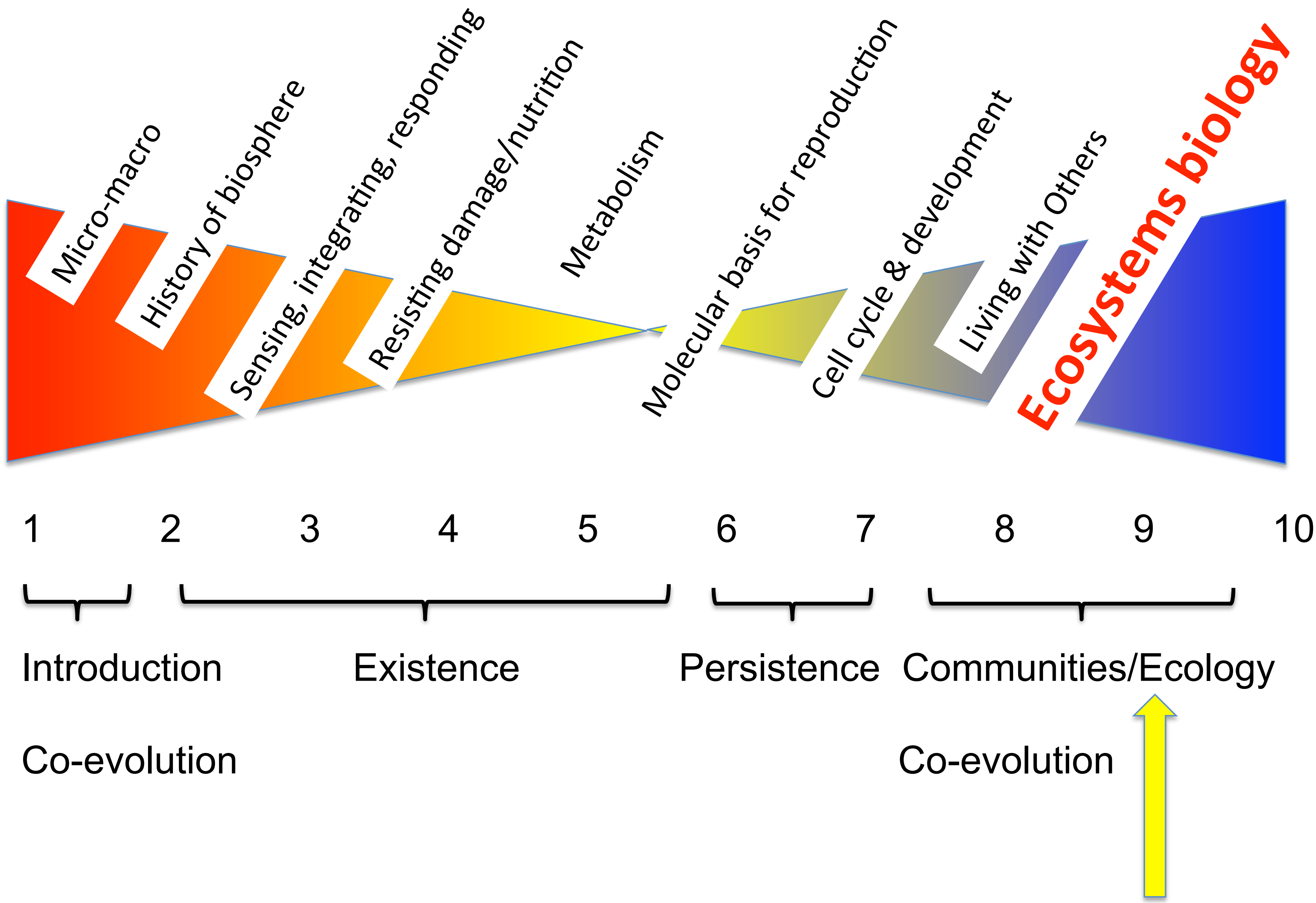
MMN – A case study

What are the constraints on the form, function and distribution of coral reefs?

How are global, anthropogenic environmental changes affecting the health of the world’s coral reef habitats?

iClicker quizzes

Where have we been, where are we, and where are we going?

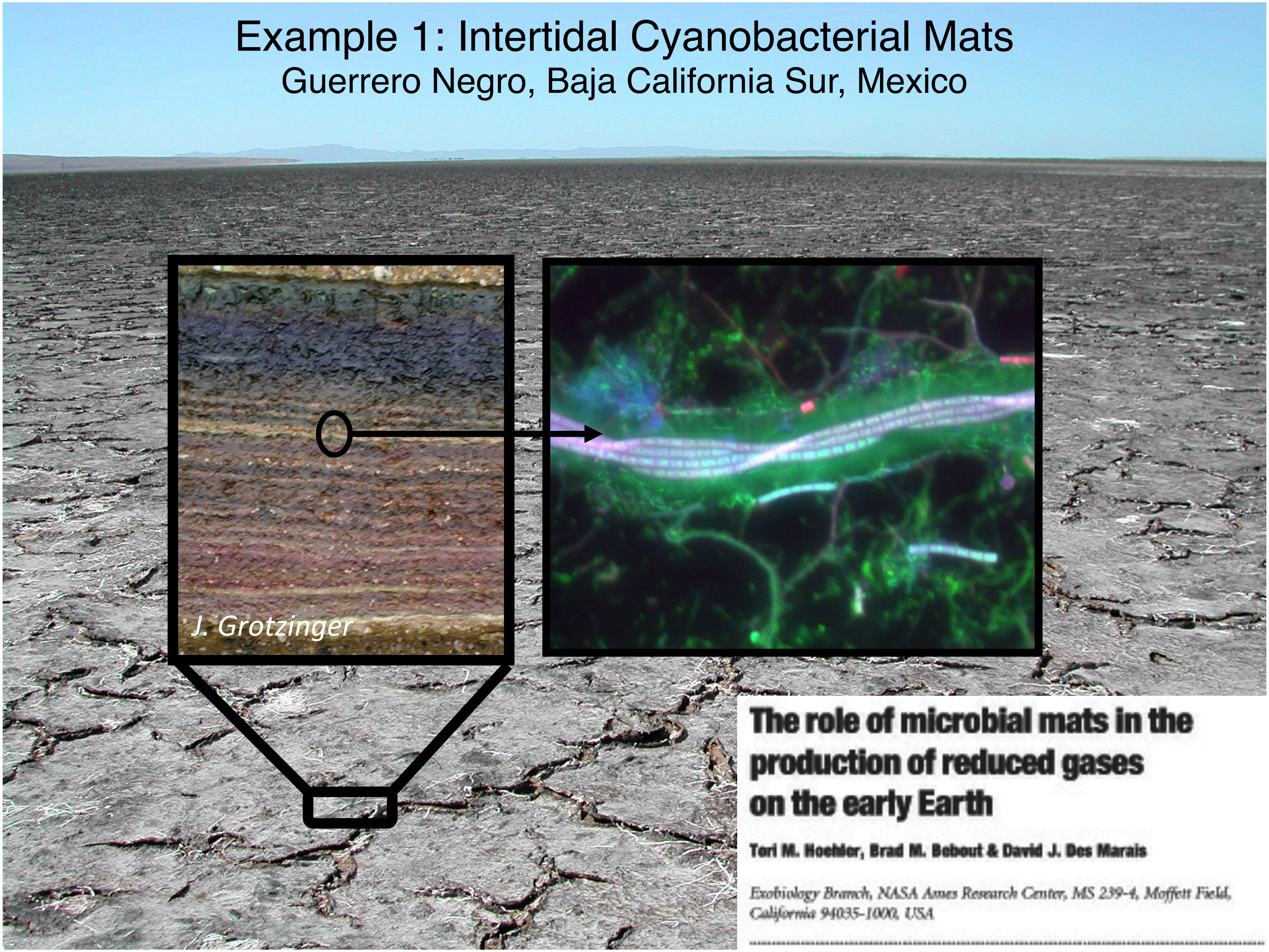


# How have microbes impacted large scale biogeochemical cycles?

- Example 1 – Microbial mats and the atmosphere
- Example 2 – Evolution of photosynthesis and ore deposits
- Example 3 – The biological pump in the oceans sequesters carbon (which affects our atmosphere)

# Example 1: Intertidal Cyanobacterial Mats

## Guerrero Negro, Baja California Sur, Mexico

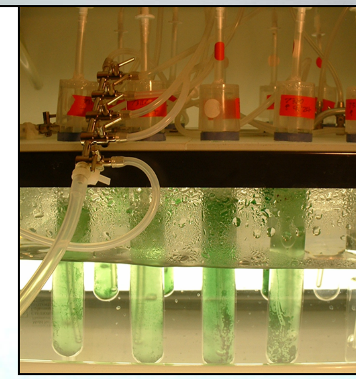



**The role of microbial mats in the production of reduced gases on the early Earth**

**Tori M. Hoehler, Brad M. Bebout & David J. Des Marais**

*Exobiology Branch, NASA Ames Research Center, MS 239-4, Moffett Field, California 94035-1000, USA*

# Example 2: Banded Iron Formations



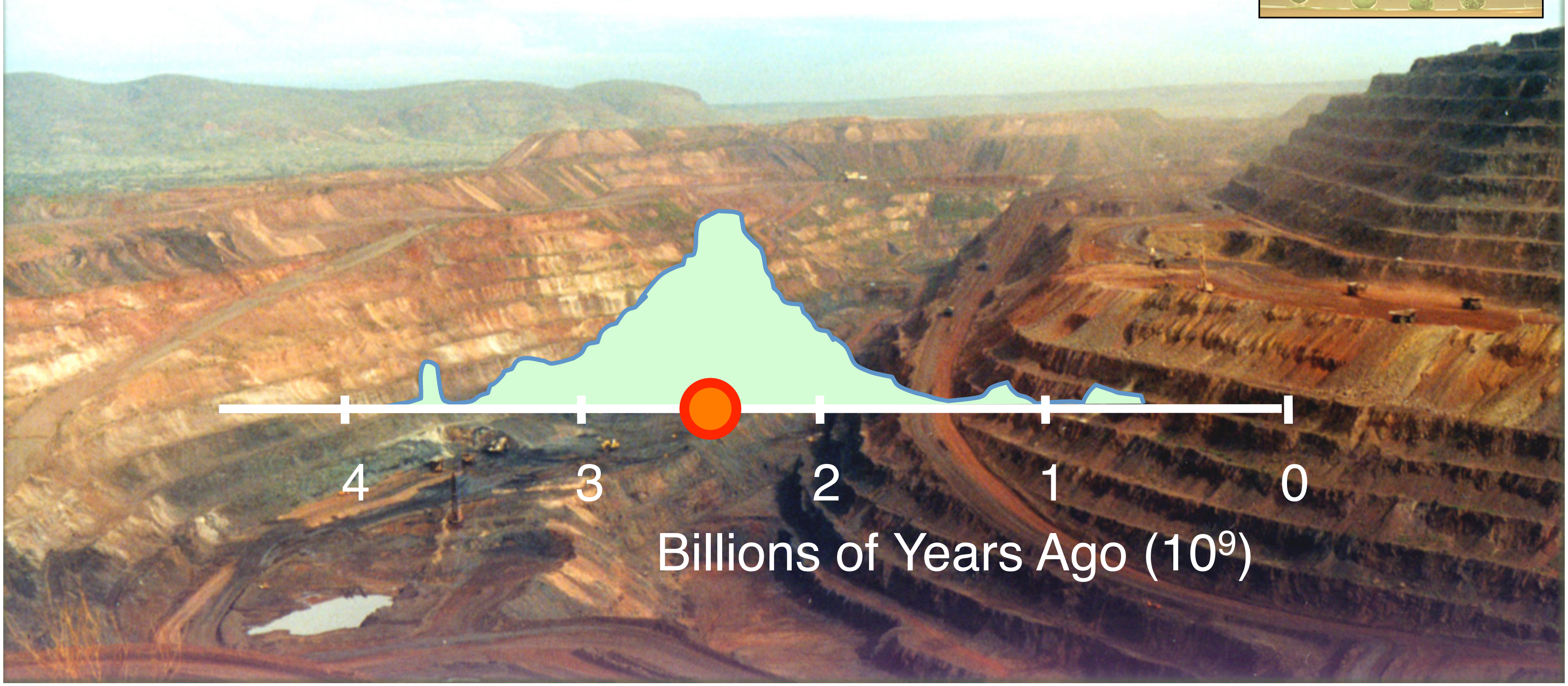
Scenario 1 (*anoxygenic photosynthesis*):

$4Fe^{2+} + CO_2 + 4H^+ = 4Fe^{3+} + CH_2O + H_2O$

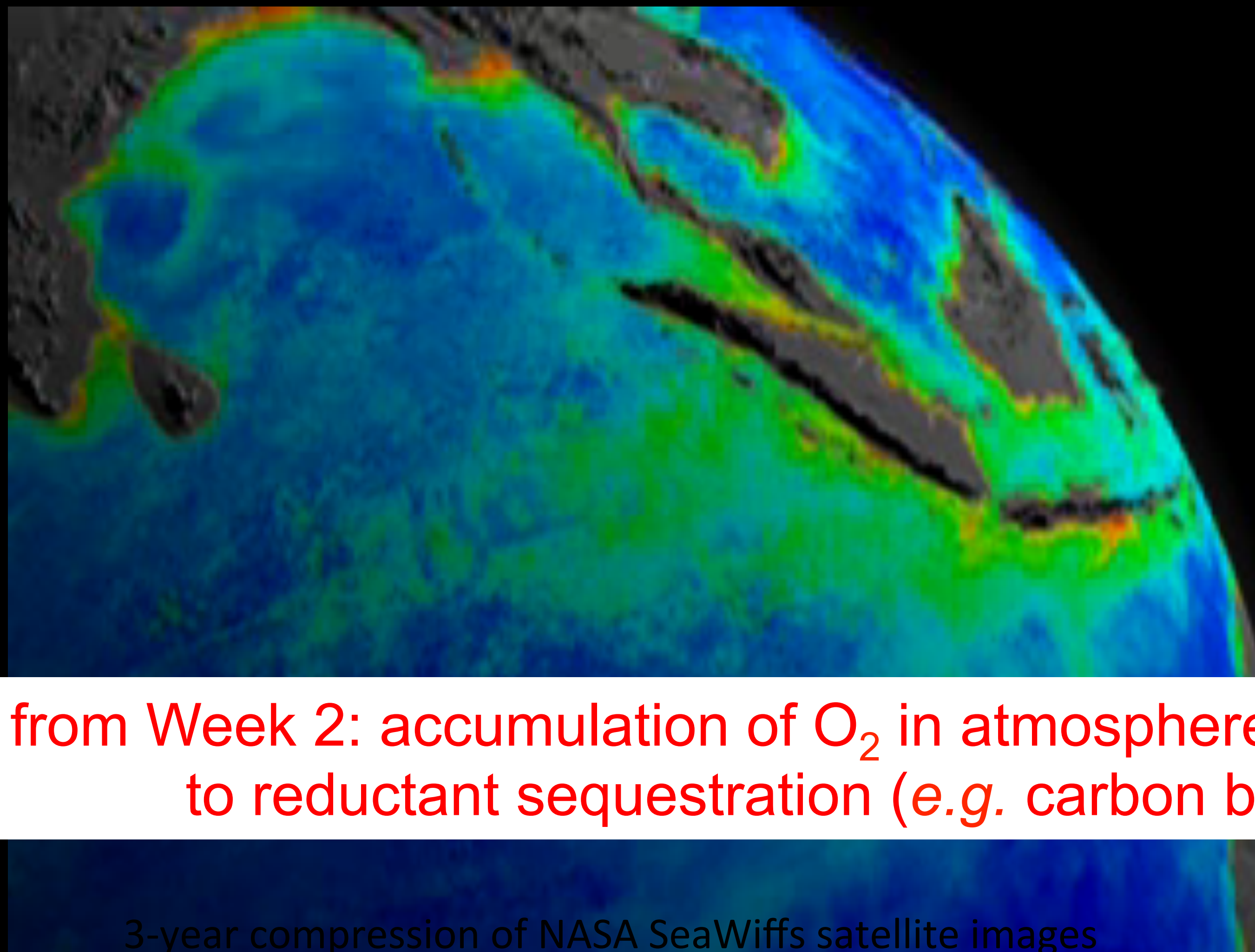
Scenario 2 (*oxygenic photosynthesis*):

i.) $H_2O + CO_2 = CH_2O + O_2$

ii.) $4Fe^{2+} + O_2 + 4H^+ = 4Fe^{3+} + 2H_2O$



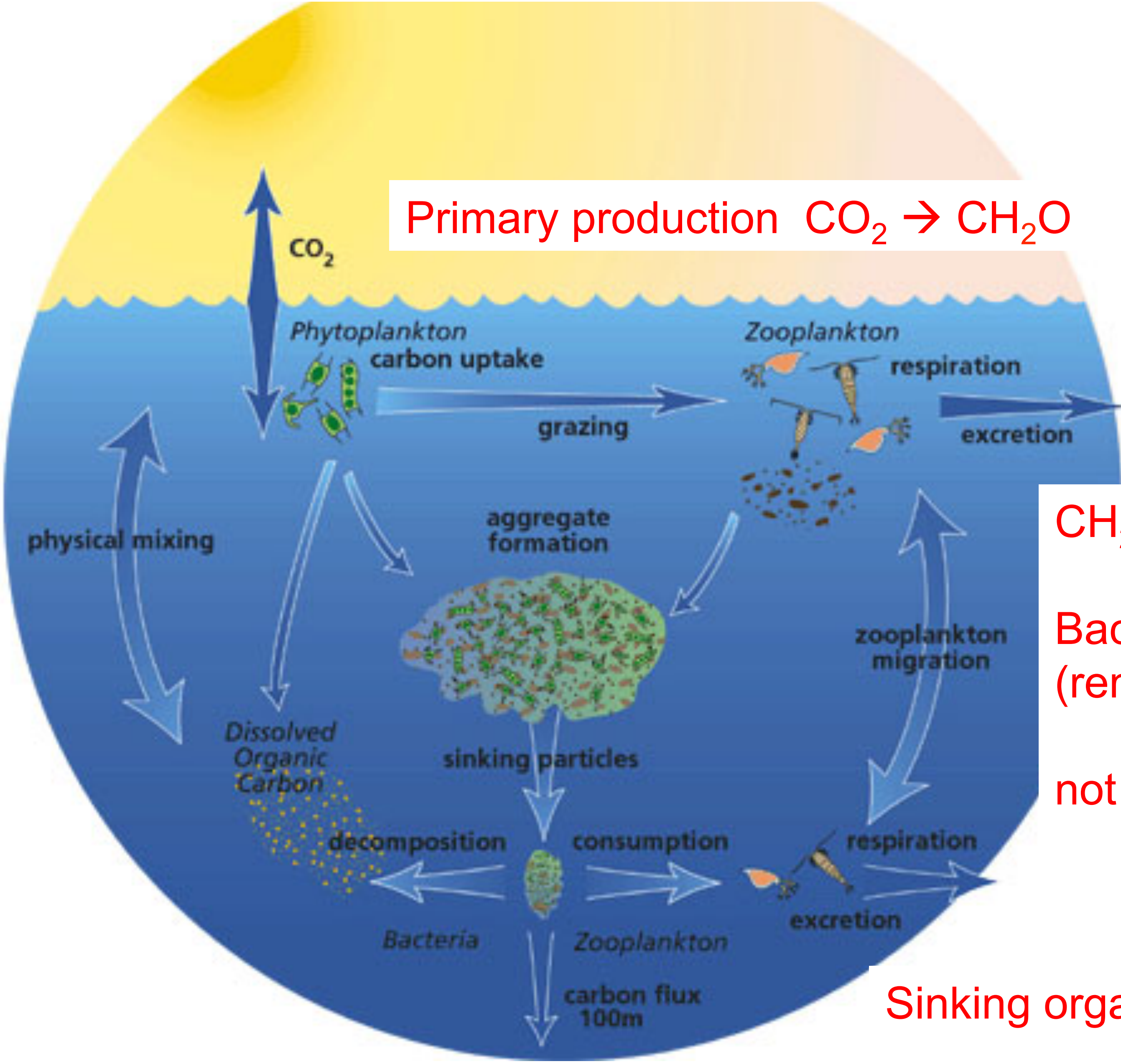
Example 3: atmospheric $O_2$ produced (and maintained at high levels) by marine phytoplankton and the “biological pump”



Recall from Week 2: accumulation of $O_2$ in atmosphere due to reductant sequestration (*e.g.* carbon burial!)

3-year compression of NASA SeaWiffs satellite images

What is the BIOLOGICAL PUMP?



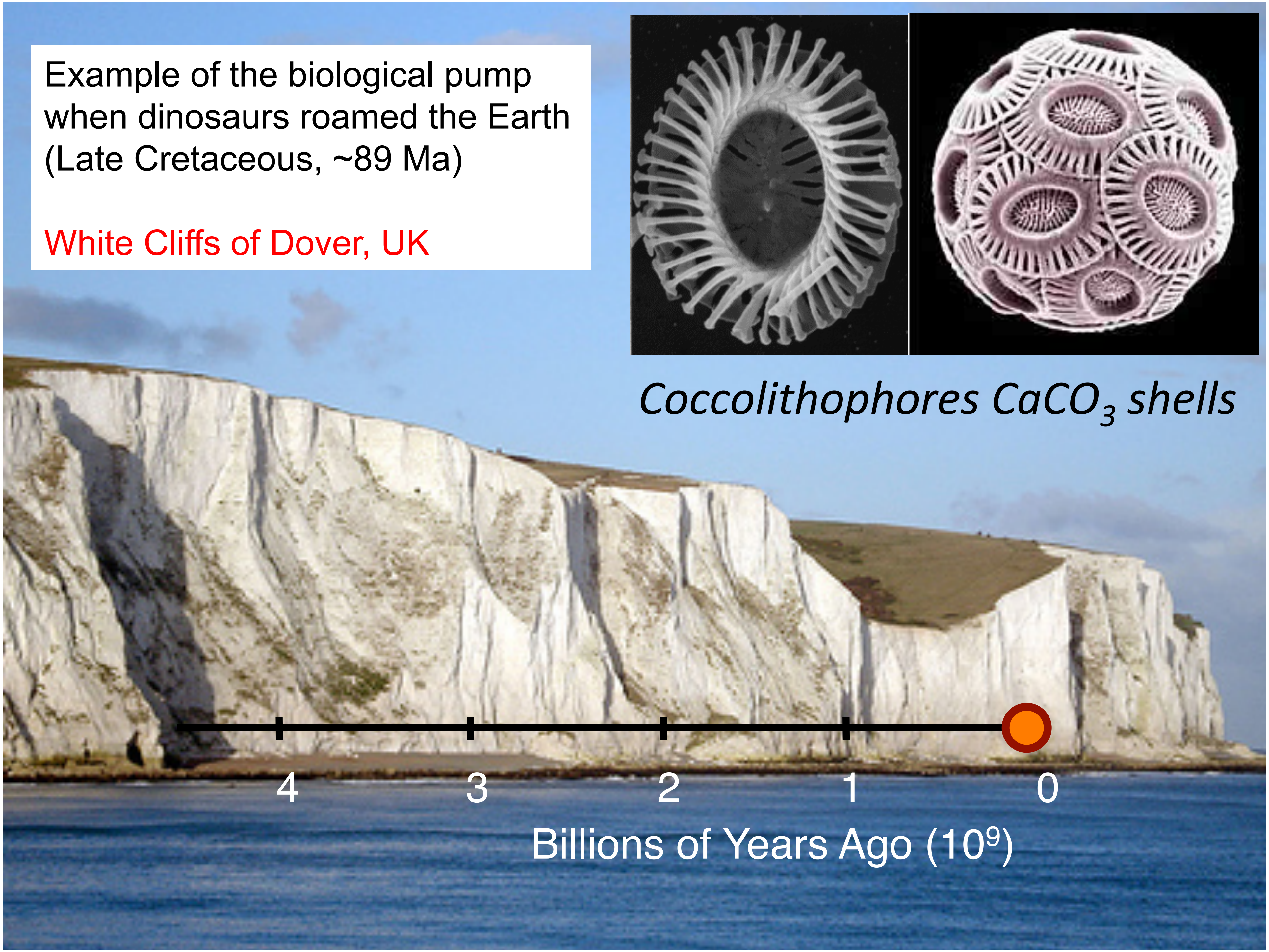

Primary production $CO_2 \rightarrow CH_2O$

$CH_2O \rightarrow CO_2$

Bacterial decay (remineralization)

not 100% efficient

Sinking organic matter, burial


Example of the biological pump
when dinosaurs roamed the Earth
(Late Cretaceous, ~89 Ma)
White Cliffs of Dover, UK
Coccolithophores $CaCO_3$ shells
4
3
2
1
0
Billions of Years Ago ($10^9$)

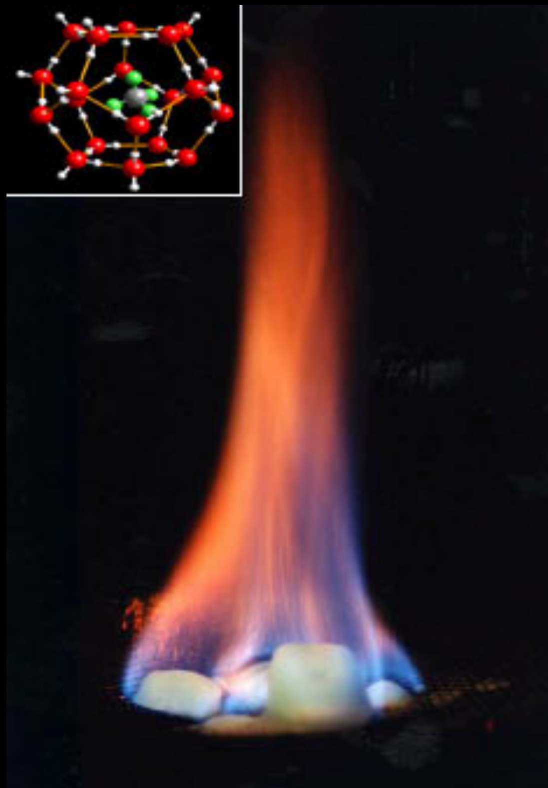
# How does microbial metabolism change the game so dramatically?

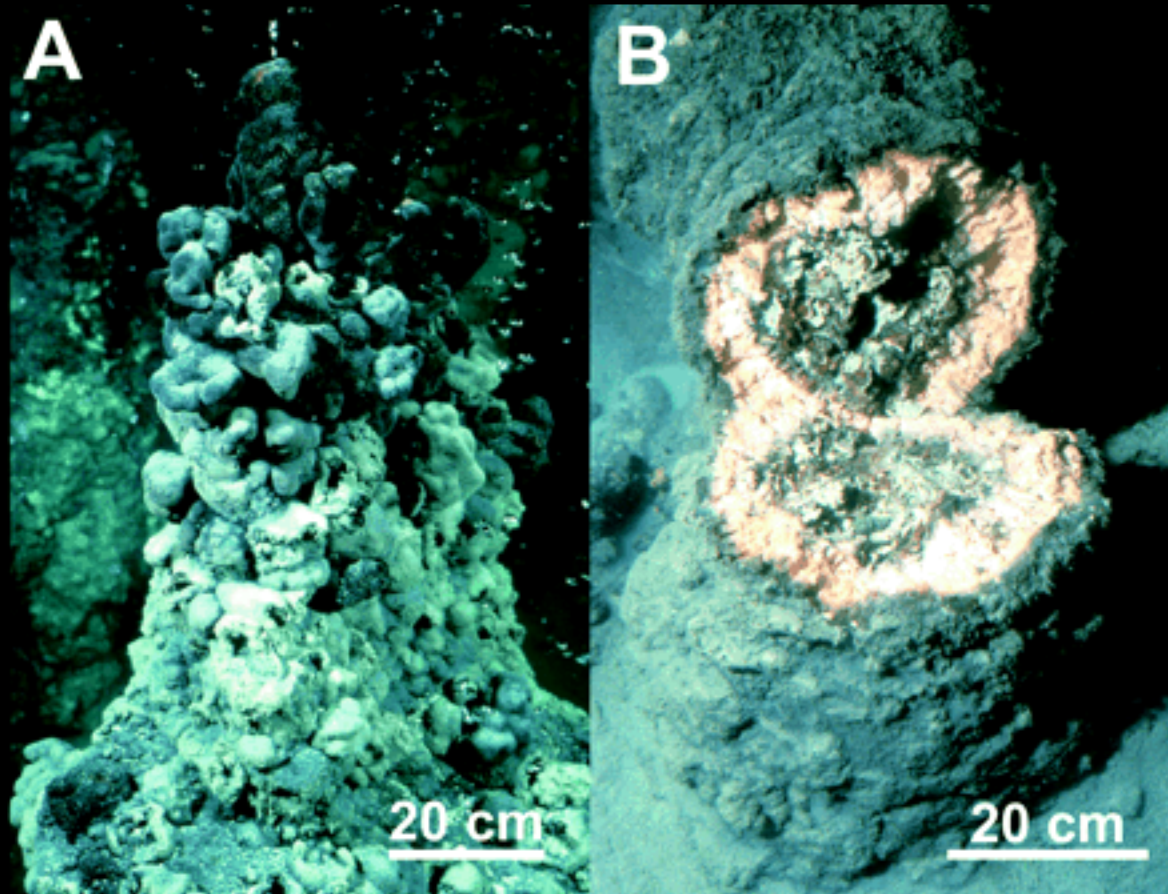
*(a.k.a. thermodynamic and kinetic underpinnings)*

Example: AOM – primary production in the dark (chemoautotrophy)

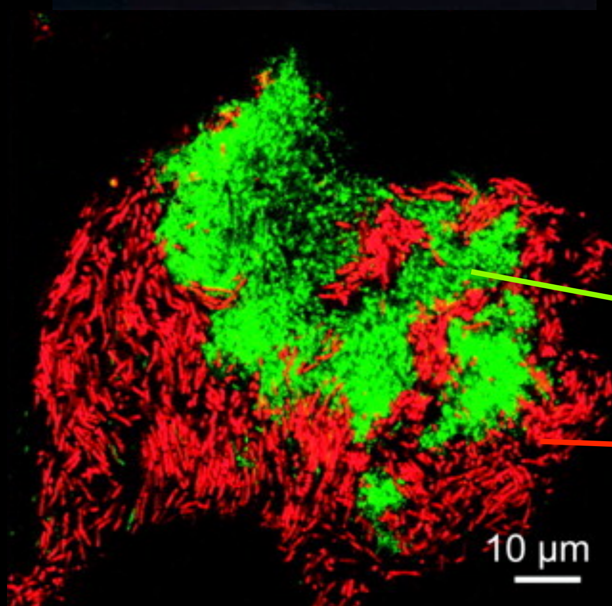
→ 90% methane (greenhouse gas) originating from marine sediments is oxidized by AOM

→ $CaCO_3$ reef formation bottom of Black Sea






$$CH_4 + SO_4^{2-} + Ca^{2+} = CaCO_3 + H_2S + H_2O$$




Sulfate reducing bacteria

ANME-1

Michaelis *et al.*, Science *2002*

# REVIEW

Catabolic redox reaction:

$A_{red} + B_{ox} = A_{ox} + B_{red}$

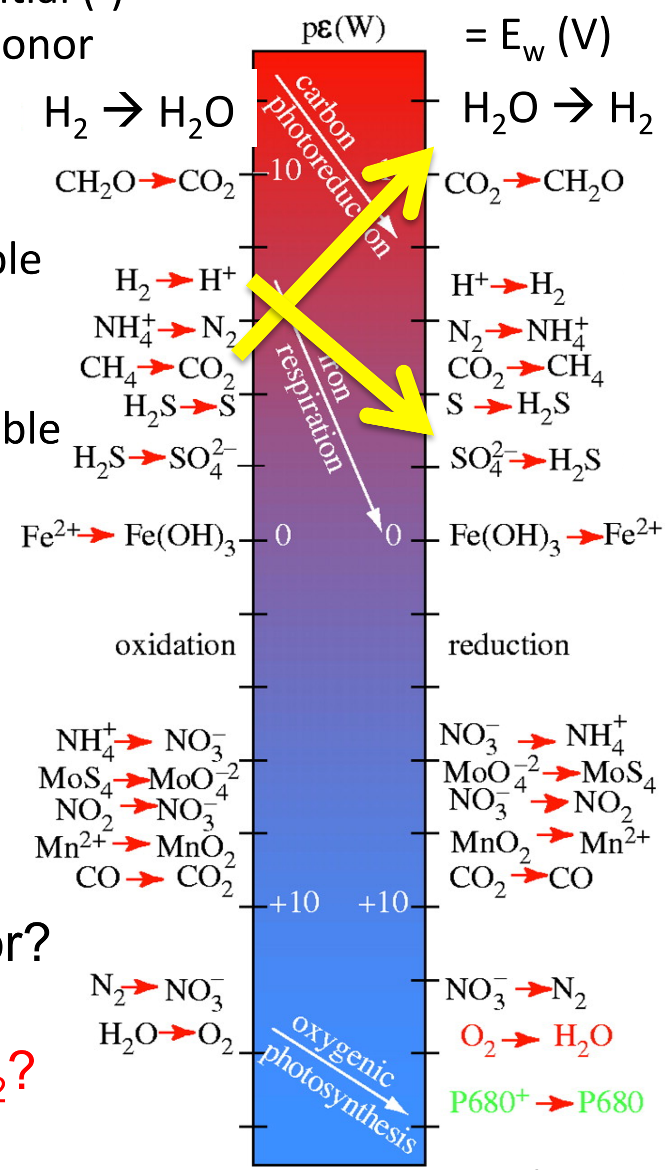
$\Delta G = -nF\Delta E$ (kJ)

n = number of $e^-$ transferred
F = Faraday constant
$\Delta E$ = difference in redox potential

Low potential (-)
Electron donor
reductant

Uphill unfavorable
($\Delta G$ -)

Downhill favorable
($\Delta G$ +)




High potential (+)
Electron acceptor
oxidant

| | e- donor (Ared)? | e- acceptor? |
| --- | --- | --- |
| AOM: | $CH_4$ | $H_2O$? $CO_2$? |
| Sulfate reduction: | $H_2$? $CH_2O$? | $SO_4^{2-}$ |

# Calculating Gibbs Free Energy from the Mass Law

Generic reaction: A + 3B → C + D + 4E

$$\Delta G = \Delta G^{o} + 2.3RT \log \frac{[C][D][E]^4}{[A][B]^3}$$

pure solids, liquids = 1

Specific case of $H_2$-exchange:

| | | $\Delta G^o$ | $\Delta G$ |
|---|---|---|---|
| AOM: | $CH_4 + 3H_2O \rightarrow HCO_3^- + H^+ + 4H_2$ | + | - |
| SRB: | $SO_4^{2-} + 4H_2 + H^+ \rightarrow HS^- + 4H_2O$ | - | - |

Net rxn: $CH_4 + SO_4^{2-} \rightarrow HCO_3^- + HS^- + H_2O$

$$\Delta G = \Delta G^{o} + 2.3RT \log \frac{[HCO_3^-][H^+][H_2]^4}{[CH_4]}$$

→ Drive AOM rxn forward by SRB consuming $H_2$ (or other intermediate)

How does this promote reef formation?

Net AOM rxn: $CH_4 + SO_4^{2-} \rightarrow HCO_3^- + HS^- + H_2O$

Bicarb/carbonate equilibrium: $HCO_3^- \rightarrow CO_3^{2-} + H^+$

Mineral formation: $Ca^{2+} + CO_3^{2-} \rightarrow CaCO_{3\ (s)}$

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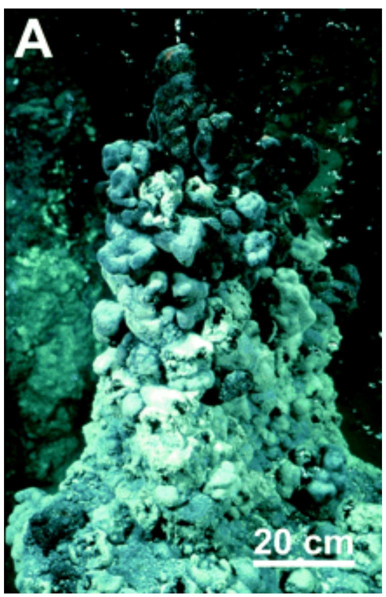



$$CH_4 + Ca^{2+} + SO_4^{2-} \rightarrow CaCO_{3\ (s)} + \underbrace{H_2S}_{HS^- + H^+} + H_2O$$

# How could microbes impact future global climate change?

- Example 1 – Marine iron fertilization experiments
- Example 2 – GAIA and the CLAW hypothesis
- Example 3 – $CO_2$ and warming of the permafrost

# Example 1: Iron fertilization experiments (Boyd et al, 2007)

- Natural
  nutrient upwelling zones, aolian dust

- Man-made (targetting HNLC regions)
-

high nutrient, low chlorophyll
→ Missing trace metals (*e.g.* Fe)
→ *cofactors in essential enzymes necessary for phytoplankton growth*

- Potential impact for climate?

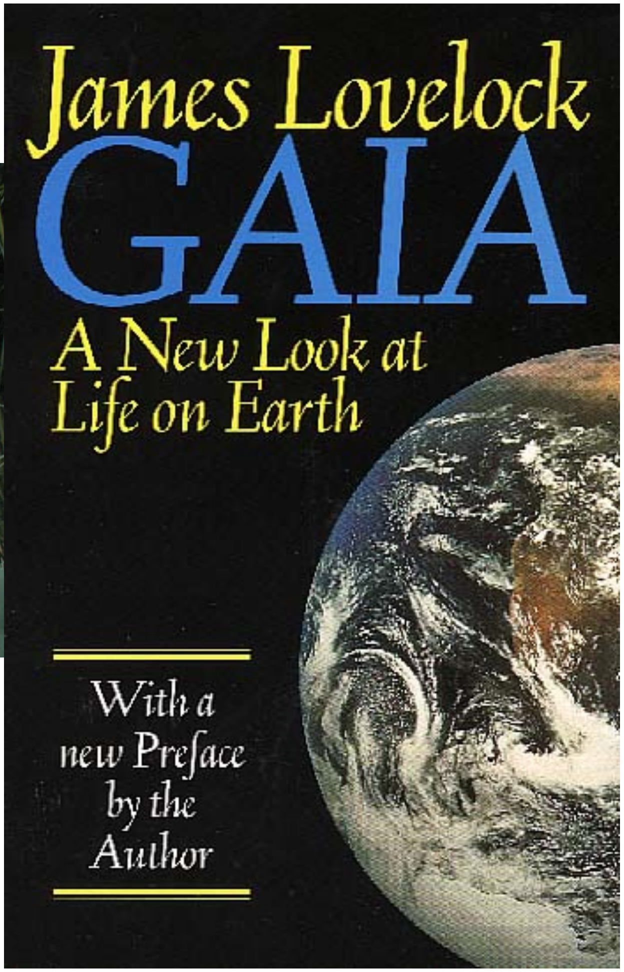
→ Draw down Atm $CO_2$
(stimulate phytoplankton growth)

Southern Ocean (HNLC)

→ But is it so simple? How else can phytoplankton affect climate?

Example 2: The GAIA hypothesis: Earth is like an organism, which maintains planetary homeostasis

*A revolutionary, but controversial idea*

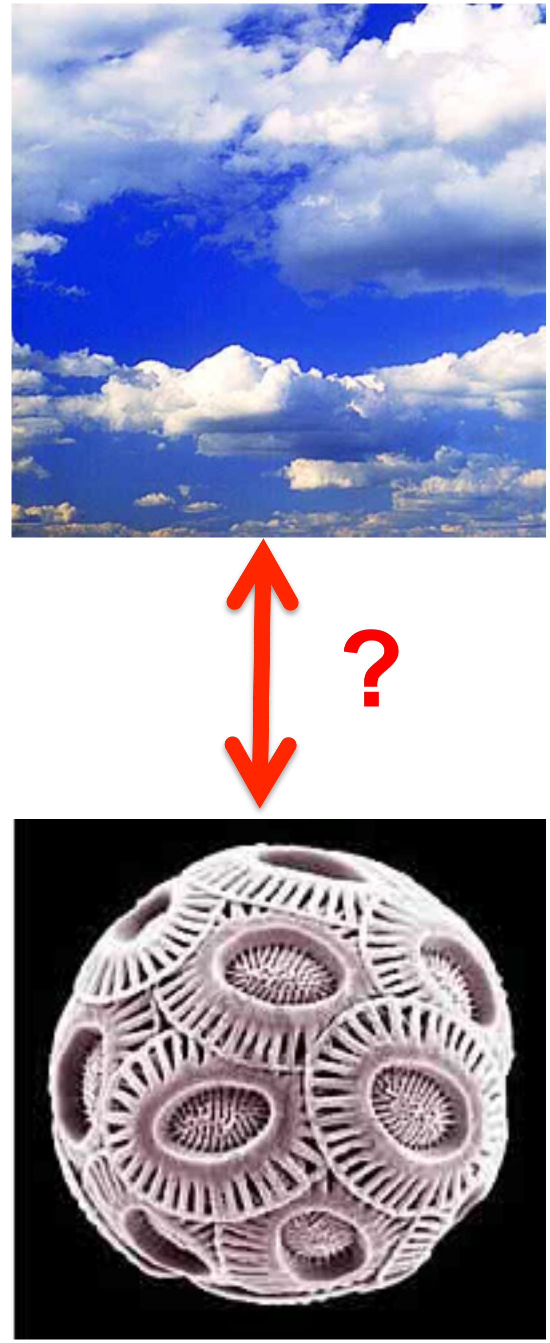


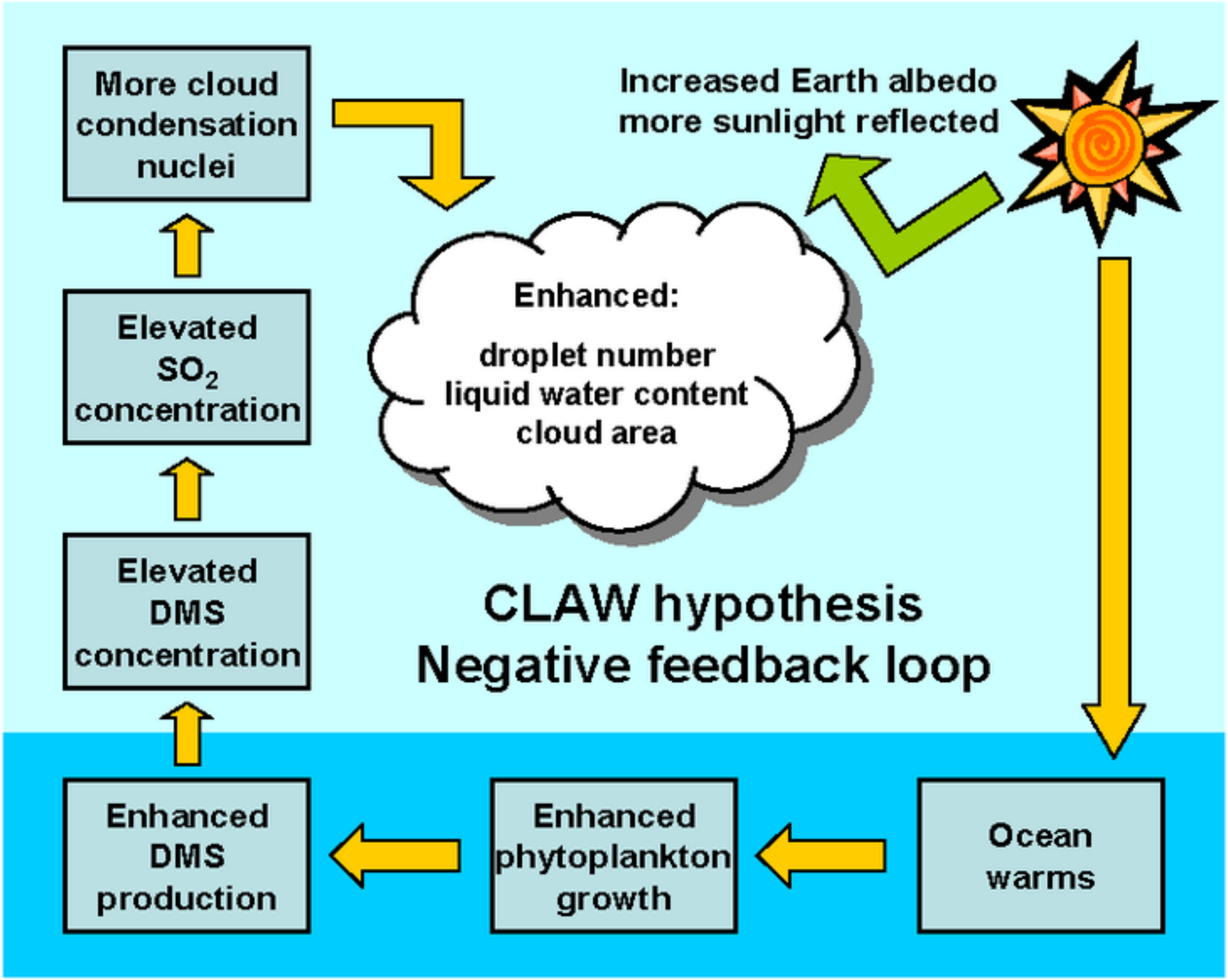

Oxford University Press, Oxford,1979

# CLAW hypothesis

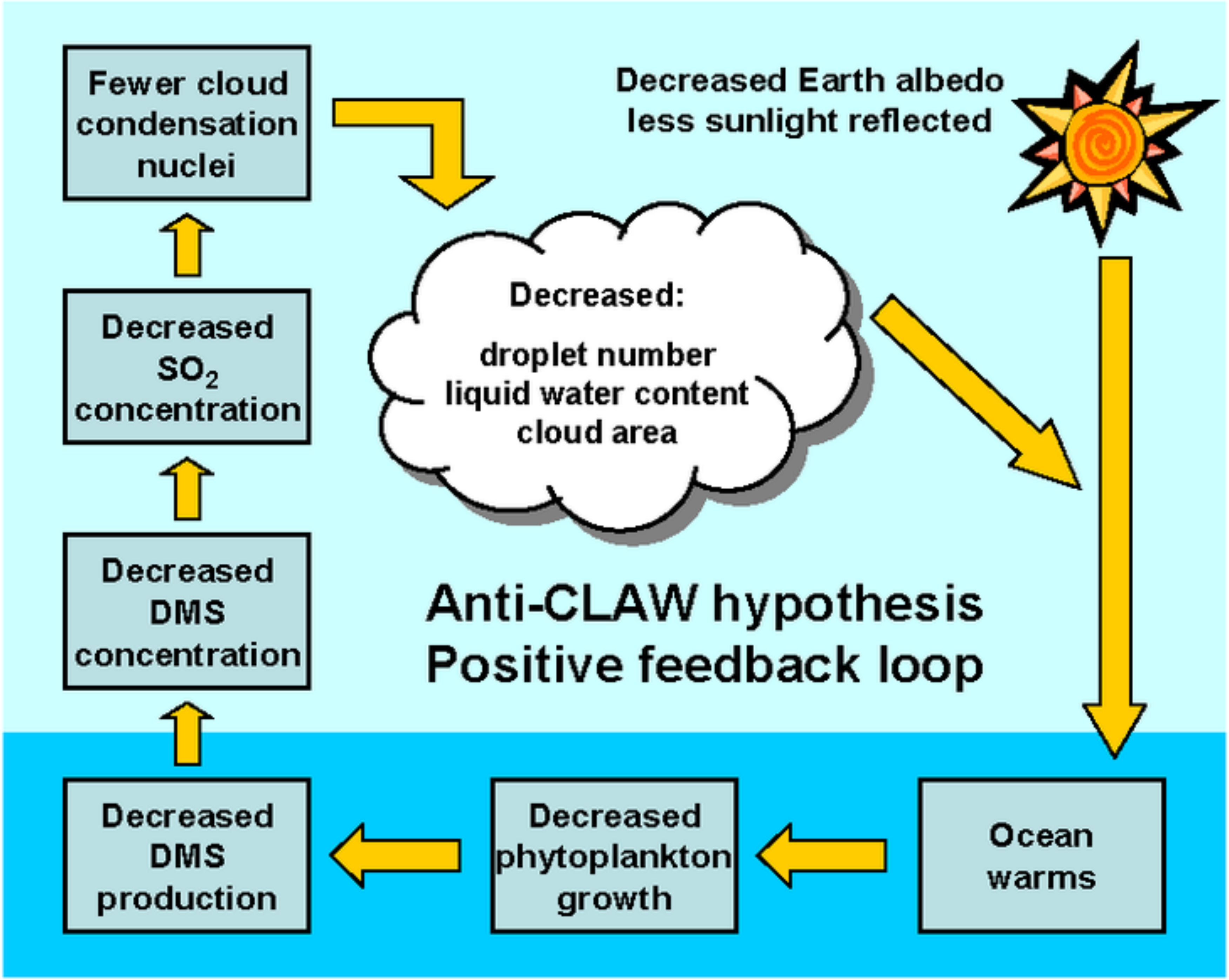
R.J. **C**harlson
J.E. **L**ovelock
M.O. **A**ndreae
S.G. **W**arren

Oceanic phytoplankton,
atmospheric sulphur,
cloud albedo and climate
*Nature* 1987



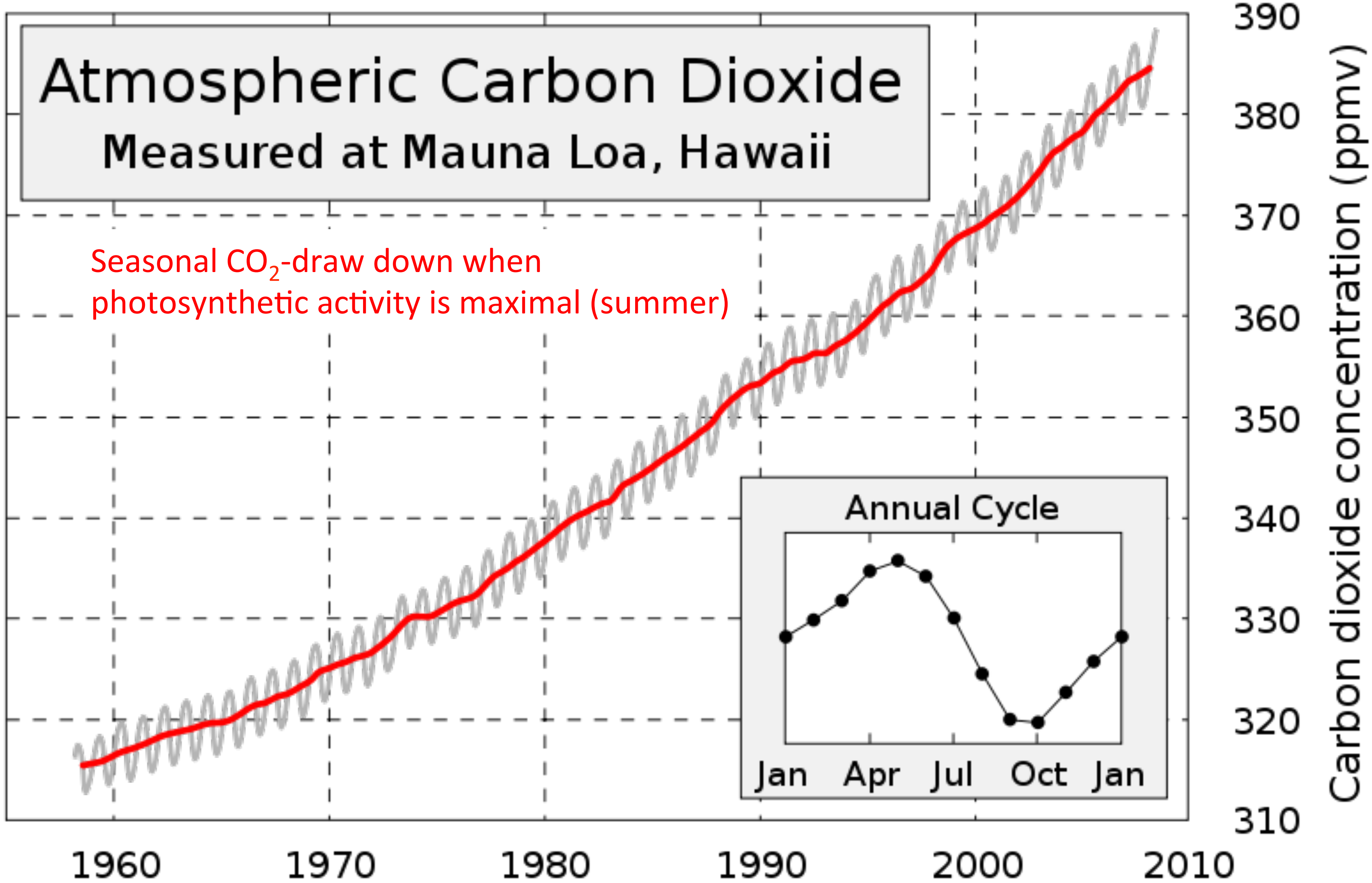


More cloud condensation nuclei
Increased Earth albedo more sunlight reflected
Elevated $SO_2$ concentration
Enhanced:
droplet number
liquid water content
cloud area
Elevated DMS concentration
CLAW hypothesis
Negative feedback loop
Enhanced DMS production
Enhanced phytoplankton growth
Ocean warms

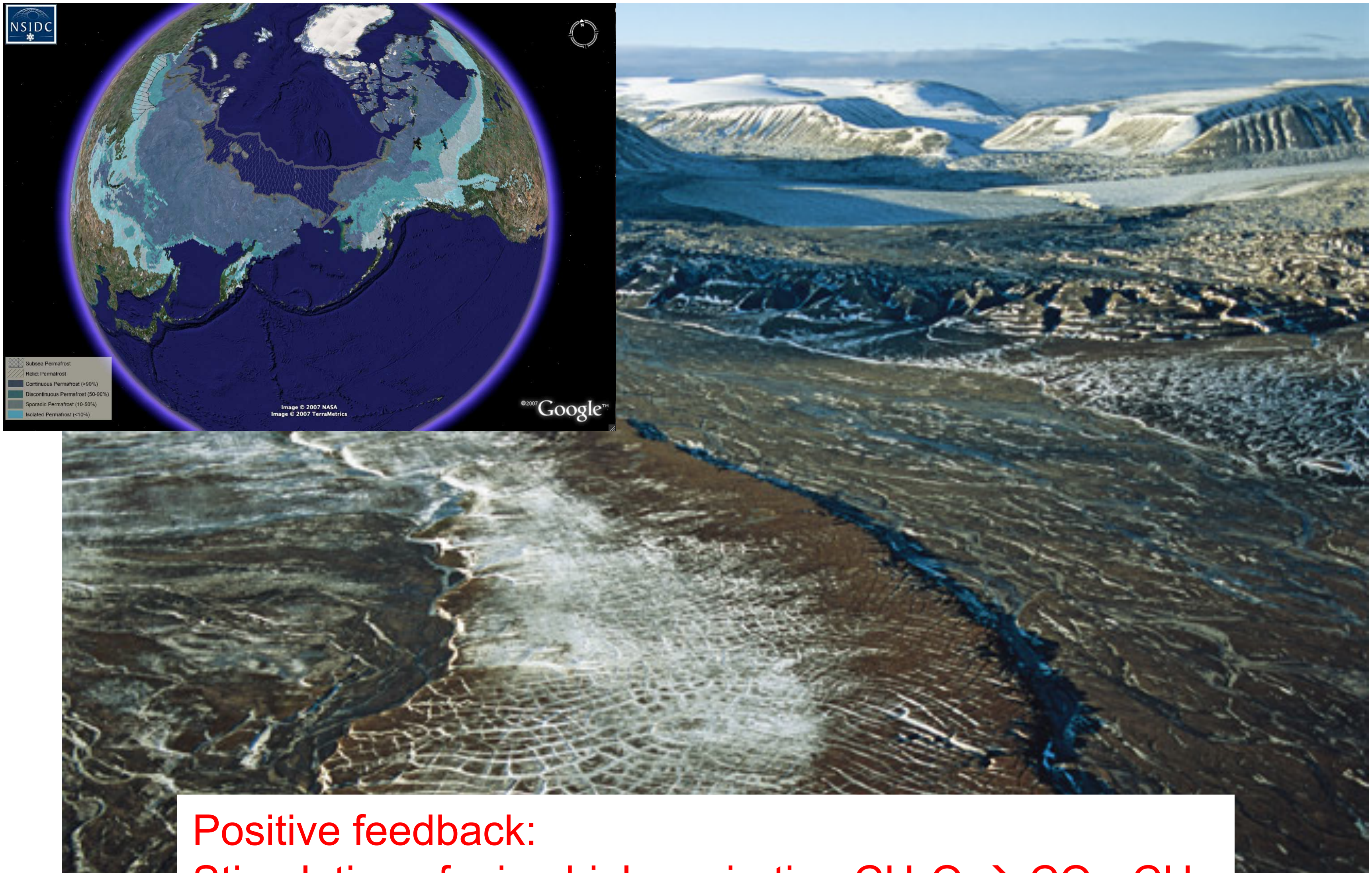

Fewer cloud condensation nuclei
Decreased $SO_2$ concentration
Decreased DMS concentration
Decreased DMS production
Decreased phytoplankton growth
Ocean warms
Decreased Earth albedo
less sunlight reflected
Decreased:
droplet number
liquid water content
cloud area
Anti-CLAW hypothesis
Positive feedback loop

→The take-home message is that complex feedback loops are at play that complicate our ability to predict!

# Example 3: Rising atmospheric $CO_2$, The Keeling Curve



What do you think will happen when permafrost at high latitudes warms?




Positive feedback:
Stimulation of microbial respiration $CH_2O \rightarrow CO_2$, $CH_4$
Release of greenhouse gases will promote warming

ECOSYSTEMS BIOLOGY – GLOBAL ISSUES

How have microbes impacted large scale biogeochemical cycles?
*The have shaped all aspects of the planet throughout Earth history, from the atmosphere to the oceans to the lithosphere.*

How is it that microbial metabolism changes the game so dramatically?
*By altering local conditions such that processes become favorable that otherwise would not be (either thermodynamically or kinetically).*

What do we need to think about when debating options for controlling global climate change?
*Biogeochemical cycles are highly complex and difficult to predict without knowing all the feedback-loops! "Geoengineering" is a VERY DANGEROUS GAME. Our understanding of these systems isn't good enough yet to roll the dice.*

ECOSYSTEMS BIOLOGY – GLOBAL ISSUES

DKN

How have microbes impacted large scale biogeochemical cycles?

How is it that microbial metabolism changes the game so dramatically?

What do we need to think about when debating options for controlling global climate change?

Break

MMN – A case study

What are the constraints on the form, function and distribution of coral reefs?

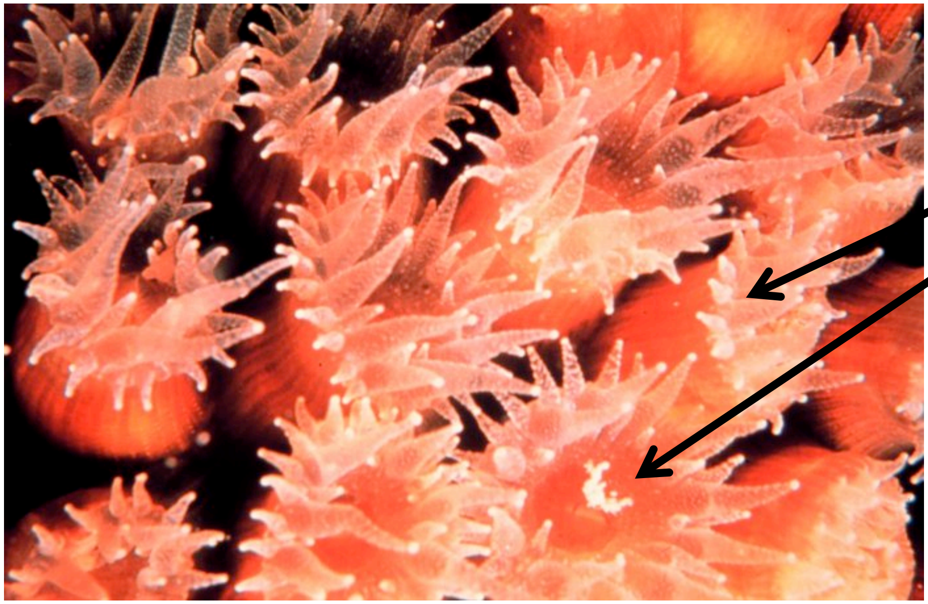
How are global, anthropogenic environmental changes affecting the health of the world's coral reef habitats?

iClicker quizzes

One system dramatically affected by anthropogenic activity

CORAL REEFS: Canary in the Coalmine

Colony



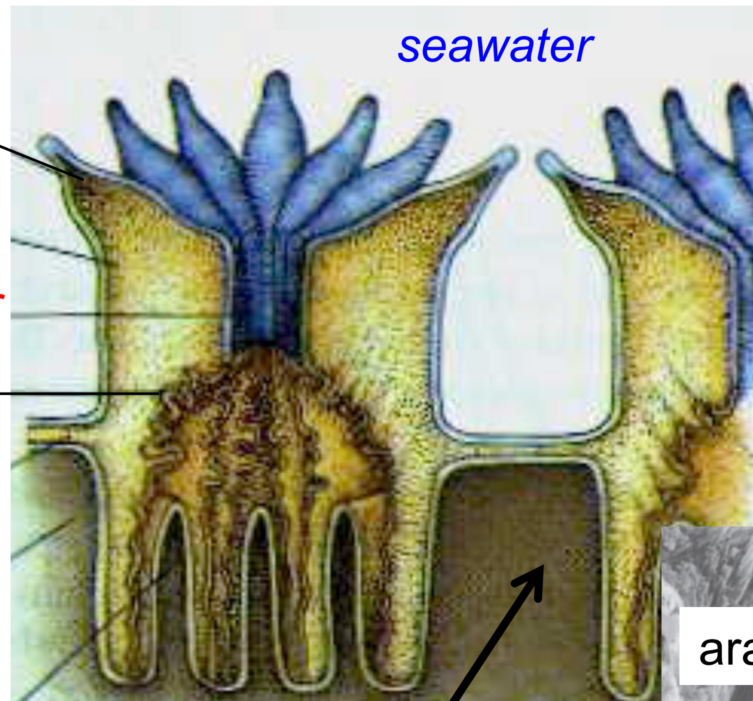
**Individual animals of the clone derived from asexual reproduction**

CORALS ALSO HAVE
SEXUAL REPRODUCTION

Coral – solitary or colonial animal with two tissue layers

1) interfaces with environment/secretes <u>exo</u>skeleton

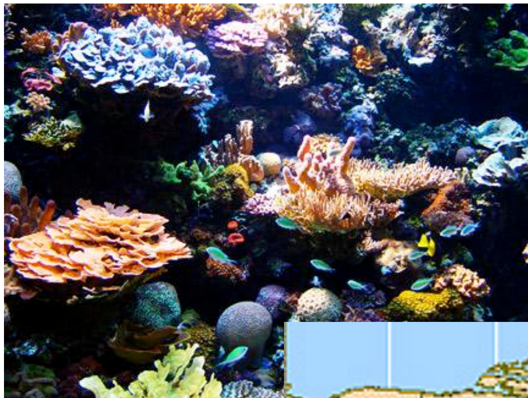
2) interfaces with 'gut' cavity



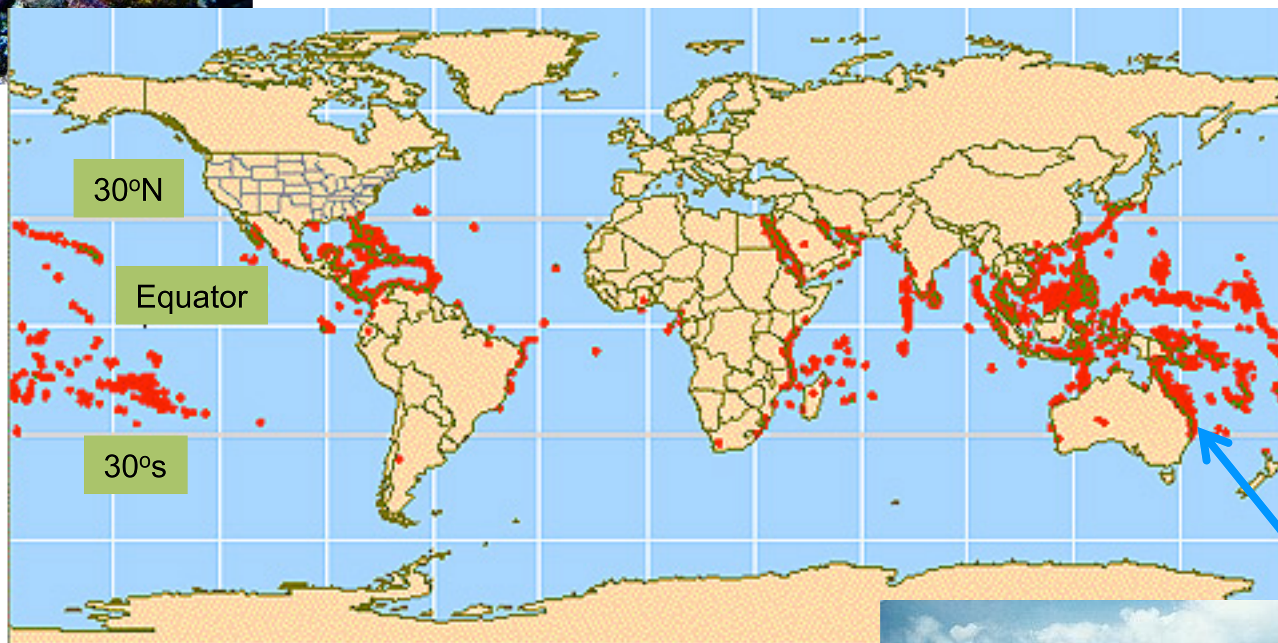


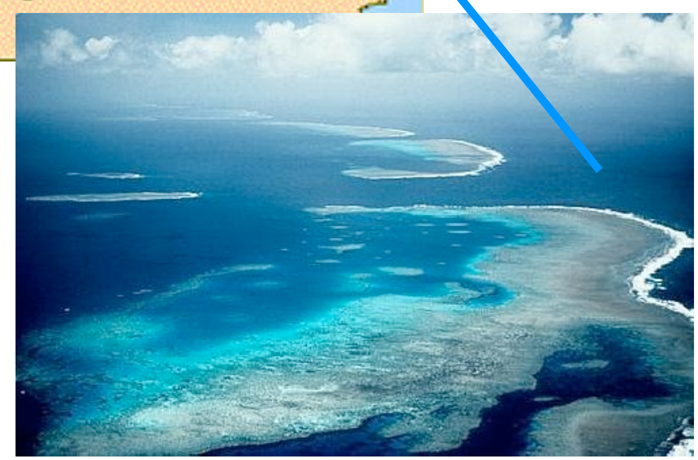
$$\xleftarrow{\text{low pH}} \quad \xrightarrow{\text{high pH}}$$

$$\boxed{Ca^{2+} + 2HCO_3^- <=> CaCO_3 + CO_2 + H_2O}$$



Coral reefs are large marine features restricted to 30ºN and 30ºS of the equator



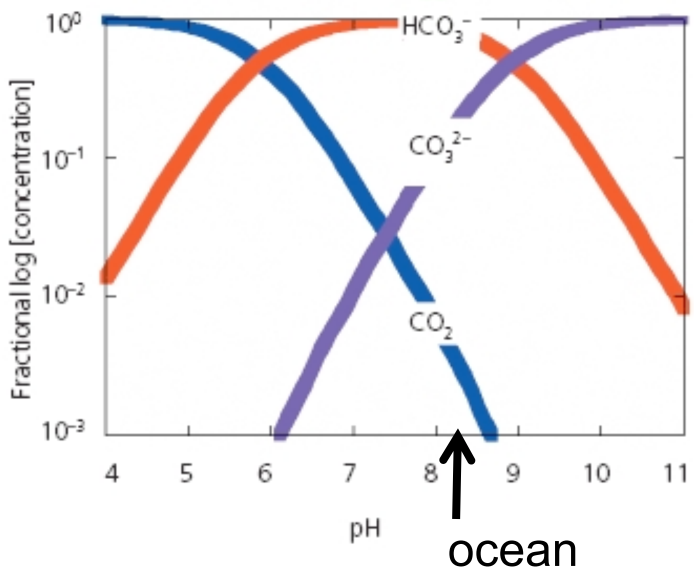
Great Barrier Reef
stretches 2600 km off of the east coast of Australia

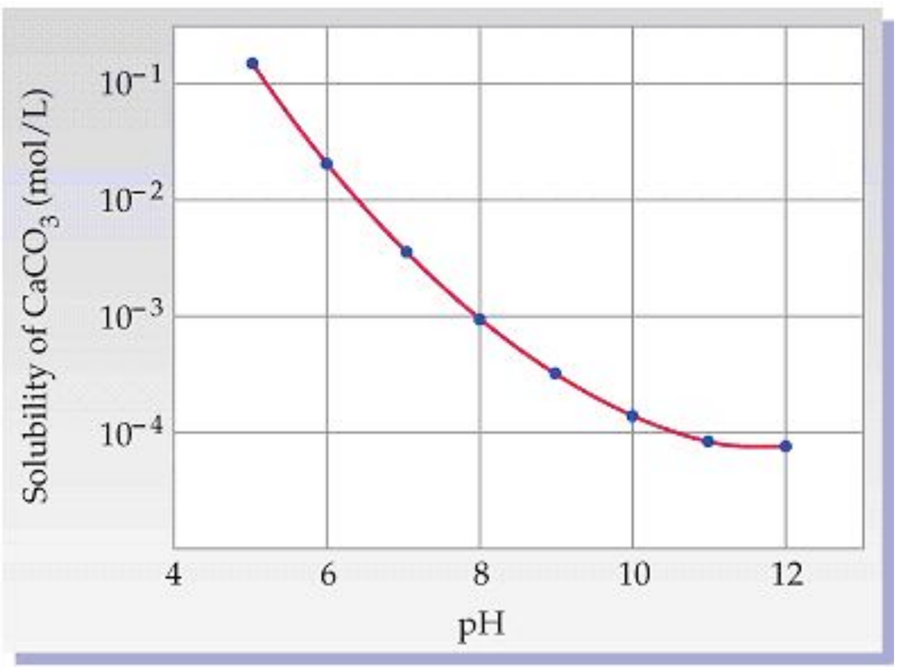
Largest single structure made from living organisms

Some non-reef-building corals of
Southern California

1cm

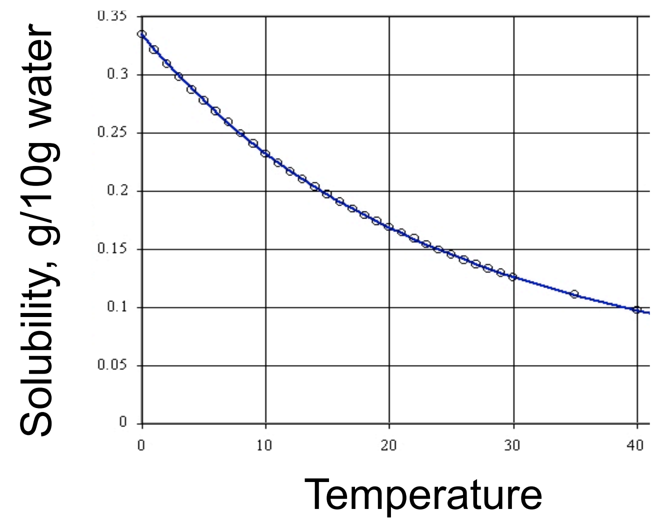
# pH

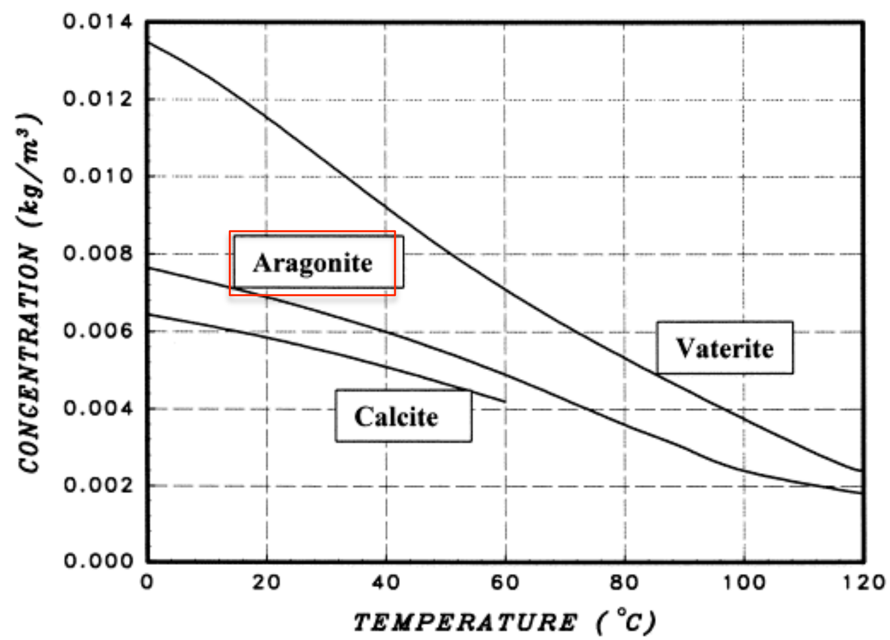



# Temperature

$CO_2$ solubility in water



PRODUCTIVITY

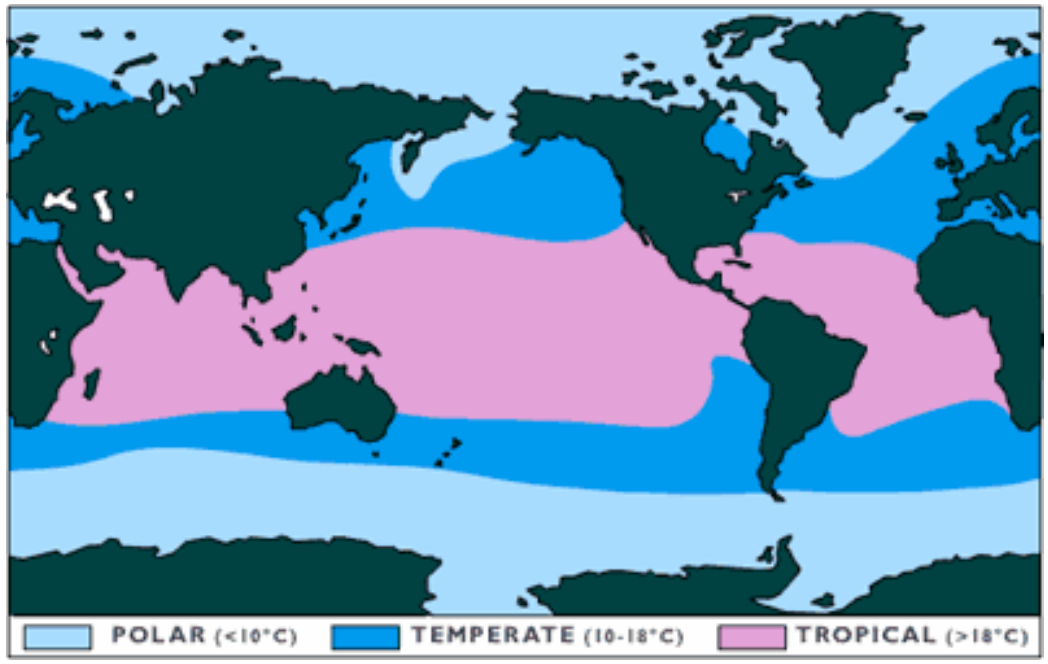
high

high

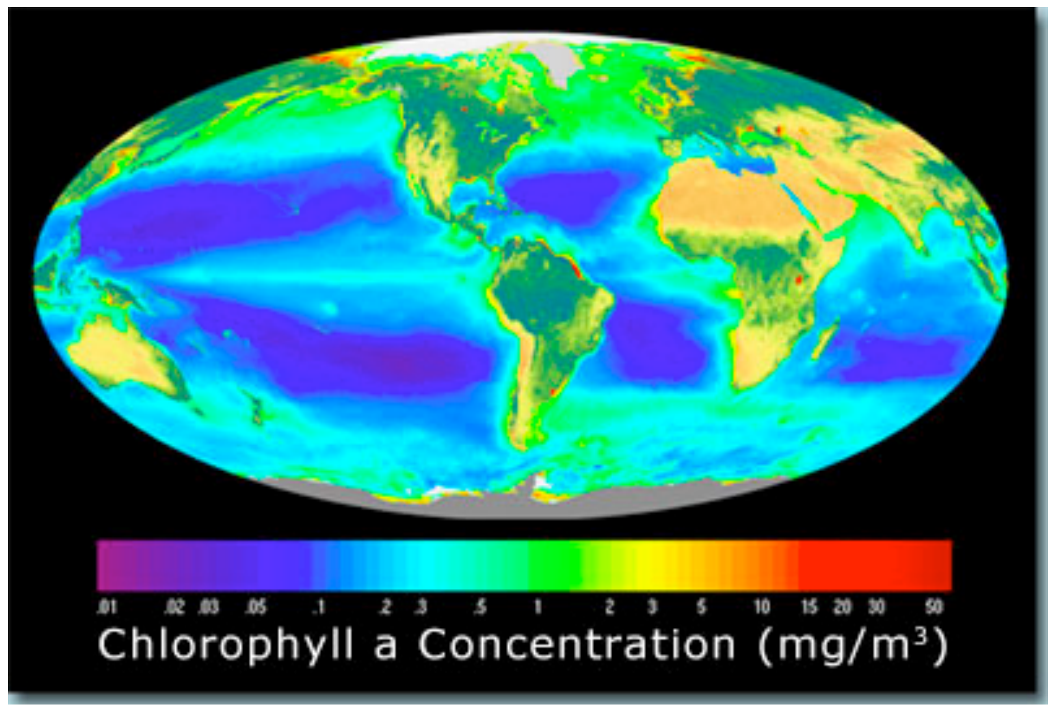
low

high

high



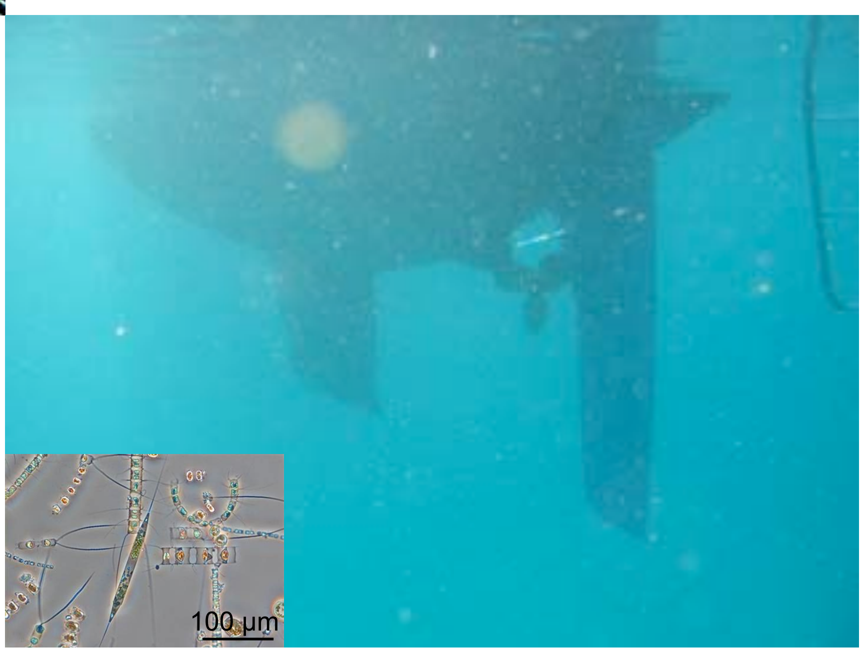

**Nutrient concentrations measured as chlorophyll concentration**



*“The [tropical] ocean is a desert, with it's life underground,*
*And a perfect disguise above.”*
*{America, ‘Horse with No Name’}*

Tropical waters are clear due to lack of nutrients, low numbers of small plants and animals.

Low visibility in temperate waters is due to high nutrient levels supporting large number of small plants/ animals.



So…the tropical regions are ‘deserts’, yet…

Coral reefs that are restricted to these regions.

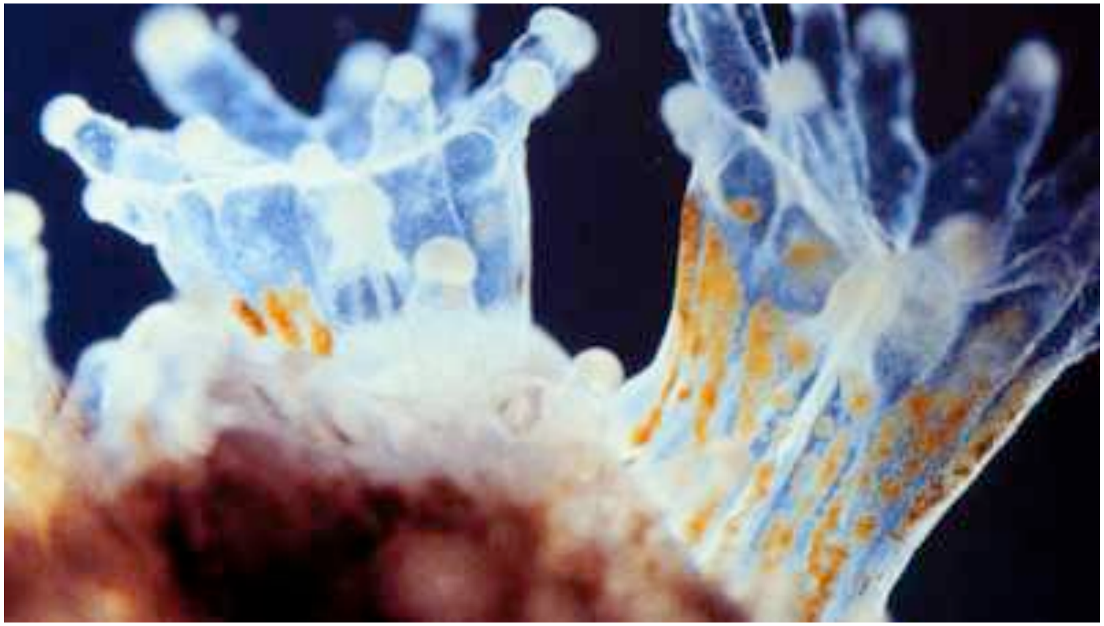
Coral reef systems are highly diverse; the corals provide a complex set of niches in the 3-D structure of the reef.

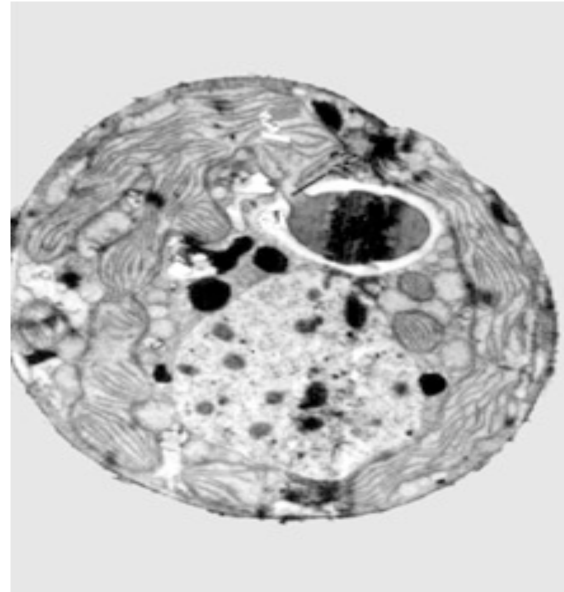
1) cover only 0.01% of the earth surface

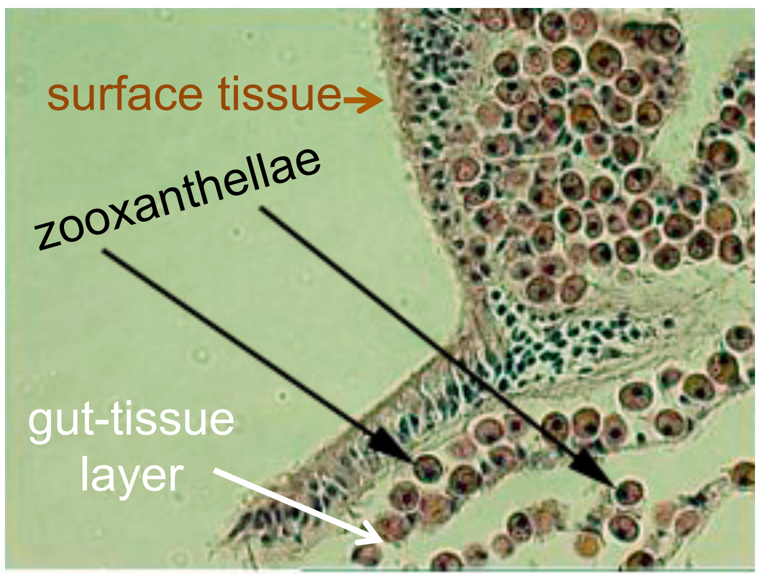
2) 1/4 of all of the ocean’s species life with corals.

HOW DO THEY DO IT?

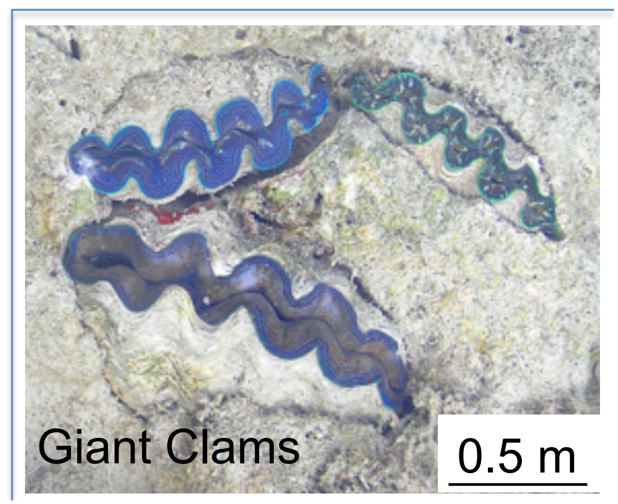
# Coral – Zooxanthella Symbiosis



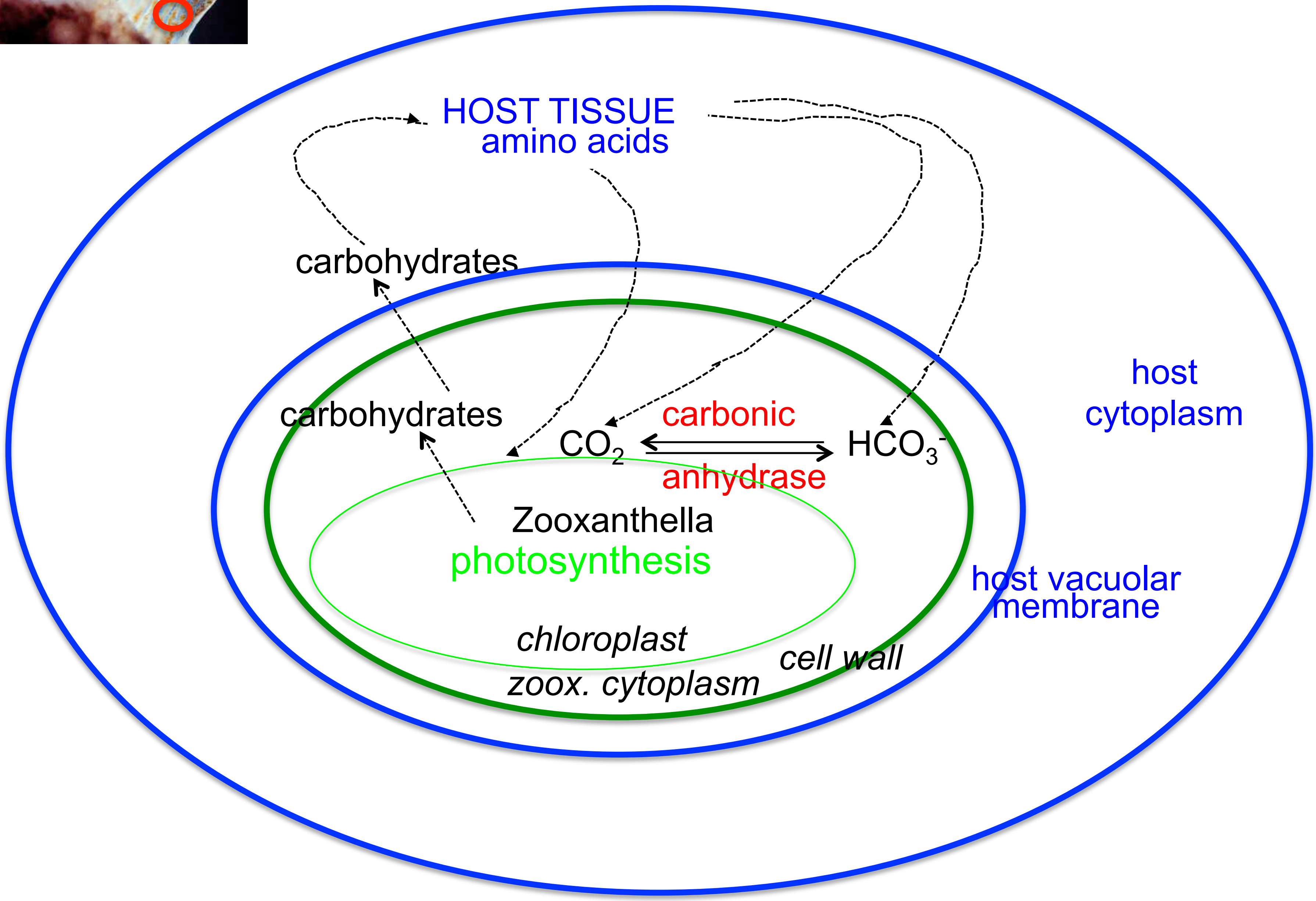


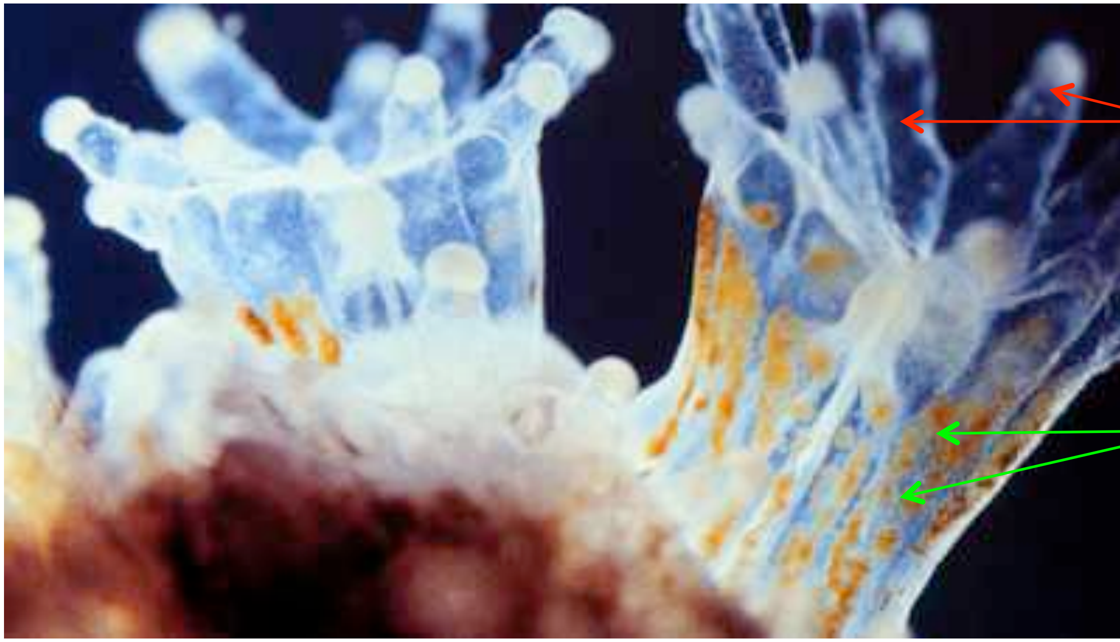



<u>Zooxanthellae</u> are unicellular algae that live in the gut-tissue layer of the coral.



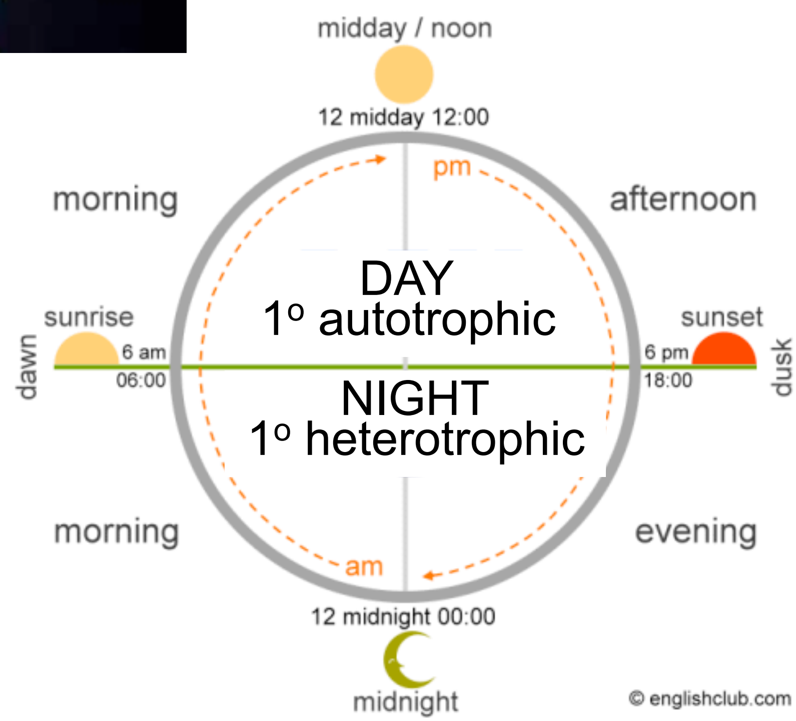
# Coral gut-tissue cell





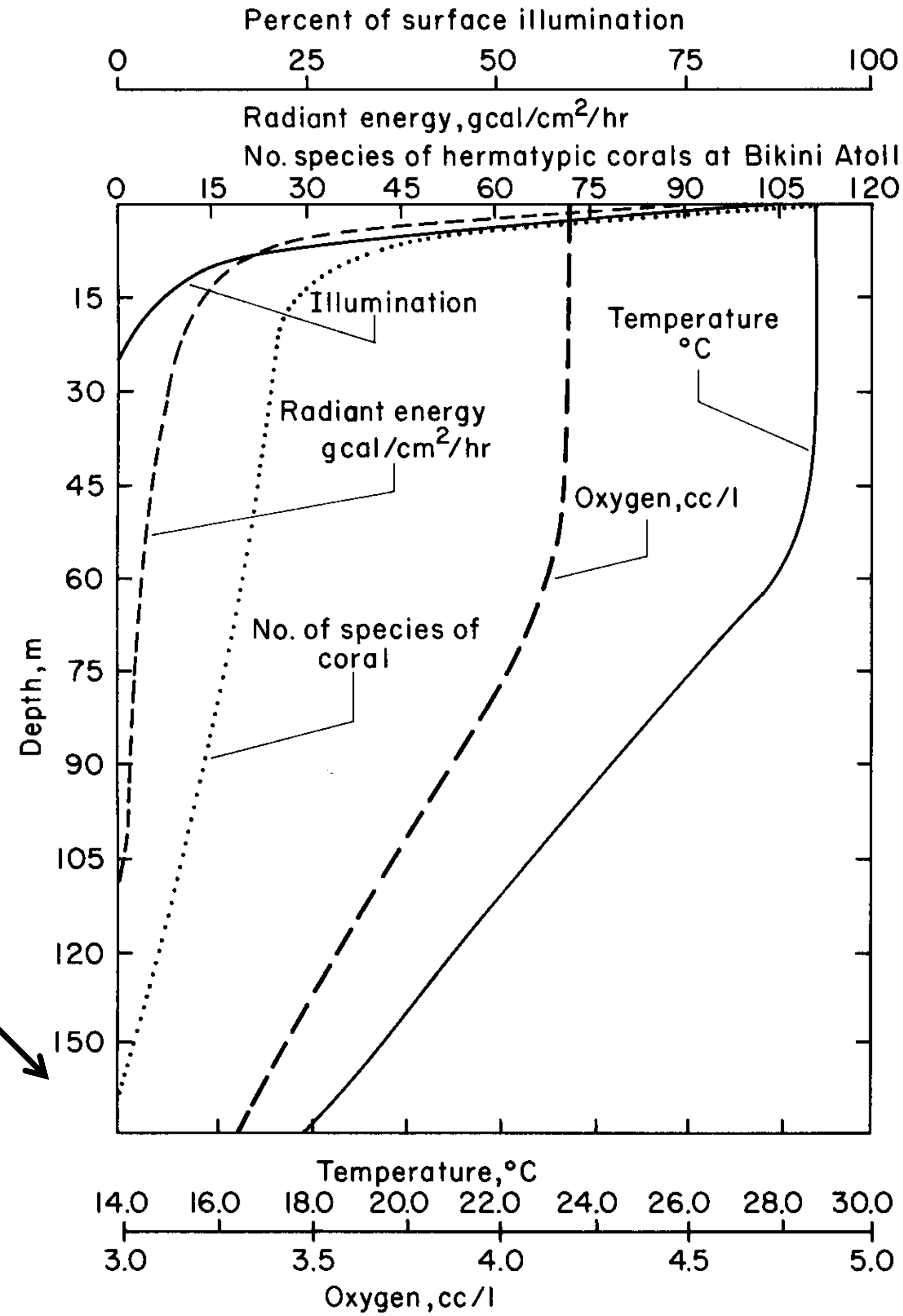
Prey capture

Light capture (symbiosis)



Coral reefs also have a depth restriction largely due to light absorption with depth.

The compensation point is the amount of light intensity on the light curve where the rate of photosynthesis exactly matches the rate of respiration.



Destruction of the coral reefs

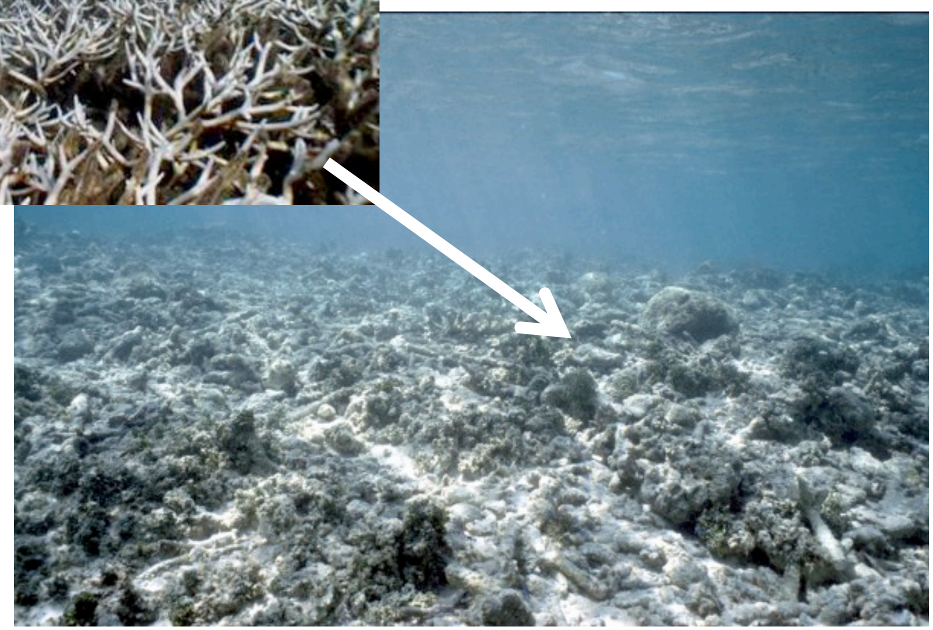
Overfishing
Destructive fishing methods

*Southeast Asia*

Destruction of the coastline
Imbalanced exchange between land and sea

*Chitales, Yucatan Penisula, Mexico*

# Coral bleaching



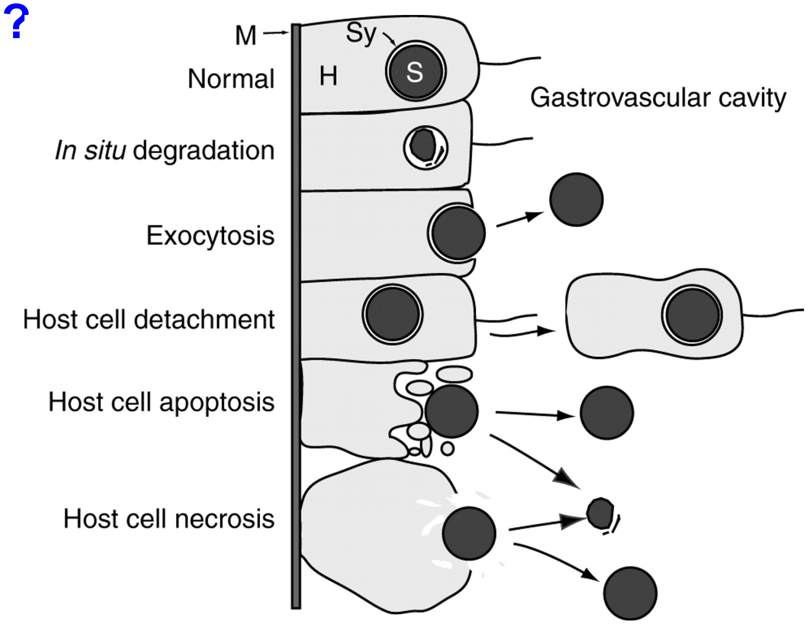
Coral Bleaching – loss of pigmentation of the corals

*Proximate cause* – loss of the symbiosis

Since the 1970's we have lost over 30% of our corals due to bleaching resulting from elevated temperatures

How and why is the symbiosis compromised?

Five different types of cellular mechanisms of symbiont loss from coral host tissues.

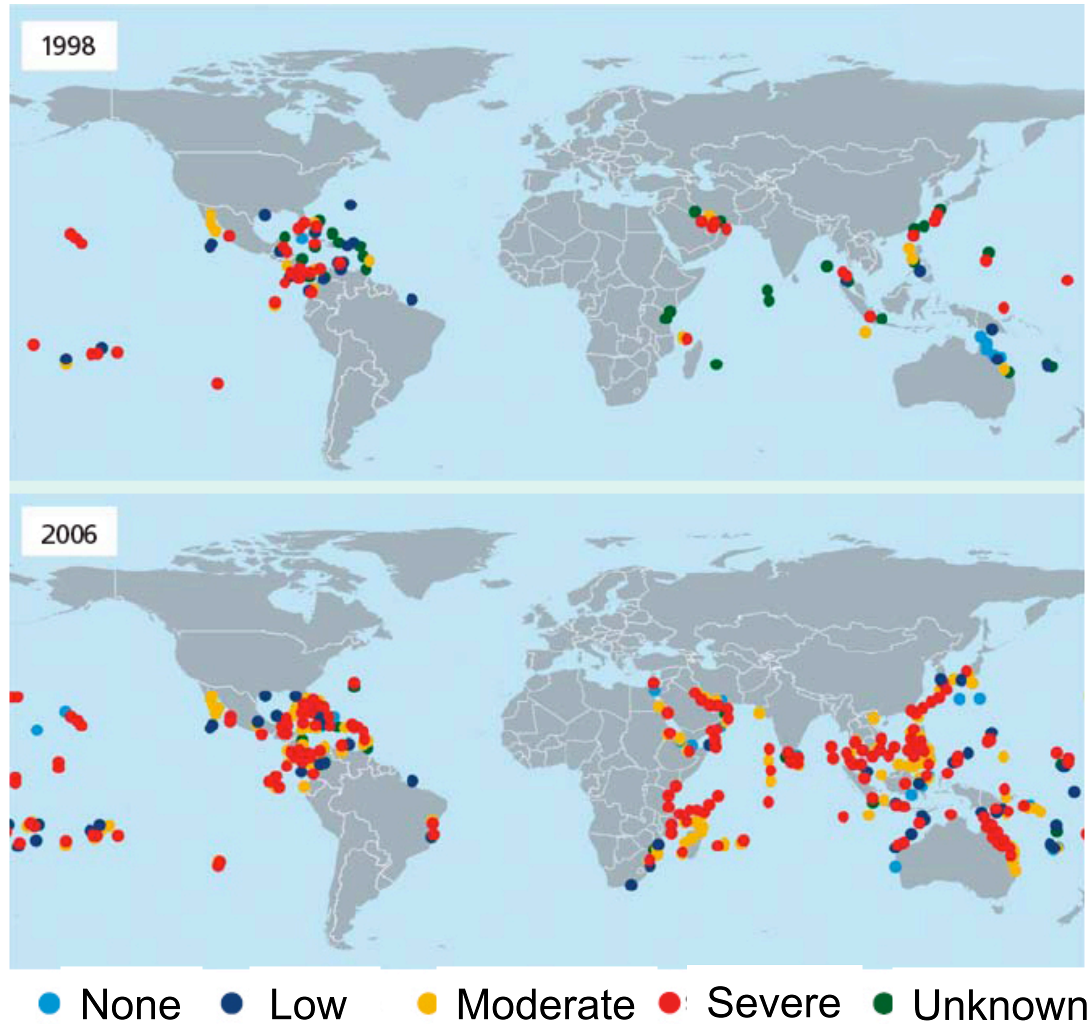


Movie on

1) global temperature change
2) ocean acidification –

OVER YOUR LIFETIME

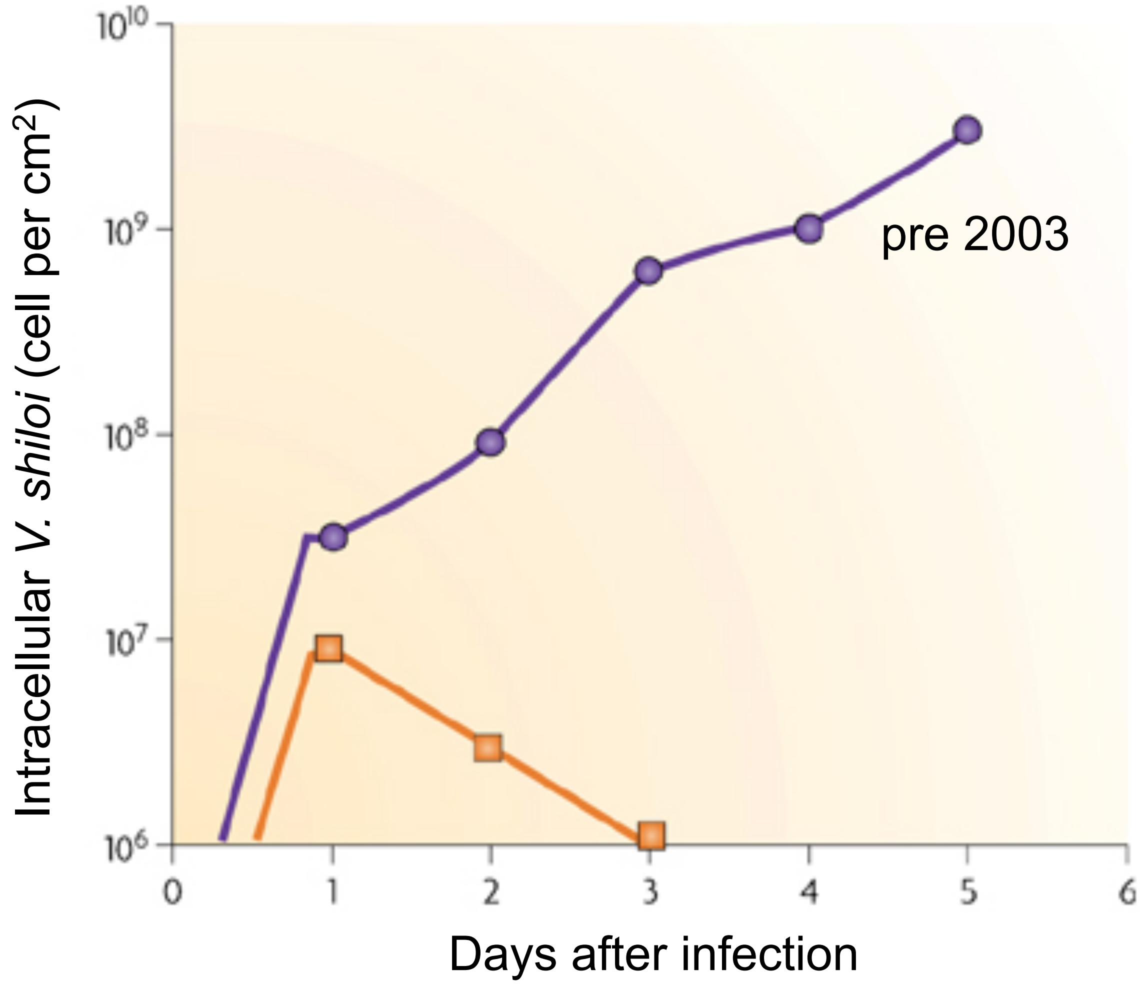
NO TIME FOR RECOVERY




low pH ← → high pH

$$Ca^{2+} + 2HCO_3^- \Leftrightarrow CaCO_3 + CO_2 + H_2O$$

Marine bacteria going to the dark side with higher temperatures.




Occurrence of *Vibrio shiloi* in coral tissues.

THERE’S HOPE, BUT WE NEED TO ACT NOW!!!

Coconut Island – O’ahu, Hawaii
[Moko o’loe]

ECOSYSTEMS BIOLOGY – GLOBAL ISSUES
MMN – A case study

What are the constraints on the form, function and distribution of coral reefs?

Coral reefs are ecosystems in which corals are the major physical and biological elements. Reef-building corals are colonial animals with calcium carbonate exoskeletons. These reefs support much of the ocean's diversity.

Coral reefs are restricted to the tropics and subtropics, areas of low nutrients. They are able to live in such environments because they form a symbiotic relationship with photosynthetic, unicellular algae.

How are global, anthropogenic environmental changes affecting the health of the world's coral reef habitats?

Global climate change and ocean acidification severely threaten the world's coral reefs.

iClicker quizzes