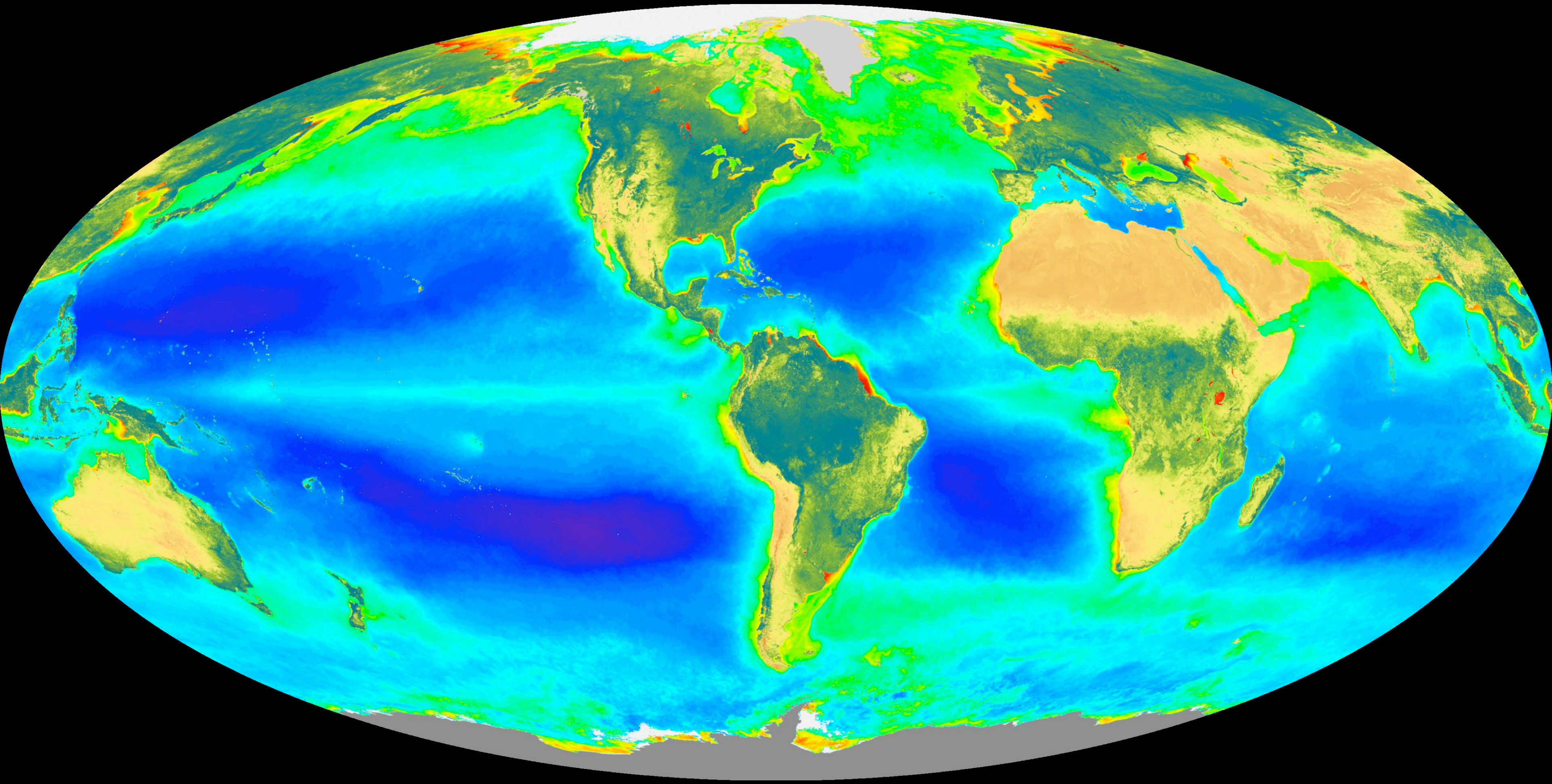
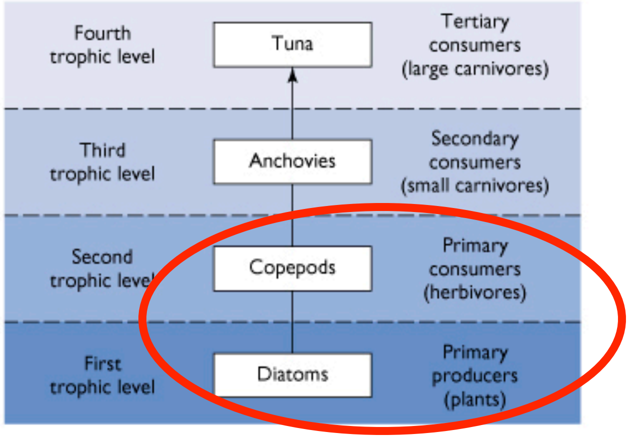
Marine Ecosystems and Food Webs

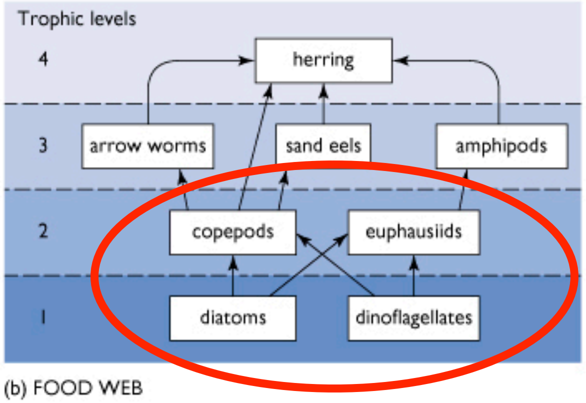


Trophic levels and dynamics



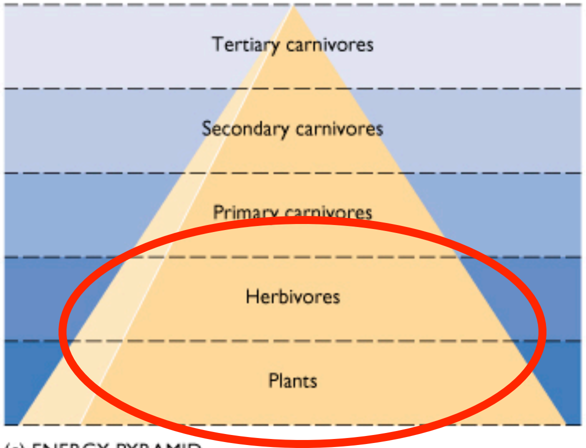
(a) SIMPLE FOOD CHAIN

Food Web



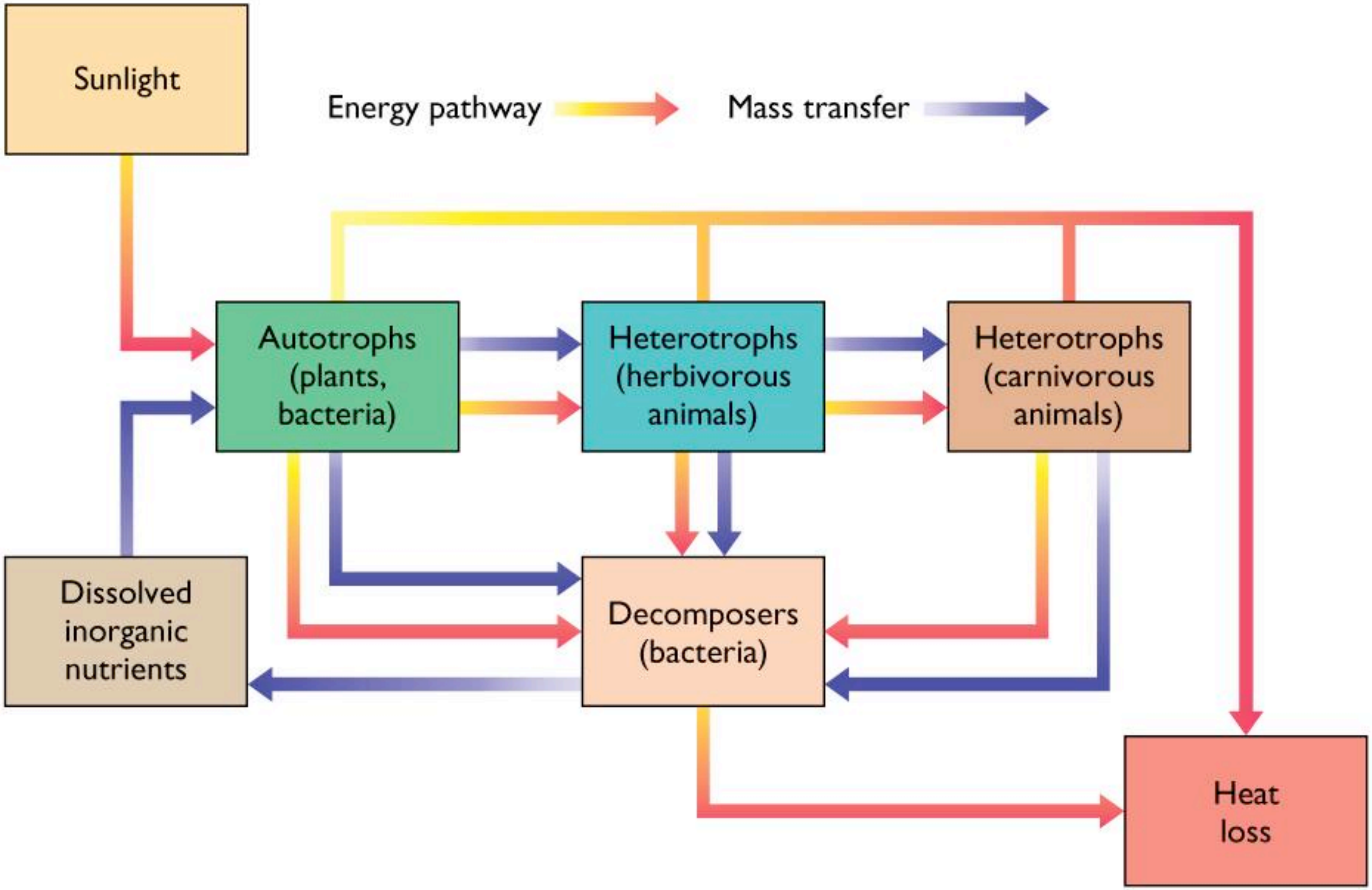
(b) FOOD WEB

Energy



(c) ENERGY PYRAMID

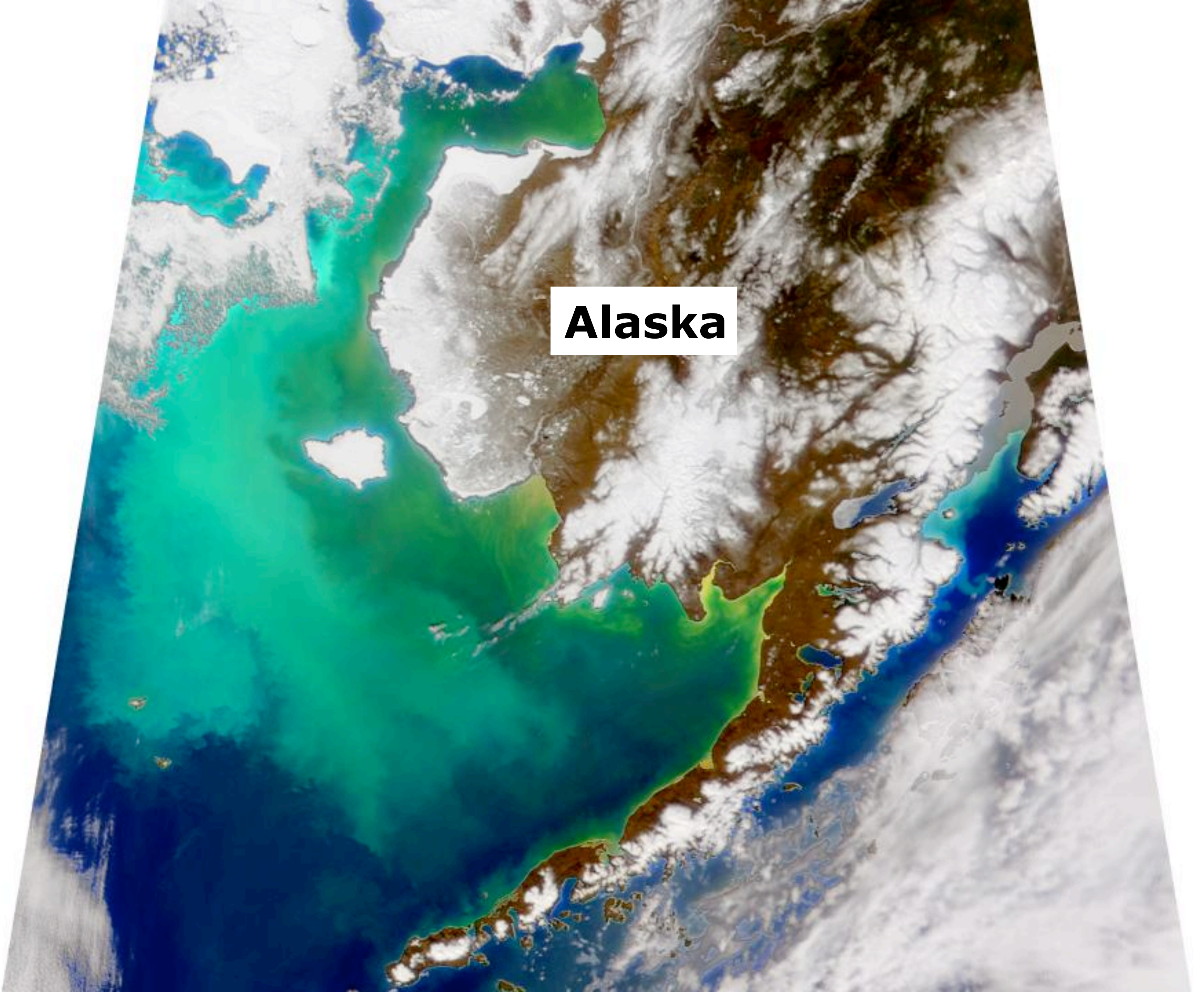
Ecosystem Model



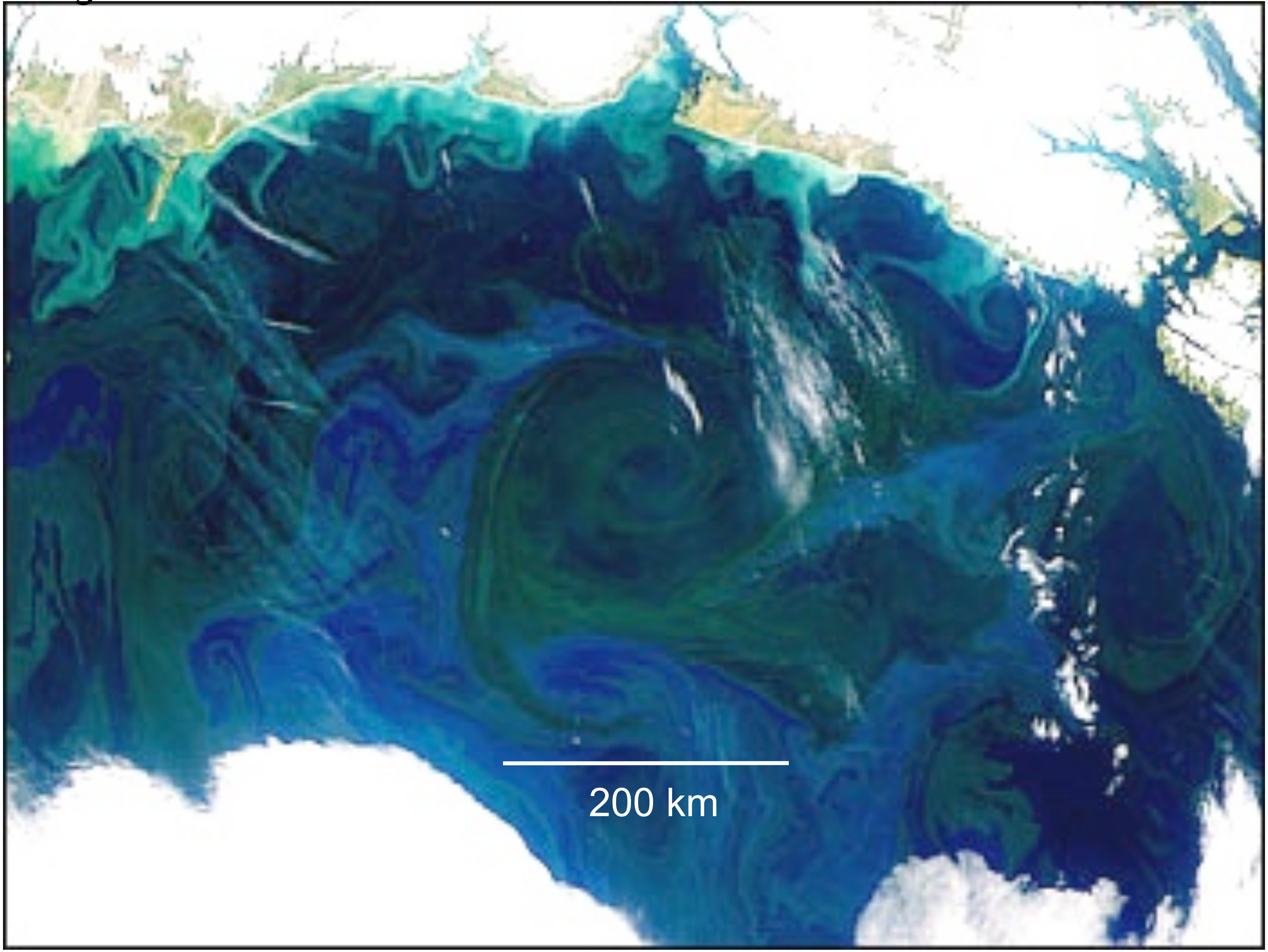
Macronutrients [] can be used to track mass transfers

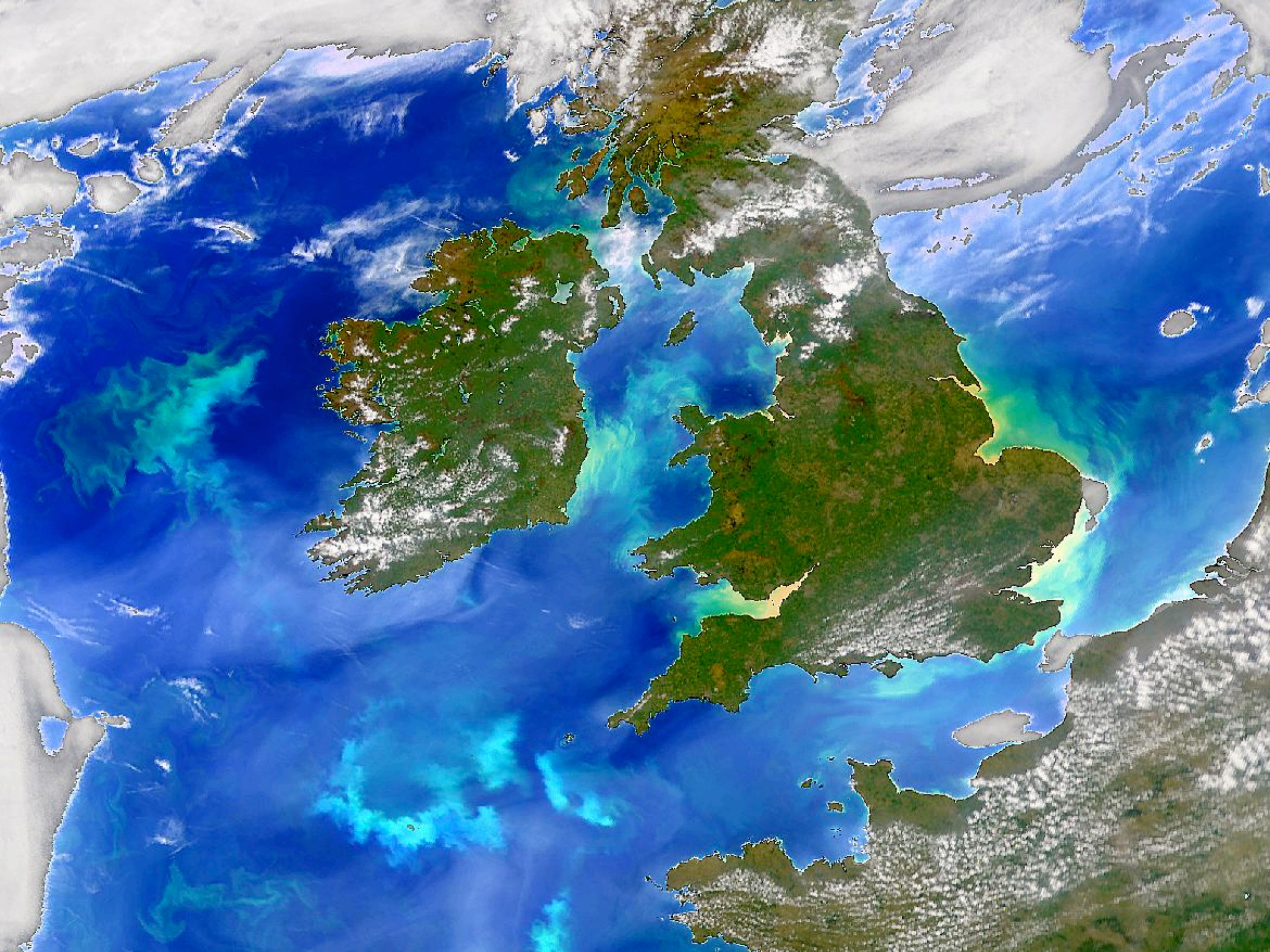
How do we measure Biomass?

Mass transfers are more easy to keep track than energy transfers


Alaska

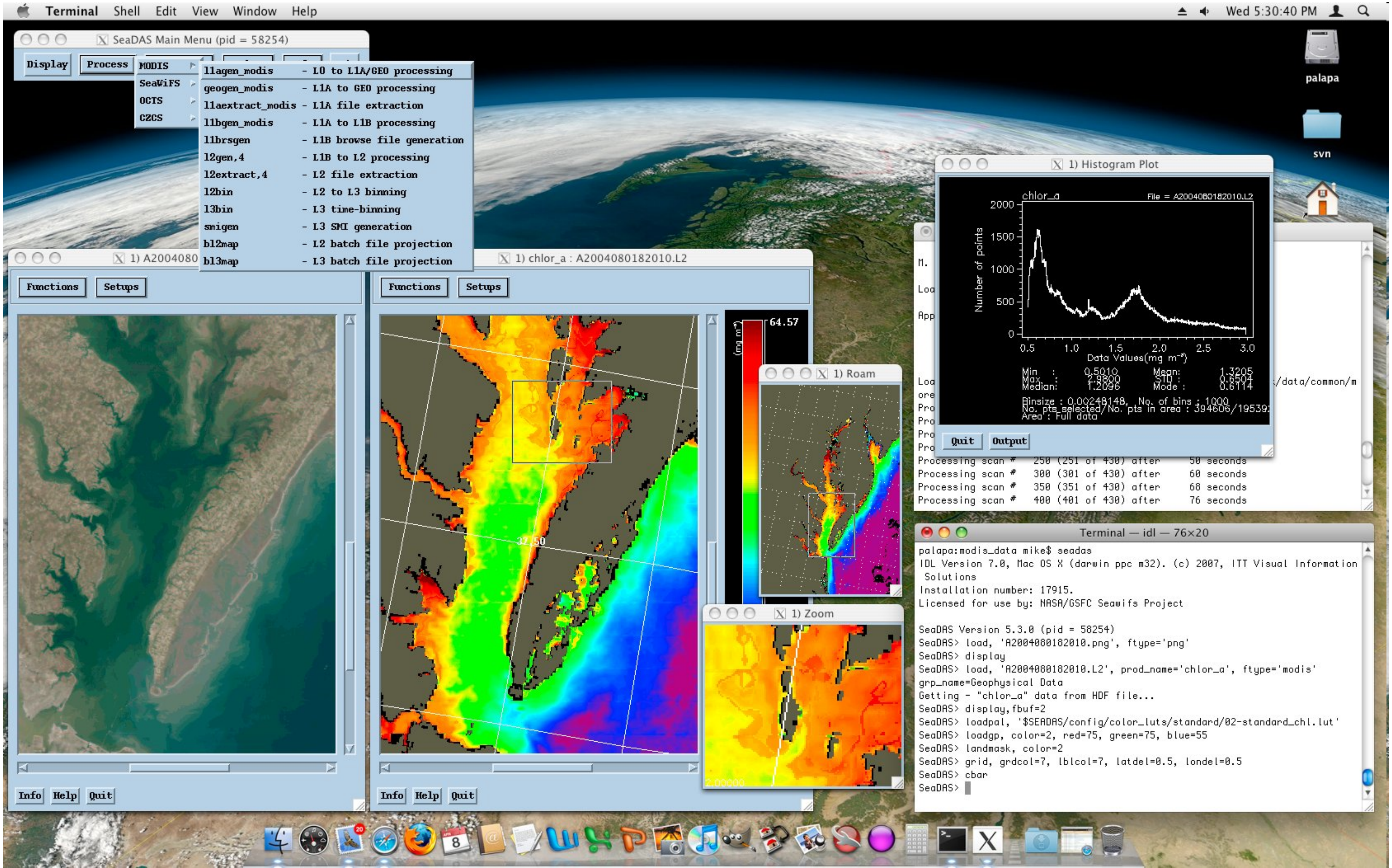
Large scale Eddies





- Color sensor satellites: **MODIS, SeaWiFS, MERIS, OCTS**, and **CZCS**

http://oceancolor.gsfc.nasa.gov/SeaWiFS



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Processing scan #   350 (351 of 430) after     68 seconds
Processing scan #   400 (401 of 430) after     76 seconds
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IDL Version 7.0, Mac OS X (darwin ppc m32). (c) 2007, ITT Visual Information
 Solutions
Installation number: 17915.
Licensed for use by: NASA/GSFC Seawifs Project

SeaDAS Version 5.3.0 (pid = 58254)
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grp_name=Geophysical Data
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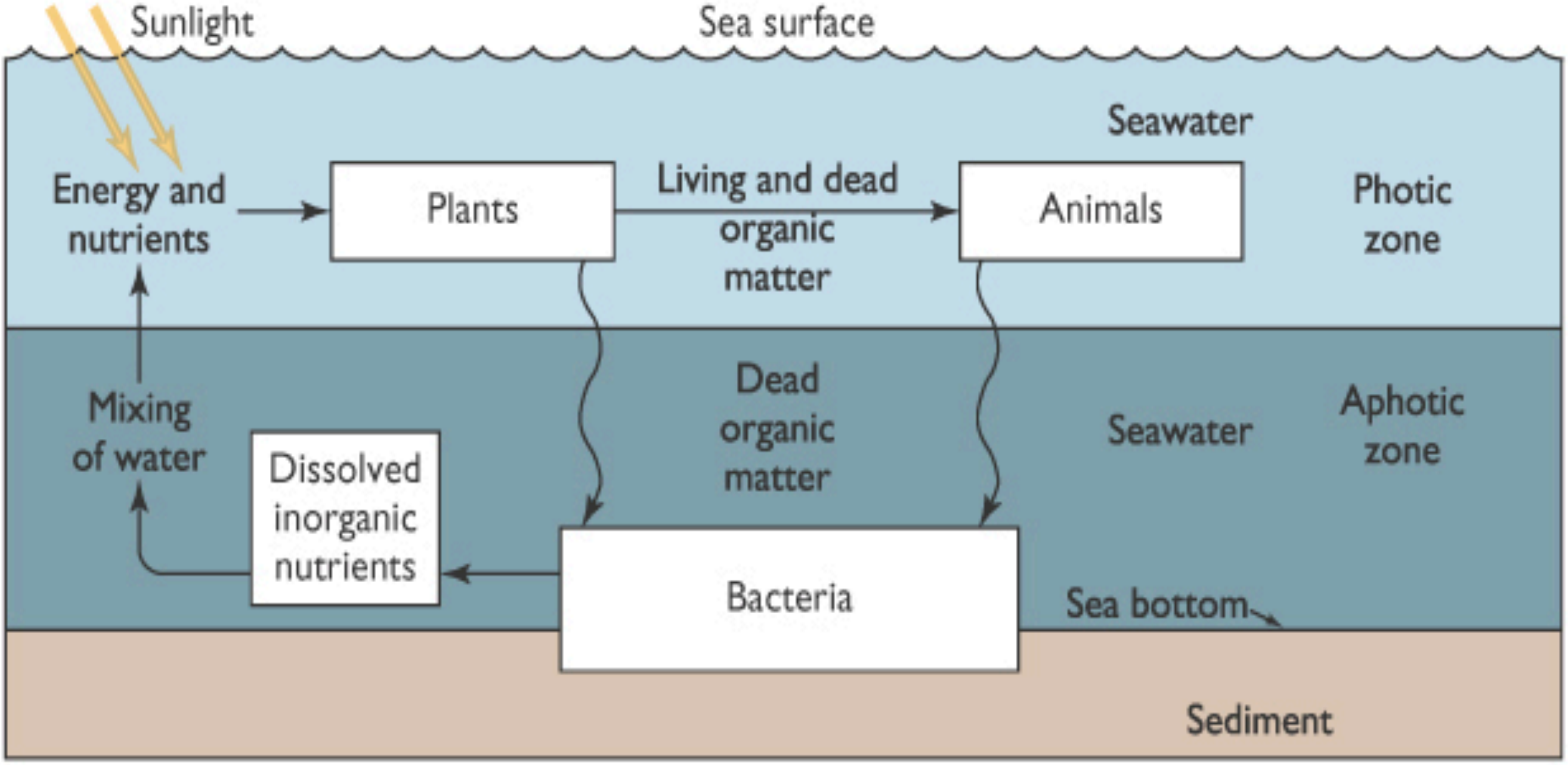
SeaDAS> landmask, color=2
SeaDAS> grid, grdcol=7, lblcol=7, latdel=0.5, londel=0.5
SeaDAS> cbar
SeaDAS> 
```

A simplified diagram of an ecosystem



(a) NUTRIENT CYCLING

A useful way to keep track of biomass in the lower trophic levels is to follow the path of MACRONUTRIENTS

Carbon C

Nitrogen N

Phosphorus P

Redfield Ratio

C : N : P

106 : 16 : 1

Atlantis in 1934 and today

Redfield A.C., *On the proportions of organic derivations in seawater and their relation to the composition of plankton*. In James Johnson Memorial Volume. (ed. R.J. Daniel). University Press of Liverpool, pp. 177-192, 1934. This works stems from his participation as a physiologist in the voyages of WHOI's first research vessel Atlantis.

C : N : P

source
1) atmosphere

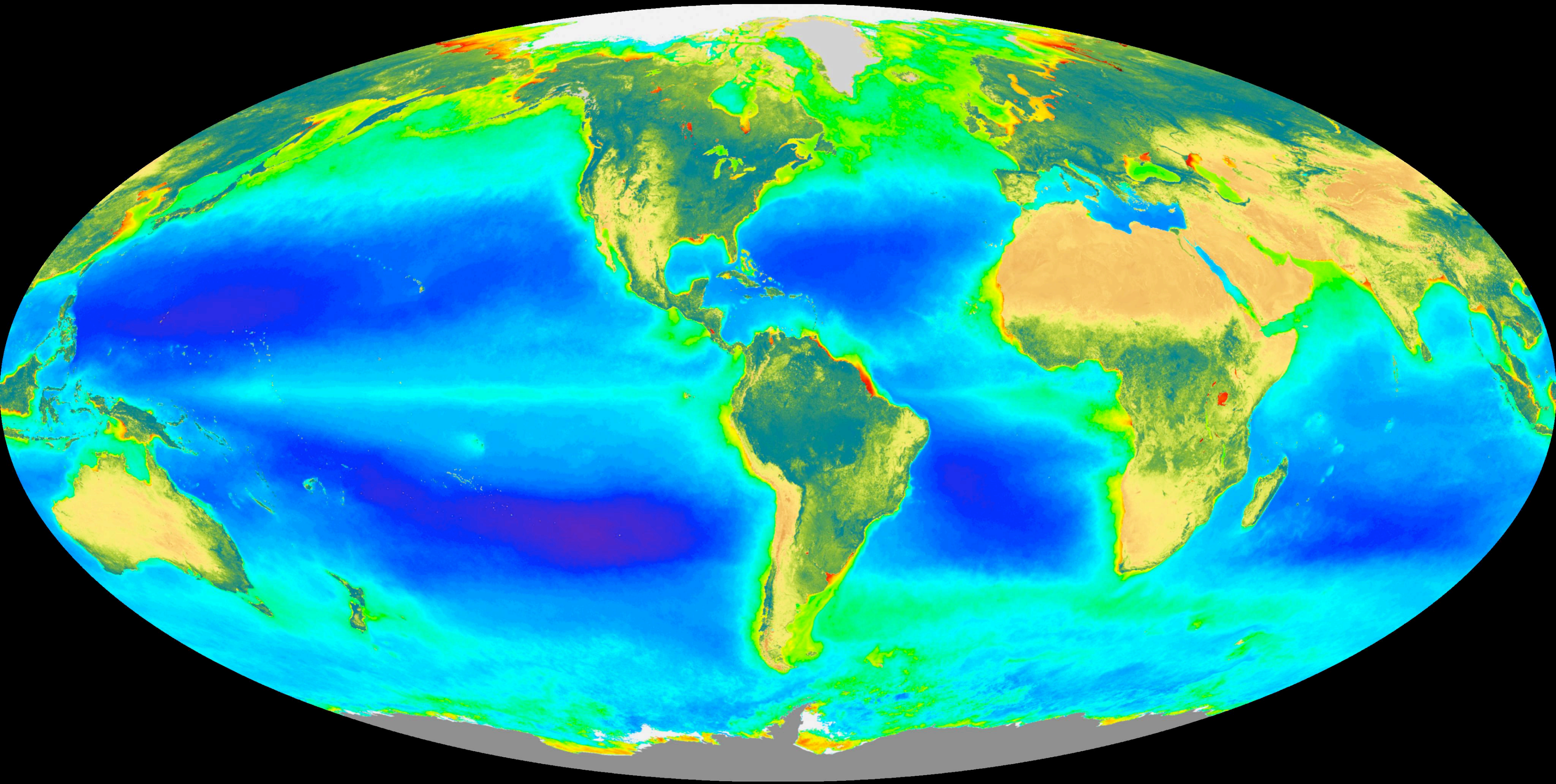
source
1) from N2 atmosphere gas
2) ocean subsurface
3) remineralization of dead organic matter
4) biological (e.g. excretions)

source
1) not biological, not atmospheric
2) fluvial

At large Nitrogen appears to be the limiting factor in ocean productivity in today's oceans

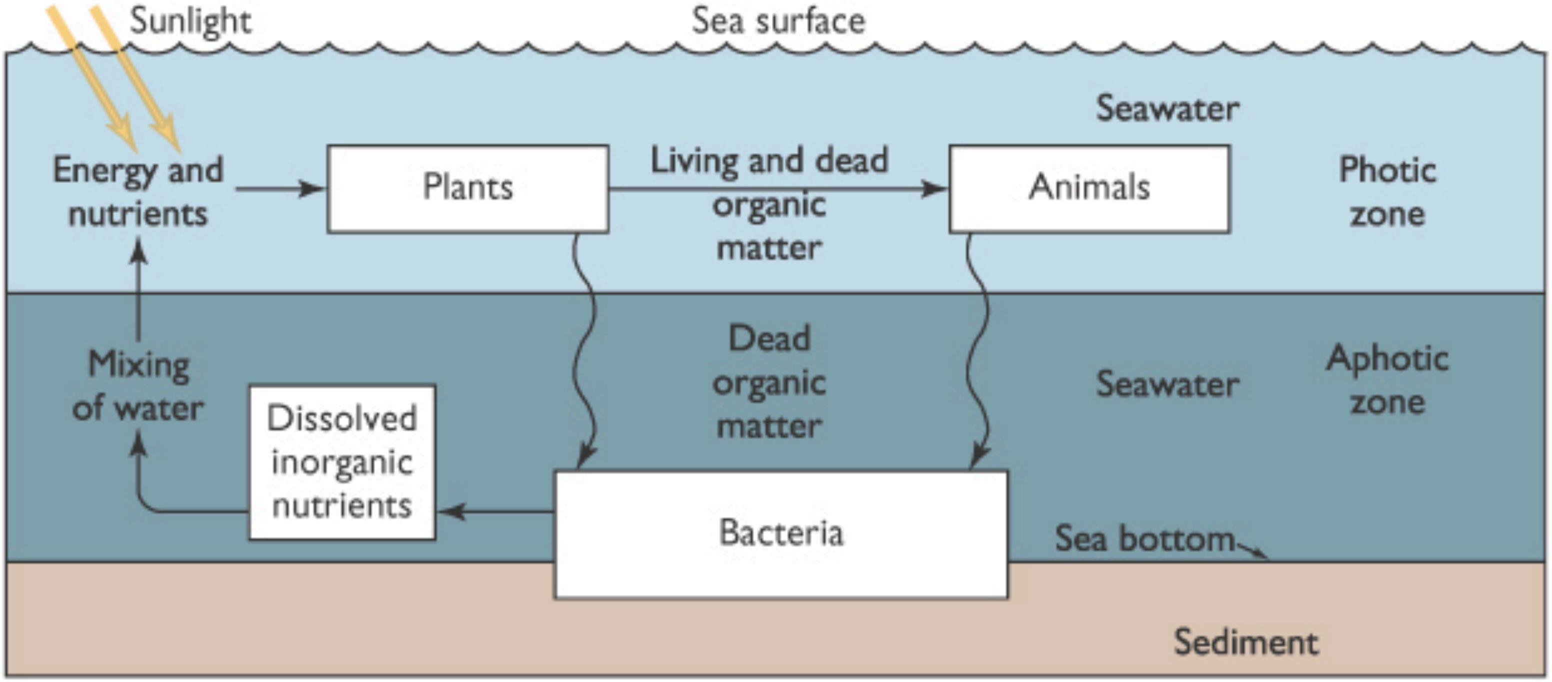
Nitrogen Cycle

Understanding the marine ecosystem dynamics



Why do we care about Nitrogen?

1) N is a currency to track mass transfers in marine ecosystem
2) N dynamics important to model exchange processes



(a) NUTRIENT CYCLING

At large Nitrogen appears to be the limiting factor in ocean productivity in today's oceans

Nitrogen

- N is an essential nutrient for all living organisms (nucleic acids and amino acids)

- N has many oxidation states, which makes **speciation** and redox chemistry very interesting

  (Speciation: Refers to the chemical form or compound in which an element occurs in both non-living and living systems.)

- NH_4^+ is preferred N nutrient

Different forms of Marine N

Libes, 1992

Bioavailable/Fixed (oxidation state)

NO_3^- 5.7*10⁵ Tg N (+5)

NO_2^- 500 Tg N (+3)

NH_4^+ 7.0*10³ Tg N (-3)

Organic N 5.3*10⁵ Tg N (-3)

Nitrate

Nitrite

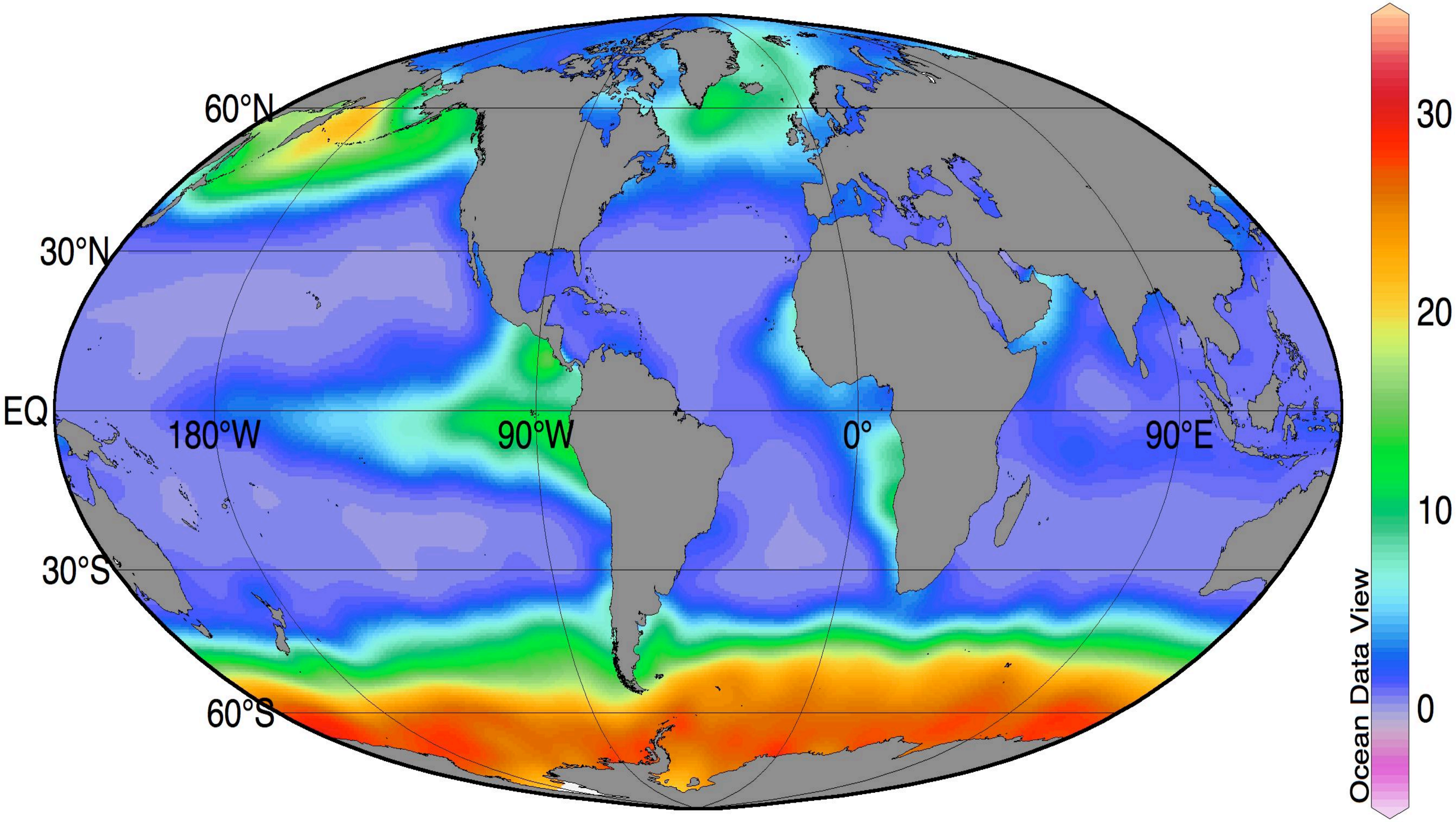
Ammonia

Non-bioavailable

N_2O 200 Tg N (+1)

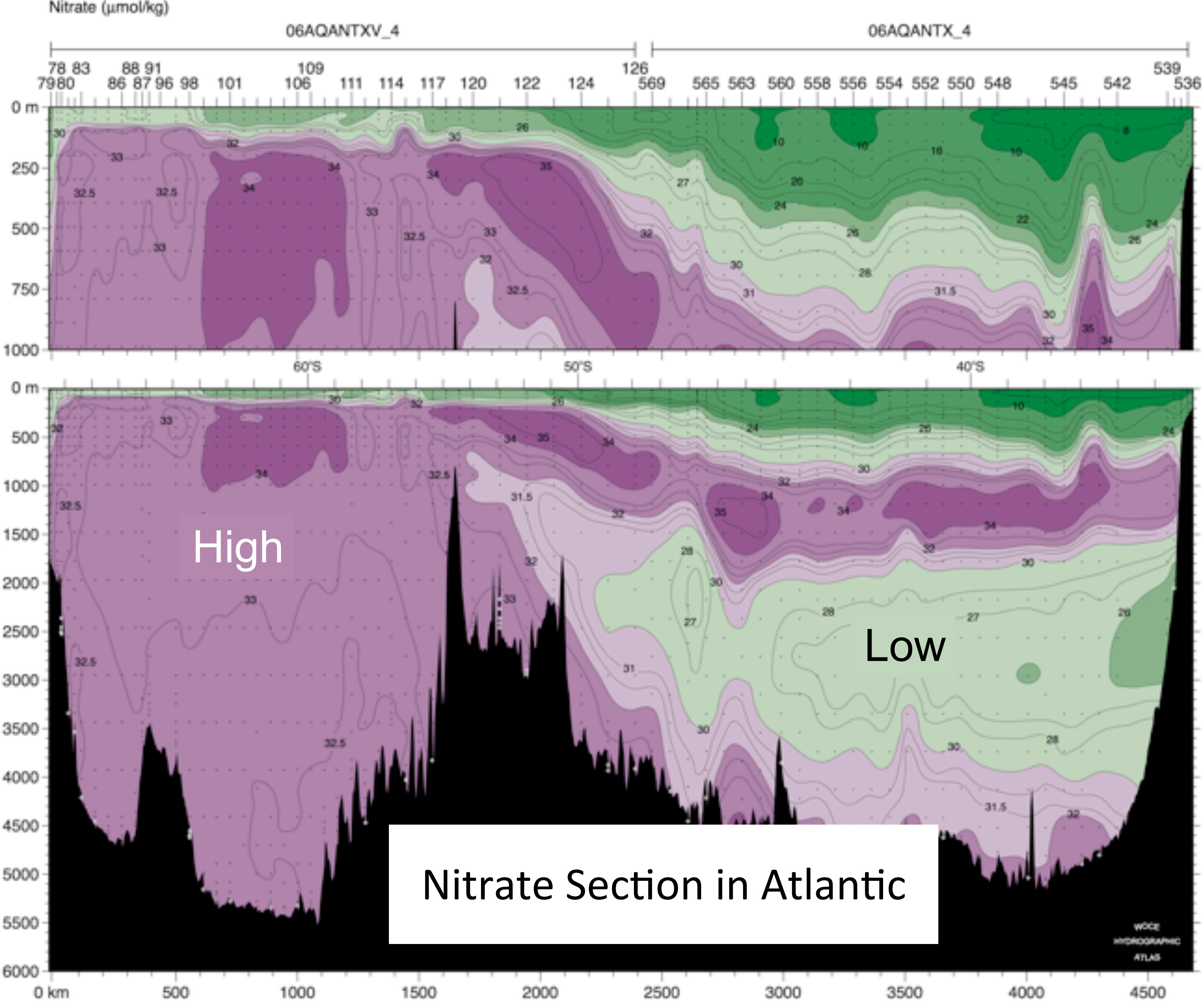
N_2 2.2*10⁷ Tg N (0)

Nitrate [µmol/l] @ Depth [m]=30



Data: eWOCE. Plot prepared with ODV

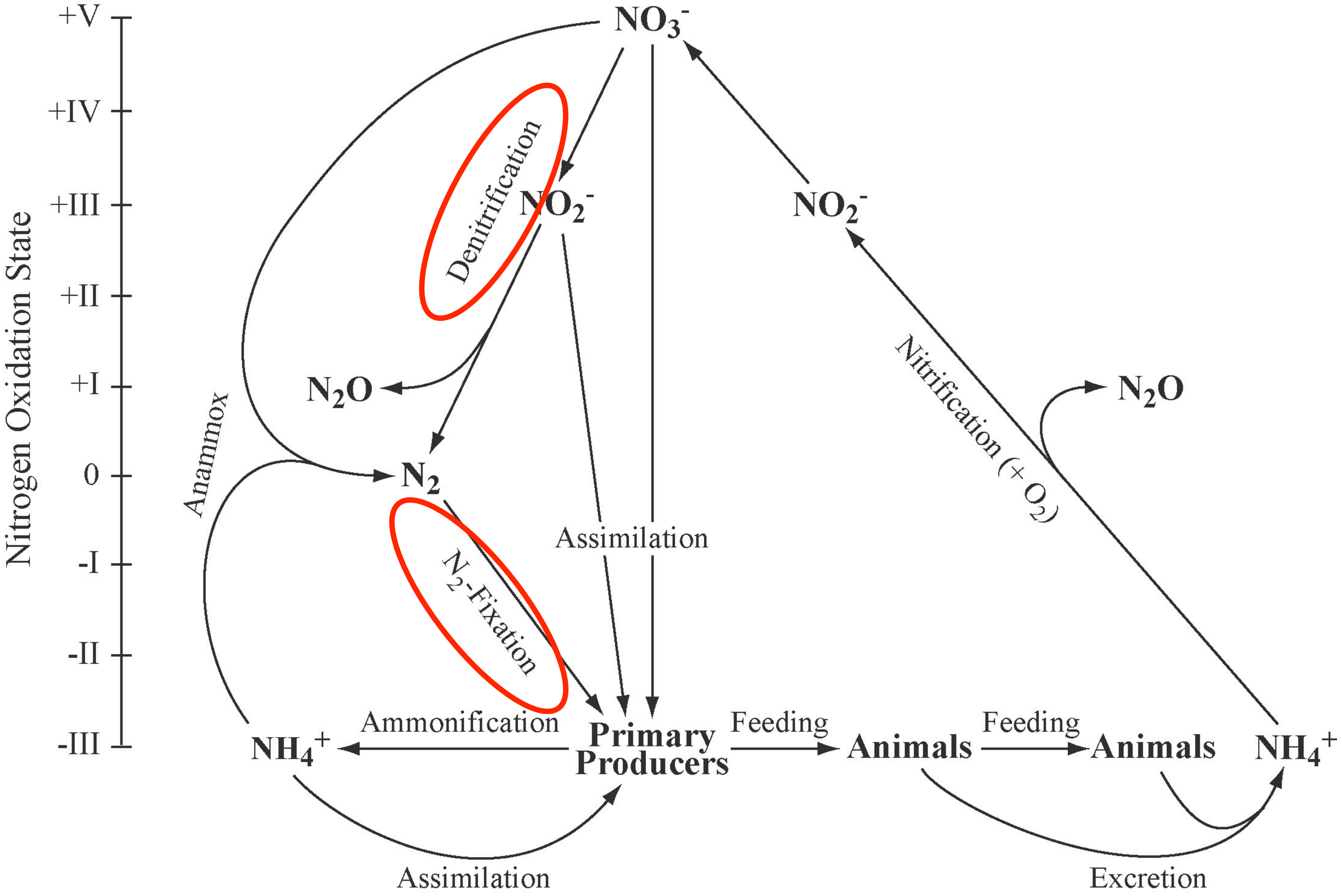
Nitrate Section in Atlantic



High

Low

Major Biological Transformations of Nitrogen



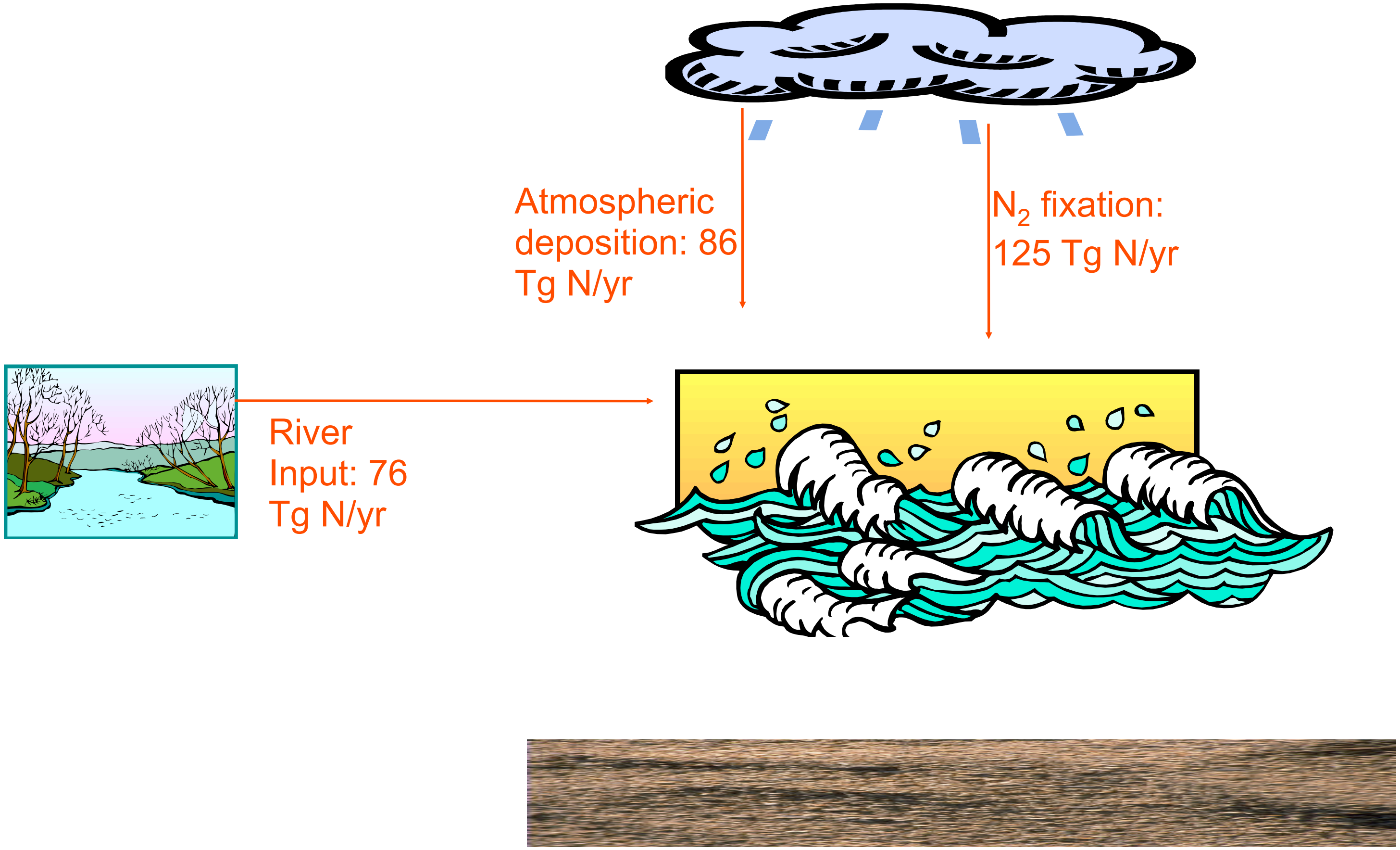
(Inspired by Codispoti 2001and Liu 1979)

Marine Fixed N Budget

Codispoti et al. (2001)

Marine Reservoir: 6.3*10^5 Tg N

Sources: 287 Tg N/yr



Atmospheric deposition: 86 Tg N/yr

N_2 fixation: 125 Tg N/yr

River Input: 76 Tg N/yr

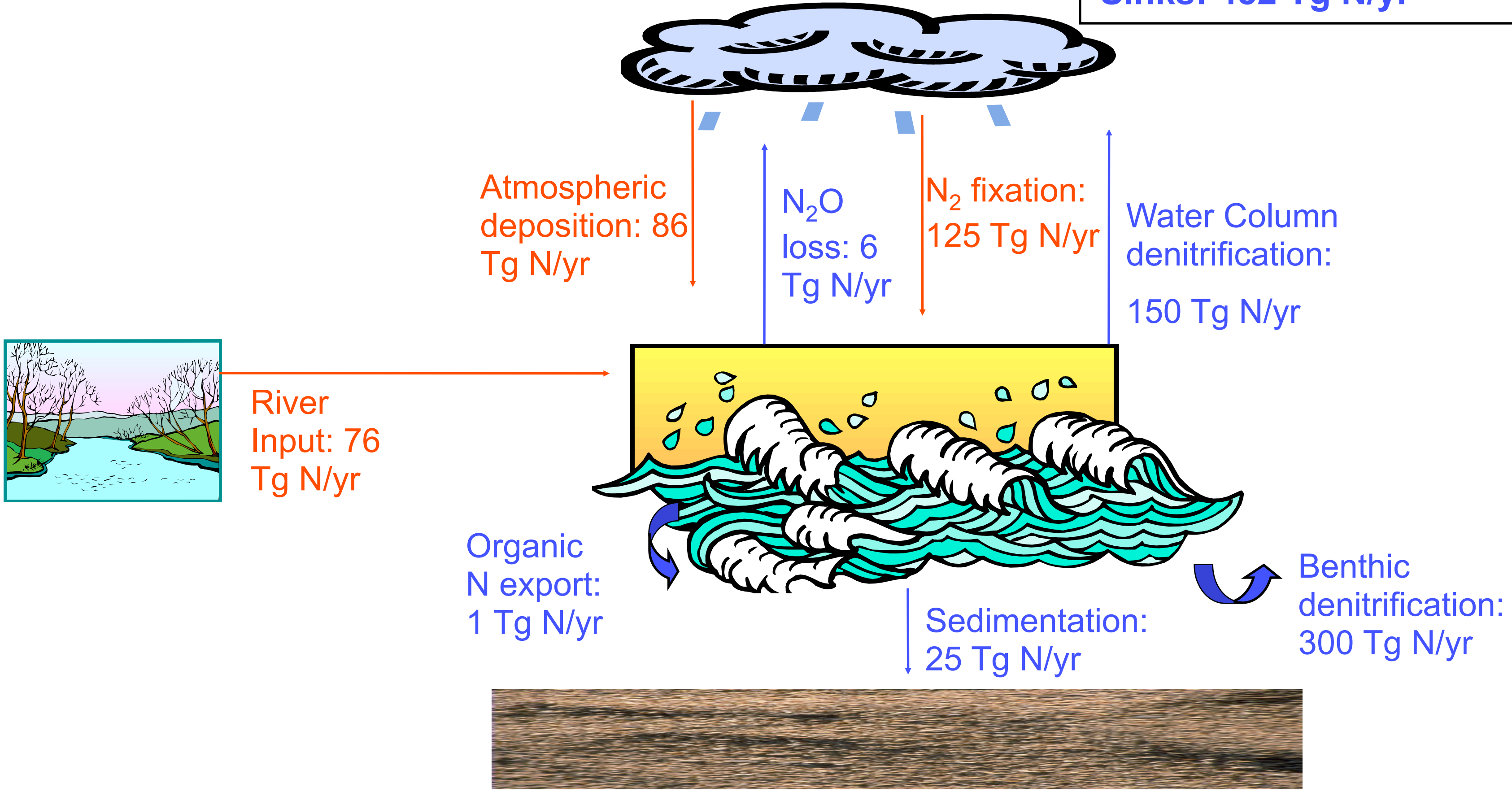
Marine Fixed N Budget

Codispoti et al. (2001)

Marine Reservoir: 6.3*10^5 Tg N

Sources: 287 Tg N/yr

Sinks: 482 Tg N/yr



Atmospheric deposition: 86 Tg N/yr

N_2O loss: 6 Tg N/yr

N_2 fixation: 125 Tg N/yr

Water Column denitrification:

150 Tg N/yr

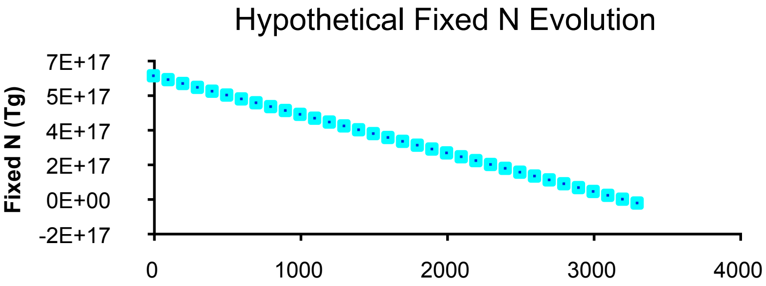
River Input: 76 Tg N/yr

Organic N export: 1 Tg N/yr

Sedimentation: 25 Tg N/yr

Benthic denitrification: 300 Tg N/yr

Marine Fixed N Budget



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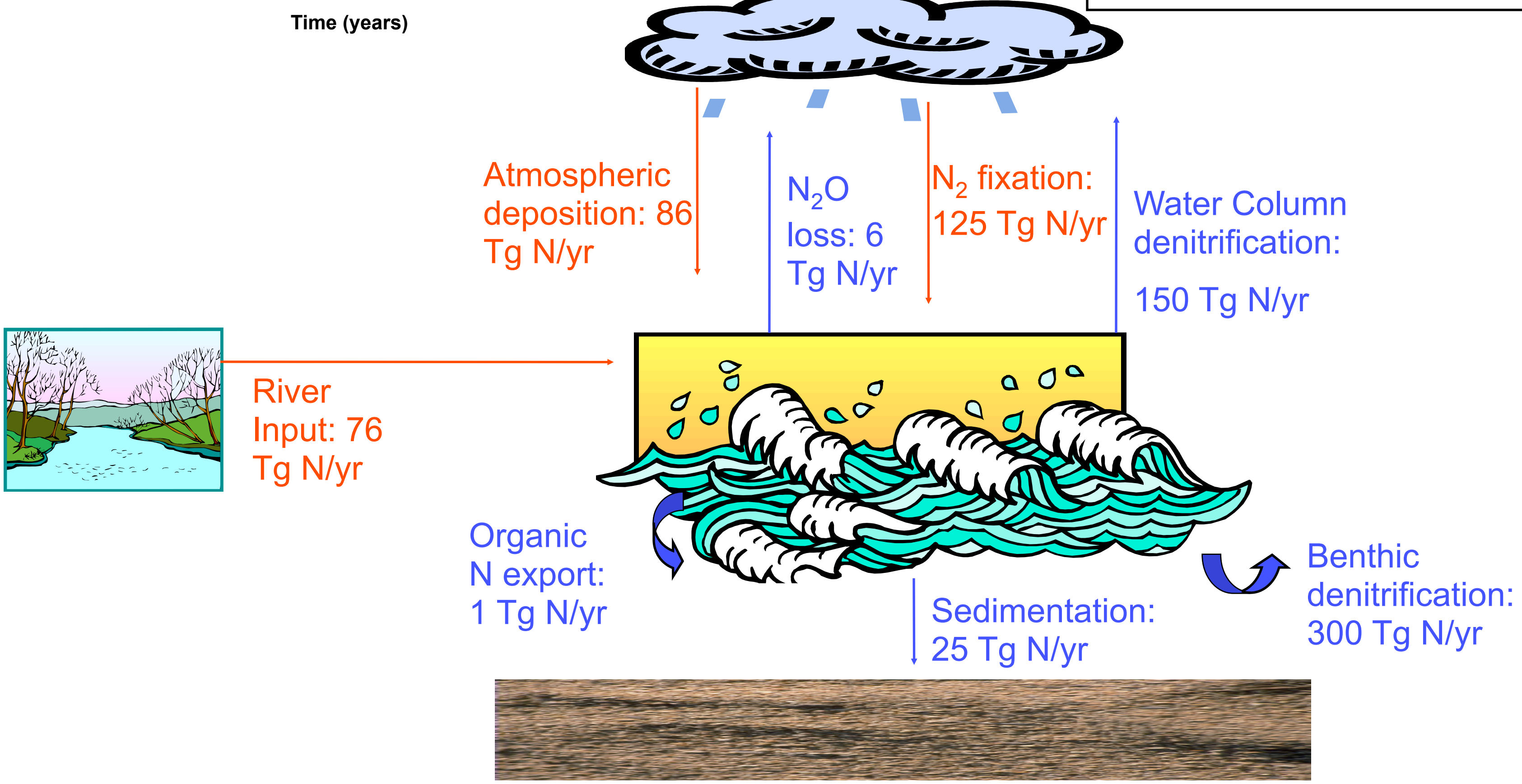

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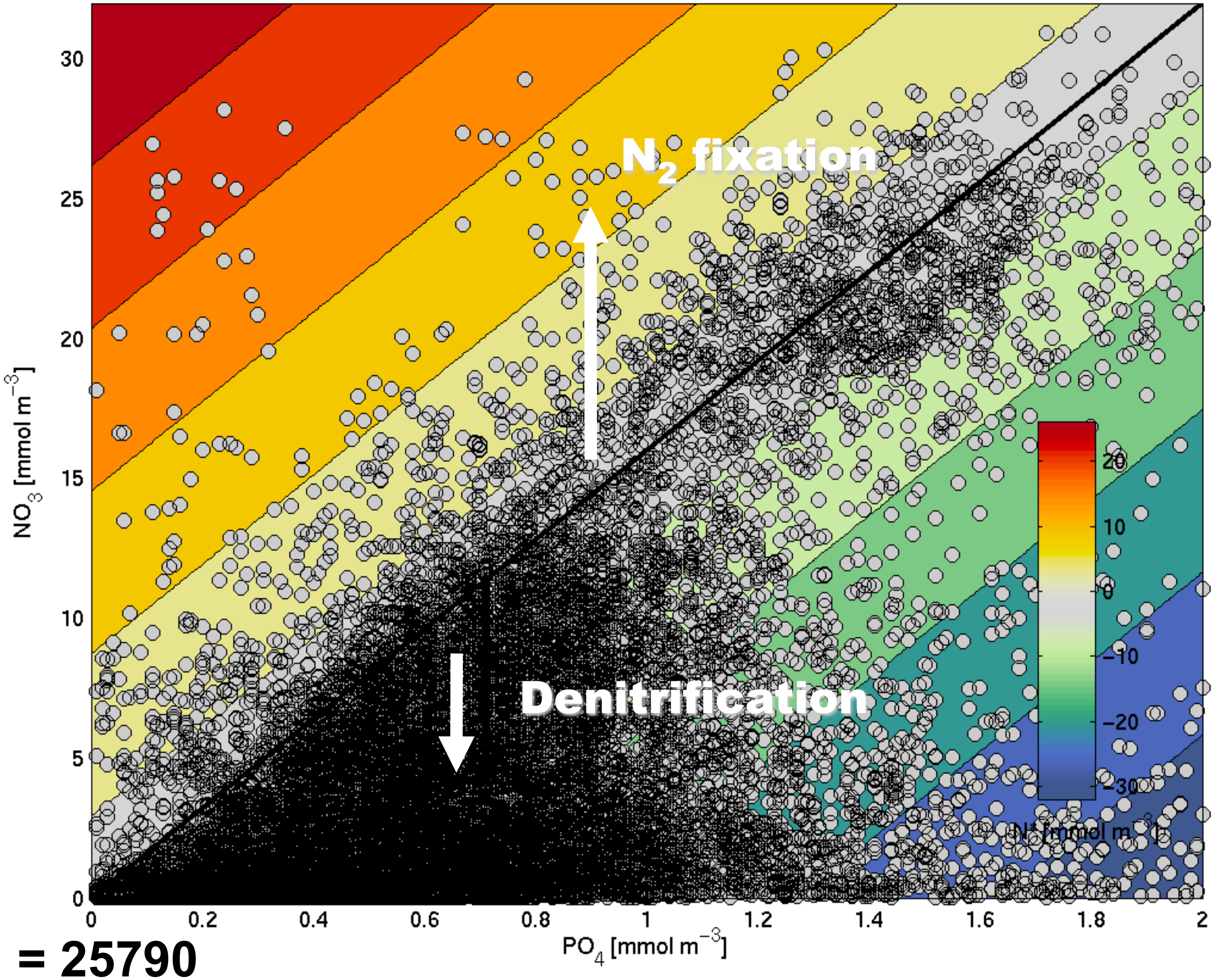
Sedimentation: 25 Tg N/yr

Benthic denitrification: 300 Tg N/yr

Oceanic Nitrogen Budget Estimates

N Budget Terms (Tg N y^{-1})	1970 (Delwiche)	1979 (Liu)	1985 (Codispoti & Christensen)	1997 (Gruber & Sarmiento)	2001 (Codispoti et al.)
Inputs					
atmospheric	4.1	49	40	15	56
runoff	30	17	25	41	41
N_2-fixation	**10**	**30**	**25**	**125**	**125**
Total Inputs	**44.1**	**96**	**90**	**181**	**222**
Outputs					
pelagic denitrification	40	50	60	85	150
sedimentary denitrification	0	10	60	85	300
burial & other	0.2	36	38	19	32
Total Outputs	**40.2**	**96**	**158**	**189**	**482**

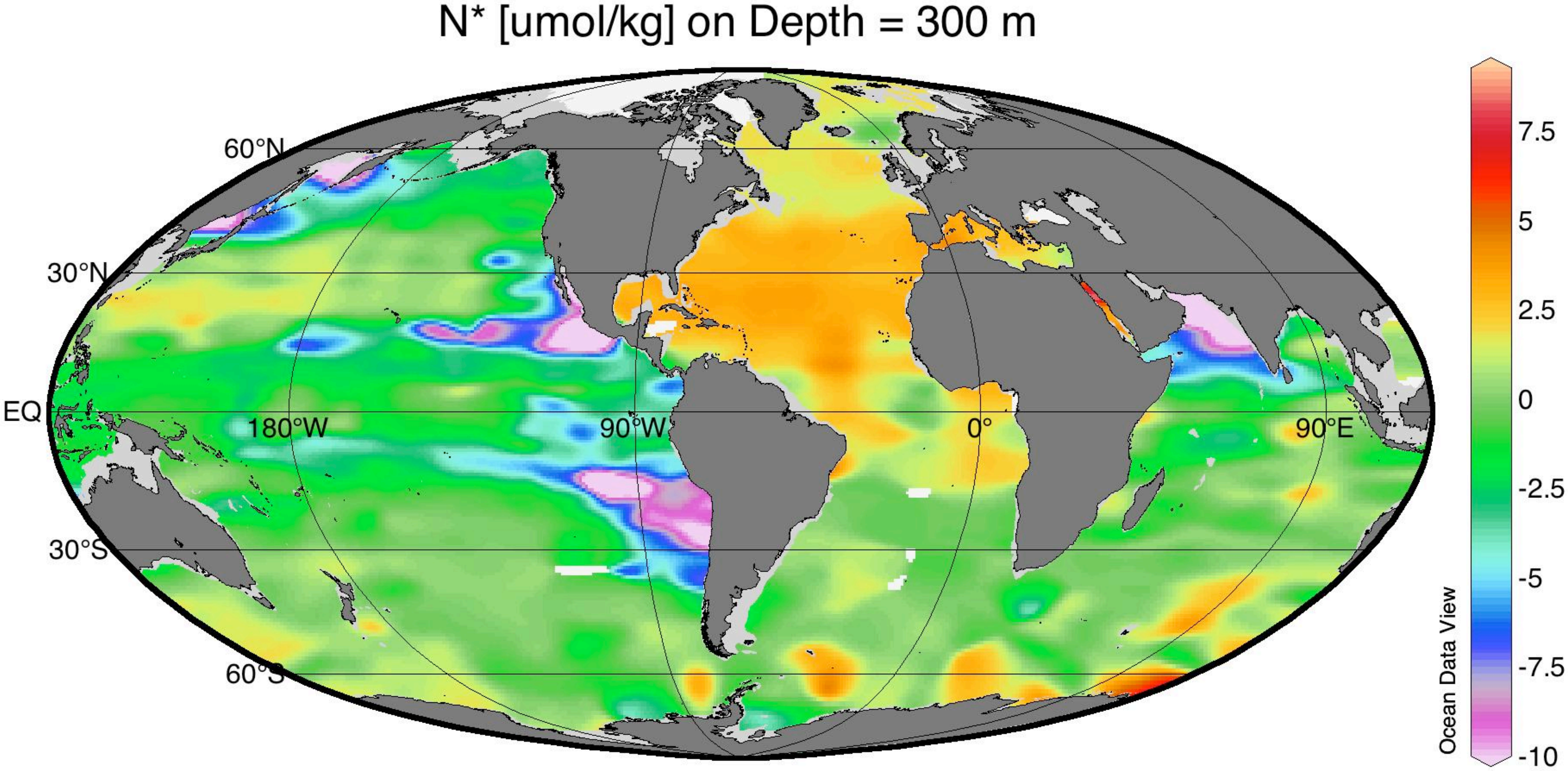
N* in modern time



N = 25790

$N^* = N - 16P$ (Gruber & Sarmiento 1997)

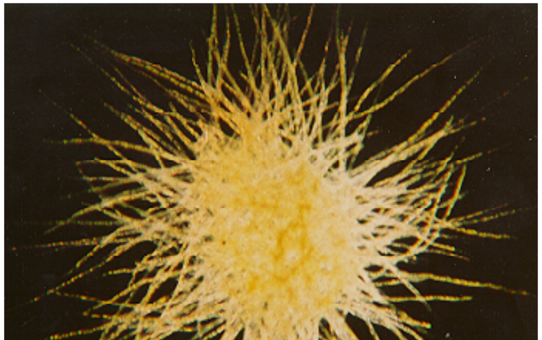
N* Distribution Shows Interplay Between N_2-Fixation and Denitrification

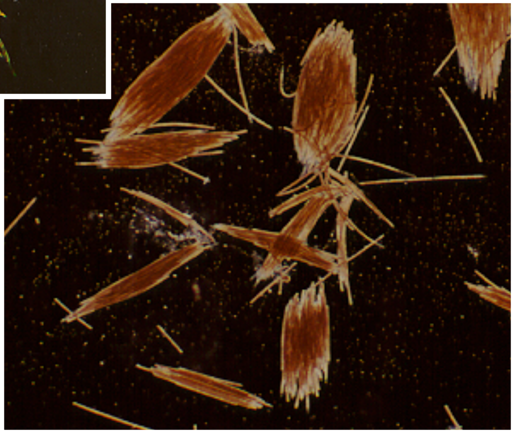


$N^* = 0.87([NO_3^-] - 16[PO_4^{3-}] + 2.9)$ (Gruber & Sarmiento 1997)

Trichodesmium: The Usual Suspect

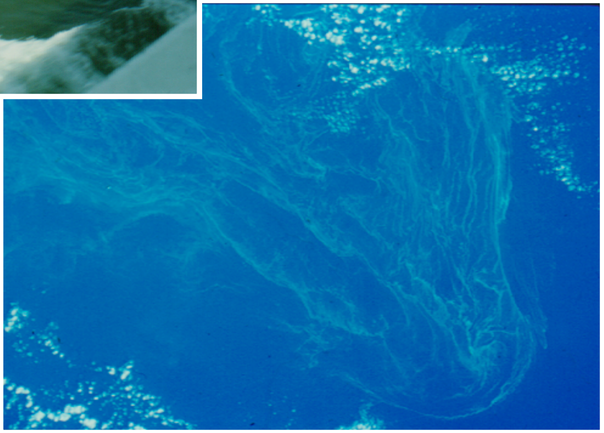
- Diazotrophs, including *Trichodesmium*, are broadly distributed in nutrient poor oceanic waters, but their contribution to the marine N budget remains poorly constrained.



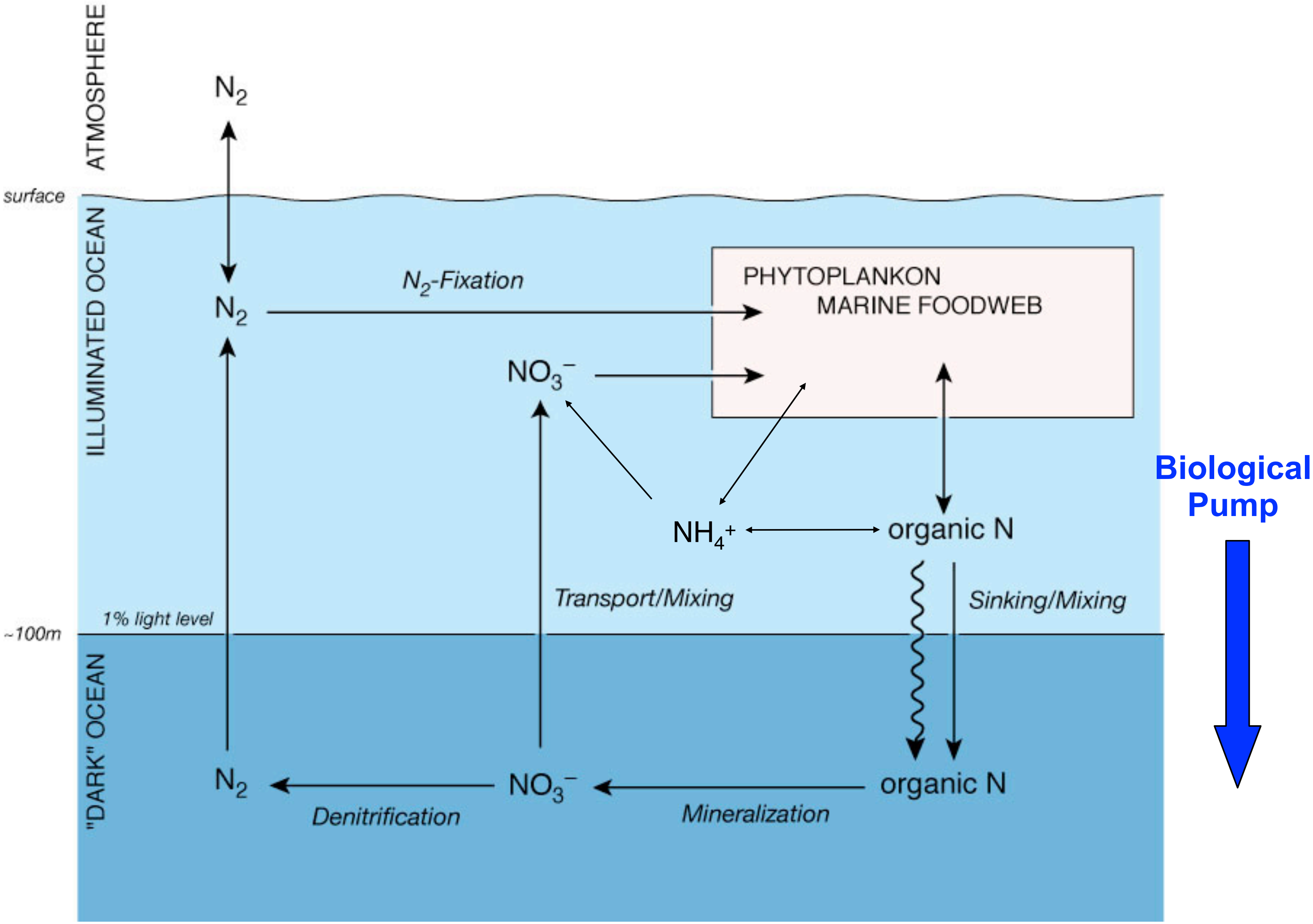


Trichodesmium puffs (above) and tufts (right). Photos by Hans Paerl.

Trichodesmium blooms from aboard ship (left) and from space (below).



Oceanic N Cycle Schematic



ATMOSPHERE

N_2

surface

ILLUMINATED OCEAN

N_2

N_2-Fixation

PHYTOPLANKON
MARINE FOODWEB

NO_3^-

NH_4^+

organic N

Transport/Mixing

Sinking/Mixing

1% light level

~100m

"DARK" OCEAN

N_2

NO_3^-

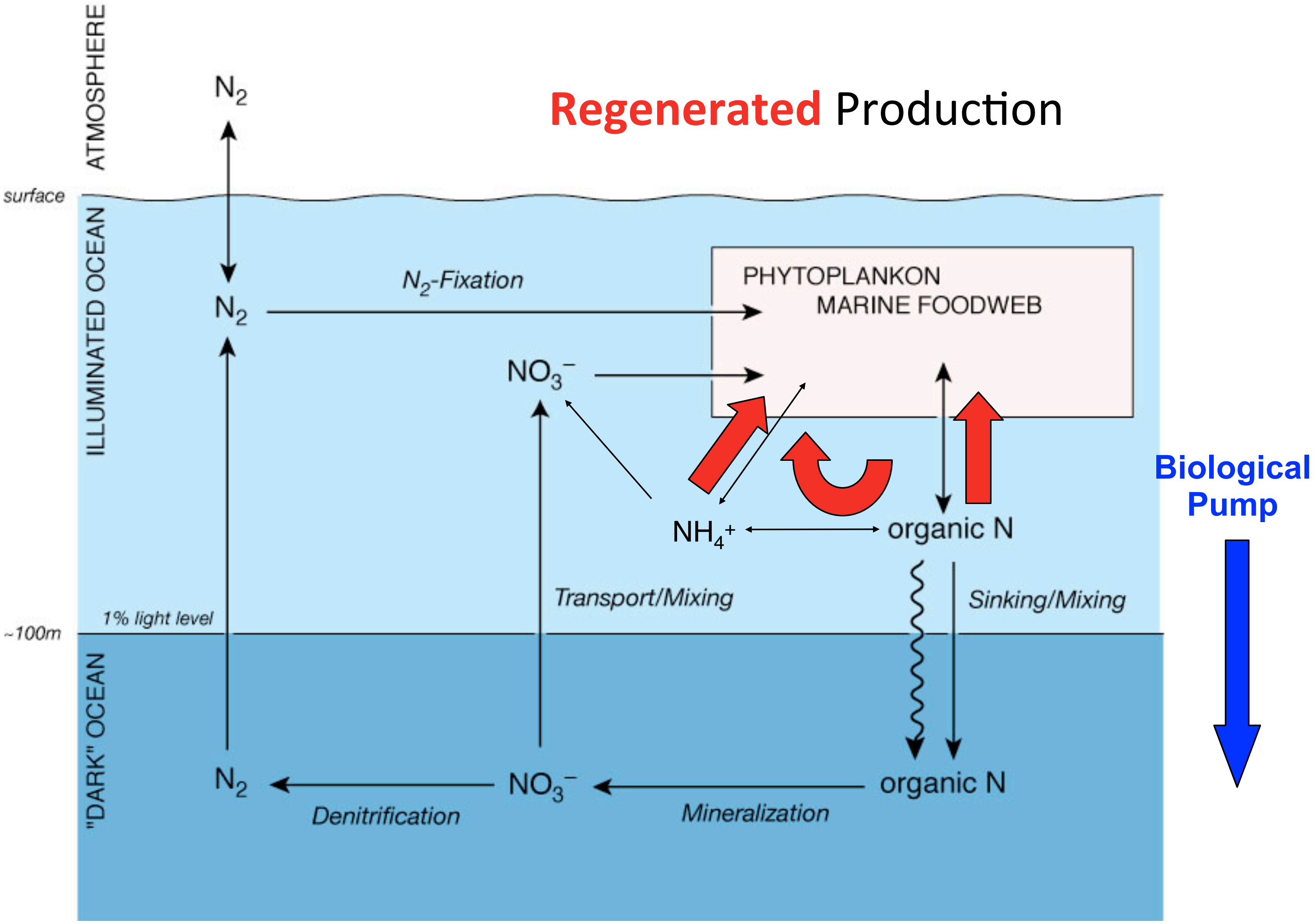
organic N

Denitrification

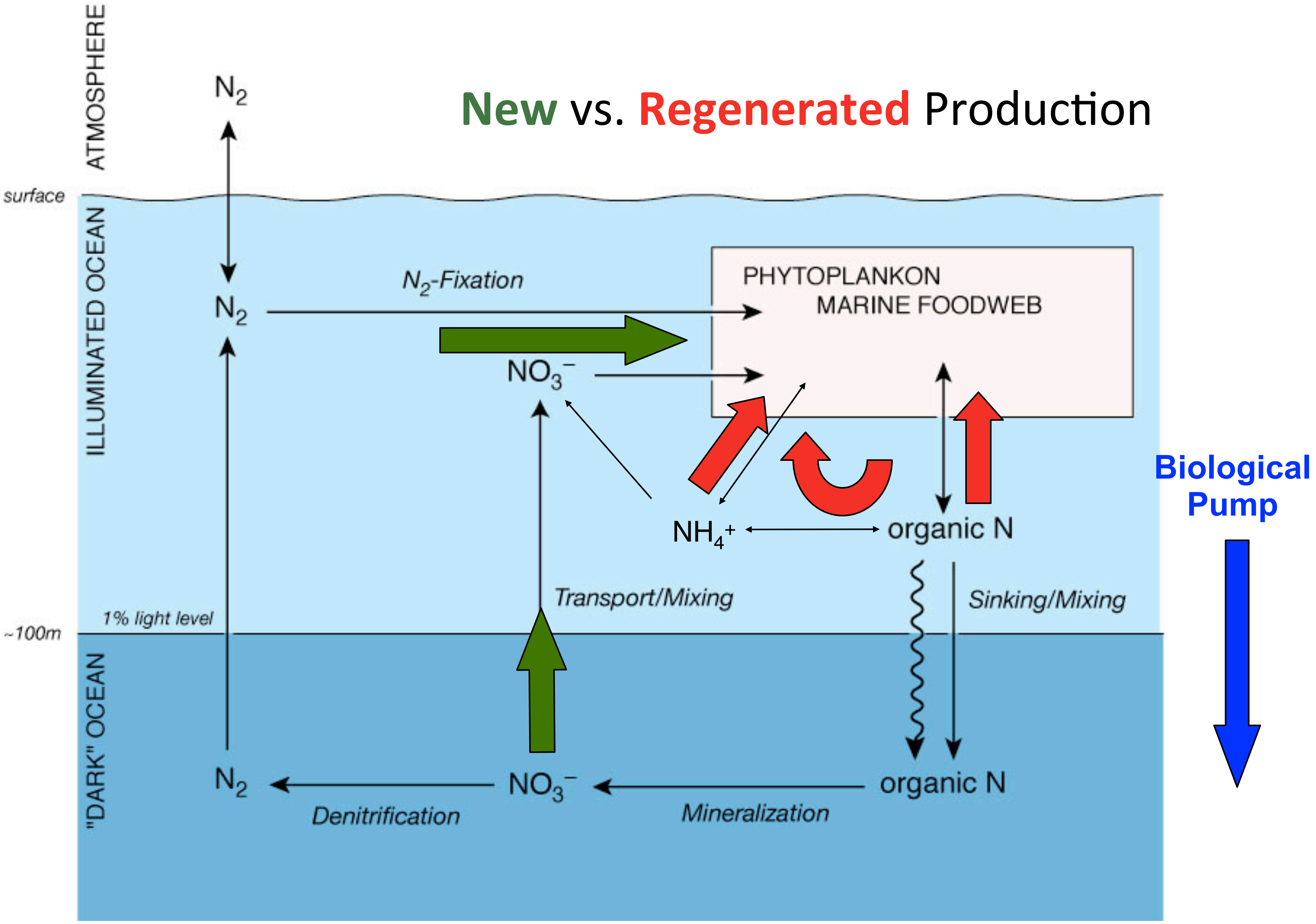
Mineralization

Biological Pump

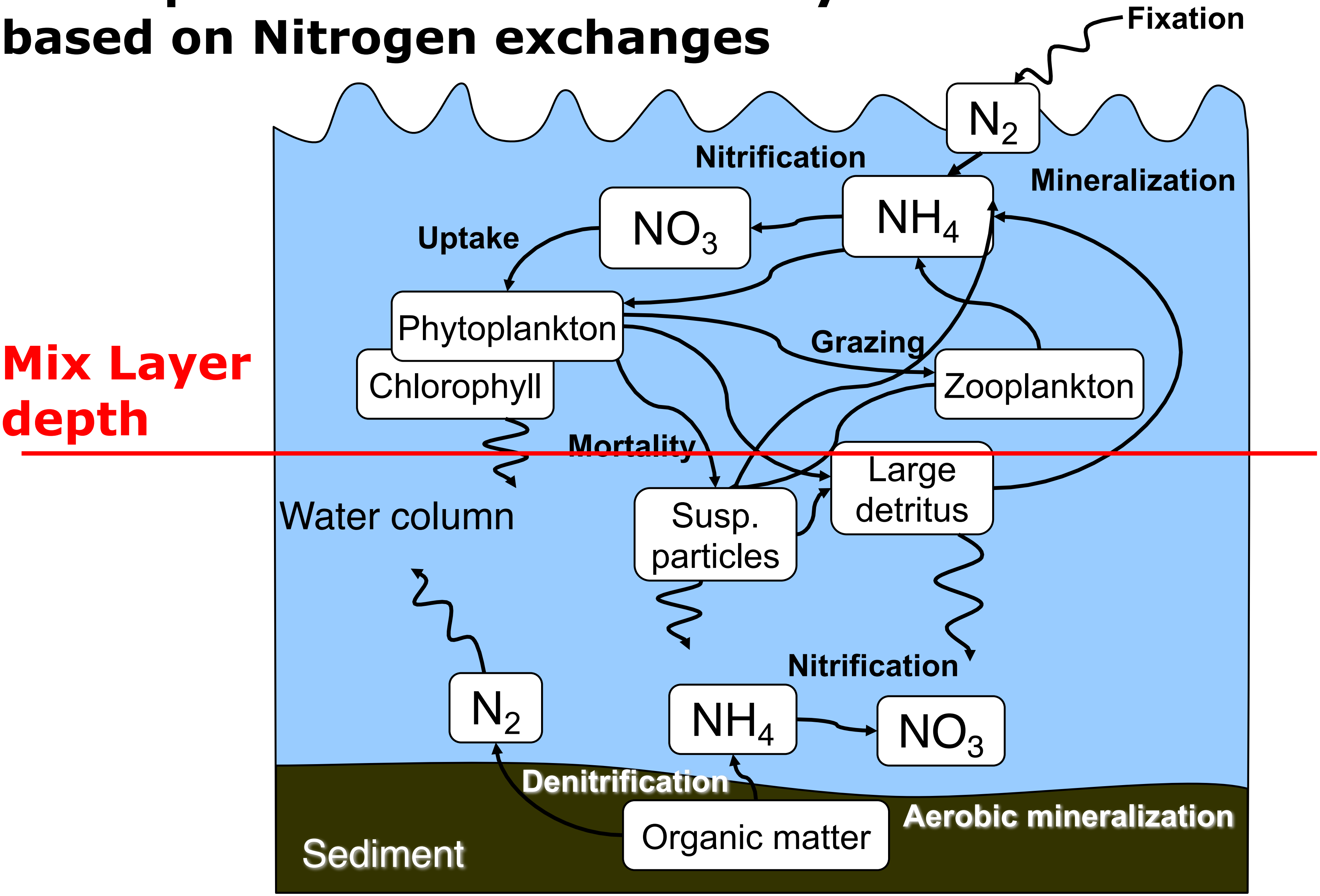
Oceanic N Cycle Schematic



Oceanic N Cycle Schematic



Description of the oceanic ecosystem based on Nitrogen exchanges



Fixation

N_2

Nitrification

Mineralization

NO_3

NH_4

Uptake

Phytoplankton

Chlorophyll

Grazing

Zooplankton

Mix Layer depth

Mortality

Large detritus

Water column

Susp. particles

Nitrification

N_2

NH_4

NO_3

Denitrification

Aerobic mineralization

Organic matter

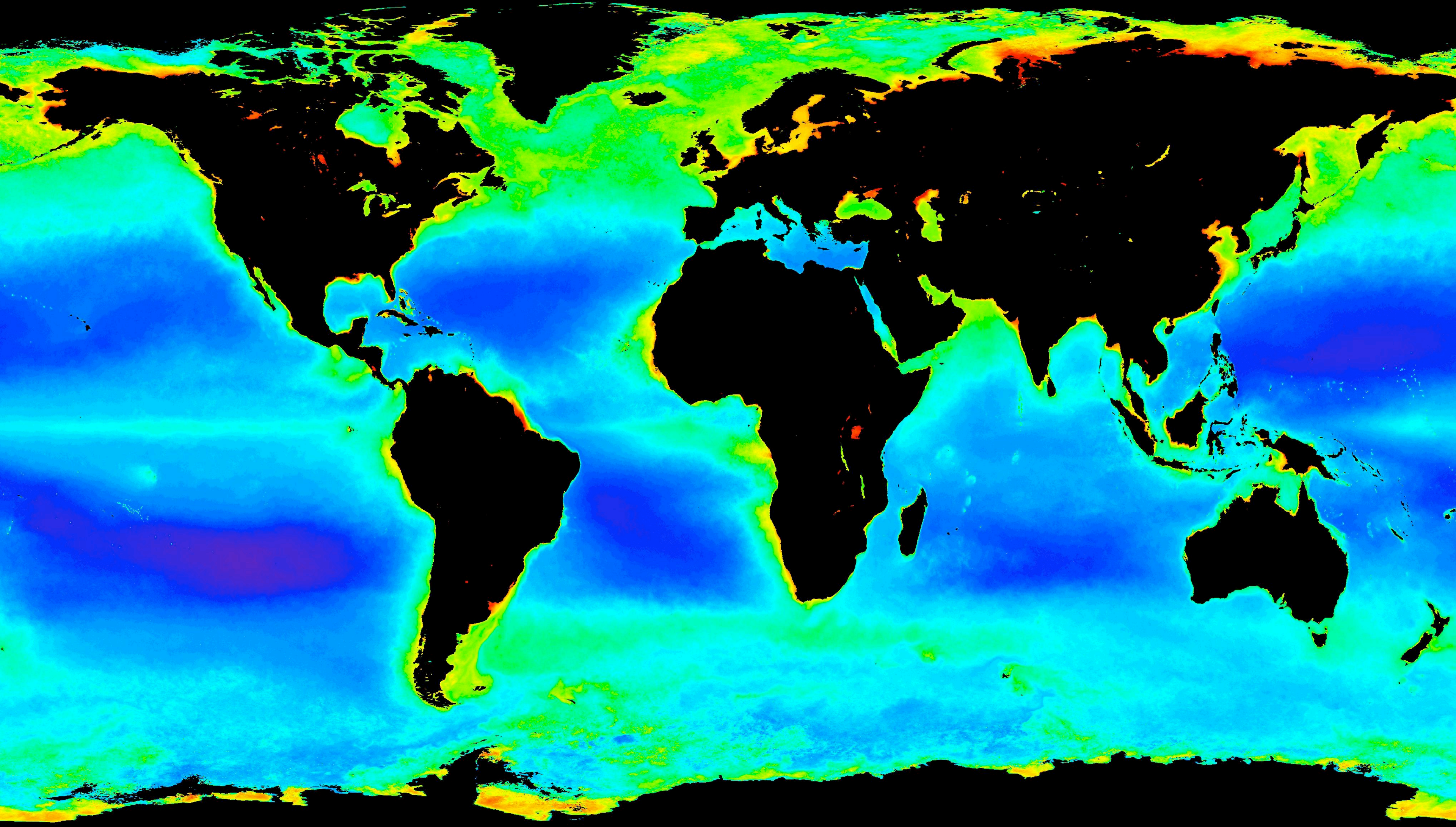
Sediment

Organic Matter Oxidation Sequence

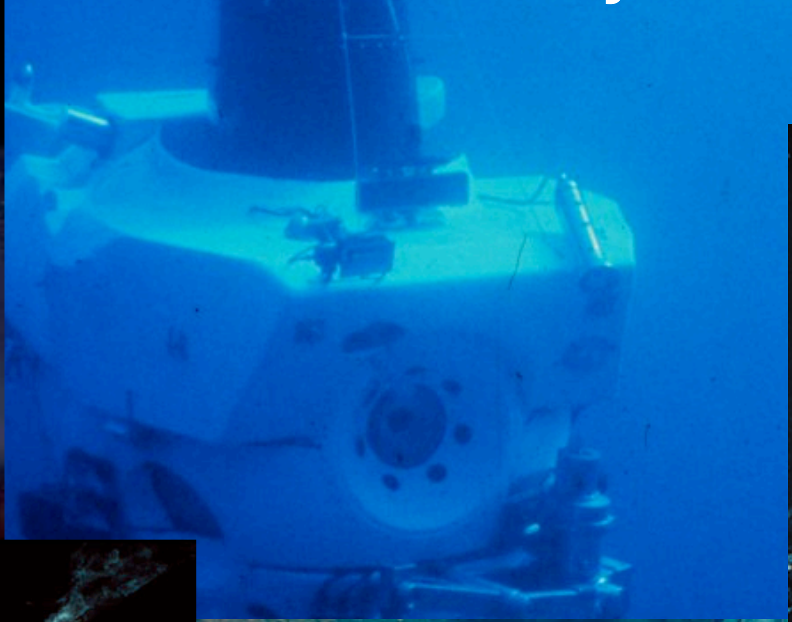
Morel & Herring, 1993

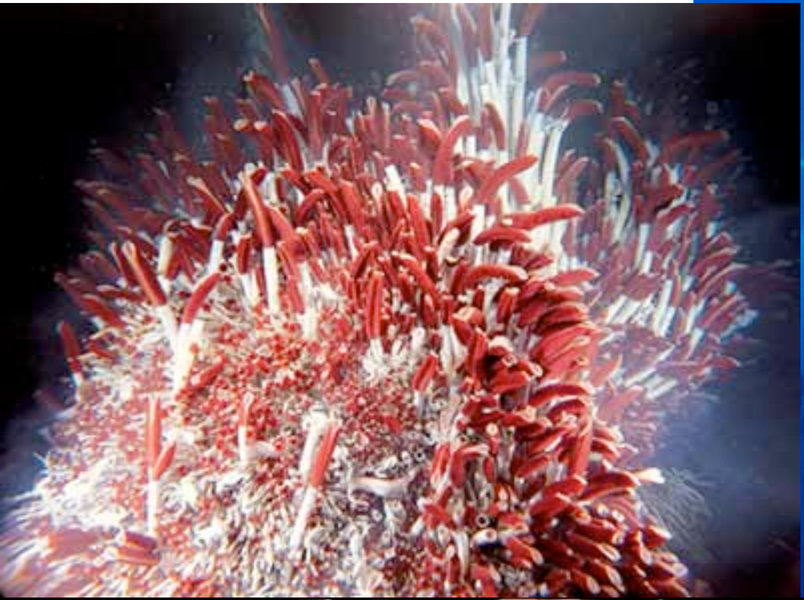
	ΔG° (kJ/mol)
Respiration $\tfrac{1}{4}CH_2O + \tfrac{1}{4}O_2 \leftrightarrows \tfrac{1}{4}CO_2 + \tfrac{1}{4}H_2O$	-119
Denitrification $\tfrac{1}{4}CH_2O + \tfrac{1}{5}NO_3^- + \tfrac{1}{5}H^+ \leftrightarrows \tfrac{1}{4}CO_2 + \tfrac{1}{10}N_2 + \tfrac{1}{2}H_2O$	-113
MnO_2 reduction $\tfrac{1}{4}CH_2O + \tfrac{1}{8}MnO_2 + H^+ \leftrightarrows \tfrac{1}{4}CO_2 + \tfrac{1}{2}Mn^{2+} + \tfrac{3}{4}H_2O$	-96.9
Fe oxide reduction $\tfrac{1}{4}CH_2O + Fe(OH)_3 + 2H^+ \leftrightarrows Fe^{2+} + \tfrac{1}{4}CO_2 + \tfrac{11}{4}H_2O$	-46.7
Sulfate reduction $\tfrac{1}{4}CH_2O + \tfrac{1}{8}SO_4^{2-} + \tfrac{1}{8}H^+ \leftrightarrows \tfrac{1}{8}HS^- + \tfrac{1}{4}CO_2 + \tfrac{1}{4}H_2O$	-20.5
Methanogenesis $\tfrac{1}{4}CH_2O \leftrightarrows \tfrac{1}{8}CH_4 + \tfrac{1}{8}CO_2$	-17.7

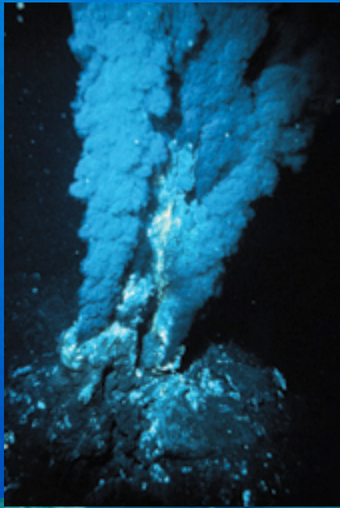
Ocean Ecosystem fueled my solar energy

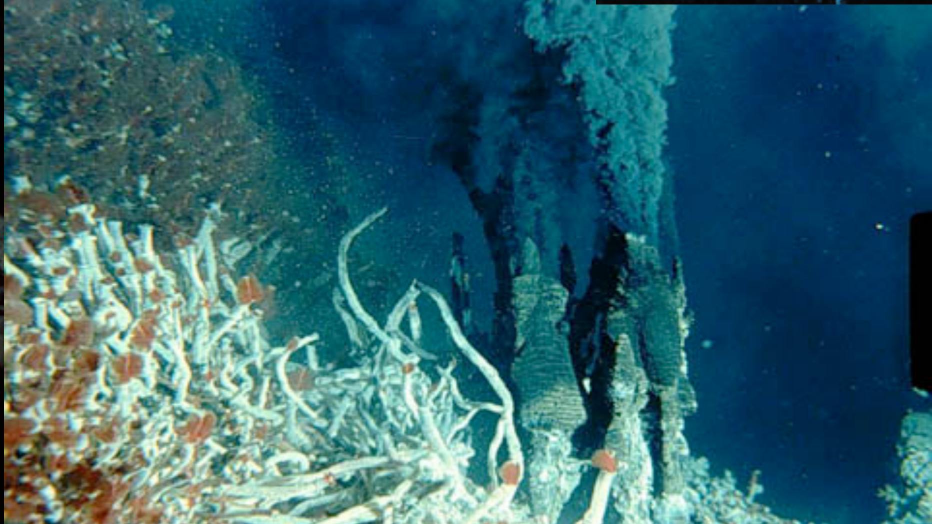


Hydrothermal Vents and the discovery of new ecosystems

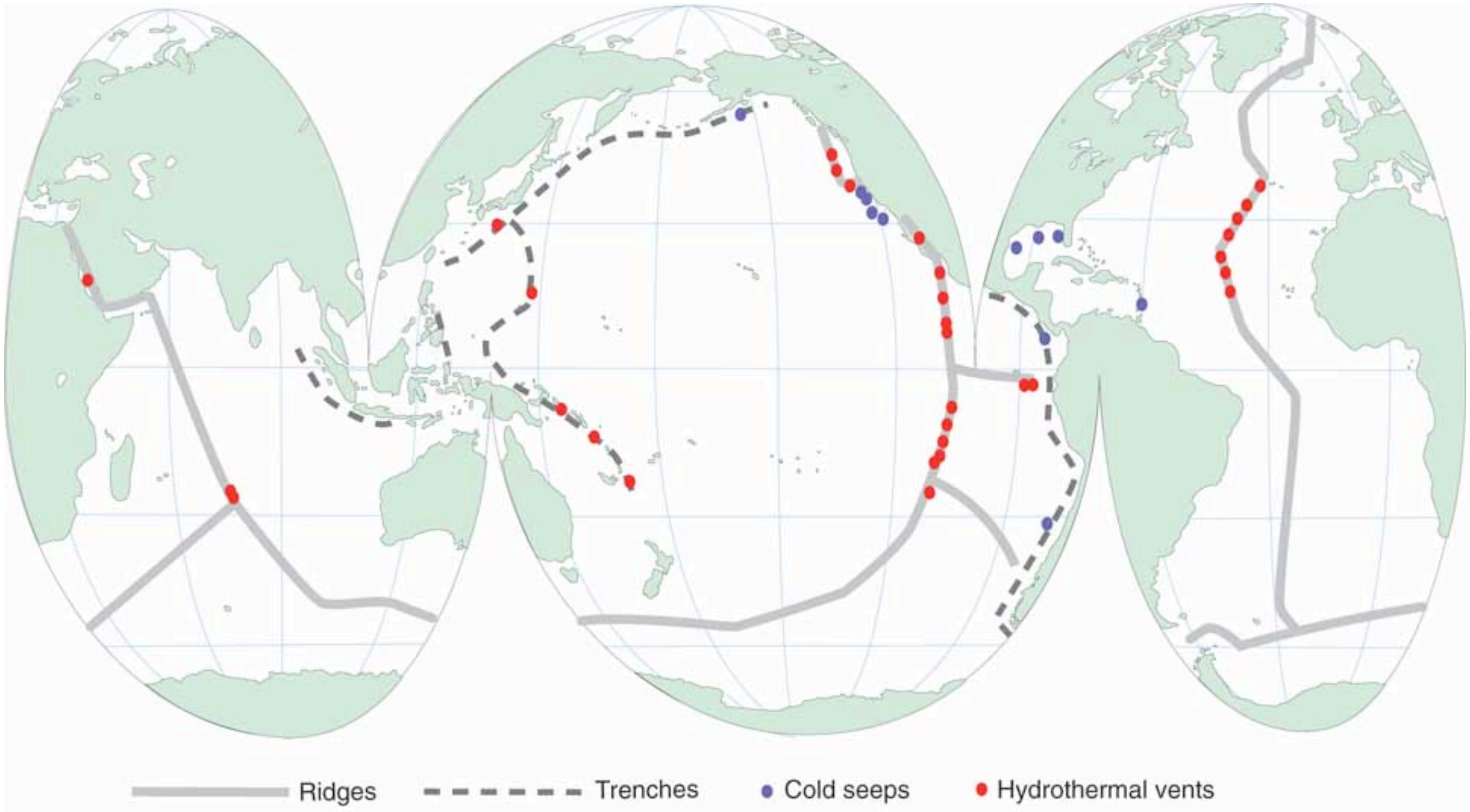


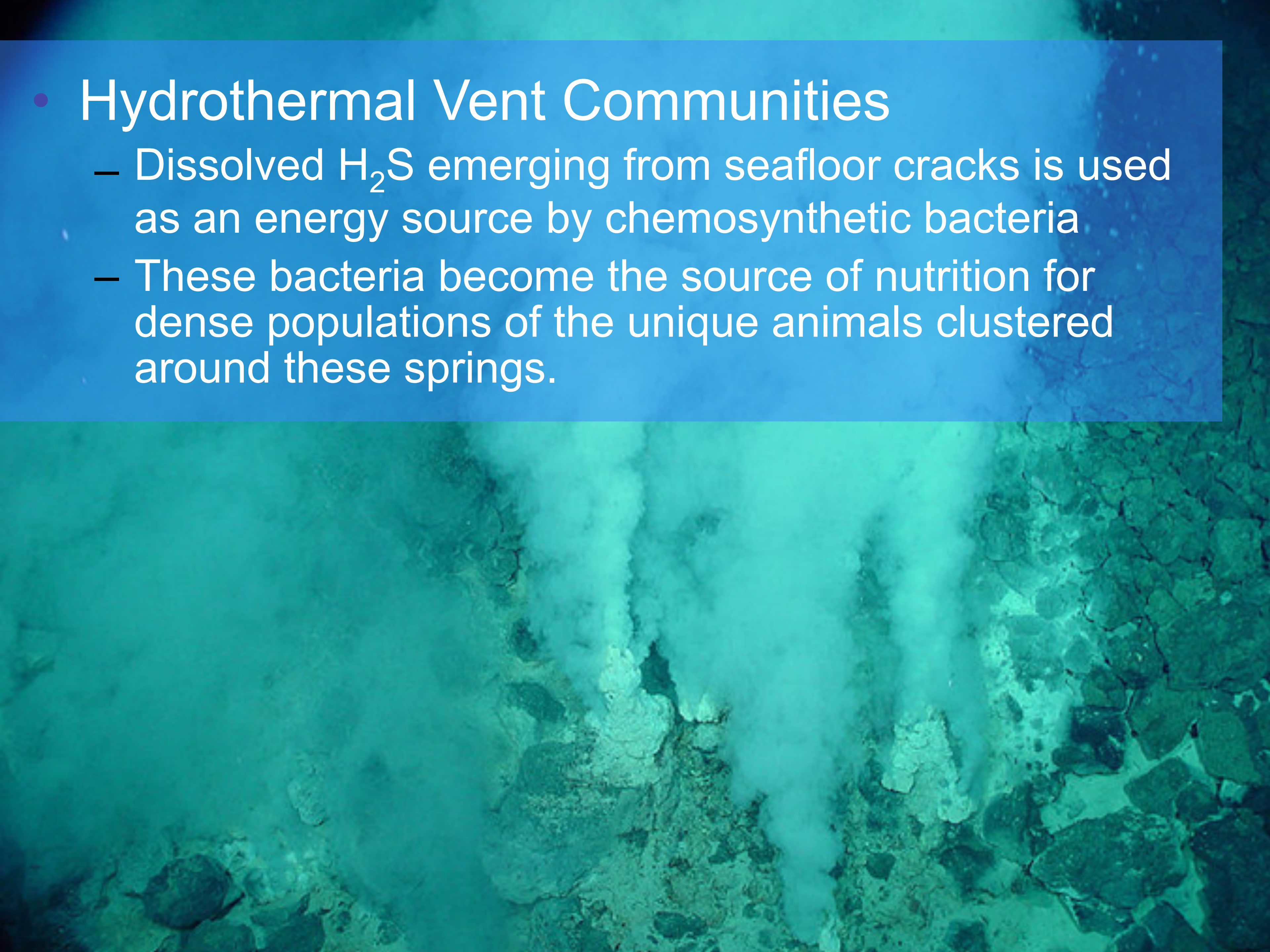






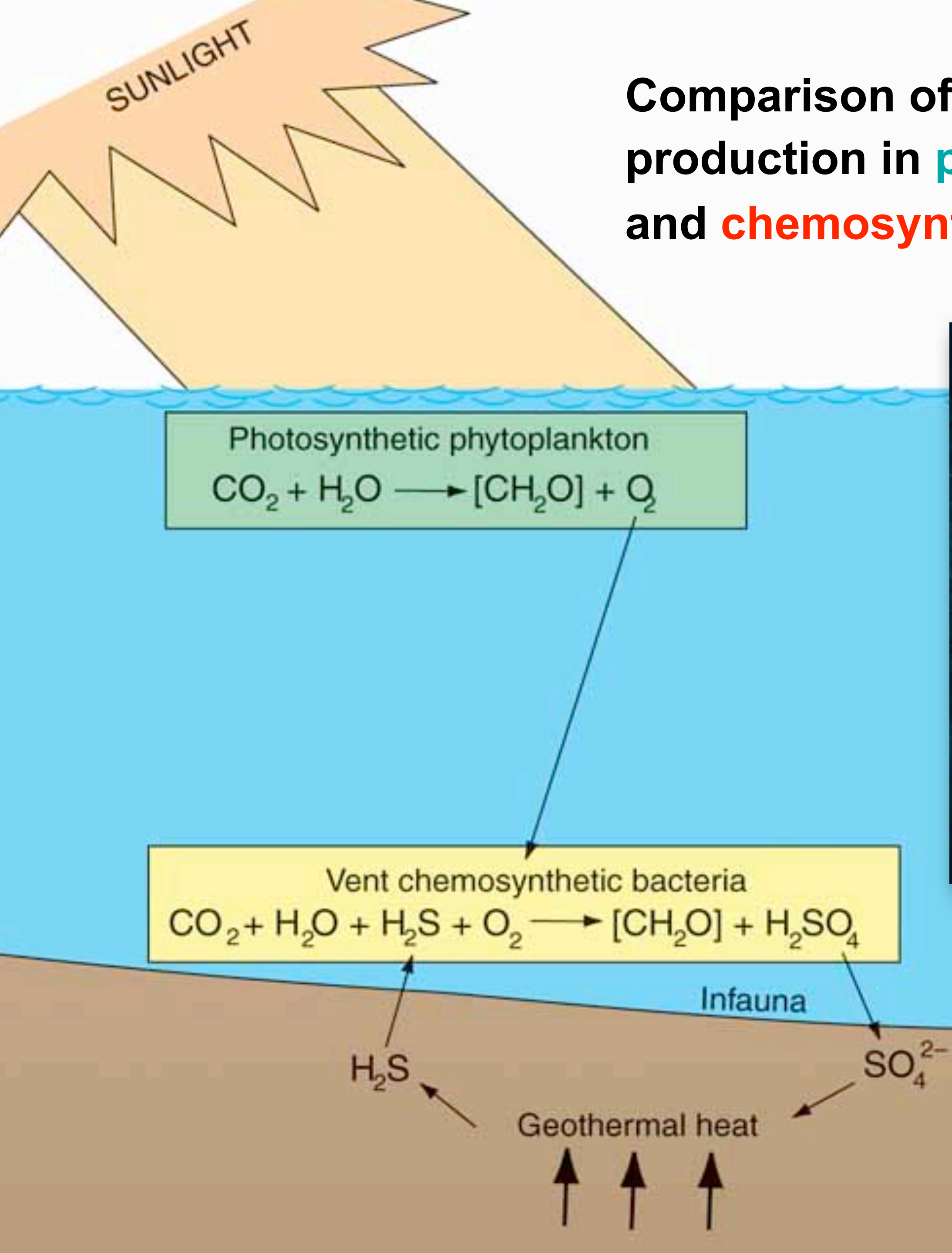
Hydrothermal vent communities (red dots) and cold seeps (blue dots).

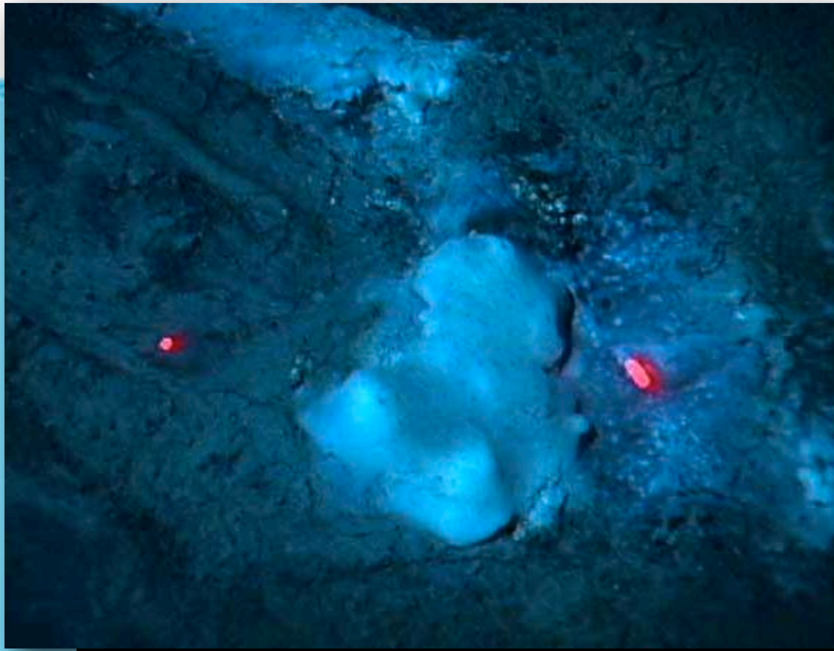




- Hydrothermal Vent Communities
  - Dissolved H_2S emerging from seafloor cracks is used as an energy source by chemosynthetic bacteria
  - These bacteria become the source of nutrition for dense populations of the unique animals clustered around these springs.

Comparison of primary production in phothsynthetic and chemosynthetic systems.



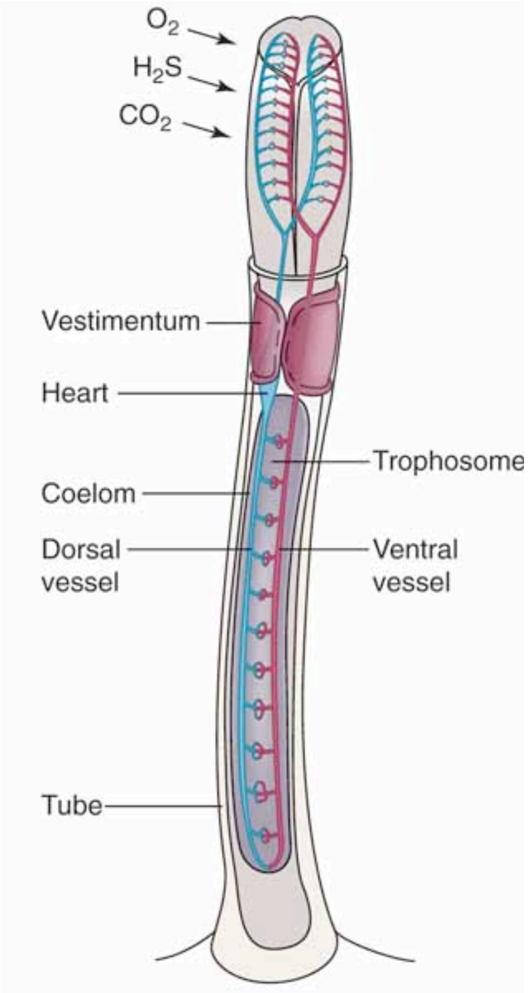


Bacterial mat consisting of sulfide-oxidizing bacteria *Beggiatoa* spp. at a seep on Blake Ridge, off South Carolina. The red dots are range-finding laser beams.

- **Hydrothermal Vent Communities**

(a)

(b)



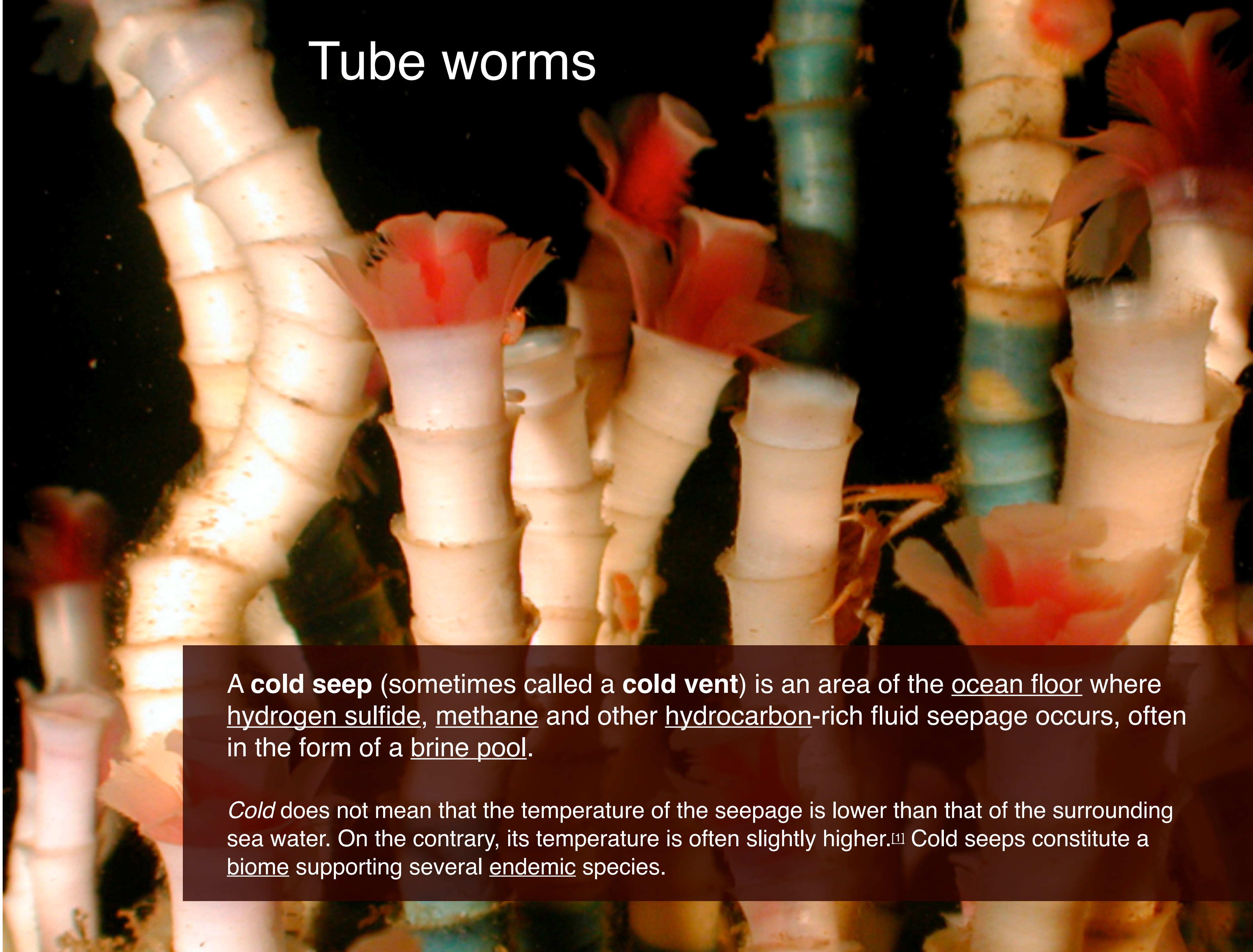
External appearance (a) and internal anatomy (b) of the tubeworm, *Riftia*.

- Cold-Seep Communities
  - Densely populated animal communities dependent on chemosynthetic bacteria, include
    - cold-water brine seeps
    - methane seeps
    - earthquake-disturbed sediments of deep-sea fans

Mussel species *Bathymodiolus childressi*

Cold seeps were discovered in **1983** by Dr. Charles Paull in the Gulf of Mexico at a depth of 3,200 meters

Tube worms



A **cold seep** (sometimes called a **cold vent**) is an area of the ocean floor where hydrogen sulfide, methane and other hydrocarbon-rich fluid seepage occurs, often in the form of a brine pool.

Cold does not mean that the temperature of the seepage is lower than that of the surrounding sea water. On the contrary, its temperature is often slightly higher.[1] Cold seeps constitute a biome supporting several endemic species.

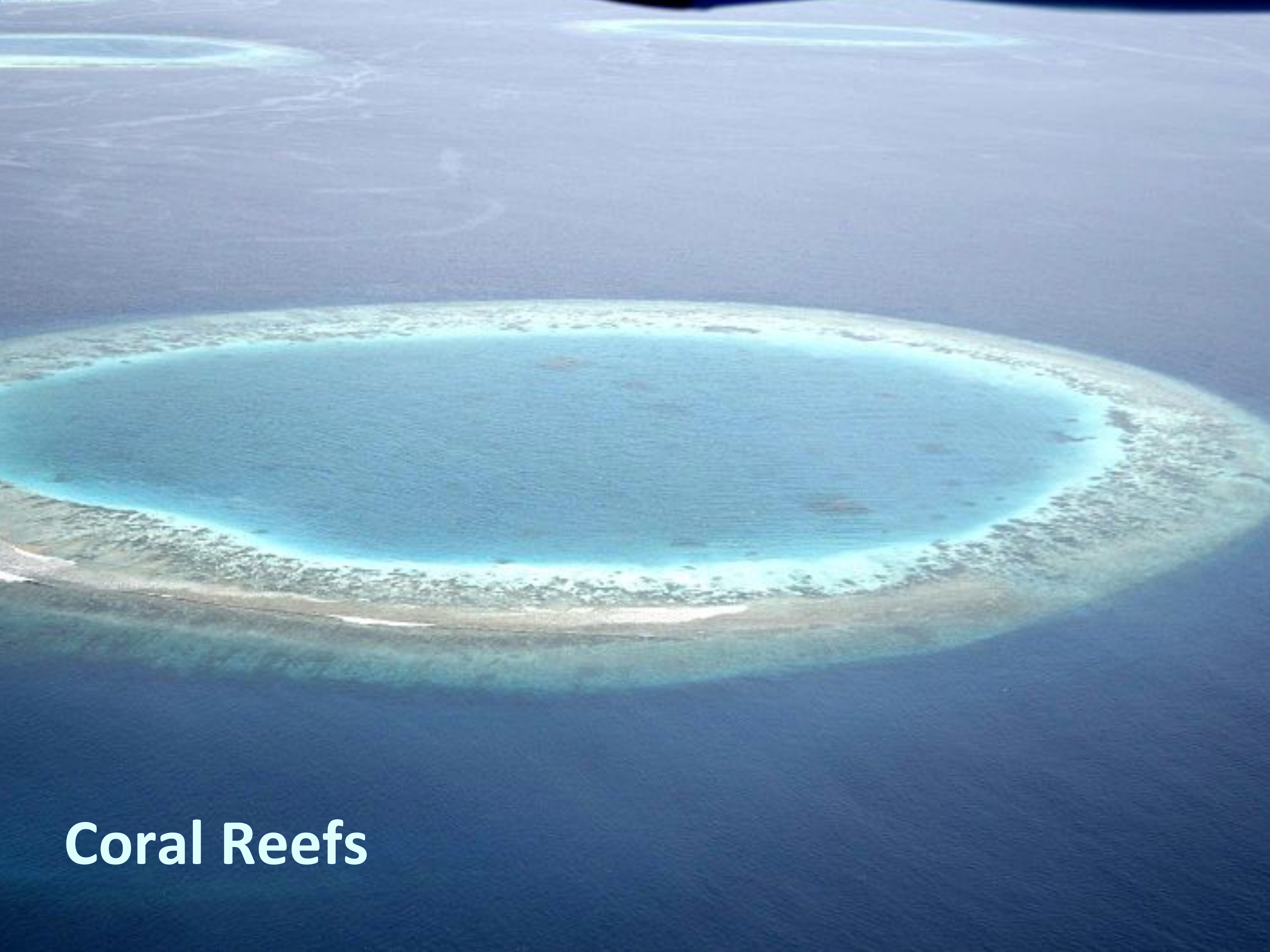
Ocean Ecosystems

Primary Source of Energy

- Surface Ocean (*photosynethesis*)
- Ocean Floor (*chemiosynthesis*, hydrothermal vents and cold seeps)

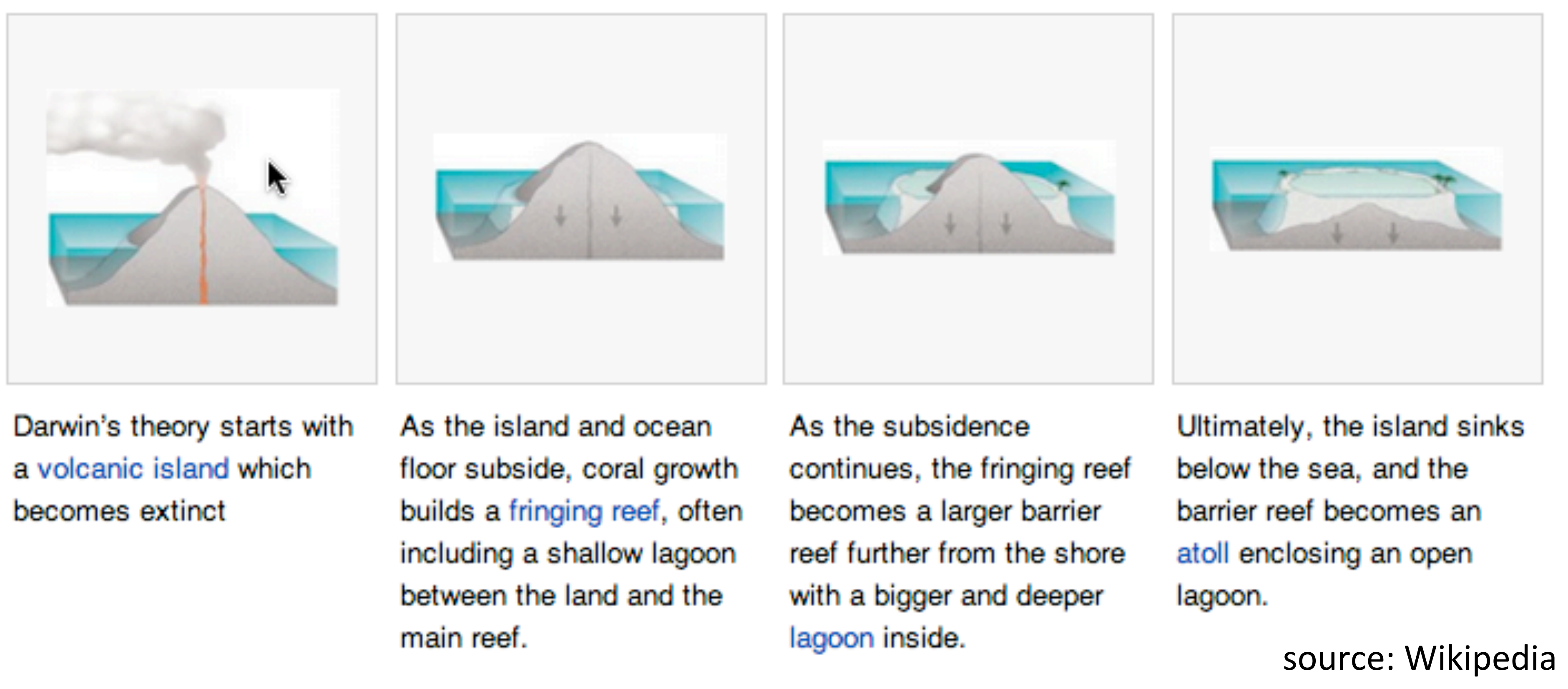
Niches and communities

- Coral Reefs
- Kelp Forests
- Intertidal community
- Polar regions



Coral Reefs

Formation of a Coral Reef



Darwin's theory starts with a volcanic island which becomes extinct

As the island and ocean floor subside, coral growth builds a fringing reef, often including a shallow lagoon between the land and the main reef.

As the subsidence continues, the fringing reef becomes a larger barrier reef further from the shore with a bigger and deeper lagoon inside.

Ultimately, the island sinks below the sea, and the barrier reef becomes an atoll enclosing an open lagoon.

source: Wikipedia

Coral Reefs

Coral Reefs & Ocean Biodiversity

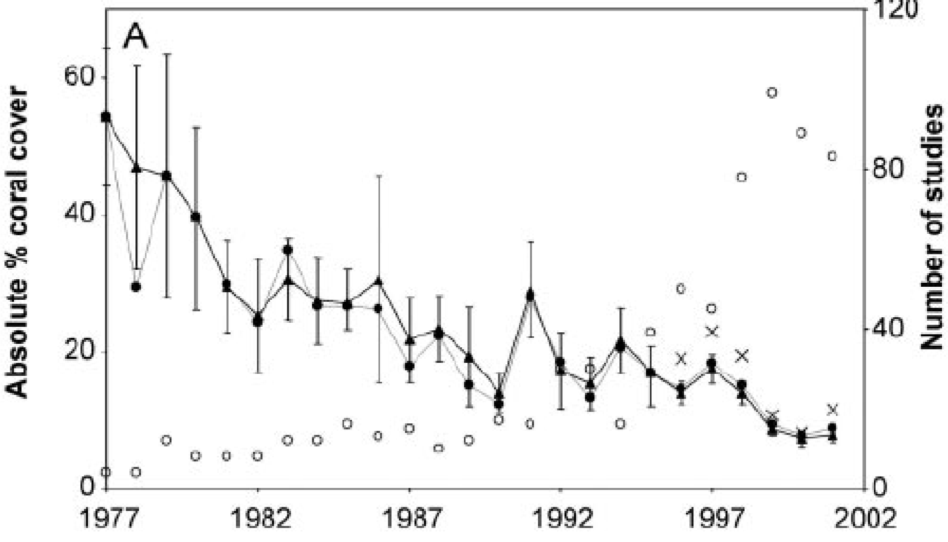
25% of all marine species (*e.g. fish, mollusks, worms, crustaceans, echinoderms, sponges, tunicates and other cnidarians*).

Coral Reefs

Coral Reefs & Ocean Biodiversity

25% of all marine species (*e.g. fish, mollusks, worms, crustaceans, echinoderms, sponges, tunicates and other cnidarians*).

Gardner et al. 2003

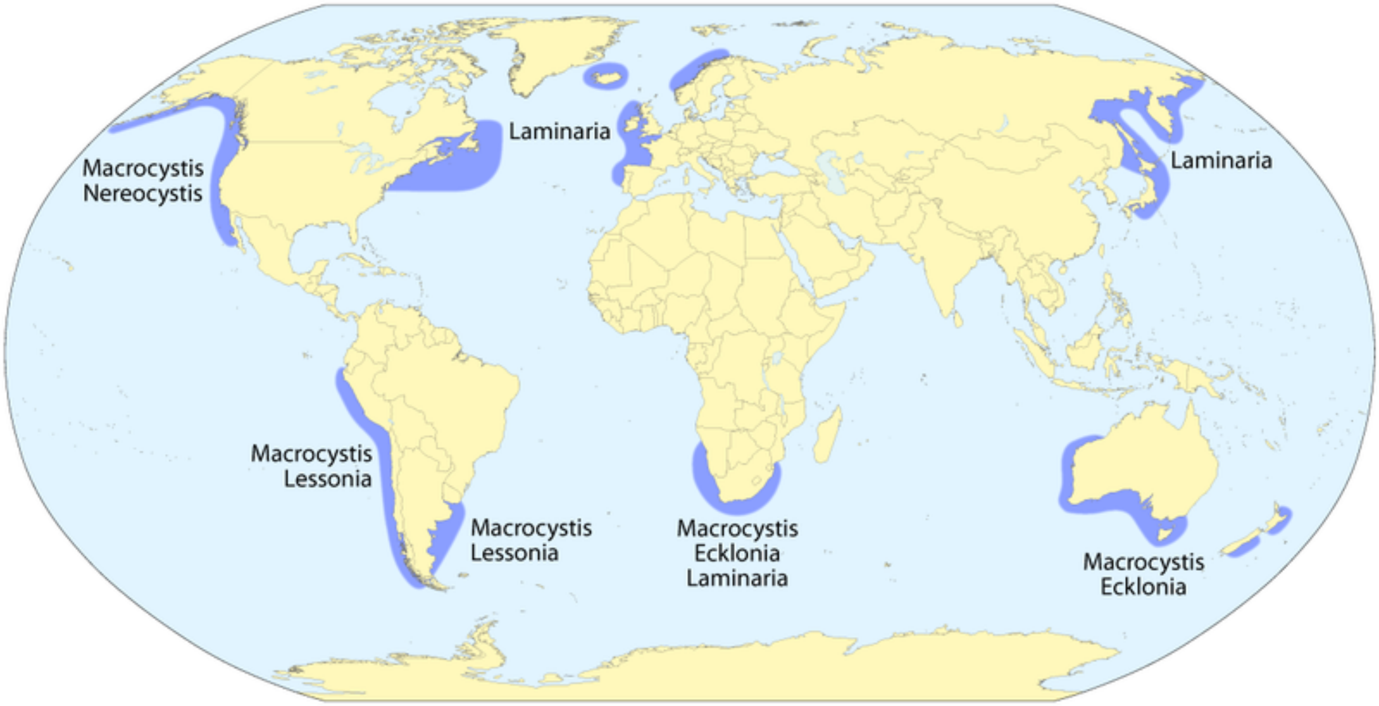


Coral Reefs

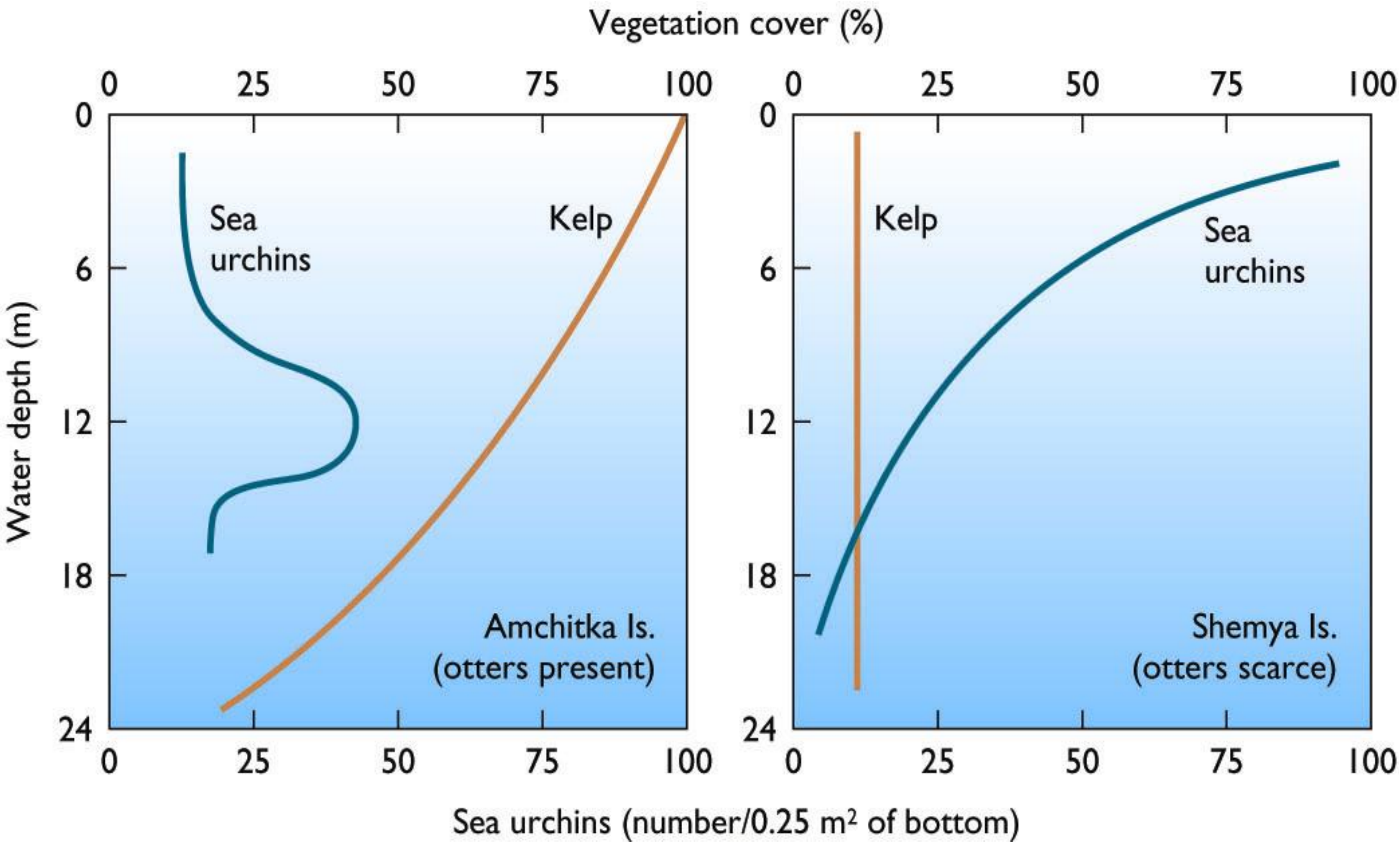
Kelp Forests

most productive and dynamic ecosystems formed by brown macroalgae

Distribution of Kelp Forests



Kelp Forests - *ecology*



Inter-tidal Community