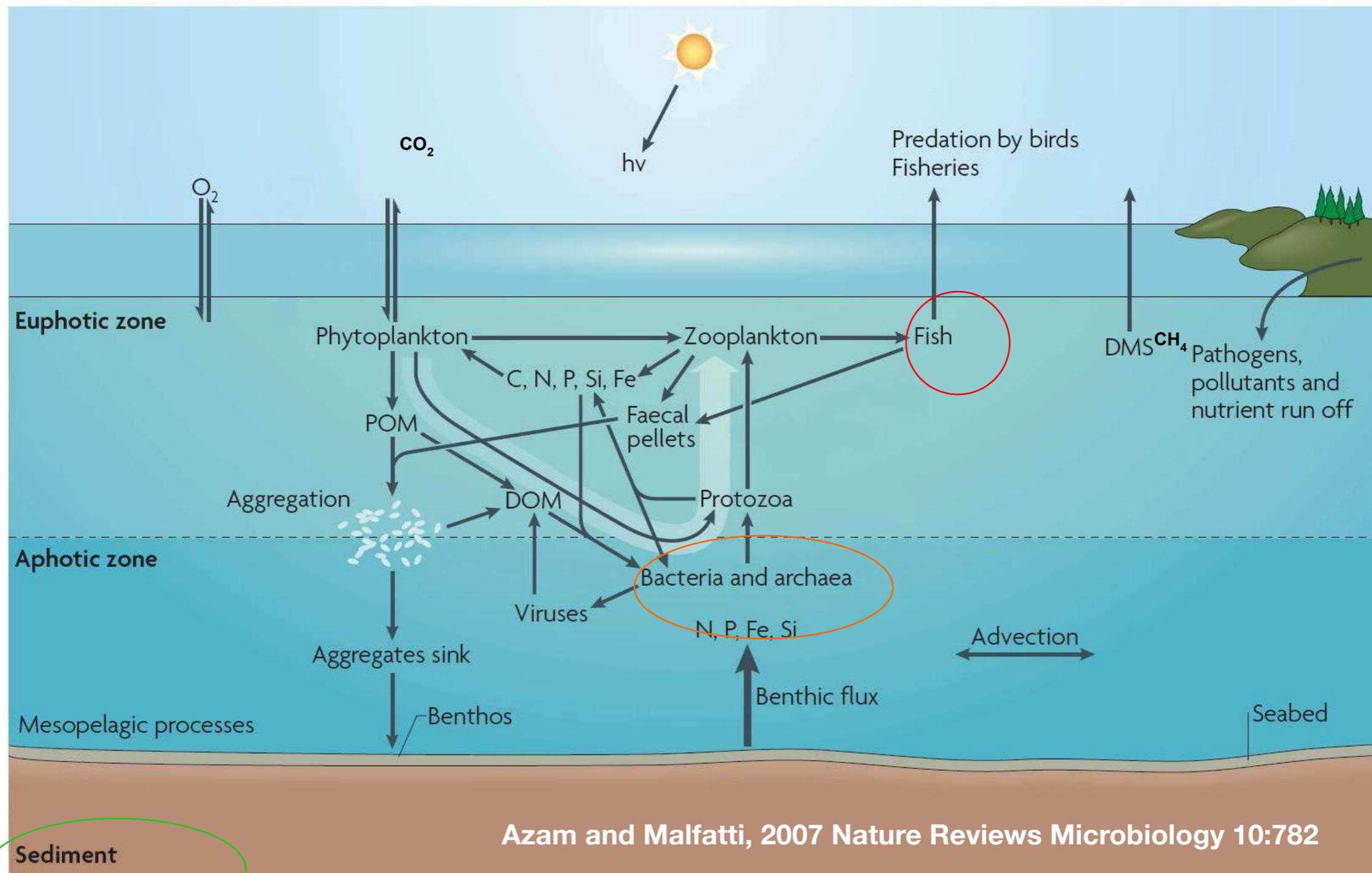


# **L04b: Biogeochemical Carbon Cycle**

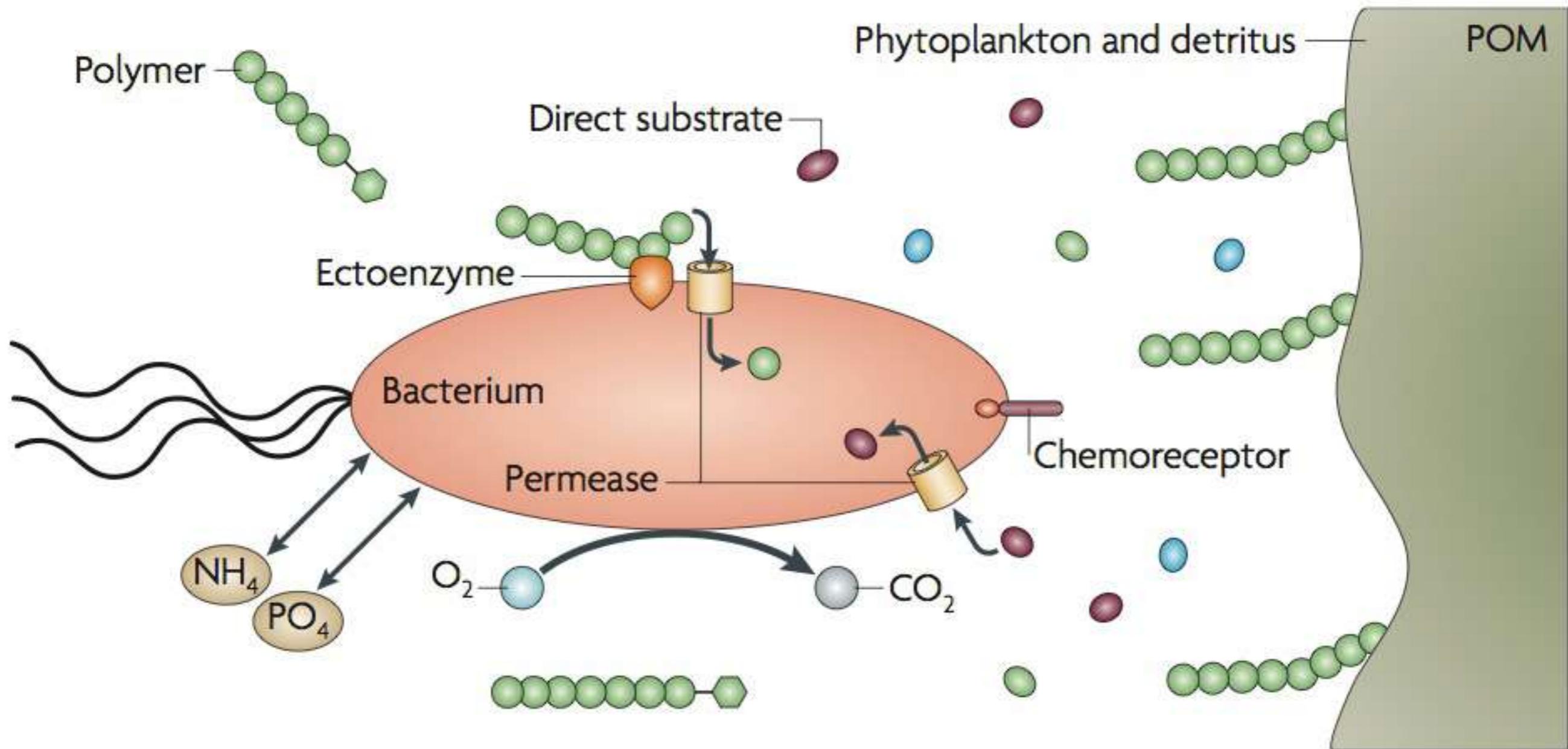
# Biological Carbon Pump - Microbial loop

## - Microbial Carbon Pump



Azam and Malfatti, 2007 Nature Reviews Microbiology 10:782

# Adaptive strategies of heterotrophic bacteria in the ocean

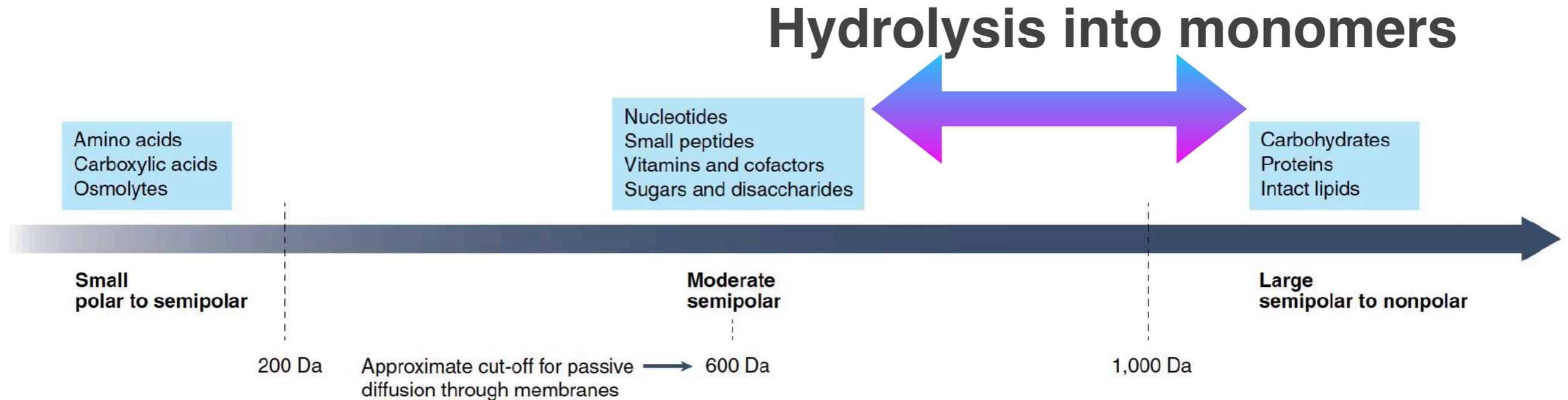


by Farooq Azam

Azam and Malfatti, 2007 Nature Reviews Microbiology 10:782

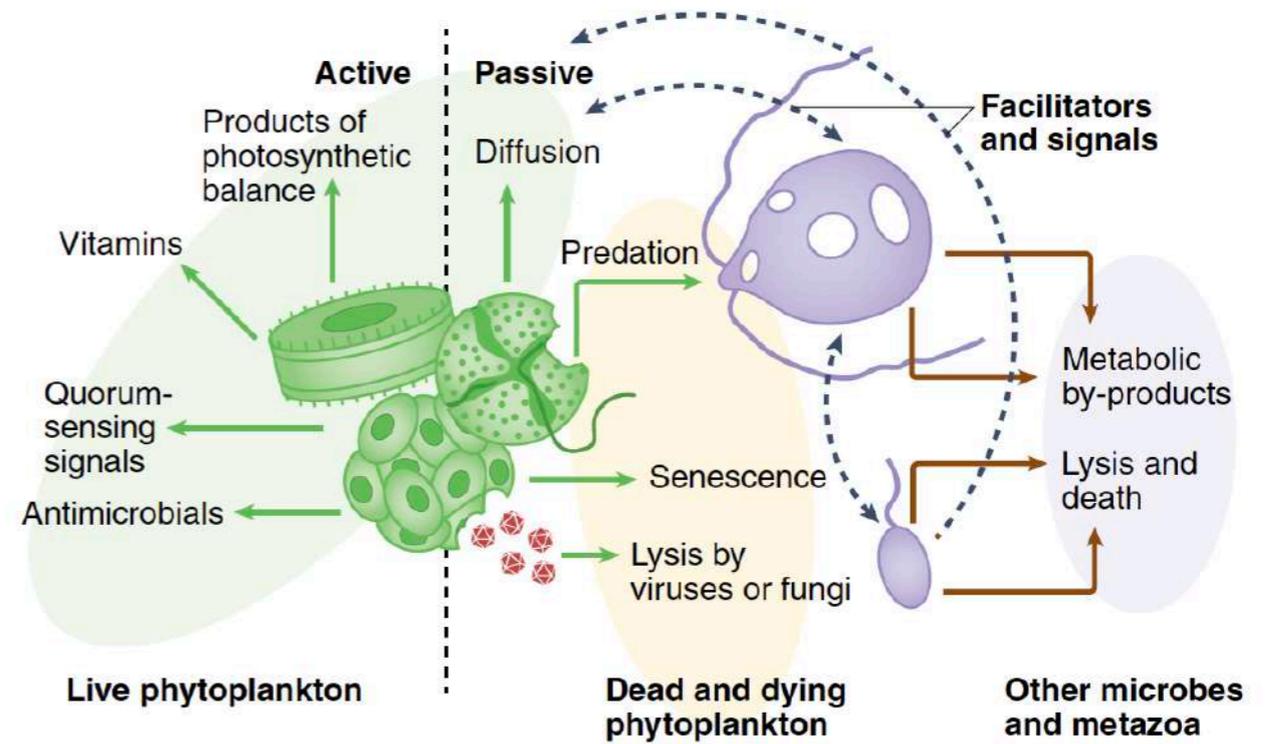
- Motility, environmental sensing, permeases and cell-surface hydrolases
- Adapted fine biochemical strategies to interact with organic matter natural and human-created

# DOM size and reactivity



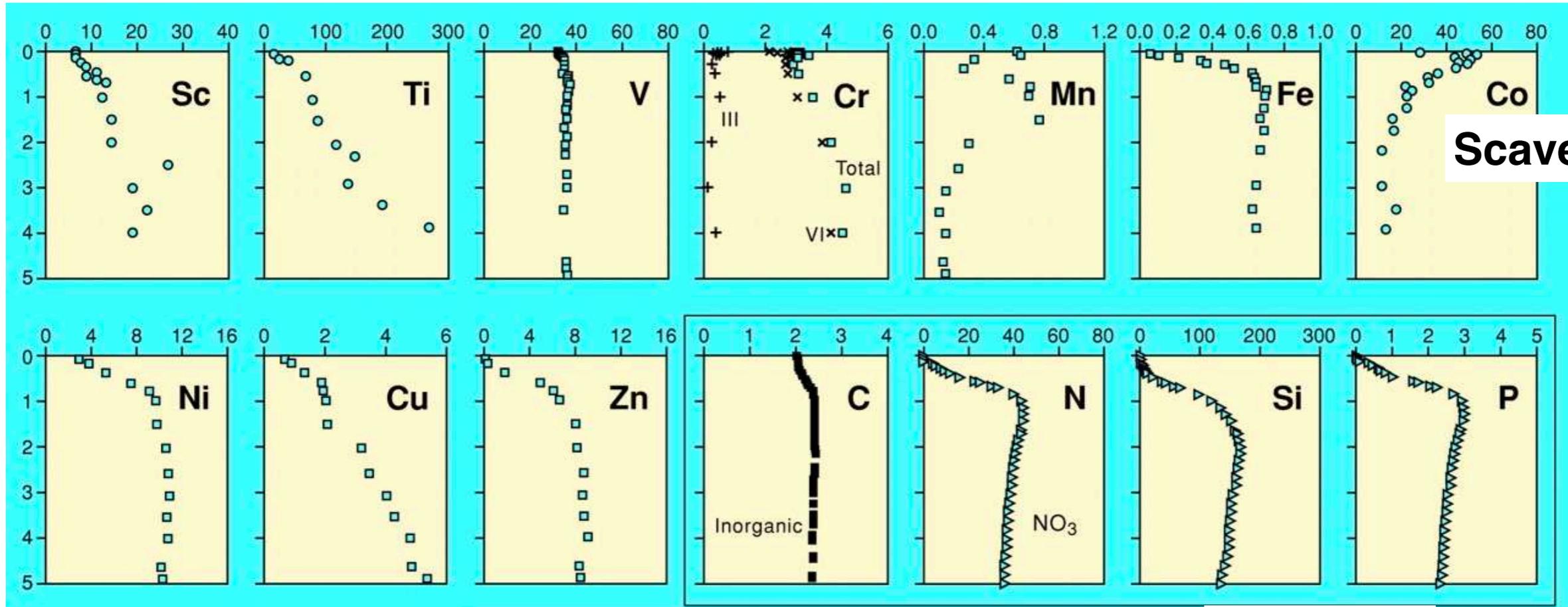
Actively photosynthesizing marine phytoplankton generate exometabolites (metabolites released into surrounding seawater) that form a pool of carbon named 'extracellular release' or 'dissolved primary production'

**Green arrows** indicate substrate metabolites derived from primary production, whereas **brown arrows** indicate those from secondary production



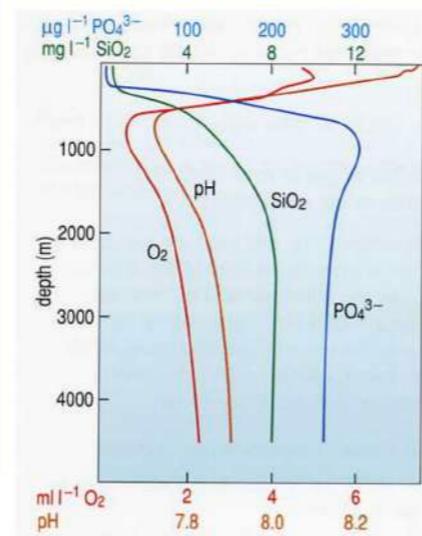
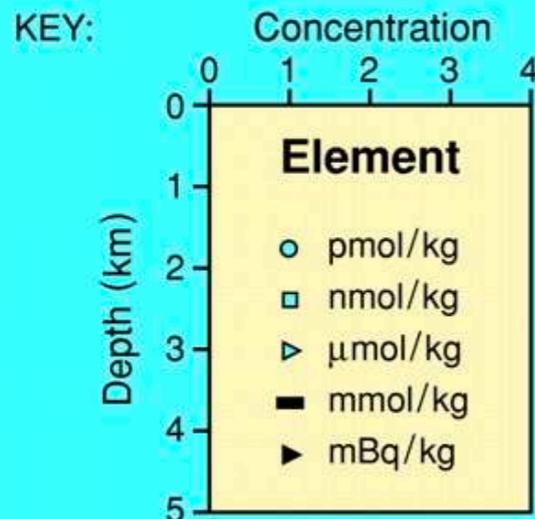
# Nutrients

## Conservative



Scavenged

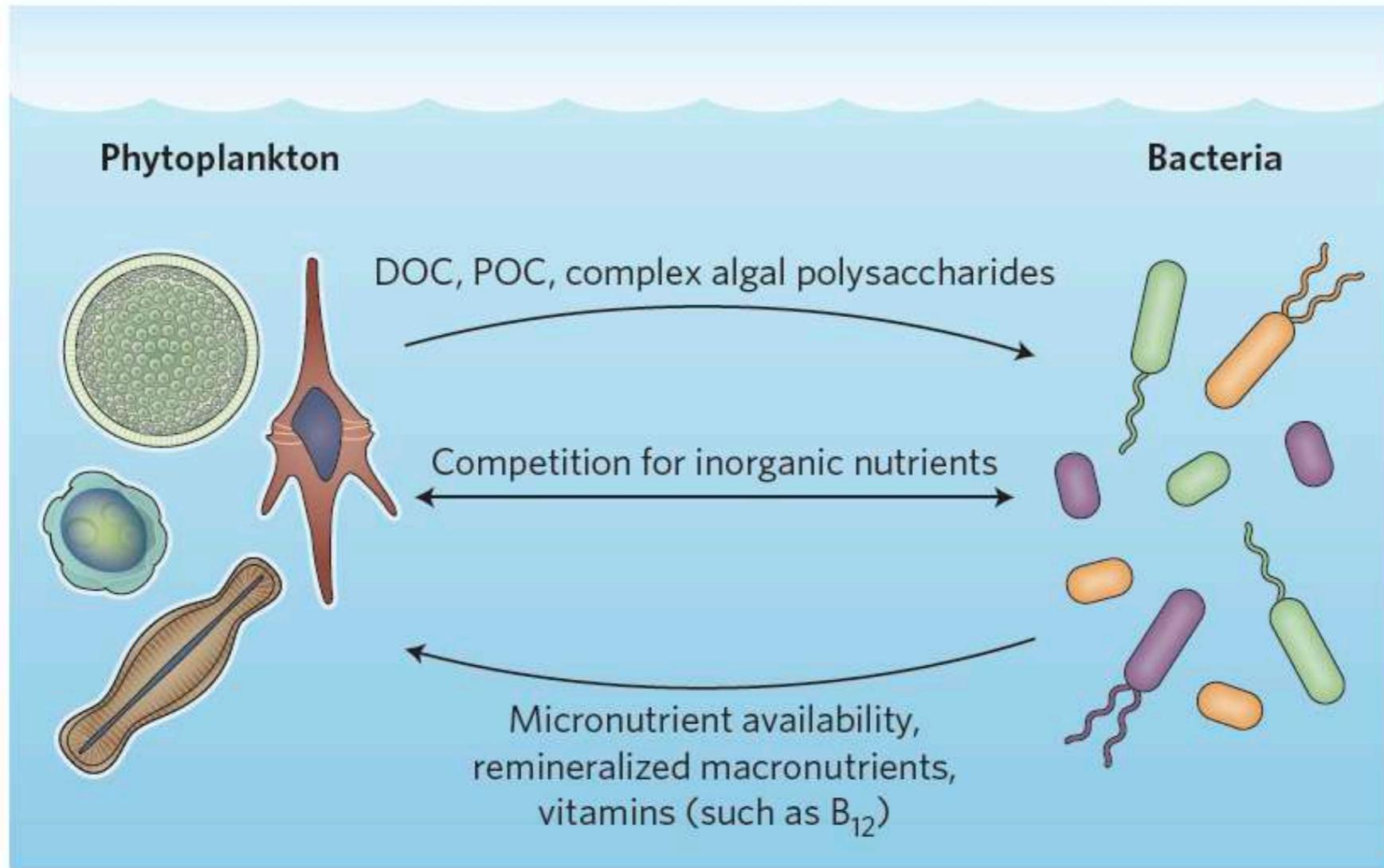
## Biolimited



- Elements in the ocean derive from rocks
- Elements have different concentrations
- Elements have different profiles
- **Conservative Elements** are well mixed in SW since their residence times are  $\gg$  the oceanic mixing time scale
- **Non-conservative elements** - Biological and other processes produce elemental concentrations that deviate from salinity-normalized concentrations in SW
- Profiles are related to biological activities

Nozaki, 2001

# Business as usual at the microscale

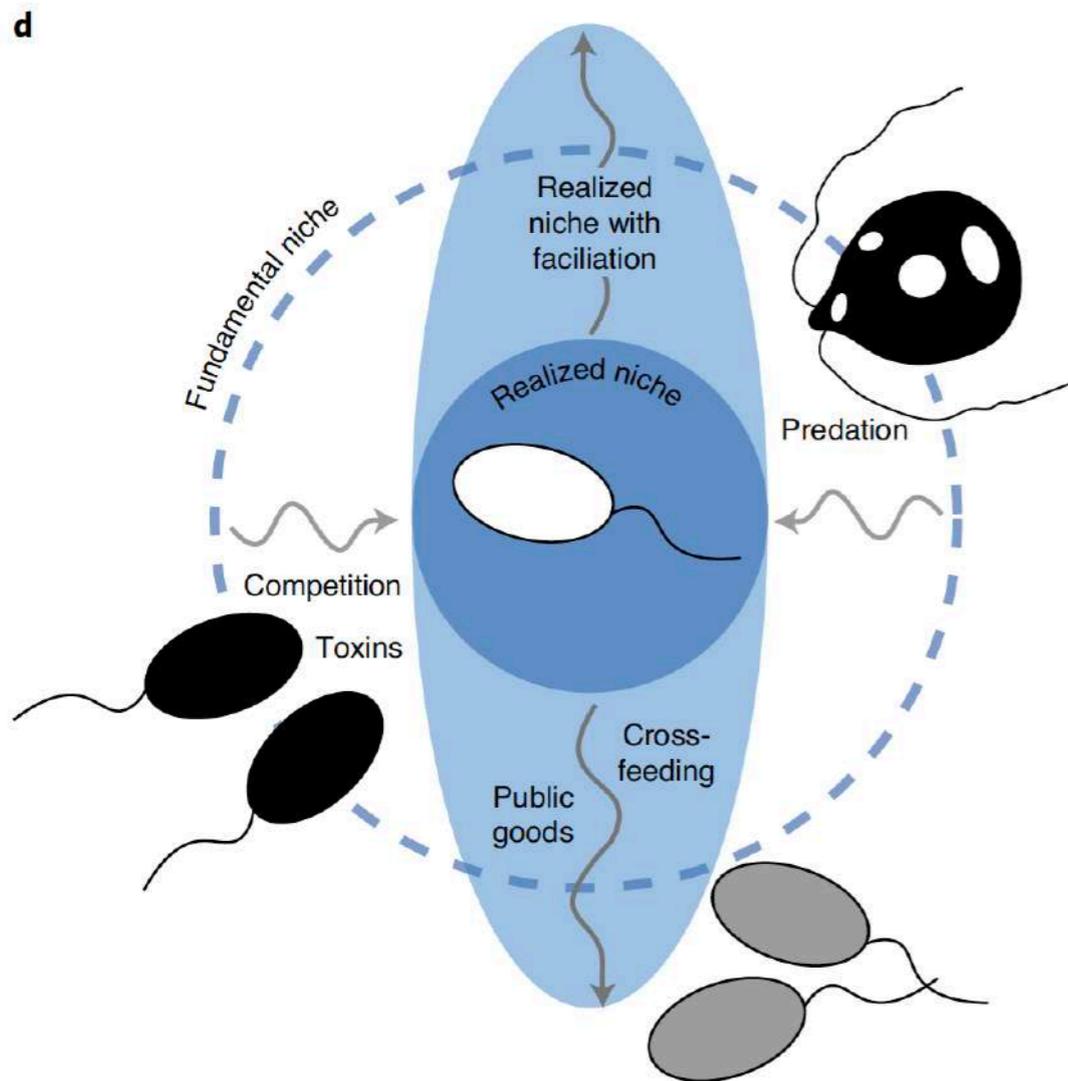


**Figure 1 | Phytoplankton-bacteria interactions and exchanges.**

Interactions between phytoplankton and bacteria can range from the reciprocal exchange of resources required for growth (for example, nutrients and vitamins) to competition for limiting inorganic nutrients. POC, particulate organic carbon.

# Microbial niche I

English ecologist, George Evelyn Hutchinson, in 1958, stated that every biotic and abiotic component that can be quantified as influencing a species is defining the niche as multidimensional space and time (dynamic volume)



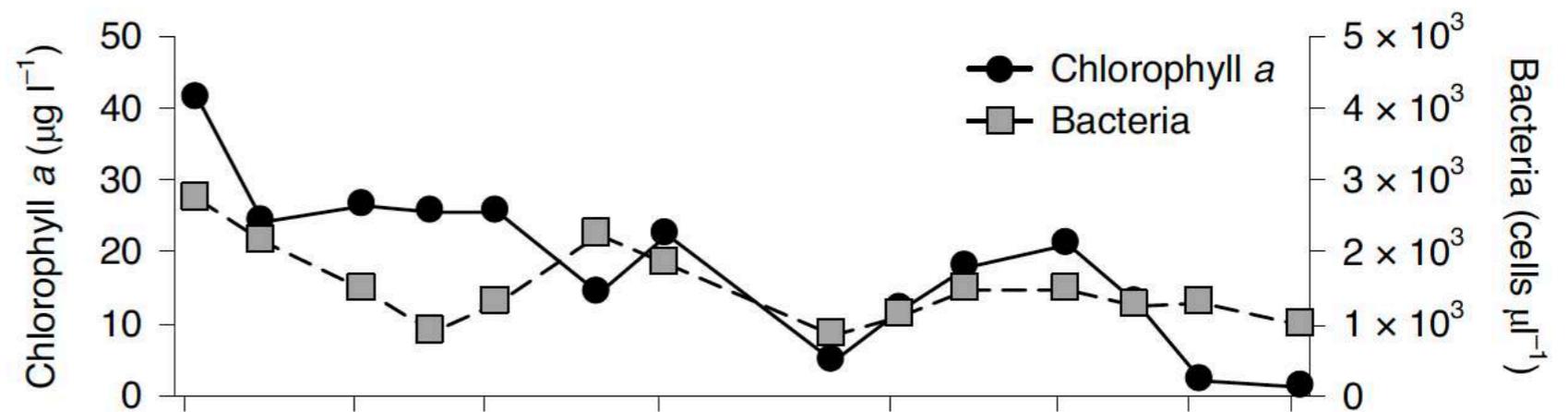
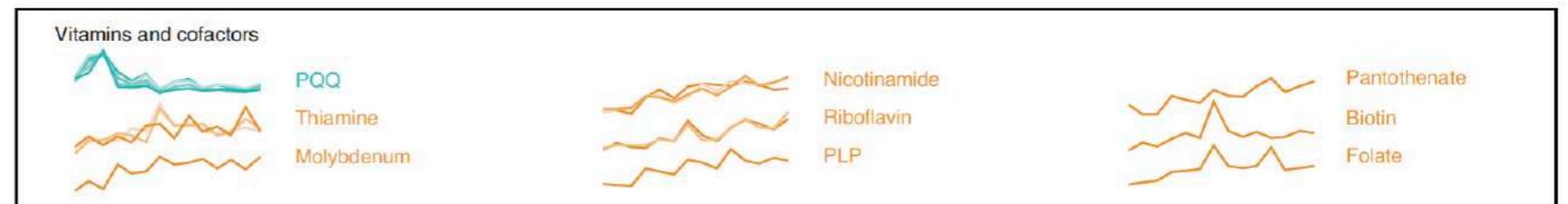
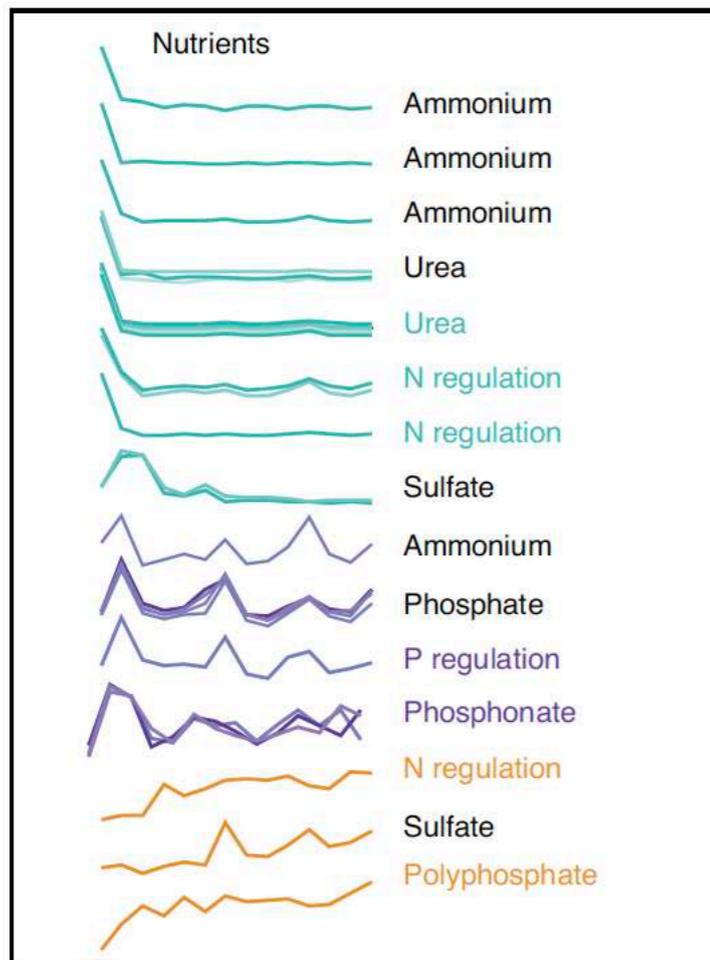
Hutchinson defined the **'fundamental' niche** as the **full range of external conditions in which an organism is viable** (that is, has an intrinsic growth rate,  $r_0, \geq 0$ ) **in the absence of interference from biotic interactions.**

The **'realized' niche** as the fundamental niche in the presence of other species.

**The realized niche is typically considered to be a more restricted ecological space than the fundamental niche due to negative interactions with competitors and predators**

# Microbial niche II

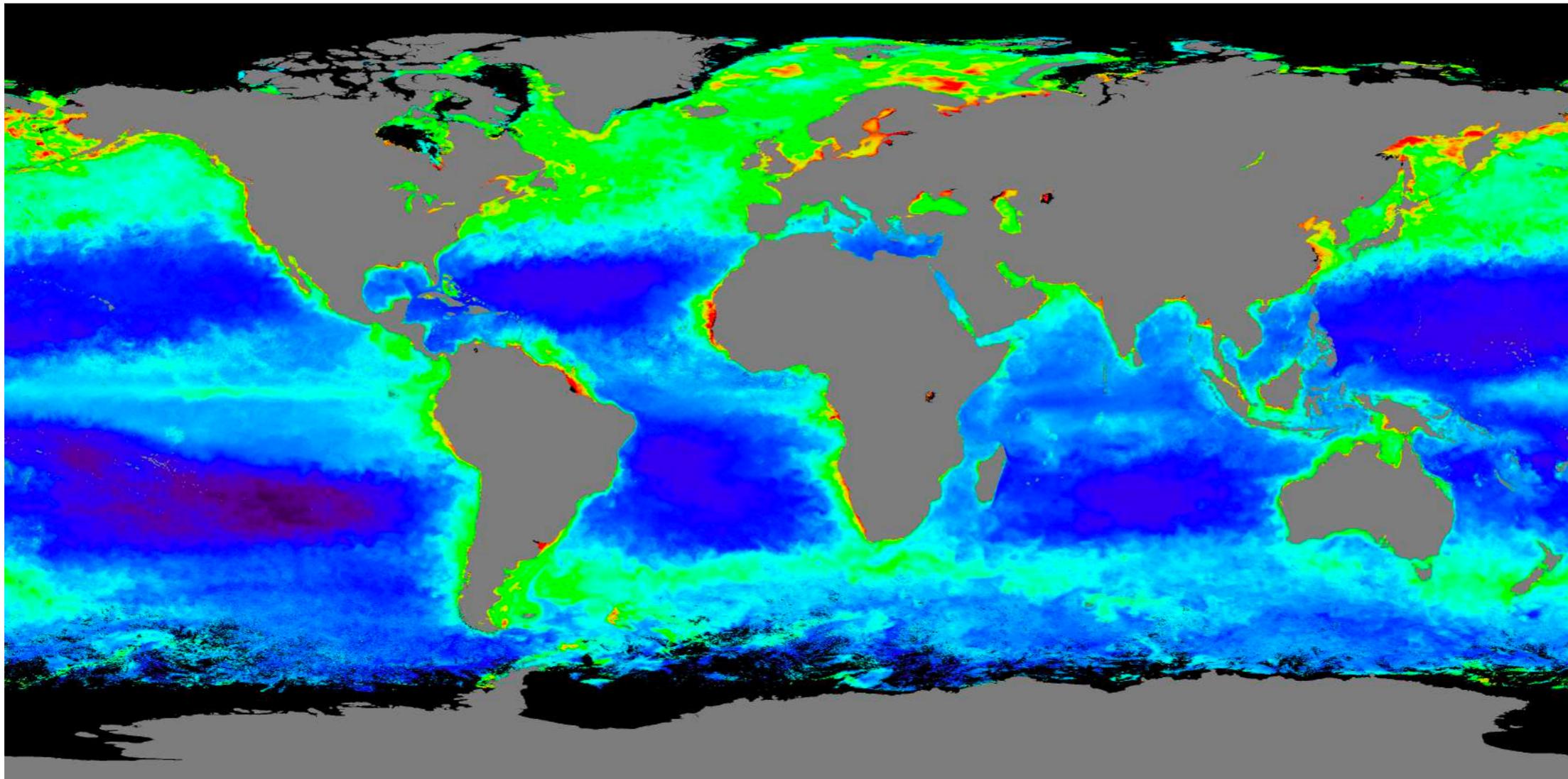
- mRNA expression to define niche
- Time course of relative gene expression indicating bacterial responses to niche dimensions



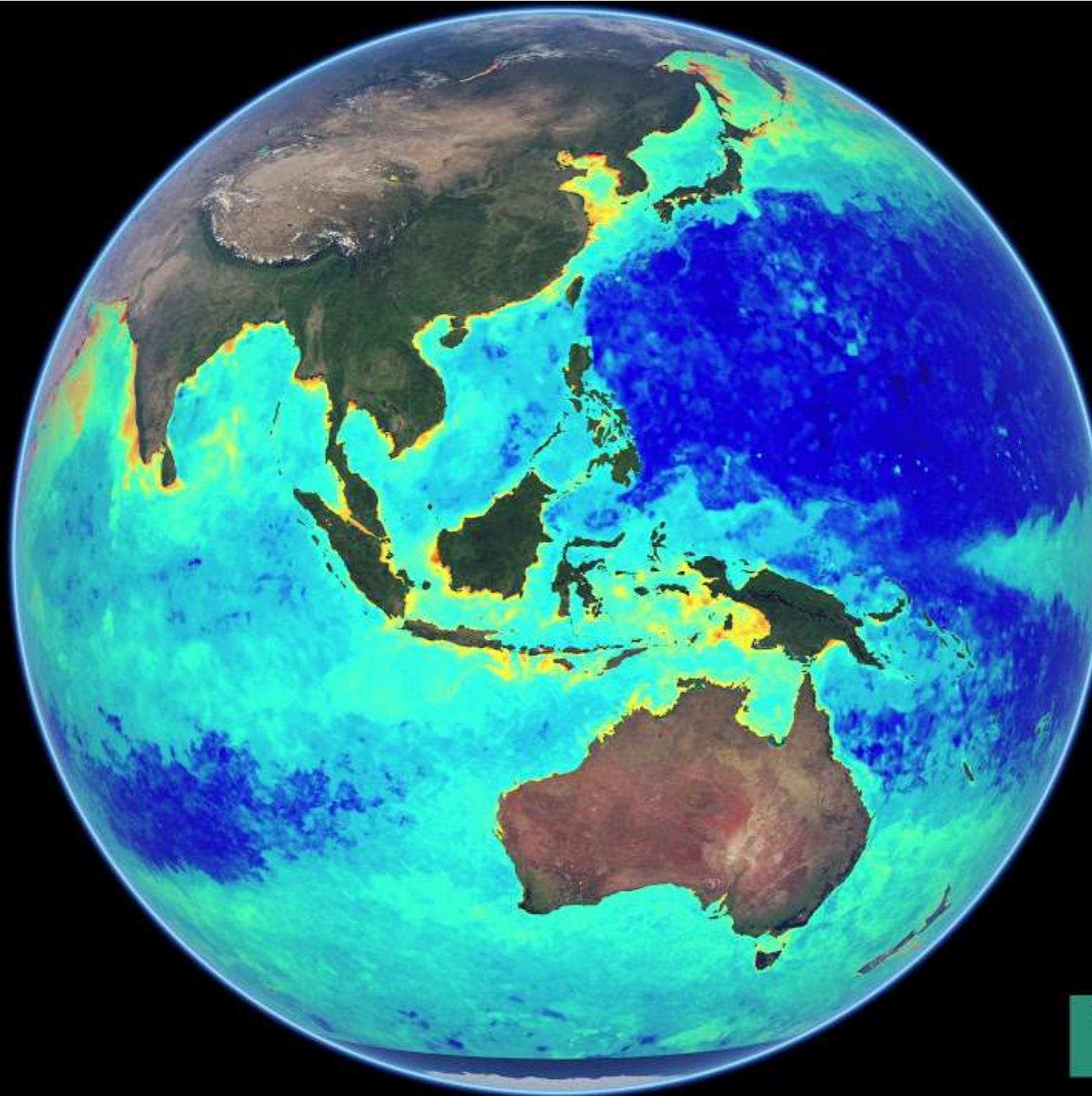
# Marine biogeochemical C cycle

- Phytoplankton (**Cyanobacteria and Eukarya**) are responsible for **half of global primary production**
- **Anoxygenic photosynthesis** accounts for ~ 5% primary production
- Primary production is variable and seasonal (temperature, light and nutrients) in global ocean
- **Hot spots** of production along the **coast** and **upwelling regions**

<https://earthobservatory.nasa.gov/>



Chlorophyll concentrations as measured by the **Sea-viewing Wide Field-of-view Sensor** (SeaWiFS) satellite and the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite between March 21 and June 20, 2006

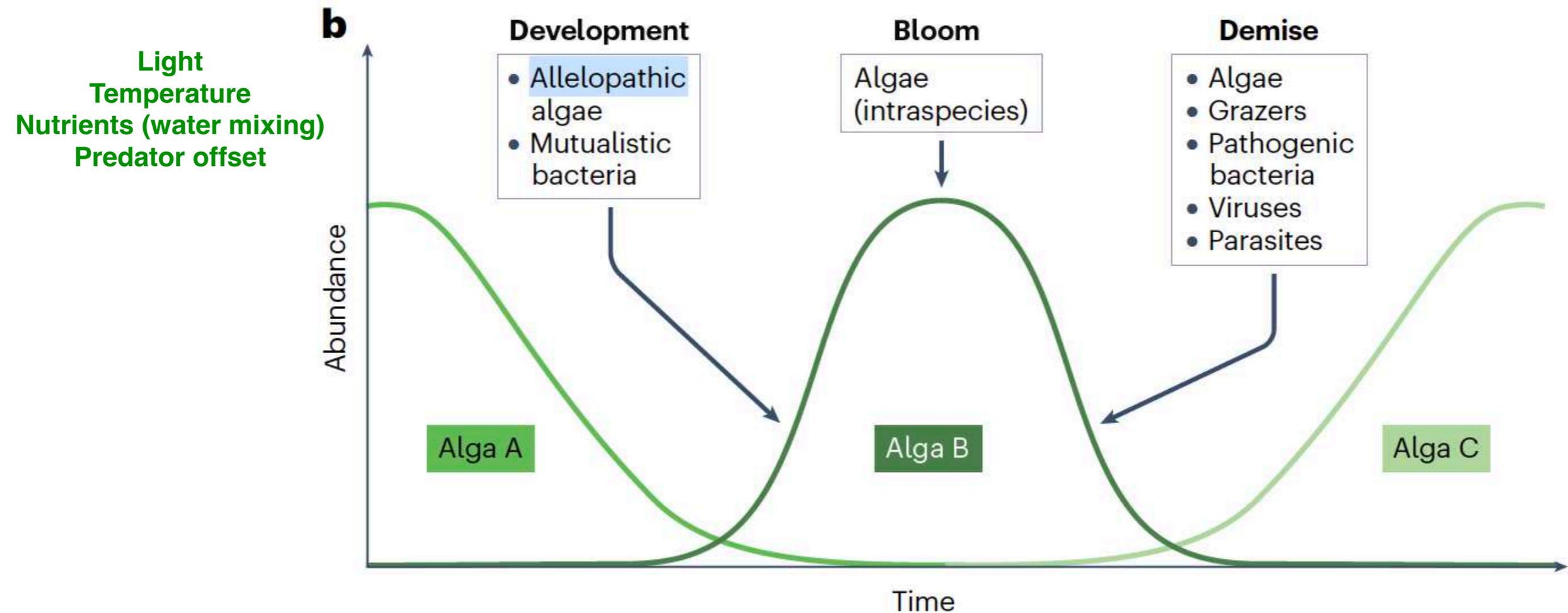


AUGUST 2017

Dr Hayley Evers-King of the Plymouth Marine Laboratory, shows a year of ocean chlorophyll measurements, as observed by satellites such as the Copernicus Sentinel-3 series, which are operated by EUMETSAT

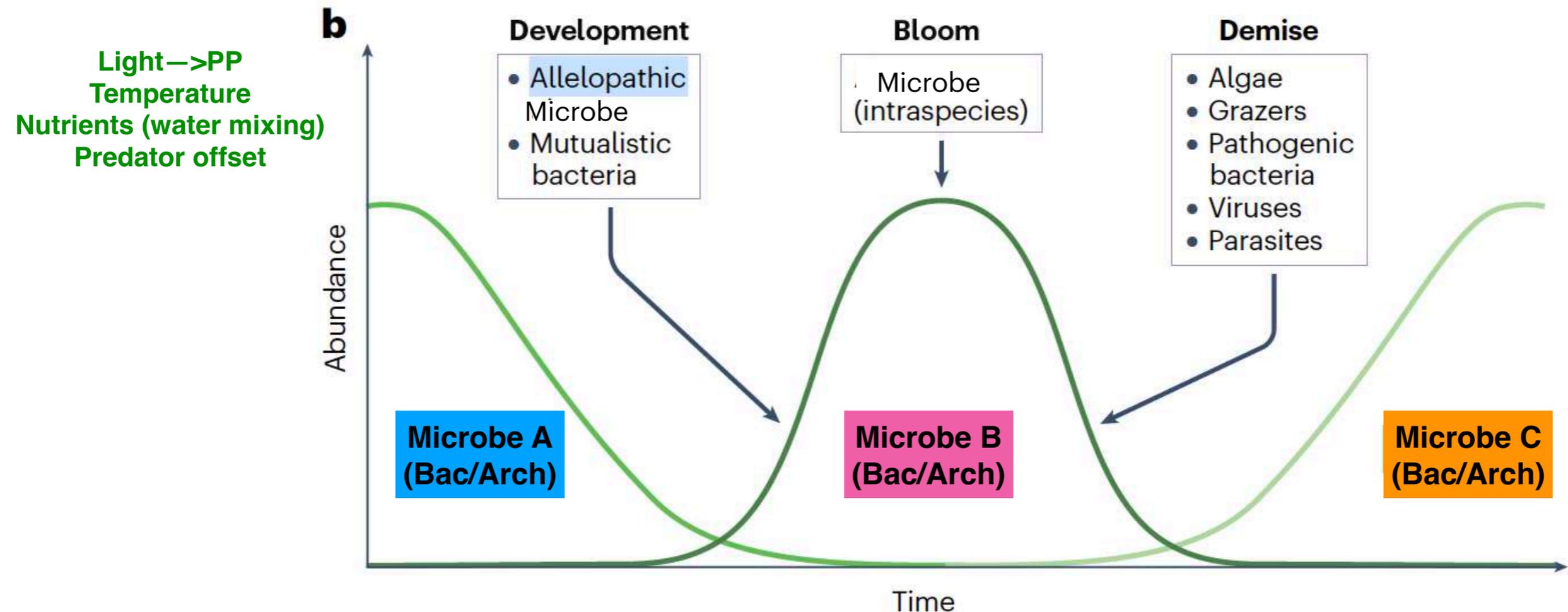
# **Microscale Microbial blooms**

# Microbial bloom: ALGAE



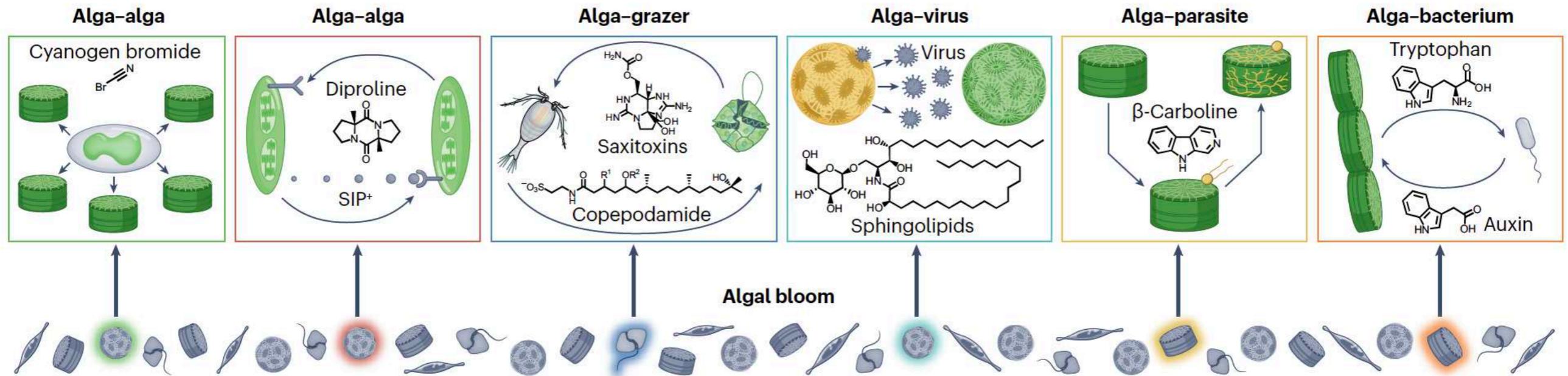
- Diverse kind of microbial interactions over time at the microscale
- Diverse allelopathic interactions regulate the bloom
- Diverse chemical communications among the microbes

# Microbial bloom: BACTERIA & ARCHAEA



- Diverse kind of microbial interactions over time at the microscale
- Diverse allelopathic interactions regulate the bloom
- Diverse chemical communications among the microbes

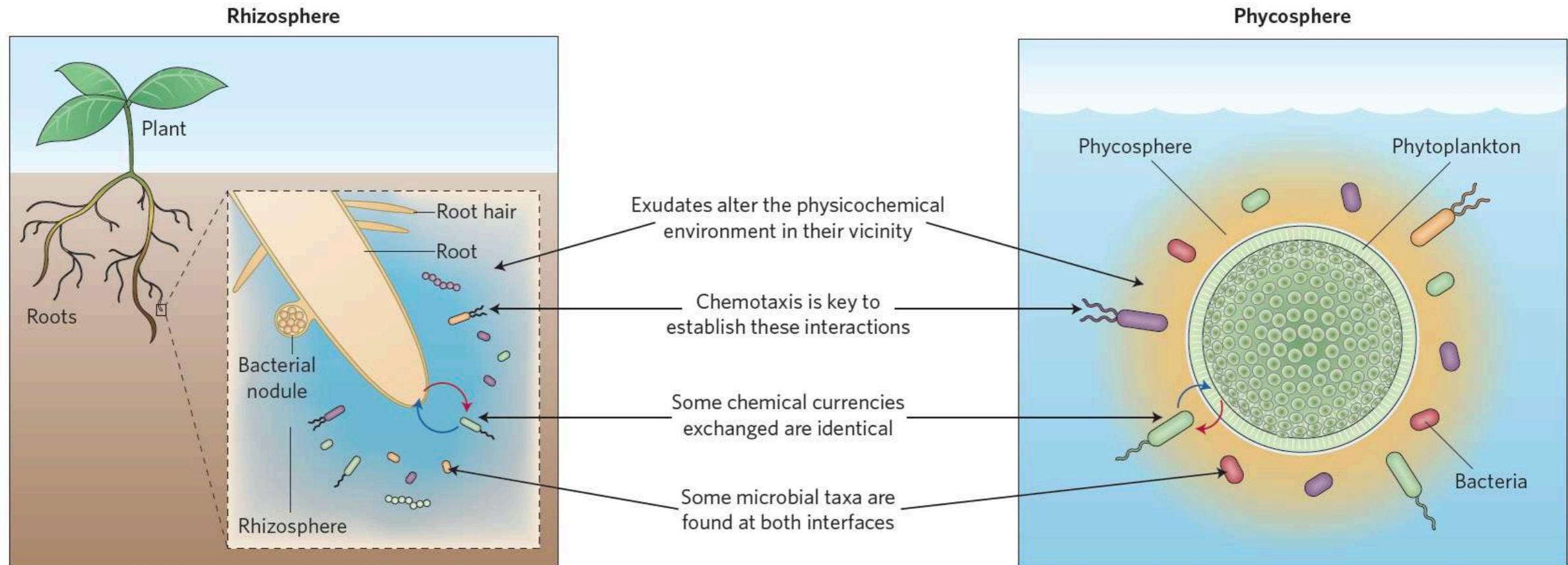
# Chemical language



- Cyanogen bromide, which suppresses competing algae
- Peptidic pheromones (SIP) + and diproline, which coordinate algal mating
- Alarm cue copepodamide, which induces algal saxitoxins
- Virus-derived spingolipids that induce cell death in neighbouring cells
- Algal β-carboline, which facilitates parasite infection
- Algal tryptophan, which is transformed by associated bacteria into the growth hormone auxin

# Phycosphere

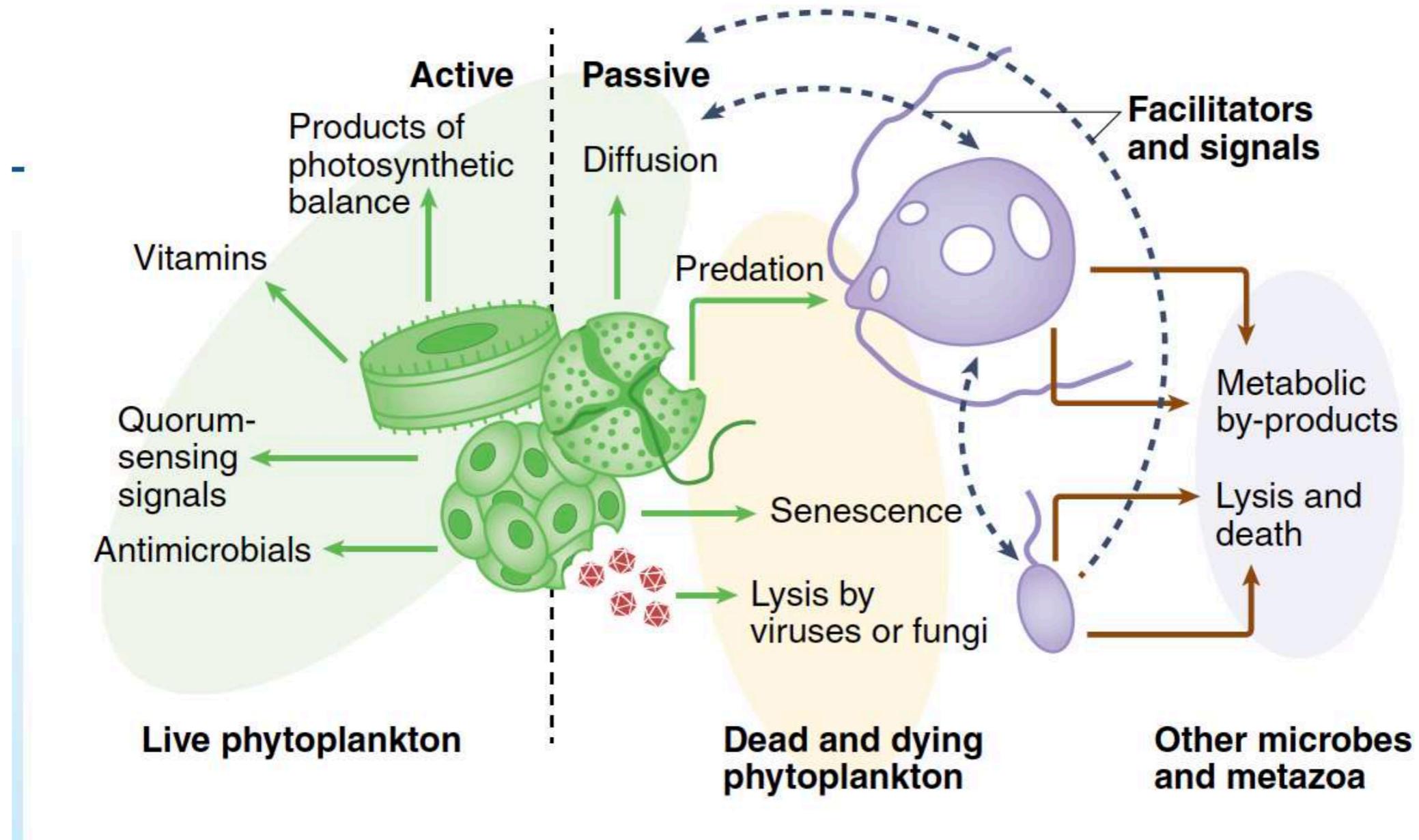
- A persistent microscale feature in the ocean where microbes interact



Seymour et al., 2017

**Figure 2 | The rhizosphere and the phycosphere are analogous microenvironments.** The phycosphere, defined as the region surrounding a phytoplankton cell that is enriched in organic substrates exuded by the cell, is an important microenvironment for planktonic aquatic bacteria. It is the aquatic analogue of the rhizosphere, which is the key ecological interface for plant-microorganism interactions in terrestrial habitats.

# Phycosphere

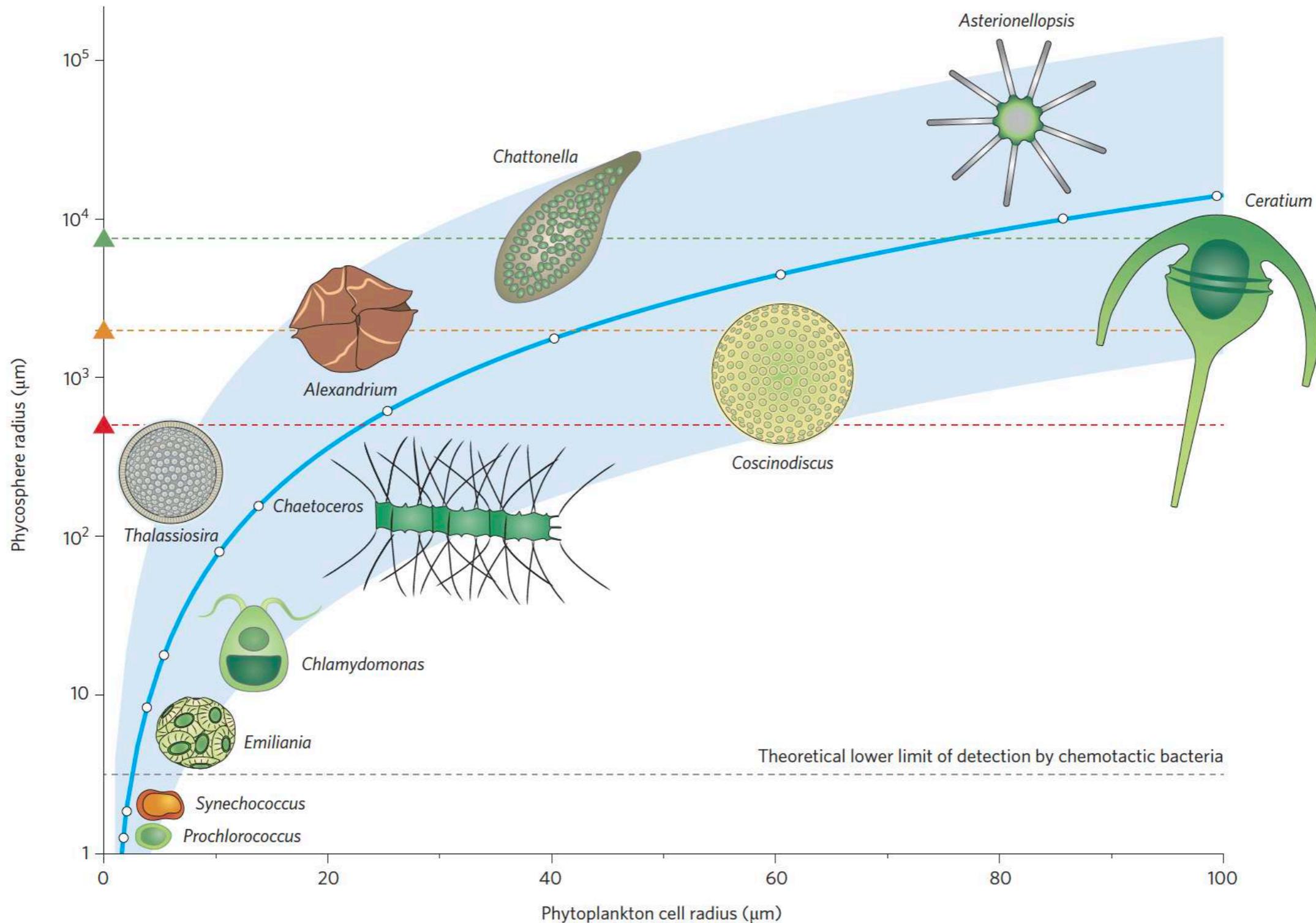


Moran et al. 2022

- Primary production has many informative functions beside Carbon and Energy units in the phycosphere

# Phycosphere radius as a function of cell radius

Seymour et al., 2017



# Costal habitat

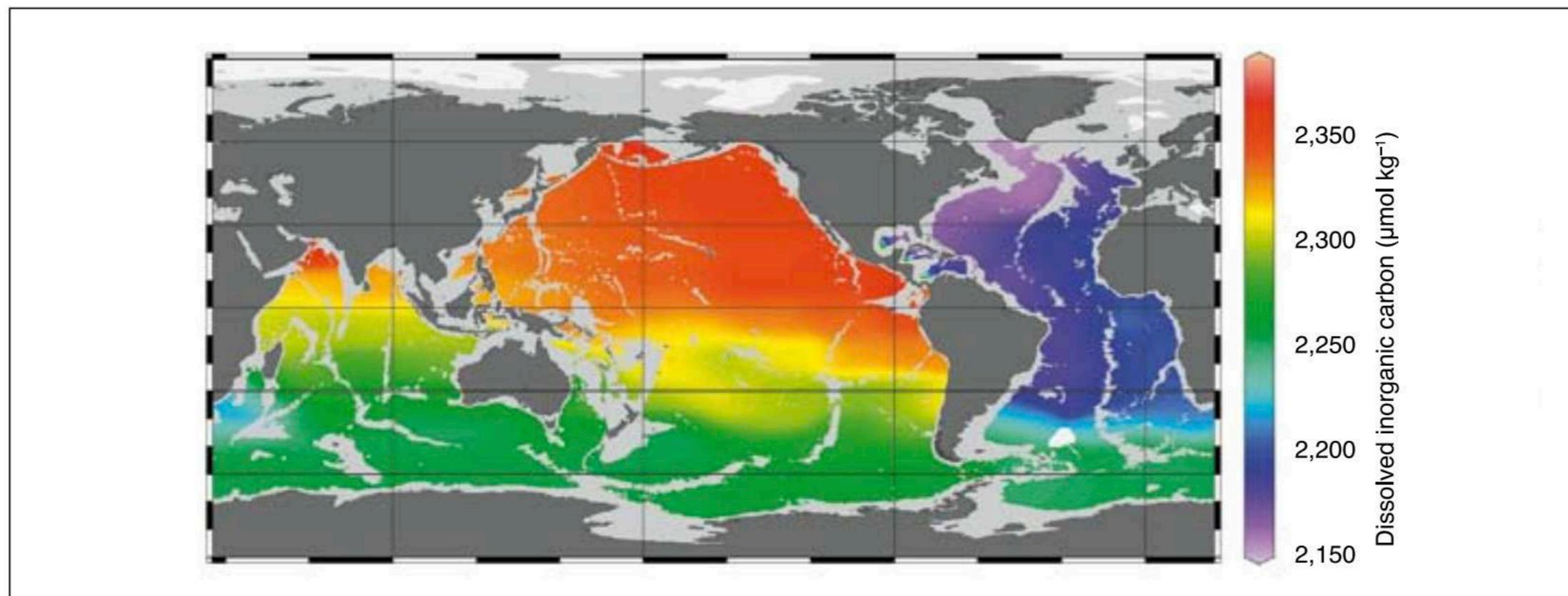
- Seaweeds, seagrasses, salt-marsh plants, mangroves account ~5% of global primary production
- Sea grasses, mangroves, and salt marshes along our coast "capture and hold" carbon, acting as something called a **carbon sink**
- **Blue carbon** is simply the term for carbon captured by the world's ocean and coastal ecosystems
- Coral reefs, high productivity, account ~1% of global primary production



<https://oceanwealth.org/tools/blue-carbon-counter/>

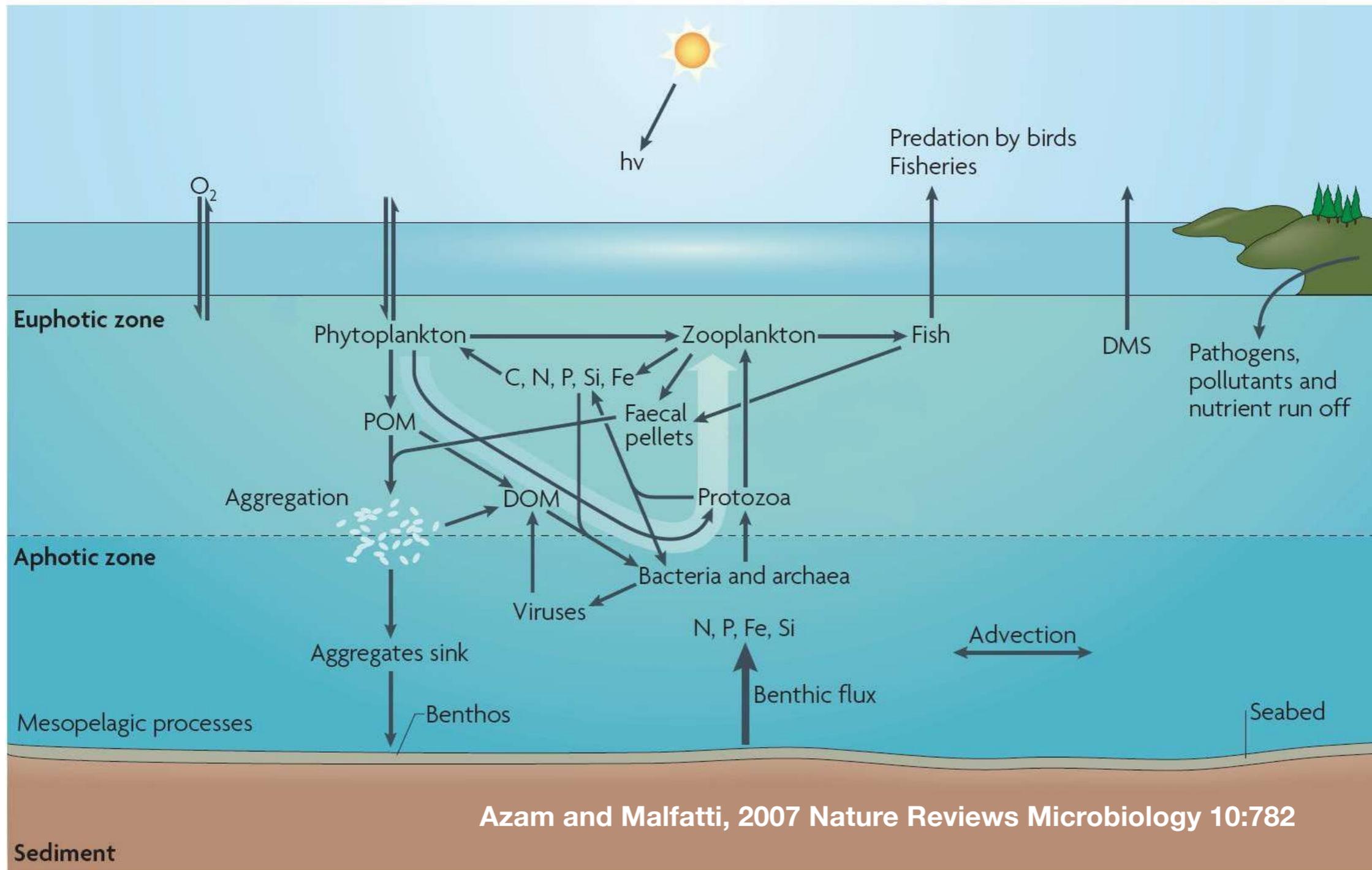
# Dark ocean

- Dark ocean primary production account for ~1 Gt C per year globally
- DIC fixation is performed by **chemoautotrophs and heterotrophs incorporate CO<sub>2</sub>** via a wide range of carboxylation reactions (anaplerotic reactions and the synthesis of fatty acids, nucleotides and amino acids) that form part of **their central and peripheral metabolic pathways**
- If **DIC fixation** is included in estimate > **5-22% C in global ocean fluxes and budget**
- Dark ocean C fixation via ocean physics reaches surface water



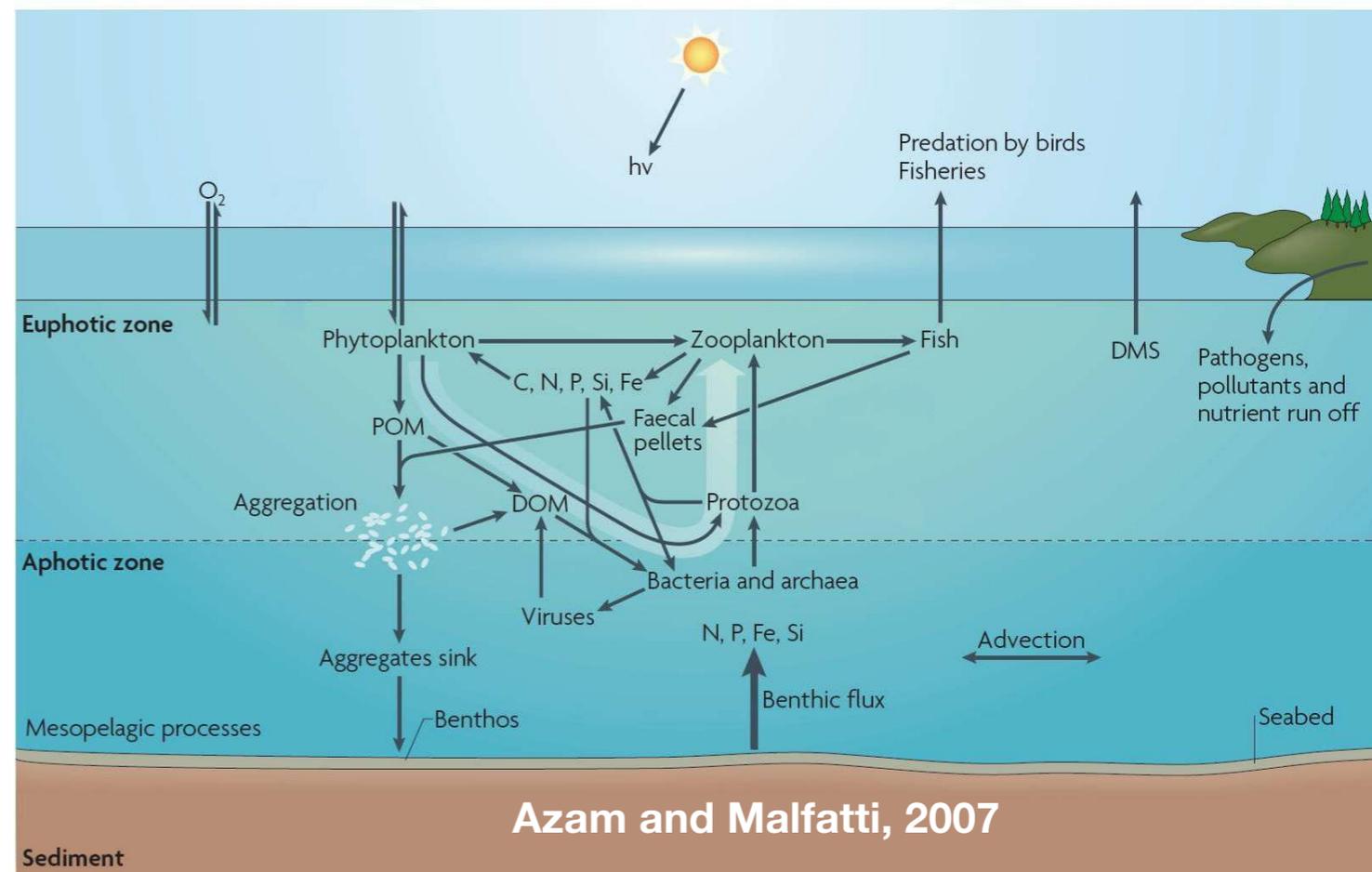
**Figure 6.7** Natural variation in total dissolved inorganic carbon concentration at 3000 m depth (data from Key et al., 2004). Ocean carbon concentrations increase roughly 10% as deep ocean waters transit from the North Atlantic to the North Pacific due to the oxidation of organic carbon in the deep ocean.

# Biological Carbon Pump - Microbial loop - Microbial Carbon Pump



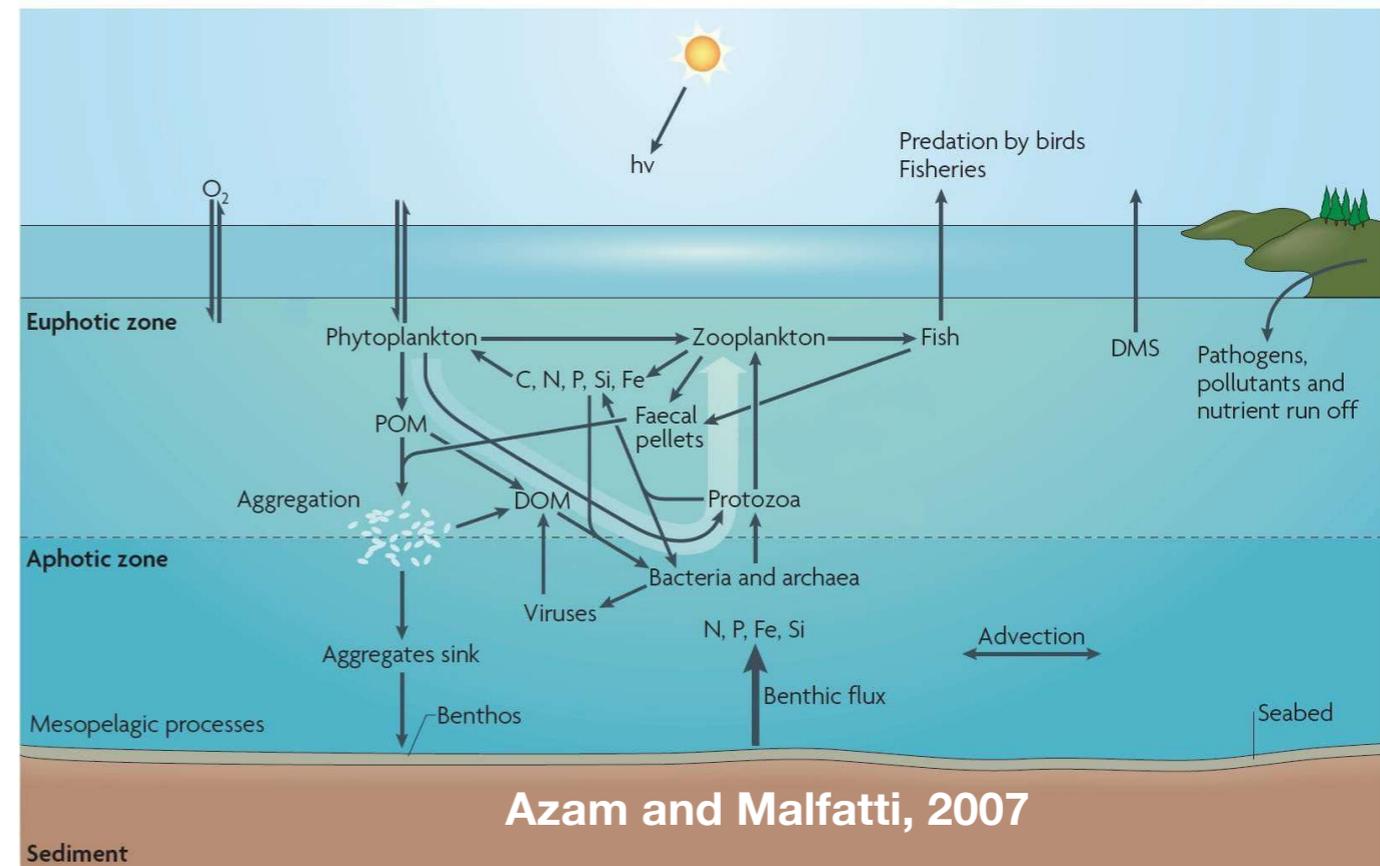
# Biological Carbon Pump - Microbial loop - Microbial Carbon Pump

- Biological pump transport fixed carbon to the deep ocean and sediment (via particle sinking)
- Life/death of plankton and other organisms from the classic food web (i.e. phyto → zoo → fish)
- POC/marine snow
- DOC → POC due to microbial action



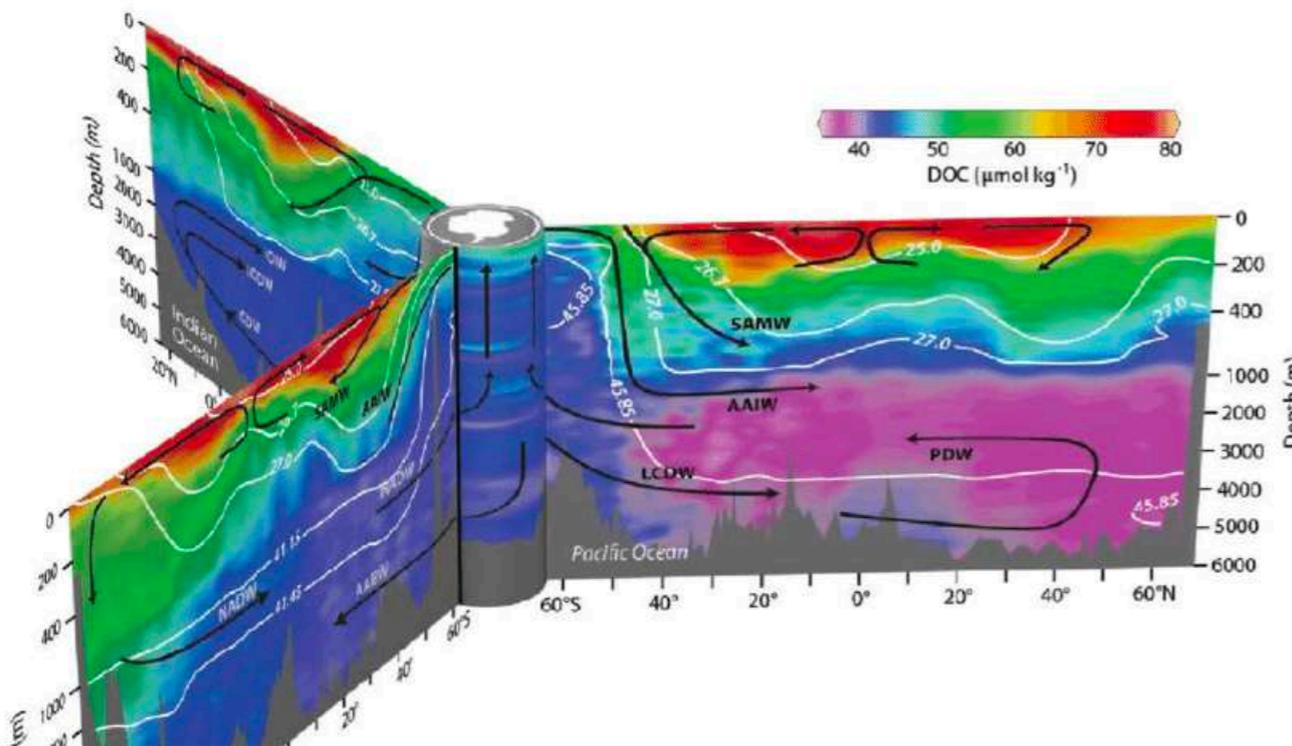
# Biological Carbon Pump - Microbial loop - Microbial Carbon Pump

- Microbial loop as a salvation pathway of DOC to higher trophic levels (Azam, F., Fenchel, T., Field, J.G., Gray, J.S., Meyer-Reil, L.A., Thingstad, F., 1983. The ecological role of water-column microbes in the sea. *Mar. Ecol. Prog. Ser.* 10, 257–263 - Pomeroy, L.R., 1974. *The oceans food web: a changing paradigm. BioScience* 24, 409–504)
- Ingestion of Bacteria/Archaea by protists plays a key role in the microbial loop
- Microbial antagonistic relationships underestimate role in microbial loop
- Virus lysis refuel the microbial loop with labile DOC

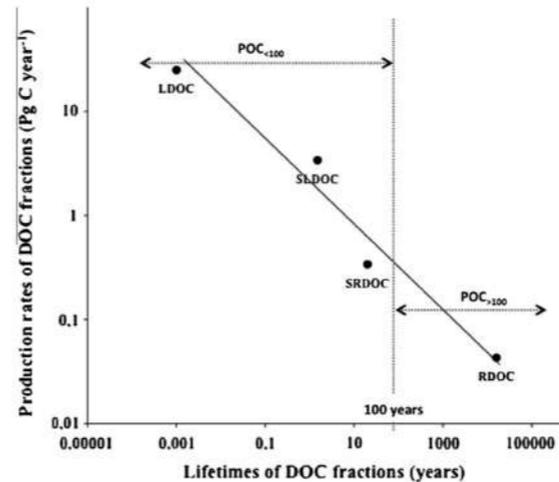
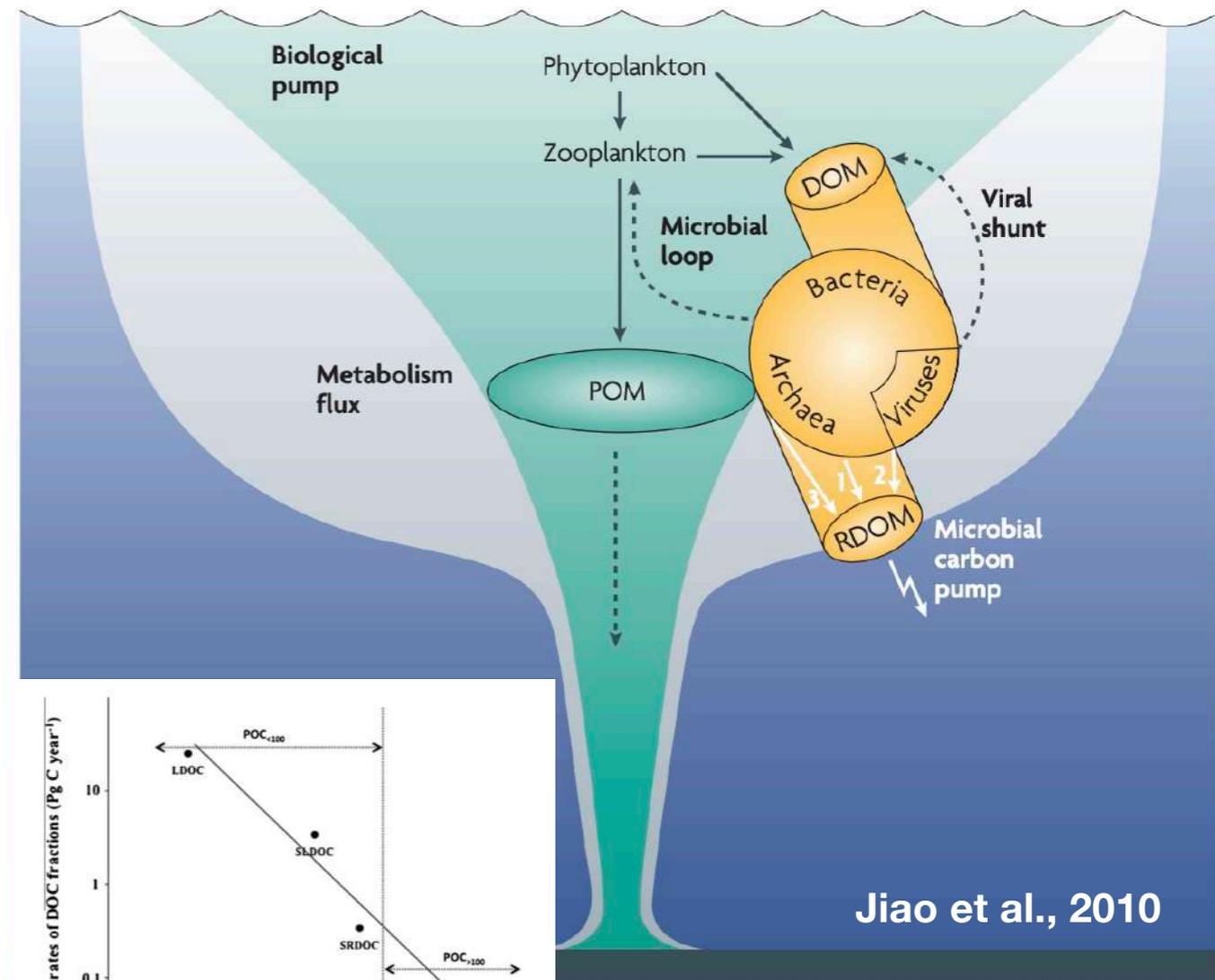


# Biological Carbon Pump - Microbial loop - Microbial Carbon Pump

- Microbial processes alter the composition of DOM → **MCP (Microbial Carbon Pump)**
- **Change in DOM reactivity**



Hansell, 2009



Legendre et al., 2015