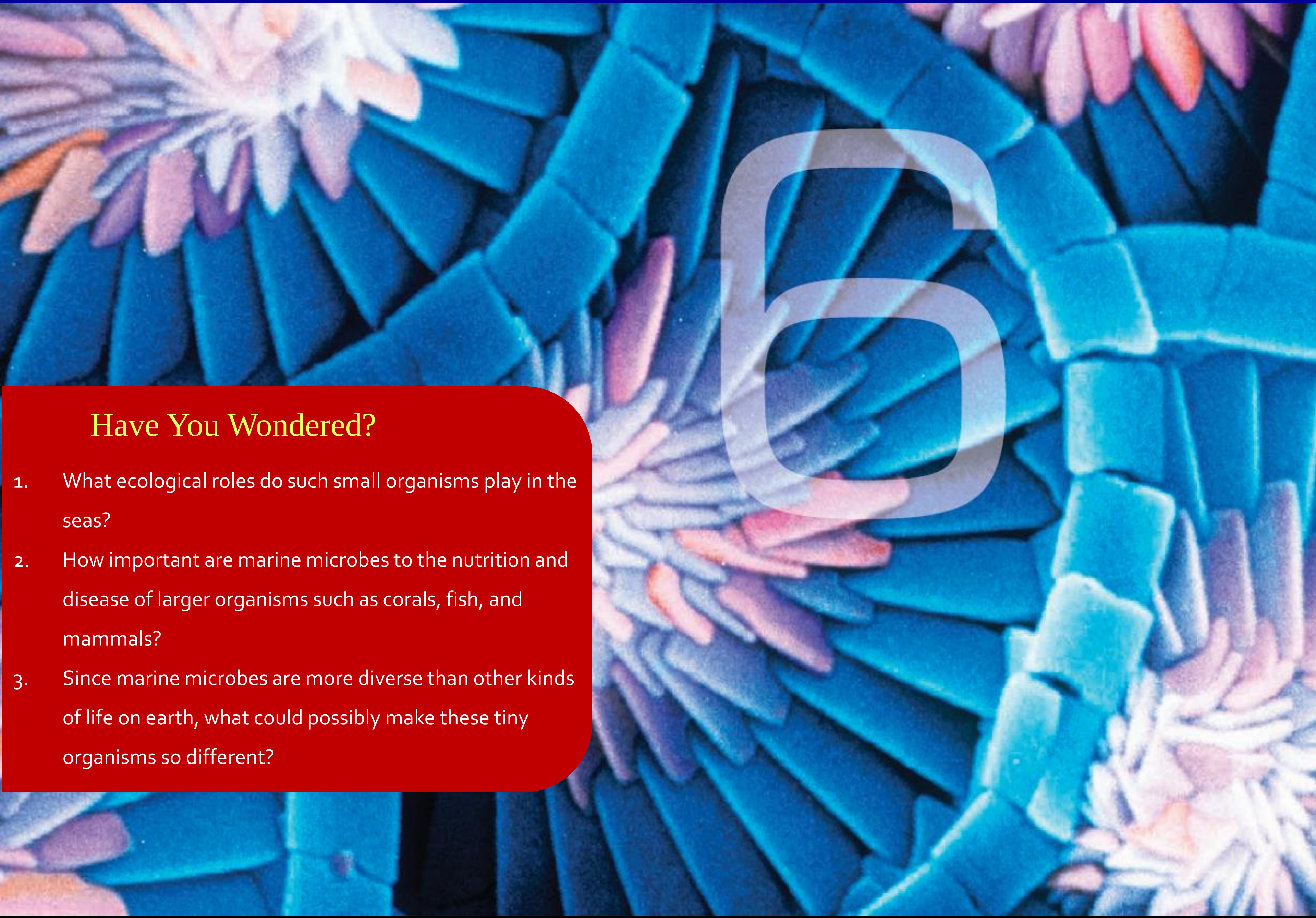


6

Have You Wondered?

1. What ecological roles do such small organisms play in the seas?
2. How important are marine microbes to the nutrition and disease of larger organisms such as corals, fish, and mammals?
3. Since marine microbes are more diverse than other kinds of life on earth, what could possibly make these tiny organisms so different?

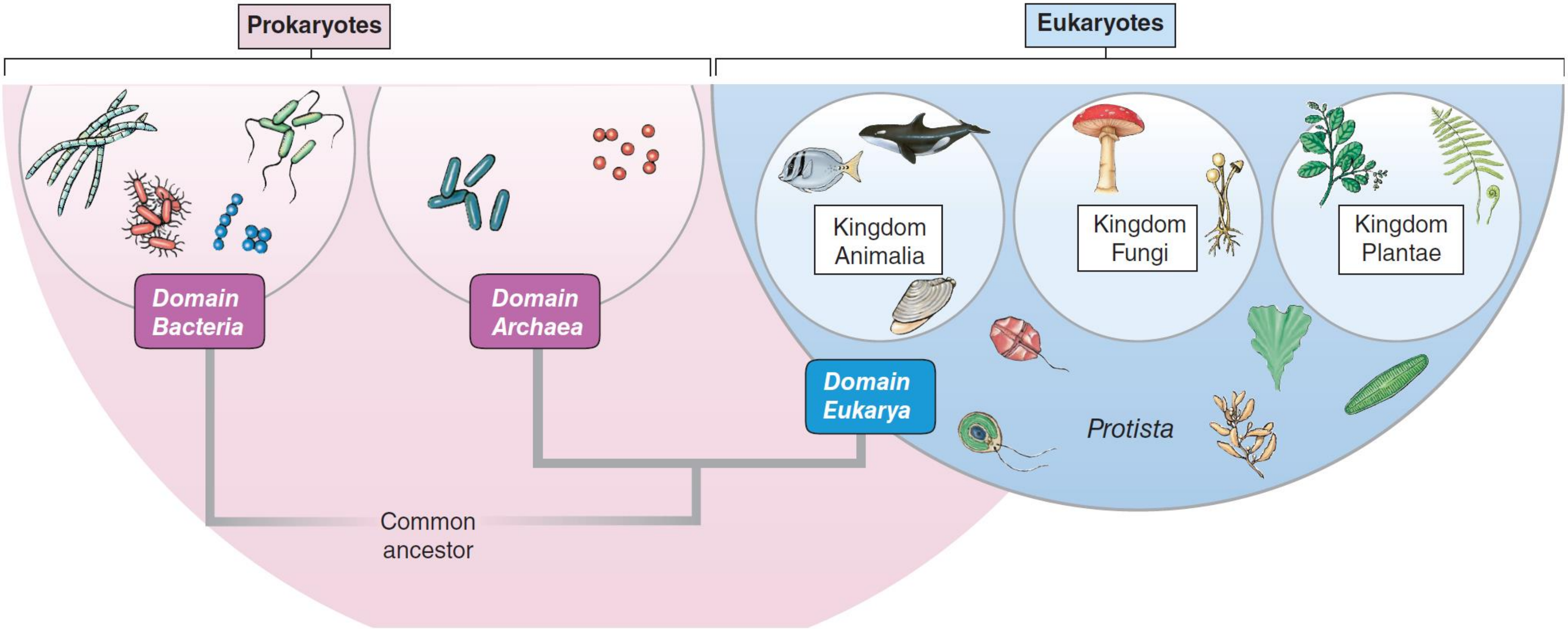
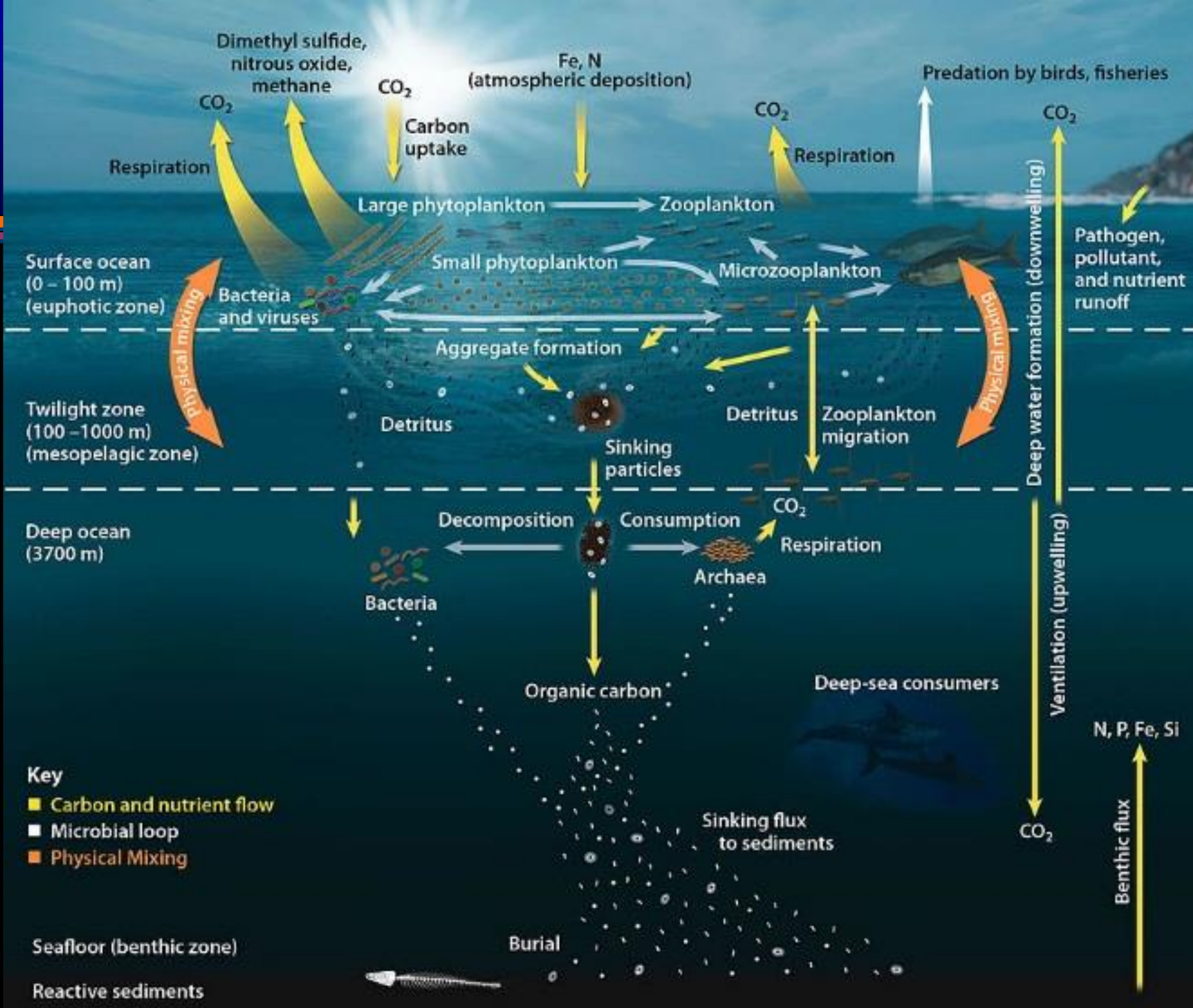
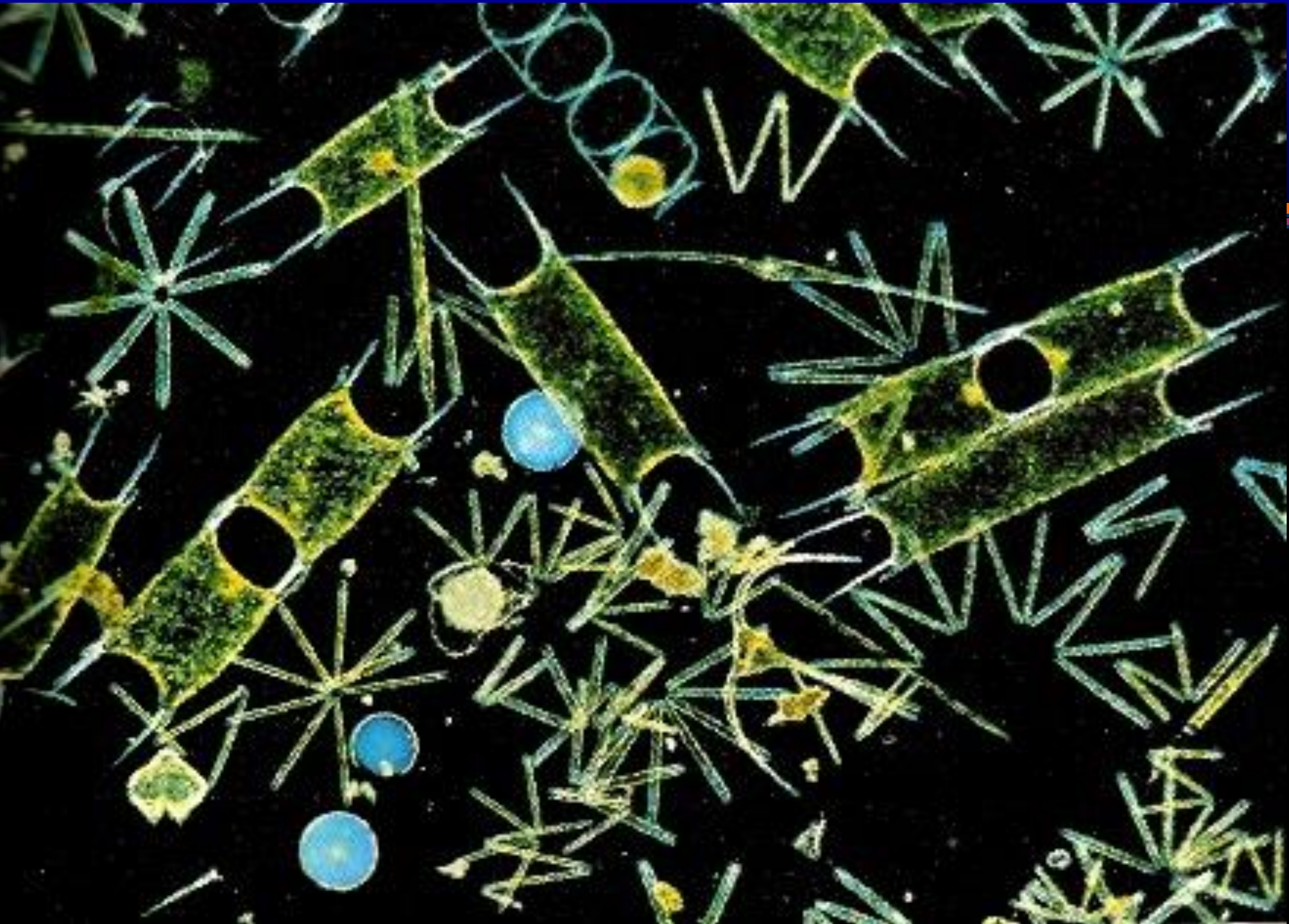


FIGURE 4.24 The major groups of living things.



Dimethyl sulfide, nitrous oxide, methane
CO_2
Carbon uptake
Fe, N (atmospheric deposition)
Predation by birds, fisheries
CO_2
Respiration
CO_2
Respiration
CO_2
Large phytoplankton
Zooplankton
Small phytoplankton
Microzooplankton
Bacteria and viruses
Surface ocean (0 – 100 m) (euphotic zone)
Pathogen, pollutant, and nutrient runoff
Physical mixing
Physical mixing
Deep water formation (downwelling)
Aggregate formation
Twilight zone (100 –1000 m) (mesopelagic zone)
Detritus
Detritus
Zooplankton migration
Sinking particles
Deep ocean (3700 m)
Decomposition
Consumption
CO_2
Respiration
Bacteria
Archaea
Ventilation (upwelling)
Organic carbon
Deep-sea consumers
N, P, Fe, Si
Key
Carbon and nutrient flow
Microbial loop
Physical Mixing
Sinking flux to sediments
CO_2
Benthic flux
Seafloor (benthic zone)
Burial
Reactive sediments



Marine Microbes

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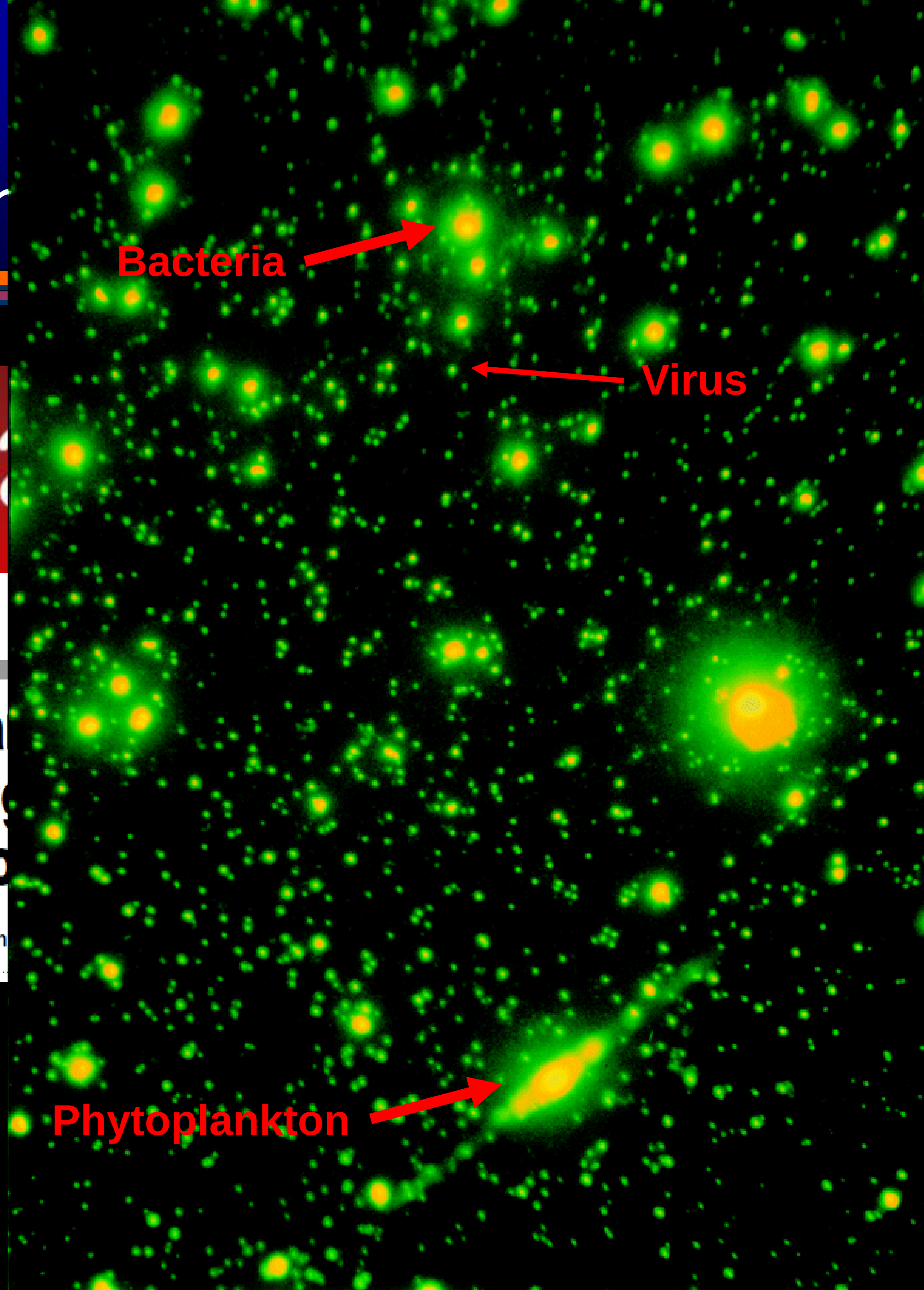

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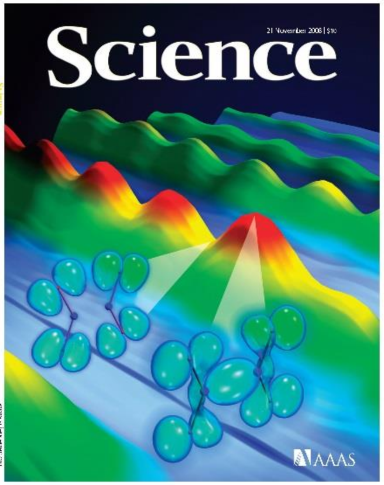


REVIEW SUMMARY

ENVIRONMENTAL SCIENCE

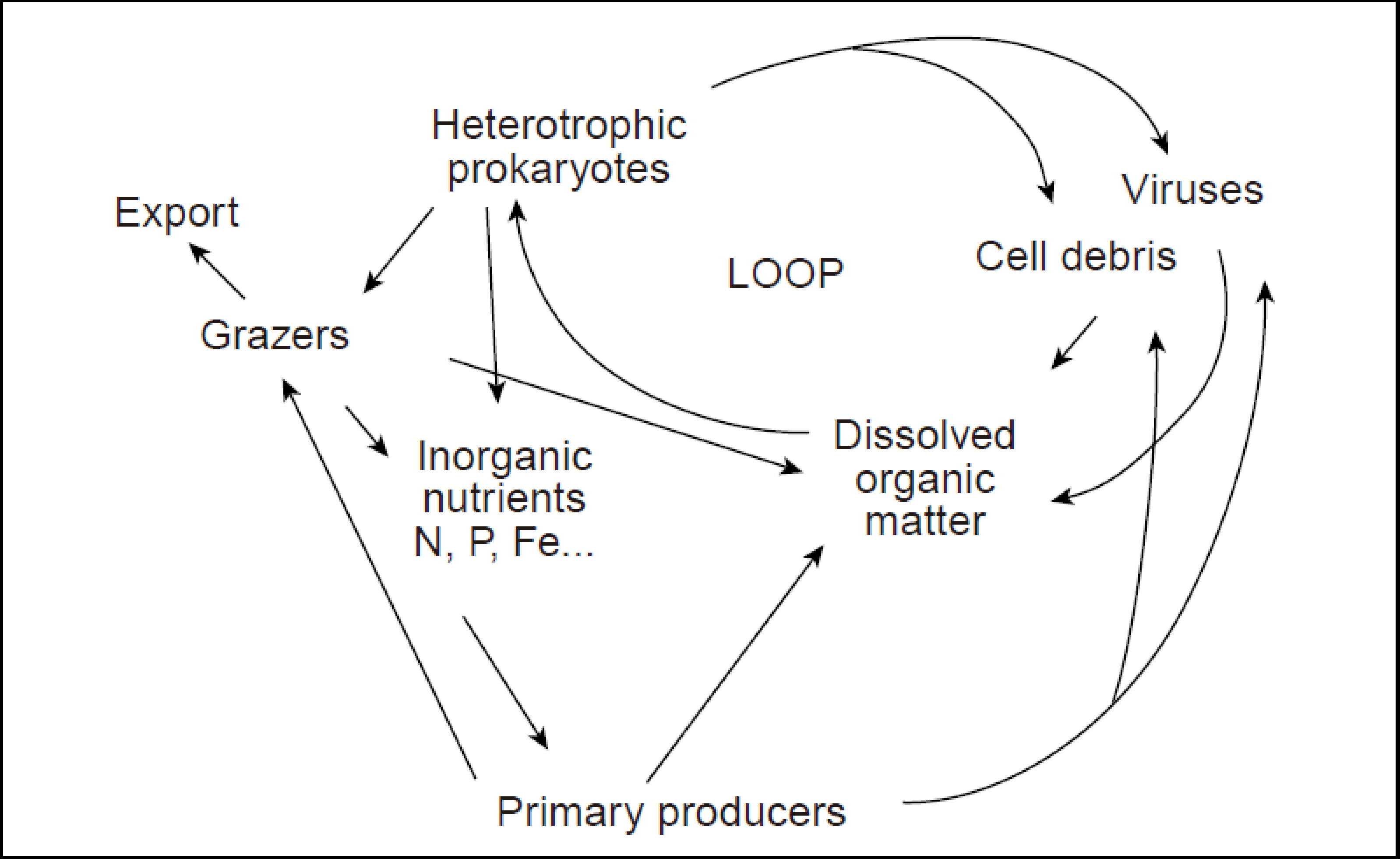
Rethinking the marine carbon cycle: Factoring in the multifarious lifestyles of microbes

Alexandra Z. Worden,* Michael J. Follows, Stephen J. Giovannoni, Susanne Wilken, Amy E. Zimmerman, Patrick J. Keeling

Marine Microbes

- *Microbes* are organisms that are invisible to the naked eye. They include viruses, one-celled organisms, and occasionally fungi. These microbes belong to all three domains of life (Eubacteria, Archaea, Eukarya) and play many roles in marine ecosystems, such as producer, consumer, decomposer, mutualist, and parasite.
- Although unseen by visitors to the ocean, they are the most numerous organisms in the sea and contribute 50- 90% of ocean biomass.

Marine Microbe and food web



Marine Microbes

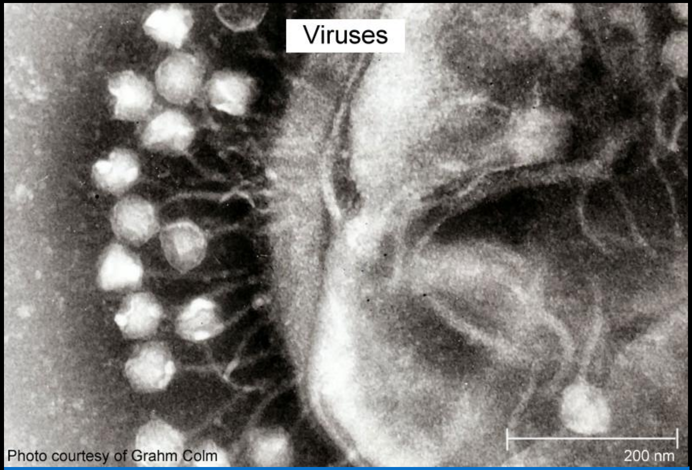


Photo courtesy of Grahm Colm

Viruses

A virus is an infectious microscopic agent made of genetic information in a protective covering. Viruses are not considered to be "alive" because they cannot reproduce unless they are inside another organism. Here, dozens of phage viruses (white circles) infect a larger bacterium.

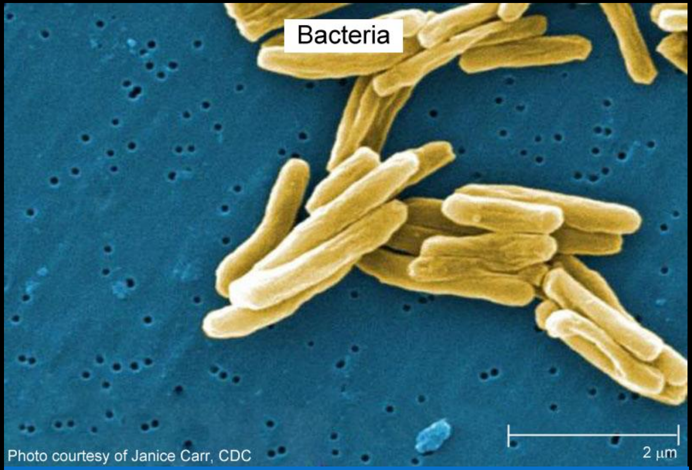


Photo courtesy of Janice Carr, CDC

Bacteria

Bacteria are microscopic, unicellular, prokaryotic organisms that make up most of the world's biomass and mainly serve as decomposers, breaking down dead organisms and organic waste and recycling it back into the environment.

Marine Microbes

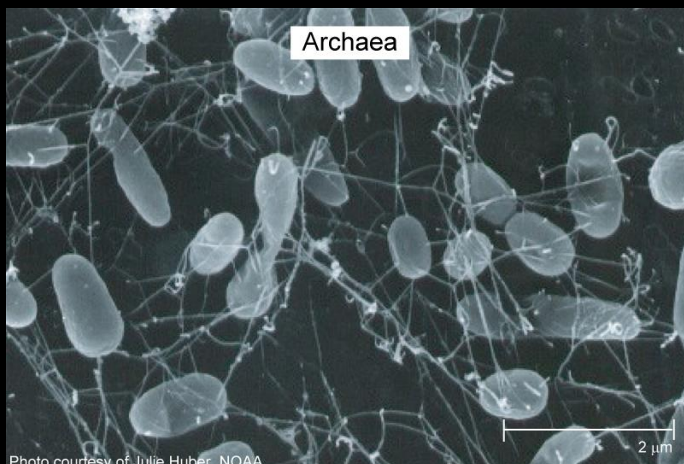


Photo courtesy of Julie Huber, NOAA

Archaea

Archaea are microscopic, prokaryotic, unicellular organisms that were once thought to be a type of bacteria, but are now known to be very different. Most are able to survive in stressful conditions: without oxygen, extreme heat or cold, and in very salty or acidic environments. In addition, their genetic make-up is vastly different than that of bacteria.

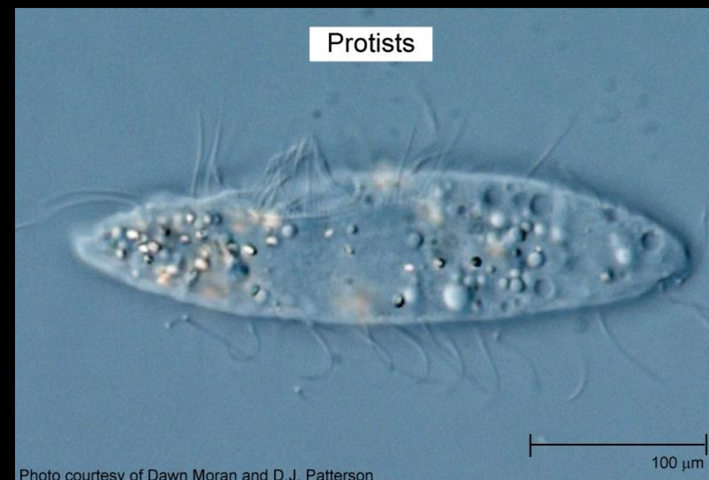


Photo courtesy of Dawn Moran and D.J. Patterson

Protists

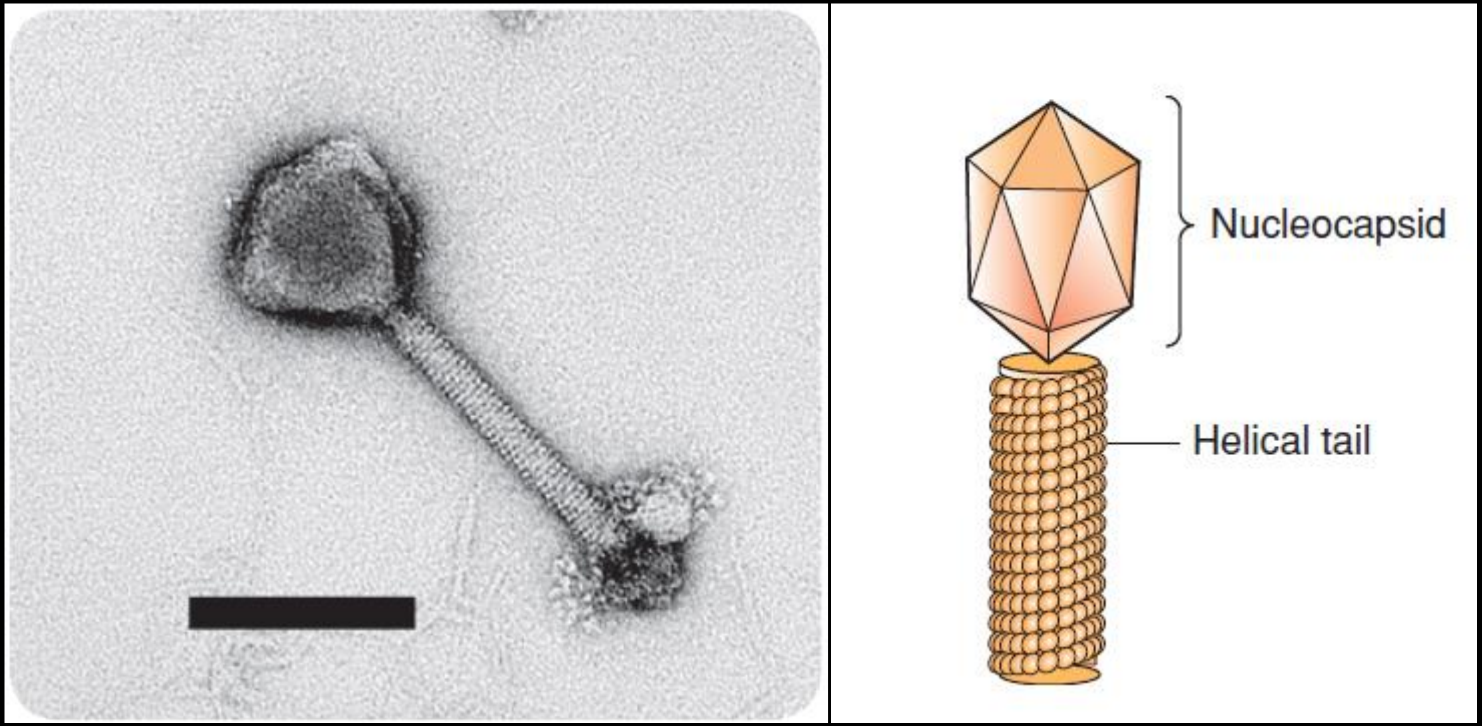
Protists are a diverse group of eukaryotes that can be unicellular or multicellular. They can be autotrophic or heterotrophic and are grouped based on the way they obtain food. They may be classified as plant-like or animal-like. This protist uses its cilia (hair-like structures covering the cell) to move through water.

Marine Viruses

1 teaspoon of seawater=10,000,000 bacteria

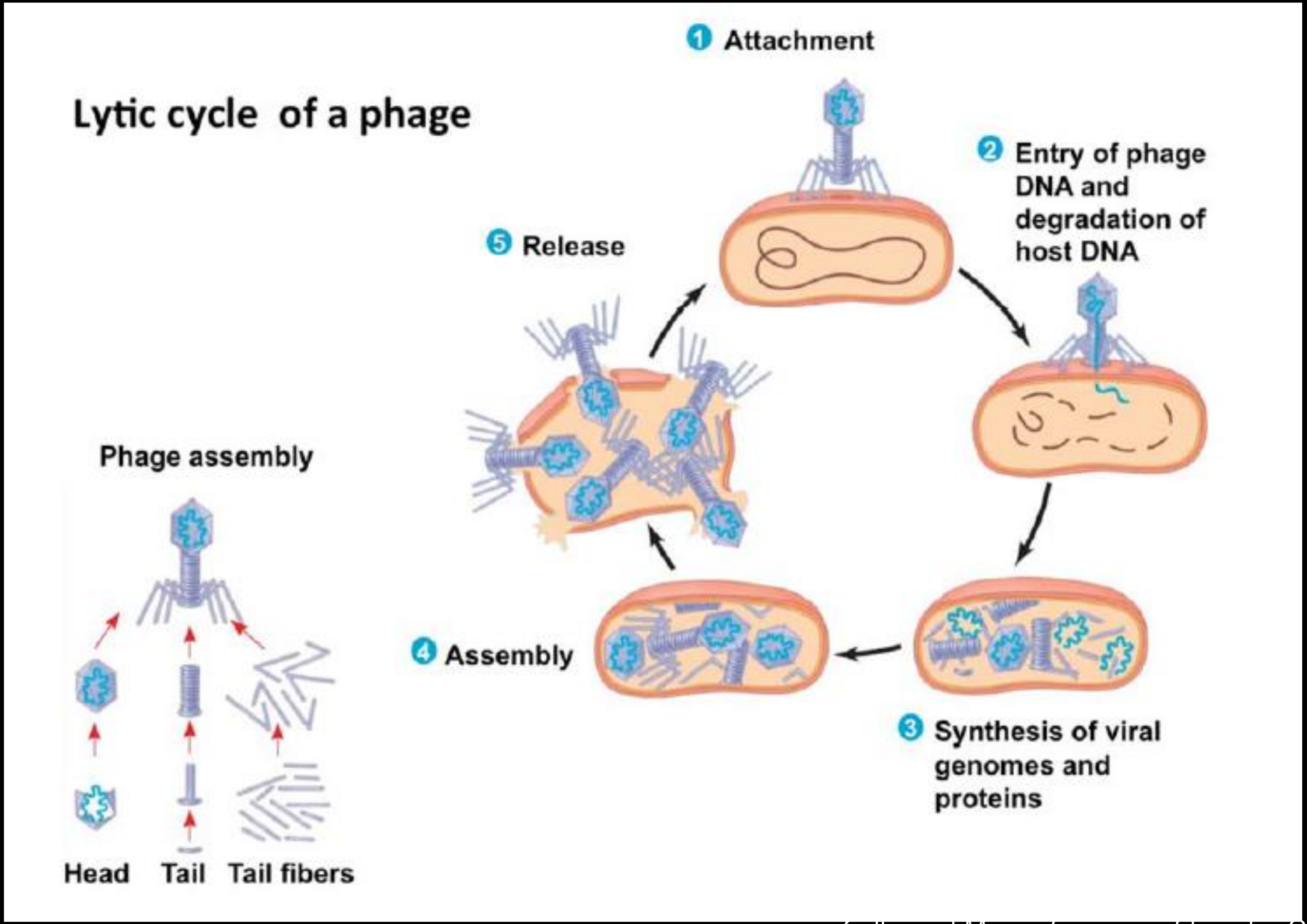
1 teaspoon of seawater=100,000,000 viruses

Marine Viruses



- Bacteriophage, infects *Prochlorococcus,* a marine planktonic cyanobacterium that is the most abundant photosynthetic cell on earth

Marine Viruses



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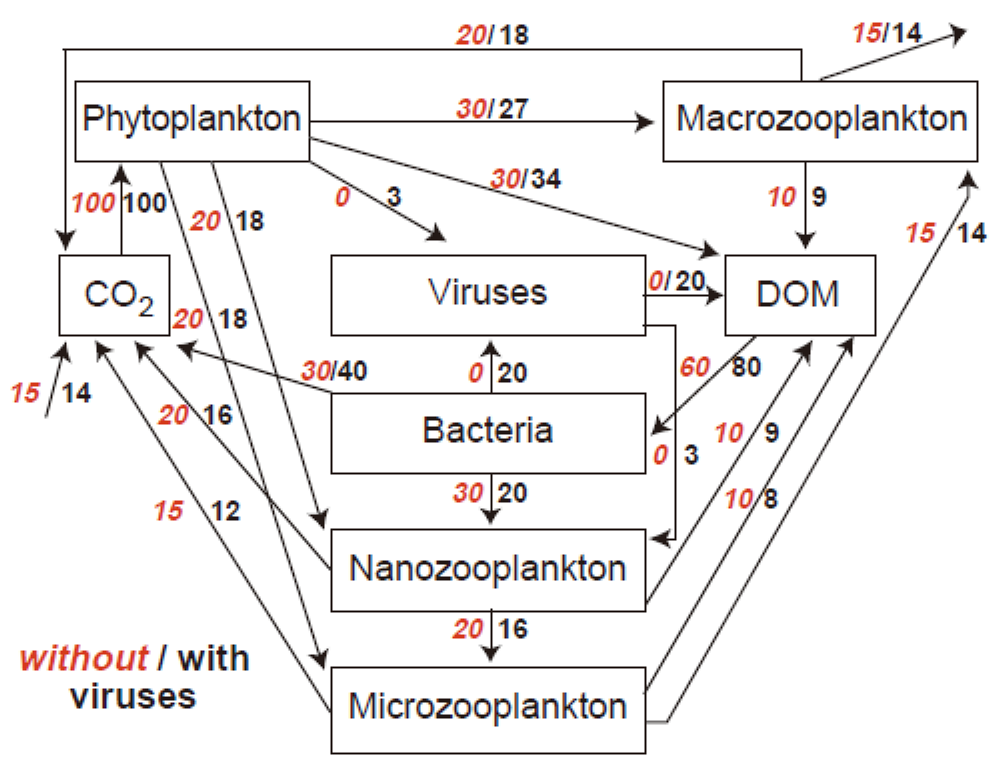


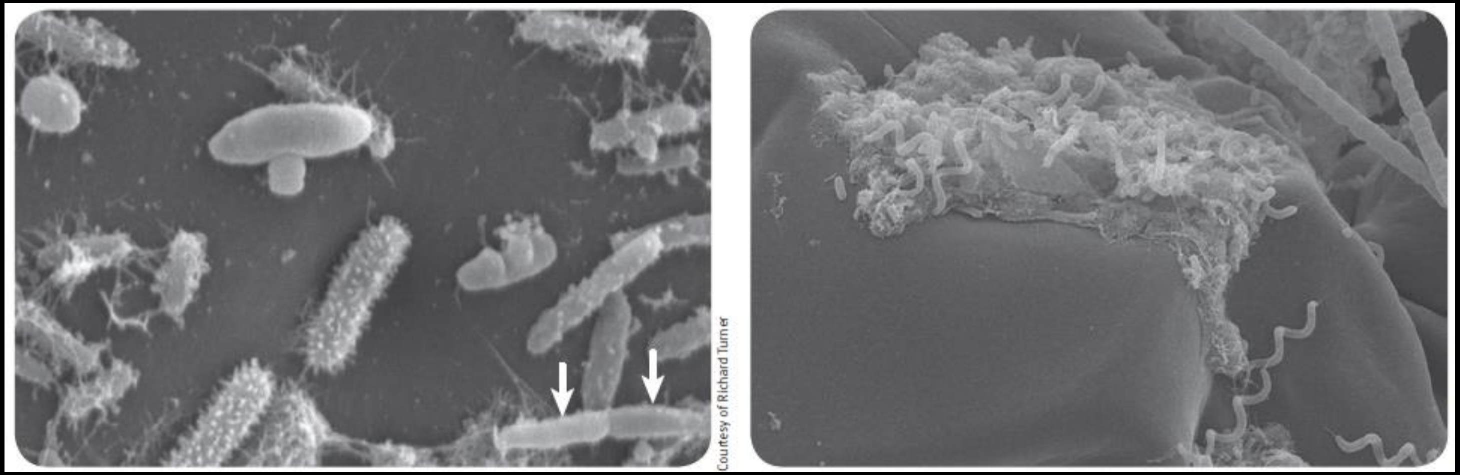
Figure 3 Modelling viral effects on carbon flow. Steady-state model of carbon flow in a hypothetical aquatic microbial food web with and without a virus component that is responsible for 50% of bacterial mortality and 7% of phytoplankton mortality. The numbers represent units of carbon transferred between boxes in a given time unit. The virus compartment includes bacterial cell debris from lysis, and lysed cells are assumed to degrade to dissolved organic matter (DOM). Nanozooplankton are heterotrophic protists 2–20 μm in diameter and microzooplankton are protists or small metazoa ~20-200 μm in diameter (see Box 1 for further descriptions). Note that the viruses lead to an increase in bacterial production and respiration, and a decrease in zooplankton production and respiration. See text and ref. 2 for details.

Ecology of marine viruses

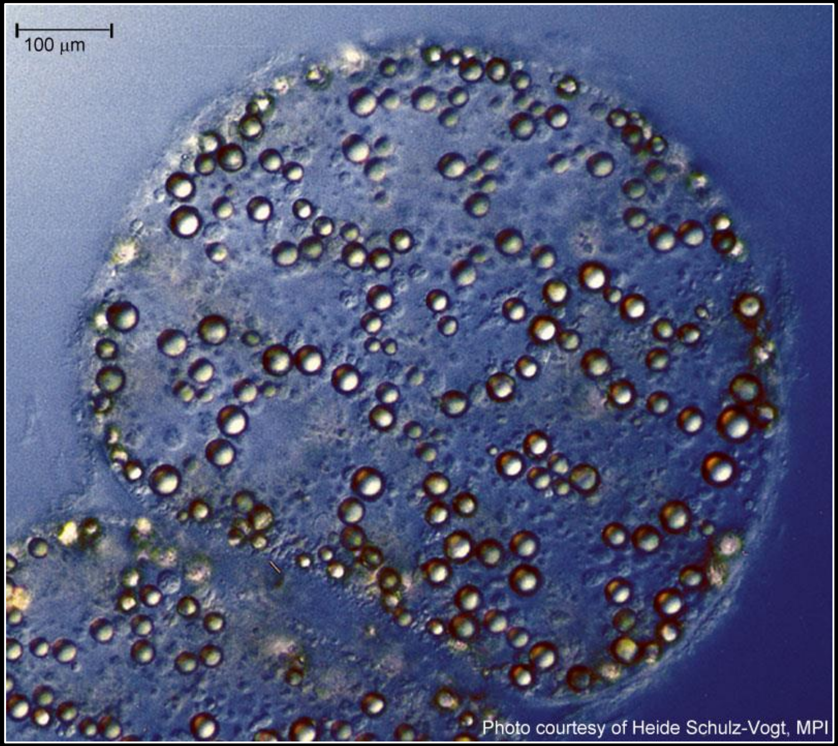
- Viruses are more abundant than other microbes in the sea. Marine planktonic viruses are responsible for the death of many bacteria and phytoplankton in the epipelagic zone. Through this process, viruses play a significant role in marine food chains and in the cycling of mineral nutrients in the sea. Many emerging diseases of marine animals are caused by viruses.

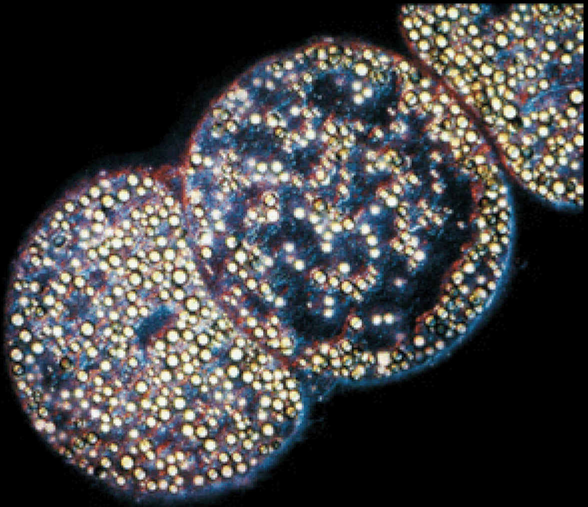
Marine Bacteria

- Marine bacteria are primary producers, decomposers, agents in biogeochemical cycles, food for other marine inhabitants, modifiers of marine sediments, and symbionts and athogens.



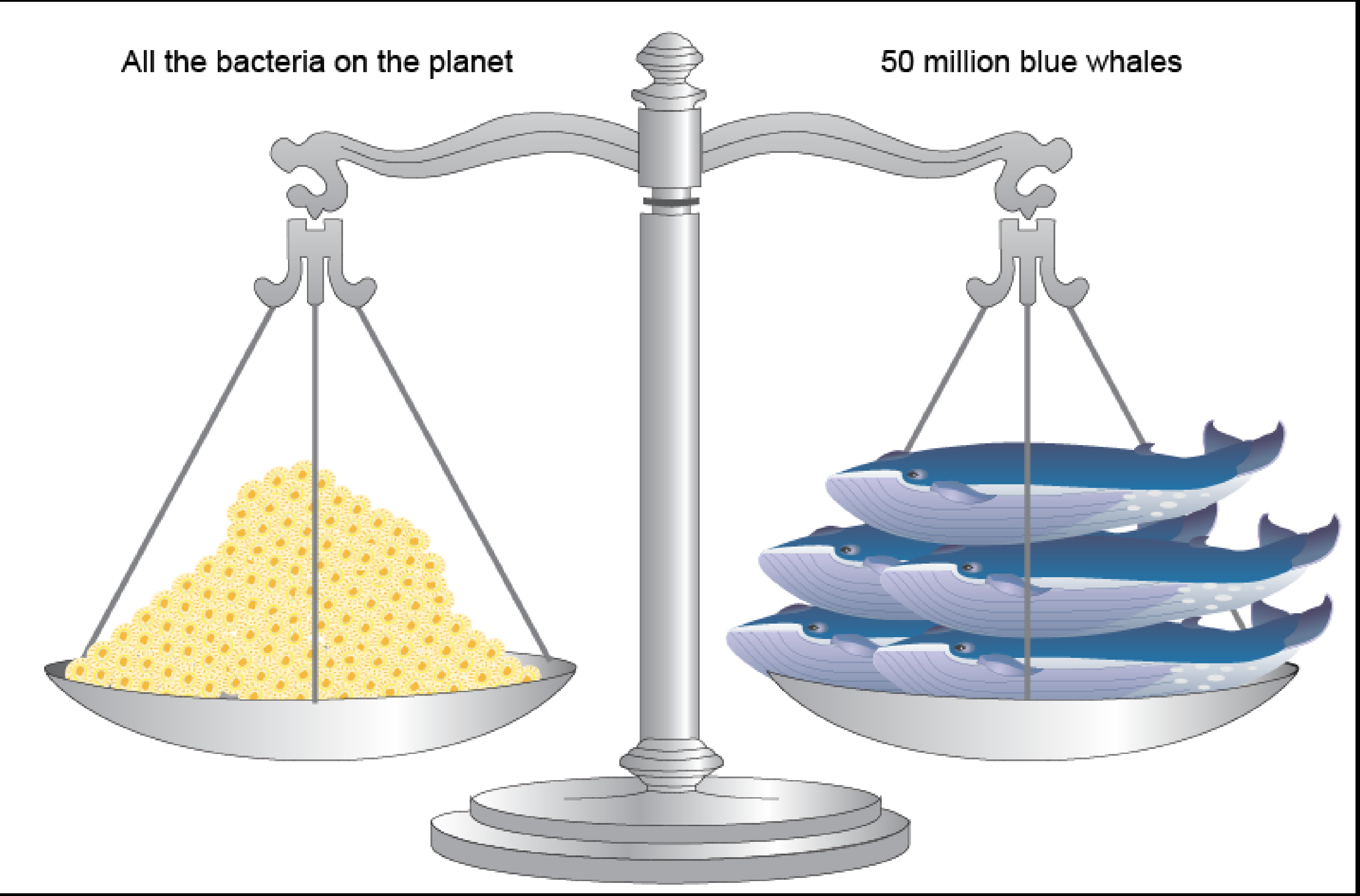
Size

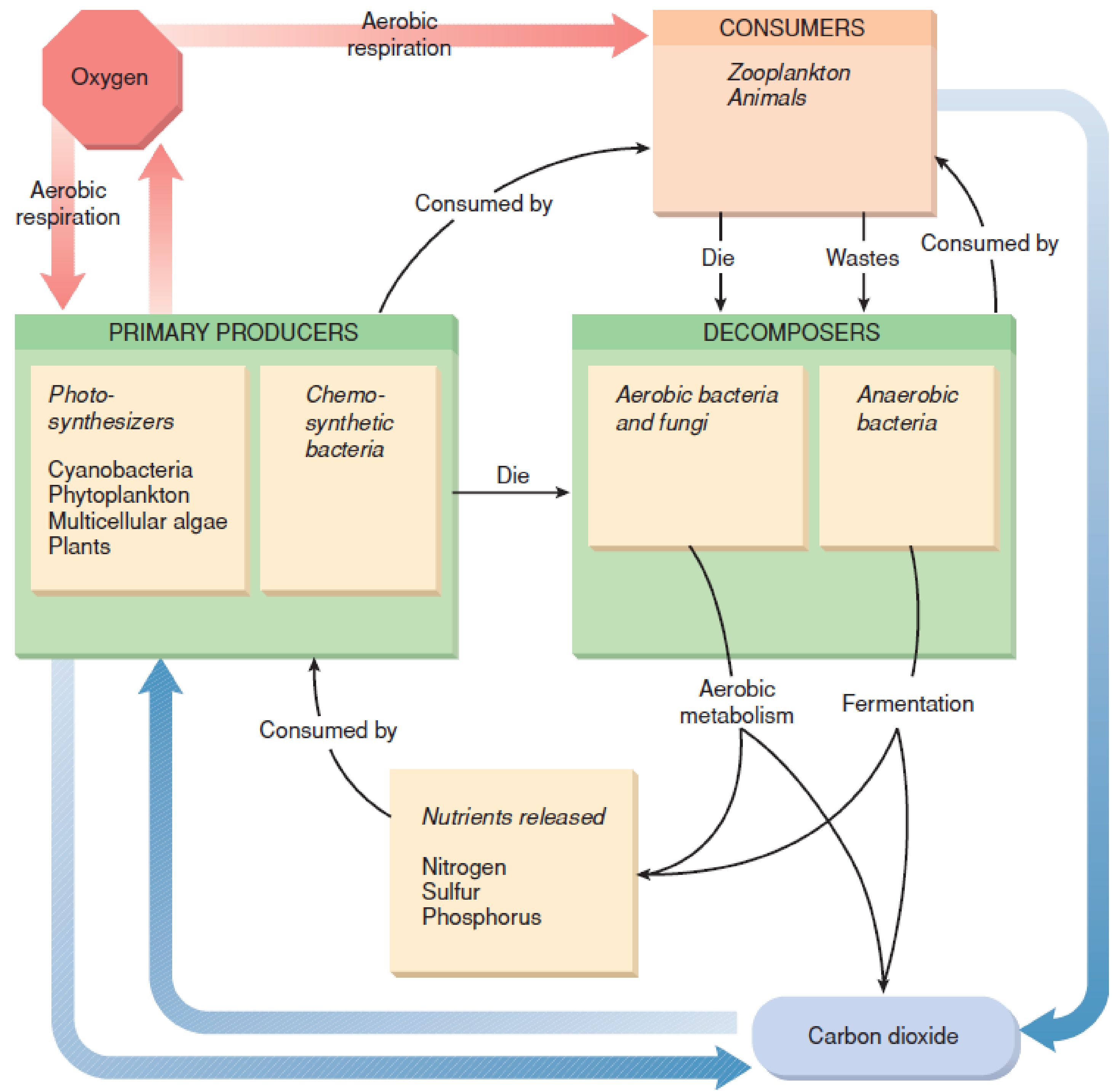




Thiomargarita namibiensis

Weight





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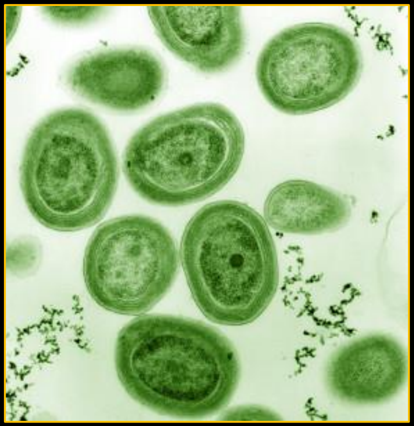
Photosynthetic marine microbes

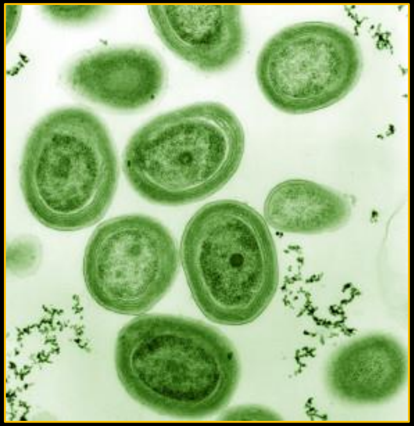
0.6 1.0 5.0 6.0-20 20-200μm



Prochlorococcus
Cyanobacterium
100,000 cells/ml
~10^{27} globally

Photosynthetic marine microbes

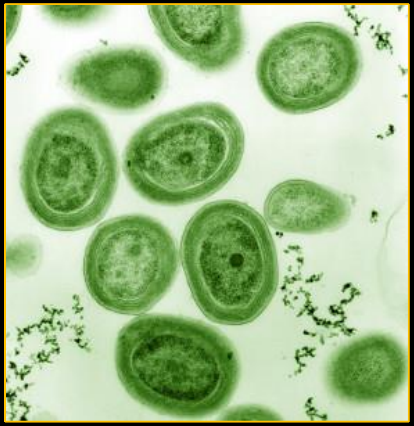
0.6 1.0 5.0 6.0-20 20-200µm

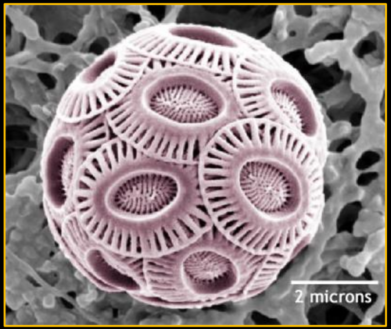


Synechococcus
Cyanobacterium
1000 cells/ml

Photosynthetic marine microbes

0.6 1.0 5.0 6.0-20 20-200μm

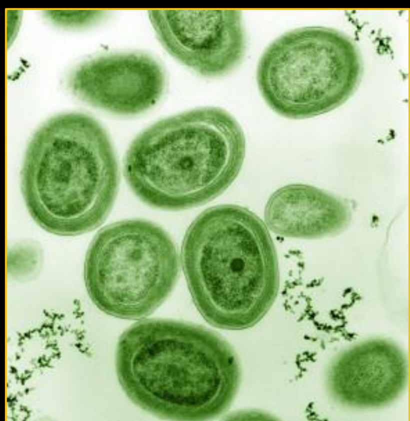


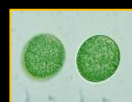


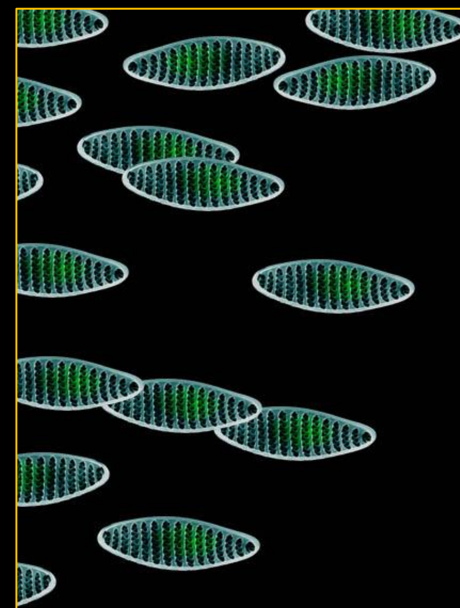
Emiliania huxleyi
Coccolithophorid

Photosynthetic marine microbes

0.6 1.0 5.0 6.0-20 20-200μm



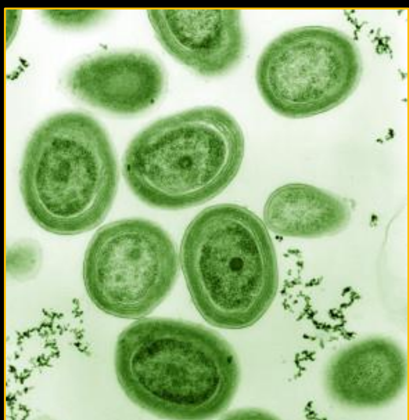


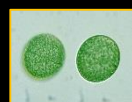


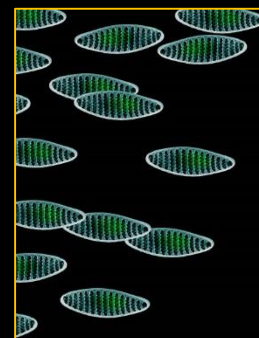
Fragillariopsis
Antarctica
diatiom

Photosynthetic marine microbes

0.6 1.0 5.0 6.0-20 20-200μm



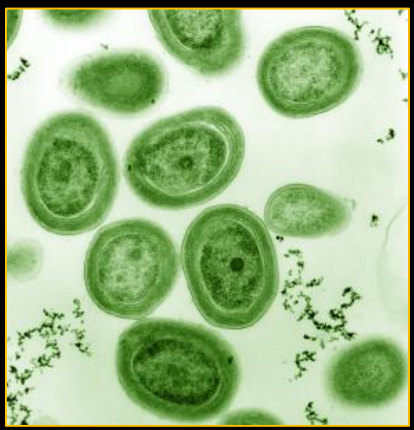


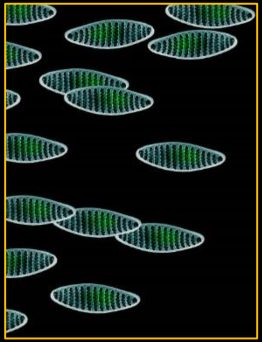


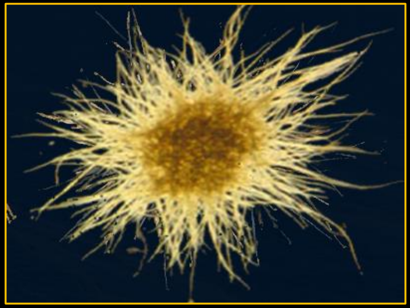
Gymnodinium catenatum dinoflagellate

Photosynthetic marine microbes

0.6 1.0 5.0 6.0-20 20-200μm





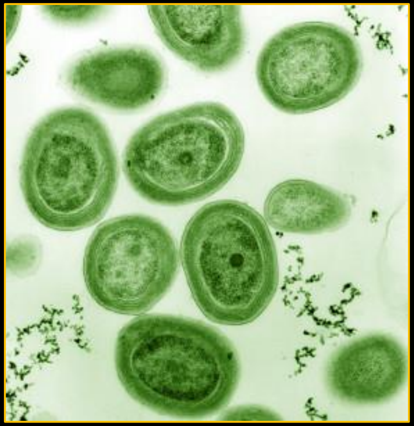


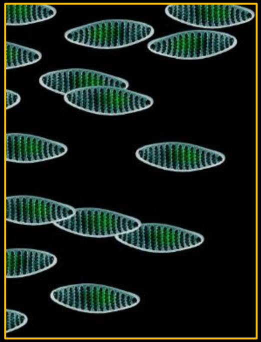
Trichodesmium sp.

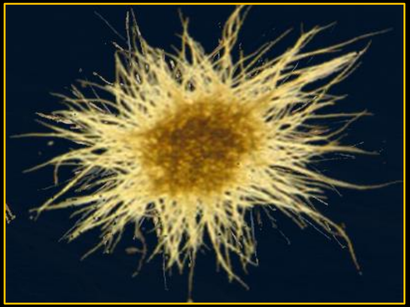
Phaeocystis antarctica

Photosynthetic marine microbes

0.6 | 1.0 | 5.0 | 6.0-20 | 20-200μm







Collectively known as

Phytoplankton

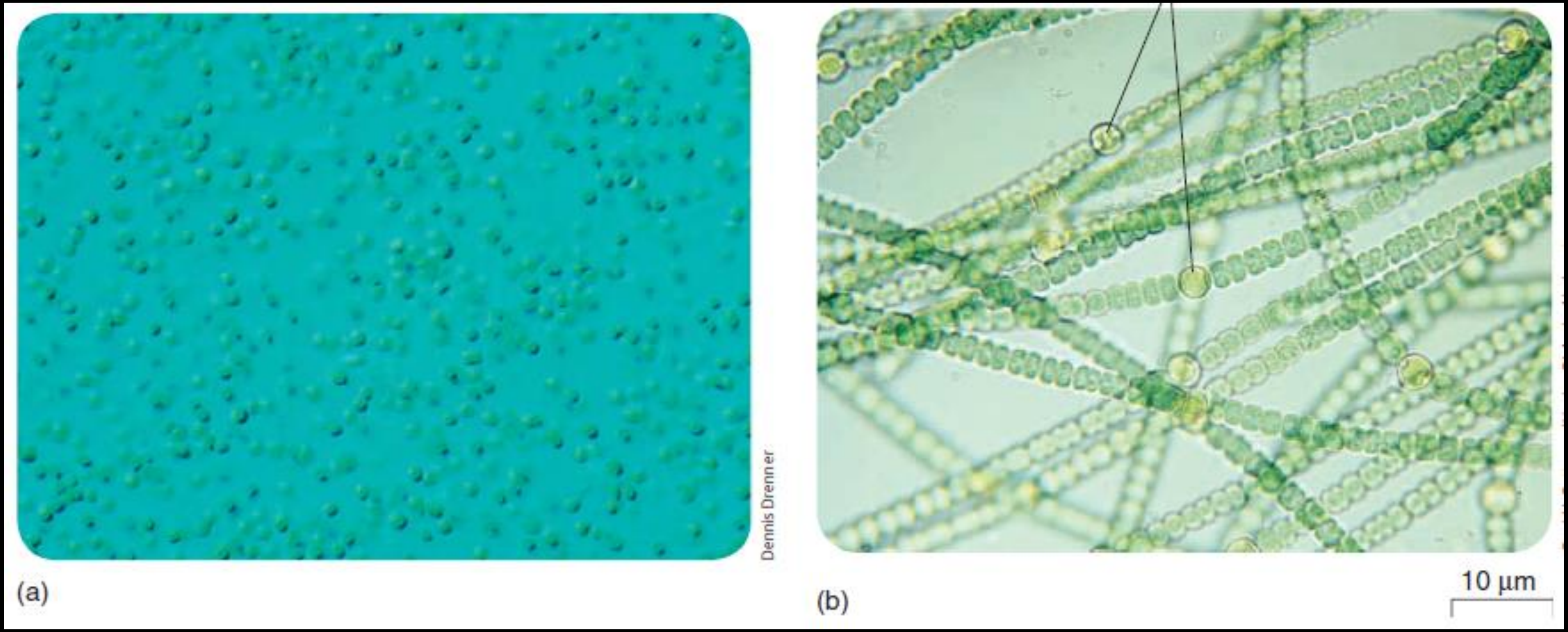
Phytoplankton

- Planktonic or free floating organisms which live by photosynthesis are termed phytoplankton.
- Photosynthesis by marine phytoplankton contributes roughly half of total global primary production.

Table 3.1 Estimates of total net primary production (NPP) by different primary producers and the amount of this production that is consumed by herbivores, decomposed, or stored in the sediments. Values in parentheses are the percentage of the total herbivory, decomposition or storage in the ocean. (From Duarte & Cebrian 1996; reproduced with permission of American Society of Limnology and Oceanography Inc.)

PRIMARY PRODUCER	AREA COVERED (10^6 KM^2)	TOTAL NPP	HERBIVORY (PG C YR^{-1})	DECOMPOSITION	STORAGE
Oceanic phytoplankton	332	43[5]	24.4(88)	14.7(77.5)	0.17(26.5)
Coastal phytoplankton	27	4.5	1.8(6.5)	1.8(9.8)	0.18(27.0)
Microphytobenthos	6.8	0.34	0.15(0.5)	0.09(0.4)	0.02(3.1)
Coral reef algae	0.6	0.61	0.18(0.6)	0.45(2.0)	0(0.7)
Macroalgae	6.8	2.55	0.86(3.1)	0.95(4.2)	0.01(1.6)
Seagrasses	0.6	0.49	0.09(0.3)	0.25(1.1)	0.08(12.0)
Marsh plants	0.4	0.44	0.14(0.5)	0.23(1.0)	0.07(11.3)
Mangroves	1.1	1.1	0.10(0.3)	0.44(1.9)	0.11(17.6)
Total	–	53.0	27.8(52)	19.0(36)	0.65(1.2)

Cyanobacteria



- (a) Probably the most common cells in the ocean are those of species of the planktonic blue-green *Prochlorococcus. (*b) The blue-green color seen in cells of this filamentous blue-green bacterium is the result of the green pigment chlorophyll a and the blue pigment phycocyanin. The enlarged cells are heterocysts, within which nitrogen is fixed for incorporation into amino acids, nucleic acids, and other nitrogen-containing organic compounds.

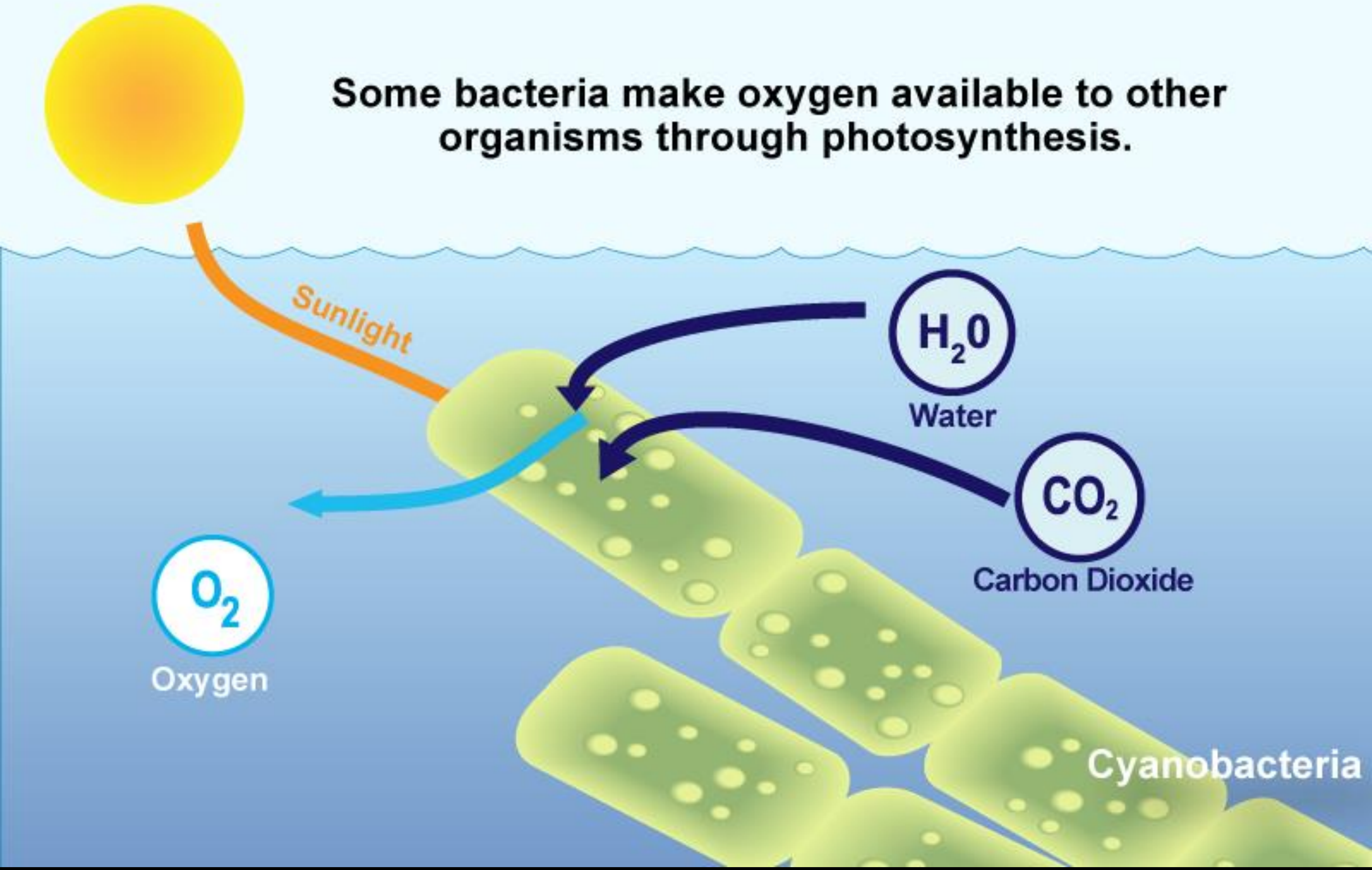
Prochlorococcus

表 1　原绿球藻在世界各调查海区的浓度分布

海区	原绿球藻的浓度(个/ml)	文献
北太平洋(ALOHA)	$1.4\times10^5\sim3.2\times10^5$	[3]，Campbell 等，1993
赤道太平洋(12°N~12°S, 140°W)	$1.6\times10^5\sim2.3\times10^5$	[6]
西赤道太平洋(20°S~7°N, 165°W)	$1\times10^5\sim5.4\times10^5$	[2]
中赤道太平洋(0°N, 140°W)	1.4×10^5(平均)	[1]
中部太平洋(48°N~8°S, 175°W)	$10^4\sim10^5$	Suzuki 等，1995
北大西洋中部	$0.8\times10^5\sim1.2\times10^5$	Li，1995
北大西洋，马尾藻海	$3\times10^6\sim7\times10^6/mm^2$(200 m 积分)	Olson 等，1990
地中海	1.9×10^4(冬季平均)	Vaulot 等，1990
太平洋 Suruga 湾	$5\times10^3\sim1\times10^4$	[14]
西北印度洋	$6\times10^4\sim7\times10^5$	[5]
红海 Aqaba 湾	1.6×10^5	Lindell 和 Post，1995
东海	$10^3\sim10^5$	Jiao 和 Yang，1998
南海	$10^4\sim10^5$	杨燕辉，2000，博士论文

原绿球藻大量地分布在热带、亚热带、温带大洋海域、边缘海以及海湾中

Some bacteria make oxygen available to other organisms through photosynthesis.



Cyanobacteria

- The photosynthetic activity of blue-green bacteria accounts for a major proportion of the production of organic matter and oxygen in the seas.
- *Prochlorococcus* and *Synechococcus* are among the smallest and most productive bacteria in plankton communities. Of the two genera, *Prochlorococcus* is believed to be the most abundant life form in the sea, and it is well adapted to the nutrient-poor open ocean of the tropics. Yet it was discovered only recently, in 1988.

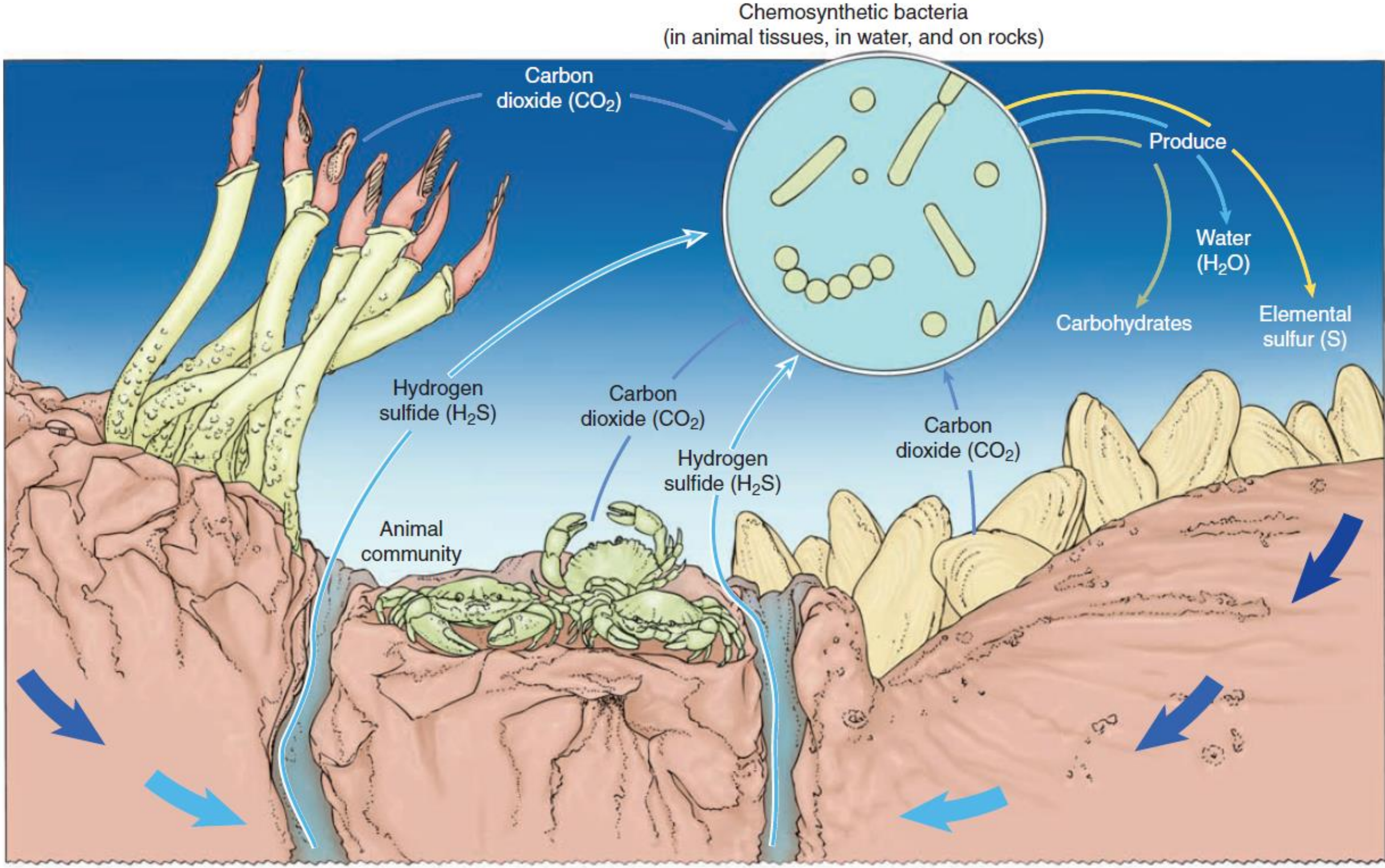
Cyanobacteria bloom

Other phytoplankton bloom

- Observable from space

Chemosynthetic Bacteria

- Light is absent from most ocean waters and sediments, but bacteria still can be autotrophic in these habitats, using inorganic chemicals rather than light as a source of energy. Such bacteria are called chemosynthetic bacteria. *Chemosynthetic bacteria* use energy derived from chemical reactions that involve substances such as ammonium ion (NH_4^+), sulfides (S^{2-}) and elemental sulfur (S), nitrites (NO_2^-), hydrogen (H_2), and ferrous ion (Fe^{2+}).
- The energy is used to manufacture organic food molecules, usually with carbon dioxide (CO_2) as the carbon source.



Chemosynthetic bacteria
(in animal tissues, in water, and on rocks)
Carbon dioxide (CO_2)
Produce
Water (H_2O)
Carbohydrates
Elemental sulfur (S)
Hydrogen sulfide (H_2S)
Carbon dioxide (CO_2)
Hydrogen sulfide (H_2S)
Carbon dioxide (CO_2)
Animal community

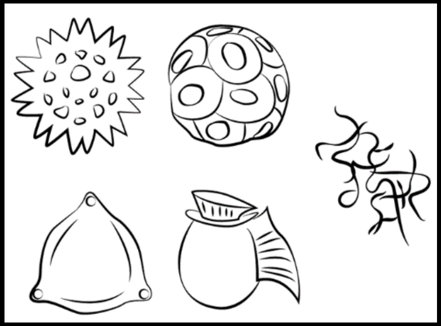
Heterotrophic Bacteria

- Heterotrophic bacteria are decomposers, which use available organic matter in their surroundings to obtain energy and material for synthesis of their own compounds and for general metabolism.
- Osmotrophy

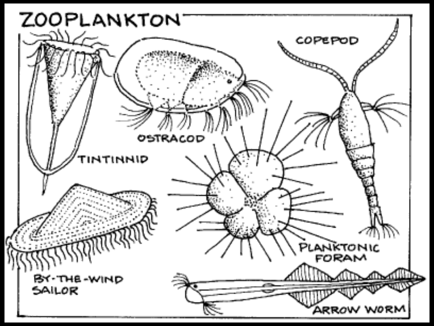
Ecology of Marine microbes

- Algal picoplankton is responsible for up to 90% of the total carbon production daily and annually in oligotrophic marine ecosystems.
- Picoplankton also play an important role in the microbial loop of these systems by aiding in providing energy to higher trophic levels.
- They are grazed by a various number of organisms such as flagellates, ciliates, rotifers and copepods. Flagellates are their main predator due to their ability to swim towards picoplankton in order to consume them.

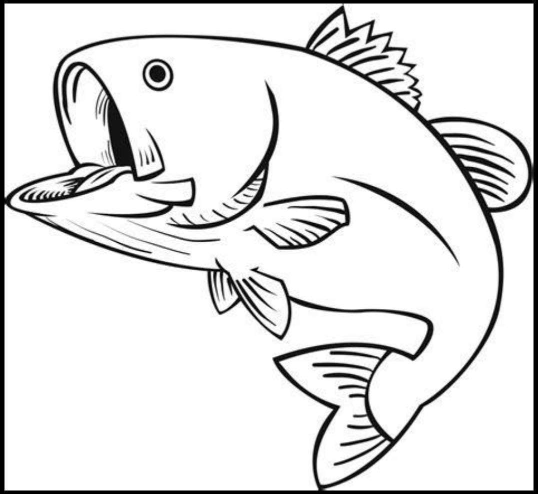
Produce food for the food web



Phytoplankton

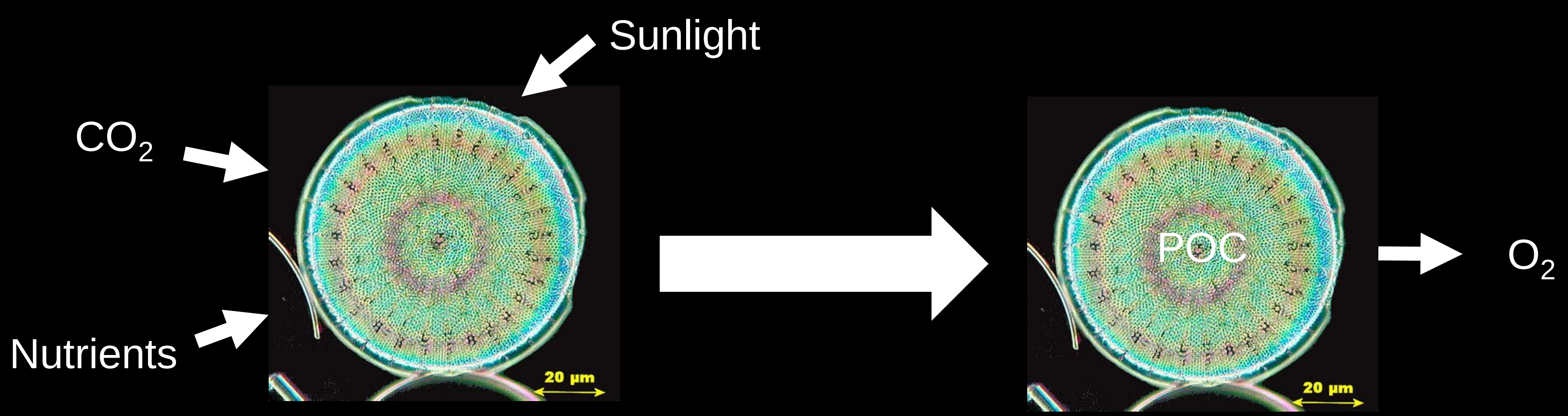


zooplankton



Higher trophic level

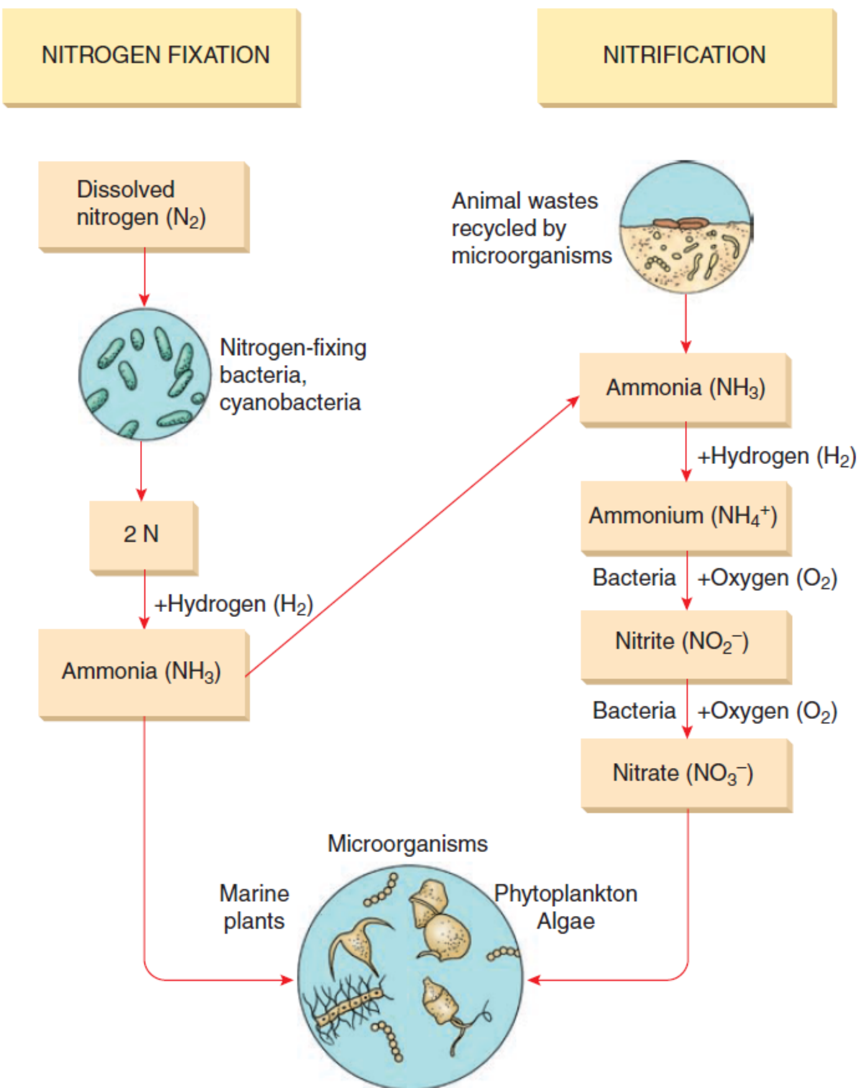
Key players in the Carbon cycle



Every day more than a hundred million tons of carbon are "fixed" into organic material.

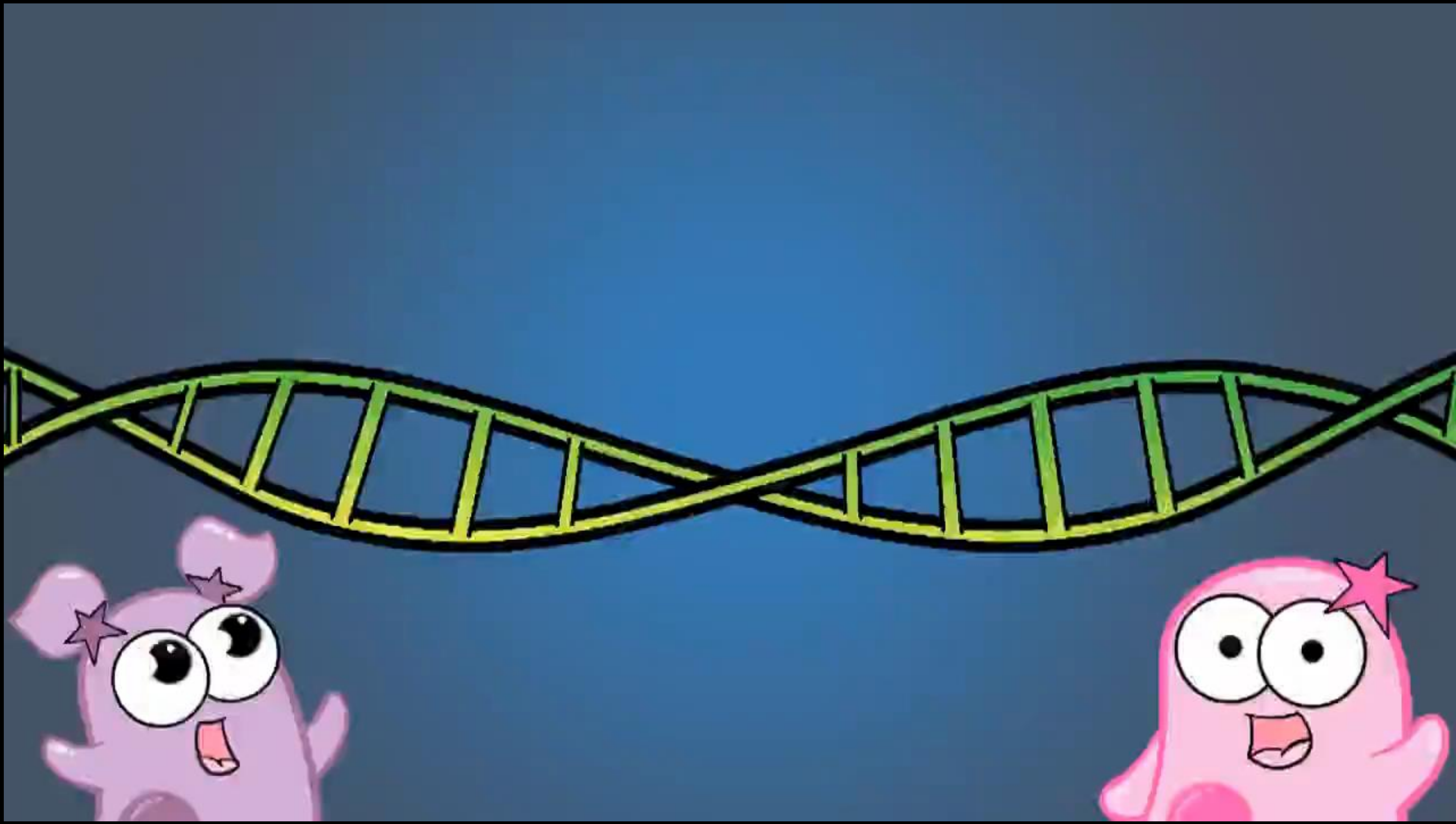
Procholorococcus accounts for an estimated 20% of the oxygen in the Earth's atmosphere

Nitrogen fixation and nitrification



- Nitrogen dissolved in seawater is converted by blue-green bacteria to ammonium ion; this process is called *nitrogen fixation*.
- In *nitrification*, bacteria convert ammonium to nitrites and nitrates, forms of nitrogen that are more readily used by primary producers.

Endosymbiotic theory



Bioluminescence

Bioluminescence

In summary

- Bacteria have cells with a prokaryotic organization. Chemosynthetic and photosynthetic bacteria extract inorganic nutrients, such as nitrogen, phosphorus, and carbon dioxide, from the environment and incorporate them into organic molecules.
- Chemosynthetic bacteria use energy derived from chemical reactions (often involving compounds of sulfur) to produce their food molecules, whereas photosynthetic ones use the radiant energy from the sun.
- Some producers, such as blue-green bacteria, release oxygen during photosynthesis. Such primary producers, as well as heterotrophic bacteria, form the base of marine food webs.
- In addition, marine bacteria play a critical role in nitrogen fixation and nitrification. As decomposers, bacteria return dead organic matter to biogeochemical cycles as inorganic matter that primary producers can incorporate into living biomass.

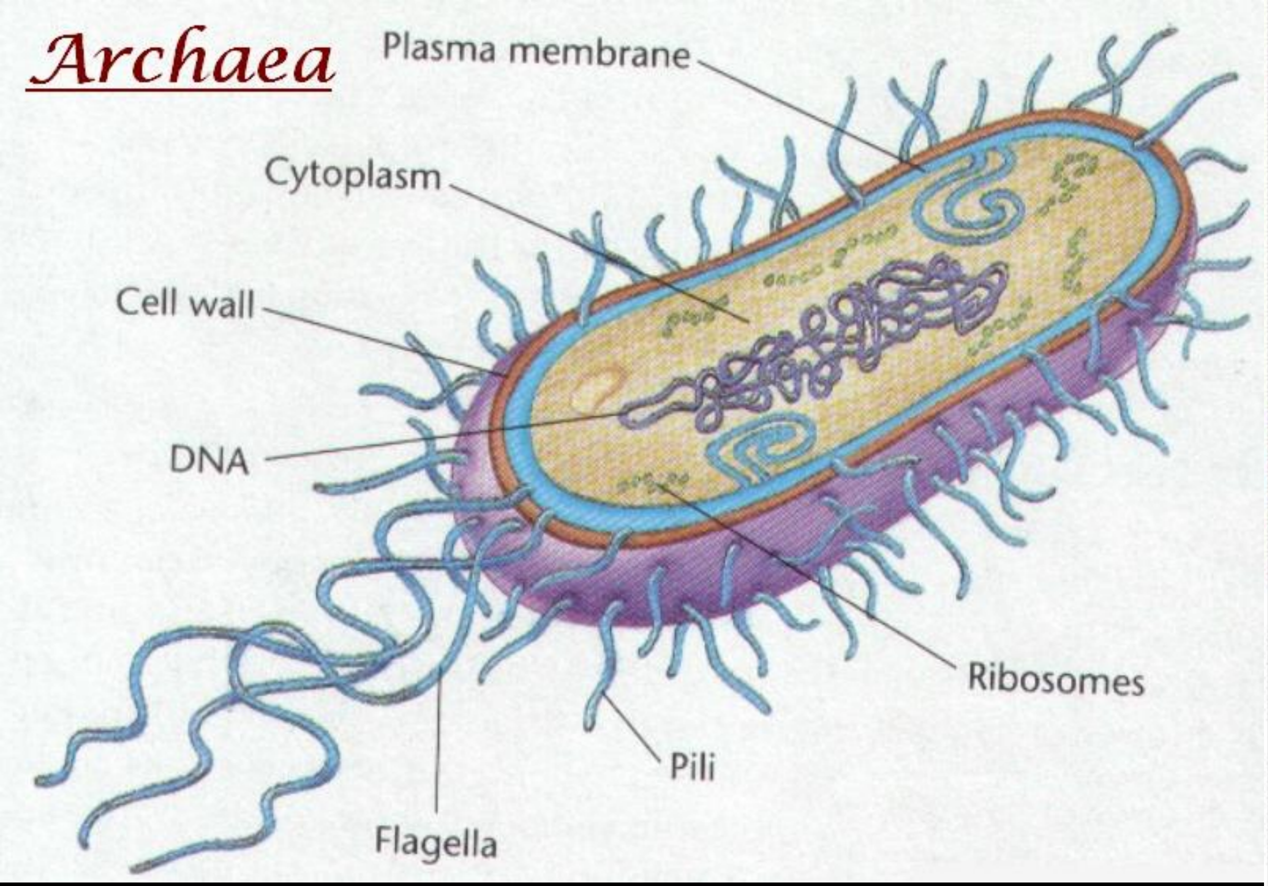
In summary

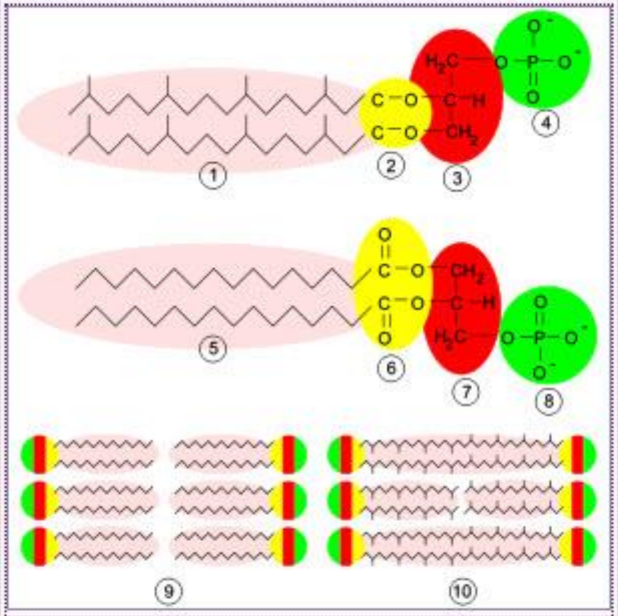
- The chemosynthetic bacteria of hydrothermal vent communities and the bioluminescent bacteria found in association with deep-sea organisms are examples of recently evolved symbiotic relationships.
- The oldest symbiotic relationships of bacteria gave rise to mitochondria and chloroplasts, which are endosymbionts in eukaryotic cells.

Archaea

- Like bacteria, *archaeons* are prokaryotes. Most *archaeons* are methanogens, anaerobic organisms that live in environments that are rich in organic matter, and they make significant contributions to methane production.
- Archaeons have an unsurpassed ability in the natural world to tolerate extreme environmental conditions.
- Archaea make up 20% of the earth mass and they are important decomposers.

Archaea





Membrane structures. **Top**: an archaeal phospholipid, **1** isoprene sidechain, **2** ether linkage, **3** L-glycerol, **4** phosphate moieties. **Middle**: a bacterial and eukaryotic phospholipid: **5** fatty acid, **6** ester linkage, **7** D-glycerol, **8** phosphate moieties. **Bottom**: **9** lipid bilayer of bacteria and eukaryotes, **10** lipid monolayer of some archaea.

Methanocaldococcus jannaschii is a methane-producing archaeon that lives at high temperatures near deep-sea hydrothermal vents. It was the first archaeon to have its genome sequenced.

Eukarya

- The domain Eukarya contains all of the organisms with eukaryotic cells. These include plants, animals, and fungi, as well as photosynthetic microbes and single-celled animal-like protozoans.

Fungi

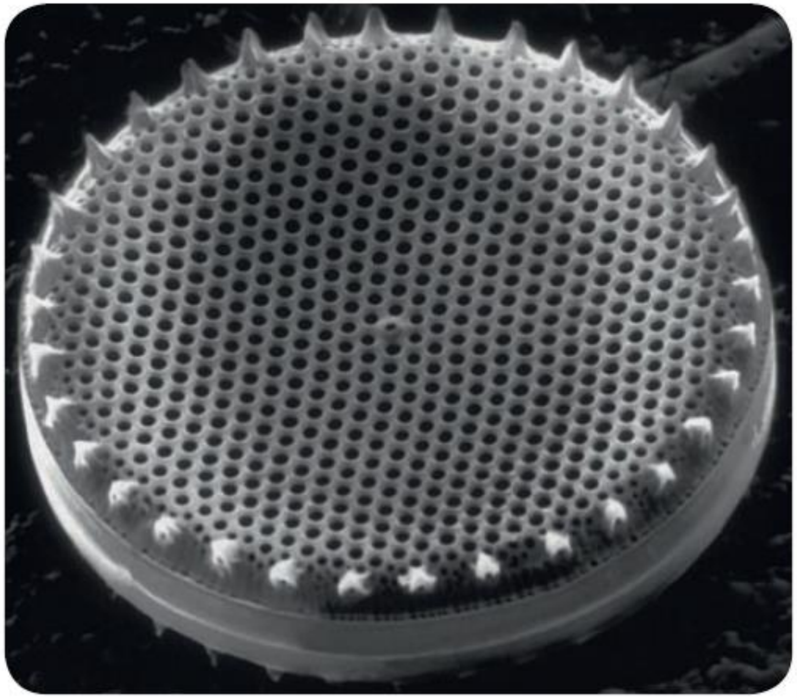
- Marine fungi are microscopic decomposers and pathogens. Most are sac fungi that can degrade the cell walls of terrestrial, maritime, and marine plants. Some fungi digest chitin and other decay-resistant molecules that otherwise would accumulate in seafloor sediments. Marine fungi take advantage of water currents and sea foam for the transport of spores. They form lichen associations with green algae and blue-green bacteria in maritime communities.

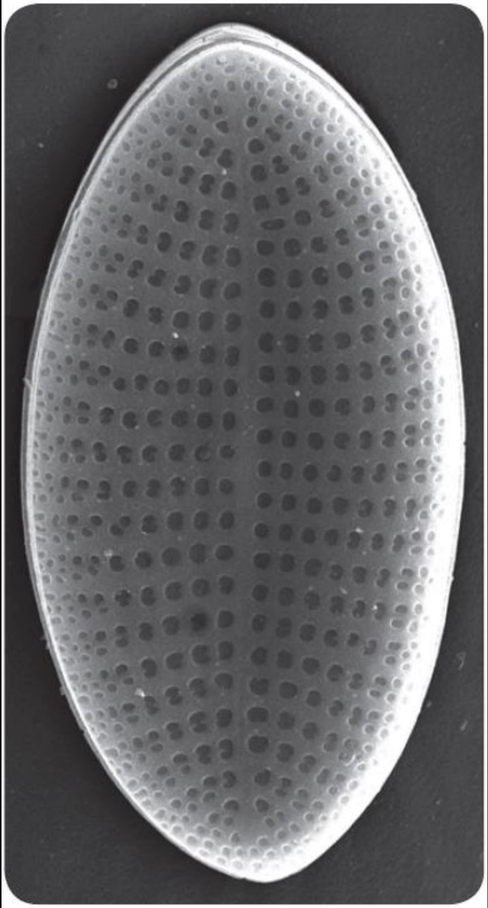
Diatom

Diatoms

- Diatoms are among the most distinctive organisms in samples of marine phytoplankton, and they also are important members of benthic communities.
- Diatoms are abundant in the oceanic province at high latitudes, whereas at low latitudes they are predominantly found in coastal waters or in areas of upwelling.
- Wherever they occur, diatoms often contribute a major portion of primary production.
- Diatoms typically store their food reserves as lipids as well as laminarin. The lipids help make diatoms more buoyant and provide a food source of high caloric value to herbivores such as copepods.

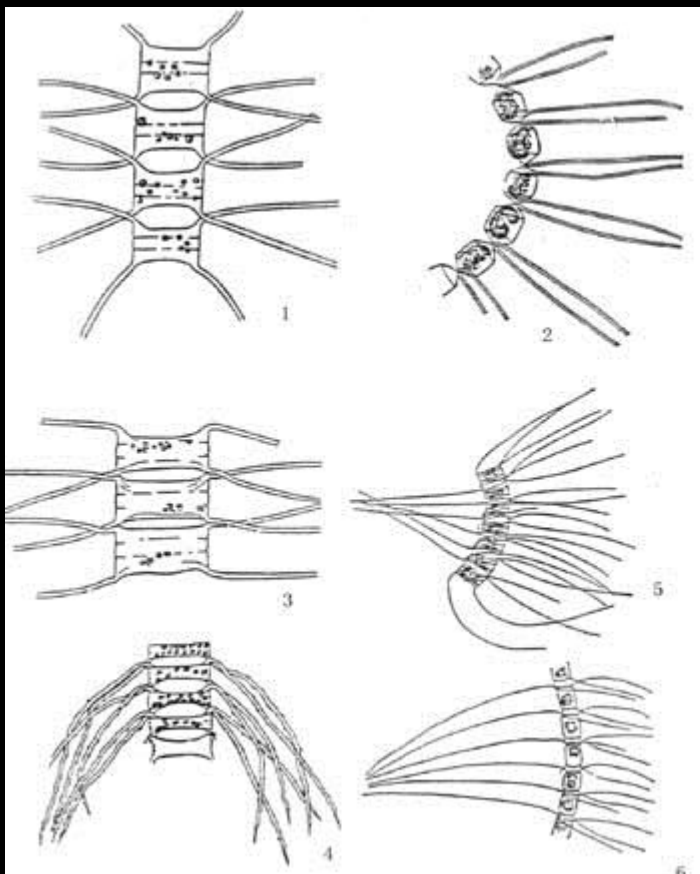
Diatom Structure


(a)


(b)

- Centric diatoms generally are planktonic, and the pennate diatoms are more typical of the benthos

Diatom



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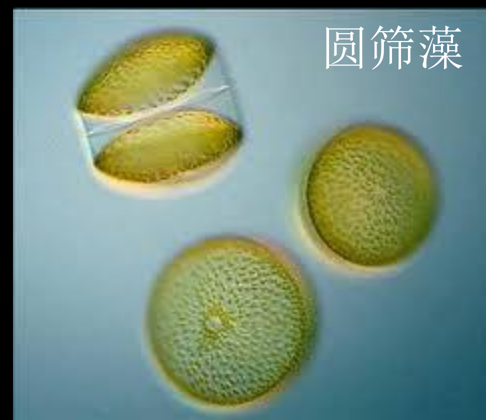
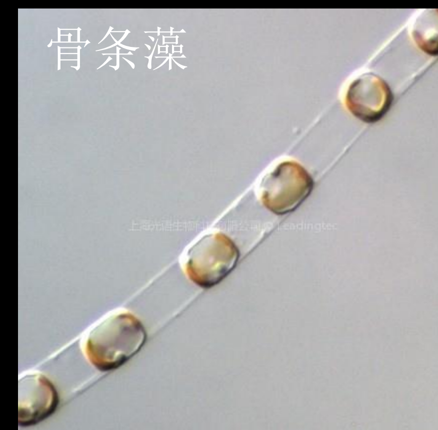
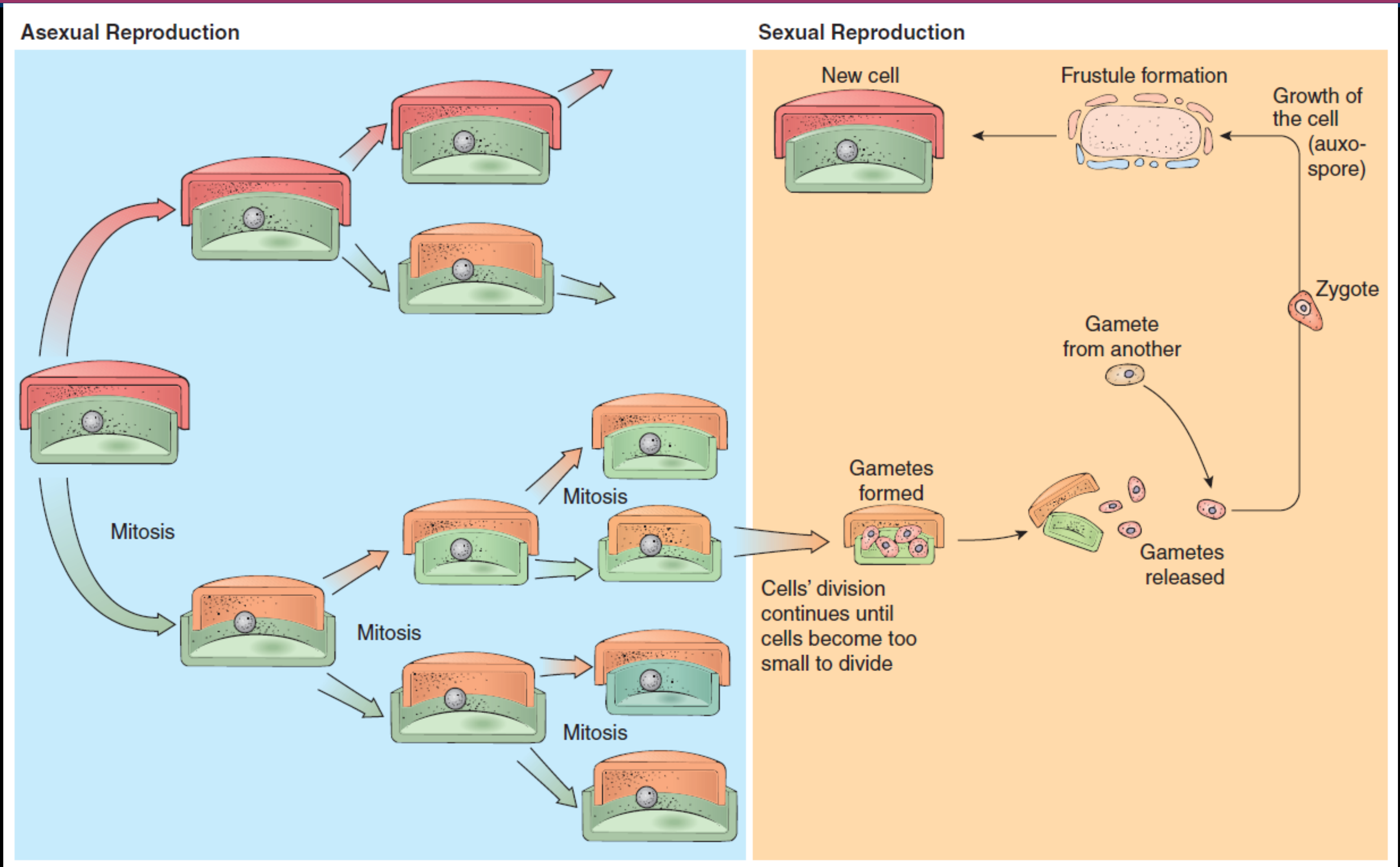
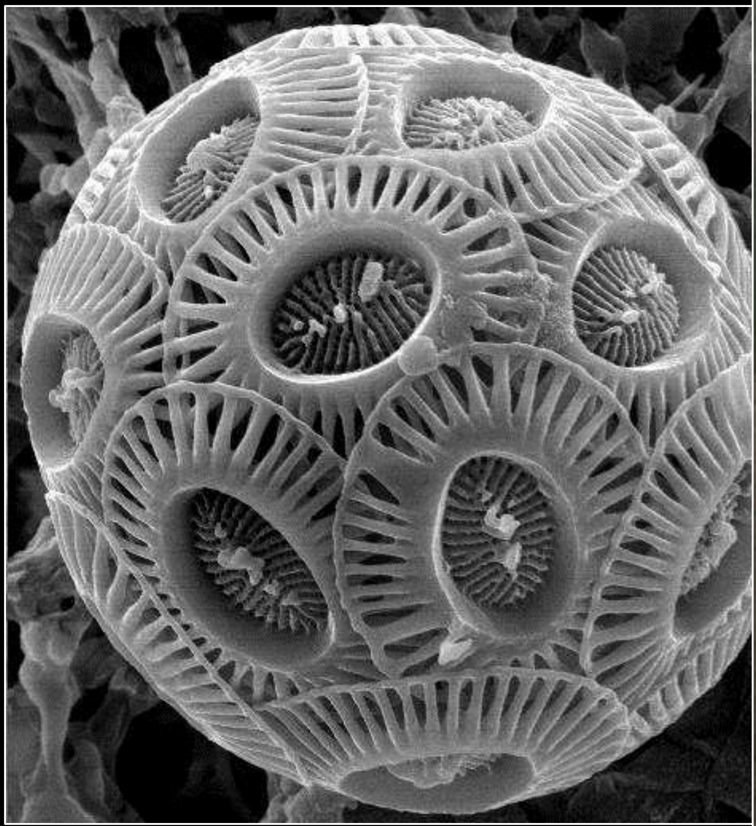




Reproduction in Diatoms



Coccolithophores

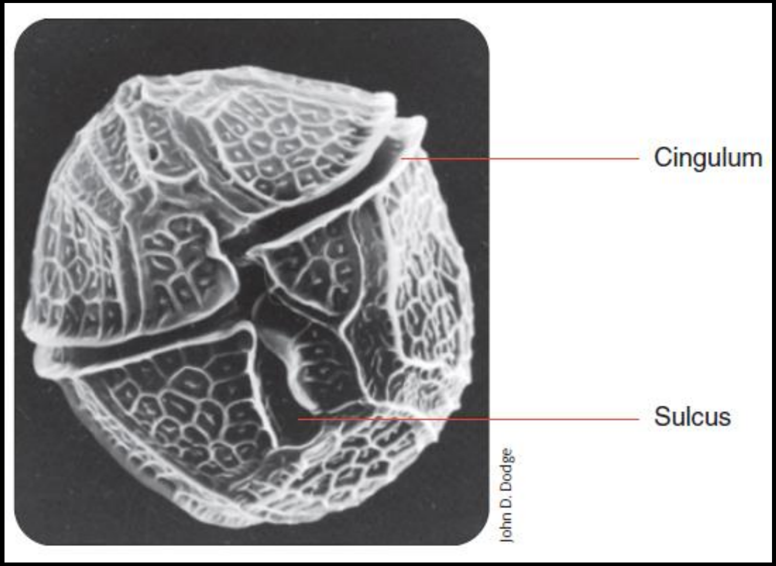


Emiliania huxley

Climate Change

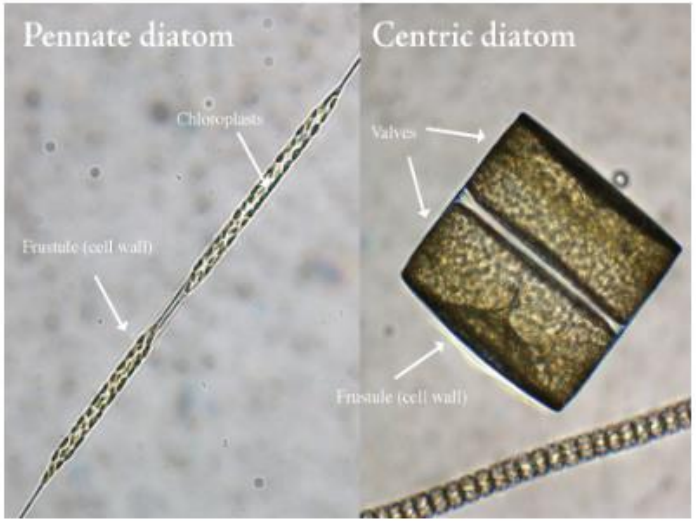
- Coccolithophores are one of the more abundant primary producers in the ocean. As such, they are a large contributor to the primary productivity of the tropical and subtropical oceans.

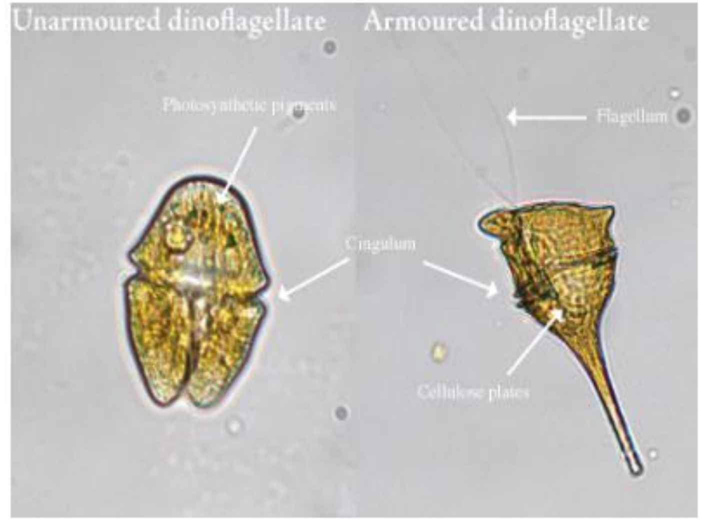
Dinoflagellates



Diatoms and Dinoflagellates

There are many different groups of phytoplankton species found in the world's oceans, but among the most common are diatoms and dinoflagellates. Most of the species featured on this site belong to one of these two groups. There are several features of a phytoplankton cell that can identify it as a diatom or dinoflagellate.





Diatoms

- Eukaryotic single-celled algae
- Divided into two major groups based on the structure and shape of the valves. These are the Centrics (Order: Biddulphiales) and the Pennates (Order: Bacillariales)
- They are most like plants in their ability to meet their nutritional needs through photosynthesis
- The presence of chlorophyll and accessory pigments, especially fucoxanthin, give them a golden color and serve to harvest light energy from the sun
- Cells are encased in a transparent glass-like silica "container" called a frustule that resembles a petri-dish. The overlapping valve is called an epitheca and the lower valve is a hypotheca
- The frustules can be ornate and very beautiful, and due to the resistance of silica, they form an important part of the fossil record
- Cells may form chains or colonies.
- Up to 100,000 species of diatoms have been recorded world-wide

Dinoflagellates

- Eukaryotic single-celled algae
- Many have two flagella, which allow the cells to have limited mobility
- Cells are covered by a theca (sheath) that can be smooth or ornamented
- Some species are able to migrate vertically through the water column, seeking nutrients, prey, or protection from harmful UV rays.
- Nearly half of known species are capable of photosynthesis and contain light-harvesting pigments (autotrophs)
- Some species survive by other nutritional modes, and may absorb organic matter or engulf prey (heterotrophs)
- Many species employ a combination of autotrophic and heterotrophic behaviors
- Of the 2000 known species, about 60 are able to produce complex toxins
- Dinoflagellates are a very successful group, at times to the detriment of the ecosystem. When conditions are favorable, a population explosion or bloom may occur, sometimes resulting in contamination of fish and shellfish and posing a threat to human and animal health.

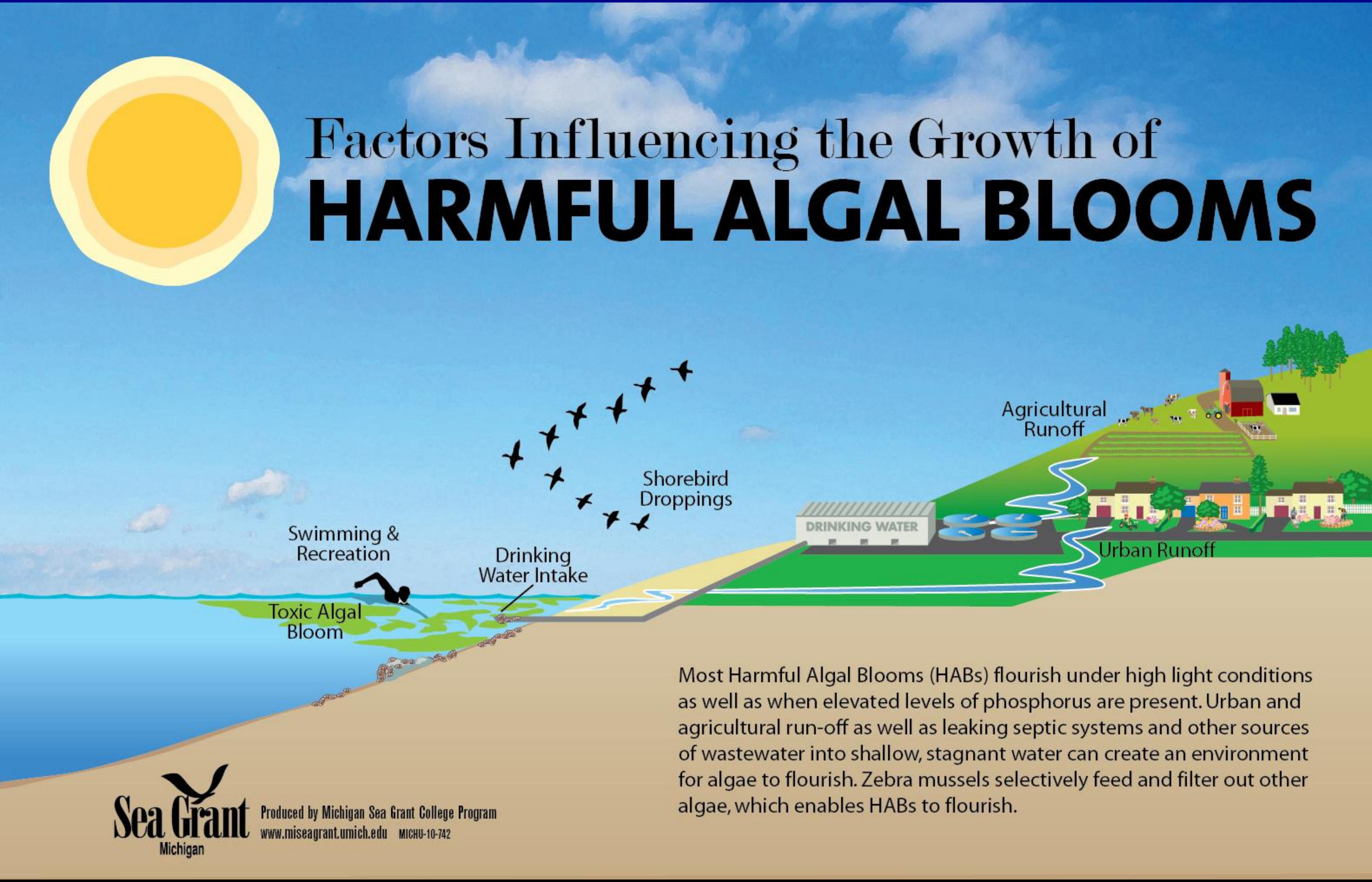
Harmful Algal Blooms

- HABs occur when photosynthetic dinoflagellates (or other primary producers) undergo a population explosion. The species that cause HABs produce potent toxins that affect the nervous system, kidneys, muscles, or other parts of animals, either directly or through consumption of contaminated food.



Ecological roles of Dinoflagellates

- Together with diatoms and coccolithophores, they are a major component of the phytoplankton that provides food directly or indirectly to many marine animals.
- Dinoflagellates are more abundant than diatoms in tropical waters, particularly in the open sea where inorganic nutrients are in low concentration.
- The zooxanthellae are photosynthetic and provide food for their host organisms, and the hosts provide carbon dioxide, other essential nutrients, and shelter.


Factors Influencing the Growth of
HARMFUL ALGAL BLOOMS
Agricultural Runoff
Shorebird Droppings
DRINKING WATER
Urban Runoff
Swimming & Recreation
Drinking Water Intake
Toxic Algal Bloom
Most Harmful Algal Blooms (HABs) flourish under high light conditions as well as when elevated levels of phosphorus are present. Urban and agricultural run-off as well as leaking septic systems and other sources of wastewater into shallow, stagnant water can create an environment for algae to flourish. Zebra mussels selectively feed and filter out other algae, which enables HABs to flourish.
Sea Grant Michigan
Produced by Michigan Sea Grant College Program
www.miseagrant.umich.edu MICHU-10-742

Photosynthesis

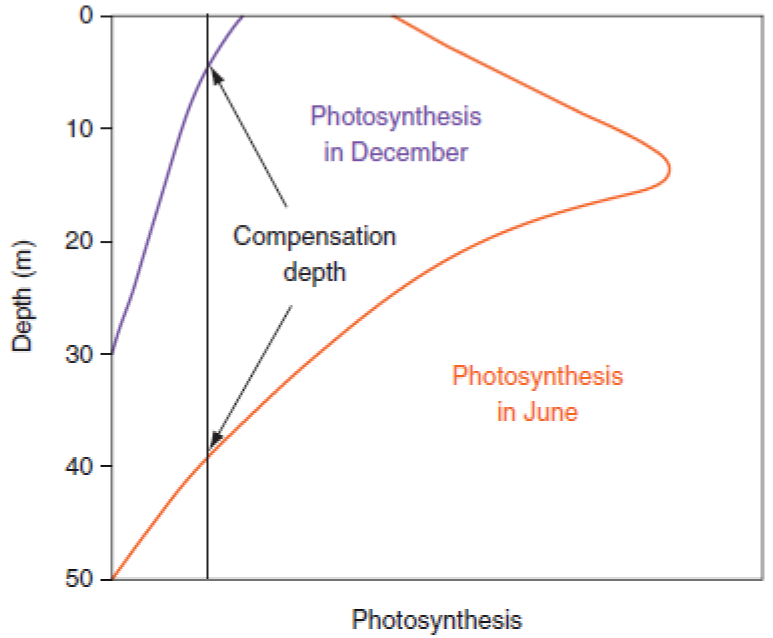


Figure 3.7

Seasonal variation in the amount of photosynthesis with depth showing the differing vertical position of the compensation depth in the North Sea.

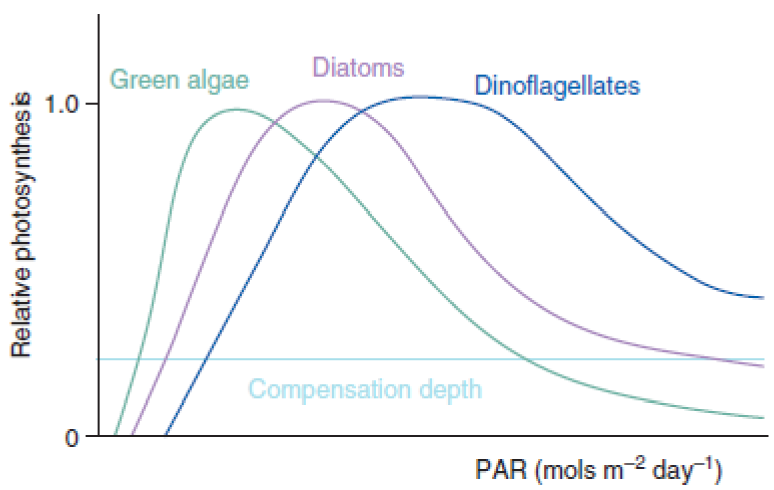


Figure 3.8

The general effect of available light on the relative photosynthesis of different phytoplankton groups showing the differences in their responses to the available photosynthetically active radiation (PAR) that is used by algae for photosynthesis.

Nitrogen

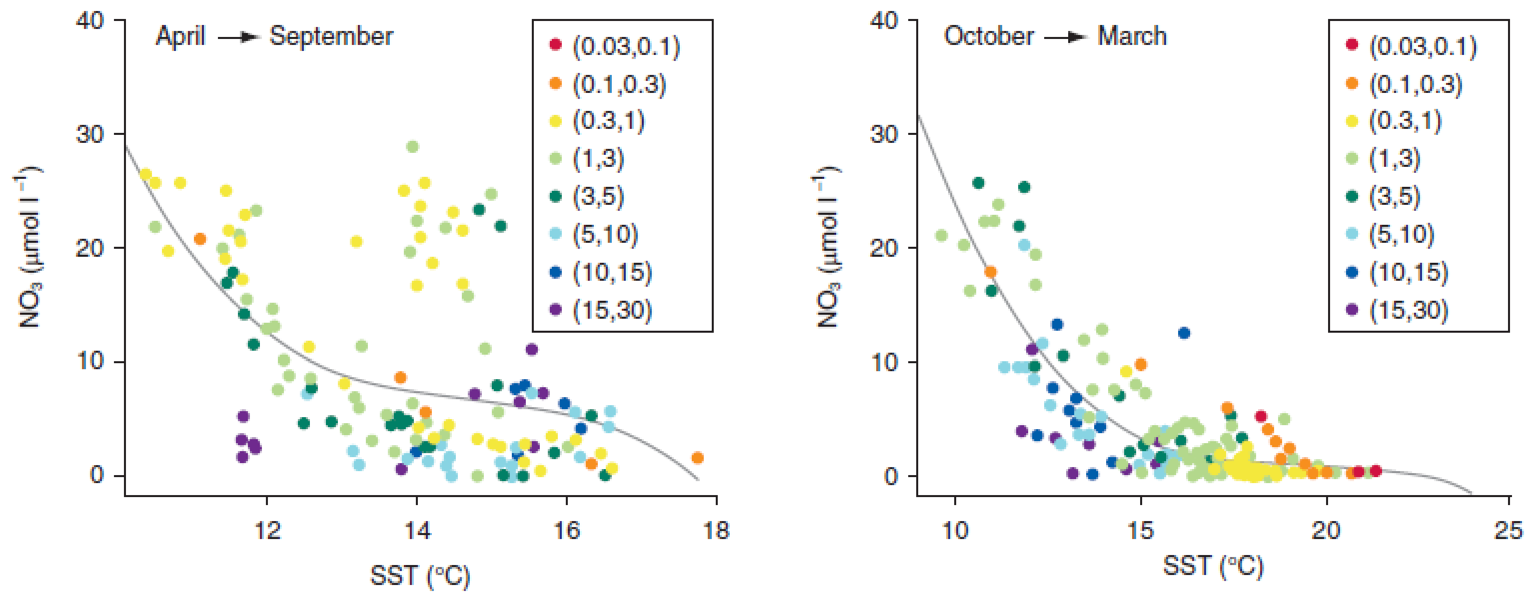


Figure 3.12

Relationship between nitrate concentrations and sea surface temperatures in the Benguela system for two periods of the year. The color scale refers to chlorophyll *a* concentration ranges in mg m^{-3}. (From Silio-Calzada et al 2008; reproduced with permission of Elsevier.)

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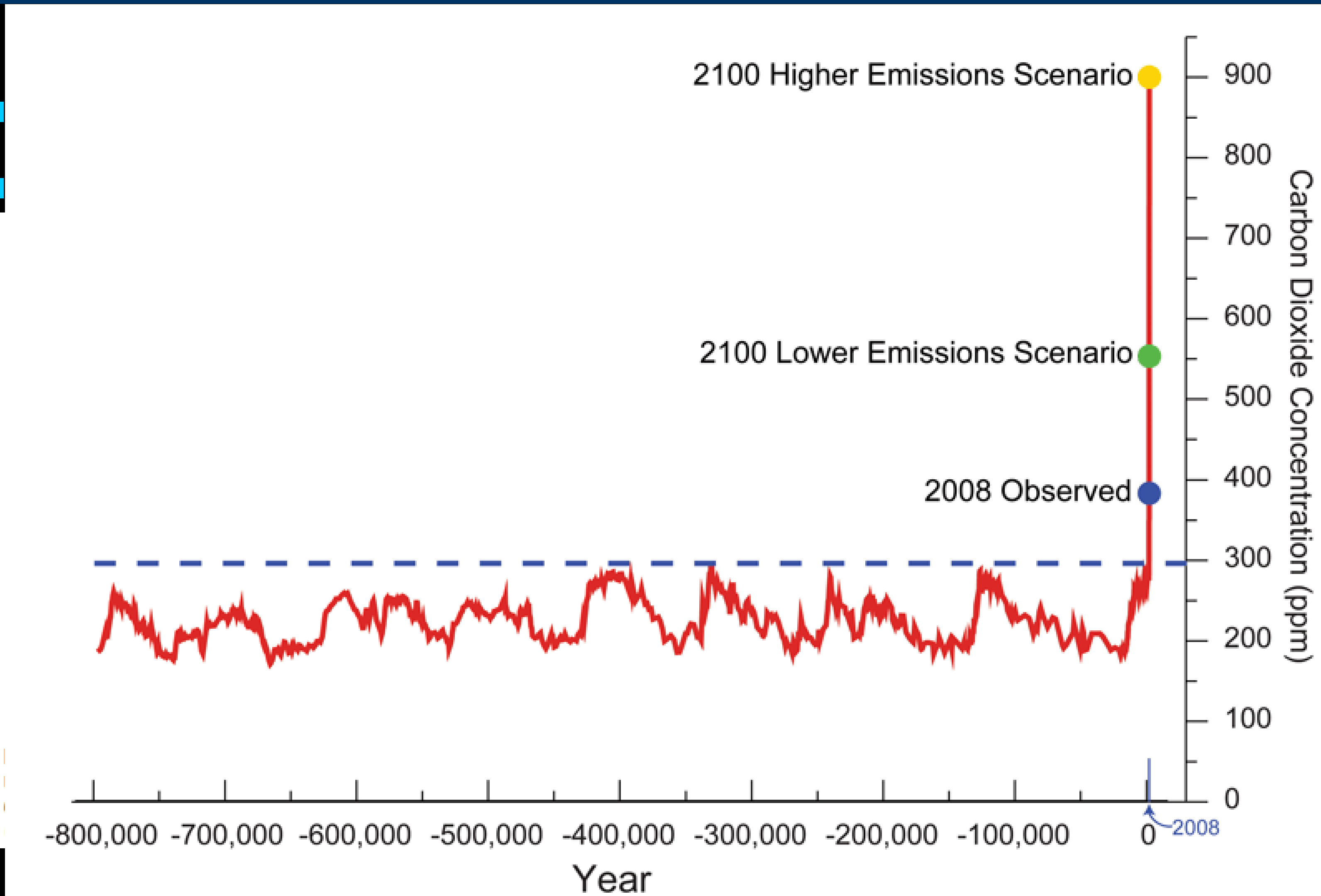
2100 Higher Emissions Scenario
2100 Lower Emissions Scenario
2008 Observed
900
800
700
600
500
400
300
200
100
0
Carbon Dioxide Concentration (ppm)
-800,000
-700,000
-600,000
-500,000
-400,000
-300,000
-200,000
-100,000
0
2008
Year

”

O_2

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The impact on atmospheric CO_2 of iron fertilization induced changes in the ocean's biological pump

March 2008

Biogeosciences 5(2)

Seasonal changes

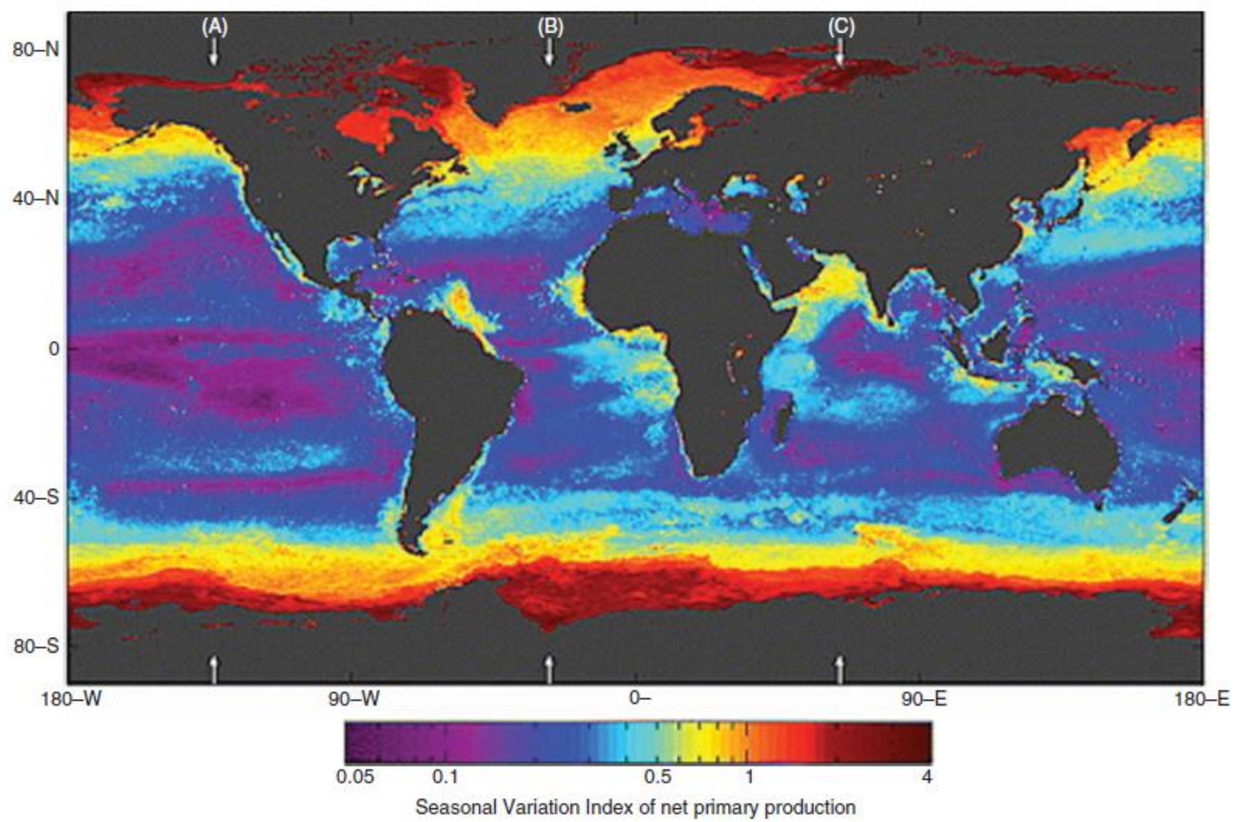


Figure 3.13

The geographic distribution of the seasonal variation index (annual standard deviation divided by average) of net primary production (NPP). (From Lutz et al 2007; reproduced with permission of AGU.)

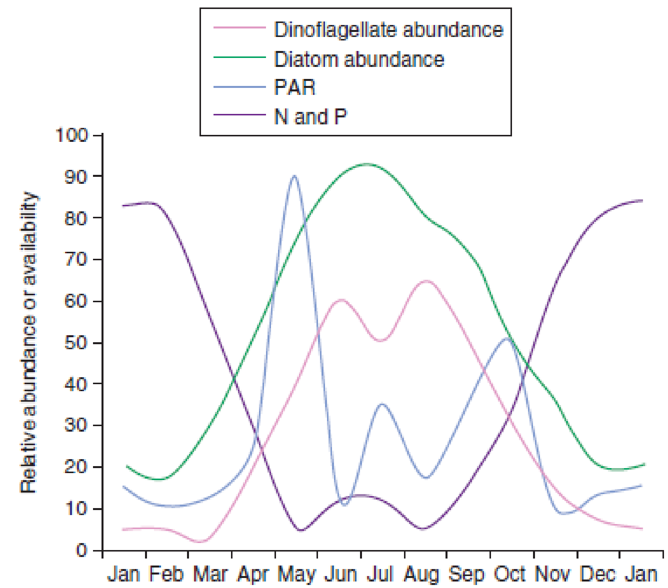
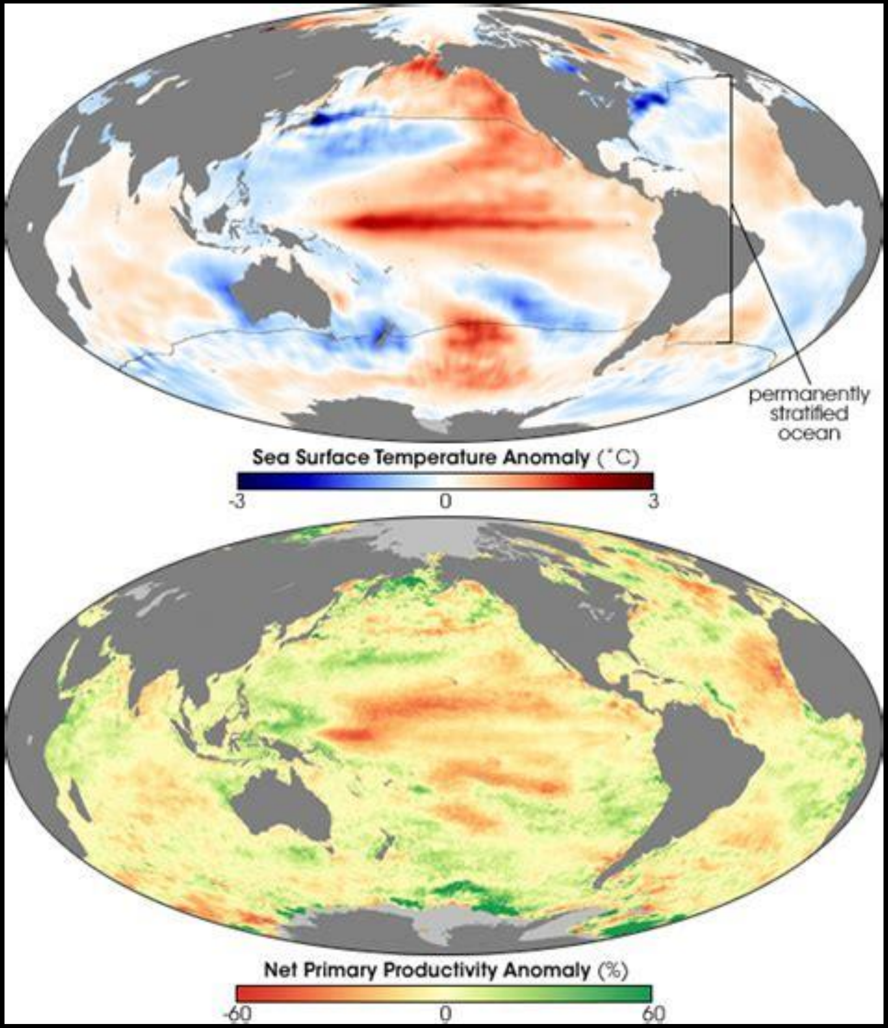


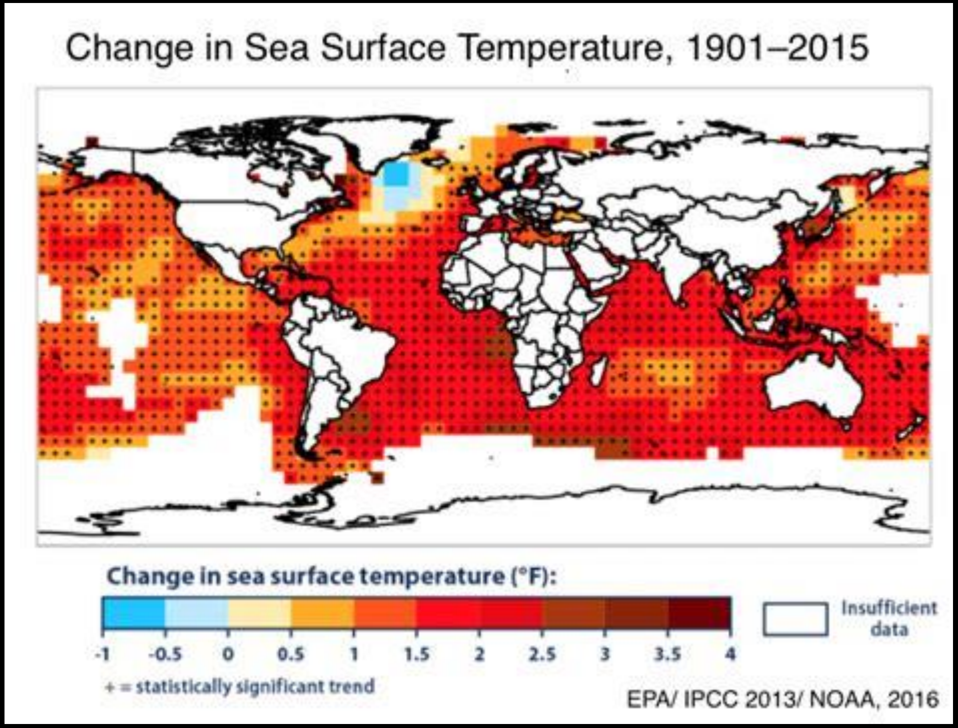
Figure 3.14

The seasonal succession of diatom and dinoflagellate abundance in North Atlantic waters. The figure also shows the change in availability of nitrogen (N), phosphorus (P), and light (PAR). The figure is a generalization of the actual pattern which tends to be more variable as it reflects local conditions and variation in the climate.

Lutz et al (2007)

Productivity





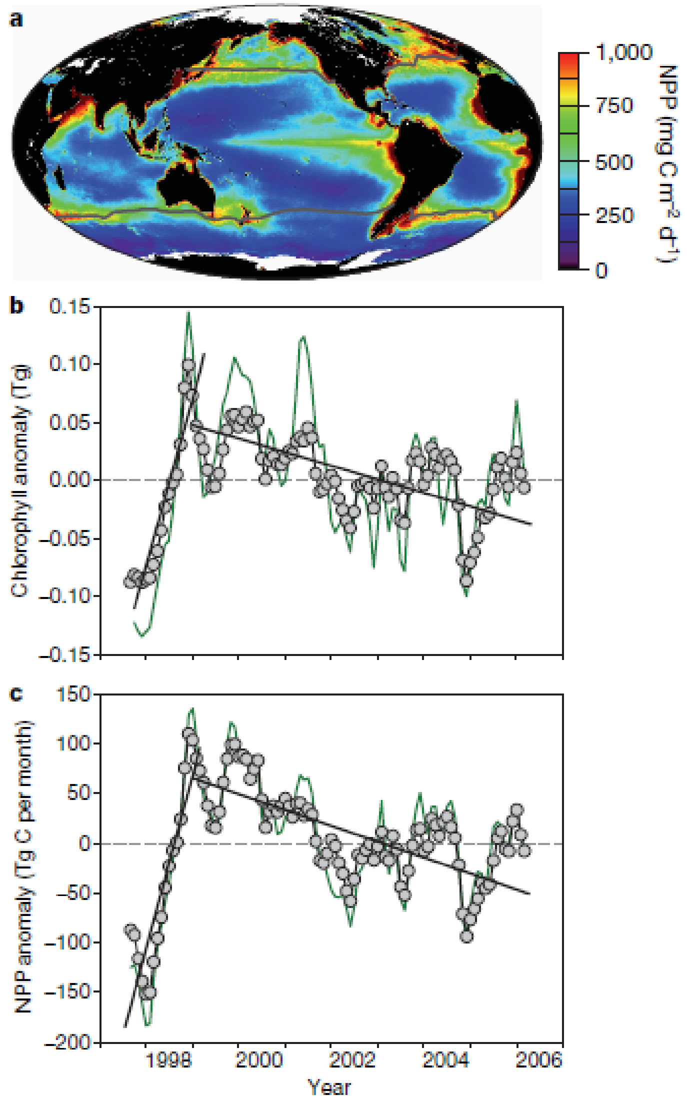


Figure 1 | Distribution and trends in global ocean phytoplankton productivity (NPP) and chlorophyll standing stocks. **a**, Annual average NPP showing high values where surface nutrients are elevated. Low-latitude, permanently stratified waters with annual average surface temperatures over 15 °C are delineated by black contour lines. **b**, Anomalies in globally integrated water-column chlorophyll concentrations (green line) are dominated by changes occurring in permanently stratified ocean regions (grey circles and black line). **c**, Anomalies in global NPP (green line) are likewise driven by changes in the permanently stratified oceans (grey circles and black line). Trend lines in **b** and **c** are least-squares fits to pre-1999 and post-1999 data.

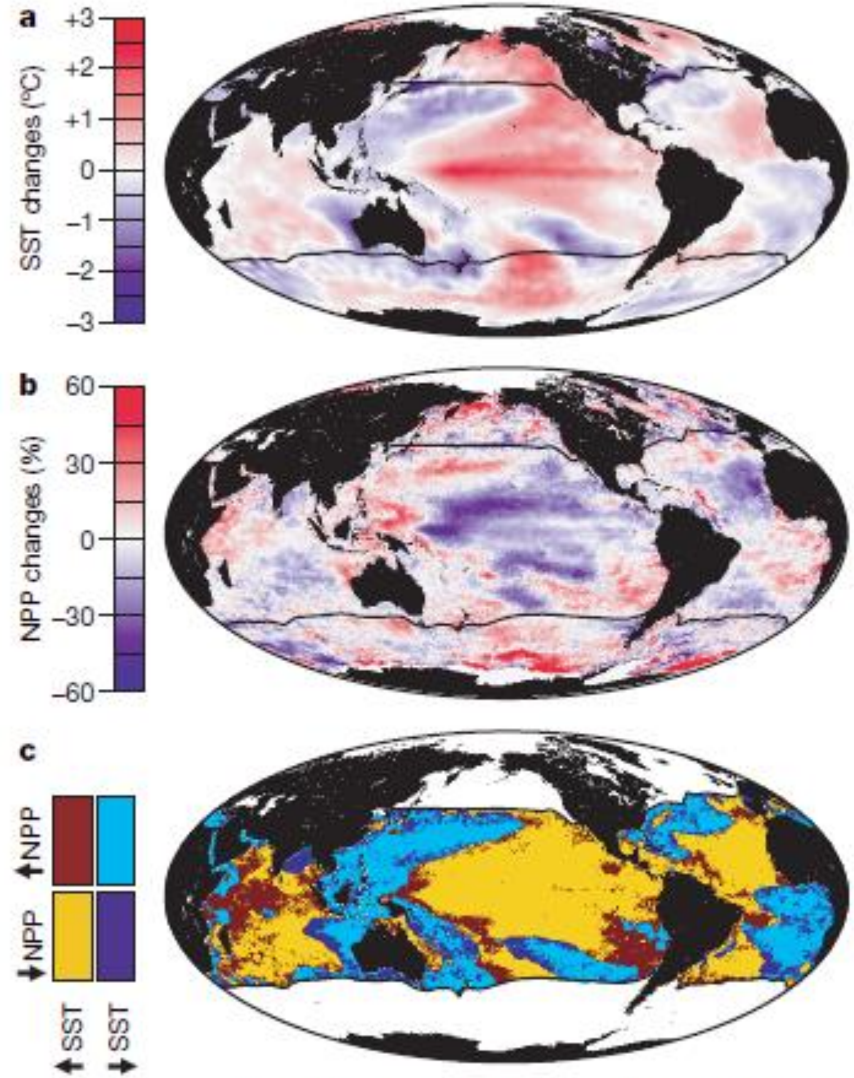


Figure 3 | Climate controls on ocean productivity cause NPP to vary inversely with changes in SST. Global changes in annual average SST (**a**) and NPP (**b**) for the 1999 to 2004 warming period (Fig. 2). **c**, For 74% of the permanently stratified oceans (that is, regions between black contour lines), NPP and SST changes were inversely related. Yellow, increase in SST, decrease in NPP. Light blue, decrease in SST, increase in NPP. Dark blue, decreases in SST and NPP. Dark red, increases in SST and NPP. A similar inverse relationship is observed between SST and chlorophyll changes. (See Supplementary Fig. 4 for additional information.)

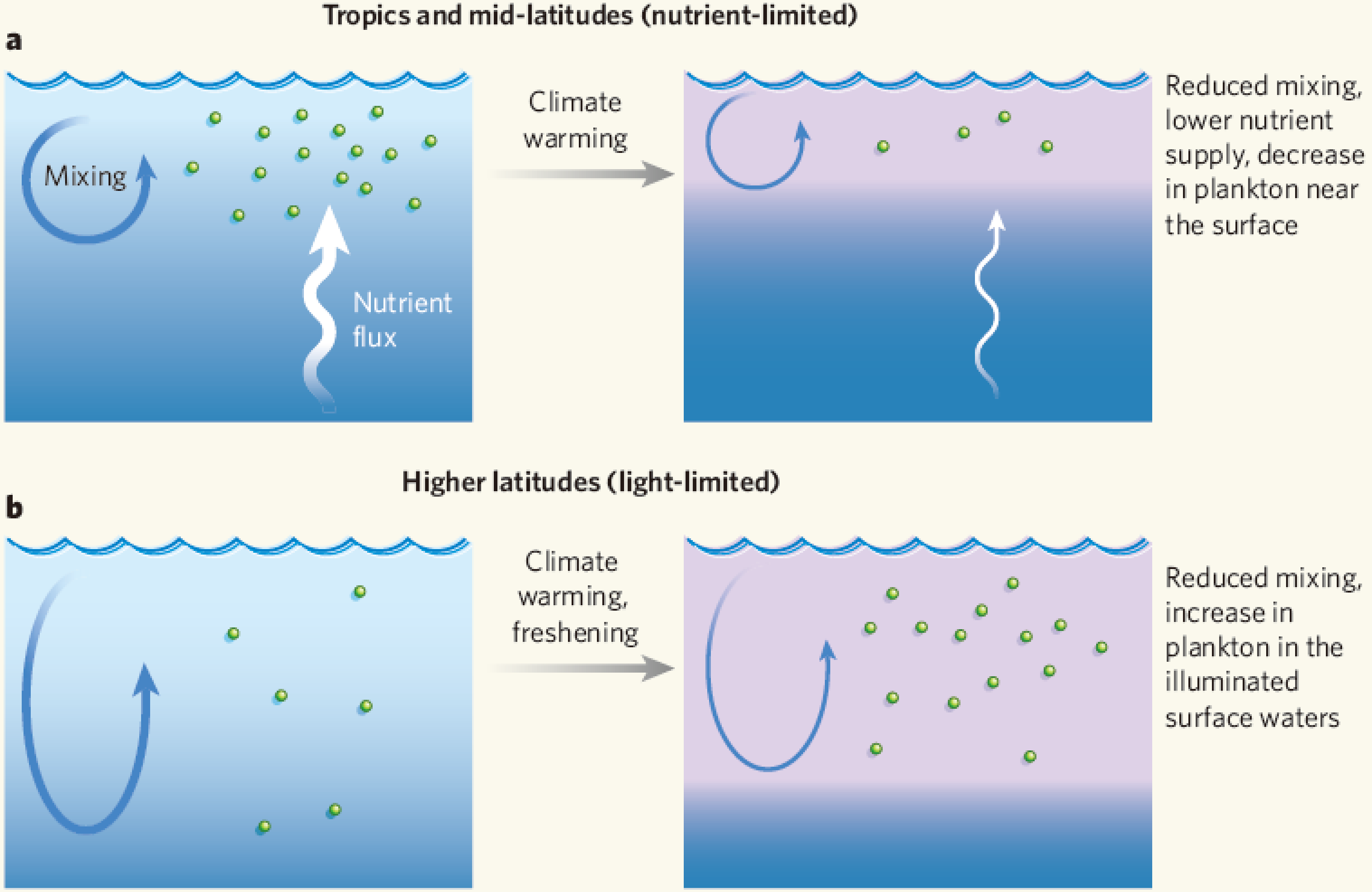
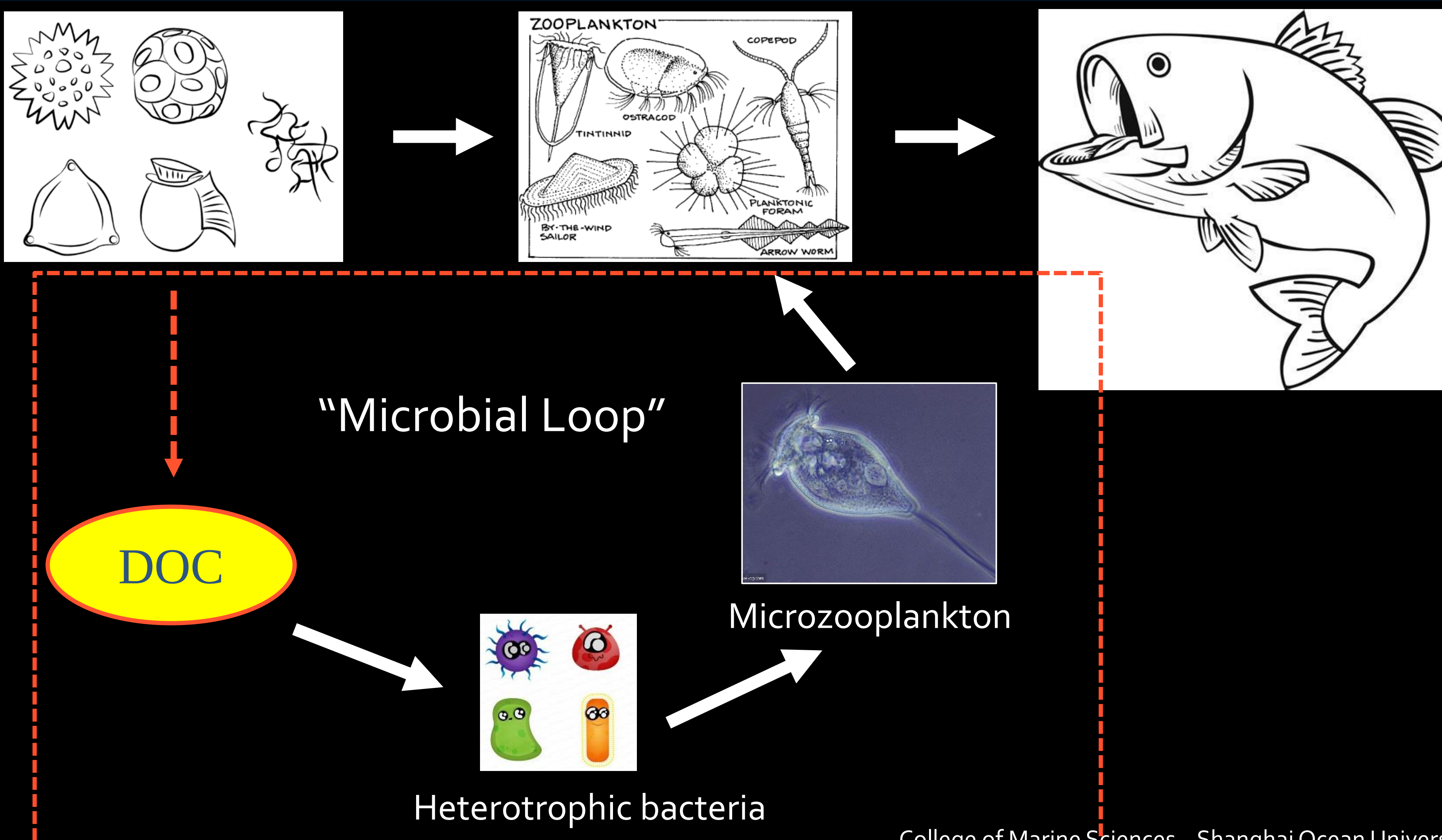
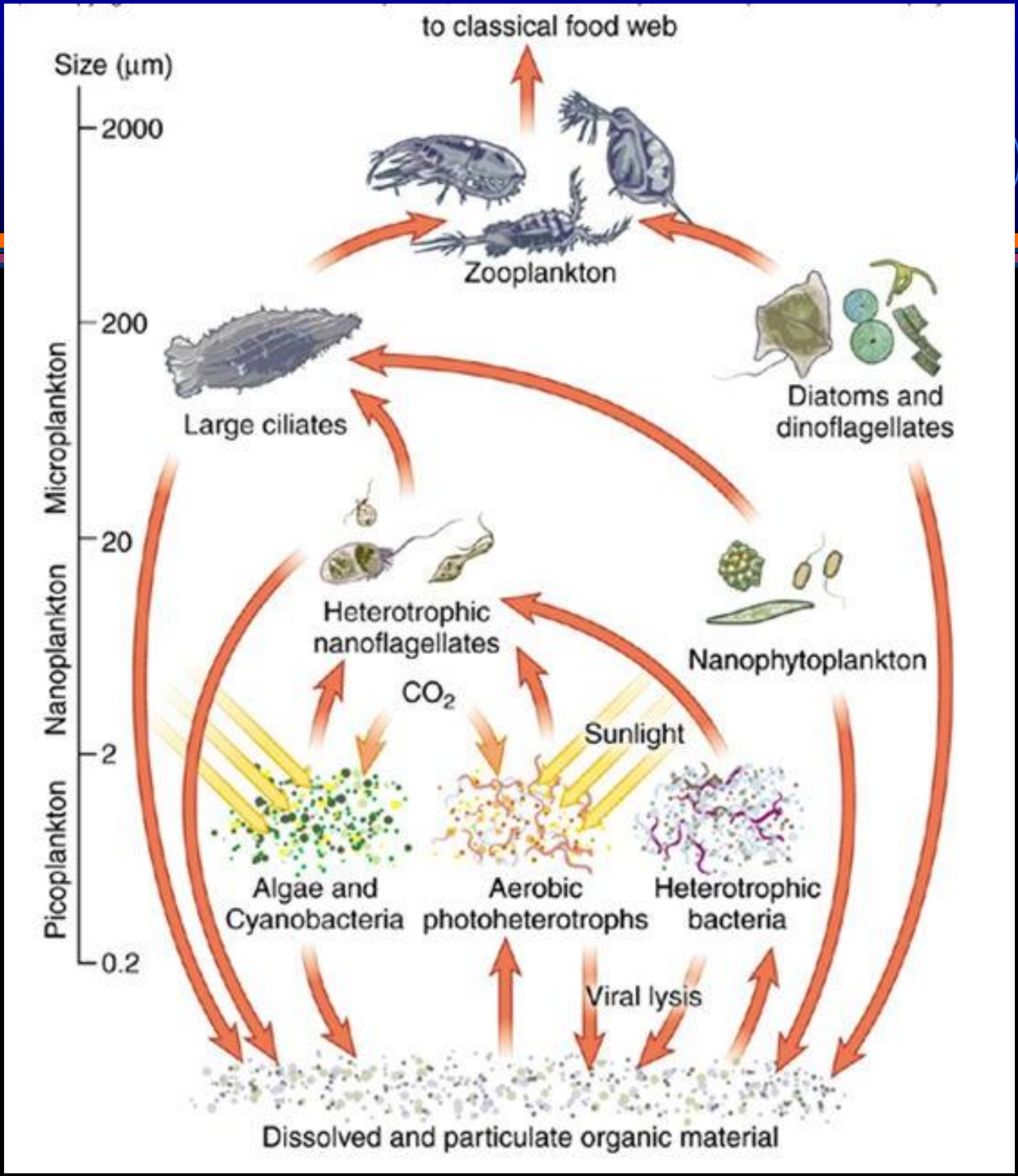


Figure 1 | Predicted phytoplankton response to increased temperature in ocean surface waters[1].
a, In the tropics and at mid-latitudes, phytoplankton are typically nutrient-limited, and satellite data tie reduced biological productivity to upper-ocean warming and reduced nutrient supply. **b**, At higher latitudes, the opposite biological response to future warming, and extra freshwater input, may occur. In these regions, phytoplankton are often light-limited; reduced mixing would keep plankton close to the surface where light levels are higher.

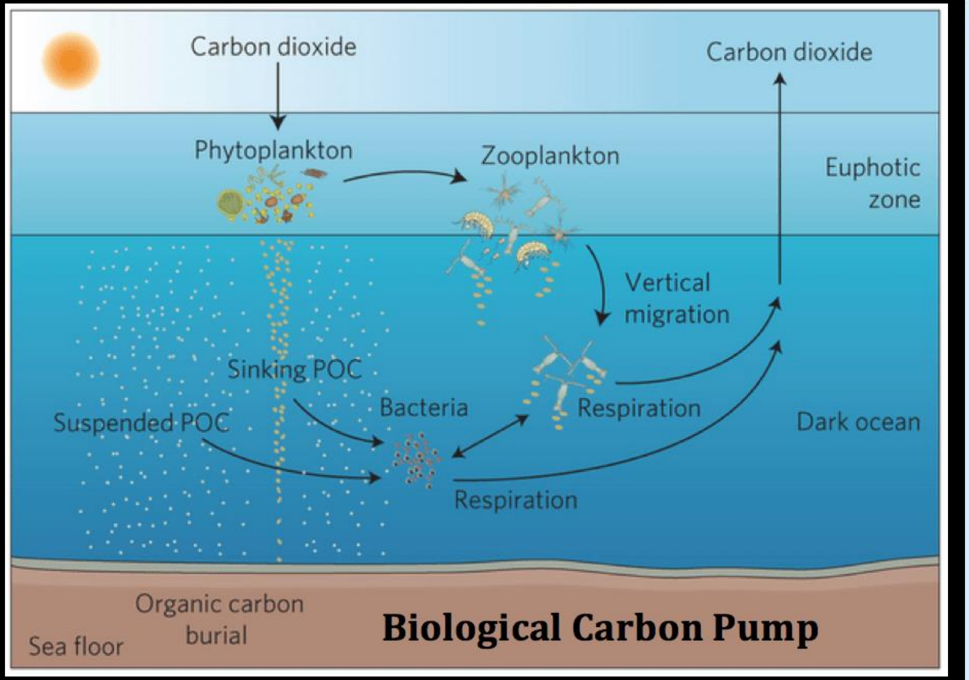
Role in the food web

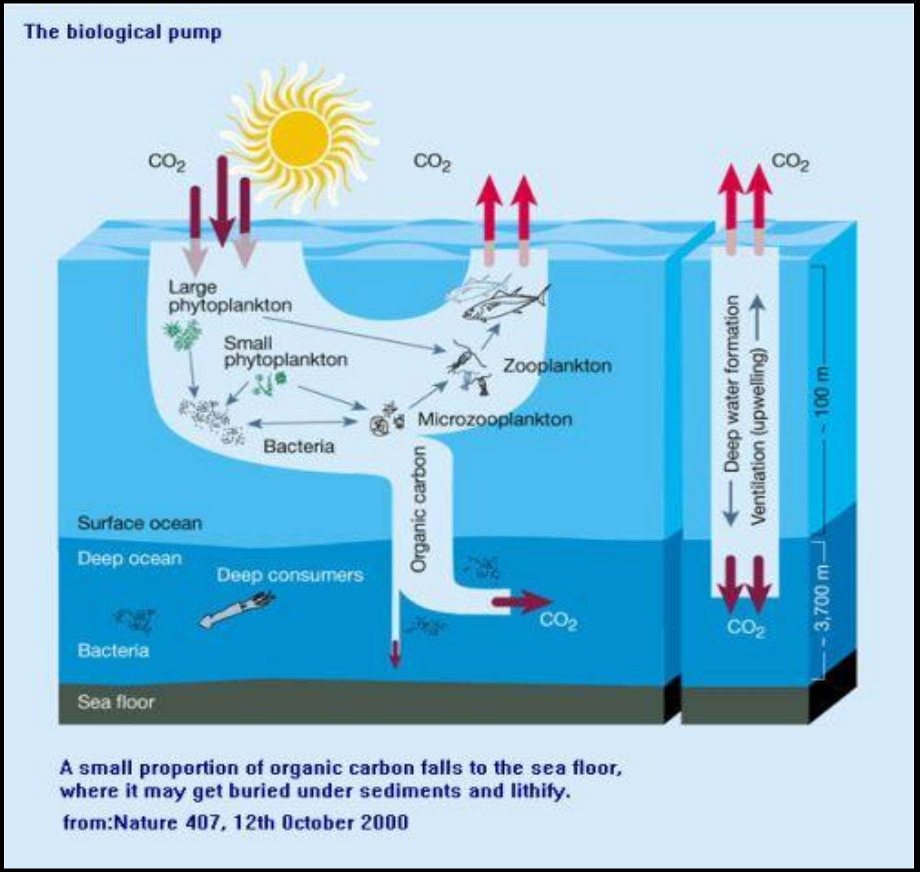


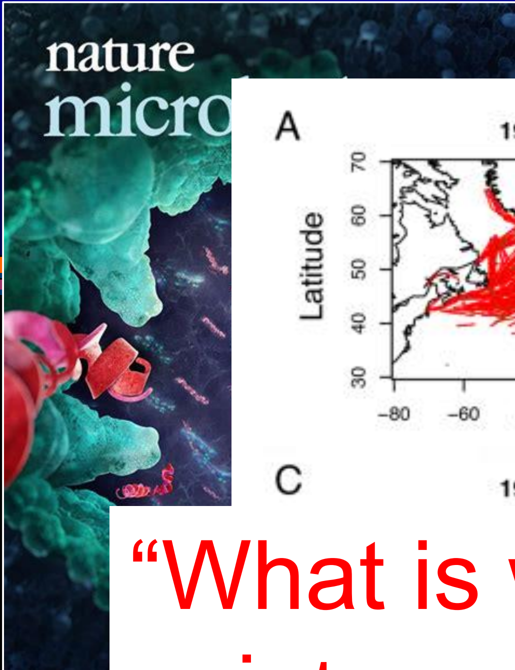
Microbial food web

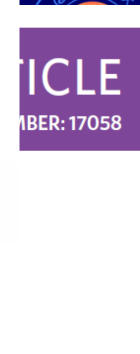


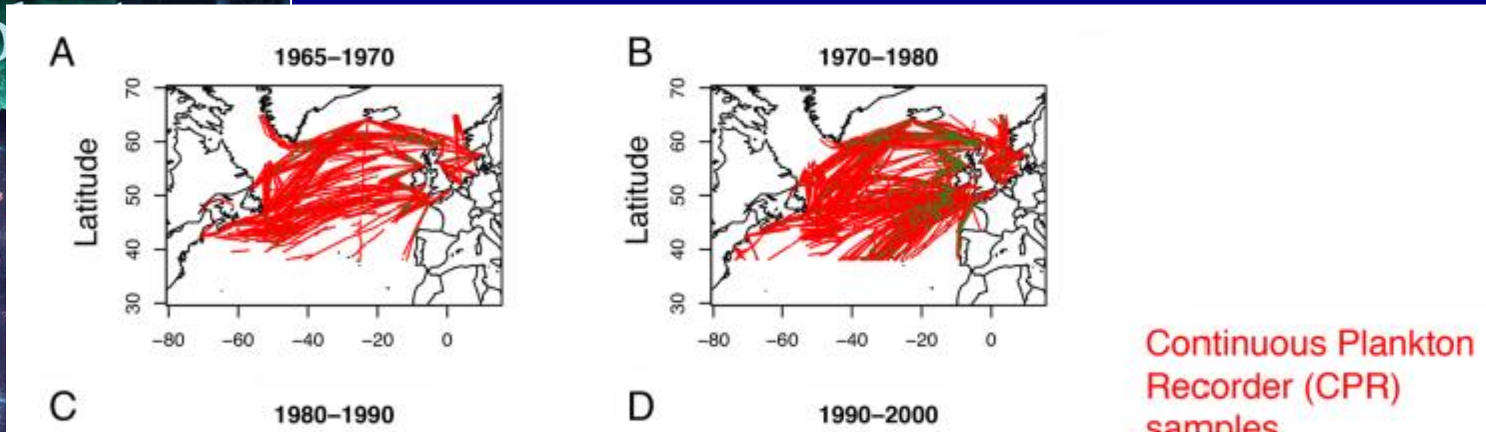
The biological pump



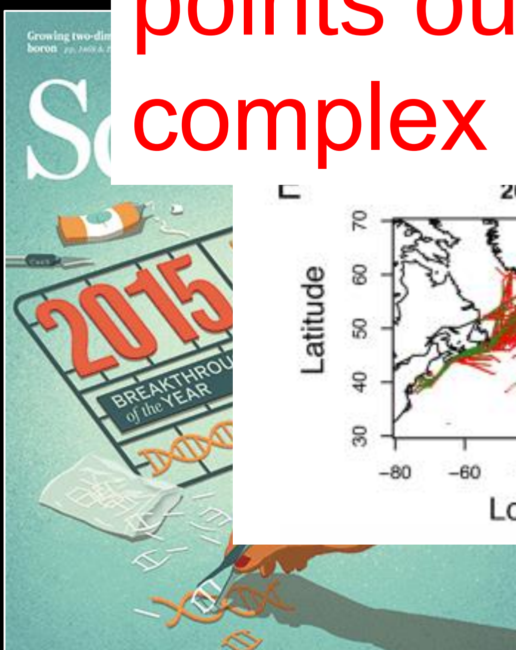


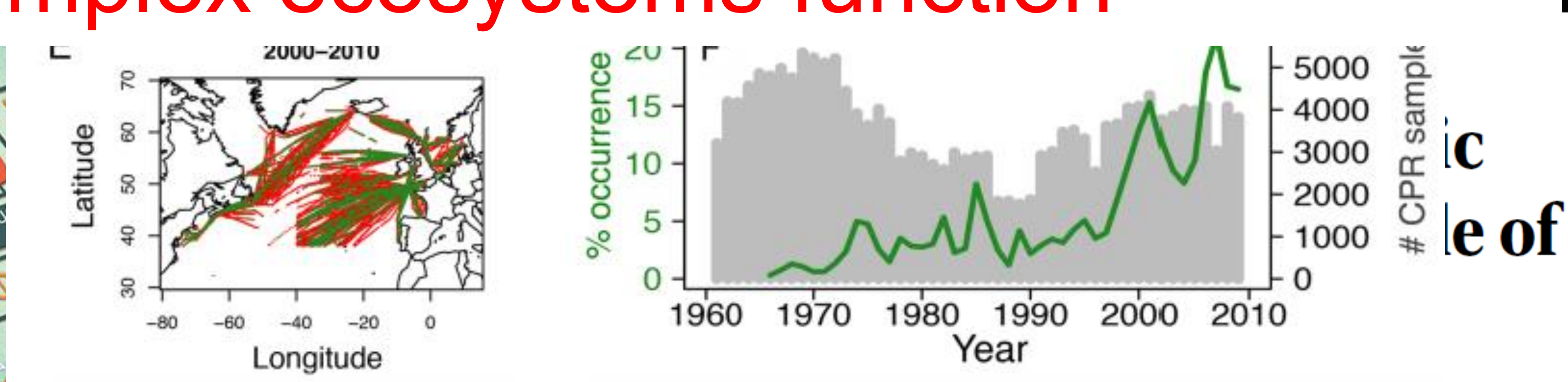




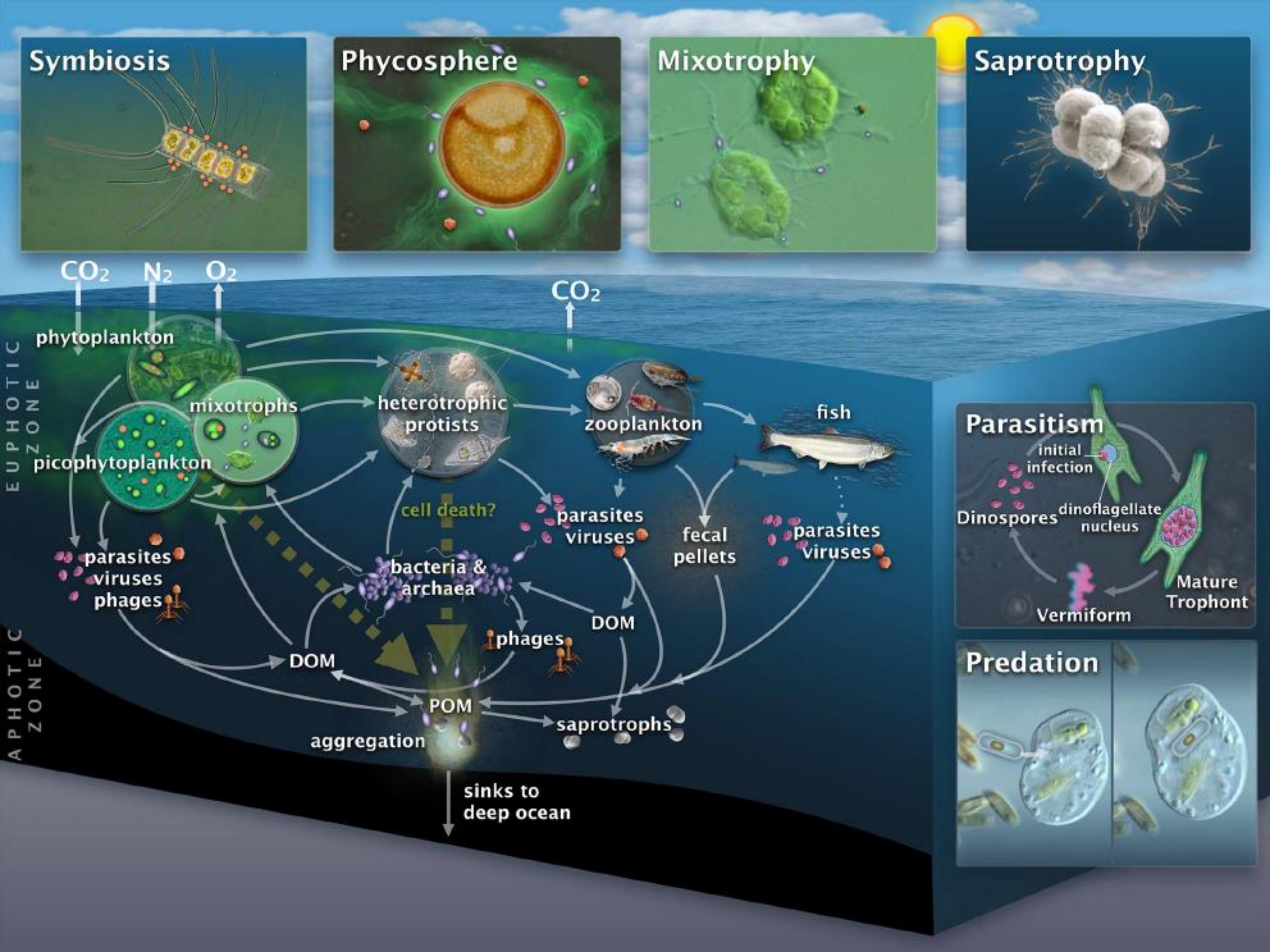


"What is worrisome is that our result points out how little we know about how complex ecosystems function"





Sara Rivero-Calle,[1,2]* Anand Gnanadesikan,[1]*
Carlos E. Del Castillo,[1,3] William Balch,[4] Seth D. Guikema[5]



Symbiosis
Phycosphere
Mixotrophy
Saprotrophy
CO_2
N_2
O_2
CO_2
EUPHOTIC ZONE
APHOTIC ZONE
phytoplankton
mixotrophs
picophytoplankton
heterotrophic protists
zooplankton
fish
cell death?
parasites viruses phages
bacteria & archaea
parasites viruses
fecal pellets
parasites viruses
DOM
phages
DOM
POM
aggregation
saprotrophs
sinks to deep ocean
Parasitism
initial infection
Dinospores
dinoflagellate nucleus
Mature Trophont
Vermiform
Predation

Key concepts

- Microbial life in the sea is extremely diverse, including members of all three domains of life, as well as viruses.
- Photosynthetic and chemosynthetic bacteria and archaeons are important primary producers in marine ecosystems.
- Primary and secondary plastid endosymbiosis accounts for the origin of all eukaryotic phytoplankton in the seas.

Key concepts

- Heterotrophic bacteria, archaeons, and fungi play essential roles in recycling nutrients in the marine environment.
- Marine eukaryotic microbes are primary producers, decomposers, and consumers, and some contribute significantly to the accumulation of deep-sea sediments.
- Populations of several kinds of photosynthetic marine microbes may form harmful blooms that affect other marine and maritime organisms directly and indirectly.

Further Reading

- Falkowski, P. G., and A. H. Knoll. 2007. *Evolution of Primary Producers in the Sea. Boston: Elsevier Academic Press.*
- Fuhrman, J. A. 1999. Marine Viruses and Their Biogeochemical and Ecological Effects, *Nature (London)* 399(6736):541–548.

Points

Which of the following is not a method of obtaining organic matter by marine microbes?

A. Chemosynthesis
B. Nitrogen fixation
C. Osmotrophy
D. Phagocytosis
E. Photosynthesis

Points

Which of the following characteristics do bacteria and archaea have in common?

A. A prokaryotic cell structure
B. Chlorophyll a
C. Kinds of membrane lipids
D. Production of methane
E. Tolerance of very high temperatures

Which of the following is not an effect of harmful algal blooms?

A. Consumption of oxygen
B. Contamination of shellfish
C. Formation of deep-sea sediments
D. Release of toxins
E. Shading of benthic plants and seaweeds

Box 1 Glossary of marine organisms

Archaea. One of the two groups of *prokaryotes*, whose cultivated members are often methane-producing or tolerant to unusually high temperature or salinity. Uncultivated archaea, such as those from the deep sea, may have other physiologies.

Autotrophs. Organisms that use CO_2 as their source of carbon. (All green plants are autotrophs.) See also *heterotrophs*.

Bacteria. One of the two groups of *prokaryotes*; also used as a generic term describing organisms that appear to be *prokaryotic* but are otherwise unidentified (some may be *Archaea*).

(Bacterio)phages. Viruses that infect bacteria.

Cyanobacteria. Type of *bacteria* that contain chlorophyll *a* and undergo photosynthesis, generating oxygen. This phylogenetic group includes the marine *prochlorophytes*.

Cyanophages. Viruses that infect *cyanobacteria*.

Eubacteria. Another name for the *Bacteria* group.

Eukaryotes. Organisms with membrane-bound nuclei; all animals and higher plants are eukaryotes. (See also *protists*.)

Eukaryotic algae. Photosynthetic *protists*.

Flagellate. A type of *protist* that moves by beating flagella (long, strand-like structures present on the surfaces of some cells).

Heterotrophs. Organisms that derive energy from preformed organic matter. (All animals are heterotrophs.) See also *autotrophs*.

Metazoa. Multicellular animals.

Microbe. Microscopic organism, occurring as a single cell or simple colony.

Phytoplankton. Photosynthetic plankton, including *cyanobacteria* and *eukaryotic algae*.

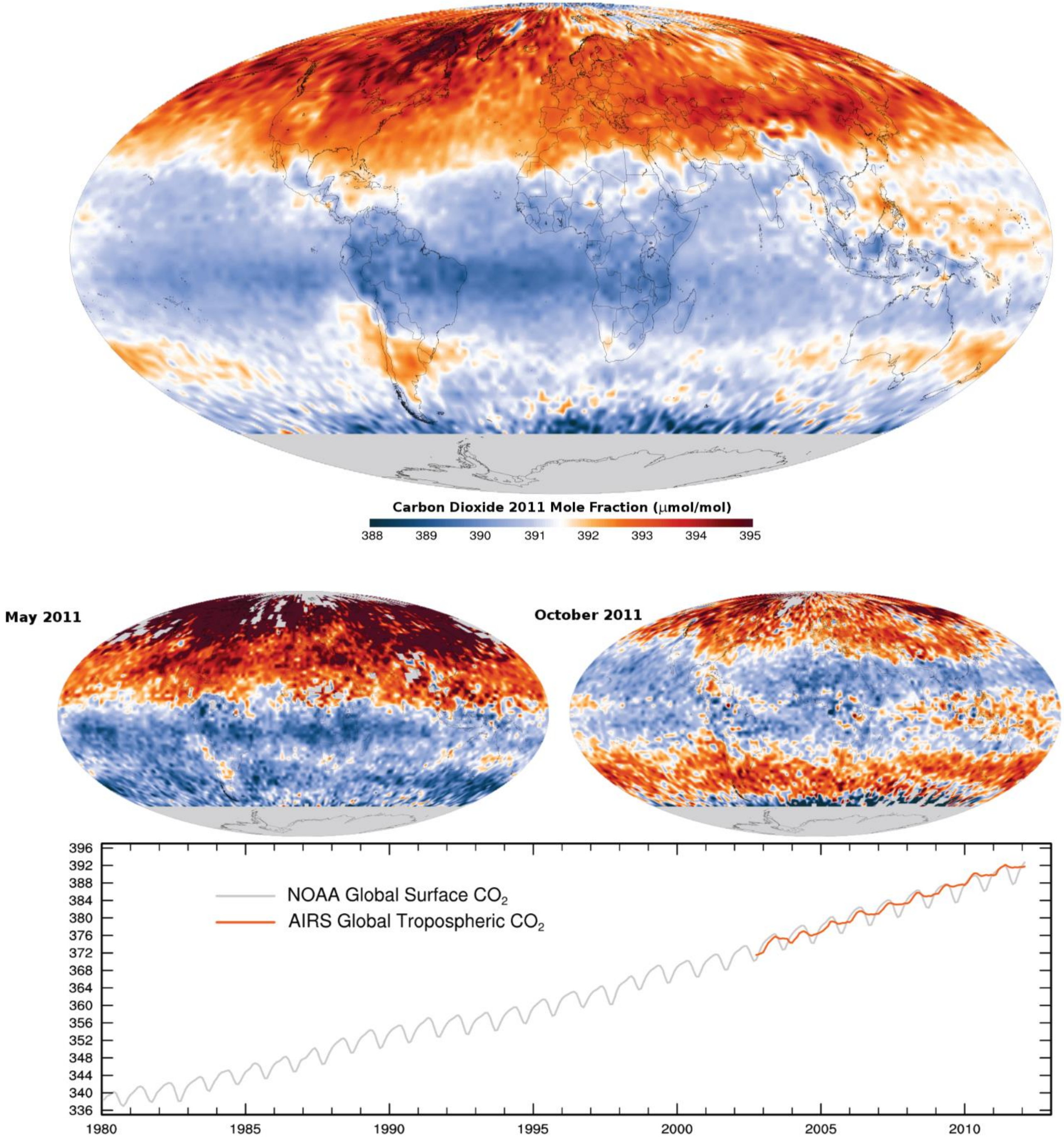
Prochlorophytes. Small photosynthesizing *bacteria* that possess divinyl chlorophyll *a* and *b* (see also *cyanobacteria*).

Prokaryotes. Cells without membrane-bound nuclei. They include two broadly different groups, the *Bacteria* and *Archaea*.

Protist. A type of *eukaryote* that is single-celled, or lives in simple colonies of single cells. Protists are generally larger and less abundant than *bacteria*. (See also *flagellates*, *eukaryotic algae* and *protozoa*).

Protozoa. Old name for non-photosynthetic *protists*. (Protozoa are distinct from the *metazoa*.)

Zooplankton. Eukaryotic (animal) plankton. Macrozooplankton are visible to the naked eye and feed on the largest prey organisms. Micro-zooplankton are just below the visible size range (~20–200 μm), and may include very small *metazoa*, animal larvae and large *protists*. Nano-zooplankton include the smallest *protists* (~2–20 μm) and eat the smallest prey, such as *bacteria*.


Carbon Dioxide 2011 Mole Fraction (μmol/mol)
388 389 390 391 392 393 394 395
May 2011
October 2011
NOAA Global Surface CO_2
AIRS Global Tropospheric CO_2
396 392 388 384 380 376 372 368 364 360 356 352 348 344 340 336
1980 1985 1990 1995 2000 2005 2010