# 1.4 TO 1.7 BIOGEOCHEMICAL CYCLES

**Enduring Understanding:** Ecosystems are the result of biotic and abiotic interactions.

**Learning Objective:** Explain the steps and reservoir interactions in the following biogeochemical cycles: water, carbon, nitrogen, and phosphorus.

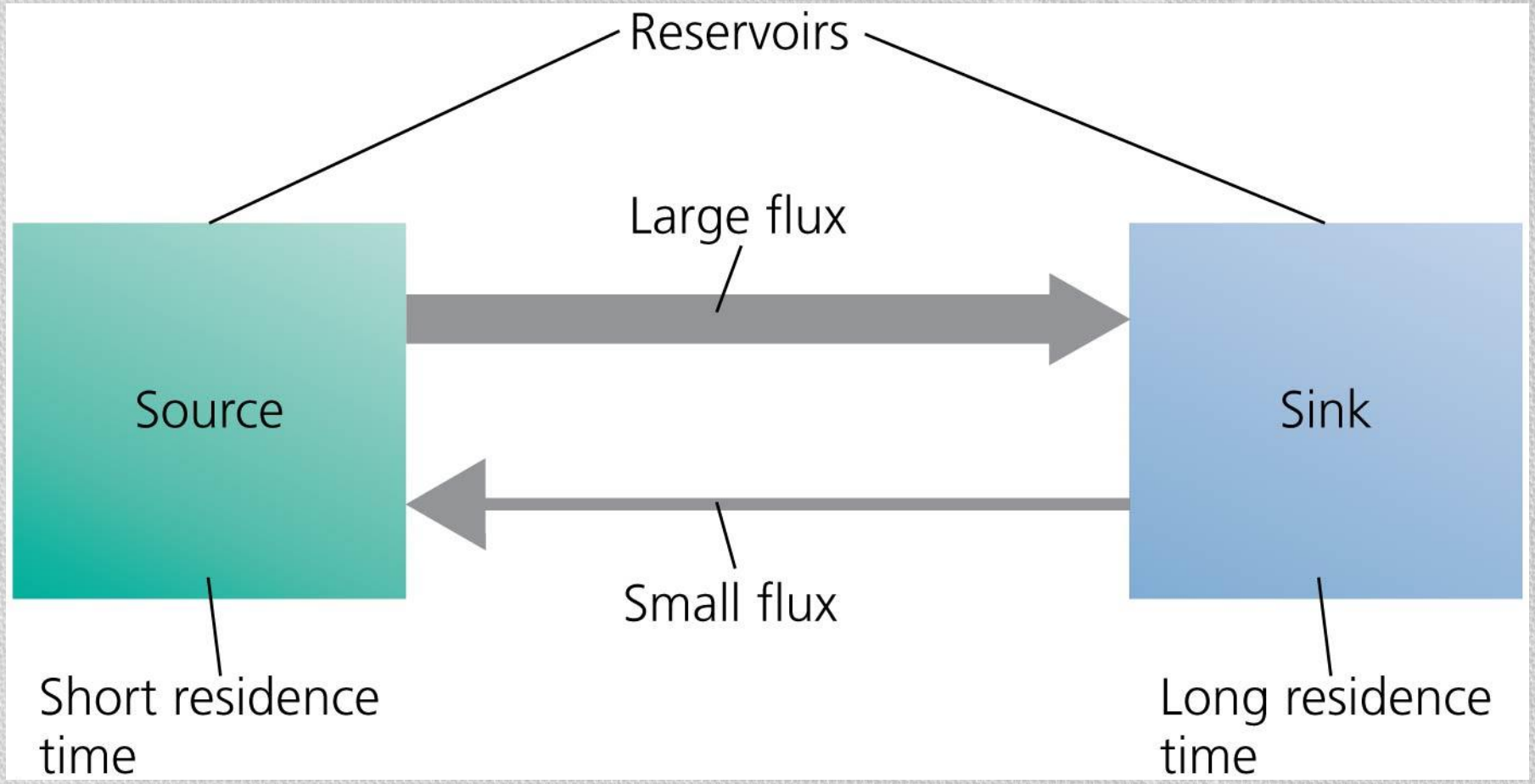
**Related Readings:** pg. 117-129, "Environment; The Science Behind the Stories" 4th edition, Withgott, Jay and Laposata, Matthew

# Nutrients naturally circulate through ecosystems in biogeochemical cycles

- **Matter is continually circulated in ecosystems**
  - Matter exists as atoms of a specific element (C, N, P) or as compounds made up of specific elements ($H_2O$)
- ***Biogeochemical cycles* move nutrients and other forms of matter through ecosystems**
  - May move through the atmosphere, hydrosphere, lithosphere, and biosphere
- ***Reservoirs* are where nutrients reside for varying amounts of time (the *residence time*)**
  - The size of a reservoir, and the average residence time spent in a reservoir may change over time
  - Is influenced by human activities
- ***Flux* is the rate at which materials move between pools**
  - Can change over time
  - Is influenced by human activities

# Components of Biogeochemical Cycles

- **Nutrients move from source to sink**
  - *Source* = a pool that releases more nutrients than it accepts
  - *Sink* = a pool that accepts more nutrients than it releases



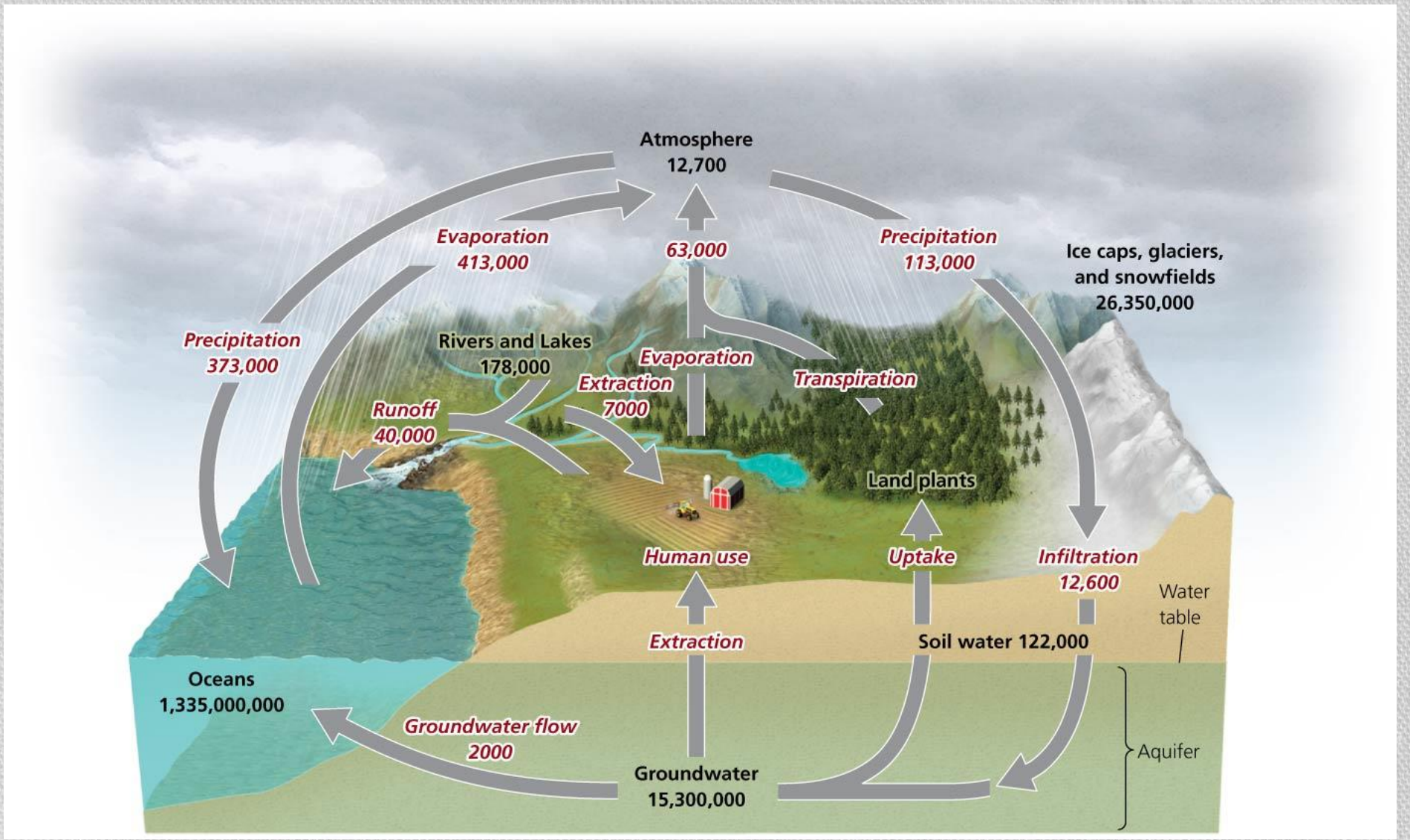
# Nutrients influence productivity

- **About 25 different chemical elements make up most living things**
  - Living things consist of organic compounds with carbon skeletons
  - Atoms of other elements are bonded to carbon skeletons and interact in chemical reactions between organic compounds in the cells of living things and with compounds in ecosystems
- **Nutrients** = elements and compounds required for survival that are consumed by organisms
- **Macronutrients** = nutrients required in larger amounts
  - Carbon, hydrogen, oxygen, nitrogen, sulfur, phosphorus
- **Micronutrients** = nutrients needed in smaller amounts
- **Limiting Nutrients**
  - The shortage of a single nutrient is enough to limit the productivity of an ecosystem
    - **Nitrogen** and **phosphorus** are often limiting for plant and algal growth; oceans are limited by nitrogen; freshwater by phosphorus

# The water cycle affects all other cycles

- **Water is essential for biochemical reactions**
  - The cells of living organisms are filled with aqueous solutions
  - It is involved in nearly every environmental system
- **Hydrologic cycle**
  - summarizes how liquid, gaseous, and solid water flows through the environment
  - **Reservoirs**
    - Oceans, aquifers, lakes, and rivers are the main reservoirs
  - **Natural Fluxes**
    - *Evaporation* is the process by which water moves from aquatic and land systems into the atmosphere
    - *Transpiration* is the release of water vapor by plants
    - *Precipitation* returns water to Earth as rain or snow
    - *Runoff* moves water from land to bodies of surface water
    - *Infiltration* moves surface water into underground aquifers

# The Hydrologic (a.k.a Water) Cycle



# Our impacts on the water cycle are extensive

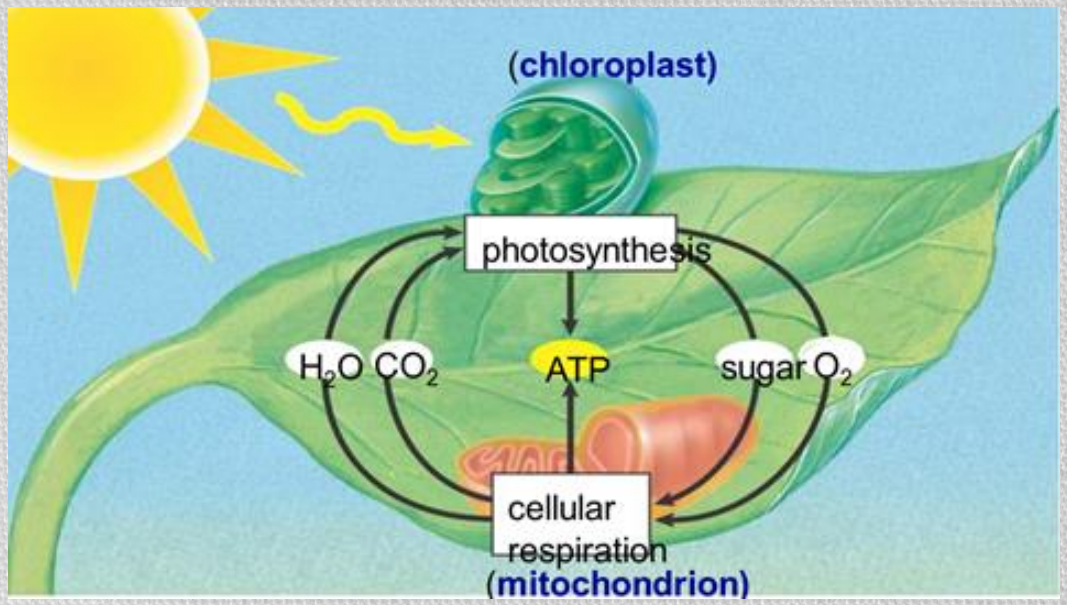
- Removing forests and vegetation increases runoff and soil erosion and reduces transpiration and infiltration
- Irrigating agricultural fields depletes rivers, lakes, and streams and lowers water tables
- Damming rivers slows movement of water from land to the sea and increases evaporation
- Emitting air pollutants changes the nature of precipitation, sabotaging the natural distillation process of evaporation and transpiration

# The carbon cycle circulates a vital organic nutrient

- **Carbon forms the "skeleton" of all organic compounds**
- **Carbon cycle**
  - describes the route of carbon atoms through the environment
- **Reservoirs**
  - Sedimentary Rock and fossil Fuels
  - Oceans
  - Forests / Plants
- **Fluxes**
  - Photosynthesis
  - Cellular Respiration
  - Combustion of organic material (wood, fossil fuels, etc)

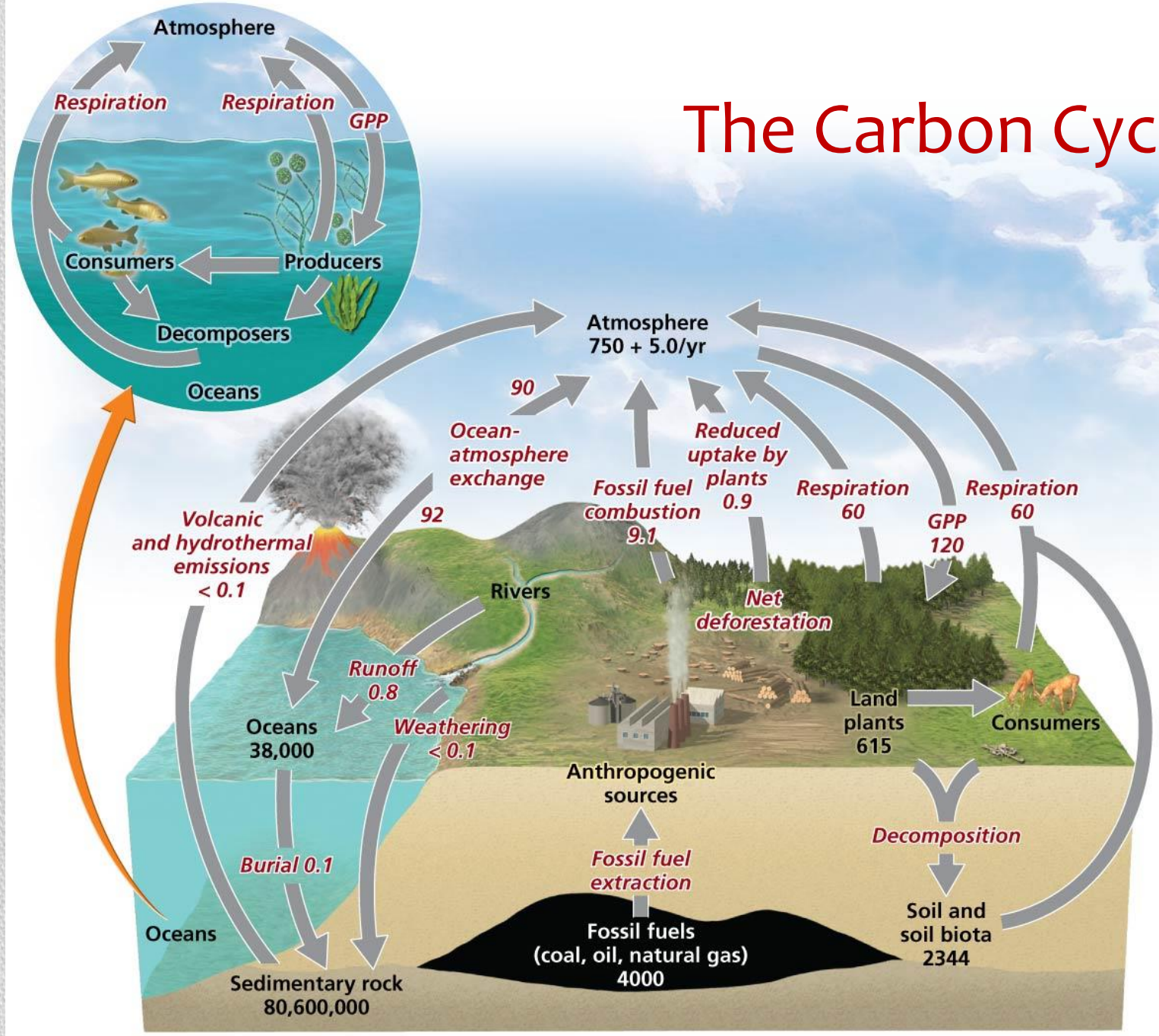
# Natural Fluxes of Carbon are Balanced

- **Photosynthesis by plants, algae, and cyanobacteria**
  - $CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$
  - Removes carbon dioxide from air and water
  - Produces oxygen and carbohydrates
  - Plants are a major reservoir of carbon




- **Respiration returns carbon to the air and oceans**
  - $C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O$
  - Plants, consumers, and decomposers

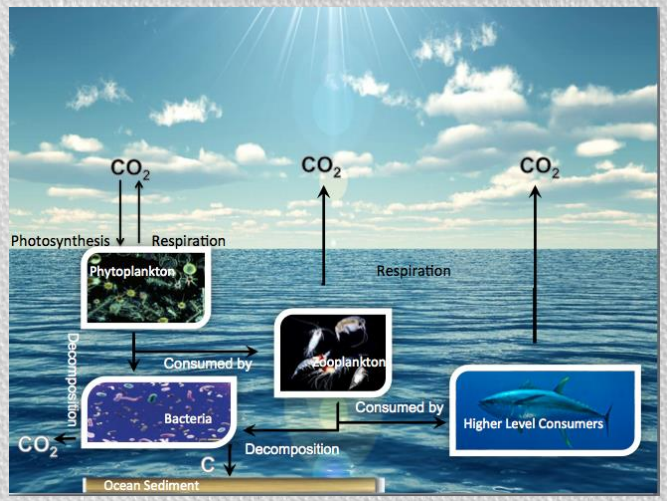
# The Carbon Cycle

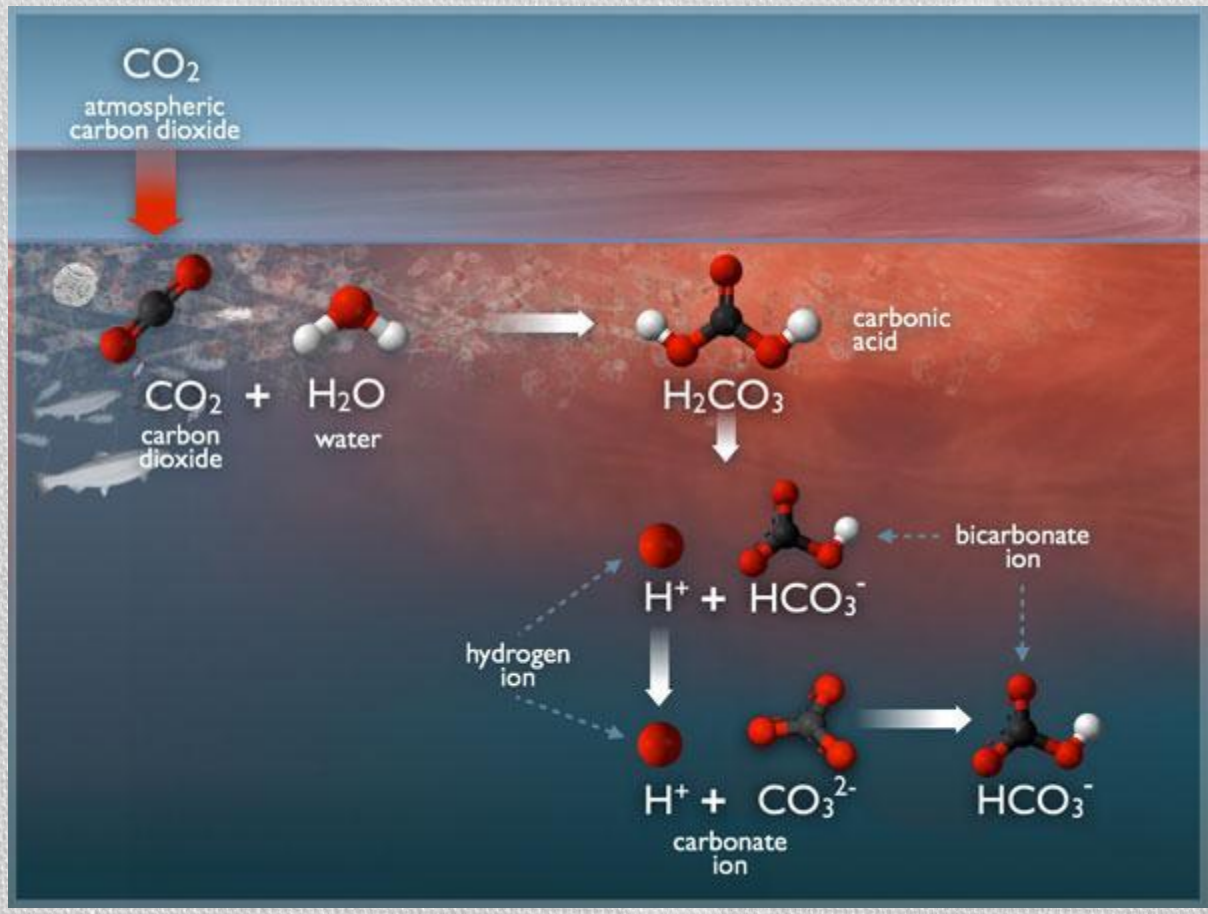


# *Sediment storage of carbon and The oceans*

- **Decomposition returns carbon to the sediment**
  - Soils and sedimentary rocks make up the largest reservoir of carbon
  - May be trapped for hundreds of millions of years in sedimentary rock (limestone Ca**C**O3)
- **Aquatic organisms die and settle in the sediment**
  - Older layers are buried deeply and undergo high pressure
  - Ultimately, some may be converted into fossil fuels
- **Oceans are the second largest reservoir of carbon**
  - Carbon dioxide is dissolved directly into the water from the atmosphere, making the water more acidic
    - $H_2O + CO_2 \rightarrow H_2CO_3$
    - $H_2CO_3 \rightarrow HCO_3^- + H^+ \rightarrow CO_3^{2-} + H^+$
  - Marine organisms take up bicarbonate ($HCO_3^-$) and combine it with Calcium (Ca) to make Calcium Carbonate ($CaCO_3$) for their shells

# Oceans are Important reservoirs in the Carbon Cycle




Shells and Corals result from reactions in the cells of some marine organisms that combine calcium ($Ca^{2+}$) with Carbonate ions ($CO_3^{2-}$) to form Calcium Carbonate ($CaCO_3$)

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$$

Increasing acidity of oceans can also dissolve shells

$$H^+ + CaCO_3 \rightarrow Ca^{2+} + HCO_3^-$$

# We are shifting carbon from the lithosphere to the atmosphere

- **Burning fossil fuels moves carbon from the lithosphere to the atmosphere**
  - Heating
  - Electricity generation
  - Transportation
- **Burning vegetation moves carbon from the biosphere to the atmosphere**
  - Forest Fires
  - Slash and Burn Agriculture

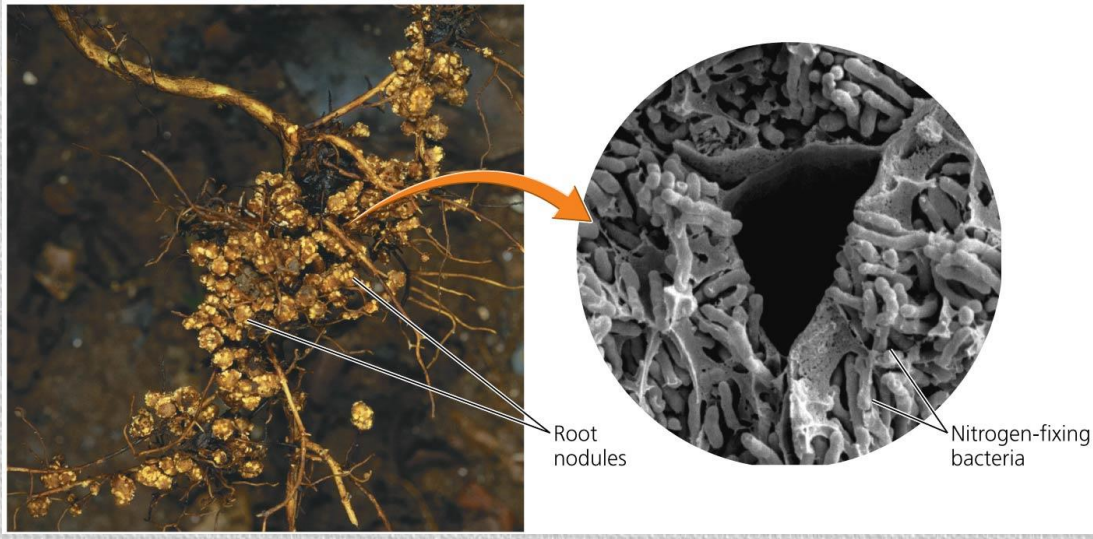
    Reduces overall ability of forests to take up carbon in the future

# The nitrogen cycle involves specialized bacteria

- **Nitrogen comprises 78% of our atmosphere ($N_2$)**
  - It is necessary for proteins, DNA, and RNA in living things
- **Nitrogen cycle** describes the routes that nitrogen atoms take through the environment
- **Reservoirs**
  - Atmosphere, 78% of the air we breathe is $N_2$
  - Nitrogen gas cannot be used by most organisms
- Specialized process allow for nitrogen to flux between earths systems
  - Nitrogen fixation
  - Nitrification
  - Ammonification
  - Denitrification
  - Assimilation

# Nitrogen Cycle

- **Nitrogen fixation**
  - lightning
  - *nitrogen-fixing bacteria* combine (fix) nitrogen (N2) with hydrogen to form ammonia ($NH_3$) and then ammonium ($NH_4^+$), which can be used by plants
- **Nitrification**
  - process by which *nitrifying bacteria* convert ammonium ions, first into nitrite ions, then into nitrate ions ($NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$)

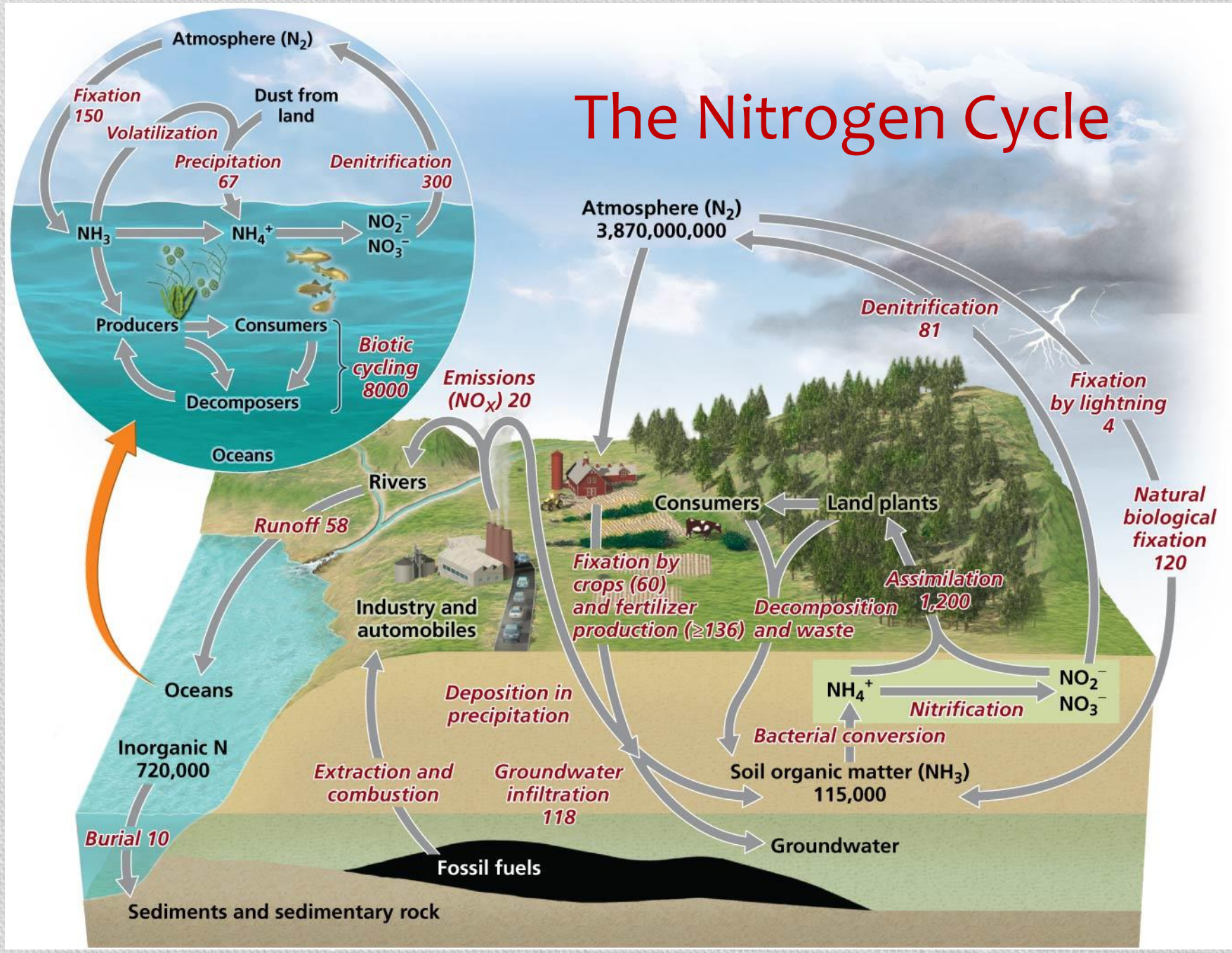


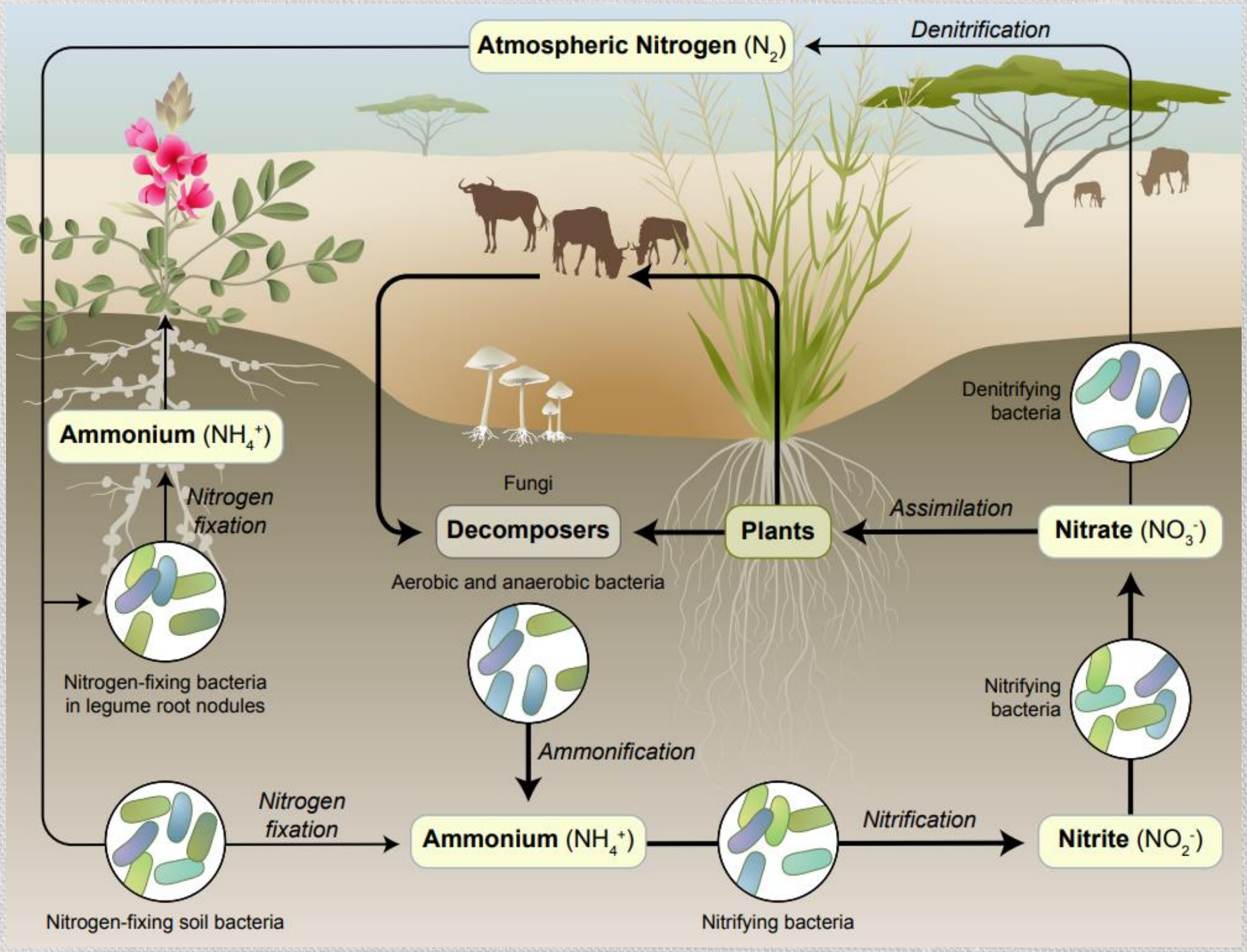

*Mutualistic relationship between legume roots and N-fixing Bacteria)*

- **Assimilation (inorganic to organic form)**
  - Plants take up $NH_3$, $NH_4^+$, $NO_3^-$
  - Plants can take up nitrate most easily
  - Plants convert these to organic compounds containing nitrogen
  - Animals obtain nitrogen by eating plants or other animals

# Decomposition and denitrification

- **Decomposition (ammonification)**
  - Decomposers get nitrogen from the organic compounds of dead and decaying plants or other animals
  - release ammonium ($NH_4^+$) ions into soil for plants assimilate directly or for to nitrifying bacteria to convert to nitrates ($NO_3^-$)
- **Denitrification**
  - *Denitrifying bacteria* convert nitrates ($NO_3^-$) in soil or water to gaseous nitrogen ($N_2$), releasing it back into the atmosphere and completing the nitrogen cycle


The Nitrogen Cycle
Atmosphere ($N_2$)
Fixation 150
Dust from land
Volatilization
Precipitation 67
Denitrification 300
$NH_3$
$NH_4^+$
$NO_2^-$
$NO_3^-$
Producers
Consumers
Biotic cycling 8000
Decomposers
Oceans
Atmosphere ($N_2$) 3,870,000,000
Denitrification 81
Fixation by lightning 4
Emissions ($NO_X$) 20
Rivers
Runoff 58
Consumers
Land plants
Natural biological fixation 120
Fixation by crops (60) and fertilizer production (≥136)
Assimilation 1,200
Decomposition and waste
Industry and automobiles
Oceans
Deposition in precipitation
$NH_4^+$
$NO_2^-$
$NO_3^-$
Nitrification
Bacterial conversion
Inorganic N 720,000
Extraction and combustion
Groundwater infiltration 118
Soil organic matter ($NH_3$) 115,000
Burial 10
Groundwater
Fossil fuels
Sediments and sedimentary rock


Atmospheric Nitrogen ($N_2$)
Denitrification
Ammonium ($NH_4^+$)
Nitrogen fixation
Nitrogen-fixing bacteria in legume root nodules
Fungi
Decomposers
Aerobic and anaerobic bacteria
Plants
Assimilation
Nitrate ($NO_3^-$)
Denitrifying bacteria
Ammonification
Nitrogen fixation
Nitrogen-fixing soil bacteria
Ammonium ($NH_4^+$)
Nitrifying bacteria
Nitrification
Nitrite ($NO_2^-$)
Nitrifying bacteria

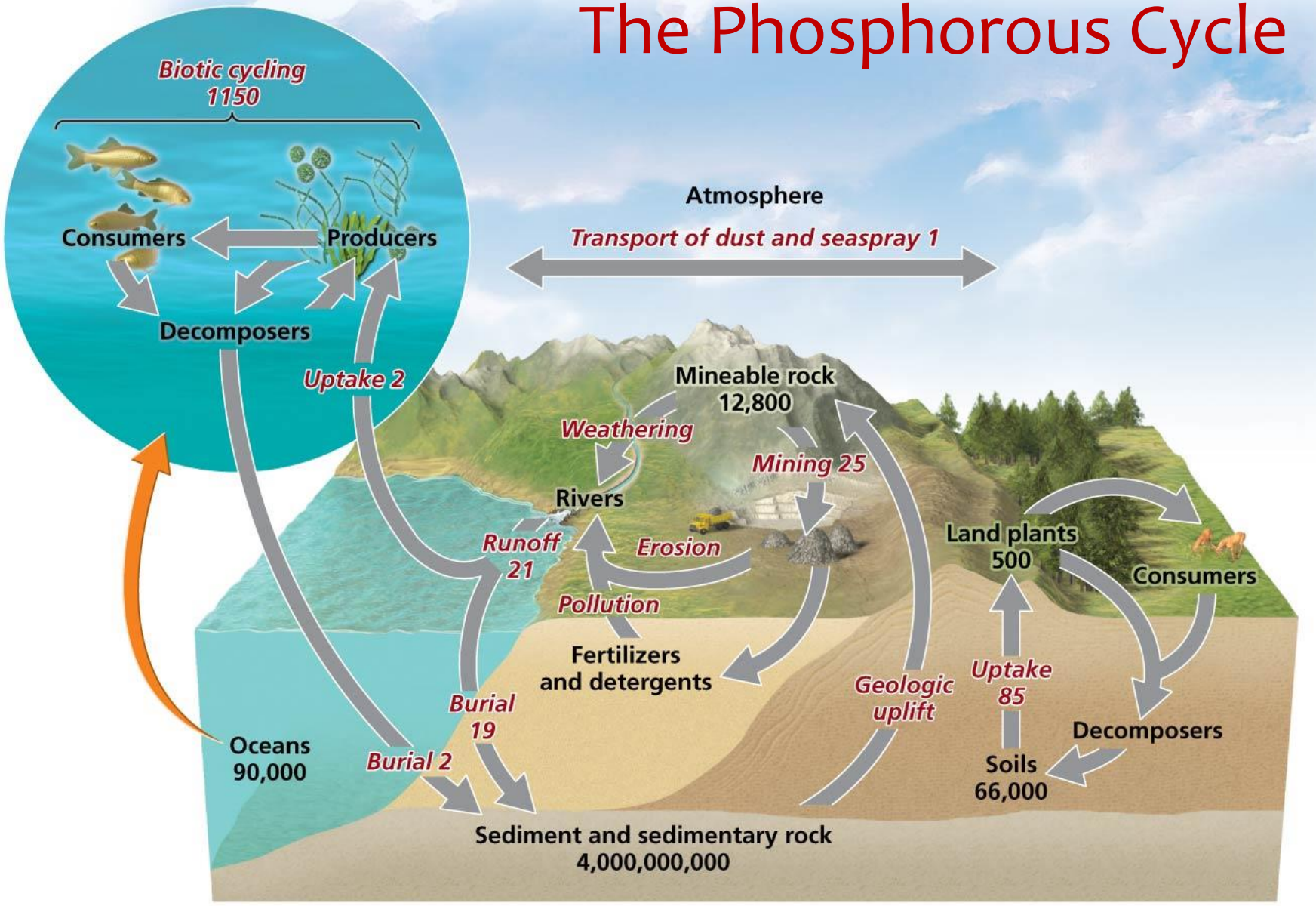
# We have greatly influenced the nitrogen cycle

- **Nitrogen Fixation was the only process that converted the abundant nitrogen in the atmosphere ($N_2$) into a form living things could utilize ($NH_4^+$, $NH_3$, $NO_3^-$)**
  - Nitrogen fixation was a crop production *bottleneck*
- **The Haber-Bosch process**
  - A form of industrial fixation
  - production of fertilizers by combining nitrogen from the atmosphere ($N_2$) and hydrogen ($H_2$) to synthesize ammonia ($NH_3$)
- **Overuse of fertilizers has negative side effects:**
  - Increases the flux of nitrogen from the atmosphere to the land
  - Causes eutrophication in estuaries and coastal ecosystems and fisheries
  - Washes essential nutrients out of the soil
- **Burning fossil fuels adds nitrogen compounds to the atmosphere ($NO_x$) that contribute to acid precipitation**

# The phosphorus cycle circulates a limited nutrient

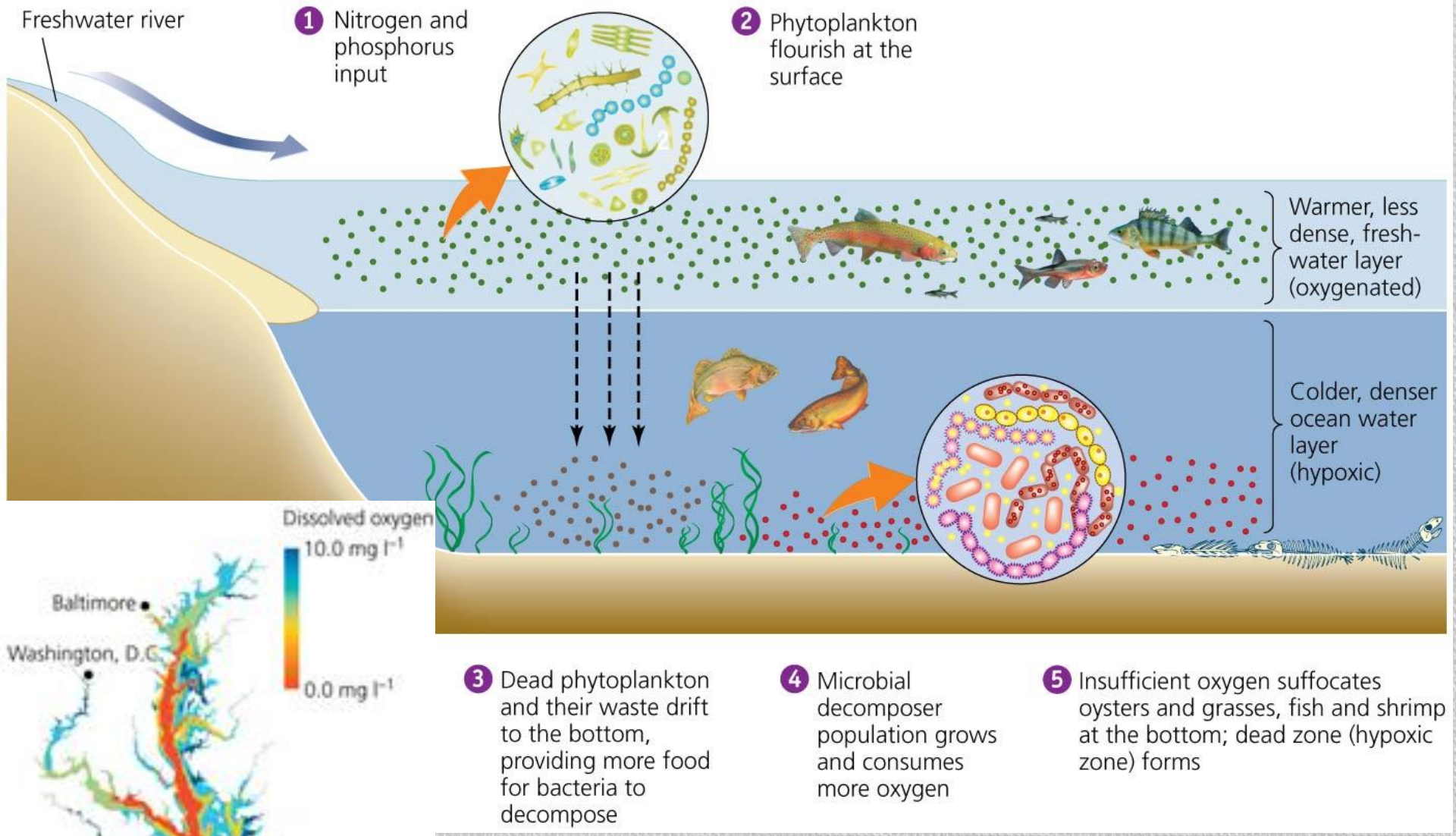
- **Phosphorus (P) is a key component of cell membranes, DNA, RNA, ATP, and ADP**
- **Phosphorus cycle**
  - describes the routes that phosphorus atoms take through the environment
- **Reservoirs and Fluxes**
  - Most phosphorus is within rocks
  - It is released by weathering
  - Thus it has an extremely long residence time in this reservoir
- **There is naturally low environmental concentrations**
  - There is no significant atmospheric component
  - It is not very soluble in water
  - Thus Phosphorus is frequently a limiting factor for plant growth

# The Phosphorous Cycle



# We affect the phosphorus cycle

- **Humans add phosphorus to fertilizers to promote crop growth**
  - Runoff from farm fields and lawns contains phosphorus
  - Increases phytoplankton growth
  - Results in eutrophication and hypoxia
- **Wastewater discharge from sewage treatment facilities also releases phosphorus**
  - Detergents have traditionally contained high levels of phosphates







# Eutrophication in the Chesapeake Bay

# Tackling nutrient enrichment

- **We rely on synthetic fertilizers and fossil fuels**
- Nutrient enrichment will be an issue
- **There are a number of ways to control nutrient pollution**
  - Reduce fertilizer use on farms and lawns
  - Apply fertilizer at times that minimize runoff
  - Plant vegetation "buffers" around streams
  - Restore wetlands and create artificial ones
  - Reduce fossil fuel combustion
  - Improve sewage treatment technologies