Chemical matter is recycled

- Some new matter my enter an ecosystem from dust or sediment. Or fixed from air molecules.
  - **Fixation**: conversion from unavailable state to available state
- Some may leave an ecosystem by erosion or elution or return to the air.
- But most cycles among **pools** within the ecosystem.
  - If some elements leave faster than replaced, pools become depleted.

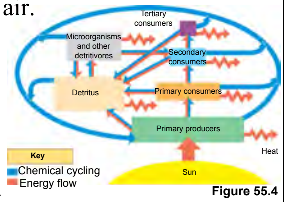
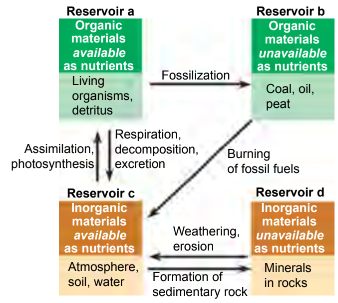


Figure 55.4

General model of nutrient cycling

- the main reservoirs of elements and the processes that transfer elements between reservoirs



Carbon cycle

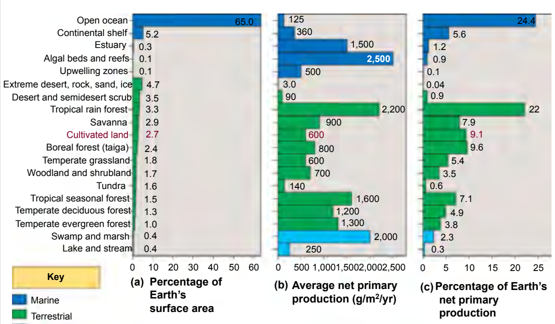
- Carbon dioxide gas (CO_2) in atmosphere, and bicarbonate (HCO_3^-) in aquatic media.
- Producers use energy (sunlight) to convert CO_2 (abiotic pool) into organic biomass (biotic pool)
  - **Carbon fixation**

$$n(CO_2) + n(H_2O) + \text{energy} \rightarrow (CH_2O)_n$$

Primary Productivity

- The total organic matter produced by all autotrophs in the ecosystem is its **Gross Primary Production** (GPP).
- Part of the GPP is used by the producers for their own respiration.
- Only the remaining primary production increases the total ecosystem biomass and is available for consumers.
  - = **Net Primary Production** (NPP)

Average net primary productivity of Earth's biomes



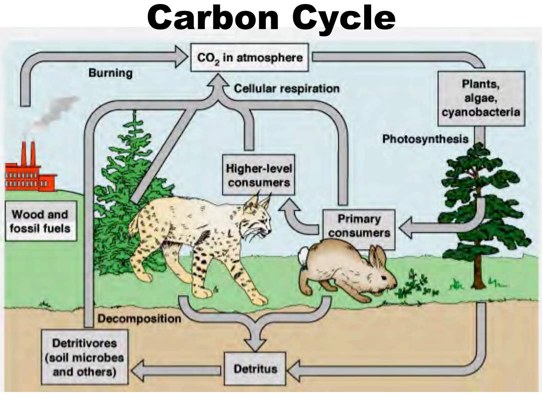
Carbon cycle

- Consumers eat carbon compounds (sugars, proteins, fats, nucleic acids) made by producers
- Respiration produces CO_2 as waste; released back into abiotic pool

$$(CH_2O)_n \rightarrow n(CO_2) + n(H_2O) + \text{energy}$$

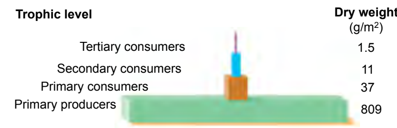
- Carbon fixation/respiration tied to energy flow
  - Biomass trophic pyramid reflects energy pyramid

Carbon Cycle



Carbon cycle

- NOTE: pyramid of biomass **production**
  - Actual **standing crop** biomass may differ



(a) a bog at Silver Springs, Florida.

Figure 55.12

- Carbon fixation tied to energy flow
  - Biomass trophic pyramid reflects energy pyramid

Carbon cycle

- NOTE: pyramid of biomass **production**
  - Actual **standing crop** biomass may differ

(b) English Channel marine ecosystem

Figure 55.12

- Carbon fixation tied to energy flow
  - Biomass trophic pyramid reflects energy pyramid

Regulation of Trophic Levels

✧**Bottom-Up Regulation model**:

↑Nutrients → ↑Vegetation → ↑Herbivores → ↑Predators

↓Nutrients → ↓Vegetation → ↓Herbivores → ↓Predators

✧**Top-Down Regulation model**:

↑Predators → ↓Herbivores → ↑Vegetation → ↓Nutrients

↓Predators → ↑Herbivores → ↓Vegetation → ↑Nutrients

Detritus-based food chains

- Much of primary production indigestible.
  - Grasslands, marshlands kelp forests
- Require detritivores/decompsers to move production from producers to consumers

Detritus-based food chains

Form of Energy	kcal/(m^2 · yr)
Solar radiation	600,000
Gross grass production	34,580
Net grass production	6,585
Gross insect production	305
Net insect production	81
Detritus leaving marsh	3,671

Combustion

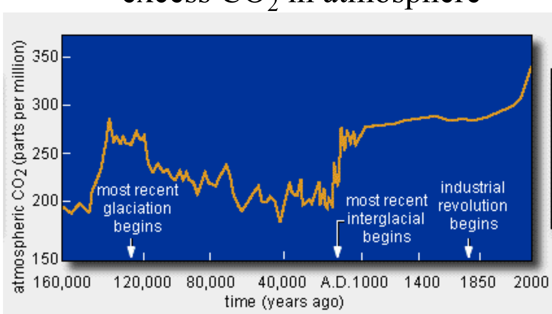
- Dead organisms return CO_2 to atmosphere when burned
  - Wood
  - Fossil fuels
- Again:

  $(CH_2O)_n \rightarrow n(CO_2) + n(H_2O)$ + energy

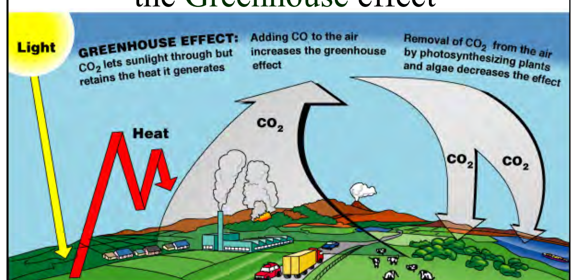
Fossil fuels: Organic litter was transformed into coal or oil

Geological pools used faster than they are replaced

Industrial age combustion → excess CO_2 in atmosphere

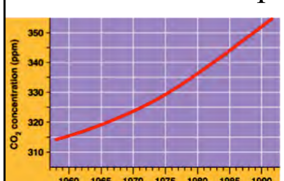


Global habitat impact: the Greenhouse effect

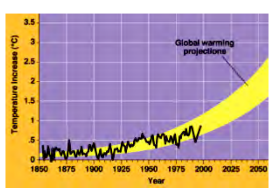


- "Greenhouse gases" (esp.., CO_2) are transparent to sunlight but absorb infrared radiation trap heat within atmosphere

Increase in atmospheric CO_2 correlates with increase in global temperature

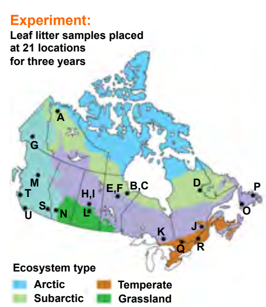


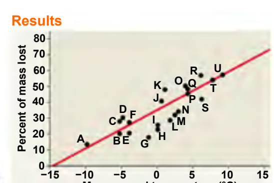
Increase in CO_2



Increase in global temperature

Temperature-dependent decomposition rates





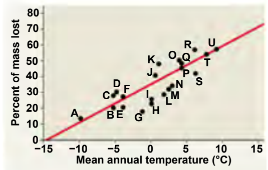
- Across ecosystems, decomposition rates highly dependent upon temperature
- Other significant factors:
  - H_2O (precipitation)
  - Litter "quality" (lignin/protein ratio)
  - O_2 (sediment composition & depth)

Figure 55.15

Temperature-dependent decomposition rates

1. ⇧CO_2 in atmosphere ➔ warmer temperatures at temperate latitudes
2. warmer temperatures ➔ ⇧ decomposition rates
3. ⇧ decomposition rates ➔ ⇧CO_2 in atmosphere
4. Back to #1 (positive feedback amplification)

Results



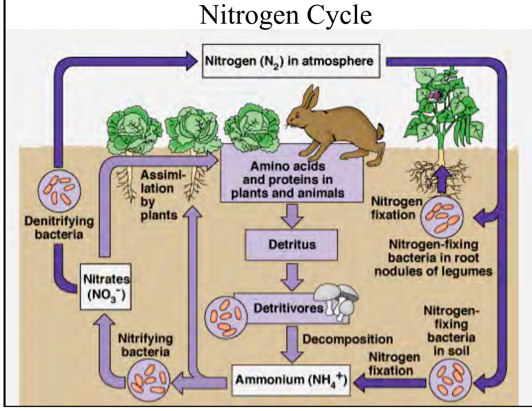
- Across ecosystems, decomposition rates highly dependent upon temperature

- Hot, damp environments have high decomposition rates — little organic matter in soil.
  - **Tropical forests: <10% total organic matter in soil**
- Cool, dry environments have low decomposition rate — much organic matter in soil.
  - **Temperate forests: as much as 50% total organic matter in soil!**

Nitrogen cycle

- Important component of proteins and nucleic acids
- N_2 forms 79% of atmospheric gas
- **Nitrogen fixation**: N_2 gas must be converted to other nitrogen compounds

Nitrogen Cycle



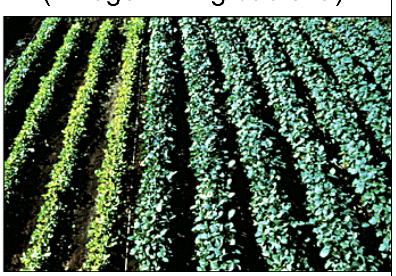
Bacteria are required for nitrogen cycle

- **Nitrogen fixing bacteria**:
  - N_2 gas → ammonia (NH_4^+)
- **Nitrifying bacteria:**
  - NH_4^+ → nitrite (NO_2^-) → nitrate (NO_3^-)
- Plants use nitrate to make organic amines

Root nodules containing nitrogen-fixing bacteria

Mutualism: Legumes and *Rhizobium* (nitrogen fixing bacteria)

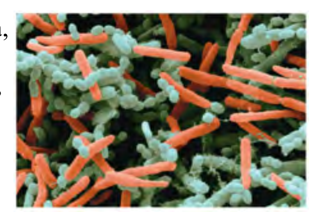
Nodules on roots



Without *Rhizobium* With *Rhizobium*

Bacteria return nitrogenous waste to atmosphere

- **Denitrifying bacteria,** decomposers covert NO_3^- back into N_2 gas
- Completes cycle



Rod-shaped and spherical bacteria in compost (colorized SEM)

Human influences on nitrogen cycle

- Industrially made fertilizers account for 30% of fixed nitrogen
- Making fertilizers burns lots of fossil fuels
- Deforestation causes loss through run off
- Acid rain production

Agriculture and Nitrogen Cycling

- Agriculture constantly removes nutrients from ecosystems that would ordinarily be cycled back into the soil
- Necessitates adding nitrogen-fertilizers back

Deforestation or over-irrigation increases runoff & nitrogen loss

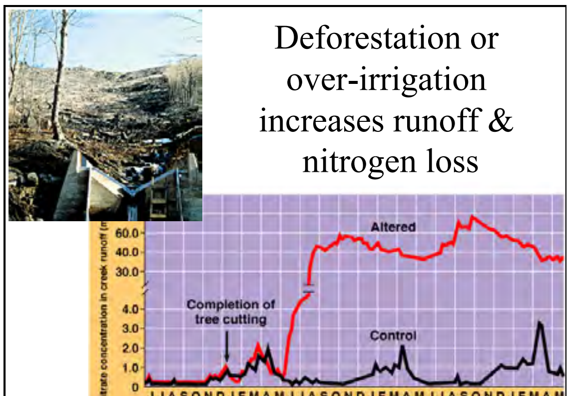


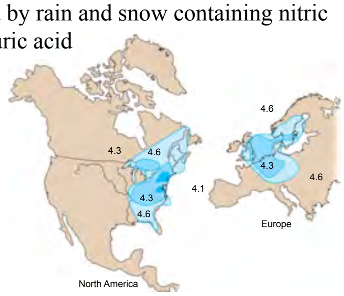
Fig. 55.16

Acid rain

- Nitrogen and sulfur compounds (from factory and auto emissions) plus water make nitric acid and sulfuric acid in the atmosphere

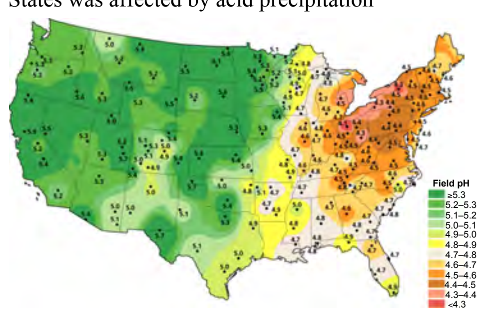
Acid rain

- North American and European ecosystems downwind from industrial regions have been damaged by rain and snow containing nitric and sulfuric acid



Acid rain

- By the year 2000 the entire contiguous United States was affected by acid precipitation



Mineral nutrient cycles

- E.g., phosphorus, calcium, potassium, iron
- Biological demand is low, but sources usually dependent upon erosion from regional rocks and transport in surface water

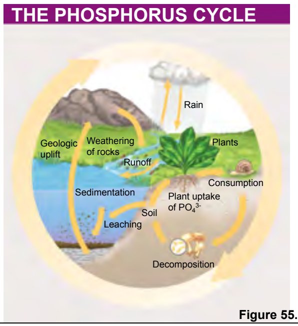


Figure 55.14

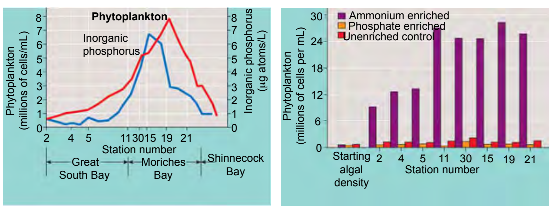
Limiting nutrient

- Productivity in a given ecosystem is limited by the availability of all vital nutrients
- The particular element whose availability is restricting greater productivity is the **limiting nutrient**
- E.g.,
  - Carbon, oxygen, & hydrogen are needed in great quantities, but are also tremendously available: ∴ rarely limiting.
  - Most trace metals are rare in the environment, but organisms don't need much of them: ∴ seldom limiting.
- Nitrogen and phosphorous are the most typical limiting nutrients in many ecosystems

Testing for the limiting nutrient

- Phytoplankton productivity in three bays along Long Island, NY

RESULTS (a) Phytoplankton abundance parallels the abundance of phosphorus in the water. Nitrogen, however, is immediately taken up by algae, and no free nitrogen is measured in the coastal waters. (b) The addition of ammonium (NH_4^+) caused heavy phytoplankton growth in bay water, but the addition of phosphate (PO_4^{3+}) did not induce algal growth.



(a) Phytoplankton biomass and phosphorus concentration

(b) Phytoplankton response to nutrient enrichment

CONCLUSION Since adding phosphorus, which was already in rich supply, had no effect on *Nannochloris* growth, whereas adding nitrogen increased algal density dramatically, researchers concluded that nitrogen was the nutrient limiting phytoplankton growth in this ecosystem.

Figure 55.8

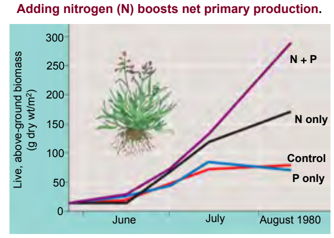
Testing for the limiting nutrient

- Salt marsh

EXPERIMENT Over the summer of 1980, researchers added phosphorus to some experimental plots in the salt marsh, nitrogen to other plots, and both phosphorus and nitrogen to others. Some plots were left unfertilized as controls.

RESULTS

Adding nitrogen (N) boosts net primary production.



Experimental plots receiving just phosphorus (P) do not out-produce the unfertilized control plots.

CONCLUSION These nutrient enrichment experiments confirmed that nitrogen was the nutrient limiting plant growth in this salt marsh.

NOTE: Once N was added, P became limiting!

Iron-limitation in oceanic ecosystems

- Offshore regions far from terrigenous runoff, isolated from mineral sources

Table 55.1 Nutrient Enrichment Experiment for Sargasso Sea Samples

Nutrients Added to Experimental Culture	Relative Uptake of ^{14}C by Cultures*
None (controls)	1.00
Nitrogen (N) + phosphorus (P) only	1.10
N + P + metals (excluding iron)	1.08
N + P + metals (including iron)	12.90
N + P + iron	12.00

*^{14}C uptake by cultures measures primary production.

Data from Menzel and Ryther, *Deep Sea Research* 7(1961): 276–281

Cultural (Anthropogenic) Eutrophication

- Sewage or fertilizer runoff adds limiting nutrients to aquatic ecosystems
- Algae stimulated to overgrow
  - Benthic algae overgrow benthic invertebrates
  - Filamentous algae clog gills
  - Thick growth dampens flow or reduces mixing
  - Nocturnal algal respiration consumes all dissolved oxygen
- Loss of diversity & community structure