Natural Systems Recycle
Essential Nutrients

Understanding Ecosystem Terms

Mean Residence Time
For a system in dynamic equilibrium:

\[ \text{Mean Residence Time} (\tau) = \frac{\text{stock}}{\text{inflow or outflow}} \]

\( \tau = \text{Average length of time a given atom or molecule spends in the system between entering and leaving.} \)
Importance of Nutrient Cycles

Types of Biogeochemical Cycles

- Gaseous
- Sedimentary

Hydrologic Cycle

(water)

Read pages 38 - 40 in textbook
Hydrologic Cycle
(water)
Pools (units are $10^6$ km$^3$)

<table>
<thead>
<tr>
<th>Change in flow of Colorado River</th>
</tr>
</thead>
</table>
| From 1960 to 1990, the Aral Sea fell from fifth to sixth among the world's largest lakes.

Humans Alter the Hydrologic Cycle

The Aral Sea
Major Molecules of Life

- **Alanine**
  \[
  \text{NH}_2 \cdot \text{C} \cdot \text{H} \cdot \text{CH}_3
  \]
- **Glucose**
  \[
  \text{H} \cdot \text{C} = \text{O} \cdot \text{H} \cdot \text{O} - \text{C} - \text{H} \cdot \text{H} - \text{O} - \text{H} \cdot \text{C} \cdot \text{O} - \text{H} \cdot \text{C} \cdot \text{O} - \text{H} \cdot \text{O} - \text{H} \cdot \text{CH}_2 \text{OH}
  \]

Amino Acid $\Rightarrow$ Protein
structure
enzymes

Monosaccharide $\Rightarrow$ Carbohydrates
structure
fuel

Note the abundance of C, H, N, & O

Major Molecules of Life

- **Uracil**
  \[
  \text{O} - \text{H} - \text{N} - \text{C} \cdot \text{H} \cdot \text{CH}
  \]
- **Palmitic Acid**
  \[
  \text{CH}_3(\text{CH}_2)_{14} \cdot \text{COOH}
  \]

Nucleotide $\Rightarrow$ DNA & RNA
structure
fuel

Fatty Acid $\Rightarrow$ Lipids
membranes
fuel

Note the abundance of C, H, N, & O

Carbon Cycle
Reciprocal Processes:

- **Photosynthesis** ($P_s$)
- **Cellular Respiration** ($R$)
Lectures 15

Active Carbon Pools

<table>
<thead>
<tr>
<th>Pool Type</th>
<th>% of Total</th>
<th>Carbon Units (G C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>1.6%</td>
<td>720</td>
</tr>
<tr>
<td>Terrestrial</td>
<td>4.6%</td>
<td>2060</td>
</tr>
<tr>
<td>Oceans</td>
<td>84.8%</td>
<td>38000</td>
</tr>
<tr>
<td>Fossil Fuel</td>
<td>9%</td>
<td>4000</td>
</tr>
</tbody>
</table>

Total Carbon Units = 39260 G C

Global Carbon Cycle

- Fossil fuel burning: 320 G C/year
- Litter fall: 60 G C/year
- Net land use change: 60 G C/year
- Runoff: 0.8 G C/year
- Gas exchange: 92.2 G C/year
- Soil burial: 0.2 G C/year

Change in atmospheric CO₂ concentration

CO₂ mixing ratio (ppm) vs. time (years)

Global Carbon Cycle

- Change in atmospheric CO₂ concentration

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Lectures 15

The Breathing Earth

Jan. - Feb.

July - Aug.

Carbon Cycle
Mean Residence Times

• Oceans ~ 422 years
• Atmosphere ~ 3 years
• Land Plants ~ 4.6 years
• At current rates of fossil fuel use, our recoverable supplies will last about 700 years! \( (4000 \text{ Pg} \div 6.4 \text{ Pg/yr} = 625 \text{ yrs}) \)

The Carbon Cycle is not Always in Balance

• In the past, \( P > R \) because …
  Fossil fuel deposits formed.
  Oxygen accumulated in the atmosphere.
• In the present, inputs of \( \text{CO}_2 \) > outputs to the atmosphere because …
  Burning of fossil fuels.
  Net destruction of terrestrial vegetation.
• Current imbalance results in rising atmospheric \( \text{CO}_2 \) concentrations.
The Missing Carbon Sink

<table>
<thead>
<tr>
<th>Net CO₂ Sources</th>
<th>Net CO₂ Sinks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil Fuel Emission</td>
<td>Atmospheric Increase</td>
</tr>
<tr>
<td>Land Use Change</td>
<td>Ocean uptake</td>
</tr>
<tr>
<td>Total Net Sources</td>
<td>Total Net Sinks</td>
</tr>
<tr>
<td>6.4</td>
<td>3.2</td>
</tr>
<tr>
<td>1.5</td>
<td>2.2</td>
</tr>
<tr>
<td>7.9</td>
<td>5.4</td>
</tr>
</tbody>
</table>

Units are Pg C/yr

Le Quéré et al. 2009, Nature Geoscience; Canadell et al. 2007, PNAS, updated

Values for more recent years.

The current growth rate of CO₂ in the atmosphere is unusually high:

- 1980's 1.58 ppm per year
- 1990's 1.49 ppm per year
- 2000-2006 1.93 ppm per year

18% of the increase may be due to reduced carbon sinks

Canadell et al. 2007
Lectures 15

Historical estimates of sources & sinks of CO₂ associated with human activity

Summary of Carbon Cycle

- Largest active pool is the ocean.
- Pool on land (plant + soil) ≈ 3x amount in atmosphere
- \( P_s = R_{\text{total}} \)
- Soil respiration ≈ 10x fossil fuel emissions
- \( P_s \) removes 1/6 of the atmospheric pool of CO₂ each year.
- Concentration of CO₂ in the atmosphere is ↑ ca. 0.4% per year (ca. \( 3 \times 10^{15} \) g C/yr)