Lecture Outline: Ecosystems And Energy

I. **Ecosystem Producers and Energy Transfer Processes**
   A. Types of Producers
      1. Producers are required in every ecosystem because everything relies on them
      2. Two major categories based on production method:
         a. Phototrophs: use photosynthesis (vast majority of ecosystems)
         b. Chemotrophs: use chemosynthesis (e.g., deep-sea ecosystems where light cannot penetrate)
   B. Cellular Respiration and Electron Acceptors
      1. Respiration dismantles fuel molecules (organic compounds) to release energy by breaking carbon-hydrogen bonds
      2. Hydrogen atoms are separated into protons and electrons
         a. Electrons are transferred down an electron transport chain, releasing energy
         b. Energy powers the pumping of protons, creating a proton gradient
         c. Proton diffusion through ATP synthase generates ATP
      3. Respiration requires a final electron acceptor to prevent the electron transport chain from filling up
      4. Types of Respiration
         a. Aerobic respiration: uses oxygen (O_2) as the final electron acceptor, reducing it into water (H_2O)
         b. Anaerobic respiration: uses something other than O_2 (e.g., iron ions in deep-sea environments)
      5. Deep-Sea Chemosynthetic Example
         a. Iron ions are used as the final electron acceptor and are reduced
         b. When the reduced iron reaches the surface where oxygen is present, O_2 oxidizes the iron
         c. The oxidation produces iron oxide, also known as rust
   C. Energy Flow Versus Material Cycling
      1. Energy flows through an ecosystem
         a. Energy enters as light (sunlight)
         b. Energy is transformed and transferred within the ecosystem
         c. Energy eventually leaves as heat

2. Materials (atoms) largely stay within the ecosystem and get recycled

D. Carbon Fixation and Decomposition

1. Producers perform **carbon fixation**: incorporating carbon from an inorganic source (like carbon dioxide, CO_2) into organic compounds
2. Consumers and producers undo carbon fixation through cellular respiration (complete oxidation of fuel)
    a. The summary reaction for the complete oxidation of fuel is the exact reverse of photosynthesis
    b. Oxygen and fuel are consumed, turning back into CO_2 and H_2O, and releasing energy
3. Decomposers break down dead and decaying matter (detritus), returning carbon back into inorganic form (CO_2) to be recycled by producers

II. **Measures of Ecosystem Production**

A. Gross Primary Production (GPP)

1. Energy converted to chemical energy of organic compounds in a given amount of time
2. Represents the total amount of energy captured by producers

B. Net Primary Production (NPP)

1. NPP equals GPP minus respiration of autotrophs (R_A)
2. $NPP = GPP - R_A$
3. Represents the chemical energy that builds up after producers use some organic material as fuel for themselves

C. Net Ecosystem Production (NEP)

1. NEP equals GPP minus total respiration (R_T)
2. $NEP = GPP - R_T$
3. Represents the total accumulation of biomass in the ecosystem (accounting for respiration by both producers and consumers)

D. Estimation of Production

1. Production estimates use indirect methods rather than direct measurement of every organism
2. Percent reflectance (greenness) measured by satellites indicates chlorophyll content
3. This measurement allows for calculation of GPP based on the number of producers present

III. **Limiting Resources**

A. Definition of Limiting Resource

1. Any resource (material or energy, e.g., light or water) that is in shortest supply relative to how much is needed for a particular ecosystem
2. Supplementing the limiting resource will cause something else to become the new limiting

resource

B. Terrestrial Ecosystems (Land)
   1. NPP is lower at poles (less light) and in deserts (lack of water)
   2. Wetter places, such as rainforests, generally have higher NPP
   3. Water is often a limiting resource on land
C. Aquatic Ecosystems (Water-based)
   1. Water is never the limiting resource
   2. Often limited by nutrients, frequently nitrogen (e.g., in ammonium) or phosphorus (e.g., in phosphate)
   3. Some aquatic ecosystems may be iron limited

IV. **Energy Assimilation and Trophic Dynamics**

A. Energy Assimilation Efficiency
   1. Energy is consumed from the lower trophic level (e.g., 200 J of chemical energy taken in)
   2. A significant portion of ingested energy is lost as feces and is not assimilated (e.g., 100 J)
   3. Assimilated energy is used for cellular respiration or incorporated into new biomass (growth/reproduction)
   4. Only about 10% of the energy from the lower trophic level is typically assimilated into new organic material in the next level
B. Thermodynamics and Trophic Levels
   1. First Law of Thermodynamics: Energy cannot be created or destroyed
   2. Second Law of Thermodynamics:
      a. Entropy (disorder) is always increasing in the universe
      b. In any energy transaction, some energy is lost as unusable heat
      c. No energetic process is 100% efficient
   3. The inefficiency of energy transfer limits the number of consumer levels
   4. Consumer levels usually end at tertiary; quaternary consumers are possible only in rich ecosystems
C. Pyramids of Energy and Production
   1. Energy Pyramids: Must always be an **upright pyramid** (narrower going up) due to the Second Law of Thermodynamics
   2. Production (Biomass) Pyramids:
      a. Usually upright
      b. Can be **inverted** (wider going up) in some aquatic ecosystems
      c. Inverted pyramids are possible due to a high turnover rate where producers are consumed almost as quickly as they reproduce

V. **Major Biogeochemical Cycles**
   A. The Water Cycle
      1. Water is indispensable for life (life is aqueous solution chemistry)
      2. Water is unique in existing in solid, liquid, and gas phases within a temperature range livable by organisms
      3. Operates at a **global scale** because water vapor is a component of air
   B. The Carbon Cycle
      1. Carbon is indispensable as the basis of four major organic macromolecules:
         a. Proteins
         b. Lipids
         c. Nucleic acids
         d. Polysaccharides (Carbohydrates)
      2. Operates at a **global scale** because carbon dioxide (CO_2) is a component of air
      3. Historically balanced by reciprocal processes: photosynthesis (CO_2 removal) and oxidation of fuels (CO_2 production)
      4. Burning fossil fuels (carbon stored long ago) upsets the balance, causing CO_2 levels to increase
   C. The Nitrogen Cycle
      1. Nitrogen is essential for life, often a limiting resource
      2. Found in amino acids (monomers of proteins) and nitrogenous bases (components of nucleotides)
      3. Operates at a **global scale** because nitrogen gas (N_2) makes up about three-quarters of the air
   D. The Phosphorus Cycle
      1. Operates fairly **locally** because phosphorus compounds are not gaseous components of air
      2. Phosphorus is essential for life because it is found in:
         a. Phosphate components of every nucleotide (and thus all nucleic acids)
         b. ATP (Adenosine Triphosphate) and GTP (Guanosine Triphosphate), key energy carrying molecules required for metabolism
         c. Phosphorylation and dephosphorylation processes used to switch proteins and enzymes between active and inactive forms

VI. **Ecosystem Disturbance and Reclamation**
   A. Impact of Deforestation
      1. Removal of producers (trees) drastically reduces the ecosystem's ability to retain nutrients
      2. Deforested valleys show a massive increase in nitrate concentration in runoff water,

demonstrating nutrient loss

B. Ecological Solutions to Damage
   1. **Restoration**: Undoing damage by putting back things that should be there that were taken out (e.g., physical reshaping the land, planting life)
   2. **Remediation**: Cleaning up messes by taking back things that were put into the ecosystem that should not be there (e.g., toxic wastes)
      a. Bioremediation utilizes microorganisms (often bacteria)
      b. Microorganisms consume or transform toxic organic compounds into less toxic substances