General Biology: Ecosystems And Energy

AI-Generated Study Guide

(Based on lectures delivered by Dr. Ty C.M. Hoffman)

Energy and Ecosystem Basics
Producers and Energy Input
All ecosystems require producers because every other organism (consumers) relies on them for sustenance. Producers are categorized based on their method of energy capture:
• Photoautotrophs: Producers that use photosynthesis, drawing energy from light. These are the producers in the vast majority of ecosystems.
• Chemoautotrophs: Producers that use chemosynthesis, drawing energy from chemical reactions. These are found in environments lacking light, such as deep-ocean ecosystems.
Energy flows through an ecosystem: it enters, typically as sunlight (light energy), is transformed and transferred (e.g., to chemical energy in food), and eventually leaves the ecosystem as heat.
Materials (chemicals and atoms) are largely recycled within an ecosystem rather than flowing through.

Cellular Respiration
Respiration is the process of breaking down fuel molecules (organic compounds) to release energy, primarily by dismantling the carbon skeleton. This process involves:
1. Glycolysis: Partial breakdown of glucose into pyruvate.
2. Mitochondrial Respiration: Pyruvate is delivered to the mitochondrion for further breakdown, ultimately resulting in $ \text{CO}_2 $ (exhaled) and water.
3. Electron Transfer: Hydrogen atoms from the fuel are separated into protons and electrons. Electrons are transferred along an electron transport chain, releasing energy used to pump protons across a membrane, creating a proton gradient.
4. ATP Synthesis: Protons diffuse back across the membrane through ATP synthesis molecules, which spin and phosphorylate ADP into ATP.
Final Electron Acceptor: Respiration requires an external particle (not the fuel molecule) to act as the final electron acceptor, removing electrons from the chain so the process can continue.
• Aerobic Respiration: Uses oxygen as the final electron acceptor. Oxygen is highly electronegative and is reduced into water by receiving electrons and protons. Most respiring organisms undergo aerobic respiration.

- Anaerobic Respiration: Uses a particle other than oxygen as the final electron acceptor. In deep-ocean ecosystems, iron ions can be reduced instead of oxygen. If reduced iron is exposed to surface oxygen, the oxygen oxidizes the iron, forming iron oxide, commonly known as rust.

Chemical Processes and Cycling

Carbon Fixation and Cycling

Carbon Fixation is the crucial chemical process producers perform: taking carbon from an inorganic source (like CO_2) and incorporating it into an organic compound. Consumers rely on producers because they must obtain their carbon already in organic form.

The processes of photosynthesis (carbon fixation) and the complete oxidation of fuel (cellular respiration) are reciprocal:

- Photosynthesis inputs: Light + CO_2 + H_2O. Outputs: Sugar + Oxygen.
- Complete oxidation inputs: Fuel + Oxygen. Outputs: CO_2 + H_2O + Energy.

Decomposers (and detritivores) are essential for material cycling, especially carbon. They feed on dead and decaying material (detritus), using it as fuel and returning the carbon back into inorganic form (CO_2), which can then be recycled by producers.

Global Balance: Historically, the carbon cycle was balanced because the rates of photosynthesis and fuel oxidation equalized. However, the burning of fossil fuels releases carbon stored millions of years ago, exceeding the rate at which producers can fix it, leading to increased atmospheric CO_2 concentration.

Major Biogeochemical Cycles

Key elements required for life cycle through the biosphere:

Cycle	Global vs. Local	Importance to Life	Key Chemical Forms/Notes
Water	Global (exists as gaseous water vapor in air)	Indispensable; life is aqueous solution chemistry/metabolism. Can exist in all three phases (solid, liquid, gas) within a livable temperature range for organisms.	Plants are critical for water and nitrogen retention in ecosystems.

Carbon	**Global (exists as gaseous CO_2)**	**Indispensable; organisms are organic compounds (proteins, lipids, nucleic acids, polysaccharides).**	**Reciprocally balanced by photosynthesis and respiration. Burning fossil fuels upsets the balance.**
Nitrogen	**Global (major component of air)**	**Essential for proteins (all amino acids contain nitrogen) and nucleic acids (all nucleotides contain a nitrogenous base).**	**Often a limiting resource in ecosystems.**
Phosphorus	**Local (no gaseous form as part of the air)**	**Essential for nucleic acids (every nucleotide contains a phosphate) and ATP (adenosine triphosphate) and GTP, the major energy-carrying molecules in metabolism. Also key for phosphorylation, which regulates protein function (like enzymes) by switching them on or off.**	**Phosphate contains phosphorus and oxygen atoms.**

Measuring Energy and Production
Ecologists use specialized definitions to measure energy conversion and accumulation:

Term	**Definition**	**Equation**
Gross Primary Production (GPP)	**The total energy converted to chemical energy of organic compounds (biomass) by producers in a given amount of time.**	**N/A**
Net Primary Production (NPP)	**The chemical energy accumulated by producers after subtracting the energy they use for their own cellular respiration (R_{A}). This is the amount of energy available to consumers.**	$\text{NPP} = \text{GPP} - \text{R}_{\text{A}}$

Net Ecosystem Production (NEP)	The total accumulation of biomass (organic material) in the entire ecosystem after subtracting the total respiration (R_{T}), including producers and all consumers.	$\text{NEP} = \text{GPP} - \text{R}_{\text{T}}$

Production estimates rely on indirect measurements, such as using satellites to measure percent reflectance of light. Plants absorb blue and red light for photosynthesis and reflect green light; the detected intensity of green light indicates the amount of chlorophyll and, consequently, the number of producers, which allows GPP to be calculated.

Limiting Resources
A limiting resource is defined as the resource in shortest supply, relative to the need, that prevents an ecosystem from increasing production.
• If an ecosystem is supplemented with a limiting resource, production will increase until a different resource becomes limiting.
• Terrestrial Ecosystems: Production is often limited by light (e.g., poles) or water (e.g., deserts).
• Aquatic/Marine Ecosystems: Water is never limiting. Production is often limited by nitrogen (e.g., in the form of ammonium) or phosphorus (e.g., in the form of phosphate), or sometimes by metals such as iron.

Energy Transfer and Trophic Dynamics
Trophic Levels represent the links in a food chain: producers form the base, followed by primary consumers, secondary consumers, and so on.
Energy Assimilation: Consumers take in energy from the trophic level below, but not all of it is assimilated (used for life processes, growth, or reproduction). A large fraction may pass through as feces. Furthermore, a significant amount of assimilated energy is immediately lost as heat through cellular respiration.
Thermodynamics and Efficiency:
• The First Law of Thermodynamics states energy cannot be created or destroyed.
• The Second Law of Thermodynamics states that entropy (disorder) is always increasing, meaning some energy is lost as heat in every transaction. No energetic process is 100% efficient.
Energy Transfer: Approximately 10% of the chemical energy stored in the biomass of one trophic level is typically transferred into new organic material (biomass) in the next higher trophic level. This inefficiency limits food chains, often ending at the tertiary or quaternary consumer level due to insufficient energy availability.
Ecological Pyramids
1. Energy Pyramids: Represent the amount of energy at each trophic level (often measured in joules). Due to the Second Law of Thermodynamics and the 10% transfer rule, energy pyramids must always be upright (narrowest at the top).

2. Production Pyramids (Biomass): Represent the total mass of organisms at each level (e.g., grams of biomass). While usually upright, these pyramids can be inverted in certain aquatic ecosystems (e.g., open oceans). This occurs when primary consumers (zooplankton) have a high turnover rate, eating producers (phytoplankton) almost as fast as they reproduce, preventing a large buildup of producer biomass at any given time. If the same system were measured by energy, the pyramid would remain upright.

Human Impacts on Ecosystems

Environmental Damage and Repair

When human activities damage an ecosystem, two approaches are used for repair:

- **Restoration: Undoing damage where materials or physical features have been removed or altered (e.g., physical rebuilding, or putting back plant life that was taken out).**
- **Remediation (Reclamation): Cleaning up messes where toxic substances (like uranium or other wastes) have been introduced into the ecosystem.**

Remediation often utilizes the diverse biochemistry of microorganisms (like prokaryotes/bacteria). Because bacteria possess the biochemical capability to break down almost any compound, they can be introduced (or genetically engineered) to consume unnatural toxic materials, converting them into less toxic substances, and thus cleaning the ecosystem.