C3L3 What Happens to Energy in an Ecosystem?

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Big Idea

- As energy flows through ecosystems in food chains and webs, the amount of chemical energy available to organisms at each successive feeding level decreases.

Energy Flows Through Ecosystems in Food Chains and Food Webs

- The chemical energy stored in the bodies and wastes of organisms flows through ecosystems from one trophic level to the next.
- A sequence of organisms, each of which serves as food for the next, is called a food chain. Chemical energy and nutrients move through by photosynthesis, feeding, and decomposition.
- Since in real life most consumers feed on more than one thing, most ecosystems form a complex network of relationships called a food web.

Usable Energy Decreases With Each Link in a Food Chain or Web

- Each trophic level in a food chain or web contains a certain amount of biomass (dry weight of all organic matter contained in organisms).
- Chemical energy stored in biomass is transferred from one trophic level to the next.
- 2nd Law of Thermodynamics: transfers are not efficient because some usable chemical energy is degraded or lost to the environment as low-grade heat.
- The percentage of usable chemical energy transferred from one trophic level to the next depends on the species/ecosystem. More trophic levels = more cumulative loss of energy to heat.
- A pyramid of energy flow is used to illustrate the energy loss for a simple food chain, assuming a 90% energy loss with each transfer.
- This large loss in chemical energy between successive levels explains why food chains and webs rarely have more than 4 or 5 trophic levels...not enough energy left to support organisms.

Some Ecosystems Produce Plant Matter Faster Than Others Do

- The amount of biomass in an ecosystem depends on how much solar energy producers can capture and store, and by how quickly they can do so.
- Gross primary productivity (GPP) is the rate at which an ecosystem’s producers (usually plants) convert solar energy into chemical energy in the form of biomass found in their tissues.
- In order to stay alive, producers have to use some of the chemical energy they store in biomass.
- Net primary productivity (NPP) is the rate at which producers use photosynthesis to produce and store chemical energy minus the rate at which they use some of this stored energy through aerobic respiration.
- Gross primary productivity is similar to the rate at which you make money, or number of dollars you earn per year.
- Net primary productivity is similar to the amount of money earned per year minus your work expenses such as transportation, clothes, food, and supplies. It is amount left over to spend on other things.
- The planet’s NPP ultimately limits the number of consumers (including humans) that can survive on Earth.
C3L4 What Happens to Matter in an Ecosystem?

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Nutrients Cycle Within and Among Ecosystems

- Elements and compounds are constantly recycled (Law of Conservation of Matter) through biogeochemical (or nutrient) cycles. Biogeochemical = Life-Earth-Chemical
- These cycles, driven directly or indirectly by incoming solar energy and the Earth’s gravity, include the hydrologic (water), carbon, nitrogen, phosphorus, and sulfur cycles.
- These systems are an important component of Earth’s natural capital, and human activities are altering them.

The Water Cycle

- The hydrologic, or water, cycle collects, purifies, and distributes the Earth’s fixed water supply.
- This cycle is powered by the sun and involves 3 major processes – evaporation, precipitation, and transpiration.
- Precipitation is converted to ice (glaciers), becomes runoff, or is stored in the aquifer as groundwater.
- The hydrologic cycle can be viewed as a cycle of natural renewal of water quality.
- Only about 0.024% of Earth’s vast water supply is available as liquid fresh water in accessible groundwater, lakes, rivers, and streams.

The Carbon Cycle

- Carbon is the basic building block of all organic compounds necessary for life.
- Carbon circulates through the biosphere, atmosphere, and parts of the hydrosphere.
- The carbon cycle is based on carbon dioxide (CO$_2$). CO$_2$ is a key component of the atmosphere’s thermostat. Even slight changes in this cycle caused by natural or human factors can affect Earth’s climate.
- Humans are altering the carbon cycle by
  - Adding large amounts of carbon dioxide to atmosphere when we burn fossil fuels.
  - Clearing carbon-absorbing vegetation from forests (especially tropical forests) faster than it can grow back.
  - Increased atmospheric temperatures are melting the permafrost, thus releasing huge carbon stores of decomposing vegetation.

The Nitrogen Cycle: Bacteria in Action

- The major reservoir of nitrogen is the atmosphere.
- Nitrogen gas (N$_2$) makes up 78% of atmospheric gases.
- Nitrogen is a crucial component of proteins, many vitamins, and nucleic acids.
- N$_2$ cannot be used directly by plants and animals.
- 2 natural processes convert N$_2$ into compounds plants and animals can use
  - Electrical discharges, or lightning, taking place in the atmosphere.
  - Nitrogen-fixing bacteria convert it in soil, aquatic systems, and in the roots of some plants.
In nitrogen fixation, bacteria and blue-green algae (cyanobacteria) combine $N_2$ with hydrogen to make ammonia ($NH_3$). Some of the ammonia is converted to ammonium ions ($NH_4^+$) which is a nutrient for plants.

Ammonia not taken up by plants can undergo nitrification which converts it to nitrate ions ($NO_3^-$), which are easily taken up by the roots of plants.

Denitrification (bottom of lakes, oceans, swamps, bogs) converts ammonia and ammonium ions back into $N_2$ and nitrous oxide gas ($N_2O$) which is released into atmosphere.

Humans affect the nitrogen cycle in 5 ways:

- We add large amounts of nitric acid (NO) when fuel is burned at high temperatures (car, truck, jet engines). This is converted to nitric acid in atmosphere which causes acid rain.
- We add nitrous oxide to atmosphere through use of inorganic and organic fertilizers.
- We release large quantities of stored nitrogen through destruction of forests, grasslands, and wetlands.
- We upset nitrogen cycle in aquatic ecosystems by adding excess nitrates from agricultural runoff of fertilizers and animal waste.
- We remove nitrogen from topsoil when we harvest nitrogen-rich crops, irrigate crops, and burn or clear grasslands and forests before planting.

The Phosphorus Cycle

- Phosphorus cycles through water, the Earth’s crust, and living organisms.
- The phosphorus cycle does not include the atmosphere and is slow compared to the water, carbon, and nitrogen cycles.
- Phosphate compounds are important in ADP, ATP, and vertebrate bones and teeth.
- Phosphates can become trapped in marine sediments for millions of years.
- Phosphate is mined and used to make fertilizer.

Humans are affecting the phosphorus cycle by:

- Removing large amounts of phosphate from Earth to make fertilizers.
- Reducing phosphate levels in tropical soils by clearing forests.
- Topsoil is eroded and runoff rich in phosphates (from fertilized lawns, agricultural land, etc) accumulates in ponds and lakes promoting algae growth.

WE ARE PUTTING TOO MUCH PHOSPHORUS INTO ECOSYSTEMS.

The Sulfur Cycle

- Sulfur circulates through the biosphere. Most of Earth’s sulfur is stored underground in rocks and minerals, in the form of sulfate ($SO_4^{2-}$) salts buried deep under ocean sediments.
- Sulfur enters the atmosphere from several natural sources.
  - Hydrogen sulfide ($H_2S$) colorless, highly poisonous, rotten-egg smelling gas given off by volcanoes & anaerobic decomposition of organic matter.
  - Sulfur dioxide ($SO_2$) comes from volcanoes.
- Particles of sulfate (SO$_4^{2-}$) from sea spray, dust storms, and forest fires.
- Certain marine algae produce volatile dimethyl sulfide or DMS (CH$_3$SCH$_3$). These particles serve as nuclei for condensing water in clouds. Variations in this compound can affect cloud cover, climate, and acid rain.

- Human activities have affected the sulfur cycle by:
  - We burn sulfur-containing coal and oil to produce electricity.
  - We refine sulfur-containing oil (petroleum) to make gasoline, heating oil, etc.
  - We extract metals such as copper, lead, and zinc from sulfur-containing rocks that are mined for these metals.
  - Once the sulfur is in the atmosphere, SO$_2$ is converted to sulfuric acid (H$_2$SO$_4$) and particle of sulfate (SO$_4^{2-}$) salts, which return to Earth as acid rain.