Chapter 3: Ecosystems

APES 2013

Date

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Case Study: Tropical Rainforest Deforestation

- Tropical Rainforest are found near the equator
- Cover about 2% of the Earth's land surface, but contain up to half of the world's known terrestrial plant and animal species
- So far, at least half of these forests have been destroyed or disturbed. It is expected that most forests will be gone or severely damaged within your lifetime.
- Three major consequences:
  - reduction of biodiversity
  - accelerate climate change due to global warming
  - change regional weather patterns which will permanently change the ecosystem

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Ecology

- Ecology is the study of how organisms interact with one another and with their physical environment of matter and energy.
- Levels of organization:
  - Population
  - Community
  - Ecosystem
  - Biosphere

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Cells

- Cells - smallest and most fundamental structures of life
- Cell Theory - all living things are composed of cells
- Eukaryotic cell - membrane-bound structure that contains a nucleus ("eu" = true, "karyote" = nucleus)
- Prokaryotic cell - membrane-bound structure that contains no distinct nucleus ("pro" = before, "karyote" = nucleus)

Species

- Species - set of individuals that mate and produce fertile offspring
- So far, biologists have identified 1.8 million species.
- We have no idea how many species are present on the Earth. Estimates range from around 4 million to 100 million. The most widely accepted estimate is between 10 and 14 million distinct species.
- In 2007, scientists began a project to list and describe the 1.8 million known species in a free Internet encyclopedia (www.eol.org).

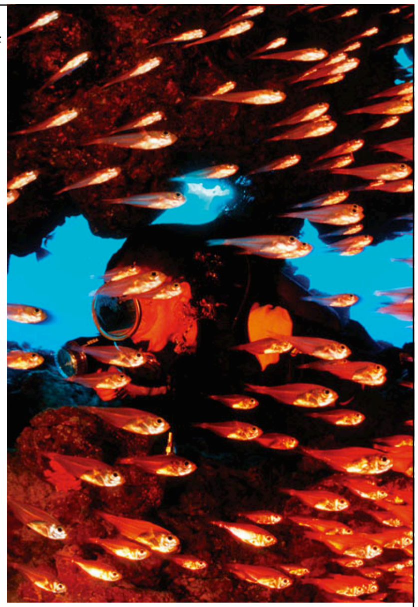
Ecology

- Ecology - how organisms interact with their biotic and abiotic environments
  - Biotic - living components (other organisms)
  - Abiotic - non-living components (soil, water, and other forms of matter and energy)
- Ecologists focus on populations, communities, ecosystems, and biosphere

Fig. 3-4

Populations

- Population - a group of individuals of the same species that live in the same place at the same time
- In a natural population there are slight genetic differences which is why the members do not all look and act exactly alike.
- Genetic Diversity - variation in a population



Habitat

- Habitat - the place where a population or an individual organism normally lives
  - A habitat's size varies based on the species. For a whale, it could be the entire ocean. For a bacterium, it could be the intestines of a termite.
- Each habitat has resources that the organisms need to survive (light, water, temperature...)

Communities

- Community - consists of all of the population of different species that live in a particular place
  - Example: forest
- Members of a community interact with each other (mainly in feeding relationships)

Ecosystems

- Ecosystem - a community of different species interacting with one another and with the nonliving components of the environment (soil, water, other forms of matter, and energy)
- Ecosystems can be very small (an old bucket full of water, a single tree), or very large (the Gobi Desert, the boreal forest)
- Ecosystems can be natural(undisturbed forest) or artificial (crop fields, tree farms, reservoirs).
- Matter and energy can move from one ecosystem to another
    - Ex. Soil and sediment being washed away by a river
    - Ex. Migration of animals

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Focus on Insects

- Considered pests because they compete with us for food, spread disease, and are a general nuisance
- Insects have been around for over 400 million years and can evolve (adapt) relatively quickly in response to environmental changes.
- Insects actually sustain our lives (estimated value in US = $57 billion)
    - Pollination is a vital natural service
    - Control other insect populations
    - Renewal of soil

Fig. 3-A

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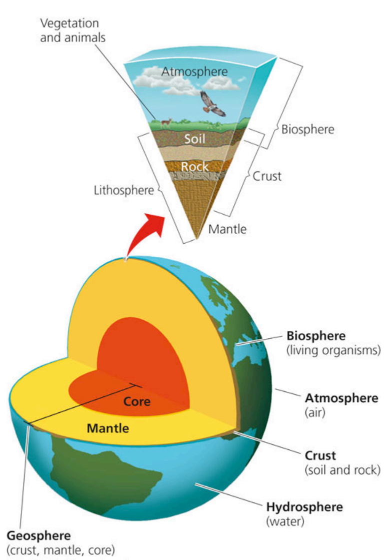
Earth's Life Support Systems



- Atmosphere - air
- Hydrosphere - water
- Geosphere - rock, soil, sediment
- Biosphere - living components

Fig. 3-6

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Atmosphere

- Atmosphere - thin spherical envelope of gasses surrounding the Earth's surface
  - Troposphere - extends about 17 kilometers above sea level in equatorial regions and 7 kilometers above sea level at the poles.
    - Almost all of the Earth's weather occurs here.
    - Contains a majority of the air we breath and consists of: Nitrogen (78% by volume); Oxygen (21% by volume); Remaining 1% is water vapor, carbon dioxide, methane, and other greenhouse gasses (gasses that trap heat and warm the lower atmosphere)
- Stratosphere - layer above the troposphere
  - 17-50 kilometers above the Earth's surface
  - Lower portion contains ozone gas (O_3) which filters out most of the sun's harmful ultraviolet (UV) radiation

Hydrosphere

- Hydrosphere - consists of all the water on or near the earth's surface
  - Forms:
    - Liquid water
    - Ice
    - Water vapor
- Most water is found in the oceans which cover 71% of the earth

Geosphere

- Geosphere - consists of the core, mantel, and crust of the interior of the earth
- Upper portion contains the nonrenewable fossil fuels and minerals we use as well as some renewable chemicals organisms need to survive

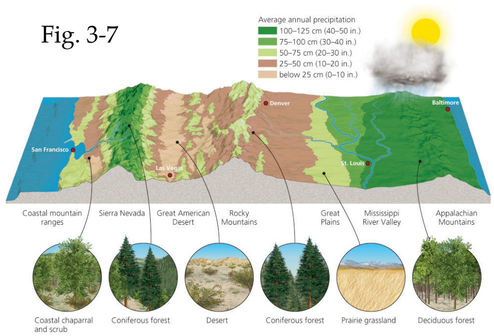
Biosphere

- Biosphere - includes the parts of the atmosphere, hydrosphere, and geosphere where life exists
- Extends from about 9 kilometers above the earth's surface to the bottom of the ocean
- In comparison, if the earth were an apple, the biosphere would be no thicker than the skin.
- The goal of ecology is to study this very thin layer and how organisms interact on and with it.

Biomes

- Biomes - large regions with distinct climates and certain species adapted to them
- Aquatic life zones - watery parts of the biosphere
  - Freshwater life zones
  - Marine life zones

Fig. 3-7



North American Biomes (39th Parallel)

Factors that Sustain Life

- One-way flow of high-quality energy from the sun
- Cycling of matter and nutrients (law of conservation of matter)
- Gravity

Solar Energy

- Energy from the sun reaches the earth as electromagnetic waves mostly as visible light, UV radiation, and infrared radiation (heat)
- Large quantities of this energy is reflected back into space by the atmosphere, clouds, and earth's surface.
- Ozone gas (O_3) in the lower stratosphere absorbs 95% of UV radiation
- The electromagnetic waves light the earth, warm the air, and cycles water through the biosphere (evaporation)
- 1% of this energy also generates winds
- Green plants and algae use about 0.1% of this energy for photosynthesis

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Solar Energy and the Natural Greenhouse Effect

- Only about 1% of total solar radiation intercepted by the earth reaches the surface.
- Most is reflected as long-wavelength infrared radiation and travels back toward space encountering greenhouse gasses (water vapor, carbon dioxide, methane, nitrous oxide, and ozone) which causes those molecules to vibrate and release IR radiation with even longer wavelengths.
- This vibration increases the molecules kinetic energy which warms the lower atmosphere and earth's surface.
- Without this, the earth would be too cold to support life.
- Human activities further add greenhouse gasses to the atmosphere.
- Clearing the rainforest further exacerbates the problem because those forests would absorb huge amounts of carbon dioxide

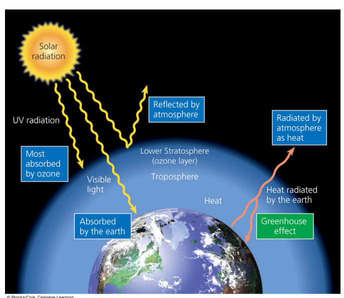

Fig. 3-8

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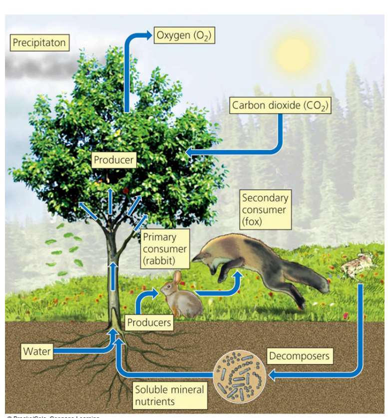
Components of Ecosystems

Fig. 3-9

- Two major components:
  - Abiotic - nonliving components
  - Biotic - living and once living components
    - Biotic factors also include dead organisms, dead parts of organisms, and waste products of organisms



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Range of Tolerance

- Range of Tolerance - ability to cope with variations in the physical and chemical environment
- Individuals within a population may have slightly different tolerances for temperature ranges because of small differences in genetic makeup, health, and age

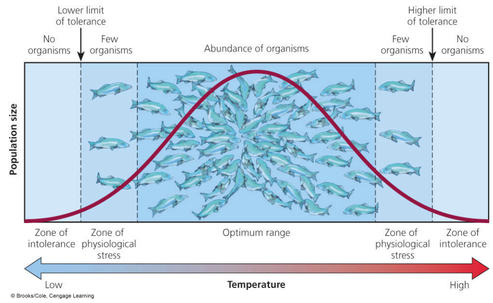

Fig. 3-10

Population Growth

- Limiting factors - abiotic factors that affects the number of organisms in a population
- Limiting factor principle - Too much or too little of any abiotic factor can limit or prevent growth of a population, even if all other factors are at or near the optimal range of tolerance
- Examples:
    - precipitation levels
    - soil nutrients
    - temperature
    - sunlight

Producers

- Trophic level - feeding level depending on its source of food and nutrients
- Producers (autotrophs) - self-feeders; make the energy they need from compounds and energy obtained from their environment
    - Most commonly plants (on land), algae (near shorelines), and phytoplankton (open ocean) that capture about 1% of the solar energy that falls on them and convert it into carbohydrates

Photosynthesis/Chemosynthesis

- Photosynthesis - producers capture sunlight to produce energy rich carbohydrates (glucose)
- Chemosynthesis - convert simple inorganic compounds into more complex compounds without using sunlight (mostly specialized bacteria)
  - Ex. extremophiles that live in geothermal vents and use hydrogen (H_2S) sulfide to survive

Types of Consumers

- Consumers (heterotrophs) - organisms that can not produce the nutrients they need and must obtain their nutrients through feeding on other organisms or their remains
- Primary Consumers (herbivores) - mostly feed on green plants
- Secondary Consumers (carnivores) - feed on the flesh of herbivores
- Tertiary Consumers (high-level consumers) - feed on the flesh of carnivores
- Omnivores - feed on both plants and animals
- Decomposers - feed on the dead bodies of plants and animals returning their bodies to the soil
- Detritus feeders (detritivores) - feed on wastes or dead bodies of other organisms

Respiration

- Aerobic Respiration - uses oxygen to to convert glucose (or other organic molecules) back into carbon dioxide and water
- Anaerobic Respiration (fermentation) - breaking down glucose in the absence of oxygen
  - The end products are usually methane gas, ethyl alcohol, acetic acid, and hydrogen sulfide

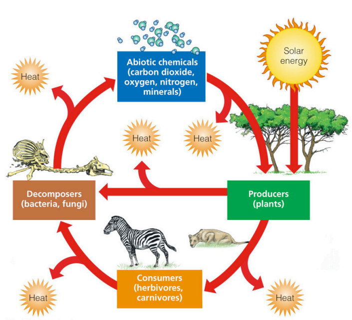

Fig. 3-12

Energy in an Ecosystem

- Food Chain - sequence of organisms in which each organism serves as a source of food or energy for the next

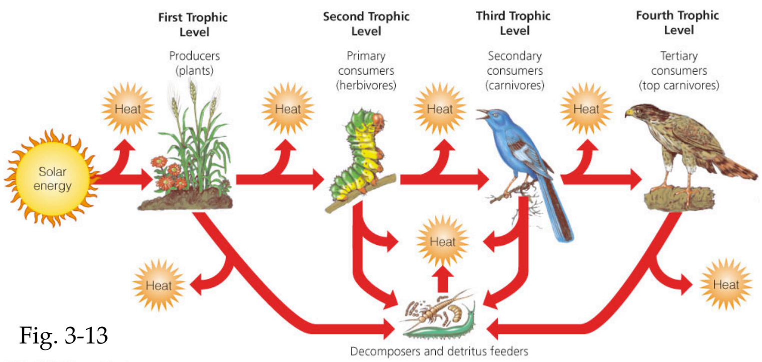

Fig. 3-13

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Energy in an Ecosystem

- Food Web - complex network of interconnected food chains

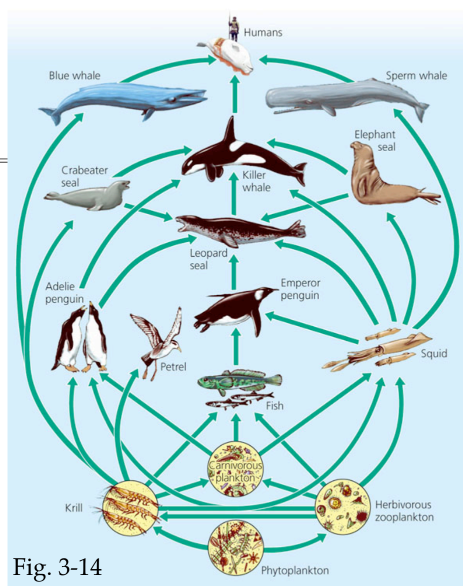

Fig. 3-14

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Usable Energy

- Biomass - the dry weight of all organic matter contained in organisms; this is what is transferred from one trophic level to another in a food chain
- Ecological Efficiency - the percentage of usable chemical energy transferred as biomass from one trophic level to another
  - This can be anywhere from 2-40% efficient (loosing 60-98%)
  - A safe bet is to assume about 10% efficiency (90% loss)

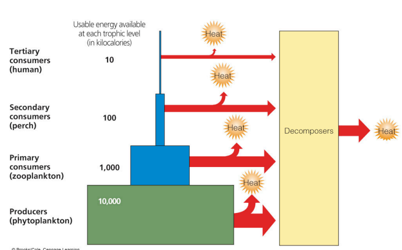

Fig. 3-15

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Productivity

- Gross Primary Productivity (GPP) - the rate at which an ecosystem's producers covert solar energy into chemical energy as biomass found in their tissues
  - Usually measured in energy production per unit area over a given time span (ex. kilocalories per square meter per year = $kcal/m^2/yr$)
- Net Primary Productivity (NPP) - 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 (NPP = GPP - R, where R is energy used in respiration)

Average NPP

- On land, NPP decreases from the equator to the poles because of the increased availability of sunlight at the equator
- In the marine habitats, NPP is highest in estuaries where nutrient levels are high, and the open ocean has the lowest because of a lack of nutrients (except at upwellings where sediments at the bottom are brought to the top). Open ocean does produce the most biomass (just because there is so much of it).
- It is estimated that humans use 20-32% of the earths NPP even though we are only 1% of the biomass.

Nutrient Cycles

- Biogeochemical Cycles (nutrient cycles) - movement of nutrients through air, water, soil, rock, and living organisms
  - Driven directly or indirectly by solar energy and gravity
  - Include: hydrologic, carbon, nitrogen, phosphorus, and sulfur
- Reservoirs - temporary storage sites (ex. atmosphere) where nutrient may accumulate

Hydrologic Cycle

- Hydrologic cycle (water cycle) - collects, purifies, and distributes the earth's fixed supply of water
  - Powered by energy from the sun. The solar energy causes **evaporation** from oceans, lakes, rivers, and soil. Evaporation changes liquid water into water vapor. Gravity then draws the water back to the earth's surface as **precipitation**.
  - 84% of water vapor in the air comes from the oceans.
  - 90% of the water that comes from the land is from **transpiration** (evaporation from the surfaces of plants)

Water Paths

- Surface Runoff - water that flows into streams and lakes which eventually goes back to the ocean
- Glaciers - usually very long term
- Aquifers (groundwater) - precipitation ends up here when it sinks through soil and permeable rock to underground layers of rock, sand, and gravel

Purification

- Evaporation and precipitation distill the water
- Water flowing above ground and below ground is naturally filtered and partially purified by chemical and biological processes (mostly by decomposer bacteria
- Only 0.024% of the earth's water is available to us as liquid freshwater

Altering the Water Cycle

- Humans draw large quantities of freshwater from lakes, streams, and underground sources (faster than nature can replace it)
- Humans clear vegetation from land for various reasons. This increases runoff, reduces infiltration that would normally recharge groundwater supplies, increase risk of flooding, and excellerates soil erosion and landslides.
  - Clearing vegetation can alter weather patterns by reducing transpiration
  - Cutting down forests increase ground temperature (reduction of shade)
- Humans increase flooding by draining wetlands for farming and other purposes and covering the land with impermeable barriers like roads and parking lots

Important Properties of Water

- Hydrogen Bonding (cohesion and adhesion)
- Liquid over wide temperature range
- Can store large amounts of heat without a large change in temperature
- Takes huge amounts of energy to evaporate because of hydrogen bonds
- Polarity allows it to dissolve many different compounds
- Filters out UV rays that would harm marine life
- Water expands when it freezes

Carbon Cycle

- Carbon cycle - the circulation of carbon through the biosphere, atmosphere, and hydrosphere
- Carbon cycle is based on CO_2 which makes up 0.038% of the volume of the atmosphere and is also dissolved in water
- If the CO_2 in the atmosphere changes even a little, it can cause huge changes in temperature.
- Producers remove CO_2 from the atmosphere through photosynthesis.
- Insoluble carbonates at the bottom of the ocean are the earth's largest store of carbon. Over millions of years, these buried deposits under high pressure and heat are converted to fossil fuels (coal, oil, and natural gas).

Nitrogen Cycle

- Major nitrogen reservoir is the atmosphere where chemically unreactive nitrogen gas (N_2) is 78% by volume.
- Nitrogen is crucial in many compounds (proteins, DNA, vitamins) but is not usable as nitrogen gas by plants or animals
- Two processes convert (fix) nitrogen into usable forms:
    - Electrical discharges in the atmosphere (lightning)
    - Nitrogen fixing bacteria

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Nitrogen Fixing Bacteria

- Combine N_2 with hydrogen to form ammonia (NH_3) which the bacteria uses and excretes the rest into the environment
- Some of the ammonia is converted to ammonium (NH_4^+) that can be used by plants
- Leftover ammonia and ammonium undergoes nitrification to nitrate ions (NO_3^-) which can be taken up by plants
- The plants then use this nitrogen to form amino acids, proteins, vitamins, and nucleic acids
- Animals will consume these plants

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Nitrogen Cycle

- Plants and animals return the nitrogen-rich organic compounds to the environment as waste and through the decomposition of their bodies
- Ammonification - specialized bacteria convert simple nitrogen containing compounds into ammonia and ammonium
- Denitrificaiton - specialized bacteria in waterlogged soil and at the bottom of lakes, oceans, swamps, and bogs convert NH_3 and NH_4^+ back into nitrate and nitrate ions and eventually into gaseous nitrogen (N_2) and nitrous oxide gas (N_2O)

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Nitrogen Cycle and Human Interaction

- Add large amount of nitric oxide (NO) into the atmosphere when N_2 and O_2 combine while burning fuel at high temperatures. This is converted to nitrogen dioxide gas (NO_2) and nitric acid vapor (HNO_3) which can return to the earth as acid rain (acid deposition)
- Add nitrous oxide (N_2O) to the atmosphere through anaerobic bacteria on animal wastes and inorganic fertilizers. These greenhouse gasses warm the atmosphere and deplete ozone.
- Release nitrogen stored in the soil and plants through deforestation and destruction of natural habitats.
- Add excess nitrates to bodies of water through agricultural runoff and sewage discharge.
- Remove nitrogen from topsoil when harvesting nitrogen-rich crops

Human Activities

- Since 1950, human activities have more than doubled the annual release of nitrogen, and it is expected to double again by 2050.

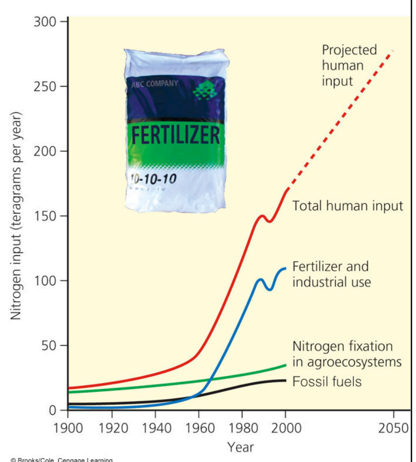

Fig. 3-20

Phosphorus Cycle

- Phosphorus is important in nucleic acids and energy carrying molecules (ADP and ATP) as well as bones and teeth.
- Phosphorus circulates through water, the earth's crust, an living organisms (does not include the atmosphere).
- Major reservoir for phosphorus is phosphate salts containing phosphate ions (PO_4^{3-}) found in rock and ocean sediments
- Water picks up the phosphate ions, and the dissolved phosphate can be taken up by plants. From there, it can be transfered up the food web.

Phosphorus as a Limiting Factor

- Phosphorus is often in low concentrations in soil so it is a limiting factor for plant growth.
- This means phosphate salts are used as inorganic fertilizers

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Phosphorus Cycle and Human Interaction

- Remove large amounts of phosphate salts from the ground for fertilizers
- Reduce phosphate in tropical soils because of clearing forests
- Soil that is eroded from fertilized crop fields carries large amounts of phosphorus into rivers, lakes, and the ocean where it stimulate the growth (overgrowth) of producers

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Sulfur Cycle

- Essential component of many proteins
- Most of earth's sulfur is stored underground in rocks and minerals and as sulfate (SO_4^{2-}) deep under the ocean sediments
- Sulfur enters the atmosphere through natural sources
  - Hydrogen sulfide (H_2S) - colorless, poisonous gas released from volcanos and organic matter broken down by anaerobic decomposers in flooded swamps, bogs, and tidal flats.
  - Sulfur dioxide (SO_2) - colorless, suffocating gas also from volcanos
  - Sulfate (SO_4^{2-}) - salt, often with ammonium; enters through the atmosphere from sea spray, dust storm, and forest fires.

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Sulfur Cycle

- Algae creates large amounts of dimethyl sulfide (DMS) which serve as a nuclei for the condensation of water into the droplets that create clouds
- In the atmosphere the DMS is converted to sulfur dioxide or sulfur trioxide and tiny droplets of sulfuric acid. When these droplets fall to the earth it is as acid rain

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Sulfur Cycle and Human Activities

- Releasing large amounts of sulfur dioxide into the atmosphere
  - Burning sulfur containing coal and oil to produce electric power
  - Refine sulfur containing petroleum to make gasoline and heating oil
  - Convert sulfur containing metallic minerals to free metals such as copper and lead.

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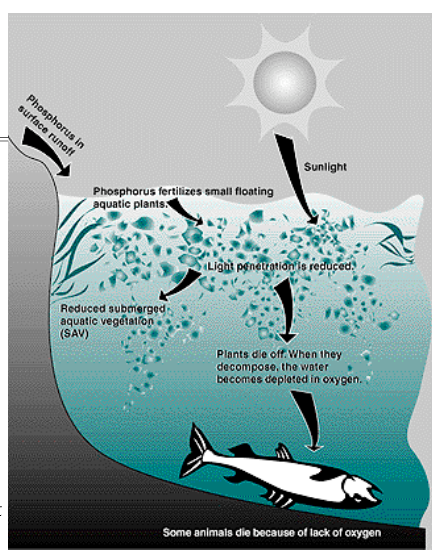
Nutrients and Eutrophication

- Eutrophication
  - Happens in agricultural and urban areas (areas with large amounts of nutrient runoff)
  - Causes extensive eutrophication
  - This leads to algal bloom
  - This leads to large amounts of O_2 consumption
  - This leads to a hypoxic environment
  - This leads to animal death



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