Chapter 54 - Ecosystems

Introduction

- An ecosystem consists of all the organisms living (biotic) in a community as well as all the abiotic factors with which they interact.
- The dynamics of an ecosystem involve two processes: energy flow and chemical cycling.

The Ecosystem Approach to Ecology

- Ecosystem ecologists view ecosystems as energy machines and matter processors.
- We can follow the transformation of energy by grouping the species in a community into trophic levels of feeding relationships.
- Trophic relationships determine the routes of energy flow and chemical cycling in an ecosystem
  - The autotrophs are the primary producers, and are usually photosynthetic (plants or algae).
    - They use light energy to synthesize sugars and other organic compounds.
  - Heterotrophs are at trophic levels above the primary producers and depend on their photosynthetic output.
    - Herbivores that eat primary producers are called primary consumers.
    - Carnivores that eat herbivores are called secondary consumers.
    - Carnivores that eat secondary producers are called tertiary consumers.
    - Another important group of heterotrophs is the detritivores, or decomposers.
      - They get energy from detritus, nonliving organic material, and play an important role in material cycling.
- Decomposition connects all trophic levels
  - The organisms that feed as detritivores often form a major link between the primary producers and the consumers in an ecosystem.
  - The organic material that makes up the living organisms in an ecosystem gets recycled.
  - An ecosystem's main decomposers are fungi and prokaryotes, which secrete enzymes that digest organic material and then absorb the breakdown products.
- The laws of physics and chemistry apply to ecosystems
  - The law of conservation of energy applies to ecosystems.
  - We can potentially trace all the energy from its solar input to its release as heat by organisms.
  - The second law of thermodynamics allows us to measure the efficiency of the energy conversions.

Primary Production in Ecosystems

- The amount of light energy converted to chemical energy by an ecosystem's autotrophs in a given time period is called primary production.
- An ecosystem's energy budget depends on primary production
  - Most primary producers use light energy to synthesize organic molecules, which can be broken down to produce ATP; there is an energy budget in an ecosystem.
  - The Global Energy Budget
    - Every day, Earth is bombarded by large amounts of solar radiation.
      - Much of this radiation lands on water and land that either reflect or absorb it.
      - Of the visible light that reaches photosynthetic organisms, only about 1% is converted to chemical energy.
      - Although this is a small amount, primary producers are capable of producing about 170 billion tons of organic material per year.
    - Gross and Net Primary Production.

Total primary production is known as gross primary production (GPP).
This is the amount of light energy that is converted into chemical energy.
The net primary production (NPP) is equal to gross primary production minus the energy used by the primary producers for respiration (R):
NPP = GPP –R
Primary production can be expressed in terms of energy per unit area per unit time, or as biomass of vegetation added to the ecosystem per unit area per unit time.
This should not be confused with the total biomass of photosynthetic autotrophs present in a given time, called the standing crop.
Different ecosystems differ greatly in their production as well as in their contribution to the total production of the Earth.

- In aquatic ecosystems, light and nutrients limit primary production

Production in Marine Ecosystems.
Light is the first variable to control primary production in oceans, since solar radiation can only penetrate to a certain depth (photic zone).
You would expect production to increase along a gradient from the poles to the equator, but that is not the case.
There are parts of the ocean in the tropics and subtropics that exhibit low primary production.
Why are tropical and subtropical oceans less productive than we would expect?
It depends on nutrient availability.
Ecologists use the term limiting nutrient to define the nutrient that must be added for production to increase.
In the open ocean, nitrogen and phosphorous levels are very low in the photic zone, but high in deeper water where light does not penetrate.
Nitrogen is the one nutrient that limits phytoplankton growth in many parts of the ocean.
Nutrient enrichment experiments show that iron availability limits primary production.
Evidence indicates that the iron factor is related to the nitrogen factor.
Marine ecologists are just beginning to understand the interplay of factors that affect primary production
Production in Freshwater Ecosystems.
Solar radiation and temperature are closely linked to primary production in freshwater lakes.
During the 1970s, sewage and fertilizer pollution added nutrients to lakes, which shifted many lakes from having phytoplankton communities to those dominated by diatoms and green algae.
This process is called eutrophication and has undesirable impacts from a human perspective.
Controlling pollution may help control eutrophication.
Experiments are being done to study this process.

- In terrestrial ecosystems, temperature, moisture, and nutrients limit primary production

Obviously, water availability varies among terrestrial ecosystems more than aquatic ones.
On a large geographic scale, temperature and moisture are the key factors controlling primary production in ecosystems.
On a more local scale, mineral nutrients in the soil can play key roles in limiting primary production.
Scientific studies relating nutrients to production have practical applications in agriculture.

Secondary Production in Ecosystems

- The amount of chemical energy in consumers' food that is converted to their own new biomass during a given time period is called secondary production.

- The efficiency of energy transfer between trophic levels is usually less than 20%
  - Production Efficiency.
    - One way to understand secondary production is to examine the process in individual organisms.
    - If we view animals as energy transformers, we can ask questions about their relative efficiencies.
    - Production efficiency = Net secondary production/Assimilation of primary production
      - Net secondary production is the energy stored in biomass represented by growth and reproduction.
      - Assimilation consists of the total energy taken in and used for growth, reproduction, and respiration.
      - In other words production efficiency is the fraction of food energy that is not used for respiration.
      - This differs between organisms.
  - Trophic Efficiency and Ecological Pyramids.
    - Trophic efficiency is the percentage of production transferred from one trophic level to the next.
    - Pyramids of production represent the multiplicative loss of energy from a food chain.
    - Biomass Pyramids represent the ecological consequence of low trophic efficiencies.
      - Most biomass pyramids narrow sharply from primary producers to top-level carnivores because energy transfers are inefficient.
      - In some aquatic ecosystems, the pyramid is inverted.
        - For example, phytoplankta grow, reproduce, and are consumed rapidly.
        - They have a short turnover time, which is a comparison of standing crop mass compared to production.
    - Pyramids of numbers show how the levels in the pyramids of biomass are proportional to the number of individuals present in each trophic level.
    - The dynamics of energy through ecosystems have important implications for the human population.
- Herbivores consume a small percentage of vegetation: the green world hypothesis
  - According to the green world hypothesis, herbivores consume relatively little plant biomass because they are held in check by a variety of factors.
    - Plants have defenses against herbivores.
    - Nutrients, not energy supply, usually limit herbivores.
    - Abiotic factors limit herbivores.
    - Intraspecific competition can limit herbivore numbers.
    - Interspecific interactions check herbivore densities.

The Cycling of Chemical Elements in Ecosystems

- Nutrient circuits involve both biotic and abiotic components of ecosystems and are called biogeochemical cycles.
- Biological and geologic processes move nutrients between organic and inorganic compartments
  - A general model of chemical cycling.
    - There are four main reservoirs of elements and processes transfer elements between reservoirs.
    - A reservoir is defined by two characteristics: whether it contains organic or inorganic materials, and whether or not the materials are directly usable by organisms.
    - Describing biogeochemical cycles in general terms is much simpler than trying to trace elements through these cycles.

One important cycle, the water cycle, does not fit the generalized scheme in figure 54.15.

The water cycle is more of a physical process than a chemical one.

The carbon cycle fits the generalized scheme of biogeochemical cycles better than water

The nitrogen cycle.

Nitrogen enters ecosystems through two natural pathways.

Atmospheric deposition, where usable nitrogen is added to the soil by rain or dust.

Nitrogen fixation, where certain prokaryotes convert N_2 to minerals that can be used to synthesize nitrogenous organic compounds like amino acids.

In addition to the natural ways, industrial production of nitrogen-containing fertilizer contributes to nitrogenous materials in ecosystems.

The direct product of nitrogen fixation is ammonia, which picks up $H+$ and becomes ammonium in the soil (ammonification), which plants can use.

Certain aerobic bacteria oxidize ammonium into nitrate, a process called nitrification.

Nitrate can also be used by plants.

Some bacteria get oxygen from the nitrate and release N_2 back into the atmosphere (denitrification).

The phosphorous cycle.

Organisms require phosphorous for many things.

This cycle is simpler than the others because phosphorous does not come from the atmosphere.

Phosphorus occurs only in phosphate, which plants absorb and use for organic synthesis.

Humus and soil particles bind phosphate, so the recycling of it tends to be localized.

- Decomposition rates largely determine the rates of nutrient cycling

The rates at which nutrients cycle in ecosystems are extremely variable as a result of variable rates of decomposition.

Decomposition can take up to 50 years in the tundra, while in the tropical forest, it can occur much faster.

Contents of nutrients in the soil of different ecosystems vary also, depending on the rate of absorption by the plants.

- Nutrient cycling is strongly regulated by vegetation

Long-term ecological research (LTER) monitors the dynamics of ecosystems over long periods of time.

The Hubbard Brook Experimental Forest has been studied since 1963.

Preliminary studies confirmed that internal cycling within a terrestrial ecosystem conserves most of the mineral nutrients.

Some areas have been completely logged and then sprayed with herbicides to study how removal of vegetation affects the nutrient content of the soil.

In addition to the natural ways, industrial production of nitrogen-containing fertilizer contributes to nitrogenous materials in ecosystems.

Human Impact on Ecosystems and the Biosphere

- The human population is disrupting chemical cycles throughout the biosphere

Human activity intrudes in nutrient cycles by removing nutrients from one part of the biosphere and then adding them to another.

Agricultural effects of nutrient cycling.

In agricultural ecosystems, a large amount of nutrients are removed from the area in the crop biomass.

After a while, the natural store of nutrients can become exhausted.

Recent studies indicate that human activities have approximately doubled the worldwide supply of fixed nitrogen, due to the use of fertilizers, cultivation of legumes, and burning.

This may increase the amount of nitrogen oxides in the atmosphere and contribute to atmospheric warming, depletion of ozone, and possibly acid rain.

Critical load and nutrient cycles.

In some situations, the addition of nitrogen to ecosystems by human activity can be beneficial, but in others it can cause problems.

The key issue is the critical load, the amount of added nitrogen that can be absorbed by plants without damaging the ecosystem.

Accelerated eutrophication of lakes.

Human intrusion has disrupted freshwater ecosystems by what is called cultural eutrophication.

Sewage and factory wastes and runoff of animal wastes from pastures and stockyards have overloaded many freshwater streams and lakes with nitrogen.

This can eliminate fish species because it is difficult for them to live in these new conditions.

- Combustion of fossil fuels is the main cause of acid precipitation

The burning of fossil fuels releases sulfur oxides and nitrogen that react with water in the atmosphere to produce sulfuric and nitric acids.

These acids fall back to earth as acid precipitation, and can damage ecosystems greatly.

By changing the pH of the soil and water, the acids can kill plants and aquatic organisms.

- Toxins can become concentrated in successive trophic levels of food webs

Humans produce many toxic chemicals that are dumped into ecosystems.

These substances are ingested and metabolized by the organisms in the ecosystems and can accumulate in the fatty tissues of animals.

These toxins become more concentrated in successive trophic levels of a food web, a process called biological magnification.

The pesticide DDT, before it was banned, provided an example of biological magnification.

- 4. Human activities may be causing climate change by increasing carbon dioxide concentration in the atmosphere

Rising atmospheric CO_2.

Since the Industrial Revolution, the concentration of CO_2 in the atmosphere has increased greatly as a result of burning fossil fuels.

Measurements in 1958 read 316 ppm and have increased to 370 ppm today

The greenhouse effect.

Rising levels of atmospheric CO_2 may have an impact on Earth's heat budget.

When light energy hits the Earth, much of it is reflected off the surface.

CO_2 causes the Earth to retain some of the energy that would ordinarily escape the atmosphere.

This phenomenon is called the greenhouse effect.

The Earth needs this heat, but too much could be disastrous.

Global warming.

Scientists continue to construct models to predict how increasing levels of CO_2 in the atmosphere will affect Earth.

Several studies predict a doubling of CO_2 in the atmosphere will cause a 2° C increase in the average temperature of Earth.

Rising temperatures could cause polar ice cap melting, which could flood coastal areas.

It is important that humans attempt to stabilize their use of fossil fuels.

- Human activities are depleting the atmospheric ozone
- Life on earth is protected from the damaging affects of ultraviolet radiation (UV) by a layer of O_3, or ozone.

Studies suggest that the ozone layer has been gradually “thinning” since 1975.

The destruction of ozone probably results from the accumulation of chlorofluorocarbons, chemicals used in refrigeration and aerosol cans, and in certain manufacturing processes.

- The result of a reduction in the ozone layer may be increased levels of UV radiation that reach the surface of the Earth.
- This radiation has been linked to skin cancer and cataracts.

The impact of human activity on the ozone layer is one more example of how much we are able to disrupt ecosystems and the entire biosphere.