The Concept of the Ecosystem

"I bequeathe myself to the dirt, to grow from the grass I love;
If you want me again, look for me under your boot-soles."
- Walt Whitman

In this lesson, we will learn answers to the following questions:

- What is an ecosystem, and how can we study one?
- Is the earth an open or closed system with respect to energy and elements?
- How do we define "biogeochemical cycles," and how are they important to ecosystems?
- What are the major controls on ecosystem function?
- What are the major factors responsible for the differences between ecosystems?

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Introduction - What is an Ecosystem?

An ecosystem consists of the biological community that occurs in some locale, and the physical and chemical factors that make up its non-living or abiotic environment. There are many examples of ecosystems -- a pond, a forest, an estuary, a grassland. The boundaries are not fixed in any objective way, although sometimes they seem obvious, as with the shoreline of a small pond. Usually the boundaries of an ecosystem are chosen for practical reasons having to do with the goals of the particular study.

The study of ecosystems mainly consists of the study of certain processes that link the living, or biotic, components to the non-living, or abiotic, components. ***Energy transformations*** and ***biogeochemical cycling*** are the main processes that comprise the field of ecosystem ecology. As we learned earlier, ecology generally is defined as the interactions of organisms with one another and with the environment in which they occur. We can study ecology at the level of the individual, the population, the community, and the ecosystem.

Studies of ***individuals*** are concerned mostly about physiology, reproduction, development or behavior, and studies of ***populations*** usually focus on the habitat and resource needs of individual species, their group behaviors, population growth, and what limits their abundance or causes extinction. Studies of ***communities*** examine how populations of many species interact with one another, such as predators and their prey, or competitors that share common needs or resources.

In ***ecosystem ecology*** we put all of this together and, insofar as we can, we try to understand how the system operates as a whole. This means that, rather than worrying mainly about particular species, we try to focus on major functional aspects of the system. These ***functional aspects*** include such things as the amount of energy that is produced by photosynthesis, how energy or materials flow along the many steps in a food chain, or what controls the rate of decomposition of materials or the rate at which nutrients are recycled in the system.

Components of an Ecosystem

You are already familiar with the parts of an ecosystem. You have learned about climate and soils from past lectures. From this course and from general knowledge, you have a basic understanding of the diversity of plants and animals, and how plants and animals and microbes obtain water, nutrients, and food. We can clarify the parts of an ecosystem by listing them under the headings "abiotic" and "biotic".

ABIOTIC COMPONENTS	BIOTIC COMPONENTS
Sunlight	Primary producers
Temperature	Herbivores

Precipitation
Water or moisture
Soil or water chemistry (e.g., P, NH_4+)
etc.

Carnivores
Omnivores
Detritivores
etc.

All of these vary over space/time

By and large, this set of environmental factors is important almost everywhere, in all ecosystems.

Usually, biological communities include the "functional groupings" shown above. A ***functional group*** is a biological category composed of organisms that perform mostly the same kind of function in the system; for example, all the photosynthetic plants or primary producers form a functional group. Membership in the functional group does not depend very much on who the actual players (species) happen to be, only on what function they perform in the ecosystem.

Processes of Ecosystems

This figure with the plants, zebra, lion, and so forth illustrates the two main ideas about how ecosystems function: ***ecosystems have energy flows*** and ***ecosystems cycle materials***. These two processes are linked, but they are not quite the same (see Figure 1).

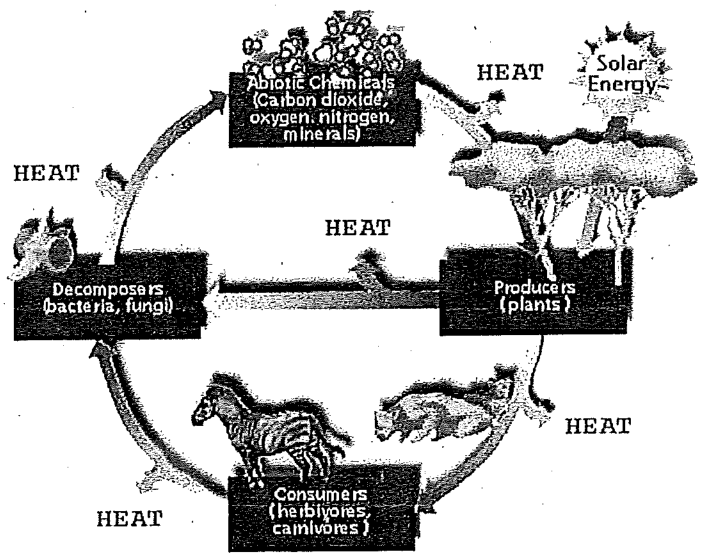

Figure 1. Energy flows and material cycles.

Energy enters the biological system as light energy, or photons, is transformed into chemical energy in organic molecules by cellular processes including photosynthesis and respiration, and ultimately is converted to heat energy. This energy is dissipated, meaning it is lost to the system as heat; once it is lost it cannot be recycled. Without the continued input of solar energy, biological systems would quickly shut down. Thus the earth is an ***open system*** with respect to energy.

Elements such as carbon, nitrogen, or phosphorus enter living organisms in a variety of ways. Plants obtain elements from the surrounding atmosphere, water, or soils. Animals may also obtain elements directly from the physical environment, but usually they obtain these mainly as a consequence of consuming other organisms. These materials are transformed biochemically within the bodies of organisms, but sooner or later, due to excretion or decomposition, they are returned to an inorganic state. Often bacteria complete this process, through the process called decomposition or mineralization (*see previous lecture on microbes*).

During decomposition these materials are not destroyed or lost, so the earth is a ***closed system*** with respect to elements (with the exception of a meteorite entering the system now and then). The elements are cycled endlessly between their biotic and abiotic states within ecosystems. Those elements whose supply tends to limit biological activity are called ***nutrients***.

The Transformation of Energy

The transformations of energy in an ecosystem begin first with the input of energy from the sun. Energy from the sun is captured by the process of photosynthesis. Carbon dioxide is combined with hydrogen (derived from the splitting of water molecules) to produce carbohydrates (CHO). Energy is stored in the high energy bonds of adenosine triphosphate, or ATP (see lecture on photosynthesis).

The prophet Isaah said "all flesh is grass", earning him the title of first ecologist, because virtually all energy available to organisms originates in plants. Because it is the first step in the production of energy for living things, it is called ***primary production*** *(click here for a primer on photosynthesis)*. ***Herbivores*** obtain their energy by consuming plants or plant products, ***carnivores*** eat herbivores, and ***detritivores*** consume the droppings and carcasses of us all.

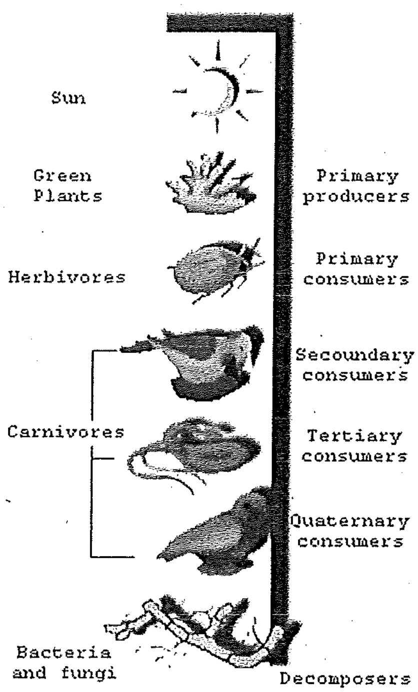

Figure 2 portrays a simple food chain, in which energy from the sun, captured by plant photosynthesis, flows from ***trophic level*** to trophic level via the ***food chain***. A trophic level is composed of organisms that make a living in the same way, that is they are all ***primary producers*** (plants), ***primary consumers*** (herbivores) or ***secondary consumers*** (carnivores). Dead tissue and waste products are produced at all levels. Scavengers, detritivores, and decomposers collectively account for the use of all such "waste" -- consumers of carcasses and fallen leaves may be other animals, such as crows and beetles, but ultimately it is the microbes that finish the job of decomposition. Not surprisingly, the amount of primary production varies a great deal from place to place, due to differences in the amount of solar radiation and the availability of nutrients and water.

For reasons that we will explore more fully in subsequent lectures, ***energy transfer through the food chain is inefficient.*** This means that less energy is available at the herbivore level than at the primary producer level, less yet at the carnivore level, and so on. The result is a pyramid of energy, with important implications for understanding the quantity of life that can be supported.

Usually when we think of food chains we visualize green plants, herbivores, and so on. These are referred to as ***grazer food chains***, because living plants are directly consumed. In many circumstances the principal energy input is not green plants but dead organic matter. These are called ***detritus food chains***. Examples include the forest floor or a woodland stream in a forested area, a salt marsh, and most obviously, the ocean floor in very deep areas where all sunlight is extinguished 1000's of meters above. In subsequent lectures we shall return to these important issues concerning energy flow.

Finally, although we have been talking about food chains, in reality the organization of biological systems is much more complicated than can be represented by a simple "chain". There are many food links and chains in an ecosystem, and we refer to all of these linkages as a ***food web***. Food webs can be very complicated, where it appears that ***"everything is connected to everything else"***, and it is important to understand what are the most important linkages in any particular food web.

Biogeochemistry

How can we study which of these linkages in a food web are most important? One obvious way is to study the flow of energy or the cycling of elements. For example, the cycling of elements is controlled in part by organisms, which store or transform elements, and in part by the chemistry and geology of the natural world. The term ***Biogeochemistry*** is defined as the study of how living systems influence, and are controlled by, the geology and chemistry of the earth. Thus biogeochemistry encompasses many aspects of the abiotic and biotic world that we live in.

There are several main ***principles and tools*** that biogeochemists use to study earth systems. Most of the major environmental problems that we face in our world toady can be analyzed using biogeochemical principles and tools. These problems include global warming, acid rain, environmental pollution, and increasing greenhouse gases. The principles and tools that we use can be broken down into 3 major components: ***element ratios, mass balance, and element cycling***.

1. Element ratios

In biological systems, we refer to important elements as ***"conservative"***. These elements are often nutrients. By "conservative" we mean that an organism can change only slightly the amount of these elements in their tissues if they are to remain in good health. It is easiest to think of these conservative elements in relation to other important elements in the organism. For example, in healthy algae the elements C, N, P, and Fe have the following ratio, called the ***Redfield ratio*** after the oceanographer who discovered it:

C : N : P : Fe = 106 : 16 : 1 : 0.01

Once we know these ratios, we can compare them to the ratios that we measure in a sample of algae to determine if the algae are lacking in one of these limiting nutrients.

2. Mass Balance

Another important tool that biogeochemists use is a simple mass balance equation to describe the state of a system. The system could be a snake, a tree, a lake, or the entire globe. Using a mass balance approach we can determine whether the system is changing and how fast it is changing. The equation is:

NET CHANGE = INPUT + OUTPUT + INTERNAL CHANGE

In this equation the net change in the system from one time period to another is determined by what the inputs are, what the outputs are, and what the internal change in the system was. The example given in class is of the acidification of a lake, considering the inputs and outputs and internal change of acid in the lake.

3. Element Cycling

Element cycling describes where and how fast elements move in a system. There are two general classes of systems that we can analyze, as mentioned above: ***closed and open systems.***

*A **closed system** refers to a system where the inputs and outputs are negligible compared to the internal changes. Examples of such systems would include a bottle, or our entire globe. There are two ways we can describe the cycling of materials within this closed system, either by looking at the rate of movement or at the pathways of movement.*

1. ***Rate*** *= number of cycles / time * as rate increases, productivity increases*
2. ***Pathways****-important because of different reactions that may occur*

*In an **open system** there are inputs and outputs as well as the internal cycling. Thus we can describe the rates of movement and the pathways, just as we did for the closed system, but we can also define a new concept called the **residence time**. The residence time indicates how long on average an element remains within the system before leaving the system.*

1. ***Rate***
2. ***Pathways***

3. ***Residence time, Rt***

Rt *= total amount of matter / output rate of matter*

(Note that the "units" in this calculation must cancel properly)

Controls on Ecosystem Function

Now that we have learned something about how ecosystems are put together and how materials and energy flow through ecosystems, we can better address the question of "what controls ecosystem function"? There are two dominant theories of the control of ecosystems. The first, called **bottom-up control**, states that it is the nutrient supply to the primary producers that ultimately controls how ecosystems function. If the nutrient supply is increased, the resulting increase in production of autotrophs is propagated through the food web and all of the other trophic levels will respond to the increased availability of food (energy and materials will cycle faster).

The second theory, called **top-down control**, states that predation and grazing by higher trophic levels on lower trophic levels ultimately controls ecosystem function. For example, if you have an increase in predators, that increase will result in fewer grazers, and that decrease in grazers will result in turn in more primary producers because fewer of them are being eaten by the grazers. Thus the control of population numbers and overall productivity "cascades" from the top levels of the food chain down to the bottom trophic levels.

So, which theory is correct? Well, as is often the case when there is a clear dichotomy to choose from, the answer lies somewhere in the middle. There is evidence from many ecosystem studies that BOTH controls are operating to some degree, but that NEITHER control is complete. For example, the "top-down" effect is often very strong at trophic levels near to the top predators, but the control weakens as you move further down the food chain. Similarly, the "bottom-up" effect of adding nutrients usually stimulates primary production, but the stimulation of secondary production further up the food chain is less strong or is absent.

Thus we find that both of these controls are operating in any system at any time, and we must understand the relative importance of each control in order to help us to predict how an ecosystem will behave or change under different circumstances, such as in the face of a changing climate.

The Geography of Ecosystems

There are many different ecosystems: rain forests and tundra, coral reefs and ponds, grasslands and deserts. Climate differences from place to place largely determine the types of ecosystems we see. How terrestrial ecosystems appear to us is influenced mainly by the dominant vegetation.

The word "biome" is used to describe a major vegetation type such as tropical rain forest, grassland, tundra, etc., extending over a large geographic area (Figure 3). It is never used for aquatic systems, such as ponds or coral reefs. It always refers to a vegetation category that is dominant over a very large geographic scale, and so is somewhat broader than an ecosystem.

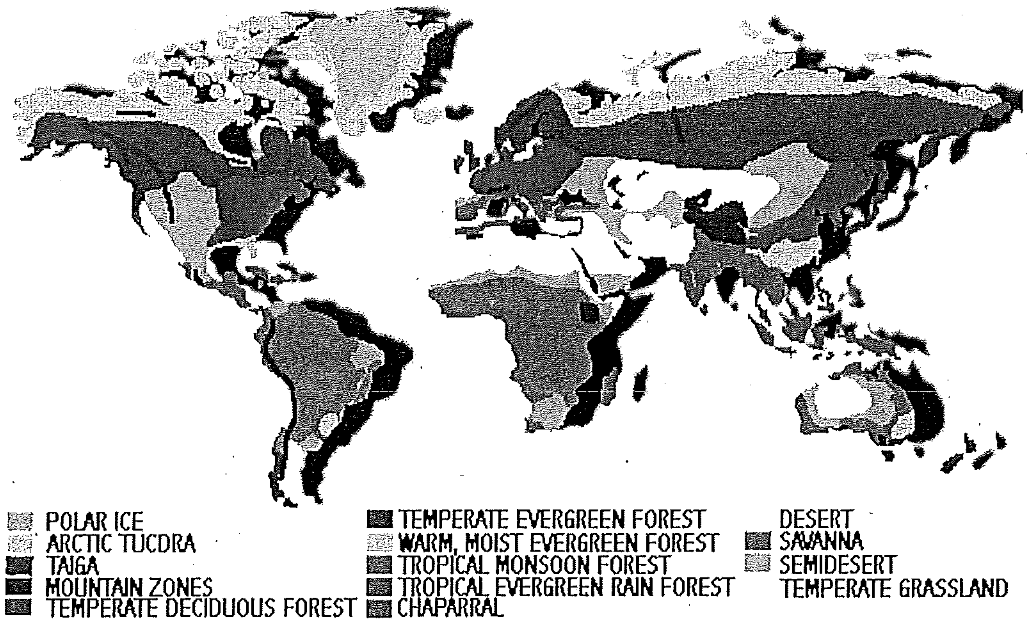

Figure 3: The distribution of biomes.

We can draw upon previous lectures to remember that temperature and rainfall patterns for a region are distinctive. Every place on earth gets the same total number of hours of sunlight each year, but not the same amount of heat. The sun's rays strike low latitudes directly but high latitudes obliquely. This uneven distribution of heat sets up not just temperature differences, but global wind and ocean currents that in turn have a great deal to do with where rainfall occurs. Add in the cooling effects of elevation and the effects of land masses on temperature and rainfall, and we get a complicated global pattern of climate.

A schematic view of the earth shows that, complicated though climate may be, many aspects are predictable (Figure 4). High solar energy striking near the equator ensures nearly constant high temperatures and high rates of evaporation and plant transpiration. Warm air rises, cools, and sheds its moisture, creating just the conditions for a tropical rain forest. Contrast the stable temperature but varying rainfall of a site in Panama with the relatively constant precipitation but seasonally changing temperature of a site in New York State. Every location has a rainfall-temperature graph that is typical of a broader region.

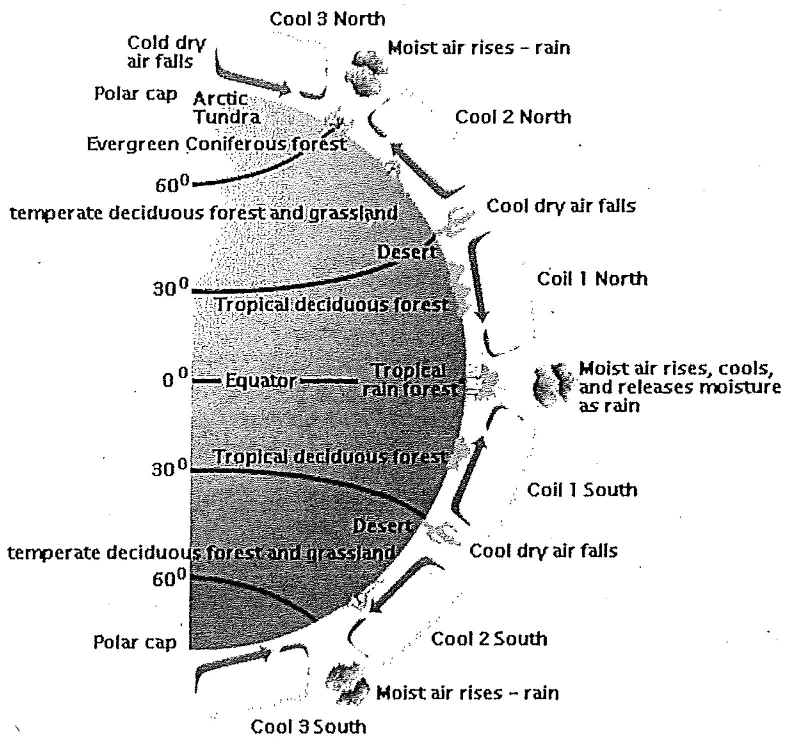

Figure 4. Climate patterns affect biome distributions.

We can draw upon plant physiology to know that certain plants are distinctive of certain climates, creating the vegetation appearance that we call biomes. Note how well the distribution of biomes plots on the distribution of climates (Figure 5). Note also that some climates are impossible, at least on our planet. High precipitation is not possible at low temperatures -- there is not enough solar energy to power the water cycle, and most water is frozen and thus biologically unavailable throughout the year. The high tundra is as much a desert as is the Sahara.

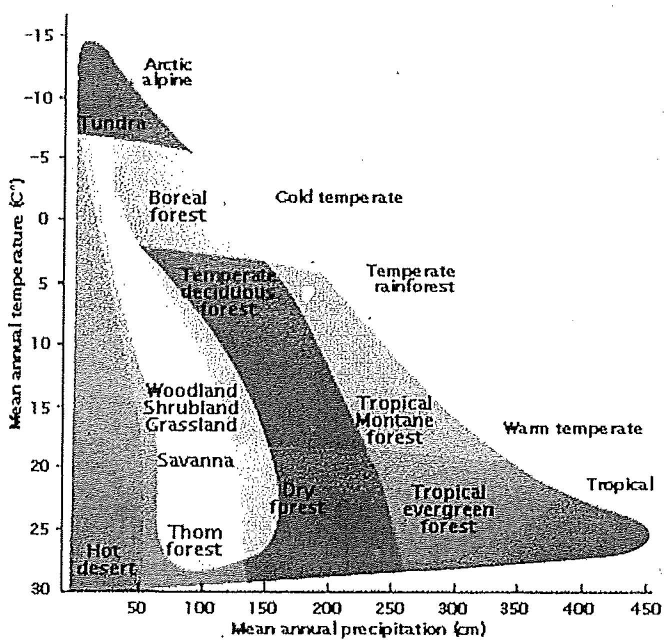

Figure 5. The distribution of biomes related to temperature and precipitation.

Summary

- Ecosystems are made up of abiotic (non-living, environmental) and biotic components, and these basic components are important to nearly all types of ecosystems. Ecosystem Ecology looks at energy transformations and biogeochemical cycling within ecosystems.
- Energy is continually input into an ecosystem in the form of light energy, and some energy is lost with each transfer to a higher trophic level. Nutrients, on the other hand, are recycled within an ecosystem, and their supply normally limits biological activity. So, "energy flows, elements cycle".
- Energy is moved through an ecosystem via a food web, which is made up of interlocking food chains. Energy is first captured by photosynthesis (primary production). The amount of primary production determines the amount of energy available to higher trophic levels.
- The study of how chemical elements cycle through an ecosystem is termed biogeochemistry. A biogeochemical cycle can be expressed as a set of stores (pools) and transfers, and can be studied using the concepts of "stoichiometry", "mass balance", and "residence time".
- Ecosystem function is controlled mainly by two processes, "top-down" and "bottom-up" controls.
- A biome is a major vegetation type extending over a large area. Biome distributions are determined largely by temperature and precipitation patterns on the Earth's surface.

Review and Self Test

- Review of main terms and concepts in this lecture.
- Self-Test for this lecture.

Suggested Readings:

- Borman, F.H. and G.E. Likens. 1970. "The nutrient cycles of an ecosystem." *Scientific American,* October 1970, pp 92-101.
- Wessells, N.K. and J.L. Hopson. 1988. *Biology.* New York: Random House. Ch. 44.