CHAPTER 11

LIMITING FACTORS; ENERGY FLOW; AND NUTRIENT CYCLING

11. 1. INTRODUCTION

At first glance a forest and a grassy field appear very different. What a contrast there is between the imposing trees of the forest and the small herbs and grasses of the open field!

Even a closer look at the forest and field reveals only a few species common to both. Shade-tolerant ferns cover the forest floor. Lizards and skinks are numerous. Birds abound in the trees. Sun-tolerant herbs and grasses, numerous butterflies, and active grasshoppers are characteristic of the grassy field. Many birds also live in the open field, but these species are generally quite different from those in the forest.

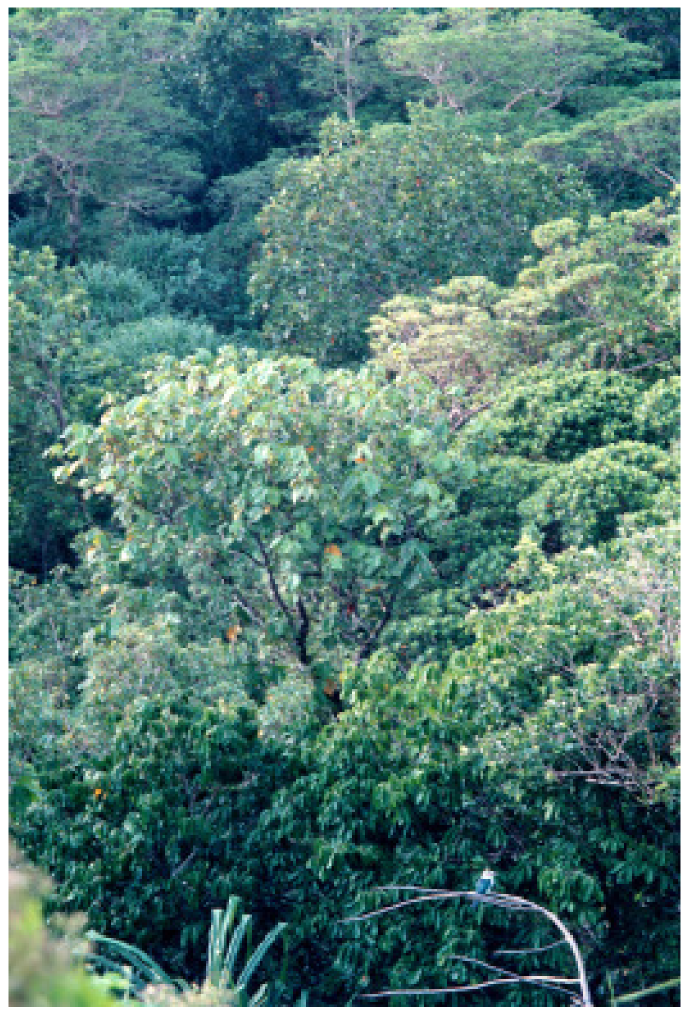
In spite of these differences, there are many close similarities between the forest and the grassy field. Through photosynthesis, trees and other green plants of the forest provide food for organisms such as insects and fruit doves, which are unable to manufacture their own food. The grasses and herbs of the open field similarly provide food for grasshoppers, mice, and other non-photosynthetic organisms.

Shelter for thousands of organisms is another necessity provided by the trees of the forest and the grasses and herbs of the open field.

Do not think, however, that the plants of the forest or meadow are independent of the animals they feed and shelter. The plants are almost as dependent on the animals as the animals are on the plants.

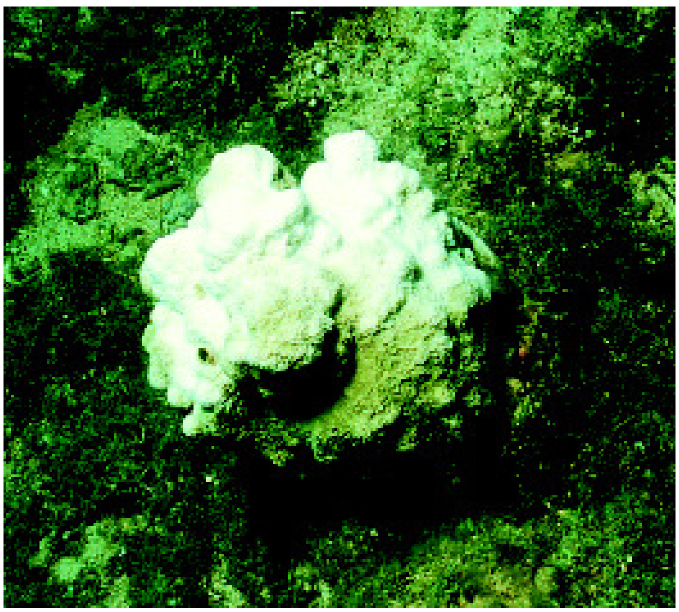
Ecology is the study of the relationships among organisms, and between organisms and their environments. It is characteristic of any science to have a few key concepts that are the product of many observations.

Even though ecology is a young science, its key concepts have been clearly defined. We must know some of these basic concepts or principles before we start our field studies. Can we define **community**, **ecosystems**, and **niche**? The following sections explain these ideas.



Within any given ecosystem, plants are almost as dependent on the animals as the animals are on the plants.

A fire set upon the savanna...



may have potentially negative consequences for nearby reefs.

The producers (green plants) of the ecosystem use light energy to form organic compounds called carbohydrates.

11. 2. THE ECOSYSTEM CONCEPT

This section summarizes one of the most important ideas of science, the **ecosystem concept**. Read it carefully, since it is the base upon which we will build our understanding of the complex but exciting interactions occurring in the ecosystems here in our islands and our surrounding seas.

Ecologists call any naturally occurring group of organisms (plants, animals, and protists) living in a particular habitat, which depend on and sustain each other, a **biotic** (living) community. It is influenced by and dependent upon **abiotic** (non-living) factors. These include sunlight, soil, topography, wind, temperature, moisture, and minerals.

The interaction of biotic and abiotic factors creates an *ecosystem*. A forest is an ecosystem, as is a pond, an open field, and a classroom aquarium.

The interacting factors within an ecosystem are marvelously interconnected. They are so interrelated that if only one vital factor changes, the entire ecosystem could be destroyed. Consider how complex an ecosystem must be that has hundreds of different plant and animal species!

Suppose a deer hunter wants deer to be easier to find. The hunter might (illegally) set fire to a savanna area to clear away the old grass. New grass shoots then sprout up. This encourages deer to leave their home forest and feed on the young grass. The hunter easily anticipates where to find the deer and they are now easy targets.

What effects will this have on the savanna ecosystem? For a long time there would be no grass for grasshoppers to eat. The starvation of these insects will affect the animals that prey on them, such as reed warblers, bitterns, and lizards.

Severe soil erosion will occur, since the grass is no longer present to absorb the energy of a heavy rainfall. When the soil erodes, many other plant species, such as savanna ferns and orchids, will disappear. The animals that eat these plants will move away or die of starvation.

The chain of events that occurs when one factor in an ecosystem is altered is long and involved. However, it is certain to occur.

Try now to imagine further changes that would occur when savanna areas are burned. Would the burning affect neighboring ecosystems? Would a nearby stream, pond, or marine area change as a result of burning the savanna?

What about wetlands that are downslope from the savanna? Sediment from upland erosion can choke these ecosystems. At greatest risk is our fragile coral reef ecosystem. Sediments can destroy reefs completely, and have already done so in some areas. Can anyone predict the long-term effects of these changes? Yes, in fact, each one of us can. First, we must understand how the different parts of an ecosystem function and interact.

11. 3. THE STRUCTURE OF ECOSYSTEMS

Let us begin by considering the basic similarities in the biotic structure of ecosystems. In any ecosystem, there is a continual demand for energy. Plants, animals, and protists require energy to sustain life processes. The sun supplies this energy in the form of light.

The **producers** (green plants) of the ecosystem use the light energy to form high energy organic compounds called **carbohydrates**. These compounds are formed from two basic inorganic compounds, water and carbon dioxide.

The process by which plants do this is called **photosynthesis**. “Photo” means “light” and “synthesis” means “putting together.” Producers then use the formed high energy compounds for their growth and metabolism. This is why biologists call producers **autotrophic** (self-feeding) organisms.

Ecosystems also have **heterotrophic** (other-feeding) organisms. Biologists call these **consumers** since they eat plants or other animals for nourishment. **Zoologists**, biologists who study animals, call animals that eat plants, **herbivores** (plant-eaters). Biologists who specialize in the study of plants are called **botanists**.

Herbivores are also called first-order consumers. This is because they obtain their energy requirements by feeding directly on producers. Deer and grasshoppers are both herbivores and first-order consumers.

Animals that eat other animals are called **carnivores** (flesh-eaters). Those carnivores that feed on herbivores are called first-order carnivores. They are also called second-order consumers.

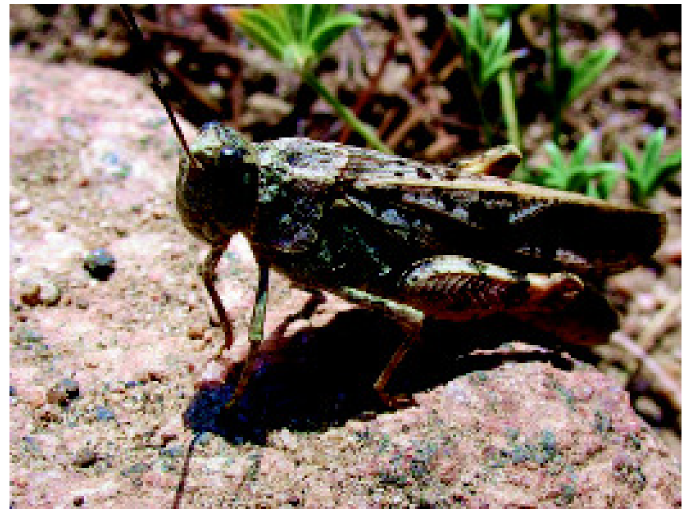
Our smaller lizards and our grasshopper-eating reed warblers are first-order carnivores. They obtain their energy from producers indirectly.

Third-order consumers (second-order carnivores) are also present in many ecosystems. What are some local third-order consumers? Examples might include our collared kingfisher, which eats small lizards, among other prey. Teachers and students on an NMC field trip to Goat Island (Aguiguan) found that our collard kingfishers take live forest birds as prey as well. It was a discovery new to science.

Many ecosystems also have a **top carnivore**. What do you think zoologists mean by this term? Here the monitor lizard, *Varanus indicus,* would be a likely candidate for this role. Read about this organism in the Forest chapter (Ch. 19).

Savanna grass is food for the grasshopper. The grasshopper, in turn, is food for the reed warbler. A reed warbler might fall prey to a monitor lizard. We can summarize this statement in the following way:

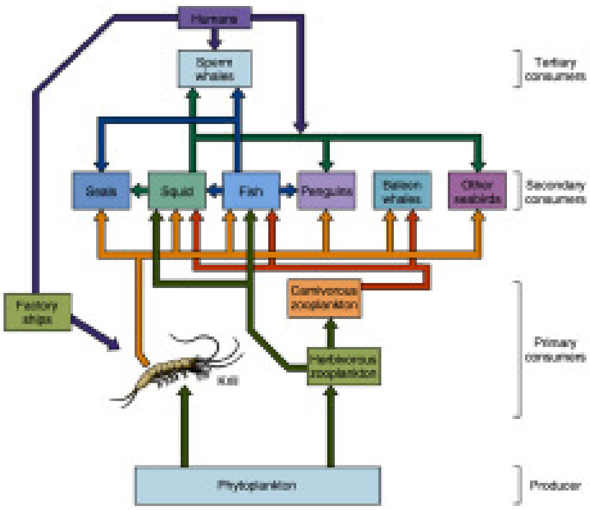
1000 Individuals		100 Individuals		10 Individuals		1 Individual
Savanna Grass	→	Grasshopper	→	Reed Warbler	→	Monitor Lizard



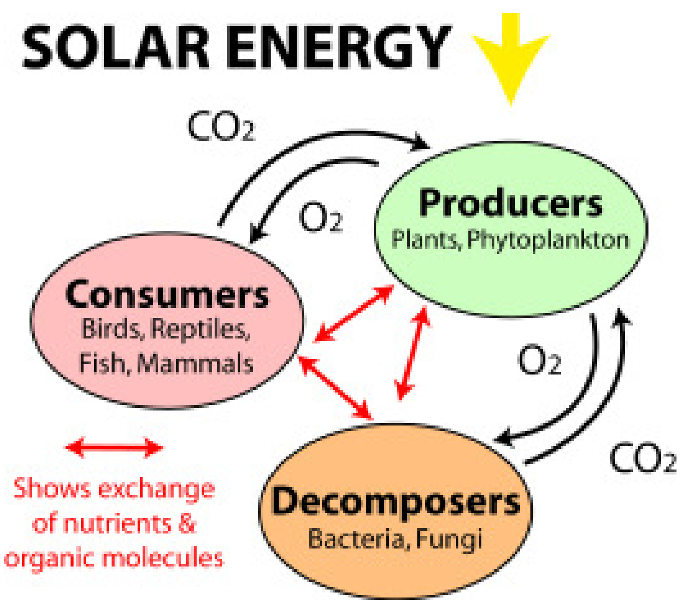
Herbivores eat plants for nourishment...

...while animals that eat other animals are called carnivores.

The monitor lizard, Varanus indicus, is a top-level carnivore.



A complex pattern like a food web is one of many highly integrated relationships that occur among the organisms of an ecosystem.



The four basic parts of an ecosystem are a source of energy, the producers, the consumers, and the decomposers.

This is a **food chain**. Most animals, however, have several sources of food. For example, monitor lizards also eat other lizards, large insects, mice, young rats, bird eggs, etc. Reed warblers likewise vary their diet, including insects other than grasshoppers. They even eat small lizards. Food chains, then, are not very distinct. Instead, they interconnect to form a **food web**.

Each species—grass, grasshopper, reed warbler, and monitor lizard—has a function or **niche** in the food chain. In this case, the niches are, respectively, producer, herbivore, and carnivore.

Some species do not have only one particular niche in the food web. Some may have many. For instance, our local Polynesian rat may be a *carnivore* when it feeds on a bird nestling. However, when it eats a farmer's vegetable crops, it is an *herbivore*. Zoologists use the term **omnivore** (many feeding) to describe this sort of niche.

A complex pattern like a food web is one of many highly integrated relationships that occur among the organisms of an ecosystem.

Another group of organisms common to all ecosystems is called the **decomposers**. These are specialized consumers that feed on dead organic matter. They return basic substances, including minerals and water, to the soil.

Most decomposers are tiny organisms, such as microscopic fungi and bacteria. But many insects and *all* fungi, including the larger mushroom species, are also decomposers.

Producers, consumers, and decomposers are all necessary biological parts of any ecosystem. Within each ecosystem, however, quite different organisms might carry out these roles. What are the producers, consumers, and decomposers for a forest, an open field, a coral reef, and a wetland marsh? These answers will become clear as you read through the chapters of this unit and the next.

Ecologists refer to the types of organisms present in an ecosystem as that ecosystem's **biodiversity**. Other differences in the biotic structure of ecosystems include population numbers, population distribution, and population growth.

Now, let us consider briefly the abiotic structure of ecosystems. All ecosystems require the same nutrients. They need the chemical elements carbon, nitrogen, oxygen, and hydrogen, along with several others in lesser amounts.

Also, all ecosystems are regulated by physical factors such as temperature, moisture, light, wind, and soil type. How these factors vary, and how the populations of organisms within each ecosystem adapt to them, are other important aspects of an area's ecology.

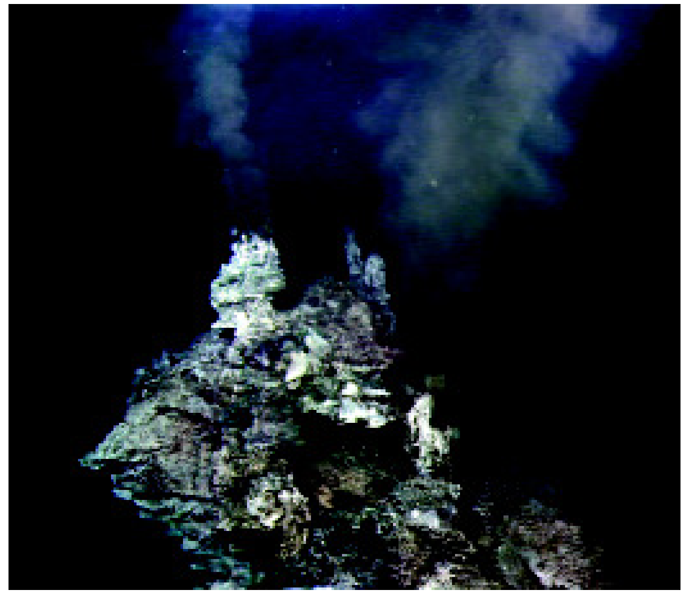
To summarize, the four basic parts of an ecosystem are a source of energy, the producers, the consumers, and the decomposers.

11. 4. THE FUNCTIONING OF ECOSYSTEMS

No ecosystem is static. Energy and nutrients are flowing continuously through an ecosystem. Ecologists measure the functioning of an ecosystem by the rates of energy flow and nutrient cycling. It is not easy, however, to measure such rates. Because of this problem, the study of the functioning of ecosystems has lagged behind the study of their structure.

Since energy is gradually lost along a food chain through **respiration** by the cells of the plants and animals, the flow of energy is one-way. Little, if any, energy recycles. In other words, the organisms at the end of a food chain do not return appreciable quantities of energy to the producers. As a result of this one-way flow, energy must continuously enter all ecosystems to replace the energy that is lost along food chains.

In almost all natural ecosystems, this energy comes from the sun. In one notable exception to this rule, there is a community of life forms in the deep ocean, called **chemo-autotrophic** organisms. These organisms live off of the chemical energy from deep ocean thermal vents located at undersea rift zones (see the chapter on open ocean ecology, Ch. 12).



Chemo-autotrophic organisms live off of the chemical energy from deep ocean thermal vents located at undersea rift zones.

Nutrients, on the other hand, do continuously recycle. The decomposers in the soil break down organic matter from plants and animals, releasing mineral nutrients. The roots of plants then absorb these nutrients. If it were not for the decomposers, the flow of nutrients would also be one-way.

11. 5. HUMAN EFFECTS ON ECOSYSTEMS

If an ecosystem is a highly integrated complex of interacting factors, what results from changing one part of it?

The immediate consequences of the removal of photosynthetic plants from an ecosystem are obvious. Solar energy could not change to biochemical energy. Then, the ecosystem would cease to function. We have already seen how human-set fires can radically change a savanna ecosystem.

Not as dramatic, but just as deadly to the ecosystem, is the excessive use of pesticides. While we may eliminate a particular rodent or insect, we may also kill other organisms. These are organisms that are dependent on that rodent or insect. These organisms may directly or indirectly die because of pesticide use.

Often, people are unaware of the broad ecological consequences when they manipulate and alter ecosystems.

Eating poisoned prey might kill a dependent organism directly. If it cannot change its diet, it may die indirectly by starvation. The overuse of pesticides inadvertently kills many beneficial predatory insects, and insectivorous bats and birds.

Often, people are unaware of the broad ecological consequences when they manipulate and alter ecosystems. These unanticipated consequences can occur even when the change seems to our advantage.

What is more important, we are also dependent organisms. We ourselves are part of the overall ecology of the ecosystems in which we live. It is, therefore, necessary for our survival that we develop an ecological awareness of our actions.

11. 6. STRUCTURE OF AN ECOSYSTEM – BIOTIC FACTORS

If asked how a forest differs from a grassy field, we would probably answer that they have different species. Yet **species composition** is just one element of the biotic structure of an ecosystem. The *number of species* present also varies from one ecosystem to another.

Ecologists describe an ecosystem with many species as being highly diversified. **Species diversity**, then, is another distinguishing feature of an ecosystem.

In a forest, most birds nest in the trees. There are few trees, however, in a grassy field. Therefore, birds must nest on the ground. The *distribution*, or location of species, also characterizes an ecosystem.

Another factor that characterizes an ecosystem is the abundance of living things. The study of **species abundance** comes under a special field of ecology called **population ecology**.

A karisu (Phragmites sp.) wetland is an example of a community dominated by a single organism.

11. 7. COMMUNITY COMPOSITION AND SPECIES DIVERSITY

The various species composing a community define a natural community. What determines the species composition of a particular community?

The prevailing climate—temperature, moisture, and wind—determines, to a large extent, which species will be present. An element of chance is also involved. Can you think of some ways in which chance can play a role in the composition of a community?

Natural communities often have a tremendous number of plant and animal species. When we attempt to identify species on a field trip, we will soon realize two things. One feature of most communities is that there are a few species that are abundant. Another feature is that there are many species that are rare. The few abundant species in a community are called **dominants**.

Ecologists first concentrate on the dominant organisms of a community. They do this to understand some of the mysteries of the particular ecosystem.

On land, the dominant organisms are usually plants. In the coastal waters, the dominant species might be a type of coral. These organisms influence the physical conditions for the other organisms and may, therefore, determine the other species' distributions. Why is this so?

A community is often named after the dominant plant. Thus ecologists speak of a KARISU (*Phragmites sp.*) wetland, a TANGANTANGAN (*Leucaena sp.*) forest, or a NIGAS (*Pemphis sp.*) coastal scrub.

Variations in the physical environment cause much of the diversity of species in a community. In general, the greater the variety in the physical environment, the greater its diversity.

It is almost impossible to limit a community to one species. This is true even in an artificially created situation, such as a commercial farm plot. Many small plants and numerous animals will find a place to live. Why?

Additionally there is a **gradation** of diversity of species according to an organism's size. For example, there might be many species of insects but only a few mammals. To date, biologists have identified several million animal species. More than three-quarters of these are insects, many being extremely tiny. How do we account for such great variation in insects and relatively little in mammals?

11. 8. DISTRIBUTION OF PLANT AND ANIMAL SPECIES

The distribution of plant species in a terrestrial community can be described both vertically and horizontally. Ecologists have subdivided communities vertically into several zones reflecting the type of plants present.

The zone closest to the ground is the **ground** or **herb** layer. It includes mosses, ferns, and other herbs. The next zone above the ground layer is the **shrub** layer. Shrubs and saplings are here. The uppermost zone is the **tree** layer. Another word for 'layer' is *strata* and some ecologists refer to these as herb, shrub, and tree strata (*stratum* for singular).

The herb layer includes mosses, ferns and other herbs.

These three layers are the main ones. In some cases, more zones are required to describe a community. The tropical rain forest, for example, has more than one tree layer. This is because some of the trees are considerably taller than others.

The layers of the vegetation determine the location of the wildlife. Each zone has its characteristic animals. Considerable interchange does take place, however, between the layers.

As a result, a community that has the most layers generally has the broadest variety of wildlife. Not all communities are equally stratified. A natural forest community is more highly stratified than a grassland community. Most forests, therefore, have a greater diversity of wildlife associated with them.

The shrub layer includes shrubs and saplings.

The individuals of a plant species are distributed in a horizontal plane as well as in a vertical one. Horizontal **distribution** may be **regular**, with individuals spaced at specific distances from one another. Distribution may also be **clumped**, as often happens when seeds germinate under their parent plant.

The most common type of distribution is **random**. Here a species shows no special pattern at all.

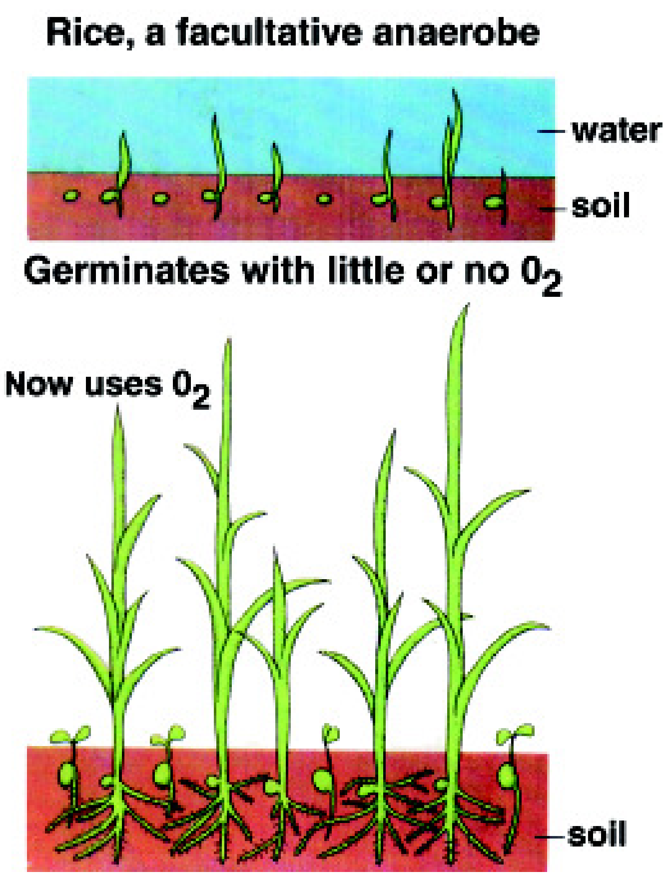
The ecologist who wishes to determine the population number of a species must know its distribution. She or he must know whether the distribution is regular, clumped, or random.

Generally it is too time-consuming to count all the individual members of a species. (Imagine counting the number of grass plants in an open field!)

The uppermost zone is called the tree layer.

Instead, the *estimate* of a population's size within a large area is made by counting the numbers in a **sample**. A sample is a small area representative of the large area. (Remember our discussion of this in Chapter One?)

The transition zone where two communities blend, is called the ecotone, ecotone edge, or sometimes just "edge."



Rice is a facultative anaerobe, meaning it can tolerate conditions both with and without oxygen at different stages in its growth cycle.

The distribution of a species may be **discontinuous** or **continuous** from one community to another. Where the distribution of species is discontinuous, researchers can identify definite boundaries.

A well-maintained farm next to a tangantangan forest is an example of such a discontinuous distribution. Farm crops are on one side, and trees are on the other. There is no gradual merging of the two vegetation types.

However, most natural communities do not have distinct boundaries. They have a continuity of species between them. Some species are not as **tolerant** of the conditions in a neighboring community as they are of the conditions in their own. Other species may be more successful under the conditions in the neighboring community. The more tolerant species will be more plentiful. This causes a gradual blending of the two communities.

The transition zone where two communities blend, is called the **ecotone**, **ecotone edge**, or sometimes just **"edge**." Generally, the variety and density of organisms are greater here at the edge than in the centers of either of the two communities.

For example, there are normally more bird species in the ecotone between a forest and a grassy field than in either the centers of the forest or the field. This is because members of each community share the ecotone edge.

Because the ecotone edge has such diversity of species, it is an excellent region in which to conduct field studies. Remember this when selecting your study sites. Do not forget to compare the edge area with the communities on either side of it.

11. 9. STRUCTURE OF AN ECOSYSTEM - ABIOTIC FACTORS

Many abiotic factors affect organisms. The common ones are temperature, moisture, light, wind, and soil characteristics.

Every organism has a **range of tolerance** for each of these factors. This range depends on the abiotic factor and on the organism. When this range is exceeded in either direction, the organism suffers. Within each range of tolerance there is an **optimum** at which the organism lives best.

Obviously, optimal conditions cannot exist in an environment for all organisms all the time. Optimums for organisms are different, and abiotic factors fluctuate. Even if the environment is stable, optimal conditions for one stage in an organism's life cycle may not be optimal for another stage.

Most organisms, therefore, spend much of their lifetimes in sub-optimal conditions. Those with the broadest tolerance to all factors generally survive best. They usually have the widest distribution, too.

Two terms ecologists often use to describe a species' level of tolerance to environmental conditions are **obligate** and **facultative**. Obligate means *must have*. Facultative means *can have*. For an obligate species, the environmental condition must be present. For a facultative species, the condition can be, but does not have to be present. Species that are able to tolerate a certain environmental condition are identified as either facultative or obligate to that condition.

11. 10. TEMPERATURE

11. 10. 1. Introduction

The ability to tolerate variation in temperature is different for every organism. Nematode eggs can withstand temperatures well below -200°C. Some pollen grains, fern spores, seeds, and bacteria spores can survive temperatures as low as -100°C. Many fungus spores can withstand temperatures as high as +150°C.

However, for each species there are temperatures below and above which it cannot live. Between these limits, each species prefers a particular temperature range. This preferred range is called its *optimum.*

The environment's temperature controls the temperature within a plant and thereby regulates its metabolic processes. For example, the rate of photosynthesis increases as temperature increases, and decreases as temperature decreases.

Temperature can affect other aspects of life as well. Oranges and many other citrus fruits can grow in tropical climates, but grow optimally in Mediterranean climates.

Citrus fruits need the cold weather to change to their characteristic ripened color. On the US mainland (and here in the CNMI), most orange-colored oranges come from California or Florida (states with Mediterranean climates). Here in our Commonwealth, orange varieties grow where temperatures never fall below 60°F (15°C). For this reason, our oranges do not develop their conventional orange color. Instead, ours are still greenish, even when fully ripe. Likewise, in full maturity, locally grown lemons and tangerines remain green.

As another example, the great majority of our local water's hard corals spawn when the coastal sea's temperature is at its warmest. This is usually around the middle of July.

The phases of the moon also determine their spawning time. Annual mass coral spawning usually begins five to seven days following the first full moon in July. Then it continues for about three days.

There is some annual variation in these spawning dates. Each year, biologists monitor the progress of the developing gametes of our coral species to predict when they will spawn. (See the Coral Reefs Introductory Chapter, Ch. 13).

11. 10. 2. Poikilotherms and Homoiotherms

Environmental temperature also directly affects animals. Some animals have body temperatures that vary with the external temperature. These are called **poikilotherms** ("poikilo" means "various" and "therm" means "heat"). Among the poikilotherms are fish, most reptiles, amphibians, arthropods, and many animals that are structurally simpler than these.

Citrus fruits need the cold weather to change to their characteristic ripened color.

The great majority of our local water's hard corals spawn when the coastal sea's temperature is at its warmest.

The mangrove plant (Bruguiera sp.) lives with its roots often covered by seawater.

Terrestrial plants and animals depend largely on precipitation for their moisture requirements.

Mammals and birds, however, have an internal temperature-regulating mechanism. It maintains them at a constant body temperature despite varying environmental temperatures. Thus they are called **homoiotherms** ("homoio" means "alike").

The metabolism of poikilotherms may become deranged in extreme temperatures. This is because external temperatures affect the metabolic processes of poikilotherms.

Within limits, however, only the internal body temperature governs the metabolic processes of homoiotherms. Environmental temperature therefore affects the growth and development of poikilotherms more than it does homoiotherms.

Temperature control is not as limiting an ecological factor here in the CNMI as it is in other climatic regions. This is because the changes in daily and monthly temperatures in the Marianas are not very great. Remember our islands' reference in the Guinness Book of World Records? "World's most equable climate: Garapan, Saipan". Here it's just about 86 degrees Fahrenheit (30½ degrees Celsius) almost all of the time.

11. 11. MOISTURE

11. 11. 1. Introduction

No environmental factor is more important to living organisms than water. This is because all living cells require water as a component of their **cytoplasm** (cell fluids and organelles). In addition, each cell requires water as a **reactant** in many of its life processes. Green plants, for example, require water as a reactant in the process of photosynthesis.

11. 11. 2. Optimal Moisture Conditions

As with temperature, organisms have optimal moisture conditions. Most animals can live within a range of moisture conditions. Depending on the species' ability to adapt to adverse moisture conditions, the range may be narrow or wide. Always, however, an overall water balance must be maintained between organisms and their environments.

Too little water can cause the death of terrestrial plants and animals through dehydration. Too much water may drown many species of animals. It may even drown a plant by preventing sufficient oxygen from reaching the roots.

Special adaptations of **hydrophytic plants** (see below), allow them to get oxygen to their root cells below water. Of special note is the mangrove plant *(Bruguiera sp.*) which lives with its roots often covered by seawater. Not only is it able to obtain sufficient oxygen, it is also able to *excrete* salt molecules as well. (See our Mangroves chapter, Ch. 17).

11. 11. 3. Precipitation

Terrestrial plants and animals depend largely on precipitation for their moisture requirements. Precipitation here includes rain, fog drip, and an occasional very brief morning dew in the winter. Elsewhere snow, sleet, and hail are included. As a result, the distribution of precipitation over the surface of the entire earth plays an important role in determining the distribution of plants and animal species.

Precipitation does not act alone, however, in determining the distribution of plants and animals. Equally important is the temperature. Precipitation and temperature, together, are largely responsible for the climate of a region.

The distribution of precipitation throughout the year is more important to a biotic community than its total distribution. We generally think of tropical regions as being continuously wet. Yet most tropical regions have unequal distribution of rainfall over a year, with distinct wet and dry seasons. Our own islands are a good example of this.

Compare two tropical regions that have approximately the same annual precipitation. In one region it is distributed fairly evenly over the year. The vegetation in this region is chiefly **evergreen**. The other region has seasonal changes in precipitation. That is, it has wet and dry seasons. In this region the vegetation is largely **deciduous**—the leaves drop during the dry season. Kapok, Red Plumeria, and Flame trees are examples of local deciduous trees. Each drops its leaves almost entirely during the dry season.

Regions which have seasonal changes in precipitation possess vegetation which is largely deciduous, i.e., the leaves drop during the dry season. Flame trees are examples of local deciduous trees.

Many factors affect precipitation. Three important ones are the direction of the prevailing winds, the topography of the land, and the temperature. If the prevailing winds blow over large expanses of water, precipitation will usually be high on nearby land masses. The presence of a high mountain range generally results in heavy precipitation on the windward side of the mountains. Warm winds can pick up and hold more moisture than cool winds can.

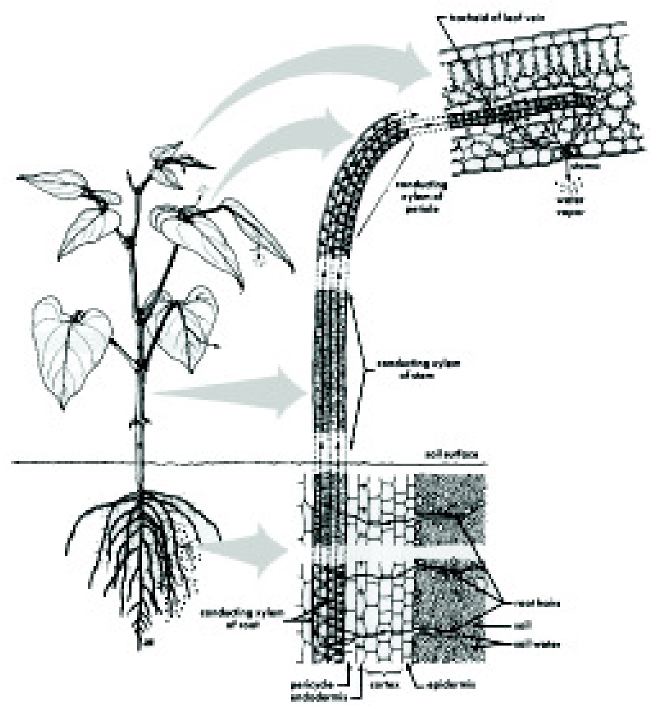
11. 11. 4. Atmospheric Humidity

Water vapor in the air also greatly affects living organisms. This water vapor is called **atmospheric humidity**. It is most commonly determined by measuring the **relative humidity**.

Relative humidity is the ratio of the mass of water present in a given volume of air compared to the mass of water required to saturate that volume of air. We commonly express relative humidity as a percentage.

So what does a relative humidity of 80% mean? It means that the air contains 80% of the water that it is capable of holding at that particular temperature.

When it is raining, the relative humidity is 100%. This means that the air already has all the **water vapor** molecules it can absorb. The remaining water vapor molecules form water droplets. These then fall as rain.



Plants give off water vapor through pores on the undersides of their leaves (called stomates) by a process called transpiration.

Plants give off water vapor through pores on the undersides of their leaves (called **stomates**). This is done by a process called **transpiration**. This process is essential to plants. It helps moderate the temperature of plant leaves on hot days. It does this in much the same manner that **perspiration** helps to cool our own bodies.

More important, though, is transpiration's role in transporting essential minerals from the roots to the leaves of plants. Without transpiration, not enough water would pass through a plant to carry the necessary amounts of nutrient minerals to the leaves.

We know that on a hot, humid day, sweat accumulates on our skin. This happens because sweat cannot evaporate as quickly when the relative humidity is high. In general, plants are affected in a similar way. When the relative humidity is high, the transpiration rate is low; when the relative humidity is low, transpiration is high.

The "sensitive or sleeping plant" (Mimosa pudica) closes its leaves regularly at night or when stressed.

Fortunately, most plants have adaptations that tend to prevent excessive transpiration that might otherwise cause death through dehydration. Euphorbs and cacti, for example, have very few pores. What does the average house or garden plant do in very dry conditions? How does this adaptation reduce water loss?

Certain plants close their leaves regularly at night or when stressed, as a measure of moisture control. These include our massive monkeypod or rain trees (*Samanea saman*), and our lowly or "sensitive or sleeping plant" *(Mimosa pudica)*.

11. 11. 5. Hydrophytes, Xerophytes, and Mesophytes

Introduction

Soils play a key role in making water available to plants. Here we describe plant types ('phytes' = plant) adapted to soils that retain and yield a great deal of water, soils that retain and yield barely any water, and soils that retain and yield a medium amount.

Hydrophytes

In some areas, water retention by the soil is so high that the soil is wet for long periods (two weeks or more). Only plants that have adapted to this extreme moisture condition can survive in these areas. Such plants are called **hydrophytes**. See the Wetlands chapters (Ch. 20 & 21) for more details on this habitat.

Some hydrophytes such as Hydrilla sp., grow totally submerged in water.

We find hydrophytic communities around ponds, swamps, and lakes. They also occur along the banks of streams. The Talofofo region of Saipan has such streams, as does the Talakaya area of Rota. No streams exist on Tinian but there is a lake and a swamp area (Hagoi and Magpo). Most marsh plants are also hydrophytes.

The dominant plants of hydrophytic communities grow with their roots anchored in the mud below water level. Their leaves either float on the surface or extend into the air above. KARISU (*Phragmites*), KANGKUN (*Ipomea*), and bulrush (*Scirpus*) are in this category.

Other hydrophytes grow totally submerged in water. *Hydrilla* is a common freshwater aquarium example of this type.

Still others—including some species of algae—float freely on the water's surface. Duckweed or *Lemna sp.* (not an algae), is an example of a free-floating hydrophyte. Duckweed commonly covers small ponds with a thick blanket of green.

Xerophytes

Where a combination of low precipitation, low relative humidity, and low soil water retention creates an excessively dry environment, a completely different type of plant community occurs. Botanists call the plants of this community **xerophytes**.

The desert is an extreme example of a **xerophytic community**. Deserts form in regions that have scant rainfall throughout the year. They also form in regions that experience long periods of drought.

Xerophytic species such as nigas (Pemphis sp.) adapt to decrease the amount of water lost through transpiration.

Less extreme xerophytic conditions occur on our beaches and exposed rocky slopes. Areas of recent volcanic ash fall are also xerophytic. This is due to the high amount of direct sunlight and high levels of heat, as well as the poor ability of ash and sand particles to retain water.

Xerophytic species adapt to decrease the amount of water lost through transpiration. The leaves and stems of many xerophytes are thick and fleshy to permit the storage of water. Two coastal strand examples are NIGAS (*Pemphis sp.)* and HUNEK (*Tournefortia sp.)*.

The leaves of xerophytes are usually small; the spines on cacti and euphorbs are all that remain of leaves on these plants. Similarly, our coastal "pine" tree, *Casuarina*, has greatly reduced leaves. Its photosynthetic stems give the appearance of pine needles, thus its name.

The leaves of many xerophytic plants have very few breathing pores (stomata). Almost all of them are located on the underside of the leaves. Why would this be so?

Some xerophytes have long tap roots that extend deep into the ground to reach moisture. Other xerophytes, like sand grass, have fibrous roots that efficiently absorb the small amount of moisture present.

Mesophytes

Plants that prefer intermediate moisture conditions are called **mesophytes**. Most of the herbs, shrubs, and trees of our local forests are mesophytes.

Most of the herbs, shrubs, and trees of our local forests are mesophytes.

Mesophytes thrive when moderate amounts of moisture are available throughout most of their growing seasons. It is difficult to spot any unusual adaptations among the plants of a mesophytic community. This is because moisture conditions are not extreme.

11. 11. 6. Adaptations and Survival

Each plant community has associated with it an animal community whose members also show adaptations.

What animals live among the bulrushes, swamp ferns, and sedges on the margin of a pond? What adaptations to hydrophytic conditions do they show? What animals live at our beach areas? What adaptations do they possess that permit them to live in this xerophytic area?

Beach animals like our ghost crab (Ocypode sp.) conserve moisture by burrowing into the sand during the day.

Adaptation to variations in environmental conditions is the key to the survival of a species. Although a particular species may prefer certain moisture conditions, it will not last long unless it can tolerate extremes from time to time.

For example, most mesophytic areas experience periods in which xerophytic conditions dominate. The plants and animals of such areas have adaptations that permit them to survive through dry periods.

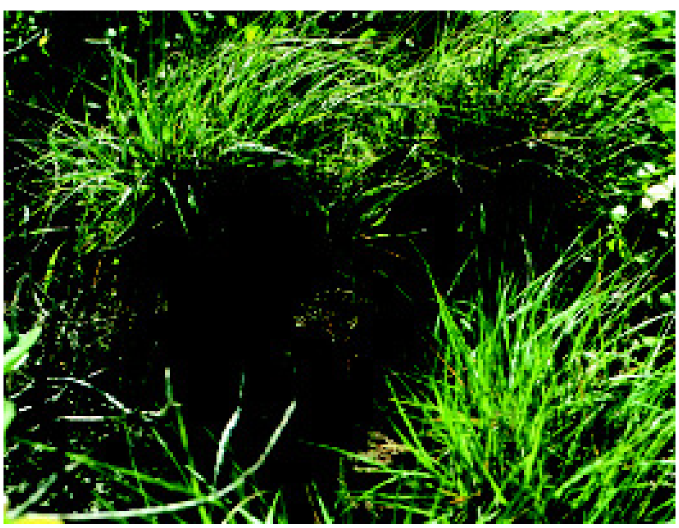
The evergreens of a mesophytic forest often have a waxy coating on their leaves. This is to slow down moisture loss during the xerophytic conditions of the dry season. As mentioned, deciduous trees drop their leaves during this time of the year to reduce water loss.

Annuals (plants that live only one year) survive long periods of drought as seeds. The seeds germinate only when favorable moisture conditions return.

Beach animals like our ghost crab (*Ocypode* sp.) conserve moisture by burrowing into the sand during the day. They are active mostly at night when the temperature is lower and the relative humidity higher.

Our geckos have the interesting adaptation of reabsorbing all the water from their urine. They then excrete only the remaining urea chemicals in a dry form. This is the whitish part of the gecko's droppings. Fecal matter makes up the darker portion.

There are many adaptations to variations in moisture conditions amongst plants and animals. Watch for them during your field studies.



Members of the plant family Graminae, "the Grasses," depend entirely on wind for pollination.

11. 12. WIND

Wind has both desirable and undesirable effects on ecosystems. Foremost among the desirable effects is bringing precipitation to an area. Winds blowing over large bodies of water, such as the Philippine Sea or the Pacific Ocean, become laden with water vapor. As these winds move inland, the vapor precipitates out, thereby adding moisture to the land.

Allergy sufferers are well aware that the wind transports the pollen grains of many plants. As a matter of fact, without wind, many species of plants would not be pollinated at all. Thus, seeds would not be produced and the species would vanish. One economically important plant **Family Graminae**, "the Grasses" depends entirely on wind for pollination.

Wind also plays an important role in increasing the distribution of plant species over a land mass. It carries spores from mushrooms and other fungi many miles. These spores land, germinate, and start new colonies.

As discussed in the last chapter, the wind also carries the seeds of many plants to new locations. In our northern islands, wind-borne spores and seeds are the first colonists among volcanic ash and lava flows.

Wind also affects the growth of plants. Strong winds blow away water vapor from the vicinity of plant leaves. The drier air outside the leaves encourages excessive transpiration by the leaves. Unless the plants have special adaptations to counteract this drying action, they will either die or be stunted in growth.

The coastal plant *Pemphis acidula* (NIGAS) is a good example of a plant that is well-adapted to harsh winds. It grows as a medium-sized tree where it is sheltered from the wind. Where winds are strong, however, to avoid strong wind exposure *Pemphis* grows only as a low-spreading scrub plant.

Pemphis acidula (nigas) is a good example of a plant that is well-adapted to harsh winds.

Strong wind alters the physical appearance of trees. In exposed areas, the wind often bends back branches on the windward side of trees. They are so bent that they permanently point away from the direction of the prevailing wind. Strong winds not only deform trees, they can uproot trees or break limbs from them, as often happens during our typhoons.

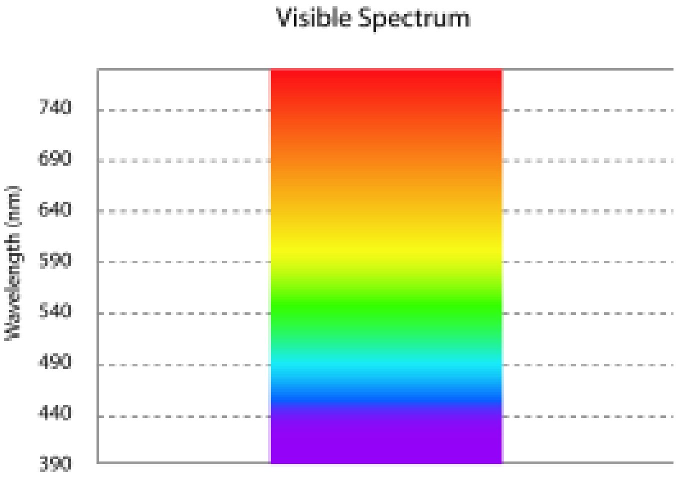
11. 13. LIGHT

11. 13. 1. Characteristics of Environmental Light

Our sun gives off **electromagnetic waves** having a wide range of **wavelengths**. At one extreme are the very short *gamma rays* and *X-rays*. Fortunately for life on the earth, only small amounts of these **radiation** forms pass through our atmosphere.

At the other extreme are the very long radio waves. Most of these do pass through the atmosphere with ease. (What evidence do we have of this?) Between the two extremes are the **ultraviolet**, **visible**, and **infrared** bands of radiation.

Radiation visible to the human eye has wavelengths between 400 and 750 millimicrons. Ultraviolet radiation has wavelengths less than 400 and infrared radiation has wavelengths greater than 750.



Radiation visible to the human eye has wavelengths between 400 and 750 millimicrons.

Some ultraviolet radiation reaches the surface of the earth where it has both beneficial and harmful effects on organisms. You may already be familiar with its effects, good and bad, on humans (moderate *suntans* vs. *sunburns* and *skin cancer*).

Some infrared radiation also gets through the atmosphere. When it strikes the surface of the earth, it warms the soil, water, and other surfaces. These in turn warm the atmosphere. Provided that atmospheric conditions are normal, the visible band of radiation passes through our atmosphere with ease. Its effects on living organisms are many and varied.

Most living organisms depend on sunlight for survival. Green plants (producers) obtain their energy requirements by converting light energy to chemical energy through photosynthesis. Consumers also obtain their energy from the sun, although by a more indirect means. Light is, therefore, of unquestionable value in the functioning of an ecosystem.

However, too much light kills many organisms. For example, excessive light destroys the chlorophyll that is vital to green plants. Thus, light is both an essential factor and a limiting factor. It must be present, but too much or too little can be harmful.

For shade-tolerant plants such as this Asplenium nidas, the maximum rate of photosynthesis occurs at very low intensities.

In this petri dish, turned 90 degrees every day, the roots and stems show tropism.

Within a particular ecosystem like a forest, the light conditions are not uniform throughout. Light may vary in intensity, duration, and quality from place to place and from time to time.

For example, the light is not as bright (intense) at the forest floor as it is at the top of the leaf canopy. The sun does not shine on the forest as many hours per day in January as it does in June. Light also does not have the same color (quality) in the depths of a forest as it does in more open areas.

11. 13. 2. Light Intensity

Many factors effect light intensity. Among these are latitude, altitude, topography, time of year, time of day, and cloud cover. Over any particular community, these factors most often are reasonably uniform.

Within a particular community, the stratum (layer) in which we find an organism directly relates to the intensity of the light that reaches it. An organism in the upper or tree stratum in a forest will probably receive much brighter light than an organism in the lower or ground stratum.

A combination of a thick canopy of leaves and prolonged cloudy periods can reduce light intensity to the **compensation intensity** for some plants. This is the intensity at which the light is just bright enough to enable photosynthesis to replace a plant's sugars as fast as respiration uses them.

If the intensity falls below this level for too long, some plant species will die. Most green plants have a compensation intensity of over 100 **foot-candles**.

1 foot-candle = amount of light given by 1 candle held 1 foot away

Light intensity has a controlling influence on any ecosystem. This is because it determines, to a large extent, the degree of **primary production** in the ecosystem. Primary production is the rate at which producers convert and store energy through the process of photosynthesis.

Up to a certain point, the rate of photosynthesis increases as the light intensity increases. However, a **saturation intensity** also exists, beyond which the rate of photosynthesis decreases.

For shade-tolerant plants, the maximum rate of photosynthesis occurs at very low intensities. This adaptation helps make it possible for many plants to live in the dense shade of the forest floor. Locally these plants include ferns, mosses, GULOS (*Cynometra sp.*), and PAIPAI (*Guamia sp.*)

Light intensity also plays a role in determining the orientation of plants and animals. That is, light intensity helps to determine the direction of growth and movement of plants. (Note: Plants move their leaves around during the day, very slowly to follow light). It also helps determine the direction of movement of some animals.

Plants display **tropisms** (from the Greek word “trope” which means “turn”). Plants exhibit **geotropism**, or response to gravity. You can plant a seed any way you like. However, the root always turns down, and the stem always turns up. Plants also exhibit **phototropism**, or response to light. Mostly this is *positive phototropism*.

In a clear display of positive phototropism, sunflower heads follow the movement of the sun across the sky each day.

Many sun-tolerant plants turn their leaves toward the sun to obtain maximum exposure. **Sunflower** heads follow the movement of the sun across the sky each day. This is so they can present the broad sides of their leaves continuously to the sun.

In areas where the light intensity is excessive most of the time, some plants exhibit *negative phototropism*. They turn their leaves so that the edges face the sun. Why do they do this?

Many animal species also orient themselves using light intensity. With animals however, this orientation is not called a tropism but, instead, a **taxis**. Humans exhibit **geotaxis**. That is, we use gravity to keep ourselves vertical as we walk around. Many animals also exhibit **phototaxis,** or orientation to the light of the sun.

Using the angle between its hive and the sun, the honey-bee (*Apis sp.*) determines its flight path from the hive to a nectar source. What does it do when clouds cover the sun? All the bee needs is a small patch of blue sky. The bee then uses *the angle of polarization* of the light in this patch of blue sky to orient itself.

The migration of birds over long distances is just as amazing as the ability of bees to find their food supply. Birds may use prominent landmarks, prevailing wind direction, and other environmental factors to help orient themselves during migration.

Evidence exists which shows that many species of birds also use the direction of sunlight for orientation. Further, they are apparently able to compensate for changes in the sun’s position during the day.

11. 13. 3. Light Duration

You may already know that seasonal changes occur in the behavior of plants and animals. At a certain time of the year a particular plant flowers; at a certain time of year a particular bird migrates. What causes these seasonal changes in behavior?

Plants such as this Ipomea exhibit photoperiodism; the flowers open early in the morning and close as the day brightens.

We may think that they are associated with the changes in light intensity that occur over the course of a year. Scientists believe, however, that these changes have more to do with changes in length of exposure, or **duration**, than with changes in intensity.

This response of organisms to the length of day is called **photoperiodism**. Plants most clearly illustrate this response. Plants can be classified as long-day, short-day, or day-neutral.

The flowering of day-neutral plants is not affected by the length of day. On the other hand, long-day plants will only flower when the length of day exceeds a certain critical value. This value is different for each species. It usually exceeds 12 hours and is commonly about 14 hours.

Short-day plants flower naturally only under conditions of short days and long nights. The critical length of day for these plants is less than 12 hours and commonly about 10 hours. Most of these plants are **perennials**. Their roots and buds were formed the previous year.

Other short-day plants require a long period of growth before they are mature enough to flower. These plants develop during the bright sunny days of the summer. Then, flowering is triggered by the shortened days of late summer or early autumn.

Although photoperiodism plays a role in migration, it does not fully explain it. It does not explain how birds find their way during migration, nor why this behavior first evolved.

Many plants are restricted to certain geographical areas. Plants that live in the Arctic must be able to tolerate long days. This is because the duration of daylight is very long in the Arctic during the growing season. On the other hand, tropical plants have adapted to short days, since the photoperiod here is about 12 hours.

The duration of light also controls the life cycles of many animals. Photoperiodism also plays a role in the migration of birds. The effect of photoperiodism is only secondary, however. The length of day controls the reproductive cycle. This, in turn, determines the times of migration.

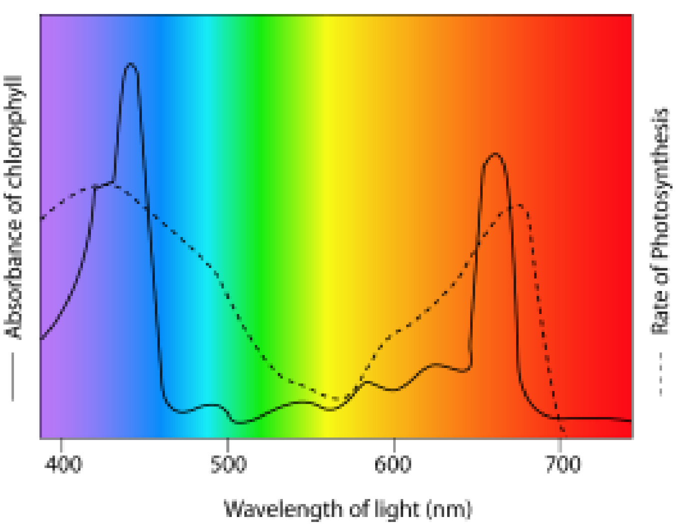
Birds need long periods of daylight for building nests and collecting food for their ever-hungry young. Under periods of long daylight, the process of raising young can be completed more quickly. Many birds migrate north to the Arctic tundra to breed because the length of day is longer there each summer. This is when food supply and temperature also favor reproduction. Southward migration in the fall occurs to let birds escape the killing cold and limited food supply.

Although photoperiodism plays a role in migration, it does not fully explain it. It does not explain how birds find their way during migration, nor why this behavior first evolved.

People can also be affected by light duration. In the Arctic, higher frequencies of depression, known as *Seasonal Affective Disorder*, occur during the long winter months. Doctors prescribe high light level lamps, light visors (a kind of baseball cap with lights embedded in the brim), and other light therapy devices to balance human light duration needs.

11. 13. 4. Light Quality

This term refers to the color or wavelength of light. As an ecological factor, it is less important than intensity and duration. Of greatest importance, however, is the role that light quality plays in photosynthesis.



Not all wavelengths of the visible spectrum are used in photosynthesis. Plants absorb only the violet and red ends of the spectrum.

Not all wavelengths of the visible spectrum are used in photosynthesis. Plants *absorb* only the violet and red ends of the spectrum. The green portion is *reflected*. This is why chlorophyll-bearing plants appear green when exposed to white light.

In the ocean, water absorbs wavelengths of light at varying depths. It absorbs red and orange colors most quickly. These colors are only visible naturally in shallow depths. Below these depths, we need artificial light to appreciate the colors of deeper living organisms.

Green and blue wavelengths travel deeper before being absorbed. Finally, at some depth, the water has absorbed all visible light wavelengths. For this reason we find most marine plants living in the top 50 feet of the ocean.

Some plants have special light absorbing adaptations. These adaptations enable them to absorb light energy and perform photosynthesis at greater depths in the ocean. They have special light-absorbing compounds that can absorb the green and blue wavelengths which penetrate to these depths. Among these seaweeds are species within the group called Rhodophyta, or red algae. They can grow deeper than algae belonging to the green, brown, and golden-brown algae groups.

The quality of light affects mainly those animals that have color vision. It is noteworthy that certain species of arthropods, fish, birds, and mammals have well-developed color vision. Surprisingly, other species in the same groups do not.

Pollinating insects can see in the ultraviolet as well as in the visible spectrums. Many flowers have distinct “landing runways” specially colored for these insects. Humans cannot see these without special lighting techniques.

Primates are the only mammals that have well-developed color vision. What advantages do you think color vision gives to an animal?

11. 14. SOIL

Soil evolution, ecology, and fertility will be discussed at length in a later chapter. To help prepare for this unit’s field studies, however, certain essential soil factors are discussed here.

11. 14. 1. Soil Ecology

Soil is the most complex environmental factor effecting life on land ecosystems. No one factor alone describes soil. Texture, acidity, nutrients, organic content, and moisture content are just a few characteristics we must consider.

Also, life exists in the soil. Insects, other invertebrates, fungi, and bacteria interact with and affect the abiotic characteristics of the soil. In fact, the soil is an ecosystem in itself.

11. 14. 2. Soil Formation

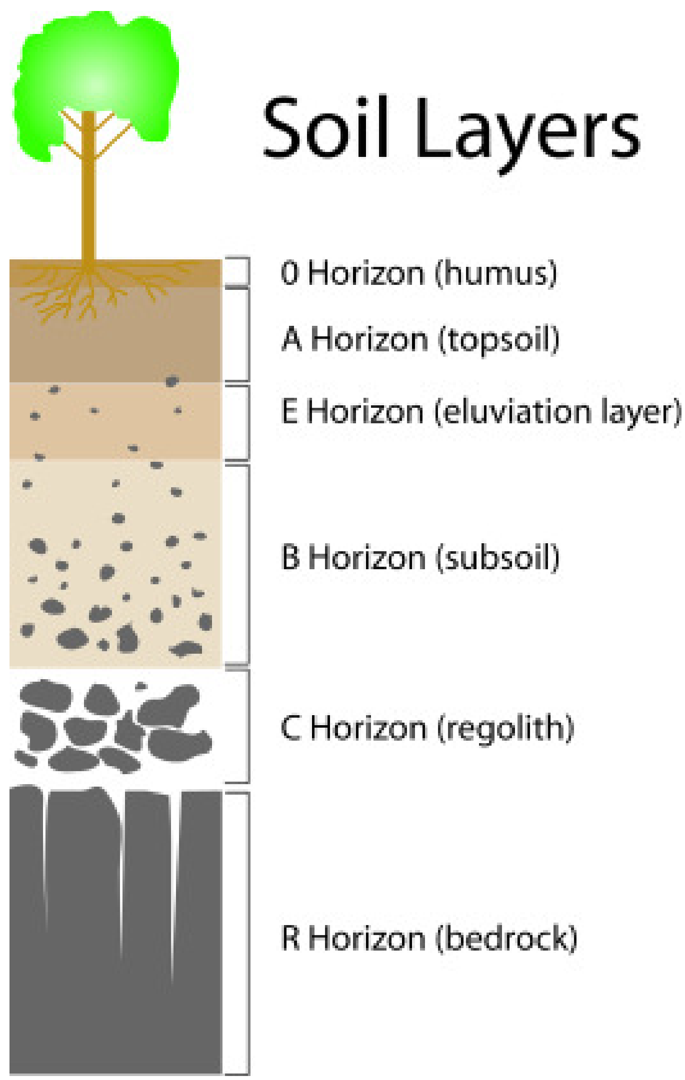
Soil formation begins with the weathering of rocks and rock fragments. As the weathered material accumulates, primitive plants take root. These further contribute to the breakdown of the rock. They add organic debris to the soil surface.

Bacteria and fungi decompose the organic matter from plant and animal remains, forming these into **humus**. This decomposition to humus is an early stage in the conversion of organic matter to soil material. Bacteria and fungi then decompose humus into simple compounds, such as water, carbon dioxide, and minerals.

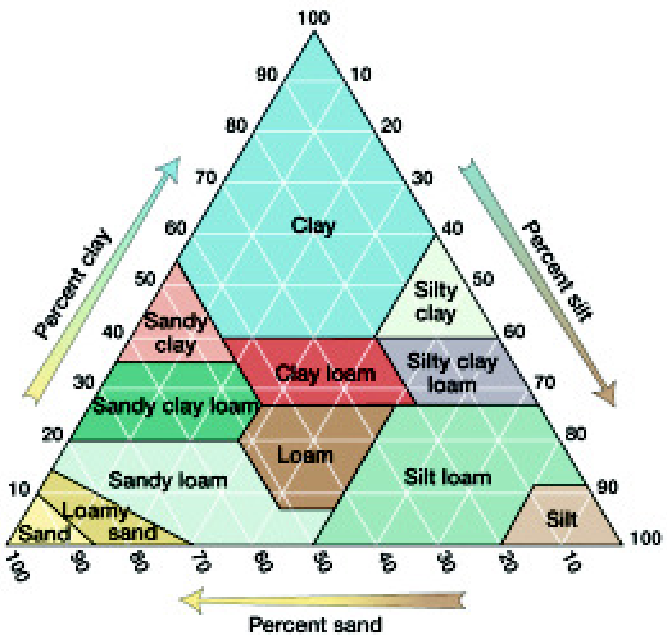
11. 14. 3. Soil Profile

At any one time the soil has a certain mineral and organic matter content. Nevertheless, it does not have a uniform mixture of these.

Red algae can grow deeper than algae belonging to the green, brown, and golden-brown algae groups.



Soil is composed of layers or horizons, each with unique characteristics. Together these horizons make up a soil’s profile.



If the size percentages of clays, silts and sand in a soil are about equal, the special name loam is given.

A soil with a pH between 0 and 7 is an acid soil. A soil exactly at pH 7 is neutral and a soil of pH greater than 7 is alkaline (also called basic).

Instead it has layers or **horizons**, each with unique characteristics. Together these horizons make up a soil's **profile**.

A soil profile results mainly from the action of percolating water. The water **leaches** materials from the surface layers and **deposits** them in deeper layers of the soil. In this way, layers (horizons) having different properties, like color, are formed.

11. 14. 4. Soil Texture

Another characteristic of the soil is the **texture** of the soil particles. The word texture refers to how soil *feels* when rubbed together in one's hands. Coarse? Smooth? Mixed between these two?

Soil texture is closely related to the average grain sizes of a soil. The largest of these grain sizes, interestingly enough, begins with a grain of **sand**. It ranges downwards through **silt**, about the size of a single particle of flour, and it ends with the smallest, a single particle of **clay,** which is sub-microscopic.

Coarse or *sandy*-textured soils consist of sand-size particles. *Silty* soils are medium textured (and medium sized). *Clay* soils are fine textured (very, very small particles). Usually there is a range of particle sizes between these extremes. If the size percentages of clays, silts and sand in a soil are about equal, the special name **loam** is given.

Particle size is important because it affects the **water-holding capacity** of a soil. Rain water percolates down into the soil. Some of this water is held between the particles. The rest percolates, under the influence of gravity, through the soil and into the groundwater below.

The **field capacity** of soil is the amount of water remaining in soil after a heavy rain, once the extra *gravitational water* has drained away.

Clay soils have a greater field capacity than sandy soils. This is because more water is trapped between the fine particles than between the coarse particles. However, much of the water trapped by the fine particles is held there by very strong chemical bonds. As a result, this water may be unavailable to plants.

Coarse soils cannot bind the water molecules as tightly. Therefore, although coarse-textured soils have a lower field capacity, they generally have more water that is available for plants than clay soils.

Loam soils have the ideal combination of both high field capacities and high water available-to-plant levels. Loam soils are usually ideal for agriculture.

11. 14. 5. Soil pH

The **pH** of the soil is another important factor. For the soil chemist, pH is a measure of its **acidity**. It can vary from 0 to 14. The lower a soil sample's pH number, the higher its acidity is. A soil with a pH between 0 and 7 is an **acid soil**. A soil exactly at pH 7 is **neutral** and a soil of pH greater than 7 is **alkaline** (also called **basic**).

The soil acidity usually varies from one horizon to the next. Generally, more acid is present in the humus layer. This is because carbon dioxide is one of the products of organic breakdown. When carbon dioxide dissolves in the water of the soil, it produces **carbonic acid** (sometimes called **humic acid**).

11. 14. 6. Other Factors

There are many other soil factors to consider when planning terrestrial studies. Among these are soil temperature, mineral content, moisture content, and organic content. We should also consider percolation rate, capillarity, pore space, and the types of organisms present in the soil. See more in the Soils Chapter (Ch. 26).

11. 15. MICROENVIRONMENTS

Although we have discussed temperature, moisture, light, wind, and soil under separate headings, it is important to recall that they are all interrelated.

Normally we would not single out any one factor and study it independently of the others. We can only do this when studying a controlled system in which only one factor is changing. We would only find such a system in a carefully designed laboratory situation.

Abiotic factors like temperature, moisture, wind, light, and soil condition act together. They create the general environment over a broad region of land. This, in turn, determines the overall biotic nature of the region. Yet, within any given region, abiotic factors vary considerably.

Microenvironments exist within the larger environment. Consider the following examples:

- The soil may be richer in a low-lying area than on the hills around it.
- The relative humidity is higher amongst tall grass than it is a meter above the grass.
- On a hot summer day, the temperature is many degrees higher next to the ground than it is one meter above it.
- Conditions in a cave or rock crevice differ greatly from those in the immediate surroundings.
- Under a fallen log, light intensity is lower than it is in the surrounding forest. However, moisture content under the log is higher.

Such *microenvironments* generally affect organisms more directly than does the overall environment.

Ecologists often perform microenvironmental studies in caves, around fallen logs, in rock crevices, and in sheltered nooks. They usually study microenvironments in that portion of the atmosphere that is within 1.5 meters of the soil.

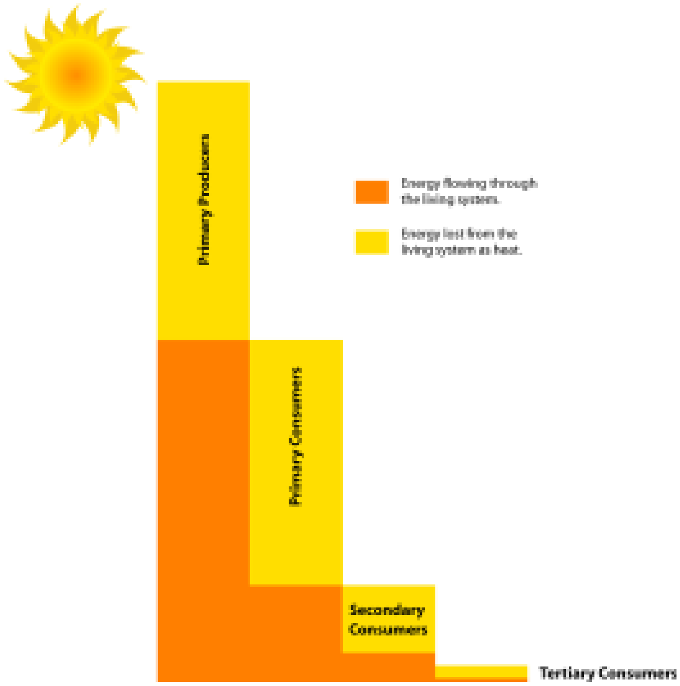
The temperature and moisture conditions within a microenvironment act together to create a microclimate. This climate usually differs greatly from the overall climate of the area.

Abiotic factors like temperature, moisture, wind, light, and soil condition act together to create the general environment over a broad region of land.

Microenvironments, such as this cave, generally affect organisms more directly than does the overall environment.

When we are working in the field, it is important that we continually remember that microenvironments exist. For example, suppose we want to measure the overall temperature and relative humidity of a region. We should keep our instruments at least 1.5 meters above the ground, to avoid microenvironmental influences.

There are, of course, many occasions when we want to make measurements of the microenvironment. For example, suppose we are trying to determine the most suitable conditions for growing certain seedlings in a forest. In this case, we would make all environmental measurements near the ground. The overall environment is not nearly as important to these seedlings as is the microenvironment.



A food chain gradually loses energy. Due to this one-way flow, little, if any, of the energy trapped by the producers returns to them.

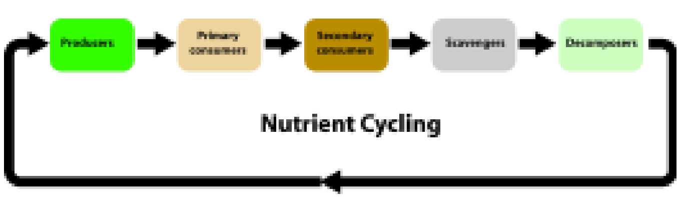
11. 16. ENERGY FLOW AND NUTRIENT CYCLING

Spend a few hours in the middle of a forest in July and August, the start of our rainy season. The constant activity there is surprising. Plants form new leaves. Insects abound. Birds and lizards, constantly searching for food, seem to dart everywhere. Activity is the essence of life. Activity, however, requires energy and nutrients.

By now you probably already remember that the ultimate source of energy is the sun. Green plants are able to convert solar energy to biochemical energy. In so doing, they support, directly or indirectly, all the other organisms of the ecosystem. Herbivores *lose heat energy* as they graze on producers. Similarly, carnivores *lose heat energy* as they prey on herbivores.

Thus, a food chain gradually *loses energy*. As a result, the flow of energy through an ecosystem is one-way. Little, if any, of the energy trapped by the producers returns to them.

As green plants convert solar energy into biochemical energy, they also absorb elements and compounds called **nutrients**. Plants absorb nutrients through their roots and stomates. Like energy, these nutrients are passed along the food chain. This happens when an herbivore grazes on a green plant. It happens again when a carnivore eats the herbivore. It happens yet again when a second carnivore eats the first one.



Unlike energy, nutrients are not lost along the food chain. Instead, they decompose and return to the environment at the end of the food chain.

Unlike energy, however, nutrients are not lost along the food chain. Instead, they decompose and return to the environment at the end of the food chain. After producers reabsorb them, the cycle begins again. Nutrients are *recycled.*

These two processes, **energy flow** and **nutrient cycling**, form the basis for the study of the functional dynamics within an ecosystem. Stated another way, ecologists measure the functioning of an ecosystem by determining the rates of energy flow and nutrient cycling.

11. 17. ENERGY FLOW

Green plants do not absorb all solar radiation that reaches the earth's surface. Only about 1% of the total **incident radiation** is converted to biochemical energy. However, this seemingly small amount of energy maintains practically all organisms on the earth.

Because all consumers ultimately rely on producers for their energy, complex energy relationships exist between the organisms of an ecosystem.

Section 11-3 described some of these relations as *food chains* and *food webs.* The complexity of relationships is simplified by categorizing organisms according to their **niches**—producer, herbivore, first-order carnivore, etc. Such categories are called feeding or **trophic** levels.

Producers occupy the first trophic level. What levels do herbivores, first-order carnivores, and second-order carnivores occupy?

Many animals are not easily categorized since they occupy more than one niche. For example, several animals are both herbivores and carnivores. You will recall that zoologists categorize them as omnivores. Can you think of some examples?

Clearly, the idea of trophic levels is a simplification of the complex interrelationships between the organisms of an ecosystem. This simplifying is still very useful, however, and ecologists have studied trophic levels extensively. The results of some of these studies are quite interesting.

One of the first studies to be made was a numerical one. Ecological experimenters counted the organisms occupying each trophic level within an ecosystem. They found that, in general, successively fewer organisms were at the higher trophic levels. In other words, the number of organisms declined as the trophic level increased. Thus, a *pyramid of numbers* exists.

• This simple food chain illustrates the pyramid of numbers:

1000 Individuals		100 Individuals		10 Individuals		1 Individual
Savanna Grass	→	Grasshopper	→	Reed Warbler	→	Monitor Lizard

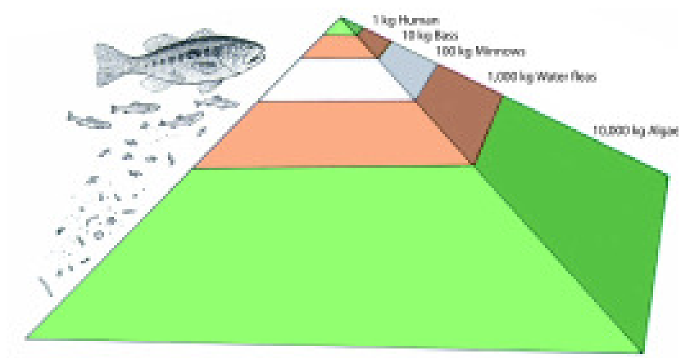
Each grasshopper must eat a large amount of grass daily to sustain itself. Yet, look at the next trophic level. A reed warbler needs fewer grasshoppers daily than the number of grass leaves that the grasshopper needs. The monitor lizard needs fewer reed warblers than the number of grasshoppers the reed warbler needs.

Ecologists soon realized that the pyramid of numbers does not give an entire understanding of the dynamics of an ecosystem. However, it does give some interesting information. This is because it treats all organisms as though they were the same, ignoring size differences.

Yet, to a hungry monitor lizard, size is important. One reed warbler makes a better meal for it than one grasshopper.

Ecologists decided that a more useful measure would be the total mass of organisms (**biomass**) at each level. To equate one gram of reed warbler with one gram of grasshopper makes more sense than to equate one reed warbler with one grasshopper.

Ecologists measured the total biomass for each level in several food chains. They discovered that there was generally a decreasing



Ecologists measuring the total biomass for each level in several food chains discovered that there was generally a decreasing amount of biomass the higher the trophic level. This resulted in the idea of a pyramid of biomass.

amount of biomass the higher the trophic level. This resulted in the idea of a *pyramid of biomass.*

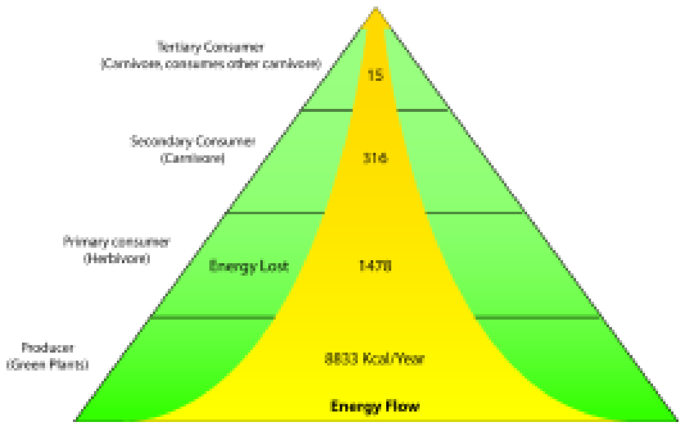
The food chain in which many of us participate clearly illustrates this:

Grain → Chicken → Human

Experienced farmers have improved chicken-raising. Now, about three grams of grain forms one gram of a chicken in the growing stage. Yet that one gram of chicken produces only a fraction of a gram of tissue in a growing human.

Although a pyramid of biomass is a more basic idea than a pyramid of numbers, it has one major fault. It equates unit masses of all organisms. For example, it implies that one gram of reed warble or one gram of grasshopper provides a monitor lizard with equivalent amounts of energy. However, experiments have shown that this is not true.

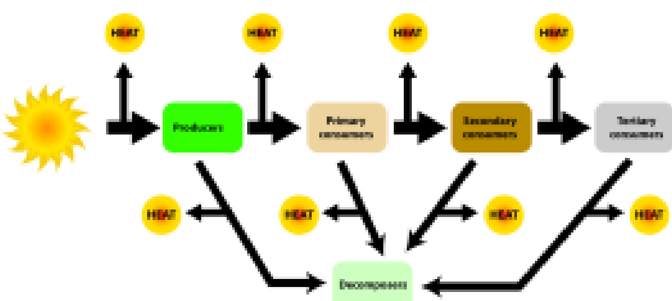
Different types of tissue have different energy contents. The most noticeable difference occurs between plant and animal tissue. On average one can obtain about 20% more energy by eating one gram of animal than by eating one gram of plant.



Ecologists now concentrate most studies on pyramids of energy.

Many animals eat plants to obtain energy for life processes. Some animals eat other animals for the same reason. The efficiency with which energy is passed along a food chain is fundamentally important. It is more important than either the numbers of organisms or their biomasses. Therefore ecologists now concentrate most studies on *pyramids of energy*.

Each level in this pyramid represents the sum of the energy used in tissue formation and that released by cell *respiration*. This represents the total *energy flow* at that level.



Energy is lost at each trophic level within an ecosystem.

To understand why total energy always decreases as trophic levels increase, consider the flow of energy through this (now familiar) food chain:

1000 Individuals Savanna Grass → 100 Individuals Grasshopper → 10 Individuals Reed Warbler → 1 Individual Monitor Lizard

Not all the energy produced by the grass is available to animals and decomposers. Much of it is lost through respiration. The grasshopper consumes part of the **net energy** produced by the grass.

But, here too, part of the energy is lost, as the grasshopper respires to carry on its life processes. The net energy available to the reed warbler is a fraction of the energy the grasshopper obtained from the grass. The reed warbler can use only a part of the energy provided by the grasshopper. For instance the **exoskeleton** of the grasshopper, made of **chitin**, is not digestible.

The reed warbler, too, must use energy for its life processes. Therefore, even less is available to the monitor lizard. If the monitor lizard has no immediate predators, then parasites and decomposers will eventually use the available energy of this animal. The rest is lost as heat.

We have already learned that energy is lost at each level in the food chain. Similarly, energy is lost at each trophic level within an ecosystem. The organisms in the ecosystem cannot recapture energy lost as heat. Hence, the flow of energy is one-way. Energy must continuously enter from the sun to keep this ecosystem operating.

Humans are as dependent as any other organism on the flow of energy through ecosystems. Our very existence depends on it. However, we can control energy flow and divert it to our use. For example, we can destroy a natural ecosystem like a forest. We can then replace it with a vegetable crop. Such a crop would yield more direct food energy for us.

As human populations increase, more crops will be necessary to supply our increasing food demands. Fewer niches and suitable habitats will be available. More natural ecosystems will be destroyed. For many organisms, the threat of extinction will become real. Alternatives do exist, however. What are they?

Humans destroy natural ecosystems, like this former Amazon Basin forest, and then replace them with vegetable crops which yield more direct food energy.

11. 18. NUTRIENT (BIOGEOCHEMICAL) CYCLES

11. 18. 1. Introduction

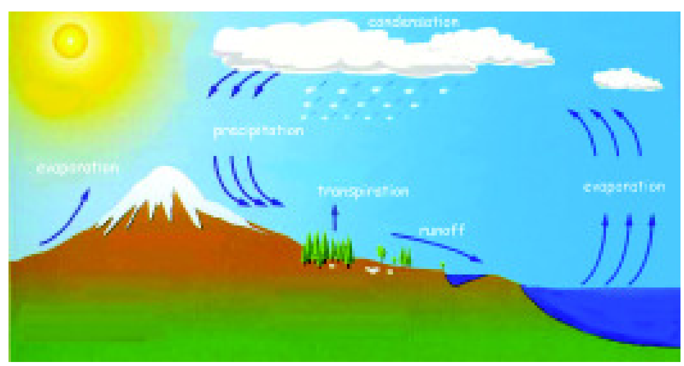
Biogeochemistry is the study of the exchange of materials between biotic and abiotic parts of an ecosystem. **Biogeochemical cycles** show the kinds of exchange that take place. The movement of nutrients through an ecosystem occurs at the same time energy is transferred. However, unlike energy flow, nutrient movement is cyclical.

In case we haven't done so before, let us now define a **nutrient**. A nutrient is any substance required for the growth and maintenance of an organism. The presence of two types of organisms (decomposers and plants) makes the cycling of nutrients possible.

The decomposers (largely fungi and bacteria), break down dead plant or animal matter into simpler organic compounds. Then other bacteria change the organic compounds into inorganic compounds.

Green plants can then reabsorb these inorganic compounds. Elements that were once in a plant or animal can, through a chain of events, eventually return to another plant. Let us see how this occurs by considering three of the basic nutrient cycles; those of *water*, *carbon*, and *nitrogen*.

Remember, there are many other important nutrient cycles. These three are discussed as examples.



The water cycle encompasses evapo-transpiration, condensation, and precipitation.

11. 18. 2. The Water Cycle

Water vapor enters the atmosphere through *transpiration* from vegetation and by *evaporation* from bodies of water and the soil. These two are sometimes combined to be called *evapo-transpiration*.

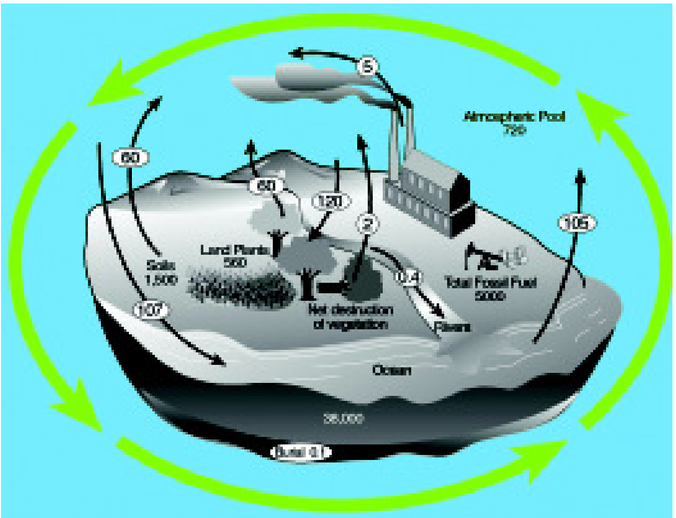
In the cool upper atmosphere, this vapor condenses, forming clouds. In time, enough water collects in the clouds to cause *precipitation*.

When this occurs, the ground absorbs some of the water falling on it. Some runs off along the surface of the ground to a stream, lake, lagoon, or other body of water.

The amount of water absorption and surface runoff depends on the nature of the soil, its parent rock material, and the amount of precipitation.

Some of the soil water percolates down to the groundwater level, and later returns to a body of water via a spring or a seep. The roots of the green plants absorb some of the remaining water in the soil. Animals can obtain some of the water they need by eating these green plants. Of course, they can also obtain it directly by drinking it from a body of water.

When plants and animals die, they decompose. The water present in their tissues is released back into the environment through decay processes.



The combustion of fossil fuels adds carbon to the atmosphere, while deforestation reduces the number of green plants which remove it. Units expressed are kg x 1000.

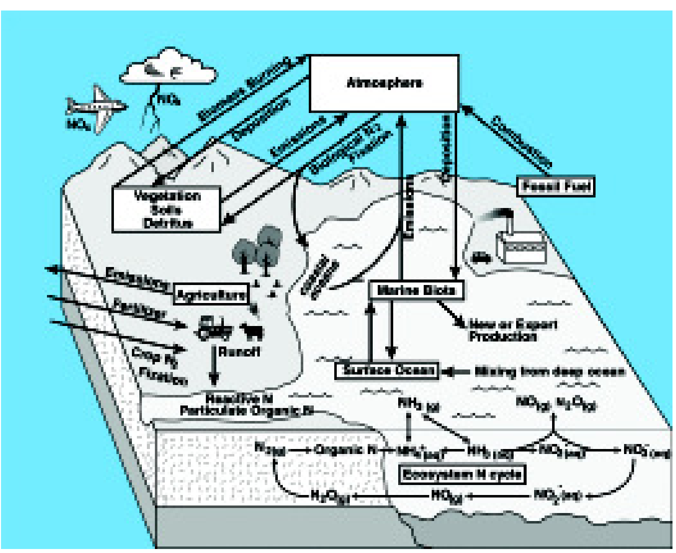
11. 18. 3. The Carbon Cycle

At one time, scientists considered the carbon cycle to be a perfect one. Carbon was returned to the atmosphere by *respiration* about as quickly as it was removed by *photosynthesis*. Lately, however, the increased *combustion* of fossil fuels has added extra carbon to the atmosphere. These fuels add carbon faster than green plants can remove it.

Carbon is present in the atmosphere as *carbon dioxide*. Plants use carbon dioxide to make organic compounds such as *carbohydrates* (sugars and starches), *vegetable oils*, and *plant proteins*.

Some carbon dioxide returns to the air as a byproduct of respiration in plants and animals. Still more is released by *decay* (the respiratory activity of decomposing organisms).

Organic matter that does not completely decompose can accumulate and become incorporated as hydrocarbon material into the earth's crust. Our energy-rich deposits of oil, coal, and natural gas resulted from the accumulation of plant and animal organic matter in the distant past.



The nitrogen cycle encompasses both biotic and abiotic sources.

11. 18. 4. The Nitrogen Cycle

All plants and animals require nitrogen to **synthesize** (make) proteins. Although almost 78% of the atmosphere is molecular **nitrogen** (**N_2**), neither plants nor animals can use this form directly.

Nitrogen must be in the form of a **nitrate** (**NO_3^-**) before the roots of a plant can absorb it. Lightning flashing through an atmospheric mixture of nitrogen and oxygen can cause this conversion.

The bacterium *Rhizobium sp.* lives in **nodules** on the roots of **legumes** like beans and tangantangan. *Rhizobium,* too, can convert molecular nitrogen to nitrates.

Plants use the nitrates they absorb to synthesize plant proteins. Animals get the nitrogen that they require for protein synthesis by eating plants or other animals.

When plants and animals die, bacteria convert their nitrogen content to **ammonia** (**NH_3**) or **ammonium** (**NH_4^+**) compounds. Bacteria also convert the nitrogen in animal metabolic wastes,—urine and fecal matter—to ammonia. Ammonia, in turn, is converted to **nitrites** (**NO_2^-**) and then to *nitrates* by different bacteria. This completes *one portion of the cycle*.

Bacteria convert some nitrites and nitrates to **molecular nitrogen** (**N_2**), to complete *the total cycle*. The nitrogen cycle need not, and often does not, involve this last step. This is because nearby plants quickly absorb most soils' available nitrogen.