

ECOLOGY - A GUIDE TO THE STUDY OF ECOSYSTEMS



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Ecology - A Guide to the Study of Ecosystems

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Licensing

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CHAPTER OVERVIEW

1: Introduction



An earth star fungus, *Geastrum* aff. *welwitschii*. The strange structures shown are but a small part of the fungus, developed by that organism under genetic control to produce and disperse its spores. Much more of the biomass of this life form is found within the soil.

The objective of this wikibook, *A Study Guide to Basic Ecology*, is to give the reader a better understanding of the way life functions on Earth, and how it is organized. This section will introduce basic concepts and definitions required to establish a course that is both biological and ecological in approach. You will learn that there are numerous terms in ecology which basically mean the same thing, and that there are also a plethora of views on precise definitions. As ecology emerged in the 19th and early 20th centuries, many concepts of ecological organization were proposed. These came from both zoologists and botanists—whom seldom read the other's literature—and from different schools of thought.

Definition of Ecology

The term **oekologie** (ecology) was coined in 1866 by the German biologist, [Ernst Haeckel](#) from the Greek *oikos* meaning "house" or "dwelling", and *logos* meaning "science" or "study". Thus, ecology is the "study of the household of nature". Haeckel intended it to encompass the study of an animal in relation to both the physical environment and other plants and animals with which it interacted.

A contemporary definition of ecology is:

The scientific study of the distribution and abundance of organisms and the interactions that determine distribution and abundance^[1].

This definition encompasses not only the plants and animals that Haeckel recognized but microscopic organisms such as [Bacteria](#), [Archaea](#) and [protozoa](#), as well. The interactions that determine an organism's distribution and abundance are processes that include energy flow, growth, reproduction, predation, competition and many others.^[2]



Ecology is essentially the study of the workings of the planet Earth.

To fully understand the science of ecology, there are some common terms that must be defined. The term **environment** describes, in an unspecified way, the sum total of physical and biotic conditions that influence an organism (Kendeigh, 1961). The subset of the planet earth *environment* into which life penetrates is termed the **biosphere**. With respect to the planet earth, the biosphere penetrates only a limited distance into the rock beneath the land and the oceans, and a limited distance out away from the planet towards space. All human effort so far has failed to demonstrate that the biosphere extends beyond these limits or that other biospheres exist elsewhere in the universe. We cannot therefore conclude that they do not exist, only that we know nothing of that existence. **Ecosystem** is perhaps the most widely used term in ecology. It is defined as the system of organisms and physical factors under study or consideration. Although the boundaries of ecosystems are sometimes quite difficult to define in nature, ecosystems—however bounded—comprise the basic units of that nature (Tansley, 1935). **Habitat** is generally considered by biologists to be the physical conditions that surround a species, or species population, or assemblage of species, or community (Clements and Shelford, 1939).

The basic physical units of the biosphere are the **lithosphere** (the land), **hydrosphere** (the water), and **atmosphere** (the air). Apparently there is no permanent biota of the atmosphere, although insects and birds among others utilize that environment extensively (Hesse, et al., 1951). These basic units are easily recognized in any **landscape**, as for example shown in the scene at right from Belarus in Europe.

- Read [Biosphere](#) (Follow links that interest you. Most subtopics will be covered in later chapters)
- Read [Ecosystem](#) (Links need only be followed to deepen your interest at this time)

 Note

Definitions of terms used in this textbook have been collected into various glossaries, the basic one being [Basic Ecology Glossary](#).

Scope of Ecology



Tropical woodlands and River Gambia. The surface of the earth is covered by an exceedingly complex biological system capturing energy from sunlight. Availability of water determines the "density" of this system.

Humanity has been studying nature for thousands of years and formally for several centuries under the science of biology, so why do we say that Ecology is a relatively new science? (Note, the term "ecology" is only about 150 years old). What is it that ecologists do or study that biologists might not? Kendeigh (1961, p. 3) wrote that "[e]cology is one of three main divisions of biology; the other two being morphology [organism structural aspects] and physiology [organism functional aspects]". The behavioral sciences encompass one facet of the interaction of an organism with its physical and biological surroundings, and therefore are part of ecology.

Several techniques are used to study Ecology; one of the methods is known as strong inference. Strong inference is defined as the method of testing a hypothesis by deliberately attempting to demonstrate the falsity of the hypothesis (Kinraide and Denison, 2003). Performing experiments is the preferred method of using strong inference. The point of an experiment is to control variables and/or patterns and to predict the outcomes.

Traditionally, Ecology is based more on weak inference (the other type of inference) rather than strong inference. In weak inference there are no experiments; rather, there are correlations between observations. Weak inference is defined as a "common sense" approach using simple system models to build understanding (Elner and Vadas).

Both weak and strong inference have been used throughout many different science courses over the last several thousands of years (Kinraide and Denison). However, strong inference is said to be more advantageous because weak inference is more prone to error. Weak inference makes people try to cling to one point of view; whereas strong inference (doing experimentation) causes people to think from more than one point of view and keep coming up with different hypotheses to test as their old hypotheses get falsified.

Ecology incorporates and overlaps with many other disciplines in both the biological and physical sciences. Certainly on one level, there is no information about the natural environment that does not have some applicability to ecology. On the other hand, such interrelationships between the sciences are much more the norm than most people realize. Ecology, according to Kendeigh (1961, p. 1), is a distinct science because of the way information about the natural world is organized; and because of its unique methodologies and point-of-view by which knowledge is extracted from such information.

Ecology has no aim, but ecologists have. The problems of the ecologist are not fundamentally different from those of any other kind of naturalist. The superficial differences in aim are due to the different points of view, or methods of approach, rather than to any essential differences in the character of the problems — (Charles Adams, 1913; cited in Hedgepeth, 1957).

It may be helpful here to list the phenomenon that ecologists are particularly interested in if only to better clarify the boundaries of this text covering basic ecology (list modified from Kendeigh, 1961, p 1). Ecologists study:

1. structural, functional, and behavioral adaptations of organisms in relation to their environment (Chapter 3);
2. interrelationships between species and their populations, and populations in their communities (Chapter 4);
3. local and geographic distributions of organisms;
4. regional variations in organism abundances;
5. temporal changes in the distribution, abundance, and behaviors of organisms; and

6. evolution of the interrelationships described.

Ecology is both a biological and an environmental science, something that should certainly be evident from the definition provided above. Many environmental sciences are minimally concerned with biology (meteorology, for example) and others (environmental toxicology, for example) necessarily combine physical and biological sciences. Environmentalism on the other hand is a political position involved with various aspects of managing the environment.

- Read [Ecology](#) (Neither links nor extended ("Main") articles need be pursued at this time)

There are many subcategories of Ecology. Plant Ecology looks at the differences and similarities of various plants in differing climates and habitats. The origins of Animal Ecology can be traced to two Europeans, R. Hesse of [Germany](#) and [Charles Elton of England](#). Physiological Ecology, or [ecophysiology](#), studies the responses of the individual organism to the environment. The idea of [Population Ecology](#) was brought forward by two famous men, [Charles Darwin](#), who looked at the similarities and dissimilarities of populations and how they replaced each other over time, and [Gregor Mendel](#). The last subcategory is [Ecosystem Ecology](#), which brought about terms such as [limnology](#), introduced by A. Thienemann.

Early History of Ecology

Because ecology is a facet of biology, it is not possible to clearly define a time or person that represents the beginning of ecological thought as distinct from biology. One of the first ecologists was probably Theophrastus, a contemporary and student of Aristotle. Theophrastus described various interrelationships between animals and between animals and their environment as early as the 4th century BC (Ramalay, 1940).

- Read [Theophrastus](#) (Links need not be pursued at this time except as necessary to clarify points)

Over the next several centuries biological knowledge gradually expanded as naturalists, such as Bufon and Linnaeus, contributed to a growing understanding of the nature of plants and animals. These early naturalists of course understood that organisms had a relationship with the environment, and especially that the distribution of forms was related to physical aspects of the geography.

- Read [Carolus Linnaeus](#) (Follow links only as needed to clarify terms and points made)
- Read [Alexander von Humboldt](#) (Follow links only as needed to clarify terms and points made)

The modern ecological concept of integrated communities of organisms began in the 19th century with the studies of August Grisebach (1838), a German botanist. A contemporary and fellow countryman, Ernst Haeckel, coined the term "ecology" in 1866. Other biologists followed Grisebach's ecological approach to natural history studies: K. Möbius (1877) investigating Danish oyster banks, Stephen A. Forbes (1887), describing a lake community as a microcosm, J. E. B. Warming (1895), describing Danish plant communities, and C. C. Adams conducting ecological studies in northern Michigan (1905) and at Isle Royale (1909).

- Read [Ernst Haeckel](#) (Follow links only as needed to clarify terms and points made)
- Read [History of Ecology](#) (Pursue only links that interest you to gain additional insight)

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Further reading

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CHAPTER OVERVIEW

2: Biological Organization

Units of the Biosphere

You have been presented with a definition of the term **biosphere** above. This chapter will consider the question: **How is the biosphere organized?** We will initially look at this organization over a range of scales so to familiarize you to important terms used in ecology. In later chapters, we will cover the details and significance of the concepts only introduced here.



A large pond and wetlands near Minsk. We can easily recognize a hydrosphere, an atmosphere, and a lithosphere, the latter dominated in some areas by yellowing grasses or sedges, in other areas by trees.

Ecologists regard *ecosystems* as basic structural units, implying that the biosphere is a collection or mosaic of definable ecosystems. However, an ecosystem is really more conceptual than actual. By this we mean that the definable boundaries of an ecosystem are more in the mind of the ecologist than geographical. We can certainly observe that there are many boundaries in nature—some fairly sharp—and what we are observing are physical manifestations between volumes wherein different conditions prevail. These are **biocycles**, subdivisions of the biosphere. Consider a lake shore, or even the water surface for that matter; the transitions between the biocycles—land, the air or atmosphere, and the body of water—are sharp and recognizable upon casual inspection. But are they really?

There is no doubt that under gravity, water in the liquid phase sorts itself out from gaseous air—a lake surface exists. But along the shore, the water moves into the earth wherever the soil or voids in the rock allow. Constantly water-saturated soil becomes a wetland. Further, atmospheric gases dissolve in the water of the lake, and molecules of water move off the lake as gaseous moisture, evident perhaps as fog on a cool morning. The sharpness of the boundaries is both actual and illusionary. Actual, because conditions encountered within each of the separate spaces or volumes (air, land, water) are very different. Illusionary, because no biocycle is completely isolated from adjacent biocycles, and typically each has influence over the other.

We have, so far considered just the physical environment. Ecosystems include organisms. And we can expect that most, though certainly not all, organisms will sort themselves out along the same physical boundaries described. That is, fish will find life conditions suitable only in the lake; conifers only in the uplands. Yet organisms are no more isolated from adjacent biocycles than are the substances of the physical world. The food of many fish will be insects living only on the land and moving through the atmosphere, which upon death or by accident, fall into the water. The conifers draw up moisture from the earth, some directly from the lake or the groundwater body connected to the lake. Ecologists use the term **biotope** to mean a topographic unit characterized by a particular set of physical conditions and a uniform assemblage of plant and animal species. Considering our example above, the lake is part of the major freshwater *biocycle* and would be a *biotope* of the region in which it is located, being perhaps just one of many ponds and lakes comprising that biotope. A **biochore** is a subdivision of the biosphere consisting of the biotopes that resemble one another; thus, our lake is but one example of the temperate zone, freshwater, lake *biochore*.

The terms "biotope", "biochore", and "biocycle" fill a need in descriptive ecology. We can speak in a general way about the life forms and climatic conditions that constitute a desert biochore, or a northern forest biochore. And we can describe, from our example illustrated by the photograph, lake, marsh, and upland forest biotopes, each with a distinct listing of species perhaps unique to just that geographical region near Minsk (in our photo example), or more broadly represented across the continent.

Gaia Theory

Consider the importance of the functional relationships between species comprising an ecosystem, and how those relationships contribute to the very survival of the ecosystem. Consider that ecosystems are not, in most cases, isolated units, but parts of a larger functioning whole, at its broadest being the biosphere. Is it possible that biosphere—all life on earth and at least those physical things utilized and modified by life on earth—is one, large integrated system?

- Read [Gaia Theory](#) (Follow links that interest you.)

Species and Habitat

In biology, the concept of **species** is basic. A species comprises a group of related organisms that share a more or less distinctive form and are capable of interbreeding. According to Ernst Mayr, species are:

groups of actually or potentially interbreeding natural populations which are reproductively isolated from other such groups.

- Read [Species](#) (Although you will be familiar with this material from biology studies, you should explore the topic to satisfy a more complete understanding)

In biology, it is generally the case that focus on the species concept is largely the concern of taxonomy and taxonomists. In ecology, the more important aspect is that of the [species population](#) (or **population** as we shall more often use the term). Note in Mayr's simple definition, that "interbreeding populations" is somewhat central. In ecology we are less concerned with all considerations of what "potentially interbreeding" might mean and more interested in the group of individuals that are, in fact, interbreeding. By which is meant, not that sexual reproduction must take place between all extant (living at the same time) members, but that there exists a gene pool that is open and potentially contributed to by each member. The concept of species would admit all those individuals separated by great distances and physical barriers as included if breeding could still take place. The species population takes into account the isolation that might actually exist, frequently dividing a single species into more than one population. Within the population, [alleles](#) presumably flow freely through time, held (at any given point in time) within the nuclei of the cells of the individual organisms constituting the population.

Using the term habitat in describing the ecological conditions surrounding an assemblage of species or a community, we are speaking of a *biotope*. Many ecologists extend the term habitat in the manner originally defined to cover physical parameters relative to a community of species, but others would substitute the term "biotope" for "habitat" in such cases. Note that this is not exactly the same as "biotope" defined above, which included the biota as well as the physical or abiotic environment. Odum (1959, p. 28) stated that "habitat... includes other organisms as well as the abiotic environment... [but a] description of the habitat of the community would include only the latter"—a point of view opposite to that expressed by most ecologists today.

Any term in ecology that attempts to separate the biotic and abiotic components of an ecological unit of organisation will encounter this difficulty. Consider that if the habitat of a bird is the place it lives, and the bird lives in a pine forest (actually up among the branches of the pine trees), then the physical environment (the "habitat") of that bird species must include a life form (pine trees); and now extend this reasoning to any manner of invertebrates, such as flea or tapeworm, that really do live most of their life on or in other organisms. A reasonably solid definition of *habitat* would be simply **the environment of a species** (Sweet, 2005).

- Read [Habitat](#) (You need follow links only as necessary to clarify terms; include the following:)
 - Read [Biotope](#)

A **niche** or *ecological niche* is essentially what a species does. We do not mean so much what activities it participates in (although these could be pertinent), but the role the species plays in the functioning of the ecosystem: the "functional status of an organism in its community" (Charles Elton, in Odum, 1959).

- Read [Niche](#) (You need follow links only as necessary to clarify terms)

Habitat Selection

The choice of habitat affects reproductive success. How do species choose which place to inhabit? Wecker (1963) and Klopfer (1963) determined this choice is partly genetic. It is also partly psychological. Habitat selection is a common behavior among [vertebrates](#). [Garter snakes](#) (*Thamnophis elegans*) choose rocks of intermediate thickness over thicker or thinner rocks, maintaining their preferred body temperature for extended periods (Huey et al. 1989, Huey 1991). Many species show some flexibility in habitat selection. Organisms are often forced to make these choices, sometimes choosing less suitable habitats. Optimal habitats are occupied more quickly, then marginal habitats, then poor habitats, where reproductive success is limited (Fretwell and Lucas 1969).

We have just touched upon the many aspects of the biology of species populations that concern or interest us as ecologists and this topic will be much expanded upon in Chapter 5 of the *Guide*.

Summarization

There is but one known **biosphere**, that of the planet earth. The biosphere can be subdivided into a number of **biocycles**, each with fairly specific gross physical characteristics and limited by geography and topography as determined by planetary dynamics, especially gravity. Biocycles are divided into **biochores**, units with both similar basic physical attributes and life forms. Biochores are made up of a multitude of **biotopes**, divisions of the landscape that feature both similar physical attributes and a more or less consistent species composition. Some ecologists would use "biotope" for just the physical properties of this level of organisation, and **biocoenosis** for the biotic component. However, such definitional division of highly integrated and complex ecological systems is difficult to uphold. At the level of the species **population** (essentially an organism and its relatives), the habitat describes where it is found, where that species occurs in the landscape. The very different term, **niche**, describes what that organism does as a functional role in the ecosystem. The ecosystem concept differs from traditional (or the "old") biology by its clear emphasis on functional relationships among organisms.

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CHAPTER OVERVIEW

3: The Abiotic World

The most basic interest of ecologists is how organisms interact with their environment. Inanimate objects do not normally "interact"—they are simply acted upon by forces in the environment. Organisms, however, cannot be totally passive within a chain of events and still sustain life. In a sense, life represents a reversal of the "normal" order of things in a universe where physical and chemical reactions proceed, on balance—and usually rather directly—towards lower energy states.



When a volcano erupts it lays down rocks on the surface of its slopes. These rocks are elevated in energy state from their previous existence as physical material deep within the earth. But on balance, in order to erupt, that material was first heated until fluid, and then tremendous amounts of energy expended (as pressure) to push the material (magma) up to spew as lava from the top of the mountain. Only a small portion of that energy remains on the volcano in the form of potential energy of rocks perched on the surface. That potential energy will eventually be released after forces of erosion loosen the rocks and they roll downslope or are ground to silt and deposited in the ocean deep.

In essence, the physical environment (as distinct from the biological environment) is composed of various forms of matter and energy. The physical environment is one of material acted upon by various forces (energy), resulting in a lower energy state of the material with a concomitant release or conversion of energy as (usually) heat or light.

- Read [Laws of Thermodynamics](#) (Links need not be pursued at this time)
- Read [Chapter on entropy](#) in the Wikibook, *Systems Theory*
- Read [Entropy](#) (You need not delve into the mathematics unless so inclined; this article goes beyond "Basic Ecology" requirements)
- Read [Time's arrow](#) (This article will give you insight on why the concept of entropy even matters; remember, ecology is concerned with events at the macroscopic level)

Living systems—organisms—respond in various ways to contacts with the physical forces of an ever-changing environment and interrelationships with other living organisms. The hereditary potentialities of an organism determine what it *can* do, but the environment determines what it actually *does* and to what degree (Greulich & Adams, 1962). This theme is important and you will see it repeated in the discussions that follow.

Organism responses can be described under four different categories:

- morphological,
- physiological,
- behavioural, and
- community relations.

Although these are more or less distinct categories and will be discussed in detail in this chapter, an organism's response to an environmental challenge seldom involves just one of these. At the very least, the growth or development of a morphological feature

involves internal physiological processes occurring between the genetic blue-print in the cells and some final expression of an anatomical trait. A protective morphological trait like horns on a bull come into play through behavioral actions. The horns are not a threat to a predator until wielded in an effective manner.

The Physical Environment

Why are all species not evenly distributed over the earth? A number of *abiotic* (non-living) factors shape the ecological patterns we observe over the face of the earth. Those factors include: water, temperature, wind, salt concentration, pH and the fact that the world is round. The fact that the earth is round has a substantial impact on the distribution of solar radiation, precipitation and wind across the Earth's surface. It is also responsible for the major movements of oceans. All of these abiotic factors naturally play an important role in the distribution and abundance of organisms across the globe.

Solar irradiation affects temperatures on Earth. Most organisms are **mesophiles** that like temperatures between 20-40 degrees C, some organisms are **psychrophiles** that like temperatures below 20 degrees C (cold-living organisms), and some organisms are **thermophiles** that like temperatures above 40 degrees C (heat-living organisms). Seasonality is somewhat associated with temperature. Some of the effects of seasonality include- (1) hibernation due to temperature and scarce resources, (2) rainfall/precipitation that determines how well certain plants or trees grow, and (3) wind.

Another aspect that is important to the diversity of animals' location is the amount of oxygen that is present in the particular area. For example, some organisms are **aerobes** which need oxygen for survival, and some are **anaerobes** which require the absence of oxygen for survival. However, not all organisms require the same amount of oxygen. Some organisms are **microaerophiles** and require little oxygen in order to live, but those organisms still do require oxygen for survival although it may not be as much as other organisms.

Dissolved oxygen plays a major role in supporting life in bodies of water. The greater the amount of oxygen in a body of water the more organisms the water can support. Algae release oxygen into the water which is later consumed by organisms during respiration. This process is efficient in the summer when the algae can consume adequate amount of sunlight. When lakes freeze over in the winter the snow covered ice blocks the sunlight from the algae. This causes a drop in oxygen production in the body of water since the organisms continue to respire. Low dissolved oxygen can cause a problem with predator/prey interactions within an ecosystem. Different organisms have different tolerance to low oxygen. If the predator can survive more efficiently than the prey, the amount of prey will rapidly decline. This can have a major effect on an entire food web. An experiment of this was conducted in the Chesapeake Bay. [\[1\]](#)

Water also plays a major role in the diversification of organisms throughout the world. As previously mentioned, the amount of precipitation is vital for plants to grow, which can provide food (serve as a food source) to other organisms. The salt concentration (salinity) is an important aspect to look at when dealing with water because some organisms are **halophiles** which are organisms that require salt in order to survive. The currents of the water that makes up the oceans is also important. The **gyres** are the surface currents in the oceans. The gyres distribute heat from the equators towards the poles causing the polar waters to have less energy than the water at the equator. The other type of current is the deep water current that sinks to the sea floor and flows towards the equator causing the polar waters to have a higher salinity and a higher density.

Meteorology plays an important aspect to life on Earth as well. The Earth is divided into three main parts- (1) Hadley Cell which is characterized as having Northeast trade winds and is mostly desert landscaping because of the cool, dry air, (2) Ferrell Cell which is characterized as having Westerlie winds, and (3) Polar Cell which is at the North and South poles of the Earth. The weather and wind effects plant dispersal (pollen and seeds getting blown) and the weather and the wind also effect the habitat range from which organisms can live in.

The pH is also a factor that contributes to life. The pH of the **ocean** is approximately 8.2. A deviation from this pH is slowly occurring, known as **ocean acidification**. Over a period of 243 years the pH of the ocean has dropped 0.075 in its pH. This slow acidification is a primary concern for calcium carbonate organisms. Structures made of calcium, including skeletons, are vulnerable to dissolution at lower pHs. **Soil** pH can range from 4.5 to 8.0, depending on area and vegetation growth. The main macronutrients in soil for vegetation are calcium, phosphorus, nitrogen, potassium, magnesium, and sulfur. Most vegetation prefers neutral to slightly basic or alkaline pH level, because at this level the macronutrients are readily picked up. **Rain water** is slightly acidic, depending on the amount of carbonic acid present. The average pH for rain water is 5.7. **Natural freshwaters**, such as lakes and

streams, are also slightly acidic with a pH from 5.5 to 7.7. Drastic alteration in pH levels can have devastating effects. One example is **acid rain**. Acid rain has been known to destroy everything it touches, from minerals, to plant life, to animal and human life. To learn more about acid rain visit [\[2\]](#).

- Read [Ocean Acidification](#)

The effect of wind on biodiversity varies greatly from one region to the next. For example, in southeast Alaskan rainforests, wind shapes the forests and the extent at which forests are composed. [\[3\]](#) While in other parts of the world wind driven damage from hurricanes and tornadoes affect the biodiversity by destroying trees and plants used for food and shelter. Storms are partially driven by wind currents, which in turn bring more moisture to certain areas of the planet. Wind also has a major effect on the amount of time it takes water to evaporate back into the atmosphere. A pond will hold water longer when no wind is present to intensify the drying effect. Wildfires that destroy habitat for plants and animals can be greatly manipulated by winds. Winds can spread fires quickly and over great distances to further disrupt biodiversity.

Another major effect of wind is erosion. Deserts are continuously being moved and reshaped by erosion and sandstorms caused by wind displacing sand from one territory to another. Wind erosion also displaces soil for plant growth by removing the most fertile top layer of soil from the earth. Soil erosion limits the growth of plants and the diversity of animals and insects that feed on these plants.



The Dust Bowl in the 1930s is an excellent example of wind destruction across the plains of North America.

The dispersal of plants is greatly effected by wind driven pollen and seed distribution. Birds that feed on small wind driven seeds from one area will excrete the seeds in another area and in turn the seed can end up in numerous areas after being blown to one or two areas. The distribution of pollen and the cross pollination on plants brings more opportunities for animals to feed and have shelter, increasing the chance for reproduction and biodiversity. With deforestation diversity is greatly reduced, but winds without the obstruction of trees allow seeds and spores to be spread over a greater distance. This will help regenerate lost habitat and increase biodiversity. [\[4\]](#)

The fact that the Earth is round leads to several of the aspects that have been previously mentioned in the above paragraphs. Since the Earth is round, solar irradiation is distributed unevenly across the Earth's surface, which simply means that more solar radiation hits at the equator than at the poles. The less solar irradiation you have, the less energy there is, causing less biomass (living organisms and less diversity). All forms of life require some quantity of solar radiation in order to survive, but the amount varies from organism to organism.

Why does the temperature vary so greatly from the tropics to the poles? It is not simply a matter of more incident irradiation hitting the equator. Rather more irradiation impinges on a smaller area near the equator when compared to the poles. Furthermore, because sunlight strikes the poles at an angle it must traverse more of the atmosphere before being absorbed by the earth. As a result of having to travel through more of the atmosphere more of the solar energy is deflected or reradiated back into space. How does this impact life on earth? Less solar irradiation per unit area means that temperatures are generally cooler towards the poles which limits the kinds of organisms that may inhabit these environments. More irradiation near the equator means more energy is added to the ecosystem which translates in more *biomass*.



New problems in global ecology include rising levels of atmospheric CO₂ concentrations and other greenhouse gases, and the resultant potential changes in global climate patterns. General Circulation Models (GCMs) (see [Global Climate Model](#)) are complex computer models developed by atmospheric scientists to help predict how increasing greenhouse gas concentrations might influence global climate patterns on a large scale.

For example, elevated temperatures, which are in part due to raised concentrations of carbon dioxide, affect turtle hatchlings. The map turtle and red-eared slider turtle both have temperature-dependent sex determination. A higher temperature results in a female hatchling, whereas a lower temperature results in a male. Thus, raised temperature result in fewer male turtles.

Global warming has a great impact on biodiversity distribution and abundance. Processes and patterns of the climate influence behavioral and physiological response of organisms, their productivity, relative competitive abilities of species, birth, growth, and death rates, nutrient cycling, decomposition, net primary production, and community structure of populations.

Organism Morphology

The form that an organism takes—termed its **life-form**—encompasses all of the structural aspects that make that species describable and unique. By **morphological adaptations** is meant the structural feature or features (called traits) that allow an organism to live successfully in its habitat; traits that have evolved over a (usually long) period of time as a consequence of the process of **natural selection**.

Natural Selection is a process that occurs over several generations. It allows select organisms to adapt to their environment over time. Natural selection often results in a species being able to survive in areas with environmental restrictions. For example, a plant that can grow taller than the others around it can get more sun light then the other plants around it and will increase its chance of survival and its overall **fitness**. For Natural Selection to occur, two requirements must be met. First there must be variation in some trait and second the trait must affect either survival or reproduction or both. Natural selection can result in **Directional Selection** or **Disruptive selection**. Directional Selection is when individuals at one end of the distribution do well and the other doesn't. Disruptive selection is when there is an intermediate that does not do as well as the individuals on the other sides of the distribution.

- Read [Wikipedia:en:Directional selection](#) (for further information)
- Read [Wikipedia:en:Disruptive selection](#)
- Read [Wikipedia:en:Stabilizing selection](#)
- Read [natural selection](#) (Links need not be pursued at this time)

Although we might conclude that adaptive morphological traits are acquired by a species slowly through the evolutionary process and therefore not subject to change within the lifespan of an individual, in fact many morphological traits are expressed or modified in response to environmental conditions. The individual organism inherits morphological variation within a range, and the expression of the trait represents a response to specifics of that individual's environment. The considerable similarity of all individuals of a species attests to the genetic basis of morphological traits, yet a degree of plasticity is usually present to be influenced by environmental factors. Individuals inherit this plasticity and not the **growth-form** of the parents. Thus *growth-form*

represents the outcome of both "nature" (genetic or inherited traits) and "nurture" (influences of environment on the growth process).

A growth-form that persists through many generations because of environmental constancy (but is not an inherited trait) is termed an **ecad**. However, any such trait is subject to natural selection and may, over time, become fixed in a population as an inherited **eco-type**. That is, if the trait is highly adaptive within the habitat of the population, and the plasticity of expression is under-utilized becoming a genetic burden, that plasticity may be lost or restricted. Eco-types are genetically based differences between individuals of the same species that come from different populations.

Organism Physiology

Physiology is the study of biochemical functions of living organisms. Whereas morphology (discussed above) is essentially about anatomy and structure, physiology is largely about processes. However, the two are so interlinked in any organism that one cannot really be discussed without consideration of the other. As already noted, physiological processes must proceed the growth of morphological traits. And a physiological response, such as an increase in blood pressure, results from short-term mechanical changes in the anatomy of the heart and arteries. Put another way, the shape and structure of a heart is a morphological trait; the pumping of blood—the function of the heart organ—is a physiological activity. Muscle contractions are mechanical actions resulting from biochemical signals and changes. One cannot occur without the other.

Biologists refer to **physiological adjustment** as a response to environmental change. By "adjustment" is meant a change in physiology or internal function that allows the organism to maintain life. An adjustment is limited by the physiological and morphological adaptations inherited by the organism. Just as we previously described "morphological variation" as essentially an adjustment to environment based upon inheritance of a range of possibility, so too is physiology controlled by both inherited (genetic) and environmental (external) factors. The important distinction here is between the terms "adjustment" and "adaptation", a distinction that can apply to both morphology and physiology.

- **Adaptations** are physiological processes or morphological traits inherited through genetics and subject to natural selection at the population level;
- **Adjustments** are activities and traits expressed within an inherited range and subject to individual modification within the life-span of the individual or even much shorter periods of time. The proper term here is **acclimatization**.

If I work out and buff my body to rival that of the current Governor of California, I am not adapting but adjusting or acclimatizing myself (considerably, comparing our growth-forms!). On the other hand, when a caterpillar changes into a pupa and then transforms itself into a butterfly, that is clearly an adaptation. The process (called metamorphosis) is an inherited one, and irreversible. Aging is a process that would appear to be largely irreversible (certainly death is), and apparently is an adaptation. Once reproductive success peaks and starts to decline, advantage for the species population goes towards eliminating older individuals (fortunately, some exceptions exist).

Organism Behavior

Behavioral responses to environmental factors can be observed as movements of one sort or another. We say that "behavior" is the way an organism "acts"—what activities it "does". Complex behaviors controlled by cognitive processes evolved from simple response behaviors, the understanding of which provides a basis for understanding how behavior confers survivability on an organism. Note that such responses are generally rapid (and mediated through nerves in higher animals) in organisms capable of locomotor activity, and generally much slower in organisms lacking means of motility. Thus, plants, although devoid of musculature, nonetheless respond to **stimuli** of various sorts—growing or turning towards a light, for example. Simple turning responses, either towards or away from a specific stimulus, are termed **tropisms**. Actual physical movement towards or away from a stimulus are called **taxes**. Similar behaviours called **kineses** involve physical movements that appear random in orientation or direction, but the intensity of activity is determined by the intensity of the stimulus.

- Read [Tropism](#) (Follow links to the various examples of tropisms to understand this concept)
- Read [Taxes](#) (Follow links as necessary to understand concepts; Kineses included here as well)

Summarization

The "home" of the biosphere is the planet earth, an accretion body orbiting a star. The physical realities of the planet, resulting from its size and location relative to that star called the "sun", determine the basic physical properties within which life developed and presently exists.

Organisms respond to changes and vagaries in the environment. Organisms, unlike non-living objects, survive because of the ability to respond. Responses take many forms, which we can categorize as morphological, physiological, or behavioral. However, most responses involve a combination of these types, and sorting of responses into specific types typically just means that one is the more obvious aspect of the response observed.

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CHAPTER OVERVIEW

4: Biological Communities

A **community** or **biocoenosis** is an assemblage of organisms (species populations) whose composition and aspect is determined by the properties of the environment and by the relations of the organisms to each other (modified from Braatne, 2005). Möbius proposed the term *biocoenosis* in 1877 in his study of oyster reefs in the North Sea, recognizing that interactions between species in a structurally complex system brought with it a higher level of functional complexity. Shelford defined a community as an "assemblage with unity of taxonomic composition and a relatively uniform appearance (Odum, 1959)." The *biotic community*, along with the physical or abiotic elements of the environment together constitute the **ecosystem**- how a community of organisms interact with their environment of Tansley (1935).

Like an "ecosystem," the size or area occupied by a community can vary considerably. Bounded by the distribution of the component species' populations where these overlap, communities produce a uniform species composition. Some species might as well be members of other surrounding (or distant) communities. Like the ecosystem concept discussed in [Chapter 5](#), the *community* concept is broadly defined as one of nested units: conceptually small units potentially being part of containing larger units. This fact is recognized when ecologists define **major communities** as those of sufficient size and completeness of organization to be relatively independent of adjoining communities, and **minor communities** as those more or less dependent on neighboring (or surrounding) assemblages.

Communities show both functional and structural (taxonomic) unity, although some species may be replaceable over time and space so that functionally similar communities can have different species compositions. The community concept emphasizes the idea that organisms live together in an orderly manner; that species distributions are more than simply individuals responding in a similar way to a particular set of physical factors. And, of course, a community has properties or characteristics that are more than the sum of its species populations and unique attributes.

- Read [Biocoenosis](#)

Communities and Biomes



A single tree could be considered a community

In simplest terms, a community is an assemblage of populations living in the same place at the same time, interacting with each other and their environment. According to this definition, there are also various spatial scales that are recognized when describing different types of communities. Spatial scale refers to the size of the organisms that make up the community and can range from very small (i.e., bacteria) to very large (i.e., animals). There are three approaches to spatial ecology: **Theoretical Ecology**, **Metapopulation Ecology**, and **Landscape Ecology** (Hanski 1998). Every community affects another adjacent community, i.e. communities intergrade continuously. Read [Metapopulation](#).

Examples of different spatial scales in communities:

- A forest - made up of trees, plants, and animals

- A single tree - made up of a community of insects and flora
- A termite gut - made up of a community of protozoa, bacteria, and archaea
- Read [Community \(Ecology\)](#).

Emergent properties of communities include stability, response and resilience to invasion and drought, and bioremediation. (Read [Bioremediation](#))

Terrestrial Biomes

The earth contains many different geographical areas that contain similar climatic conditions. As a result of natural selection, many comparable ecosystems, "biomes", have developed in these areas. A **biome** is a community on a global scale, and is usually defined by temperature, precipitation, and by the types of plants and animals that inhabit it. Generally, biome classification is determined by the climate and geography of an area. Each biome consists of communities that have adapted to the different climate and environment inside the biome. Specifically, there are special vegetation adaptations as well as physical and behavioral adaptations made by animals in order to accommodate the environment.



A desert biome near Las Vegas, Nevada

Several biomes have been identified and include **tropical forest**, **temperate forest**, **taiga**, **grassland**, **chaparral**, **desert**, **tundra**, and **aquatic** environments. **Tropical forests** are characterized by high precipitation (around 75–200 cm of rainfall a year) and high temperatures. In contrast, the coniferous forests of the **taigas** get just 30–84 cm of precipitation per year and are exposed to average temperatures of -60 Celsius degrees in the winter. **Chaparrals** also play host to extreme temperatures and low precipitation (15–40 cm of per year) while **grasslands** average 25–70 cm of rain per year and have temperatures similar to those of temperate forest and deserts. **Deserts** and **tundras** are both very dry biomes (less than 30 cm of precipitation per year), but differ widely in their average temperature ranges. While there are clearly a wide variety of biomes on Earth, they are not all equally represented in terms of land mass.



A photo from the Siberian taiga north of Khabarovsk.

Taigas are the largest terrestrial biome covering the Earth's surface. Located in the Northern Hemisphere, just below the tundras, they cover 11% of the land mass in the Northern Hemisphere and make up 27% of the Earth's total forest. In fact, the biggest forest in the world is the Siberian taiga.

Conifers that make up **taigas** exhibit needles rather than leaves as a specialized adaptation for the taiga biome. The needles have less surface area for better water retention and a wax covering with sunken stomata to help reduce water loss and to protect the

conifers from freezing weather. The dark green color of the conifer needles helps absorb energy from the sun to induce photosynthesis for survival. Conifers also display an inverted funnel shape to help shed the enormous amounts of snow load. The long cold winters and the short summers make it hard for plants and animals to survive and the **taiga** biome is consequently less diverse than others. The acidic soil of the **taiga** regions also affects the vegetation and the animals that feed on those plants.



Taiga land surface coverage

The survival and land mass coverage of the **taigas** is threatened by many factors. Since the woody bark of conifer trees is easily burned, fires, natural or man-made, pose a major threat to the **taigas**. Also, logging and clear cutting for pasture land diminishes the size of the **taigas** in certain areas. The province of Manitoba has signed away 40% of its productive taiga for cutting; an area equal to the size of North Dakota. In addition, Alberta, Canada is allowing massive deforestation in the next sixty years. The loss of a considerable portion of the **taiga** is major concern, not only because of the subsequent loss of biodiversity and oxygen production, but also because of the "**greenhouse effect**". The grasslands are also affected by disturbances. Belcher et al. 1989^[1] studied 25 km² of mixed-grass prairie in Manitoba Canada. The study showed that native prairie was affected by disturbances such as roads, trails, and plowed fireguards. These disturbances expose mineral soil allowing for infestations of leafy spurge which significantly declines the abundance of the dominant native grass species. Leafy spurge poses a threat to potential rangeland, and the conservation of native vegetation.

Aquatic Communities

There are three types of aquatic communities that occur in nature: **marine**, **freshwater**, and **estuaries**.

Marine communities are supported by water of relatively high salinity and are composed of organisms that are able to survive such high-salt conditions. The **tropical coral reef** is an example of a marine community that is usually found in shallow, tropical marine waters in latitudes ranging from 30°N to 30°S. On average, the growth of these communities is limited to depths of less than 100 feet and water temperatures greater than 72 °F (22 °C). These growth limiting factors facilitate the formation of limestone, the major structural component of the reefs. The limestone is secreted by living organisms, including Cnidarians, coralline algae, mollusks, echinoderms, and some annelid worms. Cnidarians are the chief contributor to the limestone formation as they secrete an exoskeleton of calcium carbonate.^[2]



A giant clam that is part of the Great Barrier Reef

There are three basic types of coral reefs: **Fringing Reef**, **Barrier Reef**, and **Atoll**. **Fringing Reef** is continuous with the shore line and is usually exposed during low tide. **Barrier Reef** is further away from shore and is usually separated from the shore by a lagoon with an island. The **Great Barrier Reef**, located off the cost of Australia, is the largest known coral reef. Its width varies between 10 and 90 miles along its 120-mile length. **Atoll** is a type of reef that allows some passage out to sea and surrounds a lagoon that does not have an island.

The reefs accommodate organisms of both mobile and non-mobile species. Lobsters, crabs, squid, reef sharks, and many different types of fish and sea cucumbers feed off of the reefs. Different types of algae also inhabit the reefs and serve as a food source for predators.

While the coral reef is an important marine community, many factors are negatively affecting its survival. In fact, as Jackson (1997) points out, coral reef communities have most likely been degraded long before the study of ecology was made relevant in the 1920s. ^ Today, the hulls and anchors of ships associated with the fishing industry are causing damage to the reefs and high demand from the jewelry industry is decreasing the size of the reefs considerably. Coastal development, water pollution and tourism also pose a threat to the success of the coral reef communities. Jackson proposes the need for large scale reef protection efforts with "extreme" political, economic, and social implications if there is to be any hope of reef conservation.^

[3] [http://www.reefbase.org/key_topics/reeffisheries.as]



Barker Dam Lake in California is an example of a freshwater community

In contrast to marine communities, freshwater communities are supported by water of relatively low salt concentration and are composed of organisms that would most likely not survive in high salinity conditions. Freshwater communities include rivers, lakes, streams, and ponds.

An **estuary** represents a community that is supported by freshwater and saltwater. Estuaries occupy a coastal location, with an open connection to the sea and some type of freshwater flow (i.e., rivers and streams). Therefore, they are affected by the constraints of

both types of environments, creating many small biological niches and accommodating high diversity.



An estuary of the Moore River in western Australia

Due to the variable nature of the salinity in estuaries, there are many factors that must be taken into account during estuary classification. Circulation patterns, tidal range, freshwater input, dominant habitat types, etc., are all examples of potentials for estuary variation. Therefore, estuaries are typically classified by regions (i.e. northeastern United States, southeastern United States). However, as Roman *et al.* point out, each estuary is capable of exhibiting unique characteristics due to the complex nature of the geomorphology of a specific area. ^ Even though regional classifications are generally acceptable, it is important to remember that there are always exceptions to the rule.

Aquatic Ecosystems

Aquatic ecosystems are comprised of two main types: **freshwater ecosystems** and **marine ecosystems**. The main driving force of life in these ecosystems is plant growth, from which food chains begin. Plants require four components to grow. They are water, energy in the form of solar radiation (sunlight), inorganic carbon (either carbon dioxide or bicarbonate ions), and minerals/nutrients. Something that we may take for granted is that many of these ecosystems are downstream from humans. However, this fact has not gone unnoticed in the ecosystems. Frissell points out that a number of well monitored species have been detrimentally effected from being downstream of humans. Frissell argues this is due to the fact that we need to view changes to aquatic ecosystems differently than terrestrial ecosystems. Events such as fire and windstorms dramatically effect terrestrial ecosystems, while they have little effect on aquatic systems. At the same time things such as flooding and accelerated erosion are limited in terrestrial ecosystems, but very important in aquatic systems. This is the context in which aquatic ecosystems should be viewed. ^[4]

Freshwater Ecosystems

The study of freshwater ecosystems is termed **limnology**. They can be divided into two broad categories: **lentic ecosystems**, which are contained in basins, and **lotic ecosystems**, which are flowing water systems. Glaciers are one cause of lentic environments, where retreating glaciers leave behind basins. The flowing water of lotic systems is responsible for about 6 to 30 times the productivity in **primary producers** compared to primary producers in standing water (Nelson and Scott 1962).

Saltwater Ecosystems

Saltwater ecosystem structures are dictated by temperature, salinity, currents, waves, and tides. The most productive areas of the sea are coral reefs and coastal waters. Freshwater rivers eventually empty into the ocean and terrestrial ecosystems meet the edge of the sea. In certain areas, specifically Australia, there have been increases in salinity in freshwater regions. This has been shown to be a major factor driving natural selection in this region; only the most tolerant organisms are able to survive and reproduce. Unfortunately, it appears that the salinity of these regions will continue to increase. However, the effects of the salinity changes on the ecosystem are unknown and remain to be seen in those areas. ^[5]

Limnology

Limnology (from Greek: λίμνη limne, "lake"; and λόγος, logos, "knowledge") is the study of inland waters (both fresh and saline) and their biological, physical, chemical, geological, and hydrological aspects. This includes the study of natural and man-made lakes, ponds, rivers, streams, wetlands, and groundwaters. When studying the dynamics of an ecosystem, limnology involves

variables such as pH, temperature, depth, and dissolved oxygen profiles of the body of water. Productivity of the system is tested using a transparency test with a Secchi disk, or by analyzing species diversity and abundance.

François-Alphonse Forel (1841–1912) established the field with his studies of Lake Geneva, the largest freshwater lake in Europe. Limnology is closely related to [Hydrobiology](#), the science of underwater life, which applies the principles and methods of physics, chemistry, geology, and geography to ecological problems. Much of modern hydrobiology can be viewed as a sub-discipline of ecology, but the sphere of hydrobiology includes taxonomy, economic biology, industrial biology, morphology, physiology, etc. The study of life in inland waters can be divided into **lotic** system ecology (flowing waters) and **lentic** system ecology (still waters).

One area of current research is **eutrophication**, which focuses on biotic interactions in plankton assemblage. This branch of hydrobiology involves microbial loops, water blooms, phosphorus load, and lake turnover. Another concern of limnology is the acidification of mountain lakes. Long-term studies are being carried out to monitor changes in the ionic composition of river, lake, and reservoir water as a result of acid rain and fertilization. Another goal of current research is the elucidation of the basic environmental functions of the ecosystem in reservoirs, which are important for water quality management and water supply.



Fish hatcheries breed fish in a safe environment before releasing them into a lake or river to supplement endangered species or support recreational fishing

Many populations of fish are declining in certain habitats due to environmental changes and recreational fishing. In response, fish hatcheries breed fish in a predator-free, unlimited resource environment before releasing them into a natural habitat, also known as stocking. A study by Power (1994)[^] investigated predation by sauger and walleye on paddlefish that were being stocked in Lake Sakakawea. Predators at three different sites along the lake were sacrificed, and 73% had ingested at least one paddlefish. All of the ingested paddlefish still intact were only 36-52% of adult size. These findings suggest that paddlefish are being stocked in the lake before they are large enough to avoid such predation. Another issue with stocking is that the progeny are sometimes genetically inferior to those that are born in a natural habitat. The downfall to raising fish in such an environment is that there is no competition and no "survival of the fittest."

Microorganisms have a huge influence on limnology. They are largely responsible for nitrogen balance in lakes, decomposition of water humus in bogs, annual cycling of iron, and oxidation of sulfur. Kuznetsov (1968)[^] studied this complex cycling by incubating reservoirs and using radioactive isotopes of carbon, nitrogen, iron, and sulfur to monitor what form they were in and at what rate turnover occurred. Microorganisms establish an elaborate cycle to maintain chemical stability that allows a variety of aquatic life to flourish.

Succession

The concept of **succession** was first clearly put forth by Clements (1916). The classical use of the term involves three fundamental concepts (after Mitsch and Gosselink, 1986):

1. vegetation occurs in recognizable **communities**;
2. community change through time results from the biota present modifying the environment (changes are **autogenic**);
3. changes are linear and directed towards a **climax** ecosystem (Odum, 1971).

Succession is the predictable and orderly changes in the composition or structure of an ecological community. It's a colonization of a disturbed area that eventually leads to an increase in species diversity. Succession is divided into two stages- (1) Primary Succession and (2) Secondary Succession.



Trees are growing on meadows and fields that are not cultivated anymore

Primary succession deals with the recolonization of bare ground. The primary succession has **r-selected organisms**-- species that can survive at high disturbance areas and are fast growing organisms. There are several factors that can cause disturbance- (1) people, (2) diseases, (3) fire, (4) precipitation/floods, (5) wind/hurricanes/tornadoes, (6) temperature extremes (like freezing or extreme heat), and (7) volcanoes. In other words, the communities that are in early succession will be dominated by fast-growing, well-dispersed species. The other stage of succession (as succession moves forward) will be replaced by more competitive species [Wikipedia:en:Ecological succession/Succession](#). A good example of primary succession is the ecological response to the Mount St. Helens eruption in 1980. Bishop et al. 2005^[6] describes that a primary succession landscape like Mount St. Helens may teach us fundamental mechanisms that describe the formation and function of ecological communities. The use and understanding of these mechanisms may lead to the restoration of devastated landscapes.

- Read [Wikipedia:en:Seral community](#)

The other stage of succession is **secondary succession** which is the recolonization of partially cleared areas (this occurs after primary succession). Eventually, secondary succession/colonization leads to mature communities called climax communities which are stable communities. The secondary succession communities have **k-selected organisms**--organisms that use the limiting resource the best and therefore can out-compete other individuals. The secondary succession may include a **seral community**--an intermediate stage found in ecological succession in an ecosystem that advances towards its climax community.

- Read [Succession](#)

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CHAPTER OVERVIEW

5: Community Succession and Stability

A community can be defined simply as the assemblage of the various special populations occupying the same place at the same time. (See [chapter 4](#) for more details). Therefore, as defined by the Encyclopedia of Earth, community ecology is the branch of ecology that is how interactions between and among species and the abiotic environment affect community structure, including species richness, species diversity, and patterns of species abundance. (See [chapter 7](#) for more details pertaining to species richness and species diversity). One of the most prominent community ecologists is the late Charles Elton. Recently, community ecologists have recognized that the world's flora and fauna are disappearing at alarming rates; such a discovery has led to an increase in investigations researching community stability ^[1].

Community Stability

Community stability can be defined as the ability of a community to defy change or rebound from change. The concept of rebounding from change is known as resilience. General resilience is a measure of stability that assumes system stability increases as return time to equilibrium/non-equilibrium solution decreases after perturbation/ disturbance. A rapid response means that a system recoils quickly back to its state of equilibrium. The concept of defying changing change is known as resistance. Resistance is a measure of the degree to which a variable changes after a perturbation/ disturbance ^[2] However, measuring stability in a system can be a difficult task. In 1955, Charles Elton proposed a theory that stated a positive stability-diversity relationship was a result of the stability of aggregate community measures like the total biomass ^[3]. There is much controversy on the definition of stability and how it is measured.

Stability Diversity Hypothesis

The stability-diversity hypothesis states that the more diverse a community is, the more stable and productive the community is. This hypothesis was formed from the basis that more stable and productive communities can use their resources better and more efficiently as compared to communities of less diversity. There are correlations with stability measures like constancy of community production and community resilience to species loss and also alterations to the relative abundance of different species. Early research has overlooked the possibility that unexpected fluctuations in the abundance of species may be more important than species interactions when it comes to creating stability-diversity associations ^[4].



Rainforests are diverse communities that may be classified as a type of tropical forest

There are a couple of arguments for and against this hypothesis. An argument for the hypothesis would be that pest outbreaks occur more often on cultivated (disturbed) land. The argument against this statement is that there is no co-evolutionary history with the pests that reside there.

Another statement that can be used to support the hypothesis is that tropical rain forests (which are more diverse) have fewer pest outbreaks than the temperate forests. The argument against this statement is that there is less known about tropical forest as compared to temperate forest, which are heavily studied.

Several experimental tests of the stability-diversity hypothesis have been done. An experiment by Nelson Hairston using bacteria and Paramecium in a two tiered trophic system showed that the extinction rate would decrease with an increase of bacteria species, this result had an increased stability and supported the hypothesis. He also found that the extinction rate increased when there was more Paramecium species present, this result showed an decrease in stability and rejected the hypothesis.

Another experiment to research the stability-diversity hypothesis was done by Tilman. He did a field experiment carried out over eleven years and found that variation in community biomass decreases with increased species richness. But when it came to year to year variation the biomass of a particular species increased with increasing species richness. These results concluded that diversity increases community stability but not population stability. The shortcoming of Tilman's experiment was that he only observed one trophic tier.

- Read [Wikipedia:en:Ecological effects of biodiversity](#)

Disturbance

Disturbance can be defined as a change in environmental conditions that affects the stability of an ecosystem. It is any distinct event which ultimately results in the loss of biomass (Huston 1994) and mortality of organisms. According to Sousa disturbances cause patchiness in natural systems. Disturbance renew limiting resources and allow species to coexist. These patches allow for migration between them increasing diversity which ultimately prevents local species from extinction. In areas of local species the absence of disturbance results in a decline in species diversity. These recurrent patchy disturbances are characteristics of most natural systems. Examples include fires in terrestrial plant communities, hurricanes and wind throws in forests, storms over coral reefs, burrowing activity of badgers in prairie grasslands, drift logs which batter the marine intertidal, damage caused by grazing elephants in East Africa, and many more.^[5] As can be seen via the disturbance link, wildfires and anthropogenic effects, such as deforestation, are examples of ecological disturbances. Disturbances, such as fire, often initiate succession. It should be noted that succession can be managed. For example, the most important disturbance of Mediterranean forests might possibly be forest fires. Mediterranean forests are a key factor in bio-geochemical cycles, in protection of soil from erosion, regulating water runoff in watersheds, and stabilizing slopes. Therefore, in the recent decade, research and political efforts have been geared towards fire-fighting and returning scorched areas to their pre-fire conditions^[6].



Fire is an example of a disturbance.

The connection between community stability and disturbance is one that has been questioned many times. The intermediate disturbance hypothesis suggests that in a community, the highest diversity is seen in communities with intermediate disturbance. And since an increase in diversity equals an increase stability, this hypothesis shows that communities with an intermediate amount of disturbance tend to be the most stable.

The **Intermediate Disturbance Hypothesis** takes into part both benthic and pelagic abilities. The benthic success includes adult survival and reproduction, and the pelagic success involves larval settlement. The amount of coexistence that a dominant species

can tolerate determines how many species can be supported. This hypothesis also states that further settlement by other species is maintained at equilibrium by the balance between settlement, productivity, and mortality but is independent of adult body size. Disturbance increases free space, but settlement decreases it. The three factors that determine the fate of an organism in a habitat are equilibrium free space, disturbance, and settlement. Sufficient settlement with little disturbances yields a habitat that has a stable population.[7]

Problems Determining Stability

In order to determine a community's stability, one must be able to determine the equilibrium point for that community. This may require years of observation. In some cases/communities, the equilibrium point can not be determined because the community is never at an unchanging equilibrium; an example of such a situation is the predator and prey systems. Another problem in determining community stability is in areas that have undergone disturbance but return to equilibrium too quickly. This happens in areas affected by abiotic factors that are under so much stress that they never reach their carrying capacity. If there are alternative stable states, it is sometimes difficult to determine the stability of a population. As a result the community will move towards another equilibrium never returning to its original state.

[[8]]

Charles Elton

Charles Elton was one of the most influential ecologists in history. Born in England in 1900, he studied at Liverpool College and New College, Oxford. He spent most of his time at Oxford. One of his most notable works was the book *Animal Ecology* (1927). This was the first book to give the basic principles of modern animal ecology. Throughout his career he conducted studies on many different species. He published many books and articles many of which were in the *Journal of Animal Ecology* which he founded and edited for nearly 20 years. He also received numerous awards for all his work and was a member of many different scientific clubs. He is recognized as having done more than anyone else to explain the complex interrelationships of different animal communities and their effect on their habitat. Elton died in 1991 in Oxford, England.

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CHAPTER OVERVIEW

6: Invasive Species Ecology

Everyone may not accept what a particular ecologist or group of ecologists deem as "the way things work". Ecology is a relatively young and complex science. As a result, some ecological concepts are based largely on conceptualizing rather than experimentation. It is not easy to test many ecological hypotheses, because it is nearly impossible to control all variables in nature and to replicate nature in controlled settings. The subject or science of "invasive species" involves the basics of ecological thought and has considerable import to global species diversity. However, this is a subject entangled with controversy.



Kudzu, a Japanese vine species invasive in the southeast United States, growing in Atlanta, Georgia

According to Shea Katriona et al. (2002)^[1], the Earth's ecosystems are being majorly impacted by biological invasions. She suggests that the invasions can be studied by multiple viewpoints including, (1) the characteristics of the invaders, (2) the characteristics of the invaded communities, (3) resources available, and (4) natural enemies. Katriona used the community ecology theory by linking these viewpoints and by applying recent niche concepts with the communities in which they invade, which provides a predictive framework for invasion ecology. The framework presented here, however, shows how core issues of invasion ecology can be introduced into communities and lead to better understanding of the effects of invasion on earth's ecosystems.

Species status and terminology



The mosquito fish can have both detrimental and beneficial effects.

Even for biologists, establishing the **distributional status** of a species in a particular location is not always straight-forward. Questions often arise as to what exactly makes a species native as opposed to non-native, because some non-native species have no known negative impacts (Woods and Moriarty, 2001)[^]. In fact, sometimes the same species can have both beneficial and detrimental effects. For example, the mosquito fish (*Gambusia affinis*) has been widely introduced around the world because of its suppression of larval mosquitoes, but also has negative impacts on native species of insects, fishes, and amphibians (Colautti and MacIsaac, 2004)[^]. Also, natural biological invasions, generally considered range expansions, and introductions involving human activities are important and could be considered a normal ecological process (Vermeij, 2005)[^].

Non-native and native species may be sometimes considered invasive, with invasions often following human-induced landscape changes. The subsequent "damage" to existing ecosystems is simply a value judgment (Foster and Sandberg 2004)[^]. For example, various status classifications exist based solely on the location or the discipline that a biologist is working in (Helmreich, 2005). As a result, many important terms relevant to invasion biology, such as "invasive", "weed", or "transient", include qualities that are "open to subjective interpretation" (Colautti and MacIsaac, 2004)[^]. Accordingly, attempts to redefine commonly used terms in invasion ecology have been difficult because many authors and biologists are partial to a favorite definition (Colautti and MacIsaac

2004)[^] . Also, the status and identification of any species as an invader, a weed, or an exotic are "conditioned by cultural and political circumstances" (Robbins 2005)[^]

The large number and current complexity of terms used in invasion ecology makes interpretation of the literature challenging and often intimidating. "Exotic", "alien", "transplanted", "introduced", "nonindigenous", and "invasive" are all words that have been used to describe plants and animals that have been moved beyond their native ranges by humans (Williams and Meffe 2005)[^] . "Foreign", "injurious", "aquatic nuisance", "pest", and "non-native", are also used as descriptive terms, each with a particular implication. Even the use of what seem to be simple, basic terms to articulate ecological concepts "can confuse ideological debates and undermine management efforts" (Colautti and MacIsaac 2004)[^] .

- Read [Introduced species](#) (You need follow links only as necessary to clarify terms)
- Read [Invasive species](#) (You need follow links only as necessary to clarify terms)

Table 9-1 illustrates the relationships among the most common terms describing species status. Setting aside the obvious difficulty that it is not always certain whether a species is truly native or not native to a particular location (requiring evidence of its presence prior to arrival of humans at that location), the greatest area of controversy involves the division of introduced species into **invasive** and **non-invasive** ("all others" in Table 9-1) because "harm" can be a subjective term based on individual judgement. Although there is a tendency to view "harm" or "pest" largely in economic terms, here we need to focus on the concept in an ecological sense.

Table 9-1. Terms related to introduced and invasive species

NATIVE	NON-NATIVE INTRODUCED (broad definition)		
INDIGENOUS or ENDEMIC	CULTIVATED and LIVESTOCK	Established in the wild INTRODUCED (narrow definition)	
		INVASIVE (pest)	All others not listed*

*Not listed in any "official" source as a pest species

- Consult the [special glossary](#) for this chapter.

Prevalence of Invasive Species



Acacia baileyana or Cootamundra Wattle is an invasive species on the island of Australia

Invasive species are considered a "significant component of global change" as they cause both ecological and genetic changes in the communities that they invade (Sakai et al. 2001)[^] . In fact, the number of species that are transferred from one biogeographical area to another each day is thought to be very large. Also, while the geographic trends and prevalence of these invasive species are not easily predicted, islands tend to contain the largest proportion. On average, though, most countries accommodate about 20% of invasive species in their vegetation. On a global scale, it is estimated that invasive species have come to occupy about 3% of the Earth's total ice-free surface over the last 500 years (Mooney and Cleland 2001)[^] .

Invasive Theories

The concept and implications of invasive species and invasion are explained by several ideas, including: **(1) The Biotic Resistance Hypothesis** and **(2) The Invasive Meltdown Theory**.

Biotic Resistance Hypothesis

The **Biotic Resistance Hypothesis** states that species-rich communities are more resistant to invasion because these types of communities are able to use the resources/nutrients more effectively/efficiently than communities with low species-richness.



The native cottontail rabbit among non-native plants like the garlic mustard, mugwort, and burdock

Species diversity, a term related to species richness, is also important to the Biotic Resistance Hypothesis. Species diversity has two components- (1) **Species richness** represented by s - which is the number of species in a **community** which is an assemblage of populations, and (2) **Species evenness** represented by e - which is the number of individuals of each species in a community.

There are several factors as to why invaders succeed: **(1)** they are highly competitive and which may allow them to reproduce more rapidly **(2)** proximity to the community is a crucial factor dealing with invasion and is divided into two parts- (a) abundance of the invader and (b) distance from the community that is being invaded upon, **(3)** dispersal rate of invaders to new habitat (there may be new migration paths that become available), and **(4)** degree of disturbance.

- Read [Wikipedia:en:Invasive Species](#)

Invasive Meltdown Theory



Aerial picture of the Soo Locks between Lake Superior and the lower Great Lakes in Sault Ste. Marie, Michigan, USA

The **Invasive Meltdown Theory** states that as species are added to an ecosystem, each one representing a potential disturbance, the native system is perturbed in such a way that the system reaches a threshold, at which point it cannot resist any further and invasions occur exponentially. Every individual invader is a threat, but it is their collective impact that can cause the greatest damage to a habitat. This phenomenon is termed **invasional cartels**, and creates the conditions for a meltdown.

One illustration of the meltdown hypothesis is the invasion of the great lakes by zebra mussels. The lakes, once incredibly murky, became crystal clear after 15 years of filtering action by the mussels that were brought in on cargo ships from the Black Sea. While the result was desirable, the mussels caused the natural defenses of the lake to be out of flux and the lakes a very easy target for invasion of non-native species. When the amount of species invading the lake are greater than the environment can support, a collapse or meltdown of the entire environment results.

Read more at www.greatlakesinstitute.ca/press/meltdownofthelakes_p.htm



A male Ring-Necked Pheasant at Deer Park, WA.

The counterargument to the meltdown theory involves naturalized species. A naturalized species is one that has become established without any major impact to the environment. Mitchell argues that many naturalized species get a "bad name" from the invasive species that cause a great deal of trouble, such as the zebra mussels mentioned above.^[2] A good example of a naturalized species is the Ring Necked Pheasant. Intended to be a colony of game birds, it was brought to the mid-west where it flourished without disturbing the native biota. It co-exists with native game birds like partridge and grouse.

Invasive species do not necessarily always have negative effects. For example, in North Dakota, one invasive species is being used to battle another. Leafy spurge is a weed that grows rampant throughout North Dakota and inhibits all other plant life where it grows. The solution to this has been to bring in another non-native species, the flea beetle which feeds on leafy spurge alone. Notably, it has no recorded negative impacts on the environment. Therefore, although it is technically an invasive species, it is being used to keep the North Dakota prairie ecosystem intact.^[3]



An *Aphthona flava* flea beetle is shown here feeding on leafy spurge.

Effects of Invasion

Invasive species have the capability of drastically changing ecosystems, and meanwhile can also affect the human economy. Agriculture, forestry, recreation, and disease are just some examples of issues that can be positively or negatively influenced by invasive species. Sometimes the [invasive species|invasive species](#) can be beneficial, and sometimes humans face the nuisance of a troublesome invader.

With the expanding global economy, increasing trade volume and international trade agreements influencing trade worldwide, the risks of "alien" invasions are increasing. The high disturbance of industrial areas increases the disturbances of natural habitats and allow for invasive species to establish. In the last three decades in China, the increasing biological invasions run hand in hand with the increase in economic development (Wen Lin et al. 2007)^[4]. In the last three decades China has had a significantly expanded economically with global trade and has consequently been affected by invasive species.

Economic and human factors have both indirect and direct factors which influence the transportation and redistribution of [invasive species|invasive species](#). The increase in global trade by land air and sea has intensified the redistribution of invasive species from places that would normally be isolated. The study of ecological factors on the influence of invasive species are vary rarely studied, and may lead to improving the understanding, predictions, and management of invasive species.

At times, import of an [invasive species](#) desired for economical benefit, but that species is potentially harmful to another ecological or economical aspect. Much effort is being put into accurately designing risk assessment technologies to determine the net economic benefit of incorporating a nonnative species to an environment. Keller *et al.* (2007) analyzed an Australian plant quarantine program (in which plants were used to make ornaments) to develop such a risk assessment program over a wide range of variables. They took into account long-term invasive effects over 10-500 years, and their results indicated that the benefits outweighed the costs in this case. The equation that was developed is: $E_R = ((1-a)\theta A + a\theta(1-A))V_T - a\theta(1-A)V_I - D$, where θ is the number of new species, V_T is the benefit of a single species, a is the rate of invasion, V_I is the economic loss caused by an invasive species, A is a proportional accuracy, D is the cost of administering the risk assessment preparation and execution, and E_R is the resulting annual net benefit. This equation seems very straightforward and has accurate and even possibly underestimated results for net benefit. However, the terms can be hard to determine, and in the case studied in this project, the annual cost of risk assessment analysis was estimated to be \$300,000. This is accounted for, however, by the term D , and is thus incorporated into the equation.



The *Aedes albopictus*, also known as the Asian tiger mosquito, has invaded many countries including the U.S. in the last two decades. It is a common carrier of diseases, including the West Nile virus.

Such risk assessments are important to the balance of economic and ecological success for a case in which incorporation of an invasive species would be necessary.

Invasive pests can kill plants and hamper agriculture, but sometimes can affect the health of animals and even humans. For example, the West Nile virus was never introduced to the Western Hemisphere until 1999, when mosquitoes that carried the disease were somehow transferred across the Atlantic Ocean. Mosquitos are the most prominent insect vectors of disease, and Juliano and Lounibos (2005)^[5] used this quality to study the dynamics of invasive species. The introduction, spread, and impacts of an introduced species can be fairly accurately measured in terms of spread of an associated disease. This particular study focused on the *Aedes albopictus* mosquito. This species was observed under varying conditions, and the effects of competition and predation were measured to determine whether they could slow or prevent invasion. Studies such as this can determine what types of environments (including both biotic and abiotic factors) are susceptible to invasion. This particular project emphasizes that full understanding of such a process must include introduction, spread, and long-term impact of the invasive species. If a study only monitors the current conditions, important dynamics of the system may be overlooked.

Summarization

Although there exists many terms describing what is usually called species **status** for a particular location, most terms are not especially controversial and largely reflect that different disciplines (e.g., agriculture, botany, ornithology, entomology) have developed preferred terminologies for describing essentially the same things.

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CHAPTER OVERVIEW

7: Species Richness and Diversity

Species Diversity Introduction

Species Richness (s) is a relative term that refers to the number of species in a community, and is directly associated with measuring the diversity of species in a given area. A related term, **evenness (E)**, is another dimension of diversity that defines the number of individuals from each species in the same area. Together, these terms have been used to describe species diversity patterns on Earth.

There are several hypotheses that have been proposed to explain species diversity patterns. Many of these hypotheses are based upon the idea that species are more diverse near the equator than near the poles. In other words, there is a recognized latitudinal gradient of species diversity on Earth. The hypotheses that support this latitudinal gradient can be divided into two groups: abiotic and biotic. The **biotic** hypotheses are those that explain species diversity patterns with relation to living organisms. The **abiotic** hypotheses, on the other hand, explain species diversity patterns with relation to non-living chemical and physical environmental factors.

Abiotic Species Diversity Hypotheses

Four commonly recognized abiotic hypotheses include: (1) **The Time/Stability Hypothesis**, (2) **The Area Hypothesis**, (3) **The Productivity Hypothesis**, and (4) **The Metabolic Hypothesis**.

The **Time/Stability Hypothesis** suggests that diversity is directly related to the length of time that an area of land has been around. Specifically, land that has been around for a long time, undisturbed, tends to have more diversity, and is therefore more stable when compared to land that has been around for a short period of time. For example, the land underneath a glacier that has just receded will be less diverse than land that never had a glacier.

The Area Hypothesis explains species diversity relative to land area. According to this hypothesis, the larger an area is, the more organisms it can support, which results in larger populations. Larger populations are characterized by fewer extinctions and more prevalent mutation events and are, consequently, more diverse.

The Productivity Hypothesis says that the more energy there is in a system, the more biomass there will be in that system. More biomass supports greater species diversity.

The Metabolic Hypothesis states that temperature has an impact on the metabolic rates of organisms. This expands on the idea that every population has a net energy flow that acts upon it. The main idea behind this hypothesis is that larger animals have relatively slower metabolic rates when compared to smaller animals. For example, a mouse must eat half of its body weight to keep from starving, while a human only needs to eat two percent of its body mass to live.

This phenomenon is explained by several ideas. One idea is that larger animals have proportionately less surface area and lose heat more slowly. So, pound for pound, they need less food. The other idea is that larger animals and plants must transport nutrients further and, as a result, use them up more slowly than their smaller counterparts.

The Metabolic Hypothesis, however, suggests that **Temperature** may also have an impact on an animal's metabolic rate. Research shows that a 5°C rise in body temperature is roughly equal to a 150% increase in metabolic rate. This is true for a large range of organisms, including aerobic microbes, plants, multicellular invertebrates, fish, amphibians, reptiles, birds, and mammals. Gillooly (2001) claims that the metabolic rates of these organisms are all derived from a general function using body size and temperature.



Body size, altitude, and diet account for 99.0% of the variation in the metabolic rates of birds of paradise.

According to **The Metabolic Hypothesis**, organisms with faster metabolic rates have faster mutation rates. This is because they will change quicker and get through more generations more rapidly. Therefore, you would expect to see new species created in small organisms and warm environments. It has also been suggested that body size and temperature predict the density and growth rates of a population. This means that individuals in warmer environments consume resources more quickly, which results in fewer available resources and lower population densities.

The Metabolic Hypothesis has broad implications. According to Brown (2004), the hypothesis is said to be able to predict anything from life history attributes, development rates, mortality rates, and life spans, to rates of competition and predation, population interactions, and patterns of species diversity. In addition, this hypothesis offers an explanation for the peak of biodiversity near the equator. [\[1\]](#)

Biotic Species Diversity Hypotheses

There are three commonly recognized biotic species diversity hypotheses. They include: (1) **The Heterogeneity Hypothesis**, (2) **The Competition Hypothesis**, and (3) **The Predation Hypothesis**.

The Heterogeneity Hypothesis suggests that the more spatially diverse the community is, the greater the species richness.

The Competition Hypothesis introduces the concept of **r** and **k** selection. **r-selected organisms** are described as rapid growing organisms that have broad resource requirements and **k-selected organisms** are described as slow growing organisms that have narrow resource requirements.

The Predation Hypothesis says that predation opens up niches and reduces prey. Fewer prey lead to liberated resources which, if used by other species, leads to an increase in species richness. The concept of a **keystone species** is important to this theory. The keystone species is the species that a community is dependent upon and is often a predator. The keystone species maintains stability of the community which will increase species richness.



A hawk is an example of a keystone species as it eats its prey, the mouse

In evolutionary ecology there are many questions regarding variation in species diversity among different areas. In addition to the preceding abiotic and biotic hypotheses, Emerson (2005) [\[2\]](#) predicts that species diversity can drive speciation and the prediction is supported strongly by the biogeographic theory. By controlling several physical features of the Canary and Hawaiian Islands, Emerson showed that the probability of extinction and speciation for each species on an island increased as the number of species increased. Based on this analysis, species number was positively related to diversification and species richness.

Hutchinson (1959)^[3] reports that there are so many animals on the planet because of three reasons: **(1)** The greater the length of food chain (greater species diversity), the more stable the environment is, **(2)** Smaller organisms undergo more evolutionary change due to large populations in which more mutations occur, **(3)** The greater number of **niches** available, the more species that can occupy them without competition. Communities of greater organism diversity and species richness will persist longer and outlast many communities that are less diverse, and have a shorter food chain.

Rapoport's Rule

Rapoport's Rule, named after **Eduardo H. Rapoport**, was proposed by George C. Stevens in 1989 as an additional explanation for the already widely accepted notion that species richness has an inverse relationship with latitude. Rapoport's rule introduced the idea that the length of the geographical range of a species, relative to the north and south axis of the earth, plays an important role in the already acknowledged latitudinal gradient of species richness. Specifically, species at higher latitudes have a wider geographical range than species at lower latitudes^[4].

The geographical range of a species refers to the range in latitudes, from north to south, in which a species can be found. This range is largely dependent upon climatic stresses in a given region. Accordingly, species in high latitudes have evolved to tolerate extreme and highly variable climatic conditions (i.e. temperature and precipitation) and therefore have a wider geographical range. Species in low-latitudes do not gain a competitive advantage by having such broad climatic tolerances and therefore occupy narrower geographical ranges^[5]. This distinction forms the premise behind Rapoport's rule.



Species in higher latitudes evolve to tolerate extreme climatic conditions, resulting in a wider geographical ranges.

Assuming equal dispersal abilities of high and low latitude species, more low latitude species are randomly placed outside of their narrow geographic range than high latitude species. As a result, more low latitude species are placed in environments that they are not well suited for. These species, termed "accidentals", "artificially inflate species numbers and inhibit competitive exclusion."^[6] In other words, "accidentals" would normally be competitively excluded by the better adapted individuals in the same area, but due to the unique nature of narrow tropical geographic ranges, the success of the "accidentals" is only dependent upon their proximity to the areas in which they do well. Therefore, in lower latitudes, more species exist in habitats that they would normally not survive in. In accordance with Rapoport's rule, this phenomenon, called the "rescue effect", accounts for the higher species diversity in the lower latitudes as compared to the higher latitudes^[7].

Rapoport's rule, although widely acknowledged, faces criticism from related studies. There is considerable doubt that Rapoport's rule is actually a causatory agent of the latitudinal species richness gradient but is, rather, an artifact of the phenomenon^{[8][9]}. The methods and logic used by Stevens are especially scrutinized, every possible error drawn out^{[10][11]}. For example, it has been suggested that Stevens over-emphasized species richness patterns in higher-latitudes in comparison to lower latitudes, resulting in conclusions that are only applicable to local, rather than regional, patterns. Such gaps in Stevens' methodology and evidence leave Rapoport's rule open to inquiry. Also, many exceptions to the rule have been demonstrated. However, whether or not Stevens' conclusions are completely accurate, Rapoport's rule plays a significant role in the study of species richness patterns and raises questions that promote further studies.

Diversity Measurements

Diversity is measured for three main reasons: **(1)** to measure stability to determine if an environment is degrading, **(2)** to compare two or more environments, and **(3)** to eliminate the need for extensive lists. Diversity indices provide important information about the composition of a community. These indices not only measure species richness, but also take into account the relative abundance

of species, or evenness. When measuring species diversity, species richness and evenness must always both be considered. In addition, indices provide important information about species rarity and commonness in a population. These are important and common tools used by biologists in order to understand community structure.

There are many indices that can be used to calculate diversity. Some of the more valuable indices that calculate diversity include the following: (1) **Berger Index**, (2) **Simpson's Index**, [\[12\]](#) which calculates the probability that two organisms sampled from a community of will belong to different species, (3) **Shannon-Wiener Index**, [\[13\]](#) which accounts for both abundance and evenness of the species present, and (4) **Species Evenness Index**. Each of the indices uses different mathematical approaches/calculations to test/calculate diversity between two or more communities. These tools for measuring diversity are often used when determining community similarity, ethnic diversity, and biological diversity.

To learn more about the diversity indices, read [Diversity index](#).

In addition to the previous indices, ecologists employ rank abundance curves, which are graphs ranking the most abundant species to the least abundant. They can be shown as a plot of number of species vs. number of individuals on a logarithmic scale that usually yields a normal distribution. This is because environments are usually undersampled, resulting in many singlets, especially in high diversity systems. Singlets make up the middle peak of the distribution, and the more sampling that is performed, the more the curve will shift to the right.



Coral reefs are the home to so many species that undersampling is likely to occur. Estimators can help make up for species that are underrepresented.

The number of unsampled species in cases of undersampling can be roughly estimated using the Chao estimator, in which $S_{\text{estimate}} = S_{\text{observed}} + F_1^2 / 2F_2$ where F_1 is the number of singletons sampled, and F_2 is the number of doublets. There is also a method of estimating what percent of the total species is represented in a sample, called Good's coverage estimator, in which $\text{Coverage} = 1 - (\text{number of individuals in species} / \text{total number of individuals})$. These estimator equations allow researchers to have a good idea of how their limited sampling relates to the entire sampled population.

Measurements of species diversity are constantly being improved and/or critiqued by ecologists. Hurlbert (1971)^{[\[14\]](#)} argued that species diversity itself is a "nonconcept" and that theoretic results are not dependable. His view is that ecologists should abandon the "poorly defined" idea of diversity completely, as well as diversity indices, and rely more on direct observation. He came up with alternate equations called "species composition parameters" that are more direct than diversity indices. Although he thought these equations are more reliable than diversity indices, he still stated that they shouldn't be strongly depended upon in research. Soetaert and Heip (1990)^{[\[15\]](#)} also argued that species indices are not always accurate, but worked on finding a way to improve

results. They approached the issue of sample-size dependence of diversity indices. They found that this dependence is highest for more diverse communities and those with more rare species. This is something that can be taken into account during sampling and utilization of the indices. Such endeavors to improve measurements of diversity have and will continue to improve ecological research methods as a whole.

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CHAPTER OVERVIEW

8: Island Biogeography and Habitat Fragmentation

Island Biogeography

Biogeography is the study of the geographic location of a species. Island biogeography is the study of the species composition and species richness on islands.

Island biogeography is a study aimed at establishing and explaining the factors that affect species diversity of a specific community. An island in this context, is not just a segment of land surrounded by water. It is any area of habitat surrounded by areas unsuitable for the species on the island. Other examples of "islands" include dung piles, game preserves, mountain tops, and lakes.



Mountain tops are considered islands.

In 1967, ecologists Robert MacArthur and E.O. Wilson, coined the **Theory of Island Biogeography**. This theory attempted to predict the number of species that would exist on a newly created island. It also explained how distance and area combine to regulate the balance between immigration and extinction in an island population. Immigration is the appearance of a new species in a community. Extinction is then the disappearance of a species from a community. This relationship is known as "species turnover", states that the equilibrium value for the island is proportional to the number of immigrants that come to the island, and the loss of individuals due to emigration and extinction.

E.O. Wilson and R. MacArthur did several experiments and made several predictions about the Theory of Island Biogeography. Some of their predictions included (1) species richness tends toward an equilibrium value and (2) the equilibrium value is the result of immigration, but emigration and extinction may also occur.

The equilibrium value (equilibrium diversity value) of an island depends on the area of the island- the larger the area the more resources there are on the island. Smaller islands support smaller populations, and smaller populations are more likely to become extinct. Here is where the **Target Effect** comes in play. The Target Effect says that larger islands have higher immigration rates because they are a bigger target.

Three basic types of species-area relationships have been well defined and demonstrated through various experiments within the field of ecology: "type-1" investigates species richness vs. sample area in nested samples (within a defined habitat or region), "type-2" is defined by examining the total species richness vs. total area among habitats or regions differing in area, and "type-3" examines local species richness in a sample of defined size among habitats or regions differing in area ^[1].

Another factor that determines the equilibrium diversity value is the distance from the source as discussed below. For example, the immigration rate is higher at closer islands than on islands that are further away from the mainland. Here is where the **Rescue Effect** comes in mind. The rescue effect decreases the rate of extinction due to recolonization and immigration. Immigration is a major contributor due to increasing population size and the size of the genetic pool. These two factors can reduce the probability that any particular species will become extinct ^[2]. Recolonization happens through two occurrences: Immigration and invasion; immigration is the arrival of a new species to an area, while invasion is the arrival of a species that already inhabits an area ^[3].

The last factor that contributes and/or determines the equilibrium diversity value is the species richness of the source. Species richness is the number of species in a community. Although islands are considered relatively new land, they can still have a great

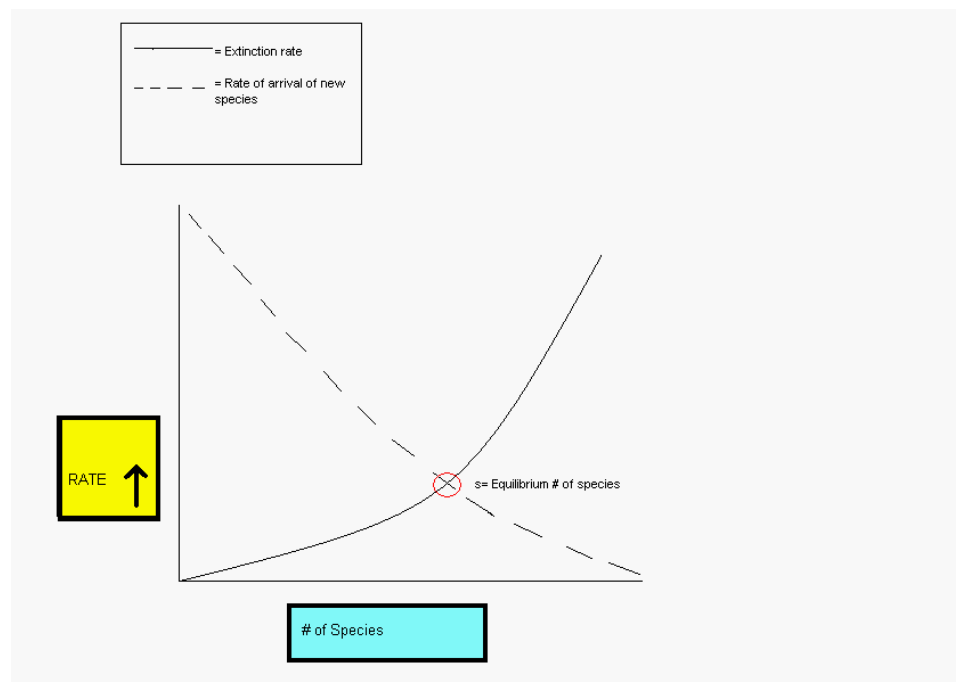
deal of diversity on them over a few years. This concept comes from the **Time/Stability Hypothesis** and to the **Species-Area Effect** which both say that the older the land is/the longer the land has been around, the more diversity and the more stable that land will contain. For example, islands may not be diverse right away because they have not been around long enough for species to migrate onto that particular land mass. The Species-Area Effect states that increased area results in increase species equilibrium. However, this relationship is not linear. The following equation describes this relationship: $S=cA^z$, where S is the number of species, c is a constant, A is the area, and z is the slope of the line (varies).

Islands may be colonized several different ways:(1) by hitchhiking on other species, (2)flying, (3) rafting, (4) swimming, (5) wind, (6) and speciation. It takes time for the new islands to gain several different species of animals due to several different aspects, but given enough time the islands will obtain life on them and become more and more diverse.

Theory of Island Biogeography

The Theory of Island Biogeography is determined by two factors. The first is the effect of distance from the **mainland**. The mainland is where new immigrant species originally inhabited. The second is the effect of island size.

These two factors establish how many species an island can hold at equilibrium. **The equilibrium species number** is the species richness of an island at which immigration balances extinction and which remains roughly constant.



For some examples of island biogeography visit:[Island Biogeography](#)

In previous chapters numerous hypotheses have been explored concerning biodiversity. Productivity hypothesis and Rapoport's Rule are major players in the world of ecological biodiversity. These hypotheses have been measured on a continental scale and oceanic scale but how well can they explore the biodiversity of islands? Earlier in this chapter colonization of islands was explained with the effect of size and distance from the mainland. How is diversity affected by the species richness gradient for island geography? Do the same patterns, or lack of, follow islands as they extend from lower latitudes to higher latitudes?

In this section three sets of islands in varying latitudes will be examined. The tropical islands of Kiribati are situated 1°33' north of the equator. The Canary Islands in the North Atlantic are located 28°06' north of the equator and the Falkland Islands in the South Atlantic at 51°40' south of the equator. The biodiversity explored included fauna and flora.

The islands of Kiribati are Gilbert Islands, Phoenix Islands and the Line Islands. Phoenix Islands will be used for this survey. The biodiversity of the islands include numerous fish, birds and wildlife. The Phoenix Islands are the third largest marine biodiversity in the world and in 2006 were protected by the Kiribata government. The island's land biodiversity is not equivalent to the biodiversity of a tropical forest but the diversity in the surrounding water is expansive. Coral Reefs and the distance from any

populous country leave Phoenix Islands undisturbed by tourists. The Phoenix Islands are susceptible to periods of drought which affect the biodiversity of plants and animals. These islands sitting almost directly on the equator support Productivity hypothesis in the water but on land it is not supported due to erratic rainfall. The Canary Islands biodiversity are one of the most expansive in the temperate regions of the world. Scientists studying Canary Islands over the past decades have been discovering a new species or subspecies about every six days. The discovery of new species at this rate makes the Canary Islands an extraordinary example of biodiversity. Twenty-Eight degrees above the equator seems like the ideal place for biomass. The European Union removed internal border checkpoints about ten years ago. Invasive species (chapter 6) have started to take control since the removal of internal borders and have decreased native plant populations by an estimated fifty percent.

The Falkland Islands are the furthest away from the equator at fifty-one degrees south of the equator. The flora on the Falkland Islands are very limited and no trees grow naturally on the islands. The fauna is more diverse than the flora with over sixty types of birds breeding on the islands. Mammals on the island are also limited with three types of seals and smaller mammals and dolphins offshore. The Falkland Islands support the Productivity hypothesis. Moving farther away from the equator diversity is limited. Biodiversity seems to be the greatest not at the equator but approximately thirty degrees north and south of the equator.

Endemism



The [Fynbos](#) of South Africa are a great example of Endemism.

[Endemism](#) comes from the word endemic which means it is unique to its own place or region and not found naturally anywhere else. The place must be a discrete geographical unit, often an island or island group, but sometimes a country, habitat type, or other defined area or zone. Endemic regions often include large bodies of water, or mountain ranges but mostly islands due to their isolation. Older islands usually have a higher degree of endemism.

Endemic Species can often become endangered or extinct due to their limited habitats and vulnerability to the actions of humans, such as large scale logging and slash and burn techniques. Some ecosystems with high endemism include, the Hawaiian forests, the [Fynbos](#) in South Africa, and many other rainforests and dry forests.

Endemic species are also affected greatly by invasive or alien species. Such is the case for the Hawaiian tree snail. The Hawaiian tree snail's existence is being threatened by the loss of habitat via deforestation (an anthropogenic impact) and by the grazing of ungulates, predation by rats, and an intentionally introduced snail, *Euglandina rosea* ^[4].

Habitat Fragmentation

“[Habitat] fragmentation *per se* is a landscape-level phenomenon in which species that survive in habitat remnants are confronted with a modified environment of reduced area, increased isolation and novel ecological boundaries ^[5].” **Habitat Fragmentation** is one of the largest causes of species extinctions, along with invasive species. We know that an ecosystem requires land and resources to maintain its diversity, but how much is enough? And when an ecosystem becomes isolated, will the edges of that isolated area remain the same kind of ecosystem as the center?

These questions are studied and answers are inferred through the study of truly isolated habitats: islands.



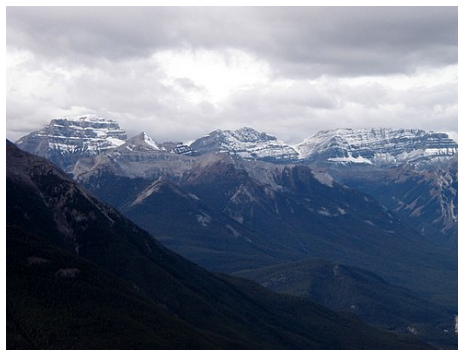
The coyote is a predator that increases with fragmented landscapes.

Islands have less diverse populations than large continents, especially those far from mainlands. Such islands have less opportunity for colonization. In order to apply what we know about islands to fragmented habitats, we must recognize colonization and extinction as constantly occurring within populations.

Anthropogenic or human-derived habitat modification is the largest cause of fragmentation. However, naturally fragmented systems are found all over the world ^[6]. Habitat fragmentation often results in lack of food and other resources for species that need them. It also eliminates habitat for species that need large unbroken blocks of habitat, examples of species that have this problem as a result of fragmentation are bobcats and upland sandpipers. This results in a increased risk of death by predation because the animal might be forced to venture outside it's patch to find food in order to avoid starvation. Certain predators like raccoons, foxes, coyotes, house cats, and crows tend to increase in fragmented landscapes. This is due to them being highly adaptable and being able to take advantage of the resources available to them. high predation in small patches makes death by predation more common for certain species. This is one of the factors that is contributing to the decline of neotropic songbirds in eastern temperate forest.

Metapopulation Theory

Metapopulation Theory states that several distinct "Patches" are stabilized by their proximity to other patches. A **Patch** is an area inhabited or potentially inhabited by a member of a metapopulation. Patches are usually small areas of land that consist of small populations. The probability of species occurrence in patches is related to the following two factors: habitat destruction and fragmentation ^[7]. Because the number of individuals in these patches is small, they can very easily become extinct. This results in **demographic stochasticity**, which are fluctuations in population size due to random demographic events.



Mountain tops are an example of a patch in a metapopulation.

The rate at which re-colonization can occur is proportional to the distance between the patches. The further the distance between two patches, the longer it will take for the patch to become colonized again. When one patch has a jump in the number of individuals that inhabit it, the surrounding patches will also be stabilized by the immigration from the species rich patch. The change in a patches inhabitants can be determined by the equation $(dp/dt) = mp(1-p) - \mu p$; where **P** is fraction of colonized patches,

M is the average recolonization rate, μ is the extinction rate, and $1-p$ is the uncolonized patches. The metapopulation is stable when the rate at which recolonization is equal the rate of extinction.

Read [[Metapopulation](#)]

Links to research: [[Eichhornia paniculata](#)] [[Maculina arion \(the Large Blue Butterfly\)](#)]

The classic concept of metapopulation was first mathematically formulated by [R. Levin](#) in 1969, but received minute attention until the 1990s when ecologists realized fragmentation of continuous populations into discrete subpopulations was occurring at a high rate.

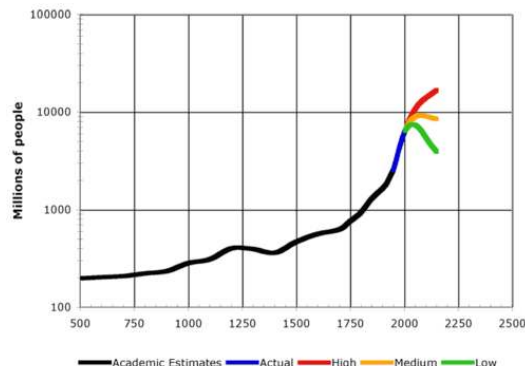
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CHAPTER OVERVIEW

9: Species and Populations



World population from 500CE to 2150, based on UN (2004)^[1] projections and U.S. census information^[2], which are both applications of demography. No matter how much data is collected, unknown variables remain, so there are alternate possibilities for the future world population.

Species and populations are probably the two most commonly used ecology terms, but they are often difficult concepts to grasp. Throughout this chapter, they will be discussed in detail, expanding on the definitions from previous chapters and explaining why there are no universally acceptable definitions. Factors influencing population growth and ways to measure and predict population growth will also be subjects of specific focus. Populations can be affected by so many factors that it is almost impossible to take every variable into account. Demography is the statistical study of the age structure of a population, and it can be used in research to determine what is causing a decline or increase in population size over time. It is worthwhile to understand species concept and population growth even though they are such broad aspects, because they are fundamental to the science of ecology.

Species Concept

You should have familiarity with the species concept from biology and have been presented with this basic tenant of the biological sciences in [Chapter 2](#) of this textbook. If need be,

- Reread [Species](#) (Follow links as necessary to understand concepts presented)

When initially considering the concept of species you may wonder why the division of organisms into species is necessary at all. According to [Ernst W. Mayr](#), a renowned evolutionary biologist, the existence and reproductive characteristics of distinct species "prevents the production of too great a number of disharmonious incompatible gene combinations."^[3] Therefore, the basis for the existence of species is genotypic in nature. However, the existence of species is not traditionally doubted whereas the appropriate definition of a species is continually a topic of debate^[4].



A mule is the infertile offspring of a horse and a donkey--an example of the gray area regarding interbreeding in the most common definition of a species.

Although a species can be defined in a number of different ways, the most common definition for a living species, suggested by [Ernst W. Mayr](#), is *any group of individuals that can breed with themselves but not with any other group*. In other words, a species is any group of individuals that is "reproductively isolated."^[5] This definition, termed the Biological Species Concept, has limitations and exceptions^[6]. Some animals that would not normally be considered part of the same species can breed with limited success. For example, a horse and a donkey can breed to produce a mule offspring but, the mule is infertile. Accordingly, there is much debate regarding the amount of successful fertility required for two individuals to belong to the same species. There are also organisms that do not interbreed at all, but propagate through direct cloning of an individual, for example many plants and insects. Other definitions must be used to define the species of organisms such as these.

So, why is such a seemingly straight-forward concept so hard to define? One problem is that the definition of a species is used in many different contexts and undoubtedly fails to satisfy them all simultaneously. In particular, there has been a great deal of discontinuity between the application of the same species concept in a taxonomic or systematic sense and in an evolutionary sense^[7]. In systematic biology species serve as fundamental units (taxa) for the description and historical progression of diversity. However, evolutionarily, species are considered only as elements of a process called speciation. Even without further knowledge of the differences between evolution and [taxonomy](#), it is apparent that the concept of a species is used in different contexts by the two. This is just one example of the many obstacles encompassing the complex debate for a universally applicable definition of a species.

In fact, it seems, after years and years of debate, that it is impossible to attain a universally suitable definition for "species". As Pigliucci (2006, p. 50) points out:

...emotions have run high for decades on the "crucial" question of what a biological species is, while at the same time plenty of researchers have conducted brilliant studies on individual species and on the process of speciation, apparently unencumbered by the lack of a universally-agreed-upon definition of what species are...

The species concept is basic to biology and therefore ecology, but it is really the **species population** that ecologists study.



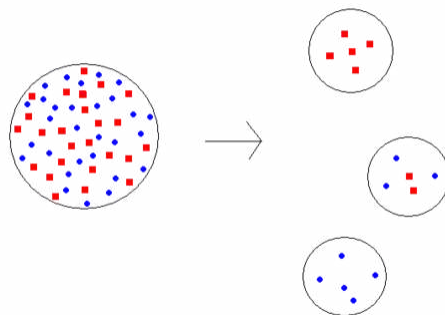
Part of a penguin (*Pygoscelis papua*) population in Antarctica

Population Biology

A *species population* is a discrete group of potentially interbreeding organisms in the same species in a given locality. Here, potential interbreeding has nothing to do with measures of fertility; instead it is a statement that all members of a population are potentially a part of a single gene pool. In a species population, there are many factors that interfere with an individual's [fitness](#) (its ability to survive and reproduce). Booth et al.(1995)^[8] describes that an individual's fitness is increased with group living, also known as the [Allee Effect](#), and that an individual's ability to survive will be increased by their size and rank. In this study, Booth shows that within the group of damselfish there was a greater chance for survival if they stayed in large groups. Within these groups the smaller individuals would benefit the most from the group living, but consequently the growth of these individuals was reduced, thus taking a longer time to reach a higher social status in the group. Reed et al. 2005^[9] support Booth's findings and also show that there is a linear relationship between log population size and population fitness. Reed suggests that "conservation efforts should ultimately aim at maintaining populations of several thousand individuals to ensure long-term persistence."

- Read [Population](#) The common use of the term in human demographics utilizes concepts and terms important to Population Biology

Diversity as a goal is split between species diversity and diversity within a population. An area that is filled with finches and owls and many species has species diversity. But if all the finches have very similar genes, or if the population has an inbreeding problem, there is not enough diversity within that population.



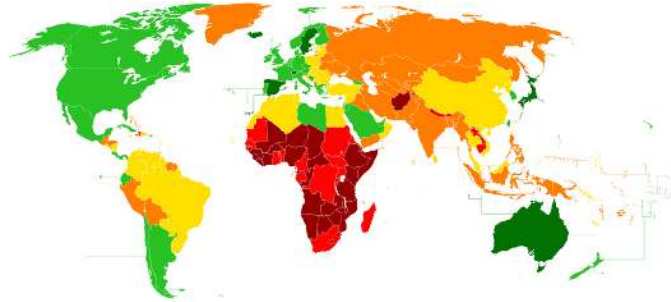
Limited diversity with separation.

When there is no diversity in the gene pool, serious effects can result. This may result from the [Founder Effect](#). A major cause of Founder Effect is when a small part of a population has moved to an area with limited interaction with other populations from the same species. A well known example is the Old Order [Amish](#) in Pennsylvania. The Amish rarely interact with people outside of the community and rarely, if ever, marry outside of the population. With the limited genetic variation, genotypic and phenotypic problems are seen more frequently in the population compared with other human populations. The Amish carry a rare allele that causes [polydactylism](#), in which there are extra fingers or toes. This recessive allele is carried by about 1 in every 14 Amish individuals compared to the outside population, where it is carried by about 1 in every 1000.

Another similar type of disturbance in a population is known as a **Bottleneck**. This disturbance occurs when a species is almost eliminated by human forces (hunting) or natural disasters. The cheetah is a prime example of a species with limited variation from a bottleneck. The cheetah's genetic make-up is so similar that a skin graft will not be rejected from one cheetah to another.

Even though the worldwide population of a species is potentially very large, not all individuals can interbreed due to obvious limitations such as separate continents, mountains or deserts, or great distances. A local population that does actually interbreed is called a neighborhood, or deme. So even though an overall population may not have inbreeding, neighborhoods could have potentially high inbreeding coefficients, which can increase the frequency of diseases or maintain a mutation in that species.

Population Growth



Population growth data can be used to determine and compare life expectancies of many regions.

Population growth is measured using time-specific life tables and age-specific life tables. Time-specific life tables are used for long-lived species, such as humans, and age-specific tables are used for short-lived species, such as annual plants and insects. Time-specific life tables assume equal birth rates for all age classes, and are useful for large populations. Age-specific life tables follow a cohort (a group of organisms of the same species and roughly similar ages) and require periodic sampling.

There are many types of useful information that studies of population growth can reveal, such as life histories for a population and life expectancies, such as in the map shown at right. Survivorship curves can also be determined by plotting the number of individuals of a cohort against time. Fecundity can be influenced by abiotic factors, such as precipitation (Milanovich et al. 2006).

Reproductive Rates

Closely related to the study of population growth is the reproductive rate of a population. **Fecundity**, m_x is the average number of offspring produced per breeding individual. A fecundity schedule is $R_0 = \sum l_x m_x$, where $l_x = n_x/n_0$ (the proportion surviving), m_x is the mean number of offspring per individual, and R_0 is the net reproductive rate of the population. If $R_0=1$, the population is stable. If $R_0<1$, the population is decreasing, and if $R_0>1$, the population is increasing.

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CHAPTER OVERVIEW

10: Resource Competition

An ecosystem can be described simply as the collection of all living and non-living components in a particular area. The living components of the environment are known as biotic factors. Biotic factors include plants, animals, and micro-organisms. The non-living components of the environment are known as abiotic factors. Abiotic factors include things such as rocks, water, soil, light, etc.

The idea of the ecosystem relates to the idea that all organisms in the environment are engaged in relationships with every other aspect (like resources and other organisms) in that environment. Ecosystems deal with energy and nutrient flow through a system/community. For example, a household or a university could be described as an ecosystem, and a city or a state could be described as a larger ecosystem.

While ecosystems may be bound and individually discussed, they do not exist independently, but interact in a complex web. The ecological relationships connecting all ecosystems make up the biosphere. Because virtually no surface on the Earth is free of human contact, all ecosystems can be accurately classified as human ecosystems.

Ecosystems vary in diversity. Some ecosystems may be very diverse with many plants and animals; whereas other ecosystems may be less diverse with fewer animals and plants. For example, tropical rain forests could be classified as an ecosystem that has high diversity; whereas temperate rain forests could be classified as an ecosystem that has lower diversity as compared to tropical rain forests.



A tropical rain forest is an example of an ecosystem that may support several amounts of plants and animals and therefore may have a high diversity

Ecosystem Concept

*Living organisms and their nonliving (abiotic) environment are inseparably interrelated and interact upon each other. Any area of nature that includes living organisms and non-living substances interacting to produce an exchange of materials between the living and non-living parts is an ecological system or **ecosystem** - E. P. Odum, 1959 (emphasis added)*



The Bald eagle *Haliaeetus leucocephalus* is a top predator; a consumer whose niche is at the top of the food web

Thus, a [Field Mouse](#) (say a Meadow vole, *Microtus pennsylvanicus*) in its burrow in the soil is interacting with the non-living elements of that burrow as it breathes, taking in oxygen and expelling carbon dioxide¹. But that activity is but a moment in time and cannot, by itself, define an ecosystem. The mouse must leave the burrow for food, interacting with plants. Plants themselves interact and exchange materials with the soil and the atmosphere and are dependent on radiation from the sun and the activity of earthworms and fungi in the soil. The latter, in turn, feed upon organic molecules left behind from the death of former living plants (and field mice). Thus, the "ecosystem" of our field mouse includes plants, and soil, and soil organisms—and of course other field mice to insure that mice will always be a part of that ecosystem. And perhaps present are Bald eagles (*Haliaeetus leucocephalus*), dependent upon trees for nesting and roosting and a stream for water (and fish as an alternative food), feeding upon Field mice, recycling those that are caught into baby Bald eagles and droppings that are food for the plants and earthworms. Already, the "area" of this ecosystem is at least as large as that required to support a **population** of Bald eagles.

It is the inclusion of all the interrelationships within a functional system that make the concept of ecosystem so broad. And the seemingly endless networks of links and interactions that give geographical breadth to an ecosystem. Of course, an ecologist could study just the organisms, activities, and biotic/abiotic interactions within the local "soil ecosystem", treating mouse and eagle excrement as we described the sun above: external, but providing important input of energy and material to the soil ecosystem. In a sense, this is what we mean by calling "ecosystem" a concept rather than just a place. We may conceive of, for the purpose of study, ecosystems over a wide range of sizes or scale, from an aquarium to an ocean, and lots of places in between. Essential are certain components that we alluded to in our description of parts of the ecosystem supporting habitat for the Field mouse, and these we will next explore in detail.

In attempting to understand any interactive, complex system, especially one as elaborate as even a simple ecosystem, it is helpful to break the system down into various component parts. By this mental process we can arrive at some understanding of the specific system and can make comparisons with other systems to further our understanding of ecosystems in general. An ecosystem consists of many component structures and these function together in various ways, suggesting an initial approach to describe any ecosystem is to consider separately its structural and functional aspects.

Basic Structural Components

Consider first an ecosystem from a structural perspective: an ecosystem consists of living (biotic) and non-living (abiotic) components. Living components include populations of organisms and the living resources they use. Non-living components include non-living resources, such as space, and the non-living physical characteristics of habitats that differ by location, such as elevation, temperature, and humidity.

We know and can observe that the **organisms** living in almost any ecosystem are not all identical individuals, but can be categorized into species (discussed previously in [Chapter 9](#)); and each species has a unique set of morphological, physiological, and behavioral attributes (see [Chapter 3](#)) that will determine how each individual functions within the whole. The species present provide ways of considering their contribution to ecosystem structure. For examples: we could describe the number of species (species richness), or the number (or biomass) of individuals of each species (species diversity), or their distribution across the physical space of the ecosystem. These are a few ways an ecologist would approach describing ecosystem structure based upon the plants and animals (and others) present in it.

In addition to the organisms themselves, there are components utilized by the organisms that comprise the **resources** of the ecosystem. These are both biotic and abiotic, inorganic and organic, and are exchanged between organisms and between organisms and the environment (previously covered in part in [Chapter 4](#)). Resources are the materials cycled by the inhabitants of an ecosystem as they carry on with life processes. We say "cycled" because all living things have a finite existence, and the substances of their material composition remain after death to be utilized in other ways.

Finally, there are those factors that are the conditions under which the organisms live. The environment of a subarctic lake is vastly different from that of a forest in the wet tropics. But consider also that conditions within a pond (an aquatic environment) are very different from those just a few yards up from the shore (a terrestrial environment). While we might be describing mostly **physical conditions**, these need not be always abiotic. In many ecosystems there are organisms that provide or create the dominant physical structure of that ecosystem. Examples are a forest and a coral reef. In a forest ecosystem, the trees are both very prominent organisms and resources to many of the other species present; but they also have a substantial effect on the conditions—the microclimates—that prevail in the forest ecosystem by providing shade and physical structure for many other organisms that may not directly utilize the trees as a food resource.

It should be clear that when we speak of ecosystem structure, we are considering various aspects of an ecosystem from a perspective that need not—indeed does not—mesh exactly with other ways of categorizing ecosystem components. Consider the trees of a forest or the coral heads of a coral reef. Each is a living organism, a resource used by many other species, and a physical structure that determines the uniqueness of its particular ecosystem compared with the environment that would occupy the same space in the absence of either trees or corals. In describing ecosystem structure, we do not break down the components into divisions of abiotic vs. biotic, inorganic vs. organic, or by species. In the next section, we will consider components on the basis of their function in an ecosystem, creating yet another set of categories independent of the structural ones.

Characteristics of Ecosystems



An example of a marine ecosystem



Acheta domesticus organism that helps maintain its ecosystem

The complexity of an ecosystem will increase as the species diversity present in the ecosystem increases. Ecosystems that are not species rich (barren ecosystems) may *appear* to be physically complex but are actually considered *functionally* complex.

Even if few species live in an environment, often because it is an unfavorable environments, that ecosystem can be still functionally complex if it include species with remarkable biochemical specializations that allow them to survive. For instance some archaea live in environments that are 113-176° F. and some organisms can get energy from inorganic chemical sources, such as bacteria that break down crude oil.

A healthy ecosystem will have high species diversity and is not likely to be damaged by human interactions, natural disasters, and climate changes. Every species within an ecosystem has a *niche*, the unique way that a given species uses its environment. New species are discovered every day and the roles they play in their environment to keep it healthy. This idea behind the species within the environment using their niches to keep it healthy can clearly be illustrated in a lake ecosystem. In a lake ecosystem, the sun hits the water and helps the algae grow. Algae use carbon dioxide and water to make sugars and oxygen. The oxygen is useful for any eukaryote organism and the sugars provide food for the algae or anything that eats the algae, such as microscopic organisms. Small fish eat the microscopic animals, absorb oxygen with their gills and expel carbon dioxide, which plants then use to grow. If the algae disappeared, everything else would be impacted. Microscopic animals wouldn't have enough food, fish wouldn't have enough oxygen and plants would lose some of the carbon dioxide they need to grow.

Soil is also an important part of an ecosystem. It provides important nutrients for the plants in an ecosystem. It helps anchor the plants to keep them in place. Soil absorbs and holds water for plants and animals to use and provides a home for lots of living organisms. The atmosphere provides oxygen and carbon dioxide for the plants and animals in an ecosystem. The atmosphere is also part of the water cycle. Without the interactions among organisms and elements in the atmosphere, there would be no life at all.

[\[1\]](#) [\[2\]](#) [\[3\]](#)

Basic Functional Components

We can recognize four functional components of an ecosystem: 1) *abiotic factors*, 2) *producers*, 3) *consumers*, and 4) *decomposers*. The latter three are living components, what Odum (1959) termed the three "functional kingdoms of nature", so important and universal is their presence in ecosystems.

Abiotic Factors



An example of organisms that live in the intertidal zone

Abiotic factors can increase or decrease the amount of **environmental stress** on an ecosystem and therefore can also affect the stability of that ecosystem. We studied many of these in detail in ([Chapter 4](#)). Do not forget that physical (essentially geological) structure can influence ecological function: the nature of interactions of species in the sea can be very different from those in the atmosphere directly as a consequence of difference in physical properties of air and water.

The **intertidal zone** is the shore area that is submerged at high tide and exposed at low tide. It is rich in oxygen and nutrients and provides a home for many different species. The organisms that live in this area are constantly exposed to a **high stress, less stable** environment. However, they have adapted to huge daily changes in moisture, temperature, turbulence (from the water), and salinity. They have to be used to living in both wet and dry conditions continually. Water is a very powerful substance and the constant impact from the moving water can have drastic impacts on both living and non-living things. Intertidal organisms are forced to bury into the sand, hide under rocks and/or attach themselves to larger structures to avoid being carried away by the waves. Also, the constant flux of the environmental temperature is enough to make any creature uncomfortable. Since this area is exposed to both water and land, the organisms here must compete with predators that hunt at both areas.



A tropical forest on a polynesian island

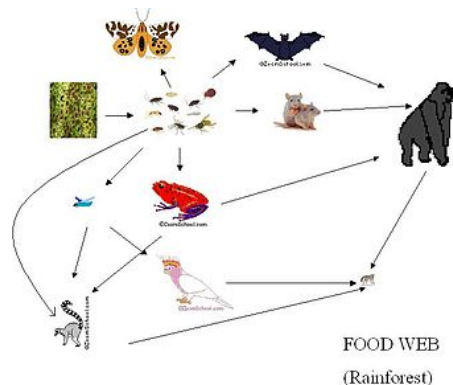
Jungles or [rainforests](#) are an example of a **low stress, more stable** environment that are vital to maintaining the ecosystems of the earth. Unlike the intertidal zone, this environment has more subtle changes that occur at a much slower rate. Jungles are very stable environments that possess some 40% of all species. It is also a very diverse environment consisting of several layers of organisms using different parts of the ecosystem. As well as increasing biodiversity, jungles are beneficial to increasing our knowledge of medicinal plants and increasing oxygen output. Since the rainforest is literally a smörgåsbord a plants and animals, discoveries are continually made of the beneficial nature of these organisms.

Read: [Intertidal Zones](#)

Food Webs

A **food web** is a series of interacting food chains. Food chains show the order in which animals consume food. Food chains and food webs are made up of Producers, Consumers, and Decomposers. **Producers** are [Autotrophic Organisms](#). "Autotrophic" means self-nourishing. The most conspicuous group of autotrophs are the **photolithoautotrophs**, organisms such as algae and flowering plants that have cells containing chlorophyll and are thus capable of fixing light energy ("photo-") to build complex organic substances from simple inorganic substances ("litho-"). In the next chapter we are going to study the energetics of this process; now, we are mostly interested in how producers "create" organic matter utilizing energy and inorganic matter. The organic compounds that are created may be used structurally within the organism or may be latter broken down into inorganic matter and energy extracted by the process. **Consumers** are [[Heterotrophic Organisms](#)], which are also termed **macroconsumers**. A simple definition of a heterotrophic organism is a species that is dependent on organic matter for food. **Decomposers** are heterotrophic organisms. These are also termed microconsumers, saprobes, or saprophytes. Decomposers are scavengers that break down dead plants and animals.

Decomposers are vital to the food web because they break down and recycle nutrients back into the soil. These nutrients are then used by producers to sustain life. Without the enzymes that decomposers provide to breakdown organic material into inorganic material, phosphorous(P) and nitrogen(N), Producers would eventually die out and the main part of food webs would cease to exist and therefore life would cease to exist. Decomposers recycle material but they do not recycle energy. Solar irradiation still provides the energy that drives the life cycle.



A foodweb of rainforest organisms

Decomposition is a natural process but decomposers speed up the process of decomposition. Bacteria, fungi and actinomycetes are three main types of decomposers. Bacteria make up about 90% of all microorganisms and are the most abundant of decomposers. They can eat anything from dead trees, dead animals and oil slicks on the surface of the ocean. Fungi and actinomycetes work on harder substances like cellulose, bark, paper and stems. These decomposers usually only work to a certain stage in decomposition then bacteria will finish the process, similar to primary and secondary succession.

A study conducted in a California river by Mary Power showed the impact that fish had on the river food web. The main fish studied in the experiment were the steelhead and roach, these fish at a juvenile stage consume insects and fish fry, which consume chironomid larvae. These larvae reduce the algae biomass in the river. She found that when the larger adult fish species were absent, smaller more abundant predators thrived and decrease the chironomid larvae population significantly, which allowed the algae biomass to increase. This results in more cyanobacteria and diatoms to flourish on the algal turfs^[4]. This study showed a good example of how consumers and producers interact, and also showed that when one trophic level is disrupted it has a domino effect on the other trophic levels involved in the food web.

With Food Webs there are a few calculations that we can use to help us better understand the system. Chain Length is essentially the number of links between trophic levels. But when we calculate this we use the mean length. So to calculate Chain Length(CL) the equation is $CL = (\# \text{ of links} / T - 1)$ where T is equal to the number of trophic levels. We can also calculate link density(LD). $LD = (\# \text{ of Links} / n)$ where n is the number of species in the web. And finally we can calculate Web Connectance(C). $C = (\text{actual links} / \text{potential links}(N))$ Where $N = n(n-1)/2$.

Food webs do pose some problems for ecological studies. Identifying trophic levels is very difficult in nature. Ecosystem boundaries are also tough to determine. Identifying all of the species in a community can be difficult. Quantifying and identifying the strengths of interactions is hard. In most cases it is very hard to determine what the eliminating nutrients are.

Biological Magnification

The focus of this chapter is trophic levels and nutrient transfer between trophic levels and the food webs. Not all transfers between trophic levels are positive. Biological Magnification is the tendency of pollutants to concentrate in successive trophic levels. The pollutants are usually toxic and cause death to the organism.

The first step in Biomagnification is when a producer takes up nutrients in the soil that it stores by accident as an essential nutrient. Producers will try to store massive amounts of nutrients, when "mistaken" nutrients are absorbed, i.e. DDT and Mercury, The concentration levels in the producers are greater than the levels in the surrounding environment. When the producer is eaten by the herbivore or omnivore the pollutants are transferred to the next trophic level. Since energy transfer between trophic levels is approximately ten percent, the next chain in the trophic level must try to consume large amounts of the previous trophic level to sustain life and the pollutant, once again, is concentrated in the next trophic level.

The pollutants, once absorbed, are stored in the bodies of the consumers. DDT and PCB's are fat soluble and when one trophic level is consumed by the other the fat moves from one consumer to the next. Water soluble pollutants usually cannot concentrate because they would easily dissolve in the organism. Polluted water leaves an organism rather easily whereas fat does not leave the body.

Three main criteria must be met for a pollutant to biomagnify:

1. The pollutant must be long lived.
2. The pollutant must be concentrated by the producers.
3. The pollutant must be fat-soluble.

Guild

Species competing for the same resources in similar fashion are known as **guilds**. They are classified according to how they acquire their nutrients, their state of mobility, and their mode of feeding. Some examples of guilds are **forbs**, geophytes, graminoids, shrubs, trees and vines. A guild is much more stable than a single species, since more than one species can balance out the system. In a study of feeding patterns on **polychaetes**, Fauchald and Jumars (1979) utilized feeding guilds as a method of generalization and determining **phylogenetic** relationships, indeed claiming that guilds were very useful in summarizing data into patterns^[5].

In a 2009 study, a guild approach was used to evaluate the roles of foraging habitats and exposure timing, as well as trophic position on Mercury (Hg) bioaccumulation. Five species of waterbirds forming three distinct foraging guilds in the San Francisco Bay (SFB) estuary were used in this investigation. Because estuarine waterbirds form well-documented, distinct guilds distinguished by their feeding method and habitat use and because the SFB estuary has a legacy of Hg contamination from historic mining in the Sierra Nevada Coast Mountain Range, Hg exposure was able to be evaluated on both large-scale foraging strategies (such as trophic position) occurring among guilds and small-scale strategies (such as foraging micro-habitats) that occur within guilds. As indicated by this study, SFB waterbirds accumulated alarming Hg concentrations. Concentrations that place them at considerable risk to deleterious reproductive effects. Such exposure was shown to vary as a function of micro-habitat, region, trophic level, and time spent in the estuary. These results have raised quite a bit of concern because the SFB estuary is among the most important sites for wintering, migrating, and breeding waterbird populations along the Pacific Flyway ^[6].



A bear is an example of a keystone species, which provides stability to a community.

Keystone Species

A keystone species is a species having a disproportionate effect on the ecosystem. They provide stability to an ecosystem. Normally they are not the dominant species but are required for a community to have stability. Many times, keystone species are predators that keep some type of herbivore from consuming all of the dominant plant species. One interesting aspect of keystone species is that, since they normally feed on predators that consume small numbers of prey, they can effectively control a system without actually needing to have a large population size.

J. Brown and E. Heske studied the effects of the removal of *Dipodomys* spp. (Kangaroo rats) from the Chihuahuan Desert shrub habitat in southeastern Arizona. Twelve years after the removal of three species of kangaroo rats, the controlled plots in the habitat went from shrubland to grassland. The density of perennial and annual grasses increased considerably, and other rodent species in the area colonized. These major changes in the ecosystem showed that the *Dipodomys* spp. have a significant effect on the diversity and biogeochemical processes, which led the researchers to believe that the kangaroo rats are a keystone species ^[7]. Some other examples of keystone species would include Starfish, Sea Otters, Bears, Beavers and Domestic Cats.

- Read: [Keystone Species](#)

All the examples of keystone species mentioned above are animals. However, this isn't always the case. *Pinus chiapensis* is an early successional, neotropical pine species found in warm, humid, mid-elevation Mesoamerican areas such as in the tropical montane areas of southern Mexico and western Guatemala. It has been discovered that forests dominated by *P. chiapensis* are the first to appear after disturbance, modifying drastically the environment by shading the forest floor, favoring soil development, increasing the rate of soil carbon sequestration, acidifying the soil, releasing nutrient cations by weathering the bed rock, and providing a source of food for birds and mammals. *P. chiapensis* trees inhibit their own development while facilitating the growth of broadleaved species typical of tropical montane cloud forests. Ultimately, *P. chiapensis* is a keystone species because of its crucial impacts in tropical montane cloud forest regeneration and its effect on ecosystem processes ^[8].

Hypotheses of Food Web Control

Each food web contains N numbers of trophic levels and with each number the cycle of dependence flip-flops according to the Oksanen's Model. There are two hypotheses involved in this model one is known as the **Bottom-up Control** hypothesis. The bottom-up control hypothesis states that both the top and the bottom trophic levels are controlled by resource limitations. For example in a three tiered food web (three trophic levels), the bottom trophic level would contain a species of plants, which of course are dependent on the resources available to it. The next trophic level would be some species of herbivore, these herbivores are limited and controlled by a species of predator which is also the third trophic level. The predator or top trophic level is then limited by the plant resources keeping the herbivores alive and reproducing.

If we were to now add a trophic level, such as a secondary predator (the original predator being the primary predator), the cycle of dependence would then flip-flop, and the **Top-bottom Control** hypothesis would apply. The top-bottom control hypothesis states that the food web cycle is predator limited. We now have our plant species ==> the herbivore ==> the primary predator ==> and the secondary predator. The plants that were resource limited are now predator limited by the herbivores. The herbivores are now resource limited by the plants abundance. The primary predator is now limited by the secondary predator and the secondary predator is now limited by the resources of the primary predator, herbivore, and plants.

This cycle repeats itself and with each additional trophic level added, the limitation of the lower trophic levels changes from either resource limited or predator limited to the other. The relationships of two trophic levels when the bottom is resource limited and the top is predator limited gives a positive slope. The more of the lower trophic level the more there is of the upper trophic level. The inverse is true when the lower trophic level is predator limited and the upper trophic level is resource limited, it creates a negative slope the more are of the upper trophic level the less there will be of the lower trophic level.

For more detailed information on this trophic cascade idea and for examples read: [Trophic cascade](#)

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- Footnote:¹ Breathing is an activity at the organism level of biological complexity. The actual use of oxygen molecules and production of carbon dioxide molecules takes place at the cellular and subcellular levels. The exchange process within the vole involves tissue and organ level activities (lungs and circulatory system).

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CHAPTER OVERVIEW

11: Predation and Herbivory

Introduction: Predation

Ultimately, the source of energy for all life originates from the sun. Plants utilize the sun's energy, animals eat plants and utilize the plants' energy, and some animals eat other animals and utilize their energy. The food chain is a cycle of predation, and although it is necessary for life to exist, it has to have limits. Prey develop defenses against their predators, and predators strive to overcome such obstacles. The balance between survival of prey and predator is part of the reason that our ecosystem is so diverse.



The skunk is an example of a prey who uses its chemical defense to scare off predators. The skunk releases a toxin or noxious compound that has a foul smell/odor to it

It is easy to think of predation in the context of common sense. Predator eats prey. However, ecologically, predation is defined as any interaction between two organisms that results in a flow of energy between them ^[1]. This definition is applicable to both plants and animals. There are four commonly recognized types of predation: (1) **carnivory**, (2) **herbivory**, (3) **parasitism**, and (4) **mutualism**. Each type of predation can be categorized based on whether or not it results in the death of the prey. Carnivory is lethal to the prey, while **herbivory** and **parasitism** may or may not be lethal to the prey. **Mutualism** is not lethal to either predator or prey but, rather, benefits both organisms.



A carnivorous plant has evolved mechanisms of attracting, trapping, and consuming insects

Carnivory

Carnivory is usually the first type of predation that comes to mind when thinking about relationships between predator and prey. Carnivory takes place when a predator consumes meat rather than plants and consequently kills its prey. Organisms that eat meat are accordingly called carnivores. Some types of carnivores do not need to eat meat in order to survive but do so anyway. **Obligatory carnivores**, on the other hand, cannot survive without meat in their diet. **Hypercarnivores** are an extreme example of obligatory carnivores and are able to eat *only* meat due to restricted digestive capabilities. Even though we sometimes associate carnivores with larger animals, carnivorous habits can occur in plants and fungi that feed on insects or microscopic invertebrates. Therefore, the concept of *meat* in the definition of carnivory is open to interpretation.

Carbone *et al.* (2007)^[2] used mathematical models to predict prey size limitations for carnivorous mammals. These limitations can be divided into two dietary groups: (1) **small-bodied species**, which feed on prey smaller than themselves, and (2) **large-bodied species**, which feed on prey of approximately the same size. A daily energy expenditure model was developed that incorporates the energy cost of hunting per unit of body mass. The resulting predictions were compared to daily energy intake estimates for 32 species. The results showed consistent differences in energy and time budgets between small and large-bodied species. Specifically, it was shown that energy expenditure by the predator increased with increasing prey size. That is, large-bodied carnivores expend more energy hunting their prey. Carnivores have, therefore, been assigned a maximum possible body mass of one ton. Even though the largest extant carnivore, the polar bear, weighs only about one half of one ton, there are documented extinct species that tipped the scales at nearly one ton. Interestingly, herbivores can grow to be much larger than carnivores, as they don't need to hunt down their prey and often aren't limited in the way that carnivores are. There are extinct herbivores that weighed in at nearly 15 tons!

[\[3\]](#) [\[4\]](#) [\[5\]](#)

Modeling Herbivory

For monophagous herbivores, we use the same model as the [Lotka-Volterra](#) Predator-Prey model.

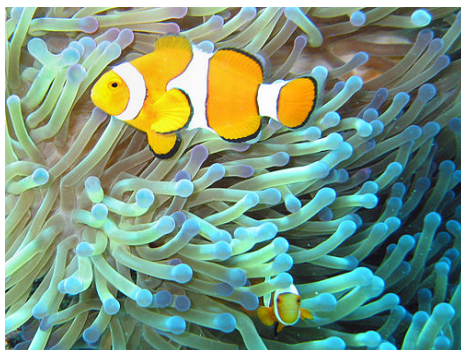
$$dP/dt = \beta\alpha NP - mP$$

For polyphagous herbivores, assuming a constant rate of herbivory,

$$dN/dt = rN(1 - N/K) - h, \text{ where } h \text{ is a constant}$$

In this population, N is dependent upon r and k , where r is the growth rate of N and k is the carrying capacity.

Parasitism and Mutualism



Clownfish and sea anemones have a mutualistic relationship in which the anemone provides a shelter for the clownfish who is immune to its stings, and the clownfish provides the anemone with food.

Parasitism takes place when one organism (**parasite**) benefits at the expense of another (**host**). This type of interaction usually harms the host but, unlike carnivory, does not always result in the death of the host. In most cases, the parasite is much smaller than the host and has a much faster reproductive rate. The tapeworm is an example of a parasite that can thrive in the human digestive system, where it uses nutrients that are important to its host. This often results in weight loss.

Interestingly, it has been proposed that sleep evolved as a defense against parasitism.^[6] Studies have been done in which different mammals slept for varying amounts of time. White blood cell counts were subsequently compared, and parasitism rates for different mammals were analyzed. Based on the data, there was a strong correlation between sleep and immune system strength

(white blood cell count). Also, mammals that slept longer were shown to be less prone to parasitic infection. It is questionable whether or not sleep evolved directly to ward off parasitism, but it is clear that sleep has an important role in boosting the human immune system.

Mutualism is similar to parasitism except that the host is not harmed. In fact, both species benefit from the interaction. One example of this type of interaction is called the **endosymbiotic theory**. The endosymbiotic theory suggests that, at some point in the past, an anaerobic cell engulfed an aerobic bacterium, and a mutualistic relationship resulted. That is, the cell provided food and shelter for the bacterium, and the bacterium made additional energy available to the cell. This mutualistic interaction proved so beneficial that natural selection favored these cells. The bacteria that were engulfed are now commonly known as mitochondria. A similar scenario involving a eukaryotic cell (already possessing mitochondria) engulfing a photosynthetic cyanobacterium is hypothesized to have resulted in chloroplasts.

Prey Defenses



Some butterfly species mimic the coloring patterns of their noxious counterparts.

Predation can result in the development of anti-predation strategies by prey populations. Consequently, predator populations develop their own strategies to overcome prey defenses. This phenomenon, known as the red-queen theory, plays an important role in evolution and predator-prey interactions.

Prey defenses can be divided into several different categories. Many organisms utilize **chemical defenses** in the form of toxic or noxious secretions that cause them to taste or smell bad. Most of these organisms exhibit **aposematic** coloring patterns, which means that they are characterized by distinct markings or bright colorings that signal to the predator that they are toxic and non-palatable (unpleasant tasting). Due to the success of aposematic organisms, organisms that are not noxious, and therefore vulnerable to predation, may exhibit similar coloring patterns to aposematic organisms in order to falsely repel their predators. This is another type of defense called **Batesian mimicry**. Batesian mimicry occurs when a palatable species imitates a non-palatable species. This type of mimicry is only successful if the population of the palatable species is smaller than the population of the non-palatable species. **Müllerian mimicry** occurs when two non-palatable species converge their coloration and patterns for reinforced protection. South American butterflies provide an example of both Batesian and Müllerian mimicry.

For more information, * Read [Wikipedia:en:Mimicry](https://en.wikipedia.org/wiki/Mimicry)

Prey also use coloring patterns to blend into their surroundings. **Crypsis** or camouflage is a means by which organisms use their shape and their coloring to blend into their environment rather than standing out. Clearly, color is an important defense that can be used in multiple ways to protect prey from their predators.

Fighting, **escaping**, and **armor** are three other possible prey responses. Some prey fight back against their predators as a form of self defense. Organisms may also try to **escape or flee** from their predators by using a **startle response** or **indirection**. During this type of defense, the prey perform an action that startles or distracts the predator long enough for them to escape. For example, some toads shoot blood from their eyes, and other animals imitate loud sounds. **Armor** is a form of physical protection. Things such as the shells on turtles, spines or needles on a pufferfish, and thorns on a plant are examples of different types of armor.

Other organisms employ **intimidation** or **threat** techniques that make them appear larger than they really are. Hissing and growling are examples of intimidation techniques that display aggression and create the illusion of an increased threat to predators. **Satiation** and **masting** are intertwined ideas that result in the survival of some prey at the expense of others. **Masting** is more commonly thought of as herding and occurs when organisms travel in very large groups. Because of the size of the groups, predators can only consume so many of them, resulting in the survival of some prey, but not all.

Predation

The predation hypothesis states that predators reduce prey. Fewer prey liberates resources, which in turn are used by other species, which increases species richness. According to Holling (1973),^[7] populations of predators and prey often mirror each other. When there is an influx in prey, predator populations tend to rise as well due to an abundance of food. As prey diversity increases, it decreases the likelihood of any single species being overly preyed. Therefore this also leads to species richness due to predation. Yoshida et al. supports this idea, and adds that predator density also has a huge impact on species richness. If there is a low predator density, then prey have less of a need to adapt. However, as predator density increases, it forces prey to evolve and to become more resistant to predation, thus forcing more species diversity. Predation also includes the concept of keystone species, or a species that the community is dependent upon, which maintains stability of the system and increases species richness. Keystone species are often predators, e.g. the African elephant, *Loxodonta africana*, a keystone species of the savannas. One problem this hypothesis encounters is what drives predator diversity.



The African elephant is a keystone species

- Read [Predation](#)
- Read [Keystone species](#)

The African elephant maintains its habitat by uprooting small trees, which left alone would overtake the savannas and turn them from a grassland into a forest or shrub thicket. By maintaining the grasslands, the elephant ensures the survival of herds of grazing antelope, and the antelope's predators, such as the prides of lions.

The first predator-prey models were proposed in the 1920s by [Lotka](#) and [Volterra](#) and predict oscillations in populations of predators and prey. Their model was expanded to include heterogeneity so the model could predict actual predator-prey behavior. (Huffaker 1958)

- Read [Lotka-Volterra Equation](#)

Mimicry

- read [Mimicry](#)

Batesian Mimicry

As a defense against predation some species have evolved to mimic the coloration and patterning of species that are poisonous or less palatable. This type of defense mechanism was first recognized by the English naturalist Henry Bates in 1862.

Müllerian mimicry

Two species that are non-palatable converge on a similar pattern or coloration. This is known as [Müllerian mimicry](#) and serves as a reinforcing warning to the predator.

Plant defenses



Cereus alacriportanus uses its mechanical defenses to keep from being preyed on by herbivores.

In their fight for survival, plants have evolved defenses against herbivory. There are three main categories of defense that plants use. The first defensive mechanism is **mechanical defense**, which includes physical features such as thorns and needles. The second type of plant defense is **masting**, which involves producing more progeny than any predators can consume. An example of this is Oak and Beach trees, which release so many cones that they can not all be consumed by predators. The final type of defense is **chemical defense**, which is comprised of five subgroups. The first chemical responses are secondary metabolites. This type of defense prevents the herbivore from using its central metabolism to digest the plant. The second type of chemical defense is producing unpalatable taste which keeps predators from consuming the plant. These plants normally contain terpenes and phenolics. Some plants that take advantage of this mechanism are milkweed and mustards. The third type of chemical defense is inhibiting absorption. These plants do not allow the predators digestive enzymes to get absorb nutrients during digestion. The more of the plant that the predator eats the greater the effect will be. An example of plants that use this method are tannins and cumerins. The fourth chemical defense is a plant's ability to make toxins. These toxins are usually alkaloids and cyanides. Deadly nightshade is a plant that uses a toxin to protect itself from any predator. The last type of chemical defense is repellants. These plants usually contain one of the chemicals [terpenes](#) or [amines](#). Citronella plants take advantage of this method.

- Read [Plant defense against herbivory](#)

Predator-Prey Models

In 1965 Rosenweig and McArthur came up with a predator prey model using linked equations that was a modification of the [Lotka-Volterra equation](#).

$$\begin{aligned}\frac{dN}{dt} &= rN - \alpha NP \\ \frac{dP}{dt} &= \beta \alpha NP - mP\end{aligned}$$

In this model:

N=Prey Species Population

P=Predator Population

α =Predation Coefficient(consists of searching, catching, and consuming)

β =Conversion Factor

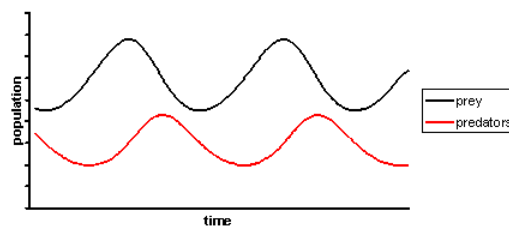
m=Mortality Coefficient

r=Growth Rate

In order to make more sense of these models we need to look at Zero Growth Isoclines(ZGI) also called a [Nullcline](#). This is where $\frac{dN}{dt} = 0$ or $\frac{dP}{dt} = 0$ is set equal to zero. Then the equation it is solved for P or N. To solve for the prey's ZGI you solve for P when $\frac{dN}{dt} = 0$. To solve for the predator's ZGI you solve for N when $\frac{dP}{dt} = 0$.

$$\begin{aligned}\frac{dN}{dt} &= 0 \\ rN - \alpha NP &= 0 \\ rN &= \alpha NP \\ r &= \alpha P \\ P &= \frac{r}{\alpha}\end{aligned}$$

In order to maintain prey population size at equilibrium, the predator population must increase or become more efficient (α increases) predators. The larger α , the fewer predators that are needed. To maintain P at equilibrium you need N prey; if m is higher you need more N or an increase in $\alpha\beta$. Also, the more efficient P (higher $\alpha\beta$), the fewer N needed. When you plot the prey's ZGI with N as the horizontal axis and $P(r/\alpha)$ as the horizontal axis, you get a horizontal line. When you plot the predator's ZGI on the same graph ($N = m/\beta\alpha$) you get a vertical line. When you plot the vectors for all different populations, you get a stable [limit cycle](#), which also leads to stable oscillations on a graph where N and P are plotted against time. This is also well known as the common Predator-Prey cycle.



There are also a few assumptions that are built into this model:

1. Size of N is limited only by P
2. N is the only food source for P
3. P can consume infinite amounts of N (never satiated)
4. N & P encounter each other randomly
5. P & N age structure is invariant

Predator-Prey cycles are an important part of understanding the relationships between predator and prey. The first realization of this cycle was believed to be noticed by an Italian mathematician named Volterra. Volterra's equations are extensively used in the study of species relationships. Volterra observed Adriatic fishing fleets rise and fall with the numbers of fish caught. As the number of fish (prey) increased so did the number of fisherman (predator) and as the fish decreased so did the number of fisherman. This cycle will eventually repeat itself.

It has also become apparent that Predator-Prey relationships are a major driving force behind evolution. As predator density increases, the number of prey consumed also increases. This forces the prey to adapt to avoid consumption. In other words, the individuals who are better at avoiding consumption live on. Since the better-adapted individuals survive to reproduce, they pass on their survival skills to their young. With a prey population that is becoming better at avoiding consumption, the predators must also adapt to become more efficient. The individuals who cannot capture any prey die off, and the better-adapted population lives on to pass on their traits. This continues in an evolutionary predator-prey cycle.^[8]

The Canadian Lynx and Snowshoe Hare are prime examples of a predator-prey relationship. The Canadian Lynx are considered a specialized predator: they will try to only feed on the Snowshoe Hare. Since the 1720s the Canadian government and the Hudson Bay Company have been keeping meticulous records of the rise and fall of Lynx and Hare numbers. Every eight to ten years, the cycle can be observed. Another excellent example of these relationships is the predation of lemmings in the high-Arctic tundra in Greenland. The lemmings have 4 main predators: the arctic fox, the snowy owl, the stoat, and the longtailed skua. This is a highly observed relationship because the number of prey has no limits other than predation. This means that they have an unlimited habitat

available to them and an unlimited food source. Since there are no other factors contributing to the number of prey, scientists are able to find many relationships between predator and prey, such as which predators are more efficient during high and low prey densities, which predators are more effective during certain seasons, and so on.^[9]

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CHAPTER OVERVIEW

12: Parasitism



This is an example of a parasite that can cause Chagas disease

Symbiosis is a form of living in which two organisms that are phylogenetically different (unrelated) co-exist over a long period of time (usually for the lifetime of one of the individuals). There are several different outcomes of symbiosis. When a symbiote lives with another organism, this can cause [commensalism](#), which is defined as two organisms that co-exist in the same space, with one of the organisms benefiting from the other while neither harming nor helping the other organism. Symbiosis may also take the form of mutualism, in which both organisms benefit. Parasitism occurs when the symbiote (which is usually a smaller organism) benefits from the other organism (the host), which is harmed, sometimes lethally.

The term parasite has come to mean a eukaryotic, pathogenic organism. Some parasites require the use of **vectors**, such as insects, that carry the parasite to a reservoir.

It is a fact that nearly half of all the animals have at least one parasitic phase in their life cycles. Essentially all free-living animals are host to one or more parasitic taxa at some point in their lives.

Examples of Parasites



Mistletoe is an example of a plant parasite

Some examples of endoparasites include [Giardia lamblia](#), an anaerobic protozoan parasite which reproduces via [binary fission](#). It affects humans, cats, and dogs, among other wild animals. Another endoparasite is the [hookworm](#), either *Ancylostoma duodenale* or *Necator americanus*, which infects humans.

Examples of ectoparasites include the Rocky mountain wood [tick](#), *Dermacentor andersoni*, and a mosquito. [Mistletoe](#), is an example of an epiparasite, called an aerial parasite. A plant parasite is a parasite that attaches to the branches of trees or shrubs.

Types Of Parasitism



Example of a endoparasite

There are several different types of parasites. Parasites that live in the body are called **endoparasites**. An example of an endoparasite is a hookworm that lives in the host's gut. Parasites that live on the outside of the body are called **ectoparasites**. An **epiparasite** is a parasite that feeds off another parasite; this is called **hyperparasitism**. An example of this situation is a wasp or fly larva being an endoparasite in a wasp larva and the wasp larva being an endoparasite in a wood boring beetle larva.

Endoparasites get access to the host's body through an organism's tissue and through ingestion of raw foods. An example of an organism that gains access through raw foods is the nematode *Ascaris lumbricoides*. It gains access to the human intestine, where it produces large numbers of eggs that are passed out of the host's digestive tract to the external environment, where they may be inadvertently ingested by humans in places without good sanitation.

- [\[Examples of Parasitism\]](#)
- [\[Parasites\]](#)
- [\[Parasitism in Plants and Animals\]](#)

Plasmodium, the protist that causes malaria, is a parasite of humans using the *Anopheles* mosquito as its vector.

Most **epiphytic** plants do not harm their host and do not use nutrients from the host, but some, such as mistletoe, are parasitic. The berries from mistletoe are covered with a sticky laxative coating and are spread by birds. These seeds develop haustorium when germination begins and penetrate the bark of young trees. Lethal infections can subsequently occur.

Brood Parasitism



The Goldeneye duck lays its eggs in the nests of other females.

Organisms called Brood parasites^[1] use the strategy of brood parasitism, which is often an overlooked type of parasitism. This involves the use of host individuals of the same or different species to raise the young of the brood parasite. This therefore leaves the parasite with no responsibility of rearing their young. This leaves them more time to focus on other things such as producing more offspring. The most common types of brood parasites are usually birds and insects. A couple of examples of birds are the Brown-Headed Cowbird, and the Goldeneye duck. Cuckoo bees and wasps are some examples of insects that are brood parasites.

The Cowbird family is the bird family in North America that is an obligate brood parasite (one that must parasitize because they are not capable of building a nest). While most brood parasites have eggs that mimic the host's, eggs the cowbird is again different. The

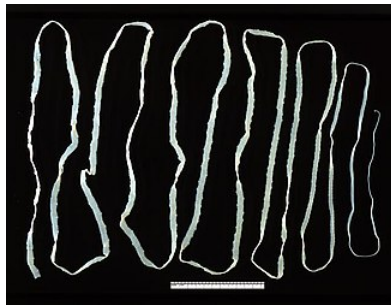
cowbird has been documented to have used over 200 different host species.

Parasitoidism

This phenomenon usually occurs in wasps, where the parasitic association usually results in the death of the host. A wasp will lay her eggs in front of, on, or in another insect, sometimes a grub. The larvae hatch inside of the grub, feeding on it and growing, until they burst out of the organism, killing it in the process.

The Host

The most important aspect of the parasite's life is the selection of a host. Without a host species the parasite does not and can not survive. For a parasite to survive, the host is required to complete the life cycle for the parasite. Since this is a vital part of the parasite's livelihood, the parasite will rarely kill their host species. Unfortunately for both parties, the simple presence of a parasite can cause much harm to the host. The choice of a host species is observed through host specificity and host range.



A full-grown tapeworm that infects humans and lives in the small intestine

Host specificity is seen whenever a parasite is supported by only a single host. The host specificity of a parasite is very important to parasites that flourish only in certain environments and conditions. Many parasites in fact are limited to only one or a few closely related host species. Even though it is possible for a parasite to infect different types of species, they still tend to parasitize certain species more than others. An example of this occurrence can be seen in the parasitic flatworm *Monogenea*. The *Monogenea* have been known to be parasitic on teleosts, elasmobranchs, amphibians, and reptiles. However, the highest concentration of these flatworms has been seen on the **teleosts**(ray-finned fishes). The *Monogenea* show high host specificity for the teleosts.

The **host range** of a parasite is when that organism is supported by a number of host species. It is also a measurement of the range of host species a parasite will/can infect. An example of a parasite that has a wide range of host species is the common mosquito that not only parasitizes humans, but other animals as well. The mosquito requires the blood of other animals to sustain its life cycle. Host specificity and host range can be compared to the concepts introduced in Chapter 11, **Ecology/Predation and Herbivory**, that discusses monophagous and polyphagous herbivores that either eat one species of plant and are dependent on that food source or eat many species of plants to have a wider range of possible sustenance.

Some parasites can manipulate their host's behavior; a good example of a parasite with this manipulation ability is the hairworm. Their lifecycle consists of a transition from an aquatic habitat, where they live off aquatic insect larvae, to a terrestrial habitat where they live off crickets and or grasshoppers. Studies of crickets infested with mature hairworms have shown that the crickets are more likely to seek water. This is when the hairworms have reached their free living stage. Once the crickets reach the water the hairworms emerge and cause the crickets to struggle about the water. This process causes an increase of predation by fish to prey on the struggling crickets ^[2].

Host Defenses

Hosts have evolved various adaptations to combat parasites initial infection and proliferation. These adaptations can be as complex as antigen specific cell mediated responses, which are most common in vertebrates, or simpler, like barrier mechanisms. Hosts also have behavior defenses that reduce the chances of an individual coming in contact with a parasite. Parasites can have an effect on host life-history evolution, sexual selection and also population dynamics ^[3].

There are two kinds of host immunities; **adaptive immunity**, whereby the host produces antibodies which are parasite-specific, and **Innate immunity**, which are non-specific. Some techniques a host may utilize to defend against parasites include evasion, preening, grooming, and self medication.

Evasion is one of the first immune defense host response against infection as it imposes several barriers to viral replication and spread ^[4]. The most common type of evasion is when we have a viral or bacterial infection and your mucus glands work to excrete the infection through the nearest exit, such as the nose. Another interesting example of evasion can be found in *Infection and Immunity* Journal at: ^[5]

Preening is a way to reinforce cospeciation between the host and the parasite. This happens when the host and parasite speciate in tandem, generating congruent phylogenies. To learn more visit: [Host defense reinforces host-parasite cospeciation](#)

Grooming is a very common way for hosts to control parasites. An example would be primates sitting together picking them off each other and eating them. Self-medication could be a possibility also: a host could eat a type of plant that might force an evasion.

Certain ectoparasites decrease the reproductive success of breeding birds; an example of one of these ectoparasites is Blow flies *Protocalliphora* spp., which cause a direct loss of nutrients to the nestlings. Some nestling birds use dietary nutrients such as carotenoids to lessen the effects that parasites have on them ^[6].

Parasite Community Effects

The effect of a parasite on the host population can cause an epidemic (outbreak) of a disease in a community. Some diseases may show cycles similar to predator-prey cycles. This shows the struggle that occurs between parasites and their hosts. In humans, whooping cough and measles are examples of diseases where parasites infect hosts. Hosts that have never been infected are susceptible to a disease the first time, but after that they are non-susceptible to the infectious host. After an outbreak enough of the hosts in the community become immune to the disease and the disease will decline in the population. This will cause the epidemic to be wiped out and it will not return until there are a number of new individuals born or new immigrants brought into the community.



A mosquito is a parasite that can infect its host with a disease.

Disease Model: $R_p = SBL$

- R_p : The replacement rate of infected hosts.
- S : The density of the susceptible host.
- B : Transmission rate
- L : The average period during which a host will be infectious.

When R_p has a value that is equal to or greater than 1 the outbreak will return in the community. This will start the cycle over again since once there are more non-susceptible hosts the outbreak will die off again. When the disease affects children the cycle will happen very rapidly do to the high turnover rate. When a disease is fatal to an individual host population, the host can be limited and controlled. This means that something as small as a parasite can control the population of large animals.

Parasites can also have an effect on competition between two species. There are some species that compete for food and resources, and parasites can give some species an advantage. One example is white tail deer and their immunity to *Parelaphostrongylus tenuis*. While the white tail deer are immune to the disease, moose, mule deer, and pronghorns are not immune. This means that the population of these species can be controlled by the parasite that has infected them. Probably the most well known example of parasitism is malaria which is caused by the mosquito.

Read: [\[Parasitism\]](#)

Phoresis

Phoresis is a defined behavior in which less mobile parasite species hitchhike on other, more mobile parasite species. An example of such behavior can be seen in the interaction between feather-feeding lice and louse flies. However, it should be noted that not all species of feather-feeding lice engage in such behavior. Feather lice (Phthiraptera: Ischnocera) are wingless. They are also permanent parasitizers of birds. Transmission to new hosts is made possible by catching a ride (hitchhiking) on parasitic louse flies. Louse flies do have wings and fly between individual hosts. Because every host eventually dies, phoresis, an evolved mode of transmission, is essential for the persistence of many parasite lineages ^[7].

Parasitic Castration

The specific blocking of host reproduction by a parasite is known as parasitic castration. This host-parasite interaction is intensity-independent, meaning a single parasite can bring about the blocking of the host's reproductive capability. Parasites benefit from parasitic castrations by diverting the energy a host puts forth in reproduction into their own growth and reproduction. The most studied parasitic castration systems involve invertebrates, particularly crustaceans, echinoderms, and molluscs. Parasitic castrations of vertebrate hosts have been seldomly recognized. In a recent study, it has been demonstrated that a common external cymothoid isopod, *Anilocra apogonae*, castrates Indo-Pacific reef fish host *Cheilodipterus quinquelineatus* ^[8].

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CHAPTER OVERVIEW

13: Ecosystems

An ecosystem can be described simply as the collection of all living and non-living components in a particular area. The living components of the environment are known as biotic factors. Biotic factors include plants, animals, and micro-organisms. The non-living components of the environment are known as abiotic factors. Abiotic factors include things such as rocks, water, soil, light, etc.

The idea of the ecosystem relates to the idea that all organisms in the environment are engaged in relationships with every other aspect (like resources and other organisms) in that environment. Ecosystems deal with energy and nutrient flow through a system/community. For example, a household or a university could be described as an ecosystem, and a city or a state could be described as a larger ecosystem.

While ecosystems may be bound and individually discussed, they do not exist independently, but interact in a complex web. The ecological relationships connecting all ecosystems make up the biosphere. Because virtually no surface on the Earth is free of human contact, all ecosystems can be accurately classified as human ecosystems.

Ecosystems vary in diversity. Some ecosystems may be very diverse with many plants and animals; whereas other ecosystems may be less diverse with fewer animals and plants. For example, tropical rain forests could be classified as an ecosystem that has high diversity; whereas temperate rain forests could be classified as an ecosystem that has lower diversity as compared to tropical rain forests.



A tropical rain forest is an example of an ecosystem that may support several amounts of plants and animals and therefore may have a high diversity

Ecosystem Concept

*Living organisms and their nonliving (abiotic) environment are inseparably interrelated and interact upon each other. Any area of nature that includes living organisms and non-living substances interacting to produce an exchange of materials between the living and non-living parts is an ecological system or **ecosystem** - E. P. Odum, 1959 (emphasis added)*



The Bald eagle *Haliaeetus leucocephalus* is a top predator; a consumer whose niche is at the top of the food web

Thus, a [Field Mouse](#) (say a Meadow vole, *Microtus pennsylvanicus*) in its burrow in the soil is interacting with the non-living elements of that burrow as it breathes, taking in oxygen and expelling carbon dioxide¹. But that activity is but a moment in time and cannot, by itself, define an ecosystem. The mouse must leave the burrow for food, interacting with plants. Plants themselves interact and exchange materials with the soil and the atmosphere and are dependent on radiation from the sun and the activity of earthworms and fungi in the soil. The latter, in turn, feed upon organic molecules left behind from the death of former living plants (and field mice). Thus, the "ecosystem" of our field mouse includes plants, and soil, and soil organisms—and of course other field mice to insure that mice will always be a part of that ecosystem. And perhaps present are Bald eagles (*Haliaeetus leucocephalus*), dependent upon trees for nesting and roosting and a stream for water (and fish as an alternative food), feeding upon Field mice, recycling those that are caught into baby Bald eagles and droppings that are food for the plants and earthworms. Already, the "area" of this ecosystem is at least as large as that required to support a **population** of Bald eagles.

It is the inclusion of all the interrelationships within a functional system that make the concept of ecosystem so broad. And the seemingly endless networks of links and interactions that give geographical breadth to an ecosystem. Of course, an ecologist could study just the organisms, activities, and biotic/abiotic interactions within the local "soil ecosystem", treating mouse and eagle excrement as we described the sun above: external, but providing important input of energy and material to the soil ecosystem. In a sense, this is what we mean by calling "ecosystem" a concept rather than just a place. We may conceive of, for the purpose of study, ecosystems over a wide range of sizes or scale, from an aquarium to an ocean, and lots of places in between. Essential are certain components that we alluded to in our description of parts of the ecosystem supporting habitat for the Field mouse, and these we will next explore in detail.

In attempting to understand any interactive, complex system, especially one as elaborate as even a simple ecosystem, it is helpful to break the system down into various component parts. By this mental process we can arrive at some understanding of the specific system and can make comparisons with other systems to further our understanding of ecosystems in general. An ecosystem consists of many component structures and these function together in various ways, suggesting an initial approach to describe any ecosystem is to consider separately its structural and functional aspects.

Basic Structural Components

Consider first an ecosystem from a structural perspective: an ecosystem consists of living (biotic) and non-living (abiotic) components. Living components include populations of organisms and the living resources they use. Non-living components include non-living resources, such as space, and the non-living physical characteristics of habitats that differ by location, such as elevation, temperature, and humidity.

We know and can observe that the **organisms** living in almost any ecosystem are not all identical individuals, but can be categorized into species (discussed previously in [Chapter 9](#)); and each species has a unique set of morphological, physiological, and behavioral attributes (see [Chapter 3](#)) that will determine how each individual functions within the whole. The species present provide ways of considering their contribution to ecosystem structure. For examples: we could describe the number of species (species richness), or the number (or biomass) of individuals of each species (species diversity), or their distribution across the physical space of the ecosystem. These are a few ways an ecologist would approach describing ecosystem structure based upon the plants and animals (and others) present in it.

In addition to the organisms themselves, there are components utilized by the organisms that comprise the **resources** of the ecosystem. These are both biotic and abiotic, inorganic and organic, and are exchanged between organisms and between organisms and the environment (previously covered in part in [Chapter 4](#)). Resources are the materials cycled by the inhabitants of an ecosystem as they carry on with life processes. We say "cycled" because all living things have a finite existence, and the substances of their material composition remain after death to be utilized in other ways.

Finally, there are those factors that are the conditions under which the organisms live. The environment of a subarctic lake is vastly different from that of a forest in the wet tropics. But consider also that conditions within a pond (an aquatic environment) are very different from those just a few yards up from the shore (a terrestrial environment). While we might be describing mostly **physical conditions**, these need not be always abiotic. In many ecosystems there are organisms that provide or create the dominant physical structure of that ecosystem. Examples are a forest and a coral reef. In a forest ecosystem, the trees are both very prominent organisms and resources to many of the other species present; but they also have a substantial effect on the conditions—the microclimates—that prevail in the forest ecosystem by providing shade and physical structure for many other organisms that may not directly utilize the trees as a food resource.

It should be clear that when we speak of ecosystem structure, we are considering various aspects of an ecosystem from a perspective that need not—indeed does not—mesh exactly with other ways of categorizing ecosystem components. Consider the trees of a forest or the coral heads of a coral reef. Each is a living organism, a resource used by many other species, and a physical structure that determines the uniqueness of its particular ecosystem compared with the environment that would occupy the same space in the absence of either trees or corals. In describing ecosystem structure, we do not break down the components into divisions of abiotic vs. biotic, inorganic vs. organic, or by species. In the next section, we will consider components on the basis of their function in an ecosystem, creating yet another set of categories independent of the structural ones.

Characteristics of Ecosystems



An example of a marine ecosystem



Acheta domestica organism that helps maintain its ecosystem

The complexity of an ecosystem will increase as the species diversity present in the ecosystem increases. Ecosystems that are not species rich (barren ecosystems) may *appear* to be physically complex but are actually considered *functionally* complex.

Even if few species live in an environment, often because it is an unfavorable environments, that ecosystem can be still functionally complex if it include species with remarkable biochemical specializations that allow them to survive. For instance some archaea live in environments that are 113-176° F. and some organisms can get energy from inorganic chemical sources, such as bacteria that break down crude oil.

A healthy ecosystem will have high species diversity and is not likely to be damaged by human interactions, natural disasters, and climate changes. Every species within an ecosystem has a *niche*, the unique way that a given species uses its environment. New species are discovered every day and the roles they play in their environment to keep it healthy. This idea behind the species within the environment using their niches to keep it healthy can clearly be illustrated in a lake ecosystem. In a lake ecosystem, the sun hits the water and helps the algae grow. Algae use carbon dioxide and water to make sugars and oxygen. The oxygen is useful for any eukaryote organism and the sugars provide food for the algae or anything that eats the algae, such as microscopic organisms. Small fish eat the microscopic animals, absorb oxygen with their gills and expel carbon dioxide, which plants then use to grow. If the algae disappeared, everything else would be impacted. Microscopic animals wouldn't have enough food, fish wouldn't have enough oxygen and plants would lose some of the carbon dioxide they need to grow.

Soil is also an important part of an ecosystem. It provides important nutrients for the plants in an ecosystem. It helps anchor the plants to keep them in place. Soil absorbs and holds water for plants and animals to use and provides a home for lots of living organisms. The atmosphere provides oxygen and carbon dioxide for the plants and animals in an ecosystem. The atmosphere is also part of the water cycle. Without the interactions among organisms and elements in the atmosphere, there would be no life at all.

[\[1\]](#) [\[2\]](#) [\[3\]](#)

Basic Functional Components

We can recognize four functional components of an ecosystem: 1) *abiotic factors*, 2) *producers*, 3) *consumers*, and 4) *decomposers*. The latter three are living components, what Odum (1959) termed the three "functional kingdoms of nature", so important and universal is their presence in ecosystems.

Abiotic Factors



An example of organisms that live in the intertidal zone

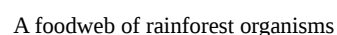
Abiotic factors can increase or decrease the amount of **environmental stress** on an ecosystem and therefore can also affect the stability of that ecosystem. We studied many of these in detail in ([Chapter 4](#)). Do not forget that physical (essentially geological) structure can influence ecological function: the nature of interactions of species in the sea can be very different from those in the atmosphere directly as a consequence of difference in physical properties of air and water.

The **intertidal zone** is the shore area that is submerged at high tide and exposed at low tide. It is rich in oxygen and nutrients and provides a home for many different species. The organisms that live in this area are constantly exposed to a **high stress, less stable** environment. However, they have adapted to huge daily changes in moisture, temperature, turbulence (from the water), and salinity. They have to be used to living in both wet and dry conditions continually. Water is a very powerful substance and the constant impact from the moving water can have drastic impacts on both living and non-living things. Intertidal organisms are forced to bury into the sand, hide under rocks and/or attach themselves to larger structures to avoid being carried away by the waves. Also, the constant flux of the environmental temperature is enough to make any creature uncomfortable. Since this area is exposed to both water and land, the organisms here must compete with predators that hunt at both areas.

Jungles or **rainforests** are an example of a **low stress, more stable** environment that are vital to maintaining the ecosystems of the earth. Unlike the intertidal zone, this environment has more subtle changes that occur at a much slower rate. Jungles are very stable environments that possess some 40% of all species. It is also a very diverse environment consisting of several layers of organisms using different parts of the ecosystem. As well as increasing biodiversity, jungles are beneficial to increasing our knowledge of medicinal plants and increasing oxygen output. Since the rainforest is literally a smörgåsbord a plants and animals, discoveries are continually made of the beneficial nature of these organisms.

Food Webs

Decomposers are vital to the food web because they break down and recycle nutrients back into the soil. These nutrients are then used by producers to sustain life. Without the enzymes that decomposers provide to breakdown organic material into inorganic material, phosphorous(P) and nitrogen(N), Producers would eventually die out and the main part of food webs would cease to exist and therefore life would cease to exist. Decomposers recycle material but they do not recycle energy. Solar irradiation still provides the energy that drives the life cycle.



Decomposition is a natural process but decomposers speed up the process of decomposition. Bacteria, fungi and actinomycetes are three main types of decomposers. Bacteria make up about 90% of all microorganisms and are the most abundant of decomposers. They can eat anything from dead trees, dead animals and oil slicks on the surface of the ocean. Fungi and actinomycetes work on harder substances like cellulose, bark, paper and stems. These decomposers usually only work to a certain stage in decomposition then bacteria will finish the process, similar to primary and secondary succession.

A study conducted in a California river by Mary Power showed the impact that fish had on the river food web. The main fish studied in the experiment were the steelhead and roach, these fish at a juvenile stage consume insects and fish fry, which consume chironomid larvae. These larvae reduce the algae biomass in the river. She found that when the larger adult fish species were absent, smaller more abundant predators thrived and decrease the chironomid larvae population significantly, which allowed the algae biomass to increase. This results in more cyanobacteria and diatoms to flourish on the algal turfs^[4]. This study showed a good example of how consumers and producers interact, and also showed that when one trophic level is disrupted it has a domino effect on the other trophic levels involved in the food web.

With Food Webs there are a few calculations that we can use to help us better understand the system. Chain Length is essentially the number of links between trophic levels. But when we calculate this we use the mean length. So to calculate Chain Length(CL) the equation is $CL = (\# \text{ of links} / T - 1)$ where T is equal to the number of trophic levels. We can also calculate link density(LD). $LD = (\# \text{ of Links} / n)$ where n is the number of species in the web. And finally we can calculate Web Connectance(C). $C = (\text{actual links} / \text{potential links}(N))$ Where $N = n(n-1)/2$.

Food webs do pose some problems for ecological studies. Identifying trophic levels is very difficult in nature. Ecosystem boundaries are also tough to determine. Identifying all of the species in a community can be difficult. Quantifying and identifying the strengths of interactions is hard. In most cases it is very hard to determine what the eliminating nutrients are.

Biological Magnification

The focus of this chapter is trophic levels and nutrient transfer between trophic levels and the food webs. Not all transfers between trophic levels are positive. Biological Magnification is the tendency of pollutants to concentrate in successive trophic levels. The pollutants are usually toxic and cause death to the organism.

The first step in Biomagnification is when a producer takes up nutrients in the soil that it stores by accident as an essential nutrient. Producers will try to store massive amounts of nutrients, when "mistaken" nutrients are absorbed, i.e. DDT and Mercury, The concentration levels in the producers are greater than the levels in the surrounding environment. When the producer is eaten by the herbivore or omnivore the pollutants are transferred to the next trophic level. Since energy transfer between trophic levels is approximately ten percent, the next chain in the trophic level must try to consume large amounts of the previous trophic level to sustain life and the pollutant, once again, is concentrated in the next trophic level.

The pollutants, once absorbed, are stored in the bodies of the consumers. DDT and PCB's are fat soluble and when one trophic level is consumed by the other the fat moves from one consumer to the next. Water soluble pollutants usually cannot concentrate because they would easily dissolve in the organism. Polluted water leaves an organism rather easily whereas fat does not leave the body.

Three main criteria must be met for a pollutant to biomagnify:

1. The pollutant must be long lived.
2. The pollutant must be concentrated by the producers.
3. The pollutant must be fat-soluble.

Guild

Species competing for the same resources in similar fashion are known as **guilds**. They are classified according to how they acquire their nutrients, their state of mobility, and their mode of feeding. Some examples of guilds are **forbs**, geophytes, graminoids, shrubs, trees and vines. A guild is much more stable than a single species, since more than one species can balance out the system. In a study of feeding patterns on **polychaetes**, Fauchald and Jumars (1979) utilized feeding guilds as a method of generalization and determining **phylogenetic** relationships, indeed claiming that guilds were very useful in summarizing data into patterns^[5].

In a 2009 study, a guild approach was used to evaluate the roles of foraging habitats and exposure timing, as well as trophic position on Mercury (Hg) bioaccumulation. Five species of waterbirds forming three distinct foraging guilds in the San Francisco Bay (SFB) estuary were used in this investigation. Because estuarine waterbirds form well-documented, distinct guilds distinguished by their feeding method and habitat use and because the SFB estuary has a legacy of Hg contamination from historic mining in the Sierra Nevada Coast Mountain Range, Hg exposure was able to be evaluated on both large-scale foraging strategies (such as trophic position) occurring among guilds and small-scale strategies (such as foraging micro-habitats) that occur within guilds. As indicated by this study, SFB waterbirds accumulated alarming Hg concentrations. Concentrations that place them at considerable risk to deleterious reproductive effects. Such exposure was shown to vary as a function of micro-habitat, region, trophic level, and time spent in the estuary. These results have raised quite a bit of concern because the SFB estuary is among the most important sites for wintering, migrating, and breeding waterbird populations along the Pacific Flyway ^[6].



A bear is an example of a keystone species, which provides stability to a community.

Keystone Species

A keystone species is a species having a disproportionate effect on the ecosystem. They provide stability to an ecosystem. Normally they are not the dominant species but are required for a community to have stability. Many times, keystone species are predators that keep some type of herbivore from consuming all of the dominant plant species. One interesting aspect of keystone species is that, since they normally feed on predators that consume small numbers of prey, they can effectively control a system without actually needing to have a large population size.

J. Brown and E. Heske studied the effects of the removal of *Dipodomys* spp. (Kangaroo rats) from the Chihuahuan Desert shrub habitat in southeastern Arizona. Twelve years after the removal of three species of kangaroo rats, the controlled plots in the habitat went from shrubland to grassland. The density of perennial and annual grasses increased considerably, and other rodent species in the area colonized. These major changes in the ecosystem showed that the *Dipodomys* spp. have a significant effect on the diversity and biogeochemical processes, which led the researchers to believe that the kangaroo rats are a keystone species ^[7]. Some other examples of keystone species would include Starfish, Sea Otters, Bears, Beavers and Domestic Cats.

- Read: [Keystone Species](#)

All the examples of keystone species mentioned above are animals. However, this isn't always the case. *Pinus chiapensis* is an early successional, neotropical pine species found in warm, humid, mid-elevation Mesoamerican areas such as in the tropical montane areas of southern Mexico and western Guatemala. It has been discovered that forests dominated by *P. chiapensis* are the first to appear after disturbance, modifying drastically the environment by shading the forest floor, favoring soil development, increasing the rate of soil carbon sequestration, acidifying the soil, releasing nutrient cations by weathering the bed rock, and providing a source of food for birds and mammals. *P. chiapensis* trees inhibit their own development while facilitating the growth of broadleaved species typical of tropical montane cloud forests. Ultimately, *P. chiapensis* is a keystone species because of its crucial impacts in tropical montane cloud forest regeneration and its effect on ecosystem processes ^[8].

Hypotheses of Food Web Control

Each food web contains N numbers of trophic levels and with each number the cycle of dependence flip-flops according to the Oksanen's Model. There are two hypotheses involved in this model one is known as the **Bottom-up Control** hypothesis. The bottom-up control hypothesis states that both the top and the bottom trophic levels are controlled by resource limitations. For example in a three tiered food web (three trophic levels), the bottom trophic level would contain a species of plants, which of course are dependent on the resources available to it. The next trophic level would be some species of herbivore, these herbivores are limited and controlled by a species of predator which is also the third trophic level. The predator or top trophic level is then limited by the plant resources keeping the herbivores alive and reproducing.

If we were to now add a trophic level, such as a secondary predator (the original predator being the primary predator), the cycle of dependence would then flip-flop, and the **Top-bottom Control** hypothesis would apply. The top-bottom control hypothesis states that the food web cycle is predator limited. We now have our plant species ==> the herbivore ==> the primary predator ==> and the secondary predator. The plants that were resource limited are now predator limited by the herbivores. The herbivores are now resource limited by the plants abundance. The primary predator is now limited by the secondary predator and the secondary predator is now limited by the resources of the primary predator, herbivore, and plants.

This cycle repeats itself and with each additional trophic level added, the limitation of the lower trophic levels changes from either resource limited or predator limited to the other. The relationships of two trophic levels when the bottom is resource limited and the top is predator limited gives a positive slope. The more of the lower trophic level the more there is of the upper trophic level. The inverse is true when the lower trophic level is predator limited and the upper trophic level is resource limited, it creates a negative slope the more are of the upper trophic level the less there will be of the lower trophic level.

For more detailed information on this trophic cascade idea and for examples read: [Trophic cascade](#)

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1. ^ Fauchald, Kristian, and Peter A. Jumars. "The Diet of Worms: a Study of Polychaete Feeding Guilds." *Oceanogr. Mar. Biol. Ann. Rev.* 17 (1979): 193-284.
 2. ^ Brown, J., Heske, E. 1990. Control of a Desert-Grassland Transition by a Keystone Rodent Guild. *Science*, New Series, Vol 250. 1705-1707.
 3. ^ Power, Mary E. 1990. Effects of Fish in River Food Webs. *Science*, Vol. 250 811-814.
 4. ^ Eagles-Smith, Collins A. *et al.* 2009. Mercury Bioaccumulation and the Risk to Three Waterbird Foraging Guilds is Influenced by Foraging Ecology and Breeding Stage. *Environmental Pollution*. Article in Press, corrected proof.
 5. ^ Castillo, Rafael F. del *et al.* 10 May 2009. *Pinus chiapensis*, a Keystone Species: Genetics, Ecology, and Conservation. *Forest Ecology and Management*, Vol. 257, Issue 11, pgs. 2201-2208.
- Footnote:¹ Breathing is an activity at the organism level of biological complexity. The actual use of oxygen molecules and production of carbon dioxide molecules takes place at the cellular and subcellular levels. The exchange process within the vole involves tissue and organ level activities (lungs and circulatory system).

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CHAPTER OVERVIEW

14: Energy in Ecosystems



An example of the concept of energy flow through trophic levels of a food chain.

There are several different factors that control the primary productivity of energy and biomass flow. Energy flow is the amount of energy that moves through a food chain. The energy input, or energy that enters the ecosystem, is measured in Joules or calories. Accordingly, the energy flow is also called calorific flow. In the study of energy flow, ecologists try to quantify the importance of different species and feeding relationships.

The largest source of energy for an ecosystem is the sun. Energy that is not used in an ecosystem is eventually lost as heat. Energy and nutrients are passed around through the food chain, when one organism eats another organism. Any energy remaining in a dead organism is consumed by decomposers. Nutrients can be cycled through an ecosystem but energy is simply lost over time.

An example of energy flow in an ecosystem would begin with the autotrophs that take energy from the sun. Herbivores then feed on the autotrophs and change the energy from the plant into energy that they can use. Carnivores subsequently feed on the herbivores and, finally, other carnivores prey on the carnivores.

In each case, energy is passed on from one trophic level to the next trophic level and each time some energy is lost as heat into the environment. This is due to the fact that each organism must use some energy that they received from other organisms in order to survive. The top consumer of a food chain will be the organism that receives the least amount of energy.

Hairston and Hairston (1993)[^], believe that there is a cause and effect relationship that results in any given trophic structure. Specifically, they state that it is trophic structure, rather than energetics that controls the amount of energy consumed at each trophic level and that "ecological efficiencies" are the product of a trophic structure, not a determining factor. Further, they state that trophic structure is instead the result of competition and predator-prey interactions. It is important to remember that many species may occupy each trophic level and are so subject to interspecific competition. This is especially true for producers, carnivores, and decomposers (Hairston, Smith, and Slobodkin, 1960)[^]. Lastly it is not lost it is just consumed by its consumers.



The Sun is Most Common Source of Energy in Every Ecosystem

Energy is the ability to do work. Life manifests itself in energy changes, subject to the laws of thermodynamics. Ecosystems exist and operate by virtue of a flow of energy through the components of the system and thermodynamics (the movement of energy) forms the very basis of the biosphere organizing principles introduced in [Chapter 2](#). Before proceeding into the relationship between ecology and thermodynamics, it is necessary to build a basic understanding of the physics of energetics, simply a further demonstration of the fact that ecology is multidisciplinary, requiring of its students a broad knowledge in all sciences.

- Read [Energy](#) - Follow links and cover details only as necessary to gain a basic understanding
- Read [Laws of Thermodynamics](#) - Read the expanded articles as needed to understand these basic principles of energy changes
- Read [Principles of Energetics](#) - You will find a constellation of related articles, including several with an ecological focus. You may wish to visit all of these to foster a deeper understanding

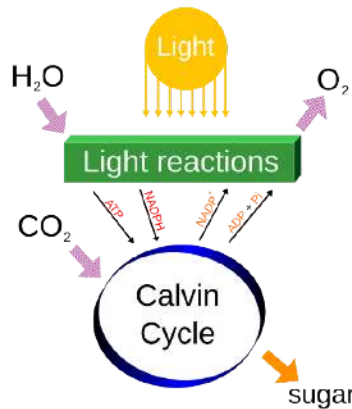
Although several sources of energy are available for exploitation on earth (e.g., geothermal, nuclear decay), the most significant is solar energy. Light and other radiation streaming out from the sun strikes the earth 93 million miles distant, providing energy to the atmosphere, the seas, and the land, warming objects that absorb this energy; that is, radiant energy is converted to heat energy (molecular motion). Differential heating causes winds and currents in the air and water, the heat energy becoming *kinetic energy* of motion. Warming results in evaporation of water into the atmosphere, setting up the hydrologic cycle ([Chapter 4](#)), the lifting of water into the atmosphere becoming *potential energy* that will convert to kinetic energy when the water begins to flow back downhill. However, the most significant solar energy driven process with respect to living systems is that of **photosynthesis**. Light energy is converted by photosynthesizing cells into a form of potential energy held in the chemical bonds of organic compounds. Organisms require both the substance and the stored energy of chemical compounds to function and grow, and eventually reproduce. Substance to provide the building blocks of cellular (and extracellular) components that comprise structure, and energy to move substances around, affect chemical reactions, and carry out all manner of intracellular and organismal processes.

Solar Constant

The **Solar Constant** is the average amount of radiant energy from the sun that reaches the Earth's atmosphere. This value is calculated at 2 calories per minute on each square centimeter of the Earth's upper atmosphere. This value can change because of Earth's elliptical path effecting seasonal changes and differences in the northern or southern slope which effect magnitude. The net radiation is what is left after some of the energy is reflected by the Earth's surface. Calculations for the solar constant are done by using the **astronomical unit (AU)** which is the mean distance between the Earth and Sun; One (AU) is equivalent to 92,960,000 miles (149,604,970 km).

Movement of the air and evaporation are important factors that regulate the temperature of the Earth from the sun's energy. The movements of air allow energy to be given off into space and without this reflection of energy the Earth would rapidly overheat and life would extinguish. This interaction is also a very important to the maintenance of the Earth's polar ice caps. A decrease in the solar constant of 2-5% would be enough to create a second ice age. Of course, as has been shown, the increasing use of industry by man, can increase earths temperature. If it were enough to cause the ice caps to melt, there would be an increase of approximately 7 degrees C. ^[1] This is due to the fact that the polar ice caps help in reflecting back the Earth's radiation. This reflection of the solar radiation is an essential part of the maintenance of the current climate that the Earth maintains. ^[2]

Organisms' Role in the Flow of Energy



A simplified overview of the process of photosynthesis.

When it comes to the flow of energy in ecosystems there are two types of organisms: **producers** and **consumers**. Plants are a common example of producers in all populations. They are able to convert carbon dioxide into oxygen and glucose, a common sugar consumed by most organisms. They do this through a process called photosynthesis which allows the plants to use sunlight as a source of energy. Producers convert energy from the environment into chemical energy in the form of carbon to carbon bonds. A classic example is the one previously mentioned where the plants convert CO_2 to O_2 and glucose.

The second type of organism is the consumer. Consumers are unable to make chemical energy the way plants do and have to use metabolic processes to get energy from carbon to carbon bonds, which is called respiration. Respiration breaks the carbon to carbon bonds and combines them with oxygen to make carbon dioxide. The energy released is used to help organisms move their muscles or as heat. Energy cannot be reused once it has been lost.

Read:

- [Energy Flow Through the Ecosystem](#)
- [Ecosystems Background Information](#)
- [Ecology](#)

Measuring Energy Flow

Flow diagrams are a visual way to understand how energy is transferred and/or transformed. A simple flow diagram usually starts with a primary producer $\rightarrow$ herbivore $\rightarrow$ predator $\rightarrow$ and so on. They can be as simple as that or as complex as the complete CO_2 cycle. The symbol $[c]$ is the consumption rate of that species. The consumption rate between forcing functions is denoted by r , ($r=[c]/t$). The forcing function, which is the flow of energy between species, is usually measured in $\text{kcal mol}^{-1} \text{year}^{-1}$. The primary producer efficiency is measured by $(\text{NPP}/\text{Total consumed}) \times 100$. Secondary production efficiency is measured by $(\text{NSP}/\text{Total consumed}) \times 100$.

For more detailed examples visit: [Energy Flow of Organisms](#)

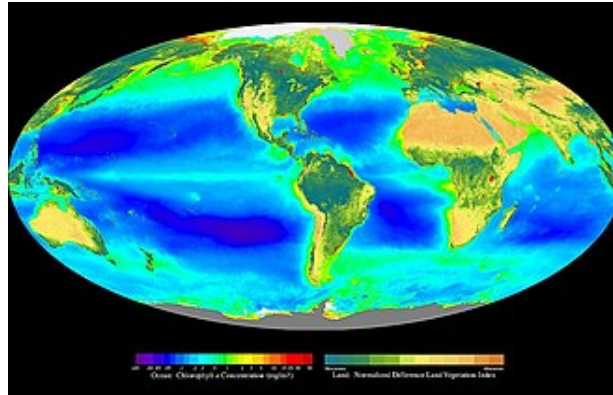
Primary and Secondary Production

The **Net Primary Production (NPP)** is the amount of carbon fixed per unit time (usually per day). Measures of net primary production include:

1. change in dry biomass per unit time
2. calorimetry
3. carbon dioxide uptake over time
4. oxygen uptake over time (comparison of the plant's light cycle to its dark cycle)
5. change in chlorophyll-a concentration, which equals the concentration of carbon dioxide fixed per day.

Ecologists look at dry mass because the high variability of water content makes accurate measurements difficult. Essentially about 95% of the dry mass is carbon and about 99.9% of the global biomass is plants (which includes algae, cyanobacteria, and other

organisms that contain chlorophyll).



Global oceanic and terrestrial photoautotroph abundance, from September 1997 to August 2000. As an estimate of autotroph biomass, it is only a rough indicator of primary production potential, and not an actual estimate of it.

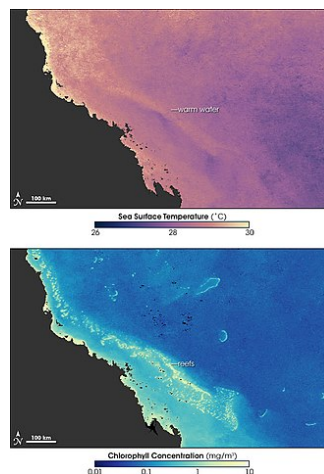
There are several different things that can limit NPP Terrestrial limiting factors include:

1. water/precipitation,
2. sunligh/temperature, and
3. nutrients.

Aquatic limiting factors include:

1. sunlight/temperature, and
2. nutrients.

The NPP of aquatic ecosystems has been vastly affected by global warming. Global warming is the primary issue due to human impacts and gas emissions. Projected increases in carbon dioxide and temperature for the next 50 years exceed the amounts in which great coral reefs have flourished over the past half-million years. Coral reefs are at a serious decline due to temperature increases and coral bleaching. ..



Two images showing the relationship of water temperature to w:coral bleaching along the Great Barrier Reef. Warm pink and yellow tones show where sea surface temperatures were warm in the top image. The warmest waters are the shallow waters over the reef near the coast, where coral bleaching was most severe in the summer. The lower image shows chlorophyll concentrations, where high concentrations (yellow) generally point to a high concentration of phytoplankton in surface waters of the ocean. In this image, the bright yellow dots actually represent the coral reefs, and not surface phytoplankton.

An estimated 30% of coral reefs are severely damaged and about 60% of coral reefs may be lost by 2030. ^[3] Coral bleaching not only affects the coral reefs, but the diverse collection of species that interact with each other within the coral reef ecosystem. An example of this is the increased consuming of corallivorous fish on recently bleached coral (Pratchett et al. 2009). ^[4] Corallivorous fish were found to increase stress on recently bleached coral due to increased feeding. The increased feeding on already stressed

corals may have contributed to the mortality of bleached coral. The Corallivorous fish however, only increased consuming for the early stages of coral bleaching, and may be a good indication of coral mortality. Coral bleaching affects reefs at a regional and global scale, and has a huge impact on the NPP of coral reef ecosystems.

The net primary production is the main factor that limits the amount of net secondary production. Net secondary Production (**NSP**) determines the amount of biomass consumed and calculates the energy content of the consumed biomass. It also determines the amount of biomass and/or energy assimilated that is equivalent to an increase in the biomass of the consumer. In this case, a growth in biomass can be defined as a growth in individuals or growth in populations that includes reproduction. Most of the energy lost in secondary production comes from maintenance respiration. Secondary producers will consume oxygen and produce heat, which results in fairly inefficient production. Endotherms have a mean efficiency of about 2% and ectotherms have a mean efficiency of about 10%. There is a loss of energy due to respiration of 98% and 90%, respectively. All other organisms have a 30%-40% efficiency rate. All animals that live off plants(herbivores) are included in this group of secondary producers.

Limiting Nutrients



Excess Nitrogen can cause ill affects such as toxic algal bloom

As mentioned above nutrients can play a role in limiting the production of a community. Other than sunlight, primary productivity is limited by nutrient availability. A **limiting nutrient** is a nutrient which is found in the lowest relative concentrations such that an increase in this nutrient will increase primary productivity, while a decrease in this nutrient will decrease primary productivity. Typically, either phosphorus or nitrogen serves as a limiting nutrient within a given ecosystem, though water availability can also serve to limit the primary productivity of an ecosystem. Trace nutrients such as molybdenum and zinc are necessary for the growth of plants and can act as limiting agents even though they are in very small quantities. Aquatic communities can also have limiting nutrients that control how much production takes place. In freshwater ecosystems net primary production is limited by phosphorus, and in the ocean the limiting nutrient is iron.

Read: [Limiting Nutrients](#)

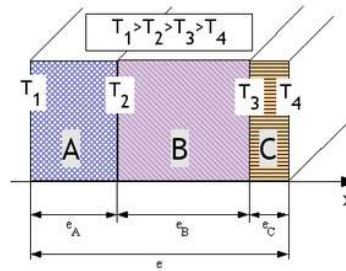
Too much of a nutrient can also have a limiting impact on a community. Recent studies have shown that excess nitrogen from human activities such as agriculture, energy production, and transport have begun to overwhelm the natural nitrogen cycle. The effects of the extra nutrients reach every environmental domain, threatening air and water quality and disrupting the health of terrestrial and aquatic ecosystems. In terrestrial ecosystems, nitrogen saturation can disrupt soil chemistry, leading to loss of other soil nutrients such as calcium, magnesium, and potassium. This means that while the nitrogen is not a limiting factor, it causes other nutrients in the soil to become limiting factors.

Read: [Nutrient Overload](#)

The Laws of Thermodynamics as they relate to Ecology

The laws of thermodynamics are fundamental concepts to chemical processes of the universe. They are extremely important in chemistry and physics, but are the basis for many biological concepts as well. The laws dictate how energy can be transported, which of course can be applied to ecology because energy transfer is what drives metabolism and, on a larger scale, food chains and food webs.

Zeroth Law of Thermodynamics



Since the temperature decreases going from block A to block C, assuming that all blocks are in thermal contact, heat energy will flow from the left to the right until all blocks are of equal temperature.

Zeroth Law of Thermodynamics is the most obvious of all three laws, simply stating that if the temperature of object A is equal to the temperature of object B, and the temperature of object C is equal to the temperature of object B then the temperature of object C equals the temperature of object A. Although this transitive property seems almost unnecessary to mention, it is of crucial importance to the subject of energy transfer in the form of heat energy, since temperature is a measure of heat. Its implications in ecology are obvious as well. Organisms require the means to survive in a climate of a certain range of temperatures, and evolution has created organisms with extremely different tolerances to temperature according to where they are located.

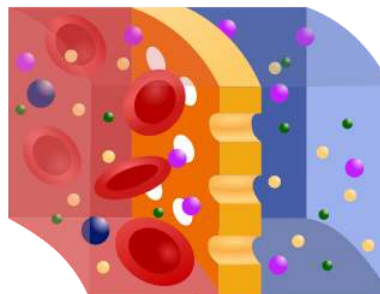
First Law of Thermodynamics

The **First Law of Thermodynamics** states that the total inflow of energy into a system must equal the total outflow of energy from the system, plus the change in the energy contained within the system. That is, energy is neither created nor destroyed, but may transform from one type to another. This is relevant to food webs in that the amount of energy being transferred through the food web cannot be larger than the amount of energy initially supplied by the primary producer (which was supplied by the sun's energy).

Second Law of Thermodynamics

The **Second Law of Thermodynamics** states that "energy of all kinds in our material world disperses or spreads out if it is not hindered from doing so." In other words, the randomness (entropy) of the universe is always increasing. This is quoted from a site devoted to demonstrating how the second law is involved in our open system of the earth and sun: <http://www.entropysimple.com>.

The second law of thermodynamics is definitely the most applicable of the four laws to ecology. It is consistent with Elton's Pyramid of foodwebs that states that although sometimes total size or number of organisms can either increase or decrease with increasing trophic levels, the total biomass ALWAYS decreases with increasing trophic levels, as energy is constantly being lost to the atmosphere (usually as CO₂). The energy from the sun allows living organisms on earth to temporarily decrease entropy, but our organized systems require an overall input of energy (provided by the sun). The second law of thermodynamics suggests a dire "heat death of the universe" will occur when all the energy of the universe is evenly distributed, and no life or concentrated matter (stars, galaxies) can exist, although this won't occur for at least 10¹⁰⁰ years.



Semipermeable membranes are prevalent in many organisms and are a way that tendency toward entropy is manipulated to create a gradient. Such gradients can allow thermodynamically favorable reactions to occur yet maintain an organized structure.

Ecosystems are far from thermodynamic equilibrium, which used to be an argument against the second law of thermodynamics. Galucci (1973) ^[5] performed a literature review of the physical theory of thermodynamics in relation to mechanisms of energy

transfer in the environment (passive and active) and ecosystem productivity. He also studied how community structure and diversity related to entropy. As a result of his research, he claimed that the earth is a "receiver, reflector, and degrader of energy." The movement of energy through a community structure is necessary for its maintenance. External energy from the sun provides primary producers with energy and with a range of temperature in which life in the community is possible. Internal energy that travels from primary producers to organisms higher in the food chain is in the form of metabolism (mass, bonds) which provides transferrable energy. Galucci claimed that diversity is a form of entropy and improves the stability of a community. His conclusion was that the hypothesis of the second law of thermodynamics being applicable to ecosystems is supported.

Hedin *et al.* (1998) ^[6] studied biogeochemical processes involving nitrogen at soil to stream interfaces from a thermodynamic point of view. More than 1400 subsurface water samples from Michigan wetlands draining from a mixed forested-agricultural landscape were observed in this study. Thermodynamic principles could predict what form of nitrogen would be available to microbes if the number of electron donors and acceptors (water pH) is known. Microbes will transform nitrogen from NO_3^- to ammonia in acidic conditions present in shallow water, but convert NO_3^- to N_2O gas in basic conditions present in deeper water. The findings agreed with this theory and were helpful because oxidizable carbon can be added to the shallow portions of the water that are not sufficient at denitrification. These findings would not have been possible (or understandable) if a thermodynamic approach to the metabolism of microorganisms had not been considered.

Third Law of Thermodynamics

The **Third Law of Thermodynamics** simply states that as temperature of a system reaches absolute zero (0 K), the entropy of the system decreases. Technically, it states that a system at absolute zero is at zero entropy, but this is theoretically not possible as it has been established that absolute zero is not able to be experimentally reached. This is why substances become gases (molecules spread out, entropy increased) at high temperatures, and freeze (become ordered crystalline structures, entropy decreased) at low temperatures. Decomposition also has a higher rate at higher temperatures for this reason.

Ecological Pyramids

An **Ecological Pyramid** (or **Trophic pyramid**) is a graphical representation designed to show the relationship between energy and trophic levels of a given ecosystem. Most commonly, this relationship is demonstrated through the number of individuals at a given trophic level, the amount of biomass at a given trophic level, or the amount of energy at a given trophic level. It is worth noting that all Ecological Pyramids begin with producers on the bottom and proceed through the various trophic levels, the highest of which is on top.

Pyramid of Biomass

An **Ecological Pyramid of Biomass** shows the relationship between energy and trophic level by quantifying the amount of biomass present at each trophic level (dry mass per trophic level). As such, it is assumed that there is a direct relationship between biomass and energy. By doing this, the earlier discrepancy is avoided because even though there is only one tree, it is much more massive than the next trophic level.

The main problem with this type of Ecological Pyramid is that it can make a trophic level look like it contains more energy than it actually does. For example, all birds have a beak and skeleton, which despite taking up mass are not eaten by the next trophic level. In a **Pyramid of Biomass**, the skeleton and beak would still be quantified even though it does not contribute to the overall flow of energy into the next trophic level.

Pyramid of Energy (Ecology)

An **Ecological Pyramid of Energy** is the most useful of the three types, showing the direct relationship between energy and trophic level. It measures the number of calories per trophic level. As with the others, this graph begins with producers and ends with a higher trophic level.

When an ecosystem is healthy, this graph will always look like the standard **Ecological Pyramid** shown at the top of the page. This is because in order for the ecosystem to sustain itself, there must be more energy at lower trophic levels than there is at higher trophic levels. This allows for organisms on the lower levels to maintain a stable population, but to also feed the organisms on higher trophic levels, thus transferring energy up the pyramid.

When energy is transferred to the next trophic level, only 10% of it is used to build bodymass, becoming stored energy (the rest going to metabolic processes). As such, in a **Pyramid of Energy**, each step will be 10% the size of the previous step (100, 10, 1, 0.1, 0.01, 0.001 etc.).

The advantages of the Pyramid of Energy:

- It takes account of the rate of production over a period of time because each rectangle represents energy per unit area / volume per unit time. An example of units might be - kJ/m²/yr.
- Two species weight for weight may not have the same energy content therefore the biomass is misleading but energy is directly comparable.
- The relative energy flow within an ecosystem can be compared using pyramids of energy; also different ecosystems can be compared.
- There are no inverted pyramids.
- The input of solar energy can be added.

The disadvantages of the Pyramid of Energy:

- The energy value for a given mass of organism is required, which involves complete combustion of a sample.
- There is still the difficulty of assigning the organisms to a specific trophic level. As well as the organism in the food chains there is the problem of assigning the decomposers and detritivores to a particular trophic level.

The best way of showing what is happening in the feeding relationships of a community is to use Energy Pyramids.

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CHAPTER OVERVIEW

15: Biogeochemical Cycles



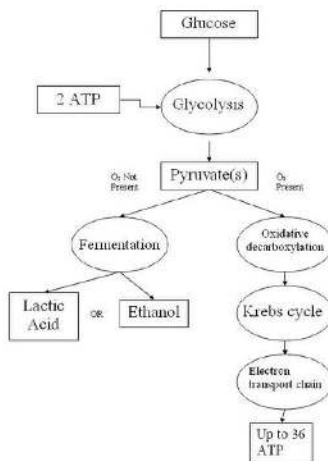
Planet earth from space

In the previous chapter on [environmental response](#), we considered the various ways that individual organisms respond to the physical, chemical and/or biological stimuli in their environment. In this chapter, we will go deeper into the interactions between the biotic and the abiotic elements of the biosphere, focusing on the nonliving components. To begin to understand this concept: the physical "home" of our **biosphere**, we first have to consider the physics of planet formation. From all we know about life in the universe, only planets can possibly offer conditions suitable for life. And indeed, since all life we know of occurs on just one planet, we need to develop an understanding of what is special or unique about our home planet. How is the earth constituted; what is the nature of this "stage" upon which life developed and upon which life continues to play out. Presently, the "ecology" of other planets, if such a thing exists, is a subject of study within the science of **exobiology**.

Nutrients move through the ecosystem in biogeochemical cycles. A biogeochemical cycle is a circuit/pathway by which a chemical element moves through the biotic and the abiotic factors of an ecosystem. It is inclusive of the biotic factors, or living organisms, rocks, air, water, and chemicals. The elements that are moving through the biotic or abiotic factors may be recycled, or they may be accumulated in a place called a **sink/reservoir** where they are held for a long period of time. The amount of time that a chemical is held in one place is called **residence**.

All the chemical elements in an organism are part of the biogeochemical cycle. The chemicals travel not only through the biotic and abiotic components of an ecosystem, but they also travel through an organism. The abiotic factors of an ecosystem include: (1) water (hydrosphere), (2) land (lithosphere), and (3) air (atmosphere). All of the living factors that are found on Earth make up the biosphere.

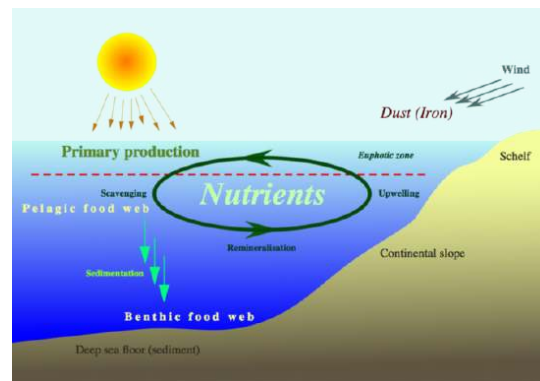
Nutrient Cycle Levels



Respiration can be both aerobic (in the presence of oxygen) and anaerobic (with out oxygen).

Nutrient cycles are broken up into three levels. There are **global nutrient cycles**, which occur when ecosystems become linked on a global scale. This is now known as an *Ecosphere*. On a smaller scale, there are **local nutrient cycles**. These cycles consist of the cycling that occurs in just one ecosystem. The smallest level includes **common nutrient budgets and fluxes**; some examples of this are carbon, H_2O , nitrogen, phosphorus, iron, and other trace elements. All of these cycles can be linked so that a community can remain at equilibrium. All of these cycles are driven by microbes. Microbes contain 350-550 giga tons of the world's carbon. They also contain 85-130 giga tons of nitrogen, along with 9-14 giga tons of phosphorus. Nitrogen is only fixed by bacteria and archaea, and they fix 85% of the 15 giga tons of nitrogen every year. Cyanobacteria are responsible for fixing 50% of the O_2 in the Ecosphere. There are also huge reserves of carbon locked up in rocks. Rocks contain 81 million giga tons of carbon, which is in the form of calcium carbonate ($CaCO_3$), commonly called limestone.

The processes that make up these cycles can be divided into two groups. The first group of processes all have an **aerobic component**. Through respiration, organic material can be converted into carbon dioxide. Respiration is done by animals, plants, and microbes. A second aerobic process is carbon fixation. This is the reverse of respiration where carbon dioxide is converted into organic material. The second group of processes are **anaerobic processes**. The first anaerobic process is fermentation. This is another way that organic material can be converted into carbon dioxide. Bacteria and fungi carry out this process when deprived of oxygen. A second form of an anaerobic process is carbon fixation. The only organisms that fix carbon anaerobically are archaea. The last anaerobic process is methanogenesis. This process takes carbon dioxide and converts it into methane. This process is also only done by archaea, but does not account for all methane because some methane can be made aerobically.



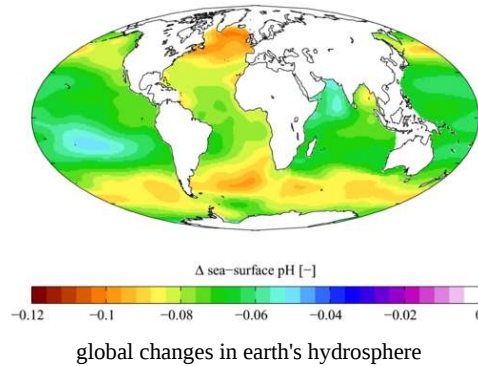
The Nutrient Cycle

There are two main types of systems on Earth, a closed system and an open system. A **closed system** occurs when the chemicals or elements used in an ecosystem are recycled instead of being lost. An **open system** occurs when the sun provides Earth with energy in the form of light which is usually used and then lost in the form of heat as it travels through the various trophic levels on Earth.

Although the biogeochemical cycles are complex and differ between the needs of nutrients by heterotrophs and autotrophs, there are three shared components of nutrient cycles: inputs, internal cycling, and outputs. Precipitation is one form of input, which brings appreciable quantities of nutrients into a cycle (Patterson, 1975). Microbes recycling dead organic material back into the system to be reused is a form of internal cycling. The export of nutrients must be offset by the input of nutrients into a system if there is to be no net loss. Carbon is exported from a cycle in the form of CO_2 via respiration of all living organisms.

The most important biogeochemical cycles are the carbon cycle, nitrogen cycle, oxygen cycle, phosphorus cycle, and the water cycle. The biogeochemical cycles always have a state of equilibrium. The state of equilibrium occurs when there is a balance in the cycling of the elements between compartments. Ecologists may also be interested in the sulfur cycle, the nutrient cycle, and the hydrogen cycle; however, ecologists are more interested in studying the carbon, nitrogen, oxygen, phosphorus, and water cycles.

The term biogeochemical gets its name from the previous cycles listed above (abiotic factors). The prefix *Bio* refers to the biosphere. *Geo* refers to the lithosphere, atmosphere, and hydrosphere. Chemical refers to the various chemicals that go through/travel through the biogeochemical cycles.



A **biogeochemical cycle** or inorganic-organic cycle is a circulating or repeatable pathway by which either a chemical element or a molecule moves through both biotic ("bio-") and abiotic ("geo-") compartments of an ecosystem. In effect, an element is chemically recycled, although in some cycles there may be places (called "sinks") where the element accumulates and is held for a long period of time. In considering a specific biogeochemical cycle, we focus on a particular element and how that element participates in chemical reactions, moving between various molecular configurations. Of the 90-odd elements known to occur in nature, some 30 or 40 are thought to be required by living organisms (Odum, 1959). We will be considering only a few of these, mainly those utilized in fairly large quantities by living organisms. The principal elements of life are **carbon**, **hydrogen**, **oxygen**, and **nitrogen**. However, a number of others are certainly important to understand as well, notably **phosphorus** and **sulfur**. Some "non-essential" elements participate in biogeochemical cycles, entering organism tissues because of chemical similarity to essential elements. For example, strontium can behave like calcium in the body.

Hydrologic Cycle (Water Cycle)

A very significant molecule (on planet Earth) that cycles through ecosystems is the water molecule (H_2O). One of the reasons that life is so dependent on water is that it is the medium of chemical reactions within cells. While it generally is the case that we discuss the water cycle in terms of the various states of water, at least some water molecules are taken up by plants and split apart (photolysed) into atoms of hydrogen and oxygen; the latter is released into the atmosphere as molecular oxygen (O_2). Thus, by virtue of photosynthesizing organisms (*photoautotrophs*), the water cycle is an important part of both the oxygen and the hydrogen cycles. Note that hydrogen ends up as part of an organic molecule, and therefore a participant in the carbon cycle.

The majority of water in the water cycle is found within the oceans and the polar ice caps, although water is present in the bodies of organisms, in freshwater lakes and rivers, frozen in glaciers, and in the ground as groundwater. Water moves more or less freely between these storage reservoirs: by evaporation, by precipitation, and by runoff from the land.

The sedimentation cycle is an extension of the hydrological cycle. The water carries materials from the land to the ocean, where they are added as sediments. The sediment cycle includes the physical and chemical erosion, nutrient transport, and sediment formation from water flows. The sediment formed from water flows is mostly responsible for the buildup of sediments at the bottom of the ocean. The sediment cycle is tied in with the flow of six important elements, which are hydrogen, carbon, oxygen, nitrogen, phosphorus and sulfur. These elements, also known as macroelements, make up 95% of all living things. The balancing of these molecules is required to sustain life. These elements have to be recycled for life to continuously regenerate.



Carbon is being released into the atmosphere.

Carbon is required for the building of all organic compounds. Carbon in the form of carbon dioxide (CO_2) is obtained from the atmosphere and transformed into a usable organic form by organisms. The reservoirs for the carbon cycle are the atmosphere, where carbon dioxide exists as a free gas, fossil organic deposits (such as oil and coal), and durable organic materials like cellulose. Mineral carbonates, such as limestone, are a significant geological sink for carbon. During the process of carbon fixation, carbon dioxide is taken up from the atmospheric reservoir (or from biocarbonates dissolved in water) by plants, photosynthetic bacteria, and algae and is "fixed" into organic substances. Animals obtain their requirements for carbon (as carbon-based molecules) by eating plants or other animals. For the biological links, the carbon cycle comes full cycle when carbon is released by either plants and animals as they respire or after life as they decompose. Organisms respire carbon dioxide as a waste product from the breakdown of organic molecules as their cells derive energy from oxidizing the molecules containing "fixed" carbon. The burning of organic material such as wood or fuels also results in the release of carbon dioxide from organic carbon.

CO_2 is a trace gas and has huge effects on Earth's heat balance by absorbing infrared radiation. During the growing season or summer, there is a decrease in atmospheric CO_2 because increased sunlight and temperature helps plants increase their carbon dioxide uptake and growth. In the winter time, more CO_2 enters the atmosphere than can be removed by plants. This happens because plant respirations and the death of plants happens faster than photosynthesis. [[Life and Biogeochemical Cycles](#)]

Carbon Cycling Experiments

The impact of land-cover and land-use change on global carbon cycle has been the focus of various studies. The Brazilian Legal Amazon has been an area of particular interest because of rapid forest clearing. In determining such an impact, models are often developed and used. In a study focusing on the net carbon flux caused by deforestation and forest re-growth over the period of 1970-1998, a process-based model of forest growth, carbon cycling, and land-cover dynamics was developed. This model was named CARLUC (for CARbon and Land-Use Change). This model, in particular, was used to estimate the size of terrestrial carbon pools in terra firme (unflooded) across the Brazilian Legal Amazon and the net flux of carbon resulting from forest disturbance and forest recovery from disturbance ^[1].

As previously mentioned, carbon cycling is driven by both abiotic and biotic factors. Net carbon fluxes can be partitioned into assimilatory and respiratory components. The complex interplay between assimilatory and respiratory sources and their responsiveness to abiotic changes such as drought and temperature are poorly understood. In a recent study, net carbon partitioning was used to disentangle abiotic and biotic drivers of all component influencing the overall sink strength of a Mediterranean ecosystem during a rapid spring to summer transition (between May and June 2006). It was ultimately determined that decreasing soil water availability rather than increasing air temperature largely affected both assimilation and respiration fluxes of understory plants and in consequence ecosystem respiration and soil respiration ^[2].

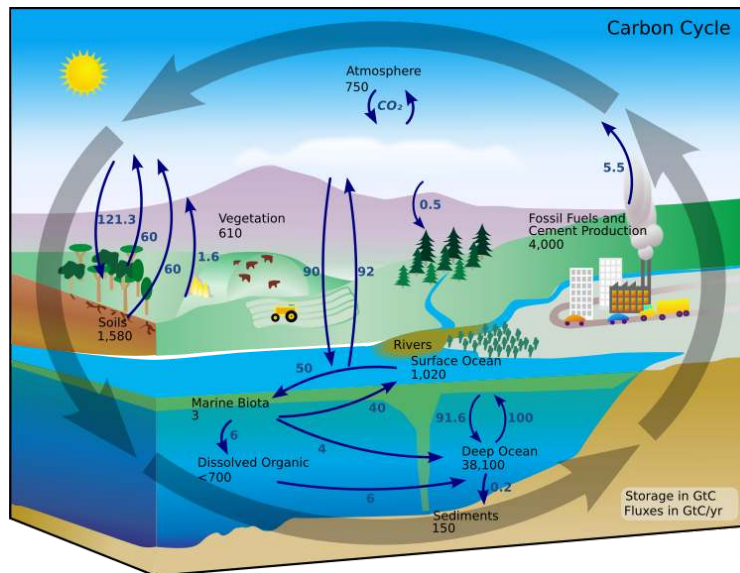
Global Carbon Cycle

Carbon is continuously cycled between the oceans, land, and the atmosphere. The atmospheric carbon is primarily carbon dioxide. Carbon on land occurs primarily in living biota and decaying organic matter. Dissolved carbon dioxide and small organisms like plankton that store carbon dioxide are major sources in the ocean. Carbon is measured in Gigatons, with the deep ocean containing almost 40,000 Gt, compared to about 2,000 Gt on land and 750 Gt in the atmosphere.

Carbon dioxide, a known "greenhouse gas," traps some of the radiation in the atmosphere that would be lost into space. This causes the atmosphere to be warmer than it would naturally be. Since pre-industrial times, man-made emissions have increased the amount

of carbon dioxide in the atmosphere by about 30%. The increase in carbon dioxide causing global warming is important for us to understand so we can predict future implications concerning our planet.

Average global temperatures have increased this past century and are predicted to increase even more in the next century. In a study done by Parmesan *et al*, the distribution and population dynamics of several species of butterflies were monitored in response to the increased temperatures. Migratory patterns of each species were observed and compared to previous patterns of distribution. The butterflies showed a northern shift, which is thought to be a response to increased temperatures. Parmesan *et al* concluded that the current and future climate warming may be a big factor in shifting species distributions [3].



Global Carbon Cycle

Nitrogen Cycle

Nitrogen is required for the manufacturing of all amino acids and nucleic acids; however, the average organism cannot use atmospheric nitrogen for these tasks and, as a result, is dependent on the nitrogen cycle to source usable nitrogen. The nitrogen cycle "begins" with nitrogen stored in the atmosphere as N_2 (the largest nitrogen reservoir). Nitrogen is also stored in the soil as ammonium (NH_4^+), ammonia (NH_3), nitrite (NO_2^-), and nitrate (NO_3^-). Nitrogen is assimilated into living organisms through three stages: nitrogen fixation, nitrification, and plant metabolism. Nitrogen fixation is a process that occurs in prokaryotes in which N_2 is converted to NH_4^+ . Atmospheric nitrogen can also undergo nitrogen fixation by lightning and UV radiation and become NO_3^- . Following nitrogen fixation, nitrification occurs. During nitrification, ammonia is converted into nitrite, and nitrite is converted into nitrate. Nitrification occurs in various bacteria. In the final stage, plants absorb ammonia and nitrate and incorporate it into their metabolic pathways. Once the nitrogen has entered the plant metabolic pathway, it may be transferred to animals when the plant is eaten. Nitrogen is released back into the cycle when denitrifying bacteria convert NO_3^- into N_2 in the process of denitrification, when detritivorous bacteria convert organic compounds back into ammonia in the process of ammonification, or when animals excrete ammonia, urea, or uric acid.

A lot of environmental problems are caused by the disruption of the nitrogen cycle by human activity. Some of the problems caused range from the production of tropospheric (lower atmospheric) smog to the perturbation of stratospheric ozone and contamination of ground water. An example of one of the problems caused is the formation of greenhouse gas. Like carbon dioxide and water vapor, nitrous oxide traps heat near the earth's surface, and it also destroys the stratospheric ozone. Nitrous oxide in the earth's atmosphere is broken down by UV light into nitrogen dioxide and nitric oxide. These two products can reduce the ozone. Nitrogen oxides can be changed back into nitrates and nitrite compounds and recycled back into the earth's surface. [Environmental Biology - Ecosystems]

Phosphorus, Iron, and Trace Mineral cycles

The phosphorus cycle is one of the slowest biogeochemical cycles. Phosphorus mainly cycles through water, soil, and sediments. The little phosphorus in the atmosphere is carried by dust particles and such. Phosphate is most often in the form of phosphate

salts, which are released from weathered rock and dissolved in ground water where plants take them up. Phosphorus is a limiting factor for plants on land and in water, including the ocean, because there is so little of it, and it is not very soluble in water. The cycle does speed up a little bit as it cycles through plants and animals. When the plants and animals die and decay, the phosphorus is returned to the soil and sediments and eventually locked back in the rock.

The iron cycle is similar to every other cycle. Iron is, however, much more abundant than phosphorus. One additional way iron gets cycled, besides rock weathering, is when a volcano erupts and sends an iron-rich dust into the atmosphere, where it eventually spreads to soil and water.

Other trace minerals, such as zinc, copper, and manganese, were once thought to be just as abundant as nitrogen, carbon, and oxygen. Their depletion is thought to be from water erosion of the soil and over cropping of land, so that they aren't able to replenish themselves quickly enough. To learn more about all the trace minerals essential to life visit: [Nutrients - Trace Minerals](#)

"Perfect" Cycles

Odum (1959) describes what are called more or less "perfect" cycles: biogeochemical cycles that involve equilibrium states. That is, there exists in nature a balance in the cycling of the element between various compartments, with the element or material moving into abiotic compartments about as fast as it moves into biotic compartments. Certain ecosystems may experience "shortages," but overall, a balance exists on a global scale.

II. Deserts are characterized by their limited precipitation. Deserts have a brief rainy season, which on average produces less than 30 cm rainfall per year. Deserts are mainly located at 30 degrees North and South latitude because of their dry air resulting from the Hadley cells (please read interlink below on a Hadley cell), which stretch between the equator and 20 to 35 degrees North and South latitude.

Deserts have the capacity to be very productive climates because they are in a high energy input area of the round earth (please refer to chapter 3 about solar irradiation and the earth being round), but they are limited by their low precipitation. Desert flora or plant life is located on only 10% of desert area. They consist of mainly annuals that grow and reproduce during the brief rainy season. The main flora are succulents that store water, have waxy cuticles to prevent water loss, may have few modified small leaves or needles, and have large, shallow root systems.

III. Chaparrals are desert types located in the Mediterranean area. Chaparrals are characterized by their distinct rainy seasons and more so by their extremes. Summer temperatures can reach a high of approximately 40 degrees Celsius, and winter temperatures can reach a low of approximately -15 degrees Celsius. Plant and animal inhabitants are drought adapted to aide survival. Plant life is similar in characteristics to desert plants, with mainly shrub/brush type species.

Soil

Soil is the foundation for terrestrial systems. It is a mixture of organic (living and nonliving) and inorganic material. The organic part is contributed by plants, animals, and microbes. The inorganic part is a result of weathering.

Soil Layering

Soil is a composition of many different layers. The first(top) layer is the **O Horizon** which is then compsed of 2 sublayers the O_i and O_a layers. The O_i is the intact organic layer which is made up of dead organic matter and leaf litter. The O_a is contains mostly humus and is situated next to the A Horizon. The entire O Horizon is about 10cm deep. Deserts usually lack the O Horizon.

The next layer is the **A Horizon**. This is what most consider the topsoil, it is a mixture of weathered rock(clay, sand, and silt) from lower layers and organic material from the O Horizon. This is the area where there are the most roots, microbes, and invertebrates. This horizon usually has a high respiration rate, and has most of the nutrients leached to lower layers by water. The top 2 layers combined (O and A Horizons) are on average about 0.5m deep.

The next layer is the **E Horizon** (or Eluviation Horizon). This layer has the least amount of dissolved nutrients. This layer can have a clay pan formed at the bottom which is highly compacted clay which prevents weathering of rock below. The also prevents tap roots from reaching the C Horizon. This may also cause the area above to become water-logged.

Below the E horizon is the Illuviation Horizon of **B Horizon**. This is the area where leechates collect, and most tap roots exist. It is usually mineral rich and contains little organic material. It is usually about 0.5m deep. Below the B Horizon is the **C Horizon**,

which is the lowest soil layer is commonly called the subsoil. This is mostly weathered parent material. This is usually about 0.5m deep also.

Lastly is the inorganic material of the soil or the **R Horizon**. This is also called bedrock which is a result of weathering from wind, water, temperature, and plants.

Particle Size



Different sizes of particles in sand

The particle size of soil is correlated to the amount of surface area of the particles and the charge of the surface area. A decrease in particle size equals an increase in surface area which in turn equals an increase in a negative charge of the surface area. The United States Department of Agriculture (USDA) designates types of soil by the size of the particles in the soil. Clay consists of particles smaller than 0.002mm and has the largest water capacity and highest nutrient capacity. Silt consists of particles smaller than 0.05mm and has a relatively median water capacity and a median nutrient capacity. Sand consists of particles smaller than 2mm and has the smallest water capacity and the lowest nutrient capacity.

Acidic Soil

Acidic soil is any type of soil that has a low pH. It is created whenever soil is very low in minerals and may be created by conifer needles. Amino acids also break down clay. The breakdown of clay is done by leaching the minerals out of the soil. This leaching of minerals is due to a high Hydronium ion $[H^+]$ concentration which results in less productive soil. Acid rain or precipitation that is unusually acidic because of emissions of sulfur and nitrogen compounds which react with the atmosphere is widely believed to be responsible for acidifying soil.

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16: Manatee



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17: Short-Tailed Hawk



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CHAPTER OVERVIEW

18: Peregrine Falcon

The peregrine falcon is the fastest animal in the world. It can attain speeds above 200 miles per hour as it dives toward its prey. Being a member of the genus *Falco*, the peregrine falcon exhibits many of the generic characteristics of falcons. It has long slender wings, a short tail, curved beak and sharp talons. The peregrine falcon is the fastest bird of prey in the world. It can reach the 322 kilometers per hour. The peregrine falcon can reproduce since it is 1 year old. The peregrine falcon can lay three or four eggs and in extreme situations one or five. The eggs are incubated for 29 or 33 days.

Peregrine falcons are found perched high in trees and cliff sides in open areas like grasslands, tundra and meadows. They have also become accustomed to living in cities atop tall building. [2] Peregrines are one of the most wide spread species of birds in the world. Peregrine falcons are found on every continent except Antarctica.

Peregrine falcons primarily prey on small birds and occasionally small mammals, lizards and insects. When preying on birds, the peregrine falcon attacks and kills its prey in mid flight, then brings it to a perch to feed. Smaller prey items, such as bats and insects can be eaten in mid flight. The peregrine falcon is one of the most successful birds of prey in the word.

Adaptations

The falcon shares many characteristics with other falcons. Like all falcons they have long tapered wings and a short tail. These physiological adaptations equate to high speed maneuverability while in flight. These characteristics increase the fitness of areal predators.

The name falcon is derived from the Latin word falcon meaning hook shaped and refers to the animal's beak and claws. Falcons typically hunt small birds and they use their beaks and claws to swiftly immobilize and kill their prey while in flight.

These combined traits make the peregrine falcon a very successful predator. It is the fastest animal in the world; clocked at over 200 miles per hour during a stoop, or dive while in pursuit of a prey item. At that speed, any small bird that the peregrine falcon places in its sights is not getting away. All falcons use their talons to latch onto prey while their sharp curved beak severs the prey's spinal column at the base of the skull.

The peregrine falcon's coloration helps it to blend into its environment. There are 19 subspecies of the peregrine falcon and each has different colorations to aid with concealment in its native environment. The majority of the subspecies of peregrine falcon have speckled underbellies and black to slate or bluish black wings and head.

The peregrine falcon has developed several behavioral adaptations that increase its survivability in the wild. Peregrine falcons perch very high in tall trees, cliff sides and buildings which tend to reduce the predation of juvenile young by small mammals and lizards. Beyond reducing predation, a tall perch increases the successfulness of the peregrine's ability to successfully live hunt. Generally speaking, the higher the peregrine falcon is in reference to it prey, the faster speeds it can attain during its pursuit the higher the probability of a successful capture.

For the most part, peregrine falcons do not build nests. Occasionally they will use nests that have already been built, but they tend to dig simple depressions out of the soil on cliff sides. This cuts down on energy expenditures and maintains an adequate energy reserve for hunting.

The peregrine falcon has also developed a proclivity towards city life. The tall buildings provide excellent opportunities to perch and the abundance of overweight pigeons provide a huge amount of biomass to feed off of. It makes the peregrines' life a lot easier and it cuts down on city pests.

Falcons share a close evolutionary history with both hawks and eagles. All three species of birds have developed excellent visual acuity and powerful talons and beaks for catching and immobilizing prey. The evolutionary aspects that separate eagles, hawks and falcons are primarily Loven behaviors and the morphology of fight appendages.

Hawks tend to attack small land mammals by grasping and killing them with its talons. Hawks kill by inflicting massive amounts of physical damage to their prey. As stated previously, falcons hunt and kill small birds by grasping them with their talons and

severing their spinal column with their sharp hooked beak. [1] Eagles, such as the bald and golden eagle, soar high above their prey, using their superior vision to pick out small mammals and fish, then swoops down and grasps its prey and carries it off to a feeding perch.

Hawks, falcons and eagles deviate from each other in terms of the morphology of their respective flight appendages. Falcons have long tapered wings and short tails which lend to its amazing areal speed and agility. Eagles have very broad wings that are designed for soaring and short tails that aid in maneuverability. Eagles are the intermediate form between falcons and hawks. Hawks have broad wings and long tails which provide a very stable platform for flight.

Habitat

Peregrine falcons can be found in open habitats such as grasslands, tundra and meadows. They can also be found in deserts and at elevation from sea level to 12,000 feet. They prefer open areas because these areas complement the peregrine falcons' hunting behaviors. They are most common in tundra and coastal areas. In recent years they have been found in urban areas and cities due to the fact that tall buildings provide the perfect perch for hunting and nesting.

Peregrine falcons are found all over the world. They inhabit every continent except for Antarctica. They are one of the most prevalent terrestrial vertebrates in the world. Though some of the populations of peregrine falcons such as southern Pacific and Island dwelling birds do not migrate, the peregrine falcon is one of the furthest migrating birds in North America. The peregrine falcon migrates very long distances during the year. Its name is derived from the Latin word peregrinus, meaning wanderer. Some falcons that live in the tundra of Alaska and Canada can be found 25,000km south in Argentina during the winter months.

Role in the Ecosystem

The peregrine falcon is an apex predator that is almost at the top of its food web. It preys on a variety of organisms that dwell within its home range. As a predator, its role in the ecosystem is a check and balance for population control. Birds of prey pick off the weak and sickly of a population of prey items which in turn tends to increase the fitness of successive generations of that population. The peregrine falcon eats birds that include mourning doves, pigeons, shorebirds, waterfowl, ptarmigan, grouse, and songbirds. Along with birds, it preys upon small reptiles and mammals including rodents and bats.

There are very few organisms that prey on the peregrine falcon. For the most part, other, larger, birds of prey such as great horned owls, gyrfalcons and golden eagles are the only predators of adult peregrines while juveniles may be taken by mammalian predators such as cats, bears, wolverines, and foxes. Another threat to adult peregrines is rival peregrine falcons. Competition for territory, resources and mates can lead to adult mortality.

Interaction with Humans

The interactions between the peregrine falcon and man are primarily positive interactions for both parties. The peregrine falcon serves as a pest controller on farms and airports. Falcon handlers train and use falcons to keep problematic bird species at airports under control. When released, the peregrine falcon peruses and kills birds that could get caught in and damage aircraft engines. Over time, the problematic bird species will stay out of the falcon's established territory. In recent years, the falcon is being replaced by specially designed sirens. On farms, peregrine falcons keep small rodent and bird populations in check. [1] This in turn maintains crop and livestock viability and reduces losses for the farm.

The art of falconry, using birds of prey such as hawks and falcons to hunt wild game, dates back to the Heian dynasty of 2200BCE. The relationship between falcon and man has been going strong for well over 4000 years. Falconers would take fertilized eggs from a roost and raise and train the chicks from birth to hunt and capture small birds and squirrels.

Today falconry is a dying art. With grasslands acquiescing to urbanization, areas to practice falconry are simply disappearing. A once popular mode of making a living has been reduced to a pastime reserved for renaissance festivals and airports.

The one interaction between the peregrine falcon and man that is detrimental to the latter is the predation of farm animals such as chickens and waterfowl. [1] These selectively bred, relatively immobile animals are easy targets for such a dynamic and specialized predator. Given the fact that this is the only real detrimental aspect of the relationship between man and the peregrine falcon, man is much better off with it than without it.

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19: North American River Otter



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CHAPTER OVERVIEW

20: Pinewoods Treefrog

Hyla femoralis

One of nine species of tree frogs indigenous to Florida (Bartlett and Bartlett)

Kingdom: Animalia
Phylum: Chordata
Subphylum: Vertebrata
Class: Amphibia
Order: Anura (tailless)
Family: Hylidae (16 species)
Genus: *Hyla*
Species: *femoralis*

Characteristic

Size: Typically these frogs are slender and range from 1 to 1.5 inches long (Johnson). However the female can be a little larger up to 1.75 inches (Bartlett and Bartlett)

Color: Varies from reddish to gray and even green they tend to have chameleon like color changes to blend in with their background (Bartlett and Bartlett) When found on barks of trees they have a dark chocolate appearance with darker blotches that enhance the camouflage effect (Carmicheal and Williams). At rest on a leaf the tree frog appears green with a golden hue that displays the dark bands decorating their skin (Carmicheal and Williams). They can be found blending in to the trunks of trees in the everglades.

Markings: The distinctive patterns of the Pinewood tree frog include a dark lateral line on both the sides that begins in the nostril area thru the eyes curving down to tympanum all the way to the posterior (Bartlett and Bartlett). (Field Guide) The best way to distinguish this tree frog from others is to note the small yellowish spots located on the underside of the inner thigh (Bartlett and Bartlett).

Physical Features: The toes of the Pinewood tree frog are very arboreal without webbing that allows the frog to climb trees (Paulson). Resting this tree frog is generally found on vegetation near the ground however with its' specialized toes can climb up to thirty feet within trees (Cowley)

The tympanum or the ear of a pinewood tree frog is an exposed large circle behind the eye (Bartlett and Bartlett). With the inner ear highly developed from its' ancestors this species can hear the calls of their mates from relatively far distances (Carmicheal and Williams).

A big difference between the males and females of the pinewood frog is that males have a dark throat with rounded subgular vocal sacs that are not present in the females (Bartlett and Bartlett).

Although all frogs do not have the ability to turn their heads they have highly developed peripheral vision (Cowley). The design of the modern amphibian head is highly developed from the ancient ancestor the labyrinthodont amphibian (Barghusen and Hopson).

Distinctive Call: Sometimes described as Morse code series of dots and dashes similar to SOS (Johnson) <USGS frog call look up > The faster moving sounds of dots and dashes are the call for a mate, while a slower sounding call heard on treetops is said to be the call for rain (Bartlett and Bartlett) Tree frogs similar to other toads and frogs hold their nostrils and mouth closed and shunted air moves rapidly between lungs and vocals sacs (Carmicheal and Williams). This sac is an inflatable membrane just below the throat and acts as a resonating chamber to amplify their unique sounds (Carmicheal and Williams).

Chemical Transport: The inefficiency of amphibians' lungs requires the exchange of gases through their moist skin (Carmicheal and Williams). More gas exchange between air and the blood stream also takes place in the mouth lining and through their smooth lungs (Brow). This helps recycle air and it is easier than taking breathes (Carmicheal and Williams). A “forced pump” extremely similar to lungfish suggest, “that in the change from aquatic to aerial respiration the machinery was already available” only a few changes in the adaptation process allowed amphibians access to terrestrial life (Lawson).

The pump works in four steps:

1. The throat moves down and draws in air through nostrils.
2. Nostrils close, as the throat moves up and force air into the lungs
3. The throat again moves down and air moves out of lungs.
4. Finally the nostrils open up the throat move up and the air forced out of lung (Bro

Ecology and Life History

Fitness: Ranked by the IUCN Red List Category the Pinewoods tree frog is a species of “LC” or least concern (Frost, IUCN - Conservation International, and NatureServe). They are considered stable or “within the $\pm$ 10% fluctuation in population range” (Frost, IUCN - Conservation International, and NatureServe).

Reproduction: The process begins with the male mounting the back of the female as she lays her eggs and he pours his sperm over them for fertilization and are secured in a pond or ditch (Wallace). Batches range from 20 to 100 gelatinous covered eggs (Bartlett and Bartlett). Laid during heavy rains in spring and summer in takes the egg, seven to ten weeks in larvae stage to develop into its' adult form (Carmicheal and Williams).

Hybridization: Occurs naturally with Pine Barren and Gray tree frogs but mating calls become very difficult to distinguish between their voices, or becomes intermediate (Bartlett and Bartlett).

Metamorphosis: During the seven to ten week period that the eggs change into tadpoles they do not have eyelids, use gills to breathe, posses tails and utilize scraping parts in their mouth for their herbivorous diets(Bartlett and Bartlett) For the most part they eat organic debris, some algae and plant tissue(Frost, Amphibian species of the world. A taxonomic and geographical reference). As the tadpole becomes an adult he must first develop organs such as lungs, a respiratory system, tougher skin, and eyelids, to keep maintain moisture and protect themselves for dry life on land (Paulson). His diet also begins to adapt to life on land. As this tree frog matures into an adult they prefer a more Invertivore diets, or they eat smaller invertebrates found in trees or on the ground (Frost, Amphibian species of the world. A taxonomic and geographical reference).

Phenology: The pinewood tree frog hibernates during the cool dry months of winter and leads a nocturnal lifestyle (Frost, Amphibian species of the world. A taxonomic and geographical reference). They are most active during the spring thru fall season and at night possibly to protect themselves for the warm tropical sun (Frost, Amphibian species of the world. A taxonomic and geographical reference)

Habitats

Description - In Kentucky they can be found in pine wood trees, within cypress tree environments, and often in roadside ditches. Although this species is often found in vegetation low to the ground it can also be located up to 30 feet high in the trees listed above. This particular frog loves to hide under or in rotting logs, stumps during the colder dryer season

Florida's damp upland hardwoods with an over story of oaks or magnolias and understory of American Holly and hophornbean are a perfect home for this amphibian (Bartlett and Bartlett). As well as the damp upland pinewoods which has the bionetwork of an over story with long leaf pines and understory of shrubby thick sometime grasses herbaceous growth (Bartlett and Bartlett). Each biosphere would also include a system of water within it for the tree frogs' reproductive behavior. An ephemeral pond often poorly drained low laying and usually man made that fills during rainy season as well as drains during drought is a great place to lay their fertilized eggs (Bartlett and Bartlett). Or the more permanent ponds, containing some amounts of water year round even though the levels fluctuate with rainfall totals, will also allow the eggs to mature from tadpole to frog rather safely (Bartlett and Bartlett). These types of ponds are surrounded by shrubs lining the rim as other submerged vegetation grows under their shadows (Bartlett and Bartlett). The large trees allow the tree frog to climb upward to call for rain or possible predation avoidance. While the wet

parts of these damp grounds create a good place for larvae development into swimming tadpoles and eventually tree climbing frogs.

Distribution: 80,000 to 1,000,000 square miles of the Atlantic and Gulf coastal plains including Virginia and Louisiana reported to be common or abundant in Florida (Frost, IUCN - Conservation International, and NatureServe).

Even though the actual number of adult population is unknown it may well exceed 100,000 with the global trend to be stable to slightly declining (Frost, IUCN - Conservation International, and NatureServe).

The migration habits are normally local and commonly between breeding pools close to their terrestrial habitats (Frost, IUCN - Conservation International, and NatureServe). The exact distance this frog will migrate for breeding is unknown but it could be much further between ponds if civilization were not as disruptive with parking lots and land barriers. Barriers prohibiting longer migrations include major highways and other urban development deterrents (Frost, IUCN - Conservation International, and NatureServe).

Note about Species Discoveries

Molecular genetics and intensified exploration especially in tropical areas has led to a significant increase in the numbers of identifiable species in amphibians (Kohler, Vieites and Bonett). At this point species identification has grown from 4533 in 1992 to 5723 by 2003, an increase of 26.3% in 11 years (Kohler, Vieites and Bonett). Even with new discoveries the truth is amphibian populations decline at 32.5 percent rate annually and are globally threatened (Kohler, Vieites and Bonett). This rate is more rapid than birds or any other mammal to date (Michelle S. Koo). Some experts name global warming and dry climates to the decrease in frog populations, while others suggest non-native species invasions or even a simple disease infecting these organisms (Michelle S. Koo). Nevertheless the affects of losing natures amphibians and bug catchers remains to be seen.

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CHAPTER OVERVIEW

21: Cottonmouth Snake

Introduction

The Cottonmouth snake, also known as a water moccasin (*Agkistrodon piscivorus*) is found near bodies of water all over the Southeastern United States. It is best known for the white lining of its mouth, which it exposes when threatened. They are the world's only semi-aquatic vipers with the capacity to deliver a painful, if not fatal, bite (5). There are three subspecies of *A. piscivorus*; *A. p. piscivorus*, *A. p. leucostoma*, and *A. p. conanti* (1). Of these three subspecies, *A. p. conanti* is dominant in Florida.

Physical Characteristics

Cottonmouth snakes are usually 30 to 48 inches in length, but can reach lengths of up to 74 inches (3). Its body is a heavy, thick build and thins quickly at the tail. Color patterns range from black or gray to tan and yellowish. A series of dark cross bands run the length of the snake and can be either brown or black, but are typically reserved for the juveniles of the species. The pattern fades with age, leaving adult cottonmouth snakes with a uniform brown, gray or black coloring. The underbelly is usually pale or white (1). The snakes are a member of the viperidae family, possessing hollow fangs to inject venom deep into its prey. It belongs to the subclass crotalinae, or pit-viper (1). Pit vipers have developed special organs found in pits, hence the name, located right behind the nostrils. These pits, covered with a temperature sensitive membrane, allow the cottonmouth to sense warm blooded animals. It is an adaptation which proves especially useful at night, when most cottonmouths prefer to hunt. Some cottonmouths may also use this adaptation to find cool places to escape inhospitable temperatures (6).

Habitat

The geographic range of *A. piscivorus* differs among the subspecies of the snakes. *A. p. piscivorus* is dominant along the Atlantic coast, as far north as Southern Virginia. The smaller subspecies, *A. p. leucostoma* is found as far west as Texas and Oklahoma and as far north as Southern Illinois. *A. p. conanti*, the Florida Cottonmouth dominates all of Florida (1). The cottonmouth snake is most commonly found around swamps, lakes, slow moving streams, marshes and even drainage ditches. They are most active at night when they hunt, but will spend the early part of the day lying on a tree branch, basking in the sun. They are known to gather around drying water holes in order to feast on the trapped fish and frogs (1). The snakes are very strong swimmers, spending most of their time in the water. They have been known to enter the sea and successfully colonize offshore islands. They occur in particularly large numbers on some of the islands on the Gulf Coast of Florida. Their success has much to do with their opportunistic feeding.

Feeding

The snake's diet mainly consists of small mammals, birds, fish, frogs and tadpoles. Fish are caught by cornering them underwater. Contrary to popular belief, the cottonmouth snake has the ability to bite and deliver its venom underwater, making it a very effective hunter (1). Even though it has the ability to catch its own prey, the main reason the snake has become so successful is due to their opportunistic feeding habits, especially when colonizing offshore islands in the gulf. The snake will scavenge for food, seeking out carrion that washes up onto the shore, or detritus that falls from the nests of birds. Cottonmouth populations are reflected by bird populations of offshore islands, with the higher concentration of snakes existing where there is a higher concentration of birds (bioone). When attacking, the snake utilizes a hemotoxin which affects the blood and its ability to clot (6). The broken down blood cells travel to the heart and coagulate in the pulmonary artery. The pain is intense, and as blood cells begin to break down there is an immediate swelling and discoloration. Severe hemorrhage occurs at any point in contact with the venom (2). The venom is produced in glands near the back of the mouth, at the junction of the upper and lower jaws. As the snake strikes, the muscles around the venom glands contract and force the toxin out through the hollow teeth and into the prey. Whereas in normal conditions the venom supply of the cottonmouth is never fully depleted; full venom replacement can take up to three weeks (2).

Behavior

The snake has been given a bad reputation over the years as a very aggressive snake that will attack anything nearby. When tested to measure the different responses of the cottonmouth to encounters with humans, 23 of 45 (51%) tried to escape while 28 of 36 (78%) resorted to threat displays and other defensive tactics. It was only when they were picked up with a mechanical hand were they likely to bite (4). The characteristic threat display that has earned the cottonmouth its name includes throwing its head back with its jaws open to show the white lining of the mouth. The tail vibrates, much like other vipers like rattlesnakes, and the head and body are curled into an S-shape, appearing as though the snake is waiting to strike. The snake is most likely to stand its ground and resort to these most common threat displays which has often been mistaken for aggressive behavior (1). The cottonmouth can be active during the day or the night. Usually during the night. They bask during the day. They are also stretched out or coiled up in the shade. On cooler days they have been known to sun themselves on rocks, tree branches or logs lying close to shore. They are most active at night. Northern species of *A. piscivorus* have been known to become inactive during the winter, however they are typically the last species to seek shelter. They do not enter full hibernation, though, as they are known to be very active upon discovery and will immediately try to burrow deeper or escape to nearby water. Shelter for the cottonmouth during these inactive periods usually consists of rotting trees, crayfish burrows or the burrows of other mammals – muskrat, beaver, etc. (4).

Reproduction and Growth

The cottonmouth snake is ovoviviparous, meaning they develop in eggs protected inside the mother's body until they hatch, or are about to hatch. This type of reproduction is found in many aquatic life forms. Nourishment is provided by the egg yolk instead of the mother; however the mother's body does provide gas exchange (8). In the case of the cottonmouth, the eggs hatch inside the mother and the young, typically 15 per litter, are birthed alive. There is typically one litter birthed every other year.

Breeding occurs during the warmer months, and most births occur after a three month gestation period. However, differences in the physiology of the individual female snake cause the actual gestation period to vary from season to season (9). Cottonmouths are not known to give parental care after birth, however there have been cases reported of defensive behavior of a mother for her litter. One report details a female positioned at the mouth of a burrow surrounded by her young. When one of the young was moved a distance away from the mother, she became agitated and faced the intruder. Once the offspring was returned, she remained at the mouth of the burrow, ready to strike (1).

Natural Predators

The cottonmouth snake is preyed upon by larger organisms, including large birds, and other reptiles like the snapping turtle and American alligator. There have also been widespread reports of cannibalism by other cottonmouths (1). Humans are also a threat to the cottonmouth. Seeing as it gained a reputation as a very aggressive snake, many people take it upon themselves to kill the cottonmouth, and even other snakes that resemble cottonmouths. The cottonmouth is listed as Least Concern (3).

Cladogram

Snakes in the genus *Agkistrodon* are closely related to those in the genus of *Crotalus* and *Sistrurus*. *Agkistrodon* and *Sistrurus* have nine large head plates, whereas *Crotalus* as well as all other vipers have a head covered in smaller scales. Both *Crotalus* and *sistrurus* have rattles on the end of their tails. *Crotalus* is best known as the rattlesnake. *Sistrurus* lives farther north in Canada and has a much smaller rattle (9)(10). What separates *Agkistrodon* is their adaptation to water. Neither *Crotalus* or *Sistrurus* have adapted to life in lakes or streams. In fact, Eastern Diamondback Rattlesnakes are known to inhabit dry, arid areas of the U.S.

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CHAPTER OVERVIEW

22: Practical Vegetation Sampling

Done using the National Vegetation Classification (NVC) survey.

US System

UK System

The National Vegetation Classification is a system of classifying natural habitat types according to the vegetation they contain. Different systems exist in different countries, including the United States and the United Kingdom. A large scientific meeting of ecologists, botanists, and other related professionals in the United Kingdom resulted in the publication of a compendium of five books [ISBN 0521797160](#) by Cambridge University Press which detail the incidence of plant species in 5 major habitat types in the United Kingdom natural environment. They are the first systematic and comprehensive account of the vegetation types of this country. They cover all natural, semi-natural and major artificial habitats in Great Britain (but not Northern Ireland), representing the fruits of fifteen years of research by leading plant ecologists. From the data collated from the books was developed a commercial software product called 'MATCH' which helps to classify vegetation identified into one of the many habitat types found in Great Britain. [\[1\]](#)

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CHAPTER OVERVIEW

23: Appendix A – Glossaries of Ecological Terms

23.1: Glossary 1 – Basic Ecology

23.2: Glossary 2 – Invasive Species

23.3: Glossary 3 – Methodologies

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23.1: Glossary 1 – Basic Ecology

Biological control or biocontrol: 1. In general, the control of the numbers of one organism as a result of natural predation by another or others. Specifically, the human use of natural predators for the control of pests or weeds. Also applied to the introduction of large numbers of sterilized males of the pest species, whose matings result in the laying of infertile eggs (Allaby, 1998). 2. The release of one species to control another (Carlton, 2001). 3. The management of weeds using introduced herbivores (often insects) as biological control agents (Booth et al., 2003). 4. Control method involving a biological control agent that is a natural enemy of a target pest (Heutte and Bella, 2003).

Biological diversity or biodiversity: Used to describe species richness, ecosystem complexity, and genetic variation (Allaby 1998).

Bioregion: A biological subdivision of the earth's surface delineated by the flora and fauna of the region (Allaby 1998).

Biota: The plants and animals of a specific region or period, or the total aggregation of organisms in the biosphere (Allaby 1998).

Community: Any grouping of populations of different organisms that live together in a particular environment (Allaby 1998).

Disturbance: An event or change in the environment that alters the composition and successional status of a biological community and may deflect succession onto a new trajectory, such as a forest fire or hurricane, glaciation, agriculture, and urbanization (Art 1993).

Ecosystem: A discrete unit, or community of organisms and their physical environment (living and non-living parts), that interact to form a stable system (Allaby 1998).

Endemic: A species or taxonomic group that is restricted to a particular geographic areas because of such factors as isolation or response to soil or climatic conditions; this species is said to be endemic to the place (Allaby 1998) and would be native.

Exotic species: This term is commonly used in publications and literature, and is similar to the terms alien species, foreign species, introduced species, non indigenous species, and non native species (Heutte and Bella 2003). Other definitions include: 1. An introduced, non native species, or a species that is the result of direct or indirect, deliberate or accidental introduction of the species by humans, and for which introduction permitted the species to cross a natural barrier to dispersal (Noss and Cooperrider 1994). 2. In North America, often refers to those species not present in a bioregion before the entry of Europeans in the 16th century, or present in later parts of that region and later introduced to an ecosystem by human-mediated mechanisms (Cohen and Carlton 1988).

Fauna: The animal life of a region or geological period (Allaby 1998)

Fitness: Survival and reproduction ability of an individual

Flora: Plant or bacterial life forms of a region or geological period (Allaby 1998).

Habitat: 1. The place, including physical and biotic conditions, where a plant or an animal usually occurs (Allaby 1998). 2. The physical conditions that surround a species, or species population, or assemblage of species, or community (Clements and Shelford, 1939).

Indigenous: A species that occurs naturally in an area; a synonym for native species (Allaby 1998), although see "endemic".

Native range: The ecosystem that a species inhabits (Booth et al. 2003).

Native species: 1. A synonym for indigenous species 2. A species that occurs naturally in an area, and has not been introduced by humans either intentionally or unintentionally (Allaby 2005). 3. In North America, a species established before the year 500 (Jeschke and Strayer 2005)

Naturalized species: 1. A species that was originally introduced from a different country, a different bioregion, or a different geographical area, but now behaves like a native species in that it maintains itself without further human intervention and now grows and reproduces in native communities (Allaby 1998). 2. A non native species that forms self-sustaining populations but is not necessarily an invasive species (Booth et al. 2003).

Niche: the role the species plays in the functioning of the ecosystem: the "functional status of an organism in its community" (Charles Elton, in Odum, 1959).

Population: A group of potentially inter-breeding individuals of the same species found in the same place at the same time (Booth et al. 2003).

Ruderal species: A plant associated with human dwellings, construction, or agriculture, that usually colonizes disturbed or waste ground. Ruderals are often weeds which have high demands for nutrients and are intolerant of competition. See also native weed or invasive native (Allaby 1998).

Species: A group of organisms formally recognized as distinct from other groups; the taxon rank in the hierarchy of biological classification below that of genus; the basic unit of biological classification, usually defined by the reproductive isolation of the group from all other groups of organisms (Allaby 1998).

Weed: 1. A plant in the wrong place, being one that occurs opportunistically on land or in water that has been disturbed by human activities (see also *ruderal species* and *native weed* or *invasive native*), or on cultivated land, where it competes for nutrients, water, sunlight, or other resources with cultivated plants such as food crops. Under different circumstances the weed plant itself may be cultivated for beneficial purposes (Allaby, 1998). 2. A native or introduced species that has a perceived negative ecological or economic effect on agricultural or natural ecosystems (Booth et al., 2003). 3. A plant growing in an area where it is not wanted (Royer and Dickinson, 1999).

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23.2: Glossary 2 – Invasive Species

Alien species: Less commonly used in scientific literature but often included in population publications, public information displays, and educational literature. This term refers to species that spread beyond their native range, not necessarily harmful, or species introduced to a new range that establish themselves and spread; similar terms include exotic species, foreign species, introduced species, non indigenous species, and non native species (Jeschke and Strayer 2005).

Aquatic nuisance species: Less commonly used in most literature. 1. A nonindigenous species that threatens the diversity or abundance of native species or the ecological stability of infested waters, or commercial, agricultural, aquacultural or recreational activities dependent on such waters (EPA 1990). 2. Aquatic species that causes economic or environmental harm to humans (Heutte and Bella 2003). 3. An aquatic species with adverse effects on humans, either directly (e.g. species that produce toxins that are harmful to humans) or indirectly (e.g. species that infest nature reserves) (Colautti and MacIsaac 2004).

Biological control or biocontrol: 1. In general, the control of the numbers of one organism as a result of natural predation by another or others. Specifically, the human use of natural predators for the control of pests or weeds. Also applied to the introduction of large numbers of sterilized males of the pest species, whose matings result in the laying of infertile eggs (Allaby, 1998). 2. The release of one species to control another (Carlton, 2001). 3. The management of weeds using introduced herbivores (often insects) as biological control agents (Booth et al., 2003). 4. Control method involving a biological control agent that is a natural enemy of a target pest (Heutte and Bella, 2003).

Biological invasion or bioinvasion: A broad term that refers to both human-assisted introductions and natural range expansions (Carlton, 2001).

Biological diversity or biodiversity: Used to describe species richness, ecosystem complexity, and genetic variation (Allaby 1998).

Bioregion: A biological subdivision of the earth's surface delineated by the flora and fauna of the region (Allaby 1998).

Biota: The plants and animals of a specific region or period, or the total aggregation of organisms in the biosphere (Allaby 1998).

Casual species: This term is becoming less common in usage. A non native species that does not form self-replacing populations (Booth et al. 2003). Similar terms include introduced species, non indigenous species, and non native species.

Chemical control: Control method that employs herbicides to control exotic plants (Heutte and Bella 2003).

Community: Any grouping of populations of different organisms that live together in a particular environment (Allaby 1998).

Cryptogenic species: Species that are neither clearly native nor exotic (Cohen and Carlton 1988).

Cultivar: A variety of a plant produced and maintained by horticultural techniques and not normally found in wild populations (Allaby 1998).

Disturbance: An event or change in the environment that alters the composition and successional status of a biological community and may deflect succession onto a new trajectory, such as a forest fire or hurricane, glaciation, agriculture, and urbanization (Art 1993).

Ecosystem: A discrete unit, or community of organisms and their physical environment (living and non-living parts), that interact to form a stable system (Allaby 1998).

Endemic: A species or taxonomic group that is restricted to a particular geographic areas because of such factors as isolation or response to soil or climatic conditions; this species is said to be endemic to the place (Allaby 1998) and would be native.

Exotic species: This term is commonly used in publications and literature, and is similar to the terms alien species, foreign species, introduced species, non indigenous species, and non native species (Heutte and Bella 2003). Other definitions include: 1. An introduced, non native species, or a species that is the result of direct or indirect, deliberate or accidental introduction of the species by humans, and for which introduction permitted the species to cross a natural barrier to dispersal (Noss and Cooperrider 1994). 2. In North America, often refers to those species not present in a bioregion before the entry of Europeans in the 16th century, or present in later parts of that region and later introduced to an ecosystem by human-mediated mechanisms (Cohen and Carlton 1988).

Fauna: The animal life of a region or geological period (Allaby 1998).

Foreign species: A species introduced to a new area or country. Similar terms include alien species, exotic species, introduced species, non indigenous species, and non native species.

Flora: Plant or bacterial life forms of a region or geological period (Allaby 1998).

Habitat: The place, including physical and biotic conditions, where a plant or an animal usually occurs (Allaby 1998).

Herbicide: Pesticide that specifically targets vegetation (Heutte and Bella 2003).

Indigenous: A species that occurs naturally in an area; a synonym for native species (Allaby 1998), although see "endemic".

Injurious species: An introduced species that causes economic or environmental harm to humans. Similar terms include aquatic nuisance species, noxious weed, and invasive species (Heutte and Bella 2003).

Intentional introduction: A species that is brought to a new area, country, or bioregion for a specific purpose, such as for a garden or lawn; a crop species; a landscaping species; a species that provides food; a groundcover species; for soil stabilization or hydrological control; for aesthetics or familiarity of the species; or other purposeful reasons (Booth et al. 2003).

Introduced species: This term, along with the terms introduced species and nonindigenous species, is one of the most commonly used terms to describe a plant or animal species that is not originally from the area in which it occurs. This term means those species that have been transported by human activities, either intentionally or unintentionally, into a region in which they did not occur in historical time and are now reproducing in the wild (Carlton 2001). Similar terms include alien species, exotic species, foreign species, non indigenous species, and non native species.

Invasibility: The ease with which a habitat is invaded (Booth et al. 2003).

Invasion: The expansion of a species into an area not previously occupied by it (Booth et al. 2003).

Invasive species: This term is subject to the most confusion and debate within invasion biology terminology. Generally, this term refers to a subset of plants or animals that are introduced to an area, survive, and reproduce, and causes harm economically or environmentally within the new area of introduction. 1. An alien species whose introduction does or whose introduction is likely to cause economic or environmental harm or harm to human health (Executive Order 1999). 2. An adjective for native or nonindigenous species that have colonized natural areas; 3. Discrimination of nonindigenous species established in cultivated habitats (as 'noninvasive') from those established in natural habitats; 4. Nonindigenous species that are widespread; or 5. Widespread nonindigenous species that have adverse effects on the invaded habitat (Colautti and MacIsaac 2004). Other definitions include the following: 5. Species that spread beyond their native range, not necessarily harmful, or species introduced to a new range that establish themselves and spread (Jeschke and Strayer 2005). 6. Species that displace native species and have the ability to dominate an ecosystem, or a species that enters an ecosystem beyond its natural range and causes economic or environmental harm (Heutte and Bella 2003).

IPM: Integrated Pest Management. IPM focuses on long-term prevention or suppression of pests. The integrated approach to weed management incorporates the best suited cultural, biological and chemical controls that have minimum impact on the environment and on people (Heutte and Bella 2003).

Manual control: Removal that involves the use of tools such as shovels, axes, rakes, grubbing hoes, and hand clippers to expose, cut, and remove flowers, fruits, stems, leaves, and/or roots from target plants (Heutte and Bella 2003).

Mechanical control: Removal that involves the use of motorized equipment such as mowers, "weed-whackers", and tractor-mounted plows, disks, and sweepers. Burning is also categorized here (Heutte and Bella 2003).

Native range: The ecosystem that a species inhabits (Booth et al. 2003).

Native species: 1. A synonym for indigenous species 2. A species that occurs naturally in an area, and has not been introduced by humans either intentionally or unintentionally (Allaby 2005). 3. In North America, a species established before the year 500 (Jeschke and Strayer 2005)

Native weed (invasive native): A species that is native to an area or bioregion that has increased in number dramatically. In cases of disturbance or change to a landscape, a ruderal species can increase in cover and compete with other native plants, threatening members of the diversity of a community. In other cases, landscape level changes can cause the increase of the population of a

species, such as white-tailed deer in the northeastern part of the United States, which are at the highest levels historically and cause damage to humans, crops, and structures, suffer high disease levels, and pose threats to humans through interactions on roads (Foster and Sandberg 2004).

Naturalized species: 1. A species that was originally introduced from a different country, a different bioregion, or a different geographical area, but now behaves like a native species in that it maintains itself without further human intervention and now grows and reproduces in native communities (Allaby 1998). 2. A non native species that forms self-sustaining populations but is not necessarily an invasive species (Booth et al. 2003).

Niche opportunity: Defines conditions that promote invasions in terms of resources, natural enemies, the physical environment, interactions between these factors, and the manner in which they vary in time and space (Shea and Chesson 2002).

Nonindigenous species: This is a common term used along with non native species and introduced species in current literature and publications; other similar terms include alien species, exotic species, and foreign species. 1. Any species or other viable biological material that enters an ecosystem beyond its historic range, including any such organism transferred from one country into another (EPA 1990). 2. A plant or animal that is not native to the area in which it occurs which was either intentionally or unintentionally introduced (Williams and Meffe 2005).

Non native species: This term, along with the terms introduced species and nonindigenous species, is one of the most commonly used terms to describe a plant or animal species that is not originally from the area in which it occurs. Similar terms also include alien species, exotic species, and foreign species. This term has also been defined as: 1. A species whose presence is due to intentional or unintentional introduction as a result of human activity (Booth et al. 2003). 2. A species that has been introduced to an area or bioregion (Heutte and Bella 2003).

Noxious weed: This term is frequently a legal term in state code, denoting a special status of the plant as, for example, prohibited or restricted. 1. Native or non-native plants, or plant products, that injure or cause damage to interests of agriculture, irrigation, navigation, natural resources, public health, or the environment (Heutte and Bella 2003). 2. Implies a species' adverse effects on humans, either directly (e.g. species that produce toxins that are harmful to humans) or indirectly (e.g. species that infest nature reserves) (Colautti and MacIsaac 2004). 3. Any species of plants, either annual, biennial, or perennial; reproduced by seed, root, underground stem, or bulblet; which when established is or may become destructive and difficult to control by ordinary means of cultivation or other farm practices (Heutte and Bella 2003).

Pathway: 1. Used to mean vector, purpose (the reason why a species is moved), and route (the geographic corridor from one point to another) (Carlton 2001). 2. Mode by which a species establishes and continues to exist in a new environment (Heutte and Bella 2003).

Pest: 1. An animal that competes with humans by consuming or damaging food, fiber, or other materials intended for human consumption or use, such as an insect pest on a cropfield (Allaby 1998) 2. Synonymous to invasive species (Jeschke and Strayer 2005).

Pesticide: A chemical or biological agent intended to prevent, destroy, repel, or mitigate plant or animal life and any substance intended for use as a plant regulator, defoliant, or desiccant, including insecticides, fungicides, rodenticides, herbicides, nematocides, and biocides (Heutte and Bella 2003).

Population: A group of potentially inter-breeding individuals of the same species found in the same place at the same time (Booth et al. 2003).

Prohibited weed: A specific legal term applied to a plant or plant part that may not be brought into a state (Heutte and Bella 2003).

Restricted weed: A specific legal term applied to a plant or plant part that may only be brought into a state in limited quantities (Heutte and Bella 2003).

Ruderal species: A plant associated with human dwellings, construction, or agriculture, that usually colonizes disturbed or waste ground. Ruderals are often weeds which have high demands for nutrients and are intolerant of competition. See also native weed or invasive native (Allaby 1998).

Seed bank: Seeds that become incorporated into the soil (Booth et al. 2003).

Species: A group of organisms formally recognized as distinct from other groups; the taxon rank in the hierarchy of biological classification below genus; the basic unit of biological classification, defined by the reproductive isolation of the group from all other groups of organisms (Allaby 1998).

Status or distributional status:

Tens rule: 1. Describes how approximately ten percent of species pass through each transition from being imported to becoming casual to becoming established, and finally becoming a weed (Booth et al. 2003). 2. Ten percent of the introduced species establish themselves in the non native continent and ten percent of these, in turn, spread or are pests (Jeschke and Strayer 2005). {note that J&S found exceptions to the 10's rule}.

Time lag: 1. Time between introduction, establishment, and spread (Jeschke and Strayer 2005). 2. The time between when a species is introduced and when its population growth explodes (Booth et al. 2003).

Unintentional introduction: An introduction of nonindigenous species that occurs as the result of activities other than the purposeful or intentional introduction of the species involved, such as the transport of nonindigenous species in ballast or in water used to transport fish, mollusks or crustaceans for aquaculture or other purposes (EPA 1990).

Vector: The physical means or agent by which a species is transported, such as ballast water, ships' hulls, boats, hiking boats, cars, vehicles, packing material, or soil in nursery stock (Carlton 2001). See also Pathway.

Weed: 1. A plant in the wrong place, being one that occurs opportunistically on land or in water that has been disturbed by human activities (see also *ruderal species* and *native weed* or *invasive native*), or on cultivated land, where it competes for nutrients, water, sunlight, or other resources with cultivated plants such as food crops. Under different circumstances the weed plant itself may be cultivated for beneficial purposes (Allaby, 1998). 2. A native or introduced species that has a perceived negative ecological or economic effect on agricultural or natural ecosystems (Booth et al., 2003). 3. A plant growing in an area where it is not wanted (Royer and Dickinson, 1999).

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23.3: Glossary 3 – Methodologies

In Ecology, as with many sciences a series of steps known as the [scientific method](#) are involved in trying to support or nullify a hypothesis.

There are two ways to support your hypothesis. The first way is by a weak inference, which is basically using one distinct hypothesis and trying to support that hypothesis through observation. The other way is by using strong inference. This method is regarded as having more credibility as it uses numerous hypotheses with a null hypothesis for each. Instead of trying to support one hypothesis as with a weak inference, the researcher tries to disprove numerous hypotheses through controlled experimentation to support a single hypothesis.

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