ECOLOGY FOR ALL!

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Ecology for All!

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CHAPTER OVERVIEW

1: Introduction to Ecology

Learning Objectives

- Introduce the scope of ecology.
- Review the nature of science and ecology's place as a branch of the natural sciences.
- Define the key levels of ecological organization: population, community, and ecosystem.
- Outline the history and expansion of ecology.

Summary

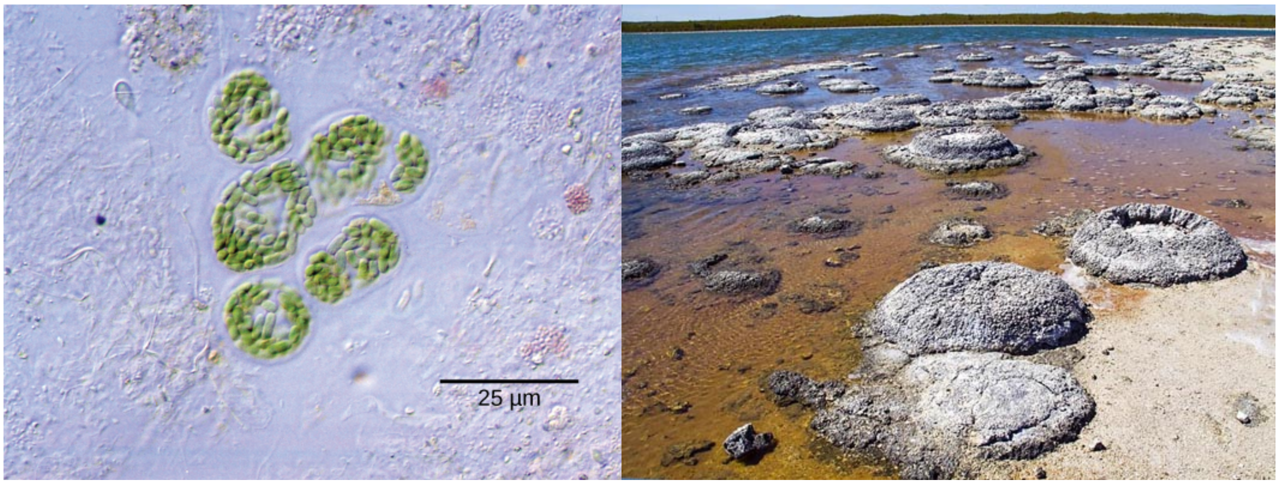
Ecology is the study of living organisms and their interactions with one another and their environments. This is a very broad definition because the scope of ecology is vast, from the interactions of bacteria and viruses in the human gut to the ebb and flow of carbon dioxide through all the plants of the world. While ecology is a relatively young scientific discipline, it grew rapidly and now contributes to many issues important to society, such as the management of wildlife, conservation of endangered species, and mitigation of the impacts of climate change.

1.1: Biology and The Scientific Method

This textbook focuses on the field of ecology. Ecology is a sub-field of biology which studies living organisms and their interactions with one another and their environments. This is a very broad definition because the scope of ecology is vast.

Among other things, ecology is the study of:

- Life processes, interactions, and adaptations
- The movement of materials and energy through living communities
- The successional development of ecosystems
- Cooperation, competition, and predation within and between species
- The abundance, biomass, and distribution of organisms in the context of the environment
- Patterns of biodiversity and its effect on ecosystem processes



(a) (b)

Figure 1.1.1: Formerly called blue-green algae, these (a) cyanobacteria, shown here at 300x magnification under a light microscope, are some of Earth's oldest life forms. These (b) stromatolites along the shores of Lake Thetis in Western Australia are ancient structures formed by the layering of cyanobacteria in shallow waters. (credit a: modification of work by NASA; credit b: modification of work by Ruth Ellison; scale-bar data from Matt Russell)

Ecology has practical applications in conservation biology, wetland management, natural resource management (agroecology, agriculture, forestry, agroforestry, fisheries), city planning (urban ecology), community health, economics, basic and applied science, and human social interaction (human ecology).

The word "ecology" ("Ökologie") was coined in 1866 by the German scientist Ernst Haeckel, and it became a rigorous science in the late 19th century. Evolutionary concepts relating to adaptation and natural selection are cornerstones of modern ecological theory.

Before we can dive into the field of ecology, we must first develop a common understanding of the practice and process of science.

1.1.1: The Process of Science

Ecology is a science, but what exactly is science? What does the study of ecology share with other scientific disciplines? Science (from the Latin *scientia*, meaning "knowledge") can be defined as knowledge that covers general truths or the operation of general laws, especially when acquired and tested by the scientific method. It becomes clear from this definition that the application of the scientific method plays a major role in science. The scientific method is a method of research with defined steps that include experiments and careful observation.

The steps of the scientific method will be examined in detail later, but one of the most important aspects of this method is the testing of hypotheses by means of repeatable experiments. A hypothesis is a suggested explanation for an event, which can be tested. Although using the scientific method is inherent to science, it is inadequate in determining what science is. This is because it is relatively easy to apply the scientific method to disciplines such as physics and chemistry, but when it comes to disciplines like archaeology, psychology, and geology, the scientific method becomes less applicable as it becomes more difficult to repeat experiments.

These areas of study are still sciences, however. Consider archeology—even though one cannot perform repeatable experiments, hypotheses may still be supported. For instance, an archeologist can hypothesize that an ancient culture existed based on finding a piece of pottery. Further hypotheses could be made about various characteristics of this culture, and these hypotheses may be found to be correct or false through continued support or contradictions from other findings. A hypothesis may become a verified theory. A theory is a tested and confirmed explanation for observations or phenomena. Science may be better defined as fields of study that attempt to comprehend the nature of the universe.

1.1.1.1: Natural Sciences

What would you expect to see in a museum of natural sciences? Frogs? Plants? Dinosaur skeletons? Exhibits about how the brain functions? A planetarium? Gems and minerals? Or, maybe all of the above? Science includes such diverse fields as astronomy, biology, computer sciences, geology, logic, physics, chemistry, and mathematics (Figure 1.1.2). However, those fields of science related to the physical world and its phenomena and processes are considered natural sciences. Thus, a museum of natural sciences might contain any of the items listed above.

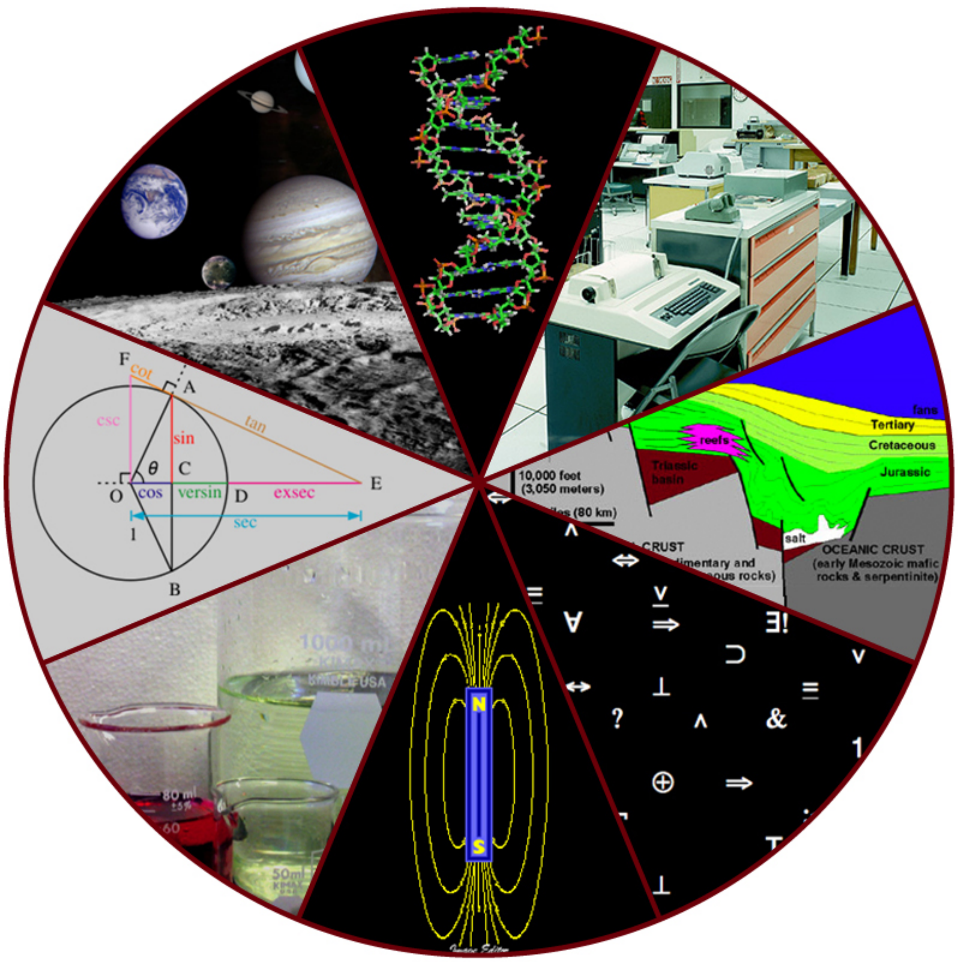


Figure 1.1.2: The natural sciences include astronomy, biology, computer science, geology, logic, physics, chemistry, mathematics, and many other fields. (credit: "Image Editor"/Flickr)

There is no unanimous agreement when it comes to defining what the natural sciences include, however. For some experts, the natural sciences are astronomy, biology, chemistry, earth science, and physics. Other scholars choose to divide natural sciences into life sciences, which study living things and include biology, and physical sciences, which study nonliving matter and include astronomy, geology, physics, and chemistry. Some disciplines such as biophysics and biochemistry build on both life and physical sciences and are interdisciplinary. Natural sciences are sometimes referred to as "hard science" because they rely on the use of quantitative data; social sciences that study society and human behavior are more likely to use qualitative assessments to drive investigations and findings.

Not surprisingly, the natural science of biology has many branches or subdisciplines. Cell biologists study cell structure and function, while biologists who study anatomy investigate the structure of an entire organism. Those biologists studying physiology, however, focus on the internal functioning of an organism. Some areas of biology focus on only particular types of living things. For example, botanists explore plants, while zoologists specialize in animals. In contrast to biologists that focus on the functioning of individual organisms or their subunits, ecologists typically treat organisms as the subunits of larger entities, such as populations, communities, or ecosystems.

1.1.1.2: Scientific Reasoning

One thing is common to all forms of science: an ultimate goal "to know." Curiosity and inquiry are the driving forces for the development of science. Scientists seek to understand the world and the way it operates. To do this, they use two methods of logical thinking: inductive reasoning and deductive reasoning.

Inductive reasoning is a form of logical thinking that uses related observations to arrive at a general conclusion. This type of reasoning is common in descriptive science. A life scientist such as a biologist makes observations and records them. These data can be qualitative or quantitative, and the raw data can be supplemented with drawings, pictures, photos, or videos. From many observations, the scientist can infer conclusions (inductions) based on evidence. Inductive reasoning involves formulating generalizations inferred from careful observation and the analysis of a large amount of data. Brain studies provide an example. In this type of research, many live brains are observed while people are doing a specific activity, such as viewing images of food. The part of the brain that "lights up" during this activity is then predicted to be the part controlling the response to the selected stimulus, in this case, images of food. The "lighting up" of the various areas of the brain is caused by excess absorption of radioactive sugar derivatives by active areas of the brain. The resultant increase in radioactivity is observed by a scanner. Then, researchers can stimulate that part of the brain to see if similar responses result.

Deductive reasoning or deduction is the type of logic used in hypothesis-based science. In deductive reason, the pattern of thinking moves in the opposite direction as compared to inductive reasoning. Deductive reasoning is a form of logical thinking that uses a general principle or law to forecast specific results. From those general principles, a scientist can extrapolate and predict the specific results that would be valid as long as the general principles are valid. Studies in climate change can illustrate this type of reasoning. For example, scientists may predict that if the climate becomes warmer in a particular region, then the distribution of plants and animals should change. These predictions have been made and tested, and many such changes have been found, such as the modification of arable areas for agriculture, with change based on temperature averages.

Both types of logical thinking are related to the two main pathways of scientific study: descriptive science and hypothesis-based science. Descriptive (or discovery) science, which is usually inductive, aims to observe, explore, and discover, while hypothesis-based science, which is usually deductive, begins with a specific question or problem and a potential answer or solution that can be tested. The boundary between these two forms of study is often blurred, and most scientific endeavors combine both approaches. The fuzzy boundary becomes apparent when thinking about how easily observation can lead to specific questions. For example, a gentleman in the 1940s observed that the burr seeds that stuck to his clothes and his dog's fur had a tiny hook structure. On closer inspection, he discovered that the burrs' gripping device was more reliable than a zipper. He eventually developed a company and produced the hook-and-loop fastener popularly known today as Velcro. Descriptive science and hypothesis-based science are in continuous dialogue.

1.1.1.1: The Scientific Method

Biologists study the living world by posing questions about it and seeking science-based responses. This approach is common to other sciences as well and is often referred to as the scientific method. The scientific method was used even in ancient times, but it was first documented by England's Sir Francis Bacon (1561–1626) (Figure 1.1.3), who set up inductive methods for scientific inquiry. The scientific method is not exclusively used by biologists but can be applied to almost all fields of study as a logical, rational problem-solving method.

Figure 1.1.3: Sir Francis Bacon (1561–1626) is credited with being the first to define the scientific method (credit: Paul van Somer).

The scientific process typically starts with an observation (often a problem to be solved) that leads to a question. Let's think about a simple problem that starts with an observation and apply the scientific method to solve the problem. One Monday morning, a student arrives at class and quickly discovers that the classroom is too warm. That is an observation that also describes a problem: the classroom is too warm. The student then asks a question: "Why is the classroom so warm?"

1.1.1.1: Proposing a Hypothesis

Recall that a hypothesis is a suggested explanation that can be tested. To solve a problem, several hypotheses may be proposed. For example, one hypothesis might be, "The classroom is warm because no one turned on the air conditioning." But there could be other responses to the question, and therefore other hypotheses may be proposed. A second hypothesis might be, "The classroom is warm because there is a power failure, and so the air conditioning doesn't work."

Once a hypothesis has been selected, the student can make a prediction. A prediction is similar to a hypothesis but it typically has the format "If . . . then . . . ." For example, the prediction for the first hypothesis might be, "*If* the student turns on the air conditioning, *then* the classroom will no longer be too warm."

1.1.1.1: Testing a Hypothesis

A valid hypothesis must be testable. It should also be falsifiable, meaning that it can be disproven by experimental results. Importantly, science does not claim to "prove" anything because scientific understandings are always subject to modification with further information. This step—openness to disproving ideas—is what distinguishes sciences from non-sciences. The presence of the supernatural, for instance, is neither testable nor falsifiable. To test a hypothesis, a researcher will conduct one or more experiments designed to eliminate one or more of the hypotheses. Each experiment will have one or more variables and one or more controls. A variable is any part of the experiment that can vary or change during the experiment. The control group contains every feature of the experimental group except it is not given the manipulation that is hypothesized about. Therefore, if the results of the experimental group differ from the control group, the difference must be due to the hypothesized manipulation, rather than some outside factor. Look for the variables and controls in the examples that follow. To test the first hypothesis, the student would find out if the air conditioning is on. If the air conditioning is turned on but does not work, there should be another reason, and this hypothesis should be rejected. To test the second hypothesis, the student could check if the lights in the classroom are functional. If so, there is no power failure and this hypothesis should be rejected. Each hypothesis should be tested by carrying out appropriate experiments. Be aware that rejecting one hypothesis does not determine whether or not the other hypotheses can be accepted; it simply eliminates one hypothesis that is not valid (Figure 1.1.4). Using the scientific method, the hypotheses that are inconsistent with experimental data are rejected.

While this "warm classroom" example is based on observational results, other hypotheses and experiments might have clearer controls. For instance, a student might attend class on Monday and realize she had difficulty concentrating on the lecture. One observation to explain this occurrence might be, "When I eat breakfast before class, I am better able to pay attention." The student could then design an experiment with a control to test this hypothesis.

In hypothesis-based science, specific results are predicted from a general premise. This type of reasoning is called deductive reasoning: deduction proceeds from the general to the particular. But the reverse of the process is also possible: sometimes, scientists reach a general conclusion from a number of specific observations. This type of reasoning is called inductive reasoning, and it proceeds from the particular to the general. Inductive and deductive reasoning are often used in tandem to advance scientific knowledge (Figure 1.1.5).

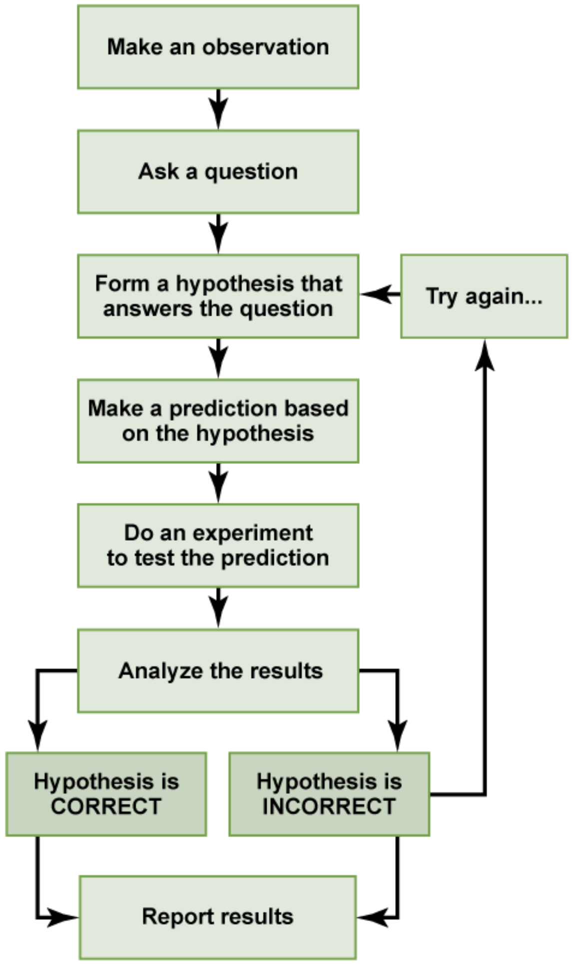


Figure 1.1.4: The scientific method consists of a series of well-defined steps. If a hypothesis is not supported by experimental data, a new hypothesis can be proposed.

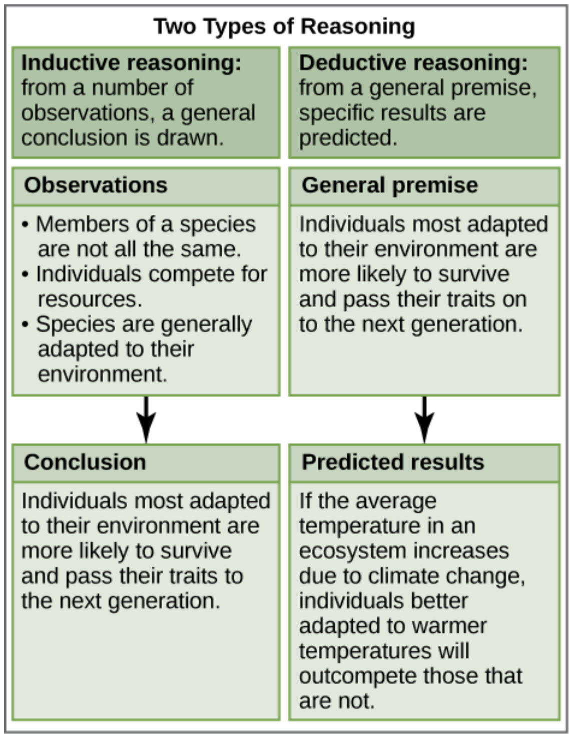


Figure 1.1.5: Scientists use two types of reasoning, inductive and deductive reasoning, to advance scientific knowledge. As is the case in this example, the conclusion from inductive reasoning can often become the premise for deductive reasoning.

The scientific method may seem too rigid and structured. It is important to keep in mind that, although scientists often follow this sequence, there is flexibility. Sometimes an experiment leads to conclusions that favor a change in approach; often, an experiment brings entirely new scientific questions to the puzzle. Many times, science does not operate in a linear fashion; instead, scientists continually draw inferences and make generalizations, finding patterns as their research proceeds. Scientific reasoning is more complex than the scientific method alone suggests. Notice, too, that the scientific method can be applied to solving problems that aren't necessarily scientific in nature.

1.1.2: Two Types of Science: Basic Science and Applied Science

The scientific community has been debating for the last few decades about the value of different types of science. Is it valuable to pursue science for the sake of simply gaining knowledge, or does scientific knowledge only have worth if we can apply it to solving a specific problem or to bettering our lives? This question focuses on the differences between two types of science: basic science and applied science.

Basic science or "pure" science seeks to expand knowledge regardless of the short-term application of that knowledge. It is not focused on developing a product or a service of immediate public or commercial value. The immediate goal of basic science is knowledge for knowledge's sake, though this does not mean that, in the end, it may not result in a practical application.

In contrast, applied science or "technology," aims to use science to solve real-world problems, making it possible, for example, to improve a crop yield, find a cure for a particular disease, or save animals threatened by a natural disaster (Figure 1.1.6). In applied science, the problem is usually defined for the researcher.

Figure 1.1.6: After Hurricane Ike struck the Gulf Coast in 2008, the U.S. Fish and Wildlife Service rescued this brown pelican. Thanks to applied science, scientists knew how to rehabilitate the bird (credit: FEMA).

Some individuals may perceive applied science as "useful" and basic science as "useless." A question these people might pose to a scientist advocating knowledge acquisition would be, "What for?" A careful look at the history of science, however, reveals that basic knowledge has resulted in many remarkable applications of great value. Many scientists think that a basic understanding of science is necessary before an application is developed; therefore, applied science relies on the results generated through basic science. Other scientists think that it is time to move on from basic science and instead find solutions to actual problems. Both approaches are valid. It is true that there are problems that demand immediate attention; however, few solutions would be found without the help of the wide knowledge foundation generated through basic science.

One example of how basic and applied science can work together to solve practical problems occurred after the discovery of DNA structure led to an understanding of the molecular mechanisms governing DNA replication. Strands of DNA, unique in every human, are found in our cells, where they provide the instructions necessary for life. During DNA replication, DNA makes new copies of itself, shortly before a cell divides. Understanding the mechanisms of DNA replication enabled scientists to develop laboratory techniques that are now used to identify genetic diseases, pinpoint individuals who were at a crime scene, and determine paternity. Without basic science, it is unlikely that applied science would exist.

Another example of the link between basic and applied research is the Human Genome Project, a study in which each human chromosome was analyzed and mapped to determine the precise sequence of DNA subunits and the exact location of each gene. (The gene is the basic unit of heredity; an individual's complete collection of genes is his or her genome.) Other less complex organisms have also been studied as part of this project in order to gain a better understanding of human chromosomes. The Human Genome Project (Figure 1.1.7) relied on basic research carried out with simple organisms and, later, with the human genome. An important end goal eventually became using the data for applied research, seeking cures and early diagnoses for genetically related diseases.

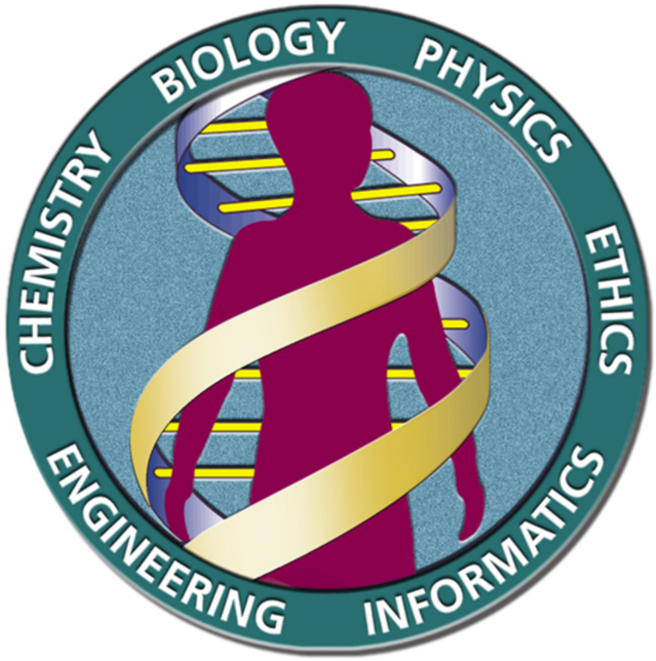


Figure 1.1.7: The Human Genome Project was a 13-year collaborative effort among researchers working in several different fields of science. The project, which sequenced the entire human genome, was completed in 2003 (credit: U.S. Department of Energy Genome Programs).

While research efforts in both basic science and applied science are usually carefully planned, it is important to note that some discoveries are made by serendipity, that is, by means of a fortunate accident or a lucky surprise. Penicillin was discovered when biologist Alexander Fleming accidentally left a petri dish of *Staphylococcus* bacteria open. An unwanted mold grew on the dish, killing the bacteria. The mold turned out to be *Penicillium*, and a new antibiotic was discovered. Even in the highly organized world of science, luck—when combined with an observant, curious mind—can lead to unexpected breakthroughs.

1.1.3: Reporting Scientific Work

Whether scientific research is basic science or applied science, scientists must share their findings in order for other researchers to expand and build upon their discoveries. Collaboration with other scientists—when planning, conducting, and analyzing results—are all important for scientific research. For this reason, important aspects of a scientist's work are communicating with peers and disseminating results to peers. Scientists can share results by presenting them at a scientific meeting or conference, but this approach can reach only the select few who are present. Instead, most scientists present their results in peer-reviewed manuscripts that are published in scientific journals. Peer-reviewed manuscripts are scientific papers that are reviewed by a scientist's colleagues, or peers. These colleagues are qualified individuals, often experts in the same research area, who judge whether or not the scientist's work is suitable for publication. The process of peer review helps to ensure that the research described in a scientific paper or grant proposal is original, significant, logical, and thorough. Grant proposals, which are requests for research funding, are also subject to peer review. Scientists publish their work so other scientists can reproduce their experiments under similar or different conditions to expand on the findings. The experimental results must be consistent with the findings of other scientists.

A scientific paper is very different from creative writing. Although creativity is required to design experiments, there are fixed guidelines when it comes to presenting scientific results. First, scientific writing must be brief, concise, and accurate. A scientific paper needs to be succinct but detailed enough to allow peers to reproduce the experiments.

The scientific paper consists of several specific sections—introduction, materials and methods, results, and discussion. This structure is sometimes called the "IMRaD" format. There are usually acknowledgment and reference sections as well as an abstract (a concise summary) at the beginning of the paper. There might be additional sections depending on the type of paper and the journal where it will be published; for example, some review papers require an outline.

The introduction starts with brief, but broad, background information about what is known in the field. A good introduction also gives the rationale of the work; it justifies the work carried out and also briefly mentions the end of the paper, where the hypothesis or research question driving the research will be presented. The introduction refers to the published scientific work of others and therefore requires citations following the style of the journal. Using the work or ideas of others without proper citation is considered plagiarism.

The materials and methods section includes a complete and accurate description of the substances used, and the method and techniques used by the researchers to gather data. The description should be thorough enough to allow another researcher to repeat the experiment and obtain similar results, but it does not have to be verbose. This section will also include information on how measurements were made and what types of calculations and statistical analyses were used to examine raw data. Although the materials and methods section gives an accurate description of the experiments, it does not discuss them.

Some journals require a results section followed by a discussion section, but it is more common to combine both. If the journal does not allow the combination of both sections, the results section simply narrates the findings without any further interpretation. The results are presented by means of tables or graphs, but no duplicate information should be presented. In the discussion section, the researcher will interpret the results, describe how variables may be related, and attempt to explain the observations. It is indispensable to conduct an extensive literature search to put the results in the context of previously published scientific research. Therefore, proper citations are included in this section as well.

Finally, the conclusion section summarizes the importance of the experimental findings. While the scientific paper almost certainly answered one or more scientific questions that were stated, any good research should lead to more questions. Therefore, a well-done scientific paper leaves doors open for the researcher and others to continue and expand on the findings.

Review articles do not follow the IMRAD format because they do not present original scientific findings, or primary literature; instead, they summarize and comment on findings that were published as primary literature and typically include extensive reference sections.

1.1.4: Contributors and Attributions

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1.2: What is Ecology?

Ecology is the study of the interactions of living organisms with their environment. One core goal of ecology is to understand the distribution and abundance of living things in the physical environment. Attainment of this goal requires the integration of scientific disciplines inside and outside of biology, such as biochemistry, physiology, evolution, biodiversity, molecular biology, geology, and climatology. Some ecological research also applies aspects of chemistry and physics, and it frequently uses mathematical models.

Link to Learning

Climate change can alter where organisms live, which can sometimes directly affect human health. Watch the PBS video “Feeling the Effects of Climate Change” in which researchers discover a pathogenic organism living far outside of its normal range (https://www.pbs.org/video/need-to-know-feeling-the-effects-of-climate-change/).

Levels of Ecological Study

When a discipline such as biology is studied, it is often helpful to subdivide it into smaller, related areas. For instance, cell biologists interested in cell signaling need to understand the chemistry of the signal molecules (which are usually proteins) as well as the result of cell signaling. Ecologists interested in the factors that influence the survival of an endangered species might use mathematical models to predict how current conservation efforts affect endangered organisms. To produce a sound set of management options, a conservation biologist needs to collect accurate data, including current population size, factors affecting reproduction (like physiology and behavior), habitat requirements (such as plants and soils), and potential human influences on the endangered population and its habitat (which might be derived through studies in sociology and urban ecology). Within the discipline of ecology, researchers work at four specific levels, sometimes discretely and sometimes with overlap: organism, population, community, and ecosystem (Figure 1.2.1).

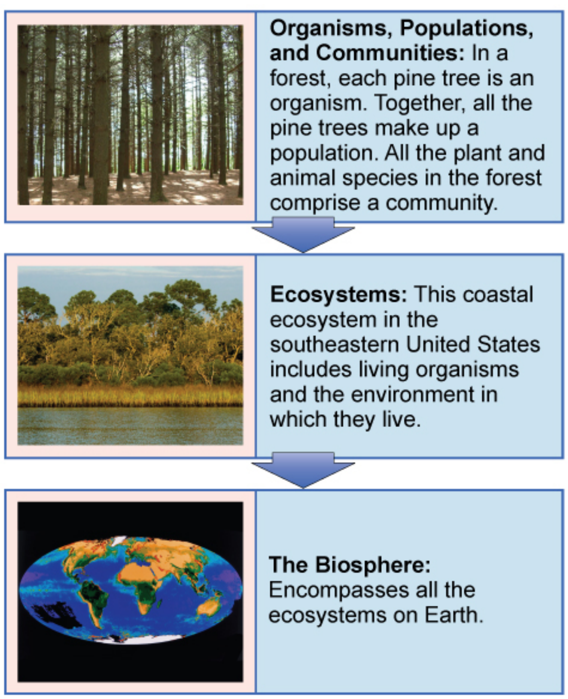

Figure 1.2.1: Ecologists study within several biological levels of organization (credit "organisms": modification of work by "Crystl"/Flickr; credit "ecosystems": modification of work by Tom Carlisle, US Fish and Wildlife Service Headquarters; credit "biosphere": NASA).

Organismal Ecology

Researchers studying ecology at the organismal level are interested in the adaptations that enable individuals to live in specific habitats. These adaptations can be morphological, physiological, and behavioral. For instance, the Karner blue butterfly *Lycaeides melissa samuelis* (Figure 1.2.2) is considered a specialist because the females preferentially oviposit (that is, lay eggs) on wild lupine. This preferential adaptation means that the Karner blue butterfly is highly dependent on the presence of wild lupine plants for its continued survival.

Figure 1.2.2: The Karner blue butterfly *Lycaeides melissa samuelis* is a rare butterfly that lives only in open areas with few trees or shrubs, such as pine barrens and oak savannas. It can only lay its eggs on lupine plants (credit: modification of work by J & K Hollingsworth, USFWS).

After hatching, the larval caterpillars emerge and spend four to six weeks feeding solely on wild lupine (Figure 1.2.3). The caterpillars pupate (undergo metamorphosis) and emerge as butterflies after about four weeks. The adult butterflies feed on the nectar of flowers of wild lupine and other plant species. A researcher interested in studying Karner blue butterflies at the organismal level might, in addition to asking questions about egg laying, ask questions about the butterflies' preferred temperature (a physiological question) or the behavior of the caterpillars when they are at different larval stages (a behavioral question).

Figure $1.2.3$: The wild lupine *Lupinus perennis* is the host plant for the Karner blue butterfly.

Population Ecology

A population is a group of interbreeding organisms that are members of the same species living in the same area at the same time. (Organisms that are all members of the same species are called conspecifics.) A population is identified, in part, by where it lives, and its area of population may have natural or artificial boundaries: natural boundaries might be rivers, mountains, or deserts, while examples of artificial boundaries include mowed grass, manmade structures, or roads. The study of population ecology focuses on the number of individuals in an area and how and why population size changes over time. Population ecologists are particularly interested in counting the Karner blue butterfly, for example, because it is classified as federally endangered. However, the distribution and density of this species is highly influenced by the distribution and abundance of wild lupine. Researchers might ask questions about the factors leading to the decline of wild lupine and how these affect Karner blue butterflies. For example, ecologists know that wild lupine thrives in open areas where trees and shrubs are largely absent. In natural settings, intermittent wildfires regularly remove trees and shrubs, helping to maintain the open areas that wild lupine requires. Mathematical models can be used to understand how wildfire suppression by humans has led to the decline of this important plant for the Karner blue butterfly.

Community Ecology

A biological community consists of the different species within an area, typically a three-dimensional space, and the interactions within and among these species. Community ecologists are interested in the processes driving these interactions and their consequences. Questions about conspecific interactions often focus on competition among members of the same species for a limited resource. Ecologists also study interactions among various species; members of different species are called heterospecifics. Examples of heterospecific interactions include predation, parasitism, herbivory, competition, and pollination. These interactions can have regulating effects on population sizes and can impact ecological and evolutionary processes affecting diversity.

For example, Karner blue butterfly larvae form mutualistic relationships with ants. Mutualism is a form of a long-term relationship that has coevolved between two species and from which each species benefits. For mutualism to exist between individual organisms, each species must receive some benefit from the other as a consequence of the relationship. Researchers have shown that there is an increase in the probability of survival when Karner blue butterfly larvae (caterpillars) are tended by ants. This might be because the larvae spend less time in each life stage when tended by ants, which provides an advantage for the larvae. Meanwhile, the Karner blue butterfly larvae secrete a carbohydrate-rich substance that is an important energy source for the ants. Both the Karner blue larvae and the ants benefit from their interaction.

Ecosystem Ecology

Ecosystem ecology is an extension of organismal, population, and community ecology. The ecosystem is composed of all the biotic components (living things) in an area along with the abiotic components (non-living things) of that area. Some of the abiotic components include air, water, and soil. Ecosystem biologists ask questions about how nutrients and energy are stored and how they move among organisms and the surrounding atmosphere, soil, and water.

The Karner blue butterflies and the wild lupine live in an oak-pine barren habitat. This habitat is characterized by natural disturbance and nutrient-poor soils that are low in nitrogen. The availability of nutrients is an important factor in the distribution of the plants that live in this habitat. Researchers interested in ecosystem ecology could ask questions about the importance of limited resources and the movement of resources, such as nutrients, through the biotic and abiotic portions of the ecosystem.

Career Connection

Ecologist

A career in ecology contributes to many facets of human society. Understanding ecological issues can help society meet the basic human needs of food, shelter, and health care. Ecologists can conduct their research in the laboratory and outside in natural environments (Figure $1.2.4$). These natural environments can be as close to home as the stream running through your campus or as far away as the hydrothermal vents at the bottom of the Pacific Ocean. Ecologists manage natural resources such as white-tailed deer populations *Odocoileus virginianus* for hunting or aspen *Populus* spp. timber stands for paper production. Ecologists also work as educators who teach children and adults at various institutions including universities, high schools, museums, and nature centers. Ecologists may also work in advisory positions assisting local, state, and federal policymakers to develop laws that are ecologically sound, or they may develop those policies and legislation themselves. To become an ecologist requires an undergraduate degree, usually in a natural science. The undergraduate degree is often followed by specialized training or an advanced degree, depending on the area of ecology selected. Ecologists should also have a broad background in the physical sciences, as well as a sound foundation in mathematics and statistics.

Figure 1.2.4: This landscape ecologist is releasing a black-footed ferret into its native habitat as part of a study (credit: USFWS Mountain Prairie Region, NPS).

Link to Learning

openstax COLLEGE

Visit this site to see Stephen Wing, a marine ecologist from the University of Otago, discuss the role of an ecologist and the types of issues ecologists explore.

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1.3: History of Ecology

Ecology is a new science and considered an important branch of biological science, having only become prominent during the second half of the 20th century (McIntosh, 1985). Ecological thought is derivative of established currents in philosophy, particularly from ethics and politics (Laferrière & Stoett, 2003).

Its history stems all the way back to the 4th century. One of the first ecologists whose writings survive may have been Aristotle or perhaps his student, Theophrastus, both of whom had an interest in many species of animals and plants. Theophrastus described interrelationships between animals and their environment as early as the 4th century BC (Ramalay, 1940). Ecology developed substantially in the 18th and 19th centuries. It began with Carl Linnaeus and his work with the economy of nature (Reid, 2009). Soon after came Alexander von Humboldt and his work with botanical geography (Silvertown et al., 2006). Alexander von Humboldt and Karl Möbius then contributed with the notion of biocoenosis. Eugenius Warming's work with ecological plant geography led to the founding of ecology as a discipline (Coleman, 1986). Charles Darwin's work also contributed to the science of ecology, and Darwin is often attributed with progressing the discipline more than anyone else in its young history. Ecological thought expanded even more in the early 20th century (Acot, 1997). Major contributions included Eduard Suess' and Vladimir Vernadsky's work with the biosphere, Arthur Tansley's ecosystem, Charles Elton's *Animal Ecology*, and Henry Cowles' ecological succession (Cowles, 1911).

Ecology influenced the social sciences and humanities. Human ecology began in the early 20th century, recognizing humans as an ecological factor. Later, James Lovelock advanced views on Earth as a macro-organism with the Gaia hypothesis (Egerton, 1973; Egerton, 2001). Conservation stemmed from the science of ecology. Important figures and movements include Shelford and the ESA, the National Environmental Policy Act, George Perkins Marsh, Theodore Roosevelt, Stephen A. Forbes, and post-Dust Bowl conservation. Later in the 20th century, world governments collaborated on human effects on the biosphere and Earth's environment.

The history of ecology is intertwined with the history of conservation efforts, in particular the founding of the Nature Conservancy (Smith & Mark, 2009).

18th and 19th century Ecological murmurs

Arcadian and Imperial Ecology

In the early Eighteenth century, preceding Carl Linnaeus, two rival schools of thought dominated the growing scientific discipline of ecology. First, Gilbert White a "parson-naturalist" is attributed with developing and endorsing the view of Arcadian ecology. Arcadian ecology advocates for a "simple, humble life for man" and a harmonious relationship with humans and nature (Worster, 1994). Opposing the Arcadian view is Francis Bacon's ideology, "imperial ecology". Imperialists work "to establish through the exercise of reason and by hard work, man's dominance over nature" (Worster, 1994). Imperial ecologists also believe that man should become a dominant figure over nature and all other organisms as "once enjoyed in the Garden of Eden" (Worster, 1994). Both views continued their rivalry through the early eighteenth century until Carl Linnaeus's support of imperialism; and in short time due to Linnaeus's popularity, imperial ecology became the dominant view within the discipline.

Carl Linnaeus and Systema Naturae

Carl Linnaeus, a Swedish naturalist, is well known for his work with taxonomy but his ideas helped to lay the groundwork for modern ecology. He developed a two part naming system for classifying plants and animals. Binomial Nomenclature was used to classify, describe, and name different genera and species. The compiled editions of *Systema Naturae* developed and popularized the naming system for plants and animals in modern biology. Reid suggests "Linnaeus can fairly be regarded as the originator of systematic and ecological studies in biodiversity," due to his naming and classifying of thousands of plant and animal species. Linnaeus also influenced the foundations of Darwinian evolution, he believed that there could be change in or between different species within fixed genera. Linnaeus was also one of the first naturalists to place men in the same category as primates (Reid, 2009).

The botanical geography and Alexander von Humboldt

Throughout the 18th and the beginning of the 19th century, European empires began to feel the pressure of their growing populations to expand, leading to an explosion of maritime exploration for territory, commerce, discover and catelog natural resources, and gain global influence. The great maritime powers such as Britain, Spain, and Portugal launched multiple world exploratory expeditions in this time leading to a vast growth of human knowledge: at the beginning of the 18th century, about twenty thousand plant species were known, versus forty thousand at the beginning of the 19th century, and about 300,000 today.

These expeditions were joined by many scientists, including botanists, such as the German explorer Alexander von Humboldt. Humboldt is often considered as father of ecology. He was the first to take on the study of the relationship between organisms and their environment. He exposed the existing relationships between observed plant species and climate, and described vegetation zones using latitude and altitude, a discipline now known as geobotany. Von Humboldt was accompanied on his expedition by the botanist Aimé Bonpland.

In 1856, the Park Grass Experiment was established at the Rothamsted Experimental Station to test the effect of fertilizers and manures on hay yields. This is the longest-running field experiment in the world (Silvertown et al., 2006).

The notion of biocoenosis: Wallace and Möbius

Alfred Russel Wallace, contemporary and colleague of Darwin, was first to propose a "geography" of animal species. Several authors recognized at the time that species were not independent of each other, and grouped them into plant species, animal species, and later into communities of living beings or biocoenosis. The first use of this term is usually attributed to Karl Möbius in 1877, but already in 1825, the French naturalist Adolphe Dureau de la Malle used the term *societé* about an assemblage of plant individuals of different species.

Warming and the foundation of ecology as discipline

While Darwin focused exclusively on competition as a selective force, Eugen Warming devised a new discipline that took abiotic factors, that is drought, fire, salt, cold etc., as seriously as biotic factors in the assembly of biotic communities. Biogeography before Warming was largely of descriptive nature – faunistic or floristic. Warming's aim was, through the study of organism (plant) morphology and anatomy, i.e. adaptation, to explain why a species occurred under a certain set of environmental conditions. Moreover, the goal of the new discipline was to explain why species occupying similar habitats, experiencing similar hazards, would solve problems in similar ways, despite often being of widely different phylogenetic descent. Based on his personal observations in Brazilian cerrado, in Denmark, Norwegian Finnmark and Greenland, Warming gave the first university course in ecological plant geography. Based on his lectures, he wrote the book ‘Plantesamfund’, which was immediate translated to German, Polish and Russian, later to English as ‘Oecology of Plants’. Through its German edition, the book had an immense effect on British and North American scientists like Arthur Tansley, Henry Chandler Cowles and Frederic Clements (Coleman, 1986).

Malthusian influence

Thomas Robert Malthus was an influential writer on the subject of population and population limits in the early 19th century. His works were very important in shaping the ways in which Darwin saw the world worked. Malthus wrote:

> *That the increase of population is necessarily limited by the means of subsistence,*
>
> *That population does invariably increase when the means of subsistence increase, and,*
>
> *That the superior power of population is repressed, and the actual population kept equal to the means of subsistence, by misery and vice (Malthus, 1798).*

In An Essay on the Principle of Population Malthus argues for the reining in of rising population through 2 checks: Positive and Preventive checks. The first raising death rates, the latter lowers birthing rates (Gilbert, n.d.). Malthus also brings forth the idea that the world population will move past the sustainable number of people (Malthus, 1798). This form of thought still continues to influences debates on birth and marriage rates to this theory brought forth by Malthus (Gilbert, n.d.) The essay had a major influence on Charles Darwin and helped him to theories his theory of Natural Selection (van Wyha, 2008). This struggle proposed by Malthusian thought not only influenced the ecological work of Charles Darwin, but helped bring about an economic theory of world of ecology (Todes, 1987).

Darwinism and the science of ecology

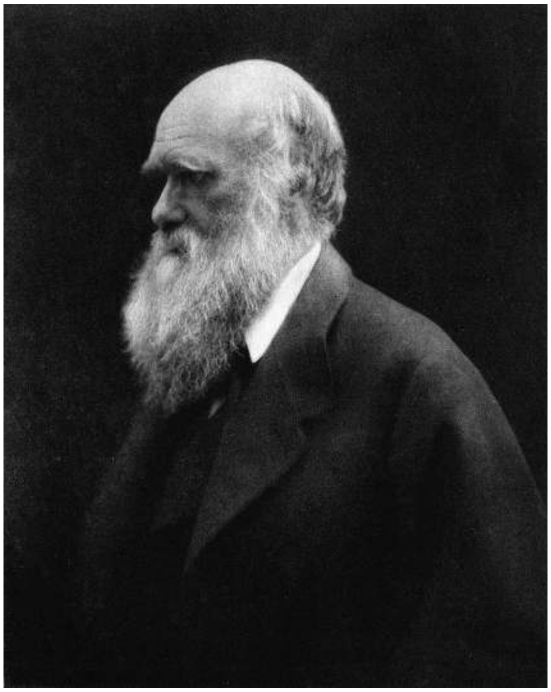

Figure 1.3.1: Julia Margaret Cameron's portrait of Darwin.

It is often held that the roots of scientific ecology may be traced back to Darwin (Stauffer, 1957). This contention may look convincing at first glance inasmuch as *On the Origin of Species* is full of observations and proposed mechanisms that clearly fit within the boundaries of modern ecology (e.g. the cat-to-clover chain – an ecological cascade) and because the term ecology was coined in 1866 by a strong proponent of Darwinism, Ernst Haeckel. However, Darwin never used the word in his writings after this year, not even in his most "ecological" writings such as the foreword to the English edition of Hermann Müller's *The Fertilization of Flowers* (1883) or in his own treatise of earthworms and mull formation in forest soils (The formation of vegetable mould through the action of worms, 1881). Moreover, the pioneers founding ecology as a scientific discipline, such as Eugen Warming, A. F. W. Schimper, Gaston Bonnier, F.A. Forel, S.A. Forbes and Karl Möbius, made almost no reference to Darwin's ideas in their works (Acot, 1997). This was clearly not out of ignorance or because the works of Darwin were not widespread. Some such as S.A.Forbes studying intricate food webs asked questions as yet unanswered about the instability of food chains that might persist if dominant competitors were not adapted to have self-constraint (Forbes, 1887). Others focused on the dominant themes at the beginning, concern with the relationship between organism morphology and physiology on one side and environment on the other, mainly abiotic environment, hence environmental selection. Darwin's concept of natural selection on the other hand focused primarily on competition (Paterson, 2005). The mechanisms other than competition that he described, primarily the divergence of character which can reduce competition and his statement that "struggle" as he used it was metaphorical and thus included environmental selection, were given less emphasis in the Origin than competition (Worster, 1994). Despite most portrayals of Darwin conveying him as a non-aggressive recluse who let others fight his battles, Darwin remained all his life a man nearly obsessed with the ideas of competition, struggle and conquest – with all forms of human contact as confrontation (Worster, 1994; Kormondy, 1978).

Although there is nothing incorrect in the details presented in the paragraph above, the fact that Darwinism used a particularly ecological view of adaptation and Haeckel's use and definitions of the term were steeped in Darwinism should not be ignored. According to ecologist and historian Robert P. McIntosh, "the relationship of ecology to Darwinian evolution is explicit in the title of the work in which ecology first appeared," (McIntosh, 1985; Haeckel, 1866). A more elaborate definition by Haeckel in 1870 is translated on the frontispiece of the influential ecology text known as 'Great Apes' as "… ecology is the study of all those complex interrelations referred to by Darwin as the conditions of the struggle for existence," (Allee et al., 1949; McIntosh, 1985). The issues brought up in the above paragraph are covered in more detail in the Early Beginnings section underneath that of History in the Wikipedia page on Ecology.

Early 20th century ~ Expansion of ecological thought

The biosphere – Eduard Suess and Vladimir Vernadsky

By the 19th century, ecology blossomed due to new discoveries in chemistry by Lavoisier and de Saussure, notably the nitrogen cycle. After observing the fact that life developed only within strict limits of each compartment that makes up the atmosphere, hydrosphere, and lithosphere, the Austrian geologist Eduard Suess proposed the term biosphere in 1875. Suess proposed the name biosphere for the conditions promoting life, such as those found on Earth, which includes flora, fauna, minerals, matter cycles, et cetera.

In the 1920s Vladimir I. Vernadsky, a Russian geologist who had defected to France, detailed the idea of the biosphere in his work "The biosphere" (1926), and described the fundamental principles of the biogeochemical cycles. He thus redefined the biosphere as the sum of all ecosystems.

First ecological damages were reported in the 18th century, as the multiplication of colonies caused deforestation. Since the 19th century, with the industrial revolution, more and more pressing concerns have grown about the impact of human activity on the environment. The term ecologist has been in use since the end of the 19th century.

The ecosystem: Arthur Tansley

Over the 19th century, botanical geography and zoogeography combined to form the basis of biogeography. This science, which deals with habitats of species, seeks to explain the reasons for the presence of certain species in a given location.

It was in 1935 that Arthur Tansley, the British ecologist, coined the term ecosystem, the interactive system established between the biocoenosis (the group of living creatures), and their biotope, the environment in which they live. Ecology thus became the science of ecosystems.

Tansley's concept of the ecosystem was adopted by the energetic and influential biology educator Eugene Odum. Along with his brother, Howard T. Odum, Eugene P. Odum wrote a textbook which (starting in 1953) educated more than one generation of biologists and ecologists in North America.

Ecological succession – Henry Chandler Cowles

Figure 1.3.2: The Indiana Dunes on Lake Michigan, which Cowles referred to in his development of his theories of ecological succession.

At the turn of the 20th century, Henry Chandler Cowles was one of the founders of the emerging study of "dynamic ecology", through his study of ecological succession at the Indiana Dunes, sand dunes at the southern end of Lake Michigan. Here Cowles found evidence of ecological succession in the vegetation and the soil with relation to age. Cowles was very aware of the roots of the concept and of his (primordial) predecessors (Cowles, 1911). Thus, he attributes the first use of the word to the French naturalist Adolphe Dureau de la Malle, who had described the vegetation development after forest clear-felling, and the first comprehensive study of successional processes to the Finnish botanist Ragnar Hult (1881).

Animal Ecology - Charles Elton

20th century English zoologist and ecologist, Charles Elton, is commonly credited as “the father of animal ecology” (Southwood & Clark, 1999). Elton influenced by Victor Shelford's *Animal Communities in Temperate America* began his research on animal ecology as an assistant to his colleague, Julian Huxley, on an ecological survey of the fauna in Spitsbergen in 1921. Elton's most famous studies were conducted during his time as a biological consultant to the Hudson Bay Company to help understand the fluctuations in the company's fur harvests. Elton studied the population fluctuations and dynamics of snowshoe hare, Canadian lynx, and other mammals of the region. Elton is also considered the first to coin the terms, food chain and food cycle in his famous book *Animal Ecology* (Elton, 2011). Elton is also attributed with contributing to disciplines of invasion ecology, community ecology, and wildlife disease ecology (Wilson, 2011).

G. Evelyn Hutchinson - father of modern ecology

George “G” Evelyn Hutchinson was a 20th-century ecologist who is commonly recognized as the “Father of Modern Ecology”. Hutchinson is of English descent but spent most of professional career studying in New Haven, Connecticut at Yale University. Throughout his career, over six decades, Hutchinson contributed to the sciences of limnology, entomology, genetics, biogeochemistry, mathematical theory of population dynamics and many more (Lovejoy, 2011). Hutchinson is also attributed as being the first to infuse science with theory within the discipline of ecology (McIntosh, 1985). Hutchinson was also one of the first credited with combining ecology with mathematics. Another major contribution of Hutchinson was his development of the current definition of an organism's “niche” – as he recognized the role of an organism within its community. Finally, along with his great impact within the discipline of ecology throughout his professional years, Hutchinson also left a lasting impact in ecology through his many students he inspired. Foremost among them were Robert H. MacArthur, who received his PhD under Hutchinson, and Raymond L. Lindemann, who finished his PhD dissertation during a fellowship under him. MacArthur became the leader of theoretical ecology and, with E. O. Wilson, developed island biography theory. Raymond Lindemann was instrumental in the development of modern ecosystem science (Dritschilo, 2008).

20th century transition to modern ecology

“What is ecology?” was a question that was asked in almost every decade of the 20th century (McIntosh, 1985). Unfortunately, the answer most often was that it was mainly a point of view to be used in other areas of biology and also “soft,” like sociology, for example, rather than “hard,” like physics. Although autecology (essentially physiological ecology) could progress through the typical scientific method of observation and hypothesis testing, synecology (the study of animal and plant communities) and genecology (evolutionary ecology), for which experimentation was as limited as it was for, say, geology, continued with much the same inductive gathering of data as did natural history studies (Cook, 1977). Most often, patterns, present and historical, were used to develop theories having explanatory power, but which had little actual data in support. Darwin's theory, as much as it is a foundation of modern biology, is a prime example.

G. E. Hutchinson, identified above as the “father of modern ecology,” through his influence raised the status of much of ecology to that of a rigorous science. By shepherding of Raymond Lindemann's work on the trophic-dynamic concept of ecosystems through the publication process after Lindemann's untimely death, Hutchinson set the groundwork for what became modern ecosystem science. With his two famous papers in the late 1950s, “Closing remarks,” and “Homage to Santa Rosalia,” as they are now known, Hutchinson launched the theoretical ecology which Robert MacArthur championed (Hutchinson, 1957; Hutchinson, 1959; Bocking, 1997).

Ecosystem science became rapidly and sensibly associated with the “Big Science”—and obviously “hard” science—of atomic testing and nuclear energy. It was brought in by Stanley Auerbach, who established the Environmental Sciences Division at Oak Ridge National Laboratory, to trace the routes of radionuclides through the environment, and by the Odum brothers, Howard and Eugene, much of whose early work was supported by the Atomic Energy Commission (Craige, 2001; Golley, 1993). Eugene Odum's textbook, *Fundamentals of Ecology*, has become something of a bible today. When, in the 1960s, the International Biological Program (IBP) took on an ecosystem character, ecology, with its foundation in systems science, forever entered the realm of Big Science, with projects having large scopes and big budgets (BioScience, 1964). Just two years after the publication of Rachel Carson's *Silent Spring* in 1962, ecosystem ecology was trumpeted as THE science of the environment in a series of articles in a special edition of *BioScience* (Dritschilo, 2019).

Theoretical ecology took a different path to establish its legitimacy, especially at eastern universities and certain West Coast campuses (MacArthur, 1955). It was the path of Robert MacArthur, who used simple mathematics in his “Three Influential Papers, also published in the late 1950s, on population and community ecology (MacArthur, 1957; MacArthur, 1958; Van Valen & Pitelka, 1974). Although the simple equations of theoretical ecology at the time, were unsupported by data, they still were still deemed to be “heuristic.” They were resisted by a number of traditional ecologists, however, whose complaints of “intellectual censorship” of studies that did not fit into the hypothetico-deductive structure of the new ecology might be seen as evidence of the stature to which the Hutchinson-MacArthur approach had risen by the 1970s (Peters, 1976).

Timeline of ecologists

A list of founders, innovators and their significant contributions to ecology, from Romanticism onward.

Notable figure	Lifespan	Major contribution & citation
Antonie van Leeuwenhoek	1632–1723	First to develop concept of food chains
Carl Linnaeus	1707–1778	Influential naturalist, inventor of science on the economy of nature[64][65]
Alexander Humboldt	1769–1859	First to describe ecological gradient of latitudinal biodiversity increase toward the tropics in 1807 (Darwin, 1859)
Charles Darwin	1809–1882	Founder of the hypothesis of evolution by means of natural selection, founder of ecological studies of soils[67]

Elizabeth Catherine Thomas Carne	1817-1873	Geologist, mineralogist and philosopher who observed rural vs urban living, spatially and culturally, finding in country living the best attack on suffocating class divides, healthier living, and best access to natural education (Hardie-Budden, 2014; Futuyma, 2005).
Herbert Spencer	1820–1903	Early founder of social ecology, coined the phrase 'survival of the fittest' (Egerton, 2007; Glaubrecht, 2008)
Karl Möbius	1825–1908	First to develop concept of ecological community, biocenosis, or living community (Baker, 1966; Nyhart, 1998; Palamar, 2008)
Ernst Haeckel	1834–1919	Invented the term ecology, popularized research links between ecology and evolution
Victor Hensen	1835–1924	Invented term plankton, developed quantitative and statistical measures of productivity in the seas
Eugenius Warming	1841–1924	Early founder of Ecological Plant Geography (Coleman, 1986)
Ellen Swallow Richards	1842–1911	Pioneer and educator who linked urban ecology to human health (Forbes, 1915)
Stephen Forbes	1844–1930	Early founder of entomology and ecological concepts in 1887 (Forbes, 1887; Cohen, 1987)
Vito Volterra	1860–1940	Independently pioneered mathematical populations models around the same time as Alfred J. Lotka (Volterra, 1926; Adams & Fuller, 1940).
Vladimir Vernadsky	1869–1939	Founded the biosphere concept
Henry C. Cowles	1869–1939	Pioneering studies and conceptual development in studies of ecological succession (Smuts, 1926)
Jan Christiaan Smuts	1870–1950	Coined the term holism in a 1926 book *Holism and Evolution* (Cooper, 1957)
Arthur G. Tansley	1871–1955	First to coin the term ecosystem in 1936 and notable researcher (Nyhart, 1998; Kingsland, 1994; Ilerbaig, 1999)
Charles Christopher Adams	1873–1955	Animal ecologist, biogeographer, author of first American book on animal ecology in 1913, founded ecological energetics (Raup, 1959; Simberloff, 1980)
Friedrich Ratzel	1844–1904	German geographer who first coined the term biogeography in 1891

Frederic Clements	1874–1945	Authored the first influential American ecology book in 1905 (Ellison, 2006)
Victor Ernest Shelford	1877–1968	Founded physiological ecology, pioneered food-web and biome concepts, founded The Nature Conservancy (Kendeigh, 1968; Berryman, 1992)
Alfred J. Lotka	1880–1949	First to pioneer mathematical populations models explaining trophic (predator-prey) interactions using logistic equation (McIntosh, 1975)
Henry Gleason	1882–1975	Early ecology pioneer, quantitative theorist, author, and founder of the individualistic concept of ecology[84][88]
Charles S. Elton	1900–1991	'Father' of animal ecology, pioneered food-web & niche concepts and authored influential *Animal Ecology* text (Ellison, 2006; Flannery, 2003)
G. Evelyn Hutchinson	1903–1991	Limnologist and conceptually advanced the niche concept[90][91][92]
Eugene P. Odum	1913–2002	Co-founder of ecosystem ecology and ecological thermodynamic concepts (Edmondson, 1991; Patrick, 1994; Gunderson et al., 2002)
Howard T. Odum	1924–2002	Co-founder of ecosystem ecology and ecological thermodynamic concepts (Ilerbaig, 1999; Kendeigh, 1968; Rotabi, 2007; Patten, 1993; Ewel, 2003; Brown, 1999)
Robert MacArthur	1930–1972	Co-founder on Theory of Island Biogeography and innovator of ecological statistical methods (Levin, 1998)

Ecological Influence on the Social Sciences and Humanities

Human ecology

Human ecology began in the 1920s, through the study of changes in vegetation succession in the city of Chicago. It became a distinct field of study in the 1970s. This marked the first recognition that humans, who had colonized all of the Earth's continents, were a major ecological factor. Humans greatly modify the environment through the development of the habitat (in particular urban planning), by intensive exploitation activities such as logging and fishing, and as side effects of agriculture, mining, and industry. Besides ecology and biology, this discipline involved many other natural and social sciences, such as anthropology and ethnology, economics, demography, architecture and urban planning, medicine and psychology, and many more. The development of human ecology led to the increasing role of ecological science in the design and management of cities.

In recent years human ecology has been a topic that has interested organizational researchers. Hannan and Freeman (*Population Ecology of Organizations (1977)*, American Journal of Sociology) argue that organizations do not only adapt to an environment. Instead it is also the environment that selects or rejects populations of organizations. In any given environment (in equilibrium) there will only be one form of organization (isomorphism). Organizational ecology has been a prominent theory in accounting for diversities of organizations and their changing composition over time.

James Lovelock and the Gaia hypothesis

The Gaia theory, proposed by James Lovelock, in his work *Gaia: A New Look at Life on Earth*, advanced the view that the Earth should be regarded as a single living macro-organism. In particular, it argued that the ensemble of living organisms has jointly evolved an ability to control the global environment — by influencing major physical parameters as the composition of the atmosphere, the evaporation rate, the chemistry of soils and oceans — so as to maintain conditions favorable to life. The idea has been supported by Lynn Margulis who extended her endosymbiotic theory which suggests that cell organelles originated from free living organisms to the idea that individual organisms of many species could be considered as symbionts within a larger metaphorical "super-organism" (Allee et al., 1949).

This vision was largely a sign of the times, in particular the growing perception after the Second World War that human activities such as nuclear energy, industrialization, pollution, and overexploitation of natural resources, fueled by exponential population growth, were threatening to create catastrophes on a planetary scale, and has influenced many in the environmental movement since then.

History and relationship between ecology and conservation and environmental movements

Environmentalists and other conservationists have used ecology and other sciences (e.g., climatology) to support their advocacy positions. Environmentalist views are often controversial for political or economic reasons. As a result, some scientific work in ecology directly influences policy and political debate; these in turn often direct ecological research.

The history of ecology, however, should not be conflated with that of environmental thought. Ecology as a modern science traces only from Darwin's publication of Origin of Species and Haeckel's subsequent naming of the science needed to study Darwin's theory. Awareness of humankind's effect on its environment has been traced to Gilbert White in 18th-century Selborne, England (Worster, 1994). Awareness of nature and its interactions can be traced back even farther in time (Egerton, 1973; Egerton, 2001). Ecology before Darwin, however, is analogous to medicine prior to Pasteur's discovery of the infectious nature of disease. The history is there, but it is only partly relevant.

Neither Darwin nor Haeckel, it is true, did self-avowed ecological studies. The same can be said for researchers in a number of fields who contributed to ecological thought well into the 1940s without avowedly being ecologists (McIntosh, 1985; Kingsland, 1985). Raymond Pearl's population studies are a case in point (Huxley, 1942). Ecology in subject matter and techniques grew out of studies by botanists and plant geographers in the late 19th and early 20th centuries that paradoxically lacked Darwinian evolutionary perspectives. Until Mendel's studies with peas were rediscovered and melded into the Modern Synthesis, Darwinism suffered in credibility (Kingsland, 2005). Many early plant ecologists had a Lamarckian view of inheritance, as did Darwin, at times. Ecological studies of animals and plants, preferably live and in the field, continued apace however (Coker, 1991).

Conservation and environmental movements - 20th Century

When the Ecological Society of America (ESA) was chartered in 1915, it already had a conservation perspective (Shelford, 1917). Victor E. Shelford, a leader in the society's formation, had as one of its goals the preservation of the natural areas that were then the objects of study by ecologists, but were in danger of being degraded by human incursion (Forbes, 1922). Human ecology had also been a visible part of the ESA at its inception, as evident by publications such as: "The Control of Pneumonia and Influenza by the Weather," "An Overlook of the Relations of Dust to Humanity," "The Ecological Relations of the Polar Eskimo," and "City Street Dust and Infectious Diseases," in early pages of Ecology and Ecological Monographs. The ESA's second president, Ellsworth Huntington, was a human ecologist. Stephen Forbes, another early president, called for "humanizing" ecology in 1921, since man was clearly the dominant species on the Earth (Adams, 1935).

This auspicious start actually was the first of a series of fitful progressions and reversions by the new science with regard to conservation. Human ecology necessarily focused on man-influenced environments and their practical problems. Ecologists in general, however, were trying to establish ecology as a basic science, one with enough prestige to make inroads into Ivy League faculties. Disturbed environments, it was thought, would not reveal nature's secrets.

Interest in the environment created by the American Dust Bowl produced a flurry of calls in 1935 for ecology to take a look at practical issues. Pioneering ecologist C. C. Adams wanted to return human ecology to the science (Adams, 1935). Frederic E.

Clements, the dominant plant ecologist of the day, reviewed land use issues leading to the Dust Bowl in terms of his ideas on plant succession and climax (Clements, 1935). Paul Sears reached a wide audience with his book, *Deserts on the March* (Sears, 1935). World War II, perhaps, caused the issue to be put aside.

The tension between pure ecology, seeking to understand and explain, and applied ecology, seeking to describe and repair, came to a head after World War II. Adams again tried to push the ESA into applied areas by having it raise an endowment to promote ecology. He predicted that "a great expansion of ecology" was imminent "because of its integrating tendency."[109] Ecologists, however, were sensitive to the perception that ecology was still not considered a rigorous, quantitative science. Those who pushed for applied studies and active involvement in conservation were once more discreetly rebuffed. Human ecology became subsumed by sociology. It was sociologist Lewis Mumford who brought the ideas of George Perkins Marsh to modern attention in the 1955 conference, "Man's Role in Changing the Face of the Earth." That prestigious conclave was dominated by social scientists. At it, ecology was accused of "lacking experimental methods" and neglecting "man as an ecological agent." One participant dismissed ecology as "archaic and sterile," (Hagen, 1992). Within the ESA, a frustrated Shelford started the Ecologists' Union when his Committee on Preservation of Natural Conditions ceased to function due to the political infighting over the ESA stance on conservation (Shelford, 1917). In 1950, the fledgling organization was renamed and incorporated as the Nature Conservancy, a name borrowed from the British government agency for the same purpose.

Two events, however, brought ecology's course back to applied problems. One was the Manhattan Project. It had become the Nuclear Energy Commission after the war. It is now the Department of Energy (DOE). Its ample budget included studies of the impacts of nuclear weapon use and production. That brought ecology to the issue, and it made a "Big Science" of it (Worster, 1994; Dritschilo, 2004). Ecosystem science, both basic and applied, began to compete with theoretical ecology (then called evolutionary ecology and also mathematical ecology). Eugene Odum, who published a very popular ecology textbook in 1953, became the champion of the ecosystem. In his publications, Odum called for ecology to have an ecosystem and applied focus (Miller, 1965).

The second event was the publication of Silent Spring. Rachel Carson's book brought ecology as a word and concept to the public. Her influence was instant. A study committee, prodded by the publication of the book, reported to the ESA that their science was not ready to take on the responsibility being given to it (Dritschilo, 2006).

Carson's concept of ecology was very similar to Gene Odum's (Blair, 1977). As a result, ecosystem science dominated the International Biological Program of the 1960s and 1970s, bringing both money and prestige to ecology (Kwa, 1987; Curlin, 1972). Silent Spring was also the impetus for the environmental protection programs that were started in the Kennedy and Johnson administrations and passed into law just before the first Earth Day. Ecologists' input was welcomed. Former ESA President Stanley Cain, for example, was appointed an Assistant Secretary in the Department of the Interior.

The environmental assessment requirement of the 1969 National Environmental Policy Act (NEPA), "legitimized ecology," in the words of one environmental lawyer (Auerbach, 1972). An ESA President called it "an ecological 'Magna Carta,'" (Schindler, 1976). A prominent Canadian ecologist declared it a "boondoggle," (Dritschilo, 2016). NEPA and similar state statutes, if nothing else, provided much employment for ecologists. Therein was the issue. Neither ecology nor ecologists were ready for the task. Not enough ecologists were available to work on impact assessment, outside of the DOE laboratories, leading to the rise of "instant ecologists," having dubious credentials and capabilities (Dritschilo, 2016). Calls began to arise for the professionalization of ecology. Maverick scientist Frank Egler, in particular, devoted his sharp prose to the task (Dale et al., 2000). Again, a schism arose between basic and applied scientists in the ESA, this time exacerbated by the question of environmental advocacy. The controversy, whose history has yet to receive adequate treatment, lasted through the 1970s and 1980s, ending with a voluntary certification process by the ESA, along with lobbying arm in Washington (Suter, 1981).

Post-Earth Day, besides questions of advocacy and professionalism, ecology also had to deal with questions having to do with its basic principles. Many of the theoretical principles and methods of both ecosystem science and evolutionary ecology began to show little value in environmental analysis and assessment (Peters, 1976). Ecologists, in general, started to question the methods and logic of their science under the pressure of its new notoriety (Ellison, 2006; Peters, 1991; Simberloff & Abele 1976). Meanwhile, personnel with government agencies and environmental advocacy groups were accused of religiously applying dubious principles in their conservation work (Chase, 1995). Management of endangered Spotted Owl populations brought the controversy to a head (Takacs, 1996).

Conservation for ecologists created travails paralleling those nuclear power gave former Manhattan Project scientists. In each case, science had to be reconciled with individual politics, religious beliefs, and worldviews, a difficult process. Some ecologists managed to keep their science separate from their advocacy; others unrepentantly became avowed environmentalists.[128]

Roosevelt & American conservation

Theodore Roosevelt was interested in nature from a young age. He carried his passion for nature into his political policies. Roosevelt felt it was necessary to preserve the resources of the nation and its environment. In 1902 he created the federal reclamation service, which reclaimed land for agriculture. He also created the Bureau of Forestry. This organization, headed by Gifford Pinchot, was formed to manage and maintain the nations timberlands.[129] Roosevelt signed the Act for the Preservation of American Antiquities in 1906. This act allowed for him to "declare by public proclamation historic landmarks, historic and prehistoric structures, and other objects of historic and scientific interest that are situated upon lands owned or controlled by the Government of the United States to be national monuments." Under this act he created up to 18 national monuments. During his presidency, Roosevelt established 51 Federal Bird Reservations, 4 National Game Preserves, 150 National Forests, and 5 National Parks. Overall he protected over 200 million acres of land (“Theodore Roosevelt and the Environment," n.d.; “Theodore Roosevelt and conservation,” n.d.).

Ecology and global policy

Ecology became a central part of the World's politics as early as 1971, UNESCO launched a research program called *Man and Biosphere*, with the objective of increasing knowledge about the mutual relationship between humans and nature. A few years later it defined the concept of Biosphere Reserve.

In 1972, the United Nations held the first international Conference on the Human Environment in Stockholm, prepared by Rene Dubos and other experts. This conference was the origin of the phrase "Think Globally, Act Locally". The next major events in ecology were the development of the concept of biosphere and the appearance of terms "biological diversity"—or now more commonly biodiversity—in the 1980s. These terms were developed during the Earth Summit in Rio de Janeiro in 1992, where the concept of the biosphere was recognized by the major international organizations, and risks associated with reductions in biodiversity were publicly acknowledged.

Then, in 1997, the dangers the biosphere was facing were recognized all over the world at the conference leading to the Kyoto Protocol. In particular, this conference highlighted the increasing dangers of the greenhouse effect – related to the increasing concentration of greenhouse gases in the atmosphere, leading to global changes in climate. In Kyoto, most of the world's nations recognized the importance of looking at ecology from a global point of view, on a worldwide scale, and to take into account the impact of humans on the Earth's environment.

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1.4: Subdisciplines of Ecology

Skills to Develop:

- Appreciate the diversity of ecological studies
- Understand how ecology interacts with other fields

Subdisciplines of ecology, and subdiscipline classification

Ecology is a broad discipline comprising many subdisciplines. The field of ecology can be subdivided according to several classification schemes:

By methodology used for investigation

- Field ecology – collection of information outside a laboratory, library or workplace setting
- Quantitative ecology – the application of advanced mathematical and statistical tools to any number of problems in the field of ecology
- Theoretical ecology – the development of ecological theory, usually with mathematical, statistical and/or computer modeling tools

By spatial scale of ecological system under study

- Global ecology – the global sum of all biospheres on Earth
- Macroecology – study of relationships between organisms and their environment at large spatial scales
- Microecology – microbial ecology or ecology of a microhabitat

By level of organisation or scope

Arranged from lowest to highest level of organisation:[1]

- Autecology – the study of individual organisms of a single species in relation to their environment
- Synecology – the study of homogenous or heterogenous groups of organisms in relation to their environment
  - Population ecology – study of the dynamics of species populations and how these populations interact with the environment – the study of homogenous groups of organisms related as a single species
  - Community ecology – associated populations of species in a given area – the study of heterogenous groups of organisms comprised of multiple associated species
  - Ecosystem ecology – study of living and non-living components of ecosystems and their interactions

By biological classification or taxon under study

- Human ecology – study of the relationship between humans and their natural, social, and built environments
- Animal ecology – scientific study of the relationships between living animals and their environment
- Insect ecology – the study of how insects interact with the surrounding environment
- Microbial ecology – study of the relationship of microorganisms with their environment
- Plant ecology – the study of effect of the environment on the abundance and distribution of plants.

By biome under study

- Benthic ecology – the study of the interaction of deep-dwelling aquatic organisms with each other and with the environment
- Desert ecology – the study of interactions between both biotic and abiotic components of desert environments
- Forest ecology – study of interactions between the biota and environment in forests
- Grassland ecology – study of area with vegetation dominated by grasses
- Marine ecology – the study of the interactions between organisms and environment in the sea
- Aquatic ecology – the study of interactions between organisms and the environment in water
- Urban ecology – study of the relation of living organisms with each other and their surroundings in the context of an urban environment

By biogeographic realm or climatic area under study

- Arctic ecology – the study of the relationships between biotic and abiotic factors in the arctic
- Polar ecology – the relationship between plants and animals and a polar environment
- Tropical ecology – the study of the relationships between the biotic and abiotic components of the tropics.

By ecological aspects or phenomena under investigation

- Behavioral ecology – study of the evolutionary basis for animal behavior due to ecological pressures
- Chemical ecology – study of chemically-mediated interactions between living organisms – which deals with the ecological role of biological chemicals used in a wide range of areas including defense against predators and attraction of mates
- Disease ecology – sub-discipline of ecology – which studies host-pathogen interactions, particularly those of infectious diseases, within the context of environmental factors;
- Ecophysiology – study of adaptation of an organism's physiology (studies the interaction of physiological traits with the abiotic environment) to environmental conditions
- Ecotoxicology – which looks at the ecological role of toxic chemicals (often pollutants, but also naturally occurring compounds)
- Evolutionary ecology – interaction of biology and evolution – or ecoevolution which looks at evolutionary changes in the context of the populations and communities in which the organisms exist
- Fire ecology – study of fire in ecosystems, which looks at the role of fire in the environment of plants and animals and its effect on ecological communities
- Functional ecology – the study of the roles, or functions, that certain species (or groups thereof) play in an ecosystem
- Genetic ecology – study of genetic material in the environment
- Landscape ecology – science of relationships between ecological processes in the environment and particular ecosystems
  - Landscape limnology – spatially explicit study of lakes, streams, and wetlands as they interact with freshwater, terrestrial, and human landscapes to determine the effects of pattern on ecosystem processes across temporal and spatial scales
- Molecular ecology – a field of evolutionary biology that applies molecular population genetics, molecular phylogenetics, and genomics to traditional ecological questions
- Paleoecology – study of interactions between organisms and their environments across geologic timescales
- Social ecology – study of relationships between people and their environment
- Soil ecology – the ecology of the pedosphere
- Spatial ecology – study of the distribution or space occupied by species
- Thermal ecology – the study of the relationship between temperature and organisms

Ecology-involved interdisciplinary fields

- Agroecology – study of ecological processes in agriculture
- Applied ecology – the practice of employing ecological principles and understanding to solve real world problems
  - Conservation ecology – study of threats to biological diversity, which studies how to reduce the risk of species extinction
  - Restoration ecology – scientific study of renewing and restoring ecosystems, which attempts to understand the ecological basis needed to restore impaired or damaged ecosystems
- Biogeochemistry – study of chemical cycles of the earth that are either driven by or influence biological activity
- Biogeography – study of the distribution of species and ecosystems in geographic space and through geological time
- Ecological design – design that minimizes environmentally destructive impacts by integrating itself with living processes
- Ecological economics – interdependence of human economies and natural ecosystems
- Ecological engineering – environmental engineering
- Ecological anthropology – study of cultural adaptations to environments
  - Festive ecology – study of the relationships between the symbolism and the ecology of the plants, fungi and animals associated with cultural events
- Ecological health
- Ecosophy – philosophy of ecological harmony or equilibrium as developed by Arne Næss or Félix Guattari
- Environmental psychology – academic study of the mind's relationship to one's immediate surroundings
- Natural history – study of organisms including plants or animals in their environment
- Systems ecology – holistic approach to the study of ecological systems

Other disciplines

Ecology has also inspired (and lent its name to) other non-biological disciplines such as:

- Media ecology
- Industrial ecology
- Information ecology
