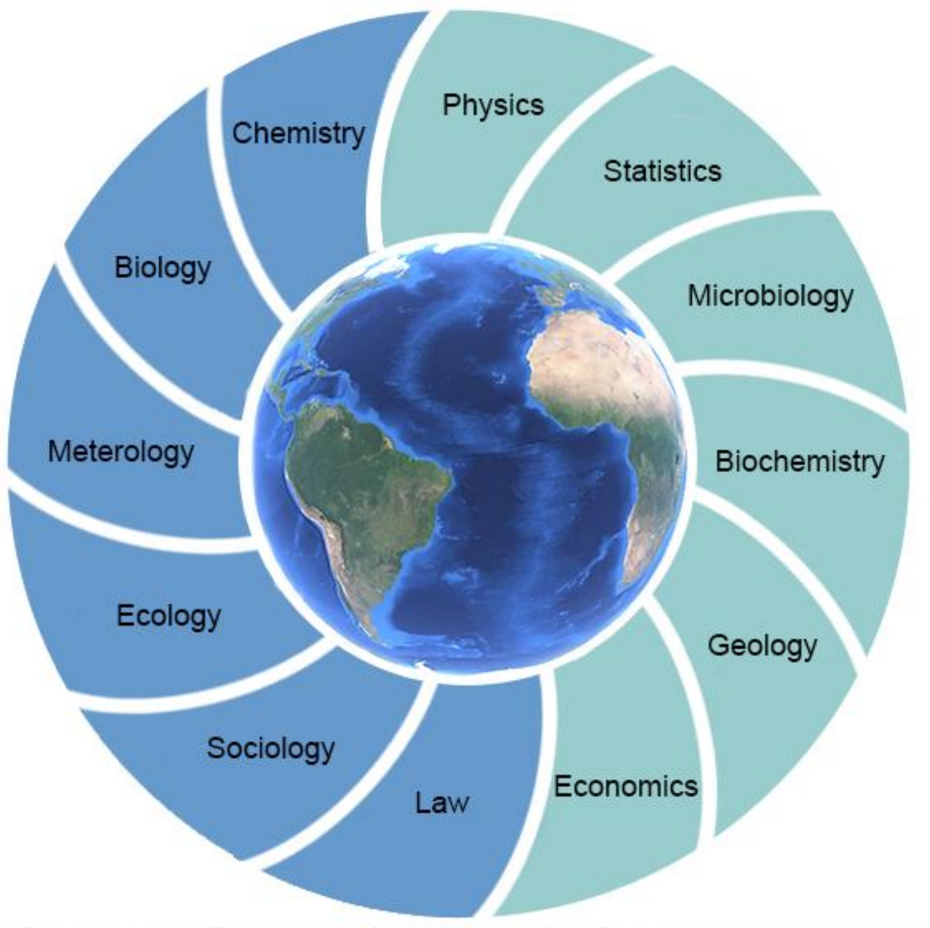
Chapter 1: Introduction to Environmental Science



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Interconnected disciplines: exploring how science, society, and law shape our understanding of Earth

Learning Outcomes

By the end of this chapter, students will be able to:

1. Describe, at an introductory level, the basic chemical and biological foundations of life on Earth.
2. Define environment, ecosystems, and environmental sciences.
3. Give examples of the interdisciplinary nature of environmental science.
4. Define sustainability and sustainable development.
5. Explain the complex relationship between natural and human systems, pertaining to environmental impact, the precautionary principle, and environmental justifications.
6. Explain the steps of the scientific method and identify how the scientific approach is used to address environmental questions.

Contents

1.1 The Chemical and Biological Foundations of Life

Elements in various combinations comprise all matter on Earth, including living things. Some of the most abundant elements in living organisms include carbon, hydrogen, nitrogen, oxygen, sulfur, and phosphorus. These form the nucleic acids, proteins, carbohydrates, and lipids that are the fundamental components of living matter. Biologists must understand these important building blocks and the unique structures of the atoms that make up molecules, allowing for the formation of cells, tissues, organ systems, and entire organisms.

At its most fundamental level, life is made up of matter. **Matter** is any substance that occupies space and has mass. **Elements** are unique forms of matter with specific chemical and physical properties that cannot be broken down into smaller substances by ordinary chemical reactions. There are 118 elements, but only 92 occur naturally. The remaining elements are synthesized in laboratories and are unstable. The five elements common to all living organisms are oxygen (O), carbon (C), hydrogen (H), and nitrogen (N) and phosphorous (P). In the non-living world, elements are found in different proportions, and some elements common to living organisms are relatively rare on the earth as a whole (**Table 1.1**). For example, the atmosphere is rich in nitrogen and oxygen but contains little carbon and hydrogen, while the earth's crust, although it contains oxygen and a small amount of hydrogen, has little nitrogen and carbon. In spite of their differences in abundance, all elements and the chemical reactions between them obey the same chemical and physical laws regardless of whether they are a part of the living or non-living world.

Table 1.1: Approximate percentage of elements in living organisms (from bacteria to humans) compared to the non-living world. Trace represents less than 1%. Biosphere – part of Earth where life exists; Atmosphere – gaseous envelope surrounding Earth; Lithosphere – curst and mantle of Earth.

	Biosphere	Atmosphere	Lithosphere
Oxygen (O)	65%	21%	46%
Carbon (C)	18%	trace	Trace
Hydrogen (H)	10%	trace	Trace
Nitrogen (N)	3%	78%	Trace
Phosphorus (P)	trace	trace	>30%

1.1.1 The Structure of the Atom

An **atom** is the smallest unit of matter that retains all of the chemical properties of an element. For example, one gold atom has all of the properties of gold in that it is a solid metal at room temperature. A gold coin is simply a very large number of gold atoms molded into the shape of a coin and containing small amounts of other elements known as impurities. Gold atoms cannot be broken down into anything smaller while still retaining the properties of gold. An atom is composed of two regions: the **nucleus**, which is in the center of the atom and contains protons and neutrons, and the outermost region of the atom which holds its electrons in orbit around the nucleus, as illustrated in **Figure 1.1**. Atoms contain protons, electrons, and neutrons, among other subatomic particles. The only exception is hydrogen (H), which is made of one proton and one electron with no neutrons.

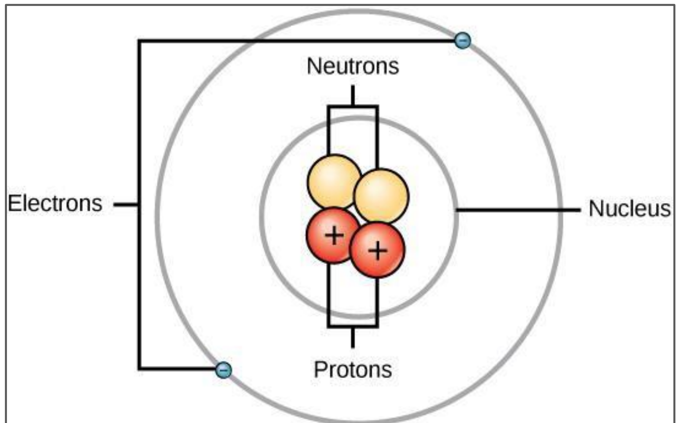

Figure 1.1. Elements, such as helium, depicted here, are made up of atoms. Atoms are made up of protons and neutrons located within the nucleus, with electrons in orbitals surrounding the nucleus. This atom has two electrons, two protons, and two neutrons.

Protons and neutrons have approximately the same mass, about 1.67×10^{-24} grams. Scientists arbitrarily define this amount of mass as one atomic mass unit (amu) (**Table 1.2**). The **mass number** of an atom is the number of protons plus the number of neutrons in the atom. Although similar in mass, protons and neutrons differ in their electric charge. A **proton** is positively charged whereas a **neutron** is uncharged. Therefore, the number of neutrons in an atom contributes significantly to its mass, but not to its charge.

Table 1.2. Protons, neutrons, and electrons

	Charge	Mass (amu)	Location in atom
Proton	+1	1	Nucleus
Neutron	0	1	Nucleus
Electron	-1	0	Orbitals

Electrons are much smaller in mass than protons, weighing only 9.11×10^{-28} grams, or about 1/1800 of an atomic mass unit. Hence, they do not contribute much to an element's overall atomic mass. Although not significant contributors to mass, electrons do contribute greatly to the atom's charge, as each electron has a negative charge equal to the positive charge of a proton. In uncharged, neutral atoms, the number of electrons orbiting the nucleus is equal to the number of protons inside the nucleus. In these

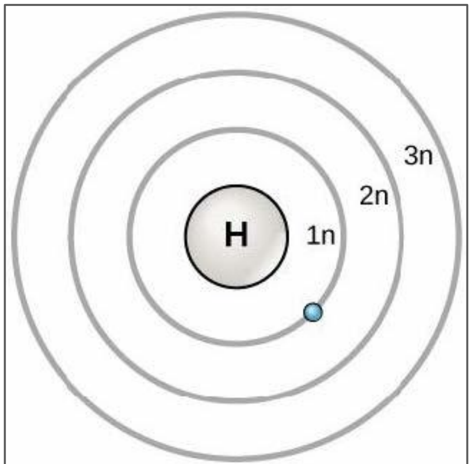

Figure 1.2. Electron orbitals

atoms, the positive and negative charges cancel each other out, leading to an atom with no net charge. Electrons fill orbitals around the nucleus of an atom from the innermost orbital moving outward (**Figure 1.2**). Accounting for the sizes of protons, neutrons, and electrons, most of the volume of an atom—greater than 99 percent—is, in fact, empty space. With all this empty space, one might ask why so-called solid objects do not just pass through one another. The reason they do not is that the electrons that surround all atoms are negatively charged and negative charges repel each other. When an atom gains or loses an electron, an **ion** is formed. Ions are charged forms of atoms. A positively charged ion, such as sodium (Na^+), has lost one or more electrons. A negatively charged ion, such as chloride (Cl^-), has gained one or more electrons. See discussion of bonds below for more information.

1.1.2 Molecules

Molecules are formed when two or more atoms join together through chemical bonds to form a unit of matter. Two of the most common types of chemical bonds are ionic and covalent bonds. Ionic bonds occur when a chemical reaction results in the donation or acceptance of one or more electrons and the atoms involved become positively or negatively charged (**Figure 1.3.**). Covalent bonds occur when two or more atoms share electrons to fill their valence shells (**Figure 1.4.**). Hydrogen bonds occur when Covalent and hydrogen bonds will be discussed further in Chapter 7. Throughout your study of environmental science, you will encounter many molecules including carbon dioxide gas. Its chemical formula is CO_2,

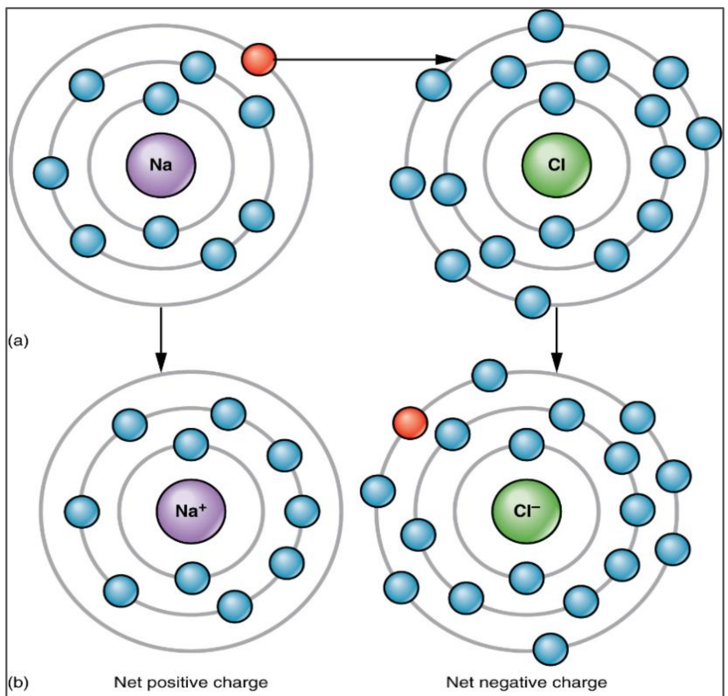

Figure 1.3. (a) Sodium readily donates the solitary electron in its valence shell to chlorine, which needs only one electron to have a full valence shell. (b) The opposite electrical charges of the resulting sodium cation and chloride anion result in the formation of a bond of attraction called an ionic bond. OpenStax College, CC BY 3.0, via Wikimedia Commons

indicating that this molecule is made up of one carbon atom and two oxygen atoms. Some molecules are charged due to the ions they contain, as is the case for nitrate (NO_3^-), a common source of nitrogen to plants. It contains one nitrogen atom and three oxygen atoms, and has an overall charge of negative one.

Isotopes are different forms of an element that have the same number of protons but a different number of neutrons and, therefore, a different mass number. Some elements—such as carbon, potassium, and uranium—have naturally occurring isotopes. Carbon-12 contains six protons, six neutrons, and six electrons; therefore, it has a mass number of 12 (six protons and six neutrons). Carbon-14 contains six protons, eight neutrons, and six electrons; its mass number is 14 (six protons and eight electrons). These two alternate forms of carbon are isotopes. Some isotopes may emit neutrons, protons, and electrons, and attain a more stable atomic configuration (lower level of potential energy); these are radioactive isotopes, or **radioisotopes**. Radioactive decay describes the energy loss that occurs when an unstable atom's nucleus releases radiation, for example, carbon-14 losing neutrons to eventually become carbon-12.

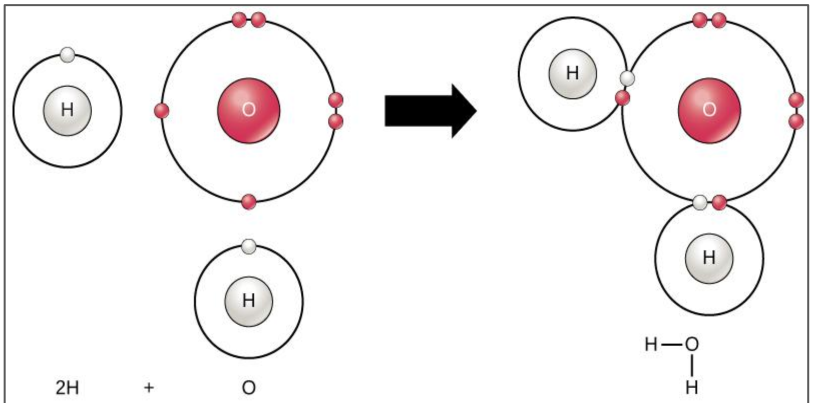

Figure 1.4. Two or more atoms may bond with each other to form a molecule. When two hydrogens and an oxygen share electrons via covalent bonds it forms a water molecule. Image credit: OpenStax Biology 2e.

1.1.3 Carbon

The basic functional unit of life is a cell and all organisms are made up of one or more cells. Cells are made of many complex molecules called macromolecules, such as proteins, nucleic acids (RNA and DNA), carbohydrates, and lipids. The macromolecules are a subset of **organic molecules** that are especially important for life. The fundamental component for all of these macromolecules is carbon. The carbon atom has unique properties that allow it to form covalent bonds with as many as four different atoms, making this versatile element ideal to serve as the basic structural component, or "backbone," of the macromolecules.

1.1.4 Hydrocarbons

Hydrocarbons are organic molecules consisting entirely of carbon and hydrogen, such as methane (CH_4). We often use hydrocarbons in our daily lives as fuels—like the propane in a gas grill or the butane in a lighter. The many covalent bonds between the atoms in hydrocarbons store a great amount of energy, which is released when these molecules are burned (oxidized). Methane, an excellent fuel, is the simplest hydrocarbon molecule, with a central carbon atom bonded to four different hydrogen atoms, as illustrated in **Figure 1.5**.

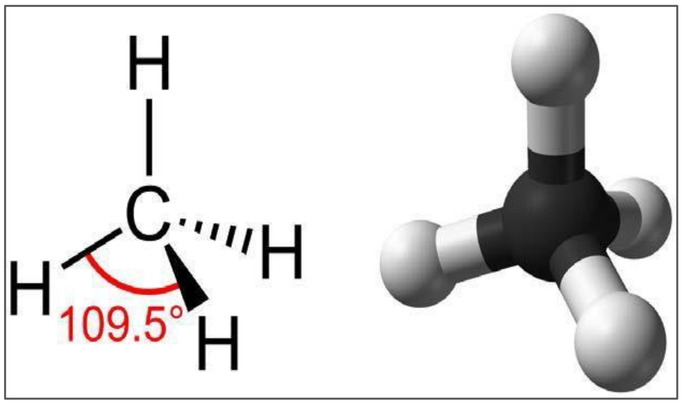

Figure 1.5. Methane (CH_4) has a tetrahedral geometry, with each of the four hydrogen atoms spaced 109.5° apart.

As the backbone of the large molecules of living things, hydrocarbons may exist as linear carbon chains, carbon rings, or combinations of both (**Figure 1.6**). This three-dimensional shape or conformation of the large molecules of life (macromolecules) is critical to how they function.

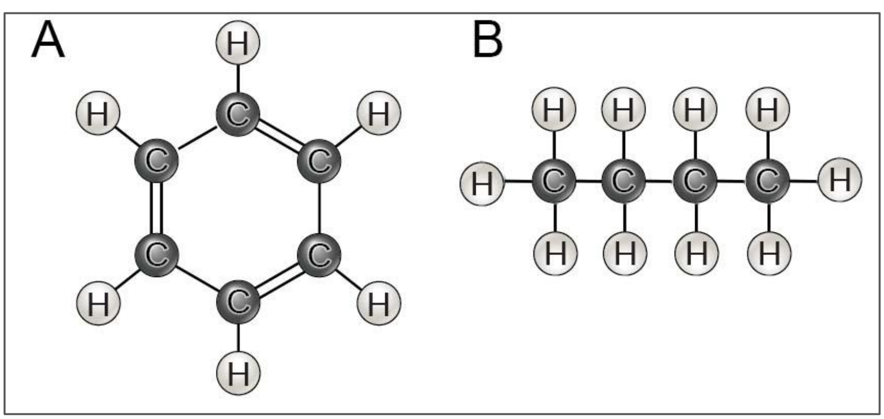

Figure 1.6. A Benzene – example of a carbon ring. **B** Butane – example of a carbon chain. Modified from openstax.org/books/biology-2e.

Test your knowledge…

Atoms form Molecules

What are the two most common types of chemical bonds and how do they differ from each other?

1.2 Biological Molecules

Life on Earth is primarily made up of four major classes of biological molecules, or biomolecules. These include carbohydrates, lipids, proteins, and nucleic acids.

Most people are familiar with **carbohydrates**, one type of macromolecule, especially when it comes to what we eat. Carbohydrates are, in fact, an essential part of our diet; grains, fruits, and vegetables are all natural sources of carbohydrates. Carbohydrates provide energy to the body, particularly through **glucose**, a simple sugar that is a component of **starch** and an ingredient in many staple foods. Carbohydrates also have other important functions in humans, animals, and plants. Carbohydrates can be represented by the stoichiometric formula $(CH_2O)n$, where n is the number of carbons in the molecule. In other words, the ratio of carbon to hydrogen to oxygen is 1:2:1 in carbohydrate molecules. This formula also explains the origin of the term "carbohydrate": the components are carbon ("carbo") and the components of water (hence, "hydrate"). The chemical formula for glucose is $C_6H_{12}O_6$. In humans, glucose is an important source of energy.

During **cellular respiration**, energy is released from glucose, and that energy is used to help make **adenosine triphosphate** (ATP). Plants synthesize glucose using carbon dioxide and water, and glucose in turn is used for energy requirements for the plant.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6\ CO_2 + H_2o + \text{ENERGY}$$

Excess glucose is often stored as starch that is catabolized (the breakdown of larger molecules by cells) by humans and other animals that feed on plants. Plants are able to synthesize glucose, and the excess glucose, beyond the plant's immediate energy needs, is stored as starch in different plant parts, including roots and seeds. The starch in the seeds provides food for the embryo as it germinates and can also act as a source of food for humans and animals.

Lipids include a diverse group of compounds such as fats, oils, waxes, phospholipids, and steroids that are largely nonpolar in nature. Nonpolar molecules are hydrophobic (“water fearing”), or insoluble in water. These lipids have important roles in energy storage, as well as in the building of cell membranes throughout the body.

Proteins are one of the most abundant organic molecules in living systems and have the most diverse range of functions of all macromolecules. Proteins may be structural, regulatory, contractile, or protective; they may serve in transport, storage, or membranes; or they may be toxins or enzymes. Each cell in a living system may contain thousands of proteins, each with a unique function. Their structures, like their functions, vary greatly.

Enzymes, which are produced by living cells, speed up biochemical reactions (like digestion) and are usually complex proteins. Each enzyme has a specific shape or formation based on its use. The enzyme may help in breakdown, rearrangement, or synthesis reactions.

Proteins have different shapes and molecular weights. Protein shape is critical to its function, and many different types of chemical bonds maintain this shape. Changes in temperature, pH, and exposure to chemicals may cause a protein to **denature**. This is a permanent change in the shape of the protein, leading to loss of function. All proteins are made up of different arrangements of the same 20 types of **amino acids**. These amino acids are the units that make up proteins. Ten of these are considered essential amino acids in humans because the human body cannot produce them and they are obtained from the diet. The sequence and the number of amino acids ultimately determine the protein's shape, size, and function.

Nucleic acids are the most important macromolecules for the continuity of life. They carry the genetic blueprint of a cell and carry instructions for the functioning of the cell. The two main types of nucleic acids are **deoxyribonucleic acid (DNA)** and **ribonucleic acid (RNA)**. DNA is the genetic material found in all living organisms, ranging from single-celled bacteria to multicellular mammals. DNA controls all of the cellular activities by turning the genes “on” or “off.” The other type of nucleic acid, RNA, is mostly involved in protein synthesis. DNA has a double-helix structure (**Figure 1.7**).

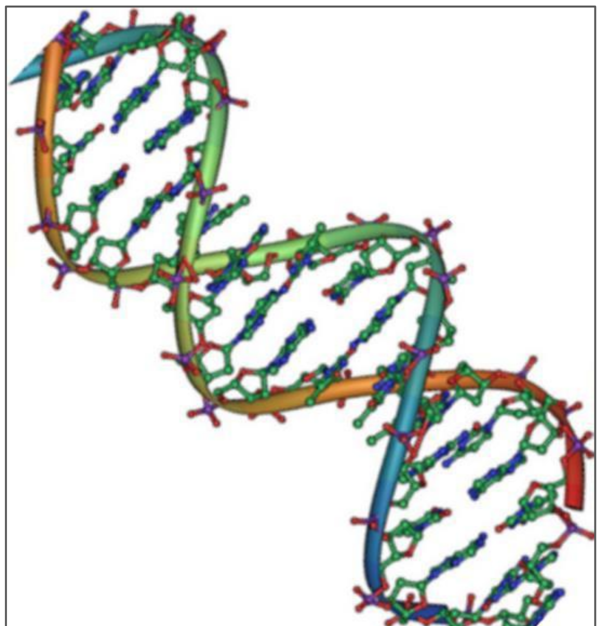

Figure 1.7. Native DNA is an antiparallel double helix. The phosphate backbone (indicated by the curvy lines) is on the outside, and the bases are on the inside. Each base from one strand interacts via hydrogen bonding with a base from the opposing strand. (credit: Jerome Walker/Dennis Myts)

Test your knowledge…

1. *What is the function of each type of biological molecule?*
2. *Explain the importance of each type of biomolecule from the perspective of various organisms: plants, animals, bacteria, etc.*
3. *Plants perform photosynthesis. Why must they also perform cellular respiration?*

1.3 Biological Organization

All living things are made of cells; the **cell** itself is the smallest fundamental unit of structure and function in living organisms. In most organisms, these cells contain **organelles**, which provide specific functions for the cell using the macromolecules discussed in the previous section. Living organisms have the following properties: all are highly organized, all require energy for maintenance and growth, and all grow over time and respond to their environment. All organisms adapt to the environment and all ultimately reproduce contributing genes to the next generation. Some organisms consist of a single cell and others are multicellular. **Organisms** are individual living entities. For example, each tree in a forest is an organism.

All the individuals of the same species living within a specific area are collectively called a **population**. Populations fluctuate based on a number of factors: seasonal and yearly changes in the environment, natural disasters such as forest fires and volcanic eruptions, and competition for resources between and within species. A **community** is the association of populations of two or more different species inhabiting a particular area. For instance, all of the trees, insects, and other populations in a forest form the forest's community. The forest itself is an ecosystem.

An **ecosystem** consists of all the living organisms in a particular area together with the abiotic, non-living parts of that environment such as nitrogen in the soil or rain water. Ecosystem limits can vary from small to large. For example, a patch of grass with a rabbit is an example of a small ecosystem. A lake or a pond can represent ecosystems. At the highest level of organization, the **biosphere** is the collection of all ecosystems, and it represents the zones of life on earth. It includes land, water, and even the atmosphere to a certain extent.

Life in an ecosystem is often about competition for limited resources, a characteristic of the process of natural selection. **Competition** in communities (all living things within specific habitats) is observed both within species and among different species. The resources for which organisms compete include organic material from living or previously living organisms, sunlight, and mineral nutrients, which provide the energy for living processes and the matter to make up organisms' physical structures. Other critical factors influencing community dynamics are the components of its physical and geographic environment: a habitat's latitude, amount of rainfall, topography (elevation), and available species. These are all important environmental variables that determine which organisms can exist within a particular area. Ecosystems can be small, such as the tidal pools found near the rocky shores of many oceans, or large, such as the Amazon Rainforest in Brazil (**Figure 1.8**).

There are three broad categories of ecosystems based on their general environment: freshwater, ocean water (marine), and terrestrial. Within these broad categories are individual ecosystem types based on the organisms present and the type of environmental habitat. Ocean ecosystems are the most common, covering 71 percent of the Earth's surface. The coastal ocean ecosystems include extremely biodiverse coral reef ecosystems, and the offshore ocean surface is known for large numbers of plankton that support all life on Earth. These two environments are especially important to aerobic respirators worldwide as the phytoplankton perform 40 percent of all photosynthesis on Earth. Although not as diverse as the other two, deep ocean ecosystems contain a wide variety of marine organisms. Such ecosystems exist even at the bottom of the ocean where light is unable to penetrate through the water.

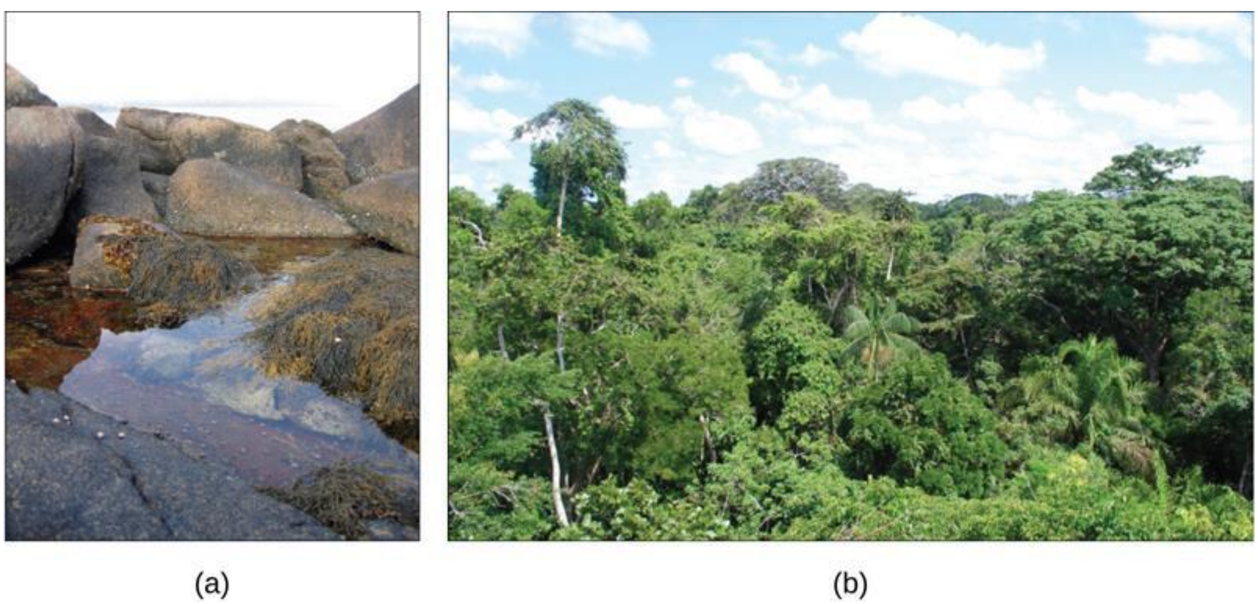

Figure 1.8. (a) A tidal pool ecosystem in Matinicus Island, Maine, is a small ecosystem, while (b) the Amazon rainforest in Brazil is a large ecosystem. (credit a: modification of work by Jim Kuhn; credit b: modification of work by Ivan Mlinaric)

Freshwater ecosystems are the rarest, occurring on only 1.8 percent of the Earth's surface. Lakes, rivers, streams, and springs comprise these systems; they are quite diverse, and they support a variety of fish, amphibians, reptiles, insects, phytoplankton, fungi, and bacteria.

Terrestrial ecosystems, also known for their diversity, are grouped into large categories called **biomes**, such as tropical rainforests, savannas, deserts, coniferous forests, deciduous forests, and tundra. Grouping these ecosystems into just a few biome categories obscures the great diversity of the individual ecosystems within them. For example, there is great variation in desert vegetation: the saguaro cacti and other plant life in the Sonoran Desert, in the United States, are relatively abundant compared to the desolate rocky desert of Boa Vista, an island off the coast of Western Africa.

All living things require energy in one form or another. It is important to understand how organisms acquire energy and how that energy is passed from one organism to another through **food webs**. Food webs illustrate how energy flows directionally through ecosystems, including how efficiently organisms acquire it, use it, and how much remains for use by other organisms of the food web. The flow of energy and matter through the ecosystems influences the abundance and distribution of organisms within them.

Ecosystems are complex with many interacting parts. They are routinely exposed to various disturbances: changes in the environment that affect their compositions, such as yearly variations in rainfall and temperature. Many disturbances are a result of natural processes. For example, when lightning causes a forest fire and destroys part of a forest ecosystem, the ground is eventually populated with grasses, followed by bushes and shrubs, and later mature trees: thus, the forest is restored to its former state. This process is so universal that ecologists have given it a name—**succession**. The impact of environmental disturbances caused by human activities is now as significant as the changes wrought by natural processes. Human agricultural practices, air pollution, acid rain, global deforestation, overfishing, oil spills, and illegal dumping on land and into the ocean all have impacts on ecosystems.

We rely on ecosystem services. Earth's natural systems provide **ecosystem services** required for our survival such as: air and water purification, climate regulation, and plant pollination. We have degraded nature's ability to provide these services by depleting resources, destroying habitats, and generating pollution. The benefits people obtain from ecosystems include: nutrient cycling, soil formation, and **primary production**. Another important service of natural ecosystems is provisioning like food production, production of wood, fibers and fuel.

Ecosystems are responsible for climate regulation, flood regulation together with disease regulation. Finally ecosystems provide cultural and esthetic services. As humans we benefit from observing natural habitats, recreation in waters and mountains. Nature is a source of inspiration for poets and writers. It is a source of aesthetic, religious and other nonmaterial benefits. Studying ecosystem structure in its original state is the only way we can make **anthropogenic** (man-made) systems like agricultural fields, reservoirs, fracking operations, and dammed rivers work for human benefit with minimal impact on our and other organisms' health.

Test your knowledge…

Biological organization: Describe how the image below represents an ecological community. What ecosystem service might the purple corals be performing?

Image source: Microsoft stock image

1.4 Environment and Environmental Science

Viewed from space, Earth (**Figure 1.9**) offers no clues about the diversity of lifeforms that reside there. The first forms of life on Earth are thought to have been microorganisms that existed for billions of years in the ocean before plants and animals appeared. The mammals, birds, and plants so familiar to us are all relatively recent, originating 130 to 200 million years ago. Humans have inhabited this planet for only the last 2.5 million years, and only in the last 200,000 years have humans started looking like we do today. There are around 8.16 billion people alive as of late 2025 (https://www.census.gov/popclock/).

Figure 1.9. This NASA image is a composite of several satellite-based views of Earth. To make the whole- Earth image, NASA scientists combine observations of different parts of the planet. (credit: NASA/GSFC/NOAA/USGS)

The word **environment** describes living and nonliving surroundings relevant to organisms. It incorporates physical, chemical and biological factors and processes that determine the growth and survival of organisms, populations, and communities. All these components fit within the ecosystem concept as a way to organize all of the factors and processes that make up the environment. The ecosystem includes organisms and their environment within a specific area. Review the previous section for in-depth information regarding the Earth's ecosystems. Today, human activities influence all of the Earth's ecosystems.

Environmental science studies all aspects of the environment in an **interdisciplinary** way. This means that it requires the knowledge of various other subjects including biology, chemistry, physics, statistics, microbiology, biochemistry, geology, economics, law, sociology, etc. It is a relatively new field of study that has evolved from integrated use of many disciplines. **Environmental engineering** is one of the fastest growing and most complex disciplines of engineering. Environmental engineers solve problems and design systems using knowledge of environmental concepts and ecology, thereby providing solutions to various environmental problems. **Environmentalism**, in contrast, is a social movement through which citizens are involved in activism to further the protection of environmental landmarks and natural resources. This is not a field of science, but does incorporate some aspects of environmental knowledge to advance conservation and sustainability efforts.

Test your knowledge…

What is the difference between Environmental Science and Environmentalism?.

1.5 The Process of Science

Environmental science is a science, but what exactly is science? **Science** (from the Latin *scientia*, meaning "knowledge") can be defined as all of the fields of study that attempt to comprehend the nature of the universe and all its parts. The **scientific method** is a method of research with defined steps that include experiments and careful observation. 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. A **theory** is a tested and confirmed explanation for observations or phenomena that is supported by many repeated experiences and observations.

1.5.1 The Scientific Method

The scientific process typically starts with an observation (often a problem to be solved) that leads to a question. 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. 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 in 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?*"

1.5.1.1 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."

1.5.1.2 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, or disprove, 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 **independent variable** is the variable that is manipulated throughout the course of the experiment. The **dependent variable**, or response variable is the variable by which we measure change in response to the independent variable. Ideally, all changes that we measure in the dependent variable are because of the manipulations we made to the independent variable. In most experiments, we will maintain one group that has had no experimental change made to it. This is the **control group**. It contains every feature of the **experimental group** except it is not given any manipulation. 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 hypothesis "*The classroom is warm because no one turned on the air conditioning*," 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 1.10**). Using the scientific method, the hypotheses that are inconsistent with experimental data are rejected.

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.

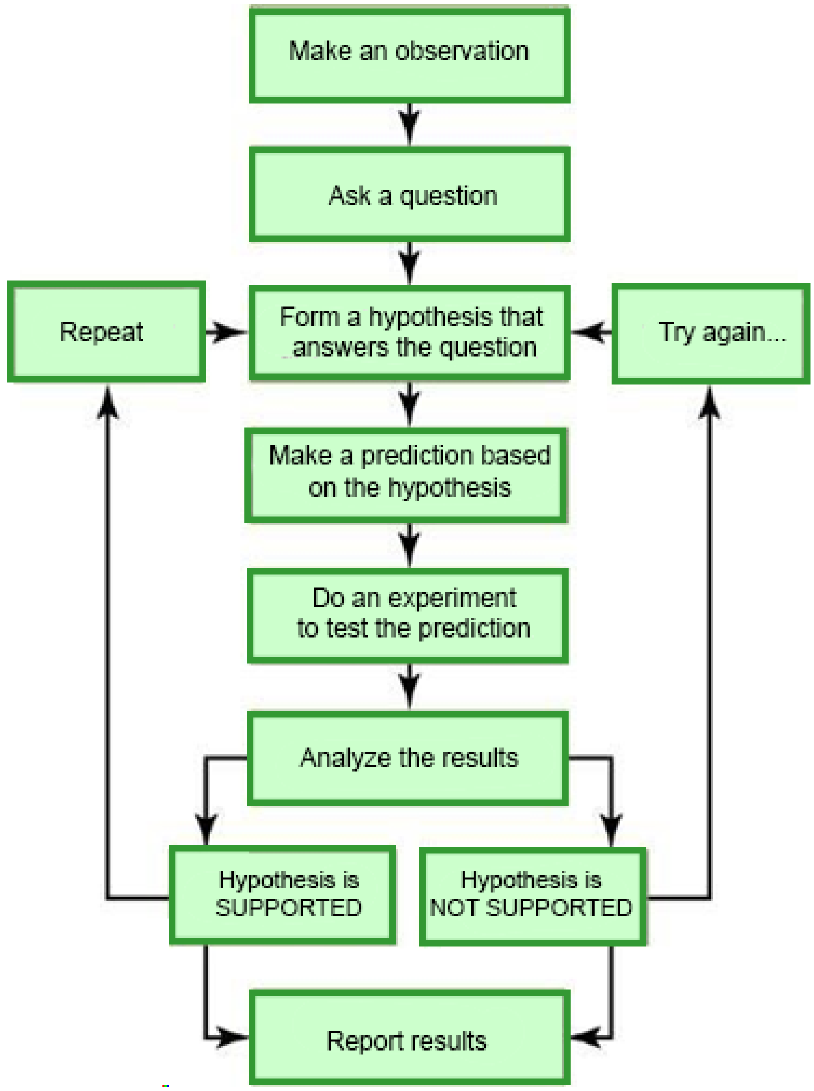

Figure 1.10. The scientific method consists of a series of well-defined steps. If a hypothesis is not supported by experimental data, a new hypothesis can be proposed.

Test your knowledge...

Developing a hypothesis

What is the relationship between a hypothesis and an experiment?

Which of the following hypotheses are testable?

A. *Animals adapt to their environment.*
B. *Mangrove trees are better than saltmarsh grasses.*
C. *Coral reefs will be healthier in warmer water.*

1.6 Sustainability and Sustainable Development

In 1983 the United Nations General Assembly passed a resolution that established the Special Commission on the Environmental Perspective to the Year 2000 and Beyond (https://digitallibrary.un.org/record/153025?ln=en&v=pdf). Their charge was:

a. To propose long-term environmental strategies for achieving sustainable development to the year 2000 and beyond;
b. To recommend ways in which concern for the environment may be translated into greater co-operation among developing countries and between countries at different stages of economic and social development and lead to the achievement of common and mutually supportive objectives which take account of the interrelationships between people, resources, environment and development;
c. To consider ways and means by which the international community can deal more effectively with environmental concerns, in light of the other recommendations in its report;
d. To help define shared perceptions of long-term environmental issues and of the appropriate efforts needed to deal successfully with the problems of protecting and enhancing the environment, a long-term agenda for action during the coming decades, and aspirational goals for the world community, taking into account the relevant resolutions of the session of a special character of the Governing Council in 1982.

Although the report did not technically invent the term **sustainability**, it was the first credible and widely disseminated study that used this term in the context of the global impacts of humans on the environment. Its main and often quoted definition refers to **sustainable development** as *development that meets the needs of the present without compromising the ability of future generations to meet their own needs*. The report uses the terms 'sustainable development', 'sustainable', and 'sustainability' interchangeably, emphasizing the connections among social equity, economic productivity, and environmental quality (**Figure 1.11**). This three- pronged approach to sustainability is now commonly referred to as the **triple bottom-line**.

Preserving the environment for humans today and in the future is a responsibility of every generation and a long-term global goal. Sustainability and the triple bottom-line (meeting environmental, economic, and social goals simultaneously) require that we limit our environmental impact, while promoting economic well-being and social equity.

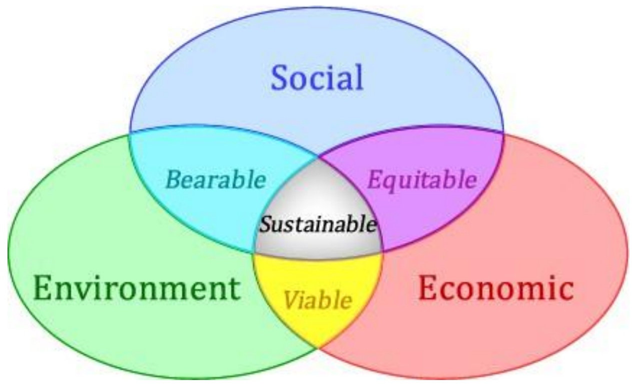

Figure 1.11. A depiction of the sustainability paradigm in terms of its three main components, showing various intersections among them. Source: International Union for the Conservation of Nature.

Examples of sustainable development include sustainable agriculture, which is agriculture that does not deplete soils faster than they form and does not destroy the biodiversity of the area. Sustainable farming and ranching do not reduce the amount of healthy soil, clean water, genetic diversity of crop plants and animals. Maintaining as much ecological **biodiversity** as possible in the agro-ecosystem is essential to long-term crop and livestock production.

In May 2024, The United Nations Environment Programme created a report entitled "Digital Public Infrastructure for Environmental Sustainability" (https://www.unep.org/resources/report/digital-public-infrastructure-environmental-sustainability) in an effort to continue sustainable development by identifying six technology innovations that would aid in information challenges. These innovations include supporting open data discovery, privacy enhancing technologies, and data markets for environmental sustainability information. They also include tools and models to speak with economy policy and environmental sustainability decision making.

Test your knowledge…

Sustainable Development

How does sustainable development differ from measuring development using economic growth?

1.7 The IPAT Equation

As attractive as the concept of sustainability may be as a means of framing our thoughts and goals, its definition is rather broad and difficult to work with when confronted with choices among specific courses of action. One way of measuring progress toward achieving sustainable goals can be with the application of the **IPAT equation**. This equation was designed in an attempt to define the different ways that a variety of factors contribute to the environmental degradation, or impact, of a particular setting. Importantly, IPAT tells us that there are more ways we impact our environment than just through pollution:

$$I = P \times A \times T$$

I represents the impacts on an environment

P is the size of the relevant human population

A is the affluence of the population

T is the technology available to the population

Affluence, or wealth, tells us the level of consumption per person. Wealthy societies consume more goods and services per person. Because of this, their environmental impact is multiplied. Technology, or impact per unit of consumption, interpreted in its broadest sense. This includes any human-created tool, system, or organization designed to enhance efficiency. As societies gain greater access to technology, they are able to do more work with fewer individuals. This equates to a greater impact per person. While this equation is not meant to be mathematically rigorous, it provides a way of organizing information for analysis.

The proportion of people living in cities has greatly increased over the past 50 years. We can use the IPAT equation to estimate the impact of these urban populations. When the impact of technology, which is much easier to access in urban settings, is combined with the impact of population, the impact on the environment is multiplied. In an increasingly urban world, we must focus much of our attention on the environments of cities and on the effects of cities on the rest of the environment. This equation also has large-scale applications in the environmental sciences, and was included in the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (2001) to project future greenhouse gas emissions across the globe (https://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf). The IPCC has continued to meet to provide “regular assessments of the scientific basis of climate change, its impacts, and future risks, and options for adaptation and mitigation” (https://www.ipcc.ch/reports/).

Test your knowledge...

Environmental Impacts

What can the three parts of the IPAT equation tell us about measuring and reducing environmental impacts?

1.8 The Precautionary Principle

The **precautionary principle** or the precautionary approach is one perspective of environmental risk management. The precautionary principle stakes that “When the health of humans and the environment is at stake, it may not be necessary to wait for scientific certainty to take protective action”. In other words, better to be safe than sorry. Proponents of the precautionary principle also believe that the burden of proof should be on the individual, company or government who is proposing the action, not on the people who will be affected by it. For example, if environmental regulations concerning pesticides were based on the precautionary principle (in the United States, they are not), then any pesticide that could potentially harm the environment or human health would not be used. Overuse of the precautionary principle can have negative consequences as well. If federal regulations concerning medicines for human use were based on the precautionary principle (again, in the United States, they are not), then any medicine that could potentially harm any person would not be used. This would effectively ban nearly all medical trials leading to new medications.

1.9 What is the Environment Worth to You?

The environment, and its benefits to individuals or groups, can be viewed and justified from multiple perspectives. A **utilitarian justification** for environmental conservation means that we should protect the environment because doing so provides a direct economic benefit to people. For example, someone might propose not developing Georgia’s coastal salt marshes because the young of many commercial fishes live in salt marshes and the fisheries will collapse without this habitat. An **ecological justification** for environmental conservation means that we should protect the environment because doing so will protect both species that are beneficial to other as well as other species and an ecological justification for conservation acknowledges the many ecosystem services that we derive from healthy ecosystems. For example, we should protect Georgia's coastal salt marshes because salt marshes purify water, salt marshes are vital to the survival of many marine fishes and salt marshes protect our coasts from storm surges. An **aesthetic justification** for conservation acknowledges that many people enjoy the outdoors and do not want to live in a world without wilderness. One could also think of this as recreational, inspirational, or spiritual justification for conservation. For example, salt marshes are beautiful places and I always feel relaxed and calm when I am visiting one, therefore we should protect salt marches. And finally a **moral justification** represents the belief that various aspects of the environment have a right to exist and that it is our moral obligation to allow them to continue or help them persist. Someone who was arguing for conservation using a moral justification would say that it is wrong to destroy the coastal salt marshes.

1.10 Global Perspective

Addressing environmental challenges requires thinking beyond borders. Today, human activities and population growth have impacts that extend across the planet, making collaborative, multilateral solutions essential. As you explore the next seven chapters, remember that environmental, regulatory, and economic conditions vary widely from one region to another. Approaches that work in the United States may not apply elsewhere. Throughout this course, be prepared to examine environmental issues from multiple cultural, geographic, and socioeconomic perspectives, recognizing that diverse viewpoints are key to creating effective and equitable solutions.

End of Chapter Review

1. What is the importance of understanding the structure and bonding of biological molecules?
2. Why is there a need to study the impact of human population growth on the environment?
3. Is sustainable development feasible at a local level near you?
4. What are the consequences of unsustainable vs. sustainable living? What impacts do these have on quality of life do we want for us and future generations?
5. Think of an environmental problem that requires a global perspective for a solution. How might this problem be examined from a variety of environmental justification perspectives?
6. How does environmental science involve science, economics, and politics?
7. A scientist is conducting an experiment examining the impact of increased CO_2 concentrations on plant growth. She grows 20 sunflowers in a greenhouse with elevated CO_2 concentrations and 20 sunflowers in another greenhouse

with ambient (normal) CO_2 concentrations. The plants are watered regularly and fertilized every other week. After 8 weeks, she measures plant height, flower width, and number of seeds. What are the independent and dependent variables in this experiment?

Resources

- Information about the field of environmental science: http://www.environmentalscience.org/
- "Process" of science http://undsci.berkeley.edu/
- United States Census. U.S. and World Population Clock: https://www.census.gov/popclock/
- United Nations General Assembly. Special Commission on the Environmental Perspective to the Year 2000 and Beyond. https://digitallibrary.un.org/record/153025?ln=en&v=pdf
- Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (2001) to project future greenhouse gas emissions across the globe https://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf
- United Nations Environment Programme. 2024. Digital Public Infrastructure for Environmental Sustainability: https://www.unep.org/resources/report/digital-public-infrastructure-environmental-sustainability
- Parts of this chapter have been modified from the OpenStax textbooks.
- OpenStax Biology 2nd Edition, Biology 2e. OpenStax CNX. Nov 26, 2018 http://cnx.org/contents/8d50a0af-948b-4204-a71d-4826cba765b8@15.1.
- OpenStax, Concepts of Biology. OpenStax CNX. Nov 26, 2018 http://cnx.org/contents/b3c1e1d2-839c- 42b0-a314-e119a8aafbdd@14.1.

Terms

Adenosine triphosphate
Aesthetic justification
Amino acid
Anthropogenic
Atom ATP
Biome
Biosphere
Carbohydrate
Cellular respiration
Community
Competition
Control group
Denature
Deoxyribonucleic acid (DNA)
Ecological justification
Ecosystem
Ecosystem service
Electron
Element
Environment

Environmental engineering
Environmental science
Environmentalism
Experiment
Experimental group
Food web
Glucose
Hydrocarbon
Hypothesis
Independent variable
Interdisciplinary
Ion
IPAT equation
Isotope
Lipid
Matter
Molecule
Moral justification
Neutron
Nucleic acid
Nucleus
Organelle
Organic molecule
Organism
Population
Precautionary principle
Primary production
Protein
Proton
Radioisotope
Ribonucleic acid (RNA)
Science
Scientific method
Starch
Succession
Sustainability
Sustainable development
Theory
Triple bottom-line
Utilitarian justification
Variable