MODULE 1: WHAT IS BIODIVERSITY?

COURSE 1: Fundamentals of Ecology
COURSE 2: Fundamentals of Biodiversity

<u>Learning Objectives</u>

Students will be able to:

- Explain basic ecological concepts and how they relate to biodiversity.
- Explain the fundamentals of biodiversity, its measures, and the major threats to biodiversity globally and in Liberia.

<u>Key Topics</u>

Course 1: Fundamentals of Ecology

- o Definitions and Applications
- o Ecosystem Concepts
- o Energy Flows and Materials Cycling
- o Population Ecology

- o Definitions and Applications

Ecology is the scientific study of the factors that govern the distribution and abundance of organisms, the interaction among organisms, and the interactions between organisms and their abiotic environment. Ecologists try to understand the processes and patterns of natural ecosystems and the species they contain.

- o Ecosystem Concepts
    - Species, habitats, ecosystems

Species refers to the largest group of similar organisms that are capable of mating and producing fertile offspring. Smaller groups of similar organisms that meet the same criteria may be referred to as **populations**, or sub-populations.

Habitats are the place or type of site where an organism or a population naturally occurs.

An **ecosystem** consists of the biological community that occurs in some locale, and the physical and chemical factors that make up its non-living or abiotic environment. An ecosystem can exist at any scale, from the size of a small tide pool up to the size of the entire biosphere. There are many examples of ecosystems -- a pond, a forest, an estuary, a grassland. Usually the boundaries of an ecosystem are chosen for practical reasons having to do with the goals of the particular study.

Ecosystems may be classified according to the dominant type of environment, or the dominant type of species present; for example, a freshwater marsh ecosystem, a tropical forest ecosystem, a mangrove swamp ecosystem. Because temperature is an important aspect in shaping ecosystem diversity, it is also used in ecosystem classification (e.g., cold winter deserts versus warm deserts). While the physical characteristics of an area will significantly influence the diversity of the species within a community, the organisms can also modify the physical characteristics of the ecosystem. For example, trees can modify the microclimate and the structure and chemical composition of the soil around them.

Biotic describes a living component of an ecosystem; for example, organisms such as plants and animals. A term describing all living things — autotrophs and heterotrophs — plants, animals, fungi, bacteria. **Biotic factors** include plants, animals, fungi, algae, and bacteria. Specific biotic categories include:

Plants: Most ecosystems depend on plants to perform photosynthesis, making food from water and carbon dioxide in the ecosystem. In ponds, lakes and the ocean, many of the plants are grasses, algae or tiny phytoplankton floating on or near the surface.

Animals: First-order consumers like mice, rabbits and seed-eating birds as well as zooplankton, snails, mussels, sea urchins, ducks and black sharks eat the plants and algae. Predators like coyotes, bobcats, bears, killer whales and tiger sharks eat first-order consumers. Omnivores like bears and rotifers (nearly microscopic aquatic animals) eat both plants and animals.

Fungi: Fungi like mushrooms and slime molds feed off the bodies of living hosts or break down the remains of once-living organisms. Fungi serve an important role in the ecosystem as **decomposers**.

Scavengers are animals that consume dead organisms that have died from causes other than predation. Scavengers aid in overcoming fluctuations of food resources in the environment. The process and rate of scavenging is affected by both biotic and abiotic factors, such as carcass size, habitat, temperature, and seasons. Examples of **scavenger** animals include: Vultures – a type of bird that eats decaying flesh. Carrion beetle – the term for one of many beetles that can eat flesh or even bat droppings. Blowflies – insects that digest the dead flesh around animals' wounds.

Abiotic factors include sunlight, temperature, moisture, wind or water currents, soil type, and nutrient availability. The abiotic factors in an ecosystem include all the nonliving elements of the ecosystem. Air, soil or substrate, water, light, salinity and temperature all impact the living elements of an ecosystem. Specific abiotic factor examples and how they may affect the biotic portions of the ecosystem include:

Air: In a terrestrial environment, air surrounds the biotic factors; in an aquatic environment, the biotic factors are surrounded by water. Changes in the chemical composition of the air, like air pollution from cars or factories, impacts everything that breathes the air. Some organisms are more sensitive to changes in the air. For aquatic organisms, both the chemical composition of the air and water but also the quantity of air and water impact anything living in the water. For example, when algal blooms become excessive, the algae reduce the oxygen in the water, and many fish suffocate.

Soil or Substrate: Most plants need soil for nutrients and to hold themselves in place with their roots. Plants in areas with nutrient-poor soils often have adaptations to compensate, like the insect-capturing Cobra Lily and Venus Fly-trap. Soil or substrate also impact animals, such as the filter-feeding nudibranchs whose gills would be clogged if the substrate suddenly included fine particles of sand and silt.

Water: Water is essential for life on Earth. Water is essential to the chemical reactions within living organisms, is one of the key components for photosynthesis and is the placeholder in cells. Water also serves as a living environment for aquatic creatures. As such, changes in quantity and quality of water impact living systems.

Light: Lack of light in the deeper ocean prevents photosynthesis, meaning that the majority of life in the ocean lives near the surface. Differences in daylight hours impact temperatures at the equator and the poles. The day-night rhythm of light impacts life patterns, including reproduction, for many plants and animals.

Salinity: The Dead Sea and Great Salt Lake are two examples of environments where salinity has reached levels that challenge most living organisms.

Temperature: Most organisms require a relatively stable temperature range. Temperature changes, especially extreme and sudden changes, that go beyond an organism's tolerance will harm or kill the organism. Temperature changes can be natural or seasonal cycles or the result of anthropogenic climate change.

Components of an Ecosystem*

Abiotic Components	**Biotic Components**
Sunlight	Primary producers
Temperature	Herbivores
Precipitation	Carnivores
Water or moisture	Omnivores
Soil or water chemistry	Detritivores

*All of these vary over space/time

Broadly speaking, **ecosystem diversity** is dependent on the physical characteristics of the environment, the diversity of species present, and the interactions that the species have with each other and with the environment. Therefore, the functional complexity of an ecosystem can be expected to increase with the number of species present and the complexity of the physical environment.

The physical characteristics that affect **ecosystem diversity** include the temperature, precipitation, and topography. There is a general trend for warm tropical ecosystems to be richer in species than cold temperate ecosystems. Also, the energy flux in the environment can significantly affect the ecosystem. An exposed coastline with high wave energy will have a considerably different type of ecosystem than a low-energy environment such as a sheltered salt marsh. Similarly, an exposed hilltop or mountainside is likely to have stunted vegetation and low species diversity compared to more prolific vegetation and high species diversity in sheltered valleys.

A **landscape** is a mosaic of diverse land forms, vegetation types, and land uses. Although there is no standard definition of the size of a landscape they are usually in the hundreds or thousands of square kilometers. Species composition and population viability are often affected by the structure of the landscape, such as the size, shape, and connectivity of individual patches of ecosystems within the landscape. In order to ensure the survival of species that range widely across different ecosystems conservation management should be directed at whole landscapes. Diversity within and between landscapes depends on local and regional variations in environmental conditions, as well as the species supported by those environments.

- Phenology

Phenology is the study of biological life-cycles throughout the year. Examples of phenological events include egg-laying and migration in birds, flowering and fruiting in plants, insect emergence, and the migratory and reproductive periods of mammals, birds, fish, and amphibians. Plants and animals don't have calendars or watches, but many of them take cues from the changing seasons. Changes in weather with the seasons, such as temperature and precipitation, signal many organisms to enter new phases of their lives. Seasonal changes can include variations in day length, temperature, and rain or snowfall. Seasonal and climatic changes are some of the non-living or abiotic components of the environment that impact the living or biotic components.

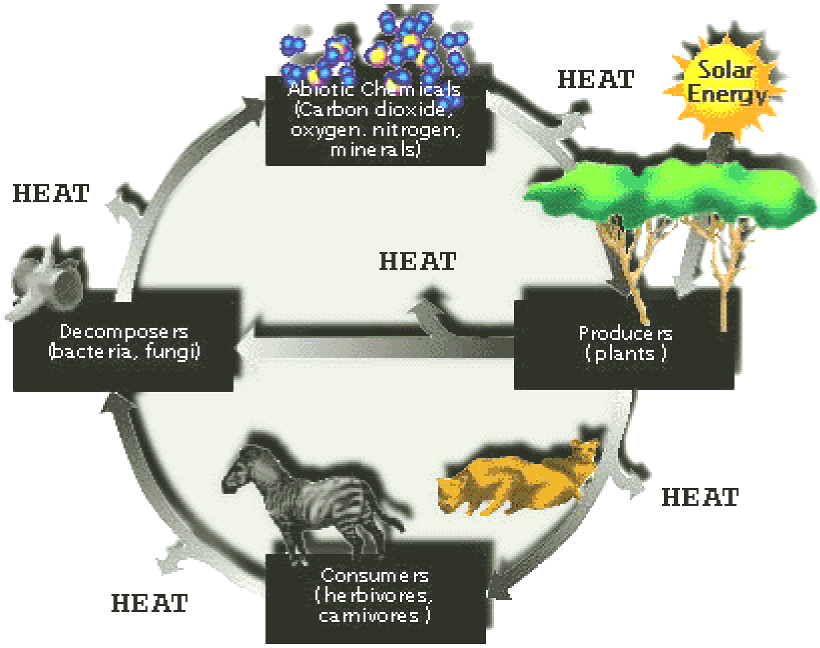
How plants react to seasonal change has a big impact on the natural environment because plants are at the base of the food chain: anything that affects plants can impact other parts of the ecosystem. Phenology is important because it affects whether plants and animals thrive or survive in their environments. Our food supply depends on the timing of phenological events. And, to scientists, changes in the timing of phenological events can be used an as indicator of changing climates. Climate change can thus be expected to have an impact on phenology.

- Niche

The **ecological niche**, a central concept in ecology, refers to a particular way of obtaining shelter and energy within an ecosystem. Each plant or animal in an ecosystem fills an ecological niche, and different organisms compete for dominance in their preferred ecological niche. In a forest ecosystem, there may be a niche that can be filled by one or more kinds of warm-blooded, insect-eating, nocturnal animals—bats, for example. Mushrooms growing in shaded wooded areas may fill another niche.

- Food chains and food webs
    - Primary production
    - Trophic Interactions: Energy input, flows, and storage in ecosystems
    - Nutrient cycles

There are two critical ideas about how ecosystems function: ecosystems have energy flows and ecosystems cycle materials. These two processes are linked, but they are not the same (see Figure).



Energy flows and material cycles

Energy enters the biological system as light energy, or photons, is transformed into chemical energy in organic molecules by cellular processes including photosynthesis and respiration, and ultimately is converted to heat energy.

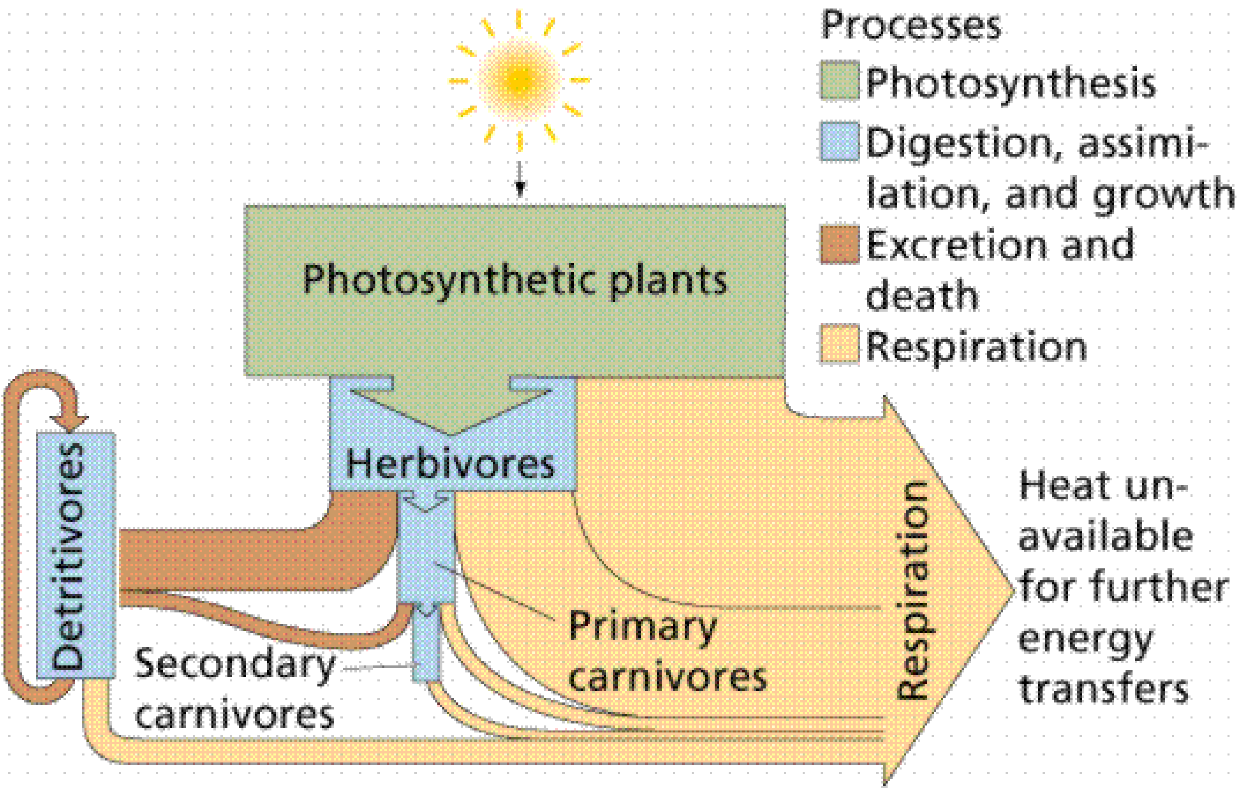
Elements such as carbon, nitrogen, or phosphorus enter living organisms in a variety of ways. Plants obtain elements from the surrounding atmosphere, water, or soils. Animals may also obtain elements directly from the physical environment, but usually they obtain these mainly as a consequence of consuming other organisms. These materials are transformed biochemically within the bodies of organisms, but sooner or later, due to excretion or decomposition, they are returned to an inorganic state (that is, inorganic material such as carbon, nitrogen, and phosphorus, instead of those elements being bound up in organic matter). Often bacteria complete this process, through the process called decomposition or mineralization. The elements are cycled endlessly between their biotic and abiotic states within ecosystems. Those elements whose supply tends to limit biological activity are called **nutrients**.

<u>The Transformation of Energy</u>

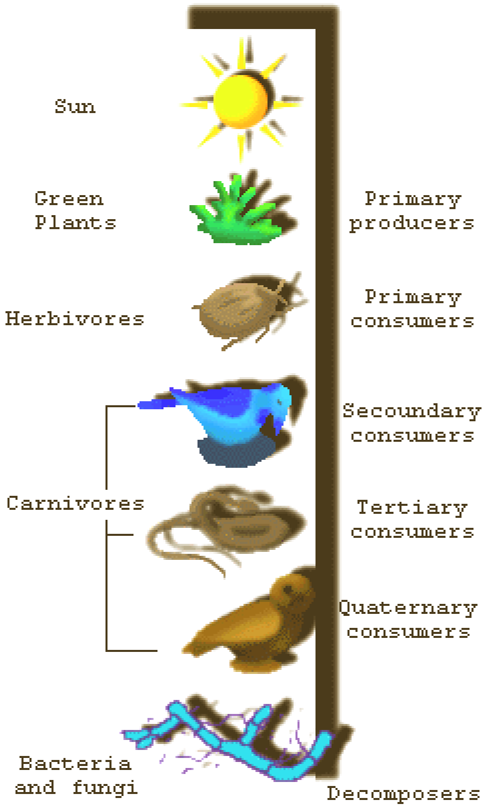
The transformations of energy in an ecosystem begin first with the input of energy from the sun. Energy from the sun is captured by the process of photosynthesis. Virtually all energy available to organisms originates in plants. Because it is the first step in the production of energy for living things, it is called **primary production**. **Herbivores** obtain their energy by consuming plants or plant products, **carnivores** eat herbivores, and **detritivores** consume the droppings and carcasses of us all.

The flow of energy between trophic levels is an important unifying characteristic of all ecosystems. The first trophic level of photosynthetic plants, which use only the Sun's energy, provides energy for herbivores in the second trophic level. Herbivores, in turn, pass some of their energy to carnivores of the third trophic level and so on. Decomposers, including bacteria and fungi, obtain energy from all other trophic levels. In each energy transfer from one trophic level to another, most of the available energy cannot be recovered in a useful form; it eventually radiates into space as waste heat. In fact, only about 10% of the energy available at one trophic level normally finds its way to the next. Thus, as energy flows through an ecosystem, it must be replaced continuously.

Trophic Interactions: The Flow of Energy through an Ecosystem



Food chains indicate who eats whom in an ecosystem. Represent one path of energy flow through an ecosystem. Natural ecosystems have numerous interconnected food chains. Each level of producer and consumers is a trophic level. Some primary consumers feed on plants and make grazing food chains; others feed on detritus.



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

PRACTICUM: TROPHIC LEVELS & ENERGY FLOWS

The concept of food chains is too simple, as in reality the organization of biological systems is much more complicated than can be represented by a simple "chain". Food chains are simplifications of complex relationships. A food web is a more realistic and accurate depiction of energy flow. Food webs are networks of feeding interactions among species. There are many food links and chains in an ecosystem, and we refer to all of these linkages as a **food web**. Food webs can be very complicated and it is important to understand what are the most important linkages in any particular food web.

Food webs are graphical depictions of the interconnections among species based on energy flow. Energy enters this biological web of life through the photosynthetic fixation of carbon by green plants. Many food webs also gain energy inputs through the decomposition of organic matter, such as decomposing leaves on the forest floor, aided by microbes.

- Population Ecology
  - Size, density, distribution, range, abundance

The term **population** is used in many different contexts, often with conflicting meanings. Generally speaking, a population is considered to be all the individuals of a species in a particular area. The area can be defined based on biological, geographical, or political criteria, each leading to different concepts of what a population is. A biologically defined **population** is one defined by how the organisms organize themselves in the landscape. An example might be: "the pygmy hippos living in Cestos-Senkwehn Rivershed Forests of Southeastern Liberia."

Geographical or political definitions of populations are also common. These are generally associated with administrative units imposed by humans. Occasionally, conflicts can arise between biological definitions and geographical or political ones.

Population size is the actual number of individuals in a population. **Population density** is a measurement of population size per unit area, i.e., population size divided by total land area. Population density may change as a result of natural or human induced factors.

The **population size** in an undisturbed ecosystem is limited by the food supply, competition, predation, and parasitism. Food webs help determine consequences of perturbations: if titmice and vireos fed on beetles and earthworms, insecticides that killed beetles would increase competition between birds and probably increase predation of earthworms, etc.

Distribution refers to the spatial arrangement or pattern of a species within an area where they are found. Chimpanzees, for example, are widely distributed and live in a wide variety of habitats, from humid evergreen forests, through mosaic woodlands and deciduous forest, to dry savanna woodlands. Distribution should not be confused with dispersal, which can be defined as the movement of individuals away from an existing population or parent.

Range is the area contained within the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred or projected sites of occurrence, excluding cases of vagrancy and introductions outside its natural range.

Abundance refers to the relative representation of a species in a particular ecosystem. For example, sometimes, due to financial, logistical, or time constraints, ape surveys can only deliver abundance indices such as nest-group encounter rate, instead of total population size estimates. Abundance estimates are obtained by sampling a subset of the population of interest.

  - Species Interactions: Competition, Predation, Commensalism, Mutualism

Species interactions within ecological webs include four main types of two-way interactions: **mutualism**, **commensalism**, **competition**, and **predation** (which includes herbivory and parasitism).

In **competition**, individuals seek to obtain the same environmental resource. **Predation** includes any interaction between two species in which one species benefits by obtaining resources from and to the detriment of the other. One can conceptualize **competition** as occurring horizontally on the same resource level, while predation takes place vertically between different resource levels. Because the use of a limited resource by one species decreases availability to the other, **competition** lowers the fitness of both. The coexistence of populations under competition and predation indicates that these populations have accommodated themselves to each other's presence and have evolved ways to survive in spite of the pressures. In other words, they have coevolved.

Mutualism describes an interaction that benefits both species. Pollination is a common mutualistic interaction. A well-known example exists in the mutualistic relationship between alga and fungus that form lichens. The photsynthesizing alga supplies the fungus with nutrients, and gains protection in return. The relationship also allows lichen to colonize habitats inhospitable to either organism alone. Commensalism occurs when one species benefits, and the other species is neither benefited nor harmed.

- Population dynamics: Growth, natural regulation, and carrying capacity

A **population** is a group of individuals of the same species that share aspects of their genetics more closely with each other than with other groups of individuals of that species. The geographic **range** and **distribution** of populations (i.e., their spatial structure) represent key factors in analyzing population diversity because they give an indication of the likelihood of movement of organisms between populations, and consequent genetic and demographic interchange. Similarly, an estimate of the overall population size provides a measure of the potential genetic diversity within the population; large populations usually represent larger gene pools and hence greater potential diversity.

Individual organisms living in distinct population groups may periodically disperse from one population to another, facilitating genetic exchange between the populations. This group of different but interlinked populations, with each different population located in its own, discrete patch of habitat, is called a **metapopulation**. Understanding how the patches and their constituent populations are arranged within the metapopulation, and the ease with which individuals are able to move among them, is key to describing the population diversity and conserving the species.

Populations are the biological units upon which most conservation and management is focused. If a species is endangered, a common goal is to increase the size and range of its populations. If a species is invasive, we may seek to reduce the size and distribution of its populations. If a species is harvested, simply maintaining population size and distribution over a long period may be desired. Population concerns are thus pervasive in the field of conservation biology.

Demography is a term for analyzing and understanding the dynamics of populations. The study of demography consists of the statistical characteristics of a **population** such as size, density, birth and death rates, distribution, and movement or migration. Demographic analysis can useful for identifying the forces limiting the recovery of an endangered species or identifying the thresholds at which a population can be harvested in a sustainable fashion. It can also be useful for understanding the key processes within populations (e.g., *mortality* versus birth or migration) that regulate their growth.

Population dynamics are the changes in a population over time. These changes might be in total numbers, numbers of young, sex ratios, or other parameters. Only by understanding what makes a population rise and fall over time can one be successful at influencing such dynamics. Population dynamics result from changes in the number and composition of individuals in a population. Such changes can be accounted for by five basic components: births, deaths, sex ratio, age structure, and dispersal.

Births and deaths are obvious factors and their relative balance determines whether a population increases (births outweigh deaths) or decreases (deaths outweigh births) over time. Often the challenge of rescuing an endangered species amounts to trying to bring birth rates back into balance with death rates. Harvest management provides another example as it typically concerns striking a balance between how many individuals can be removed from a population (deaths) for human consumption versus how many can be replaced by the population (births) through internal recruitment. Successfully balancing removals with recruitment leads to long-term harvest sustainability.

Population trend refers to changes over time and can include changes in ranging behavior (e.g., distance and route) and distribution, biogeography (e.g., size of population) and life-history (e.g., birth and death rates). For instance, Khuel et al. (2017) collected data on West African chimpanzee (*Pan troglodytes verus*) populations based on ape- and bio-monitoring programs across several countries, including Taï National Park, Côte d'Ivoire, and Sapo National Park, Liberia, to determine that chimpanzee population have been drastically reduced. These results prompted the uplisting of the chimpanzee from Endangered to Critically Endangered on the IUCN RedList. Declines in these populations have been attributed to an increase in human population growth associated with greater poaching pressure and a higher deforestation rate, and was exacerbated by civil war.

Conservation and management of endangered species in the wild not only requires understanding distribution and population size at a fixed point in time, but also how these patterns are changing over time in response to both natural and human induced influences. Species-level range changes are underpinned by local-level changes in abundance. Spatial variation in population trends across species ranges can potentially affect how species respond to global changes.

Birth and death rates change in populations for many reasons. Some changes are caused by forces imposed externally by the environment (e.g., the effects of weather and predators). Populations often also regulate themselves internally through the influences of one individual on another (e.g., the effects of crowding and competition). Thus, a very important question is whether birth and death rates are related in some fashion to the number of individuals in a population.

To put it another way: are the factors causing the population to change **density-dependent** or **density-independent**? **Density** refers to the number of individuals per unit area (for example, per m^2, per acre or hectare, or per square kilometer or square mile). We need to make this distinction because the relative importance of density-dependent versus density-independent factors has implications for how we can best manage a population.

Let's look in more detail first at **density-dependent factors**. As the number of individuals in a population increases, the amount of resources available for each individual potentially decreases, and the health of individuals decreases correspondingly. Reproductive output is highly dependent on an individual's health. Most organisms first try to survive and, if they are successful and have resources to do so, then attempt to reproduce. In a density-dependent situation, as health declines due to crowding, mortality may increase and reproduction decrease. The specific mechanisms through which density-dependence factors regulate populations include parasites, starvation, predation, and disease.

In contrast, **density-independent factors** act on a population regardless of its size. Consider the effects of a drought. Whether there are 10, 100, or 1 million fish in a pond, if drought strikes and the pond dries up, all die. Other environmental catastrophes work in a similar fashion, be they volcanic eruptions, fires, floods, or landslides. Weather-related mortality is a particularly common form of density-independent mortality.

POPULATION DYNAMICS

- **Population ecology** is the study of populations in relation to their environment, including environmental influences on density and distribution, age structure, and population size

- **Density** is the number of individuals per unit area or volume.

- **Dispersion** is the pattern of spacing among individuals within the boundaries of the population.

- In most cases, it is impractical or impossible to count all individuals in a population. **Sampling techniques** can be used to estimate **population size** and **population densities**.

- **Population size** can be estimated from small samples, an index of population size (e.g., number of nests), or the mark-recapture method.

- Wildlife populations are not static: they fluctuate due to four processes: **births**, **deaths**, **emigration**, and **immigration**.

- **Death rates** and **birth rates** are of particular interest to wildlife biologists.

- **Immigration** is the influx of new individuals from other areas.

- **Emigration** is the movement of individuals out of a population.

- A **life table** is an age-specific summary of the survival pattern of a population. Life tables reveal important aspects about wildlife populations, e.g., the proportions of males and females.

- An organism's **life history** comprises the traits that affect its schedule of reproduction and survival. Life history traits are products of natural selection. The age at which reproduction begins
    - How often the organism reproduces
    - How many offspring are produced during each reproductive cycle

- A **survivorship curve** is a graphic way of representing the data in a life table.
- Survivorship curves can be classified into three general types:
    1. low death rates during early and middle life and an increase in death rates among older age groups

2. a constant death rate over the organism's life span
3. high death rates for the young and a lower death rate for survivors.

- A **reproductive table** is an age-specific summary of the reproductive rates in a population.

Population Change and Population Density

- *K*-selection, or density-dependent selection, selects for life history traits that are sensitive to population density
- *r*-selection, or density-independent selection, selects for life history traits that maximize reproduction
- The concepts of *K*-selection and *r*-selection are oversimplifications but help us to understand and assess life history of wildlife species.
- The **exponential model** describes population growth in an idealized, unlimited environment. Exponential growth cannot be sustained for long in any population
- The **logistic model** describes how a population grows more slowly as it nears its carrying capacity. Many factors that regulate population growth are density dependent.
- A more realistic population model limits growth by incorporating **carrying capacity**. **Carrying capacity** (*K*) is the maximum population size the environment can support. **Carrying capacity** varies with the abundance of limiting factors (resources).

Class Exercise

In small groups, list some wildlife species in Liberia that are examples of K-selection and r-selection

There are two general questions about regulation of population growth:

- What environmental factors stop a population from growing indefinitely?
- Why do some populations show radical fluctuations in size over time, while others remain stable?

Other aspects of populations can have important effects on their **population dynamics**. Consider sex ratios in a population. Imagine two populations of the same number of individuals. One has few males and many females. The other has few females and many males. Which population is likely to have a higher growth rate or ability to compensate for harvest? It's hard to say exactly, but generally speaking males can find and fertilize many females, with the number of females being more of a factor limiting population growth than the number of males.

Age structure is another factor that can occasionally limit population growth. Age structure refers to the composition of young versus older individuals in a population. For many animals, development patterns are fairly continuous and breeding begins at a particular age. For example, many short-lived plants and animals reach sexual maturity in their first year and rarely deviate from this fixed pattern. More long-lived species often delay maturation for many years (consider trees or elephants), investing in growth rather than reproduction early in life, and such a population may be composed mostly of non-breeding juveniles. Similarly, if individuals are able to live long enough, they may undergo senescence and cease breeding at a certain age. Thus, age and reproductive status are closely linked. This is important because the number of potential breeders in a population is key to its persistence and effective management. The total number of individuals, which may include many non-breeders, can be very misleading about a population's status.

For many other species reproduction is more a function of *size* than *age*. Many plants have to achieve a threshold size regardless of their age before they can reproduce. For such species, a concept analogous to age structure is size or stage structure. This refers to the composition of immature versus reproductive individuals in a population and relates to the array of sizes of individuals present. For example, a rainforest tree germinates in the dark understory of a forest. If it gets lucky and there is a treefall nearby, it may have the opportunity to grow rapidly in its first few years and shoot up into the canopy where it matures and starts to flower and generate fruits. If it is unlucky, it can remain small and essentially undergo no growth for decades before it dies or before some event transpires to provide it with ample light to grow into a reproductively mature individual. The point is that in such species, size, not age, is the key reproductive attribute of individuals.

Age and stage structure can be important factors influencing population growth. Consider a large population of mature cacti that have been alive for many decades and that carpet a desert basin. The population has all the appearances of being healthy. However, closer inspection might reveal a complete absence of young cacti caused by invasion of the area by an introduced mammal that consumes all fruits dropped. For many decades, the only indication of a problem would be the imbalanced size structure, which would not be evident merely through counts of the more obvious adults. The same situation also applies to animal populations, especially long-lived species such as whales, elephants, or turtles. Such animals may have adults in abundance in particular populations yet few juveniles present. Such an imbalanced age structure is of concern over the long-term and is not obvious without close inspection of age- or size structure within the population.

Population Growth: There are four variables which govern changes in population size.

- births
- deaths
- immigration
- emigration

A population gains individuals by birth and immigration and loses individuals by death and emigration. Populations vary in their capacity to grow. The maximum rate at which a population can increase when resources are unlimited and environmental conditions are ideal is termed the population's biotic potential. Each species will have a different biotic potential due to variations in the species' **reproductive span** (how long an individual is capable of reproducing); the **frequency of reproduction** (how often an individual can reproduce); "**litter size**" (how many offspring are born each time); **survival rate** (how many offspring survive to reproductive age).

Natural Regulation refers to the fact that there are always limits to population growth in nature. Populations cannot grow exponentially indefinitely. Exploding populations always reach a size limit imposed by the shortage of one or more factors such as water, space, and nutrients or by adverse conditions such as disease, drought and temperature extremes. The factors which act jointly to limit a population's growth are termed the environmental resistance. The interplay of biotic potential and density-dependent environmental resistance keeps a population in balance.

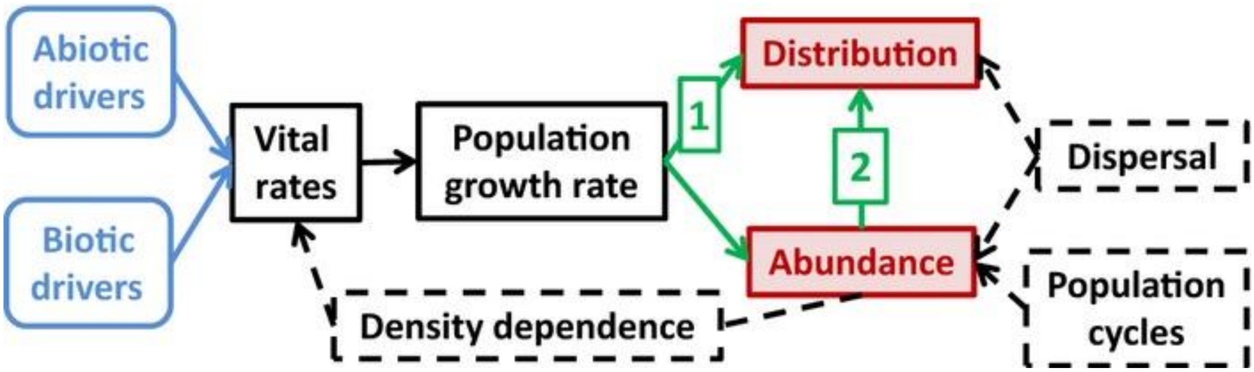
Carrying capacity refers to the number of individuals who can be supported in a given area within natural resource limits, and without degrading the natural social, cultural and economic environment for present and future generations. The carrying capacity for any given area is not fixed. It can be altered by improved technology, but mostly it is changed for the worse by pressures which accompany a population increase.

For populations which grow exponentially, growth starts out slowly, enters a rapid growth phase and then levels off when the carrying capacity for that species has been reached. The size of the population then fluctuates slightly above or below the carrying capacity. Reproductive lag time may cause the population to overshoot the carrying capacity temporarily. Reproductive lag time is the time required for the birth rate to decline and the death rate to increase in response to resource limits. In this scenario, the population will suffer a crash or dieback to a lower level near the carrying capacity unless a large number of individuals can emigrate to an area with more favorable conditions. An area's carrying capacity is not static. The carrying capacity may be lowered by resource destruction and degradation during an overshoot period or extended through technological and social changes.

Change in population size over time is known as **population growth**. Population growth is in many ways the most important concern of population managers. There are either too few individuals, as in the case of endangered or overharvested species, or too many individuals, as in the case of invasive species. Therefore, what we often seek is a level of population growth that will yield adequate numbers of individuals to permit species persistence and, in cases of economically valuable species, to permit sustained human use of the species.

By studying growth of a population as it responds to changes in habitat, weather, or harvest, we then can begin to understand what factors limit populations and manage them accordingly. A useful starting point for understanding population growth is the concept of **exponential population growth**. Exponential growth occurs when a population faces no resource limitations (unlimited food, shelter, etc.) and can grow at its maximum biological potential (limited only by birth rates). Although rare, exponential population growth does occur in nature. A population may take off for example, when an invasive species first enters an area where it has no competition, or following a catastrophic mortality event (such as a severe winter or drought) and the few surviving individuals can enjoy unfettered reproduction for a period of time. Notably, human population growth follows patterns of exponential growth although it is beginning to show indications of environmental limitation.

Exponential population growth models are not particularly useful because limitations on resources or space almost always influence population growth. Eventually competition for breeding sites, water, food, light, nutrients, or cover begin to reduce birth rates below what is biologically possible, particularly at high population densities. In fact, most environments have a **carrying capacity,** which is the maximum number of individuals that the resources available within a particular area can support.



- Population fragmentation

Population fragmentation occurs when groups of animals living in the wild become separated from other groups of the same species. Population fragmentation is often caused by habitat fragmentation, which as the name implies describes the emergence of discontinuous habitat (fragmentation) in the environment. Habitat and population fragmentation can be caused by natural processes or by human activity such as land conversion. The extent to which habitat fragmentation leads to population fragmentation, however, differs among landscapes and taxa. To detect fragmentation, it is necessary to undertake regular or periodic surveys to detect change.

One fundamental concern in biodiversity conservation is that population fragmentation might seriously compromise the long-term survival of many wild species. The fragmentation of a population may have important consequences for population genetic diversity and structure due to the effects of genetic drift and reduced gene flow. This decreases the fitness of the population for several reasons. First, inbreeding forces competition with relatives which decreases the evolutionary fitness of the species. Secondly, the decrease in genetic variability causes an increased possibility that a lethal homozygous recessive trait may be expressed; this decreases reproduction rates, indirectly decreasing the population. The intensity of these processes will vary among the resulting fragments depending on their effective population sizes and their immigration rate from other fragments.

One solution to the problem of population and habitat fragmentation is to link the fragments by preserving or planting corridors of native vegetation. This has the potential to mitigate the problem of isolation (but not any loss of interior habitat) and facilitate migration and transfer between populations. Information on population fragmentation can provide vital information to support and help design conservation management strategies and plans.

PRACTICUM: SPECIES INTERACTIONS

MODULE 1: WHAT IS BIODIVERSITY?
COURSE 2: Fundamentals of Biodiversity

- Definitions and Applications of Biodiversity
- Threatened species and habitats
  - IUCN Red List
  - Threatened species in Liberia
- Why conserve biodiversity?
  - Utilitarian values (goods & services)
  - Intrinsic values

Key Topics

- Definitions and Applications of Biodiversity

READING: Harrison et al (2006) "What is Biodiversity"

Biodiversity can be defined as *the sum total of all of the plants, animals, fungi, and microorganisms on Earth; their genetic and phenotypic variation; and the communities and ecosystems of which they are a part.*

Biodiversity is the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems. **Biodiversity** is the variety of life on Earth at all its levels, from genes to ecosystems, and the ecological and evolutionary processes that sustain it.

In popular usage, the word "biodiversity" is often used to describe all the species living in a particular area. If we consider this area at its largest scale – the entire world – then biodiversity can be summarized as "life on earth." However, scientists use a broader definition of biodiversity, designed to include not only living organisms and their complex interactions, but also interactions with the abiotic (non-living) aspects of their environment. The diversity of species, ecosystems, and landscapes that surround us today are the product of perhaps 3.7 billion (i.e., 3.7×10^9) to 3.85 billion years of evolution of life on Earth.

- Evolution

The theory of **evolution** is one of the great intellectual revolutions of human history, drastically changing our perception of the world and of our place in it. Charles Darwin put forth a coherent theory of evolution and amassed a great body of evidence in support of this theory. The basic idea of biological evolution is that populations and species of organisms change over time.

The theory of evolution entails the following fundamental ideas:

> *Species (populations of interbreeding organisms) change over time and space*. The representatives of species living today differ from those that lived in the recent past, and populations in different geographic regions today differ slightly in form or behavior. These differences extend into the fossil record, which provides ample support for this claim.
>
> *All organisms share common ancestors with other organisms*. Over time, populations may divide into different species, which share a common ancestral population. Far enough back in

time, any pair of organisms shares a common ancestor. For example, humans shared a common ancestor with chimpanzees about eight million years ago, with whales about 60 million years ago, and with kangaroos over 100 million years ago. Shared ancestry explains the similarities of organisms that are classified together: their similarities reflect the inheritance of traits from a common ancestor.

Evolutionary change can be gradual and slow or rapid.

- Natural selection

Natural selection is one of the basic mechanisms of evolution, along with mutation, migration, and genetic drift. Darwin's grand idea of evolution by natural selection is relatively simple but often misunderstood. Because resources are limited in nature, organisms with heritable traits that favor survival and reproduction will tend to leave more offspring than their peers, causing the traits to increase in frequency over generations. Natural selection causes populations to become adapted, or increasingly well-suited, to their environments over time. Natural selection depends on the environment and requires existing heritable variation in a group.

Darwin's process of **natural selection** has four components.

Variation. Organisms (within populations) exhibit individual variation in appearance and behavior. These variations may involve body size, hair color, facial markings, voice properties, or number of offspring. On the other hand, some traits show little to no variation among individuals—for example, number of eyes in vertebrates.

Inheritance. Some traits are consistently passed on from parent to offspring. Such traits are heritable, whereas other traits are strongly influenced by environmental conditions and show weak heritability.

High rate of population growth. Most populations have more offspring each year than local resources can support leading to a struggle for resources. Each generation experiences substantial mortality.

Differential survival and reproduction. Individuals possessing traits well suited for the struggle for local resources will contribute more offspring to the next generation.

From one generation to the next, the struggle for resources (what Darwin called the "struggle for existence") will favor individuals with some variations over others and thereby change the frequency of traits within the population. This process is natural selection. The traits that confer an advantage to those individuals who leave more offspring are called adaptations.

In order for natural selection to operate on a trait, the trait must possess heritable variation and must confer an advantage in the competition for resources. If one of these requirements does not occur, then the trait does not experience natural selection.

To find out how **natural selection** works, imagine a population of beetles:

1. **There is variation in traits**.

For example, some beetles are green and some are brown.

2. **There is differential reproduction**.

Since the environment can't support unlimited population growth, not all individuals get to reproduce to their full potential. In this example, green beetles tend to get eaten by birds and survive to reproduce less often than brown beetles do.

3. **There is heredity**.

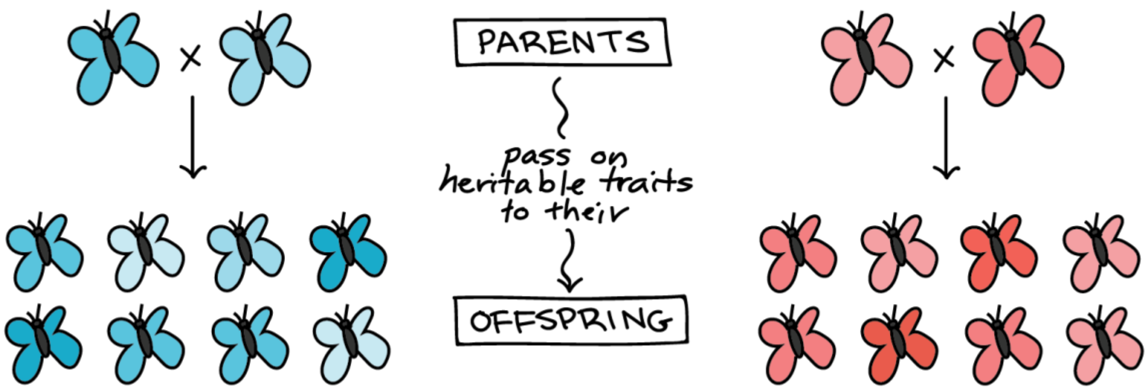
The surviving brown beetles have brown baby beetles because this trait has a genetic basis.

4. **There is natural selection**

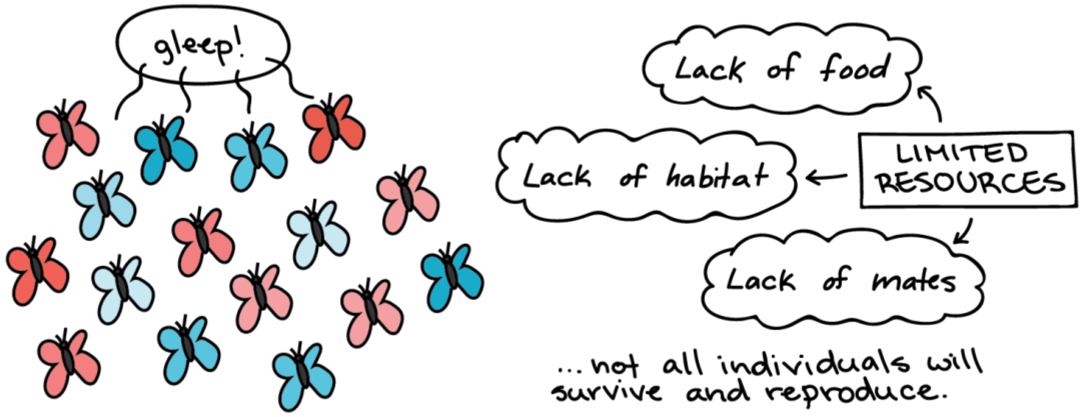
The more advantageous trait, brown coloration, which allows the beetle to have more offspring, becomes more common in the population. If this process continues, eventually, all individuals in the population will be brown. If you have variation, differential reproduction, and heredity, you will have evolution by natural selection as an outcome.

Darwin's concept of natural selection was based on several key observations:

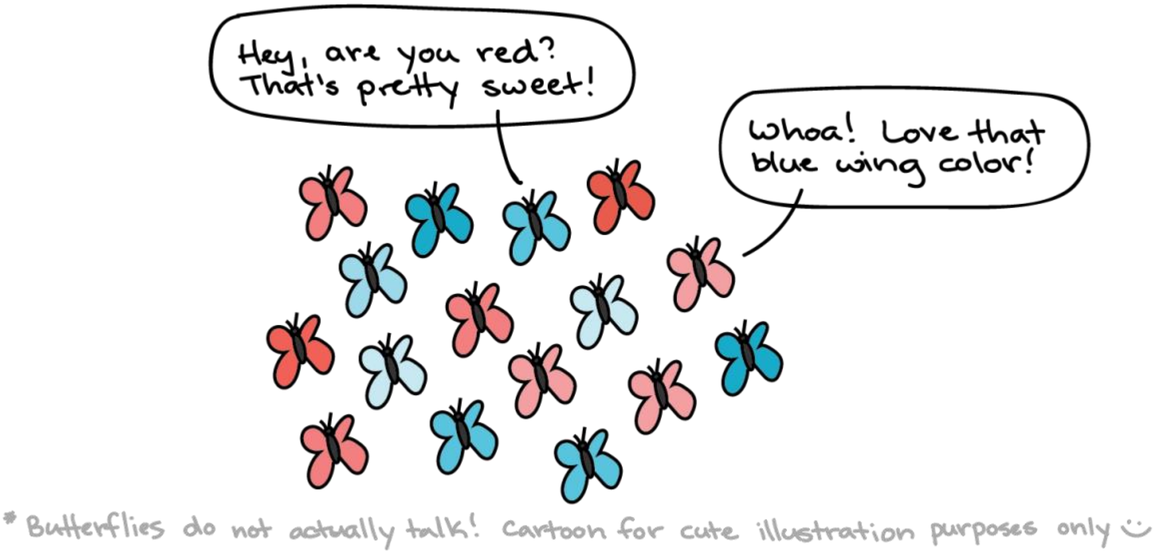
Traits are often heritable. In living organisms, many characteristics are inherited, or passed from parent to offspring. (Darwin knew this was the case, even though he did not know that traits were inherited via genes.)



More offspring are produced than can survive. Organisms are capable of producing more offspring than their environments can support. Thus, there is competition for limited resources in each generation.



Offspring vary in their heritable traits. The offspring in any generation will be slightly different from one another in their traits (color, size, shape, etc.), and many of these features will be heritable.



Based on these simple observations, Darwin concluded that, in a population, some individuals will have inherited traits that help them survive and reproduce (given the conditions of the environment, such as the predators and food sources present). The individuals with the helpful traits will leave more offspring in the next generation than their peers, since the traits make them more effective at surviving and reproducing.

Because the helpful traits are heritable, and because organisms with these traits leave more offspring, the traits will tend to become more common (present in a larger fraction of the population) in the next generation. Over generations, the population will become **adapted** to its environment (as individuals with traits helpful in that environment have consistently greater reproductive success than their peers).

- Levels of biodiversity

Biodiversity is classified at many levels, from genetic diversity to species diversity to ecosystem diversity. Biodiversity is also mapped over 'ecoregions,' categorized based on climate, vegetation, and altitude; the study of biogeography looks at the distribution of organisms in space, and through time.

- Genetic diversity

Genetic diversity refers to any variation in the nucleotides, genes, chromosomes, or whole genomes of organisms. Genetic diversity is responsible for variation between individuals, populations and species. Genetic diversity among organisms exists at the following different levels:

- within a single individual (e.g., different alleles of the same gene)
- between different individuals of a single population (e.g., gene mutations causing changes in some individuals within a population)
- between different populations of a single species (population diversity)
- between different species (species diversity)

The presence of unique genetic characteristics distinguishes members of a given population from those of any other population. Large populations will usually have a greater diversity of alleles compared to small populations. This diversity of alleles indicates a greater potential for the evolution of new combinations of genes, and subsequently, a greater capacity for evolutionary adaptation to different environmental conditions. In small populations, individuals are likely to be genetically, anatomically, and physiologically more homogenous than in larger populations, and less able to adapt to different environmental conditions. Genetic diversity is, therefore, a key component for conservation efforts associated with population management.

- Species diversity

Biodiversity is measured through alpha diversity or the number of species within a locality, beta diversity or the change in the composition of species between adjacent areas, and gama diversity or all species in a region. The highest biodiversity is found in tropical regions such as the Upper Guinean Forest Ecosystem.

Functional diversity describes the interactions between the individual organisms (e.g., reproductive behavior, predation, parasitism) of a population or community, and their specializations for their environment (including ways in which they might modify the environment itself) are important functional aspects of biodiversity. These functional aspects can determine the diversity of different communities and ecosystems.

Although the **morphological species concept** is largely outdated as a theoretical definition, it is still widely used. According to this concept, species are the smallest groups that are consistently and persistently distinct, and distinguishable by ordinary means.

The **biological species concept** holds that a species is a group of interbreeding natural populations that is reproductively isolated from other such groups."

The **phylogenetic species concept**, defines a species as the smallest diagnosable cluster of individual organisms within which there is a parental pattern of ancestry and descent.

Despite their differences, all species concepts are based on the understanding that there are parameters that make a species a discrete and identifiable evolutionary entity. If populations of a species become isolated, either through differences in their distribution (i.e., geographic isolation) or through differences in their reproductive biology (i.e., reproductive isolation), they can diverge, ultimately resulting in speciation.

Species diversity is the number of different species in a particular area weighted by some measure of abundance such as number of individuals or biomass.

Species richness is the number of different species in a particular area.

PRACTICUM: A COMPARISON OF SPIDER COMMUNITIES

- How many species on the planet?

Global biodiversity is frequently expressed as the total number of species currently living on Earth, i.e., its species richness. Between about 1.5 and 1.75 million species have been discovered and scientifically described. Scientists expect that the scientifically described species represent only a small fraction of the total number of species on Earth today. Many additional species have yet to be discovered, or are known to scientists but have not been formally described. Scientists estimate that the total number of species on Earth could range from about 3.6 million up to 117.7 million, with 13 to 20 million being the most frequently cited range.

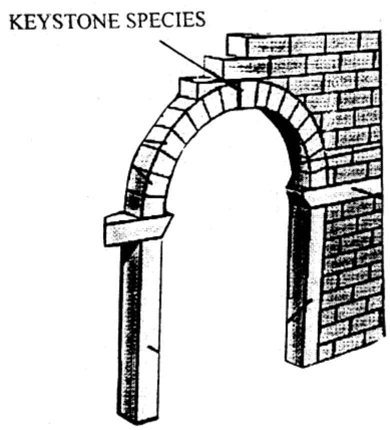
While it is important to know the total number of species of Earth (as a measure of the overall biodiversity of the planet, and for comparisons of biodiversity of different regions), it is also informative to have some measure of the proportional representation of different groups of related species (e.g., bacteria, flowering plants, insects, birds, mammals). This type of diversity is usually referred to as the taxonomic or phylogenetic diversity. Species are grouped together according to shared characteristics (genetic, anatomical, biochemical, physiological, or behavioral), which gives us a classification of species based on their phylogenetic, or apparent evolutionary relationships. We can then use this information to assess the proportion of related species among the total number of species on Earth. Table 3 contains a selection of well-known taxa.

Most public attention is focused on the biology and ecology of large, charismatic species such as mammals, birds, and certain species of trees (e.g., mahogany, sequoia). However, the greater part of Earth's known species diversity is found in other, generally overlooked groups, such as mollusks, insects, and groups of flowering plants. To count the number of species, we must define what constitutes a species. There are several competing theories, or "species concepts". The most widely accepted concepts to define species are: the *morphological species*, the *biological species*, and the *phylogenetic species*.

- Keystone, umbrella, flagship, endemic species

A **keystone species** is an organism that helps define an entire ecosystem. Without its keystone species, the ecosystem would be dramatically different or cease to exist altogether. Keystone species have low

functional redundancy. This means that if the species were to disappear from the ecosystem, no other species would be able to fill its ecological niche. The ecosystem would be forced to radically change, allowing new and possibly invasive species to populate the habitat.



The keystone species concept is one of the best-known ideas in community ecology. The name derives from the center stone in an arch supporting its weight by inward-leaning stones. Removal of the keystone causes the arch to collapse.

Any organism, from plants to fungi, may be a keystone species; they are not always the largest or most abundant species in an ecosystem. However, almost all examples of keystone species are animals that have a huge influence on food webs. The way these animals influence food webs varies from habitat to habitat.

A keystone species is often, but not always, a **predator**. Just a few predators can control the distribution and population of large numbers of prey species. **Herbivores** can also be keystone species. Their consumption of plants helps control the physical and biological aspects of an ecosystem.

Umbrella species are often conflated with keystone species. Both terms describe a single species on which many other species depend. The key distinction between umbrella species and keystone species is that the value of an umbrella species is tied to its geographic species range.

Umbrella species have large habitat needs, and the requirements of that habitat impact many other species living there. Most umbrella species are migratory, and their range may include different habitat types. The identification of an umbrella species can be an important aspect for conservation. The minimum species range of an umbrella species is often the basis for establishing the size of a protected area.

A **flagship species** acts as a symbol for an environmental habitat, movement, campaign, or issue. They can be mascots for entire ecosystems. The identification of a flagship species relies heavily on the social, cultural, and economic value of a species. They are often "charismatic megafauna" – large animals with popular appeal due to their appearance or cultural significance. Flagship species may or may not be keystone or indicator species. Flagship species can sometimes be symbols of general ideas about conservation, not representatives of specific ecosystems. However, specific issues are often associated with a specific animal.

Conservation biologists are interested in areas that have a high proportion of **endemic species** i.e., species whose distributions are naturally restricted to a limited area. It is obviously important to conserve these areas because much of their flora and fauna, and therefore the ecosystems so formed, are found nowhere else. Areas of high endemism are also often associated with high species richness.

- Where is the world's biodiversity?

A common way to measure biodiversity is to count the total number of species living within a particular area. Tropical regions, areas that are warm year-round, have the most biodiversity. Temperate regions, which have warm summers and cold winters, have less biodiversity. Regions with cold or dry conditions, such as mountaintops and deserts, have even less. Generally, the closer a region is to the Equator, the greater the biodiversity. At least 40,000 different plant species live in the Amazon rain forest of South America, one of the most biologically diverse regions on the planet. Only about 2,800 live in Canada's Quebec province.

Biodiversity can also refer to the variety of ecosystems—communities of living things and their environments. Ecosystems include deserts, grasslands, and rain forests. The continent of Africa is home to tropical rain forests, alpine mountains, and dry deserts. It enjoys a high level of biodiversity. Antarctica, covered almost entirely by an ice sheet, has low biodiversity.

- What are biodiversity hotspots?

READING: Myers et al (2000), "Biodiversity Hotspots for Conservation" AND Taylor, SJ (2005), "African Biodiversity Hotspots"

PRACTICUM: AFRICA'S BIODIVERSITY HOTSPOTS POSTER

Biodiversity is not distributed evenly on the Earth. It is richer in warmer and temperate climates; as one approaches the Polar Regions one generally finds fewer species. Flora and fauna diversity depends on climate, altitude, soil and other biotic and abiotic factors. Conservation biologists focus their attention on areas that have high levels of endemism (and hence diversity) that are also experiencing a high rate of loss of ecosystems; these regions are **biodiversity hotspots**. Because biodiversity hotspots are characterized by localized concentrations of biodiversity under threat, they represent priorities for conservation action.

Some places in the world have a large number of **endemic species**—species that exist only in that place. The Cape Floristic Region in South Africa is home to about 6,200 plant species found nowhere else in the world. Areas with high numbers of endemic species are called biodiversity hotspots. Scientists and communities are making a special effort to preserve biodiversity in these regions.

- Biodiversity in Liberia

Tropical rain forests occur in regions near the equator, like Liberia. The climate is always warm (between 20° and 25° C) with plenty of rainfall (at least 190 cm/year). The rain forest is probably the richest biome, both in diversity and in total biomass. The tropical rain forest has a complex structure, with many levels of life. More than half of all terrestrial species live in this biome. While diversity is high, dominance by a particular species is low. While some animals live on the ground, most rain forest animals live in the trees. Many of these animals spend their entire life in the forest canopy. Insects are so abundant in tropical rain forests that the majority have not yet been identified.

Liberia is home to two of the three remaining large blocks of Upper Guinean Rainforest in West Africa, an equivalent of 40+ percent of this forest type. These biologically rich forests are home to approximately 240 timber species, 2,000 species of flowering plants, 125 mammal species, 590 bird species, 74 reptiles and amphibians, and over 1,000 insect species.

Liberia contains the highest remaining portion (42%) of the Upper Guinea Massif including plants with high endemism. The country boasts of over 2000 vascular plant species, 600 bird species, 75 reptile species, 150 mammal species, etc. Of these, 0.8% are endemic, meaning they exist in no other country, and 4.2% are threatened. Liberia is home to at least 2200 species of vascular plants, of which 4.7% are endemic. 1.3% of Liberia is protected under IUCN categories I-V.

The Guinean Forests of West Africa biodiversity hotspot includes two distinct sub-regions, which incorporate several important forest refugia. The first sub-region, Upper Guinea, stretches from southern Guinea into eastern Sierra Leone and through Liberia, Ivory Coast and Ghana into western Togo. The second subregion, Nigeria-Cameroon, extends along the coast from western Nigeria to the Sanaga River in southwestern Cameroon.

Liberia's forests shelter populations of endangered pygmy hippopotamuses, western chimpanzees, red colobus monkeys, and a number of other threatened or endangered species. Coastal areas contain small but important tracts of mangrove forest, which protect the coast from erosion and provide spawning grounds for marine species. Wetlands throughout the country include habitats for many bird species, both resident and migratory. The forests themselves contain a number of valuable timber species, many of which are harvested commercially, as well as many non-timber forest products (NTFPs) providing value through customary use and trade.

Classes of threatened species of animals, plants, and other organisms in Liberia

Class	Total Species	Total Endemic	Total Threatened
Amphibians	38	4	1
Plants	2,200	103	46
Mammals	193	n/a	17
Birds	590	1	22
Reptiles	67	2	2
Mollusks	n/a	n/a	1
Other Vertebrates	n/a	n/a	1
Ants	1,000	n/a	n/a
TOTAL		110	89

Sources: World Conservation Monitoring Centre, IUCN, FAO (NBSAP)

It is important to note that Liberia's biodiversity is not fully known and there are many species that have not been discovered or recorded.

Of the diverse terrestrial ecosystems in Liberia, the forest domain is the largest in terms of area, number of species, and ecosystem diversity. Liberia's forests are among the world's most exceptionally diverse forest ecosystems known as the Upper Guinean Forest ecoregion (UGF), a humid coastal rainforest belt stretching across several West African countries. At the close of the millennium, Liberia harboured the largest remaining proportion of the UGF, with 42%, followed by the Ivory Coast (28%), Ghana (16%), Sierra Leone (5%) and Togo (1%).

There are two permanent categories into which Liberia's forests are classified with respect to use. These are protected area systems and national forests. Areas designated for commercial logging or as proposed protected areas are almost always an integral part of a national forest. In other words, national forests are transitory in use as they can be given to concessions for logging or proclaimed as protected or proposed protected areas.

According to the U.N. FAO, 44.9% (about 4,329,000 ha) of Liberia is forested. Of this 4.0% (175,000) is classified as primary forest, the most bio-diverse and carbon-dense form of forest. Currently, the total forested landscape of protected areas is 384,080 hectares, which is about 8.9% of the total forested area of the country. Between 1990 and 2010, Liberia lost an average of 30,000 ha or 0.61% per year. In total, between 1990 and 2010, Liberia lost 12.2% of its forest cover or around 600,000 ha.

While there are numerous threats to habitat and biodiversity, the threats related to forest activities include shifting cultivation, poaching and hunting of bush meat in association with unregulated timber extraction, firewood gathering, charcoal production, and human settlements. Currently, there also is a lack of data with which to fully assess the extent of the impact and there is no land use planning. The latter partly results from the unclear land tenure system and limited land use feasibility studies. Logging and road infrastructure also have contributed to forest fragmentation.

- Extinction

Extinction is the complete disappearance of a species from Earth. Thus, extinction is the final and irreversible event of species loss. For example, the Liberia greenbul, a bird species endemic to Liberia is now suspected to be extinct as it has not been seen for more than 10 years.

In contrast, extirpation is the local or regional disappearance of a species from only a part of its range. Regional or national biodiversity reports may sometimes misleadingly refer to the 'extinction' of a species within the area under consideration when it is still found in other regions. The distinction is important since careful use of these two terms can help establish whether we are dealing with a complete genetic loss of the species. Nevertheless, extirpation may include the loss of unique components of a species' overall genetic diversity. Moreover, extirpation events represent the early stages of the extinction process and therefore should serve as important warnings for the need to implement conservation action for the species.

It is hypothesized that we are currently on the brink of a "sixth mass extinction," but one that differs from previous events. The five other mass extinctions predated humans and were probably the ultimate products of some physical process (e.g., climate change through meteor impacts), rather than the direct consequence of the action of some other species. In contrast, the sixth mass extinction is the product of human activity over the last several hundred, or even several thousand years.

- Past and present rates of extinctions
    - Speciation vs. extinction rate

It is important to realize that extinction is an important part of the evolution of life on Earth. The current diversity of species is a product of the processes of extinction and speciation over 3.8 billion years of life. There might be 40 million species alive today, but between 5 and 50 billion species have lived at some time during the history of the Earth. Therefore, an estimated that 99.9% of all the life that has existed on Earth is now extinct; a species is assumed to be extinct when there is no reasonable doubt that the last individual has died. However, extinction has not occurred at a constant pace through the Earth's history. There have been at least five periods when there has been a sudden increase in the rate of extinction, such that the rate has at least doubled, and the extinctions have included representatives from many different taxonomic groups of plants and animals; these events are called **mass extinctions**.

Each of the first five **mass extinctions** represents a significant loss of biodiversity – but recovery has been good on a geologic time scale. Mass extinctions are apparently followed by a sudden burst of evolutionary diversification on the part of the remaining species; some evolutionary biologists suggest this is because the surviving species started using habitats and resources that were previously "occupied" by more competitively successful species that went extinct. However, these bursts of diversification do not mean that the recoveries from mass extinction have been rapid; they have usually required some tens of millions of years.

- General characteristics of vulnerable species, rarity, distinctiveness

A small geographic range makes a species particularly vulnerable to global extinction. Many of the threats to species are geographically restricted, so species with large ranges will survive somewhere even if they are locally extirpated. Species with small ranges do not have this "reserve." Species with small geographic ranges tend to be rare within them—they have low population densities.

Large animals, by virtue of their low population densities, are at increased risk of extinction. Moreover, an animal species that produces few offspring each year and that suffers a major loss in numbers from human activity will need more time to recover than a species with high reproductive rates. **Vulnerability** is a function of intrinsic rate of reproduction (the larger the individual, the slower it reproduces) and the social/commercial value of the species to humans as a resource (e.g., ivory from rhinos and elephants, medicinal properties, etc.).

- Population Viability Analysis

Population viability analysis (PVA) is a species-specific method of risk assessment frequently used in conservation biology. It is traditionally defined as the process that determines the probability that a population will go extinct within a given number of years. Quantitative criteria are used to determine whether a taxon is threatened or not, and, if threatened, which category it belongs in. Biological attributes of populations that contribute to the likeliness of extinction include:

1. Population decline
2. Small range and fragmentation, decline or fluctuation
3. Small population size and fragmentation, decline or fluctuations
4. Very small or restricted population

The **minimum viable population** is the population size below which the probability of extinction is increased, or the minimum number of interacting local populations necessary for long-term persistence of a metapopulation.

READING: USAID (2018) "Liberia tropical forest biodiversity analysis"

PRACTICUM: Exploring biodiversity in Bomi County

- Why conserve biodiversity?
    - Goals and principles of conservation
        - Intrinsic vs. Utilitarian values

Humans depend upon biodiversity in many ways, both to satisfy basic needs like food and medicine, and to enrich our lives culturally or spiritually. Despite its importance, determining the value or worth of biodiversity is complex and often a cause for debate. This is largely due to that fact that the worth placed on biodiversity is a reflection of underlying human values, and these values vary dramatically both among societies and individuals. Values are also dynamic; they change over time and vary according to specific situations. The value of biodiversity is often divided into two main categories:

Intrinsic (also known as inherent) value, and
Utilitarian (also known as instrumental, extrinsic, or use) value.

Determining the value or worth of biodiversity is complex. Economists typically subdivide utilitarian or use values of biodiversity into *direct use value* for those goods that are consumed directly, such as food, and *indirect use value* for those services that support the items that are consumed, including ecosystem functions such as nutrient cycling. A living thing's *utilitarian value* is determined by its use or function. Usually utilitarian value is measured in terms of its use for humans, such as for medicine or food. However, it can also represent the value of an organism to other living things or its ecological value; pollinators, such as bees, are essential to the reproduction of many plants. Biodiversity supports a myriad critical ecosystem process and services, such as CO2 sequestration, water purification, the prevention of erosion, and so on.

In contrast, **intrinsic value** describes the inherent worth of an organism, independent of its value to anyone or anything else. In other words, all living things have a right to exist – regardless of their utilitarian value. **Intrinsic value** is generally defined as the inherent worth of something, independent of its value to anyone or anything else. One way to think about intrinsic value is to view it as similar to the inalienable right to exist. From this viewpoint, species are protected based on the idea that they have a right to exist, just as all humans do. The United Nations Charter for Nature (1982) also notes biodiversity's intrinsic value: "Every form of life is unique, warranting respect regardless of its worth to man."

Intrinsic value is a frequently misunderstood term as some consider values that are not easily defined, such as aesthetic values, to be intrinsic values. However, as discussed earlier, aesthetic values are better considered as a kind of extrinsic value, because aesthetic values provide humans with a service of sorts – our own satisfaction. Others consider a species' value to the structure and function of an ecosystem (such as an invertebrate decomposer's ability to cycle nutrients) as its intrinsic value because it does not have any obvious value to humans. However, this ecosystem value is still utilitarian value, except it focuses on one organism's usefulness to another organism, rather than to humans.

If one accepts the idea that biodiversity has intrinsic value, then species conservation requires less justification. In other words, if a species is intrinsically valuable, regardless of its use to humans or to other species, it should be conserved, and then the onus is on those who do not want to conserve the species to provide a justification for its removal. Intrinsic value is a central tenet of many religions. For example, many of the world's largest religions, including Christianity, Judaism, Islam, Buddhism, and Hinduism, consider everything on earth to be inherently sacred, or sacred as a result of being created by a divine being, and thus, intrinsically valuable, and humans are responsible to care for and respect these creations.

<u>Why do values matter?</u>
Values are central to conservation decisions. When we measure biodiversity or set conservation priorities, we must decide which species, populations, or ecosystems to study, monitor, manage, or conserve, and these choices depend upon what we currently value.

Should we give priority to a species/ecosystem that is nationally endangered but globally common, or to a species/ecosystem that is nationally common and globally rare? Should we value areas with greater numbers of species over those with many endemic species (those that are found only in that one place in the world)? There are no correct answers to these questions – the responses depend upon what the decision-makers value and what information is available to make these decisions. Values are also the basis of arguments used to justify the conservation of species or ecosystems, for example whether a particular area is valuable for recreation, logging, or fishing.

In most countries, conservation efforts focus on the species listed as endangered and threatened, although to date these lists include mainly vertebrates and vascular plants. Since we know so little about other components of biodiversity (invertebrates, non-vascular plants, microbes, etc.), our current endangered species lists may be omitting information critical to better decision-making about our imperiled species. Also, people are often biased towards “charismatic” species, such as lions and panda bears.

Ultimately, every decision people make, consciously or not, is based on what they, as individuals, value and these are the values that will be learned by their children.

- Human uses of forests
  - Direct Uses
    - Food and medicine

<u>Food</u>

Humans have spent most of their existence as hunter-gatherers dependent on wild plants and animals for survival. Around 10,000 years ago, the first plants were cultivated, marking a fundamental shift in human history. Biodiversity played a central role in the development of agriculture, providing the original source of all crops and domesticated animals. And today people still depend on biodiversity to maintain healthy, sustainable agricultural systems.

Though humans have used over 12,000 wild plants for food, only twenty species now support much of the world’s population. Of all the plants that we depend on, none are more important than the grass family, the Gramineae. The grass family includes the world's principal staples: wheat (*Triticum aestivum*), rice (*Oryza sativa* L.), and corn (maize, *Zea mays*). Rice and corn formed the basis of civilizations in the Far East and the Americas, while wheat, together with barley, formed the basis of the civilizations in the Near East.

Though agriculture depends on relatively few plants and animals, genetic diversity is essential to improve the productivity of crops and livestock, and to create varieties and breeds that are resistant to pests or disease. Biodiversity acts as a form of insurance for agriculture by helping to ensure that crops can adapt to future environments. Changing climates may require drought-resistant or salt-tolerant crops, for instance. Sorghum, emmer, and spelt were once widely grown grains but have been largely replaced by wheat. However, because of their unique environmental adaptations – sorghum, for example, can be grown in drier climates that do not support wheat – these grasses may become more important in the future, should climatic conditions change.

For many rural peoples in developing countries, wild species are still an important source of food and income, including green leafy plants, fruits, fungi, nuts, and meat. Furthermore, with the exception of only a few species, the world's marine fisheries are dominated by wild-caught fish, representing 85.8 percent of the 100.2 million tons produced in 2000, according to the Food and Agriculture Organization.

The importance of forests to humans cannot be underestimated. We depend on forests for our survival, from the air we breathe to the wood we use. Besides providing habitats for animals and livelihoods for humans, forests also offer watershed protection, prevent soil erosion and mitigate climate change. Forest products are a vital part of our daily lives in more ways than we can imagine.

Over 2 billion people rely on forests, which provide us with shelter, livelihoods, water, food and fuel security. All these activities directly or indirectly involve forests. Some are easy to figure out - fruits, paper and wood from trees, and so on. Fruit trees are an important source of income and food. In some areas fruit trees are commonly planted along the field borders and around the wells. Mango, coconut, and many others grow wild in the forest. Other forest products are less obvious, such as non-timber forest products (NTFPs) that go into everyday items like medicines, cosmetics and detergents.

Building materials and fuel
For rural populations, wood is an important source of energy for cooking and heating. According to the World Resources Institute, more than 50% of all harvested wood is used as fuel, burned either directly or after being converted to charcoal. Fuelwood, charcoal, and other fuel from wood are the major sources of energy for households in low-income countries such as Liberia. Wood after burning produces charcoal, a substitute for coal that is used in a variety industrial activities as well as for domestic heating purposes.

Trees and several grasses, most notably bamboo and rattan, are basic commodities used worldwide for building materials, paper products, and fuel. The worldwide production of timber and related products – including homes, furniture, mulch, chipboard, paper and packaging – is a multi-billion dollar industry. Outside of large market economies, products from particular species of wild-growing woody plants are key sources of shelter (e.g., termite-resistant support poles), household items (furniture, utensils, baskets, etc.), long-burning fuels, and dyes. Plants such as Rattan (the common name which describes 13 genera and about 700 species) are used for cane furniture, as well as for matting, basketry, and handicrafts.

Clothing and other textiles
Fibers extracted from plants and animals are used to produce textiles and cloth. While synthetic fibers, such as polyester, that are manufactured from petroleum products are becoming increasingly common, cotton (*Gossypium* sp.) is still the single most important textile fiber in the world, and accounts for over 40 percent of total world fiber production. The earliest fabric known is linen, created from the flax plant (*Linum usitatissimum*); it has been used for centuries and is historically significant for its use to produce sails. Some other fibers from plants include jute (*Corchorus spp*.), hemp (*Cannabis sativa*), sisal (*Agave sisalana*), and ramie (*Boehmeria nivea*). Fabric manufacturers also harvest wood for its fiber, using wood cellulose to make fibers. Silk fibers are created from the cocoons of the larvae of several different species of silkworm moths. The domesticated *Bombyx mori* (Mulberry silkworm) is the most common; its primary food is the leaves of plants of the family Moraceae, particularly *Morus alba* (White mulberry). There are other less common varieties, commonly known as "wild silk."

- Timber and industrial materials

Agro-based industries are wholly dependent on forests for raw materials. Forests provide jobs for more than 13 million people across the world. In addition, 300 million people live in forests, including 60 million indigenous people.

The important industries partly or totally dependent of forest products are paper industry, cardboard, matchbox, plywood etc. Wood pulp for paper making, rayon, cellophane and cellulose for allied industries are noteworthy. The wood collected from the forest is used to produce materials for ship and rail and other transport equipment making.

Many industrial products are extracted from woody plants. Some of the most important of these are cork, rubber, latex, shellac, resins, perfumes, waxes, and oils. A list of a few of these products and their source is provided in the table below.

Examples of Industrial products extracted from plants and animals

Originating plant or animal	**Product/End use**
Cork oak (*Quercus suber)*	cork
Pará rubber tree (*Hevea brasiliensis*)	rubber
Jojoba plant (*Simmondsia chinensis)*	jojoba oil

- Non-Timber Forest Products (NTFPs)

According to Liberia's Community Rights Law (2009), NTFPs may be extracted from forest lands and are utilized within the household or are marketed or have social, cultural or religious significance. These include plants and plant materials used for food, fuel, fiber, storage and fodder, medicine, bio-chemicals, as well as mammals, birds, reptiles, fishes and invertebrates.

Medicines
Wild species of plants and animals have long been the source of important pharmaceutical products. Natural products play a central role in traditional healthcare systems. The World Health Organization estimates that some 80% of people in developing countries obtain their primary health care in the form of traditional medicines. Since time immemorial humans have been depending on the forest to cure them of various ailments. Even today man is dependent on the forest for herbs and plants to fight against disease.

Some 80 percent of people in the developing world population still use plants as a primary source of medicine. For example, while Tanzania has approximately 600 Western-trained doctors, its 30-40,000 traditional healers treat a vast majority of its population. These healers rely on plants and plant parts for their remedies.

Many Western medicines were developed from a plant or an animal source; more than half of the top 150 most-prescribed drugs in the United States originate from living organisms. For example, the antibiotic penicillin is derived from an ordinary bread mold, *Pencillium notatum*. Other examples include aspirin and common acne medicines that are derived from salicylic acids, first taken from the bark of willow trees (*Salix* sp.). While many of these drugs are now more efficiently synthesized than extracted from material collected in the wild, we still depend on the chemical structures in nature to guide us in developing and synthesizing new drugs. While plants are still the primary source for medicine, the aquatic realm is currently leading the next wave of medical discoveries. Marine organisms produce many novel compounds, including some of the most powerful toxins on earth.

Fodder
Fodder from the forest forms an important source for cattle and other grazing animals in agro-pastoral systems.

Fencing
Fences created with trees and shrubs are preferred in developing countries as they are cheap to maintain yet give protection. Species that have thorns or are prickly and have stiff branches and leaves that are not edible are preferred. These species should be fast growing, hardy, and long lived.

  - Indirect use: Non-consumption

Recreational uses of biodiversity—fishing, hunting, and various non-consumptive uses, such as bird-watching—also contribute to the economy. One of the most rapidly growing values of biodiversity in wild ecosystems is related to tourism. Worldwide receipts from international tourism in 1990 totaled $250 billion, and domestic tourism is believed to be as much as 10 times higher. However, how much of the tourist trade is attracted specifically by biodiversity is difficult to tell.

- Ecosystem services

Ecosystem services are benefits people obtain from ecosystems. These services can be classified into four types:

- *Provisioning services*, which are the products people obtain from ecosystems;
- *Regulating services*, which are the benefits people obtain from the regulation of ecosystem processes;
- *Cultural services*, which are the nonmaterial benefits people obtain from ecosystems
  - e.g., sacred sites, traditional use, amenity values, tourism.
- *Supporting services*, which are the natural processes that maintain the other services.
  - e.g., photosynthesis, pollination, flood control, water and soil protection, water filtration and nutrient retention.

After oceans, forests are the world's largest storehouses of carbon. Forests provide a wide variety of ecosystem services that are critical to human welfare. These include:

- Absorbing harmful greenhouse gasses that produce climate change. In tropical forests alone, a quarter of a trillion tons of carbon is stored in above and below ground biomass
- Providing clean water for drinking, bathing, and other household needs
- Protecting watersheds and reducing or slowing the amount of erosion and chemicals that reach waterways
- Providing food and medicine
- Serving as a buffer in natural disasters like flood and rainfalls
- Providing habitat to more than half of the world's land-based species

Looking at it beyond our narrow, human – not to mention urban – perspective, forests provide habitats to diverse animal species. They are home to 80% of the world's terrestrial biodiversity, and they also form the source of livelihood for many different human settlements, including 60 million indigenous people.

Often the values of ecosystem services are not considered in commercial market analyses, despite their critical importance to human survival. How can we assign a value to the atmospheric regulation of oxygen? In some ways, its value is infinite since without it we could not survive. Also, many ecosystem services cannot be replaced or if they can, it is only at considerable cost. An attempt to estimate the value of ecosystem services was made by. According to one study (Costanza et al., 1997), the earth provides a minimum of $16 to $54 trillion dollars' worth of "services" to humans per year, based on the value of 15 ecosystem services and two goods in 16 biomes.

Many services provided by biodiversity go beyond what is needed for our immediate survival, including the many cultural, spiritual, and aesthetic values people place on nature and natural areas. Some feel that people have an innate connection or kinship with nature. Nature also provides insight and understanding of our role in the world, and has value for education, as well as for scientific research.

Furthermore, each species has an ecological value as part of an ecosystem, and species diversity contributes to ecosystem function and resilience. While species diversity is related to ecosystem function and resilience, there is not necessarily a one to one correspondence. In other words, a hypothetical ecosystem with 150 species is not necessarily twice as good at providing ecosystem services than one with 75 species. However, regardless of diversity levels, the wholesale removal of species from ecosystems is likely to disrupt the ability of an ecosystem to provide these services.

<u>Regulating Services: atmosphere and climate regulation</u>
Life on earth plays a critical role in regulating the earth's physical, chemical, and geological properties, from influencing the chemical composition of the atmosphere to modifying climate. Over the last century, humans have changed the atmosphere's composition by releasing large amounts of carbon dioxide. This excess carbon dioxide, along with other 'greenhouse' gases, is believed to be heating up our atmosphere and changing the world's climate, leading to 'global warming'. There has been much debate about how natural processes, such as the cycling of carbon through phytoplankton in the oceans, will respond to these changes. Will phytoplankton productivity increase and thereby absorb the extra carbon from the atmosphere? Recent studies suggest that natural processes may slow the rate of increase of carbon dioxide in the atmosphere, but it is doubtful that either the earth's oceans or its forests can absorb the entirety of the extra carbon released by human activity.

The amount of solar radiation absorbed by the earth depends primarily on the characteristics of the surface. Although the link between solar absorption, thermodynamics, and ultimately climate is very complex, newer studies indicate that vegetation cover and seasonal variation in vegetation cover affects climate on both global and local scales. New generations of atmospheric circulation models are increasingly able to incorporate more complex data related to these parameters. Besides regulating the atmosphere's composition, the extent and distribution of different types of vegetation over the globe modifies climate in three main ways:

- affecting the reflectance of sunlight (**radiation balance**);
- regulating the release of water vapor (**evapotranspiration**); and
- changing wind patterns and moisture loss (**surface roughness**).

The amount of solar radiation reflected by a surface is known as its *albedo*; surfaces with low albedo reflect a small amount of sunlight, those with high albedo reflect a large amount. Different types of vegetation have different albedos; forests typically have low albedo, whereas deserts have high albedo. Deciduous forests are a good example of the seasonal relationship between vegetation and radiation balance. In the summer, the leaves in deciduous forests absorb solar radiation through photosynthesis; in winter, after their leaves have fallen, deciduous forests tend to reflect more radiation. These seasonal changes in vegetation modify climate in complex ways, by changing evapotranspiration rates and albedo.

Vegetation absorbs water from the soil and releases it back into the atmosphere through **evapotranspiration**, which is the major pathway by which water moves from the soil to the atmosphere. This release of water from vegetation cools the air temperature. In the Amazon region, vegetation and climate is tightly coupled; evapotranspiration of plants is believed to contribute an estimated fifty percent of the annual rainfall. Deforestation in this region leads to a complex feedback mechanism, reducing evapotranspiration rates, which leads to decreased rainfall and increased vulnerability to fire.

Supporting Services: Soil and water conservation

Biodiversity is also important for global soil and water protection. Terrestrial vegetation in forests and other upland habitats maintains water quality and quantity, and controls soil erosion.

In watersheds where vegetation has been removed, flooding prevails in the wet season and drought in the dry season. Soil erosion is also more intense and rapid, causing a double effect: removing nutrient-rich topsoil and leading to siltation in downstream riverine and ultimately, oceanic environments. This siltation harms riverine and coastal fisheries and damages coral reefs.

One of the most productive ecosystems on earth, **wetlands** have water present at or near the surface of the soil or within the root zone all year or for a period of time during the year, and the vegetation there is adapted to these conditions. Wetlands are instrumental for the maintenance of clean water and erosion control. Microbes and plants in wetlands absorb nutrients and in the process filter and purify water of pollutants before they enter other aquatic systems. Wetlands also reduce flood, wave, and wind damage. They retard the flow of floodwaters and accumulate sediments that would otherwise be carried downstream or into coastal areas. Wetlands also serve as breeding grounds and nurseries for fish and support thousands of bird and other animal species.

Supporting Services: Nutrient cycling

Nutrient cycling is yet another critical service provided by biodiversity – particularly by microorganisms. Fungi and other microorganisms in soil help break down dead plants and animals, eventually converting this organic matter into nutrients that enrich the soil.

For example, nitrogen is essential for plant growth, and an insufficient quantity of it limits plant production in both natural and agricultural ecosystems. While nitrogen is abundant in the atmosphere, only a few organisms (commonly known as nitrogen-fixing bacteria) can use it in this form. Nitrogen-fixing bacteria extract nitrogen from the air, and transform it into ammonia, then other bacteria further break down this ammonia into nitrogenous compounds that can be absorbed and used by most plants. In addition to their role in decomposition and hence nutrient cycling, microorganisms also help detoxify waste, changing waste products into forms less harmful to the environment.

Supporting Services: A genetic library for crop and livestock improvement

Humans only cultivate a small fraction of the plant and animal species on earth. To ensure that we can sustain existing agricultural systems, we depend on biodiversity, especially the wild counterparts of cultivated food and domesticated animals, as a genetic library that we can use to create new varieties or breeds that are more tolerant of pests or disease or more suited to certain environmental conditions.

There are other cases in history when a widely-grown crop has failed due to disease, with devastating consequences. One famous example is the Irish potato famine, which led to the death of 1 million people. In the mid-19th century, a blight (or fungus-like pathogen) destroyed much of the crop. European potato crops were particularly susceptible to infection since they had originated from only a few sources and thus were genetically very similar. To combat this disease, a long search began to find a plant resistant to the blight. By the early 20th century, a related plant in Mexico provided the solution. Hybridizing this plant with potatoes produced a resistant strain. Unfortunately, this was not a permanent solution. Today, potato blight is once again a concern, and it is likely the solution lies in existing biodiversity. As the world's crops become increasingly homogenized, it is important to remember the lessons of this event: agricultural systems with higher genetic diversity are often more resilient, and ultimately, biodiversity may solve these crises.

Supporting Services: Pollination and seed dispersal
An estimated 90 percent of flowering plants depend on pollinators such as wasps, birds, bats, and bees, to reproduce. However, plant pollinators are increasingly threatened around the world. In the pine forests of western North America, corvids (including jays, magpies, and crows), squirrels, and bears play a role in seed dispersal. In tropical areas, large mammals and frugivorous birds play a key role in dispersing the seeds of trees and maintaining tree diversity over large areas.

Pollination is critical to most major crops and virtually impossible to replace. For instance, imagine how costly fruit would be (and how little would be available) if natural pollinators no longer existed and each developing flower had to be fertilized by hand. Many animal species are important dispersers of plant seeds. While scientists hypothesize that the loss of a specific seed disperser could cause a plant to become extinct, to date there is no definitive example where this has occurred. Unfortunately, declines and/or extinctions of species are often unobserved and thus it is difficult to tease out the cause of the end result, as multiple factors are often operating simultaneously. Similar problems exist today in understanding current population declines. For example, in a given species, population declines may be caused by loss of habitat, loss in prey species, or loss of predators, a combination of these factors, or possibly some other yet unidentified cause, such as disease.

Regulating Services: Natural pest control
Agricultural pests (principally insects, plant pathogens, and weeds) destroy more than one-third of US crops. Destruction varies depending on the crop, where it is grown, and the type of pest. production losses due to pests, pathogens, and weeds amount to 15%, 14%, and 13% on average for the principal cereals and potatoes. Without natural predators that keep pests in control, these figures would be much higher. Natural pest control saves farmers billions each year, and pesticides are no replacement for the services provided by these crop-friendly predators.

Cultural Services: Inspiration
We value biodiversity for its ability to inspire creativity and to help us solve problems. **Biomimicry** is a relatively new term that refers to the study of models in the natural world as an inspiration to solve problems in agriculture, medicine, manufacturing, and commerce.

One important concept that speaks to our deep connections to biodiversity is **biophilia**, which refers to the notion that the love of nature may have been ingrained into our genes by natural selection. Our very survival through human evolution depended on a detailed knowledge of natural history. This was vital for finding food, shelter, materials, and medicine. Those lacking the ability to develop an intimate knowledge of biodiversity were simply less successful at surviving and reproducing.

The idea of kinship between animals and people is common in many parts of the world. In the islands of the South Pacific, fishing families have a unique relationship with certain animals, usually turtles or sharks. For each family, these special species (or groups of species) are considered sacred and it is taboo to hunt them; this relationship is carried on through the generations.

The natural world has played a central role in the development of human spiritual traditions. Religions help define the relationships between humans and their environment. Many religious guidelines arose as a response to natural phenomena, particularly threatening ones. Rules to protect crops, sustain fisheries, or avoid danger developed from the natural world. Punishment was meted out through crop failures or other threats to survival; the reward was a healthy life and continued survival.

Animist belief systems integrate a series of allowed and prohibited actions. Punishment for prohibited actions is usually grave and results in a series of taboos. These taboos often apply to vulnerable natural resources. Nature is used in religious imagery, and many religious traditions view the contemplation of nature as an important spiritual value:

- In Thailand, trees are marked with yellow cloth to denote their sacredness to the Buddhist faith. This practice has saved some sacred groves from illegal logging, since to destroy these trees is a severe crime.
- In Japan, Shinto temples are often located in large groves of trees, where spiritual forces are believed to exist.
- Human stewardship over plants and animals (God’s other creations less able to protect themselves) is a central tenet of Christian, Judaism, and Islam. For example, the Garden of Eden and Noah’s Ark are important symbols that define human responsibility for biodiversity.

The natural world also provides a rich source of material and symbols used in art and literature. Plants and animals are central to mythology, dance, song, poetry, rituals, festivals, and holidays around the world. The natural world also influences areas as diverse as housing styles, type of dress, and regional farming methods. Nature is incorporated into language and many metaphorical expressions use plants and animals, such as "happy as a clam" or "fat as a pig." In many Asian cultures, bamboo has a central role in arts and traditions and is common in proverbs, for example “Make sure your life is as pure as a bamboo flute.” What plants and animals represent varies from culture to culture. Rats are considered pests in much of Europe and North America, delicacies in many Asian countries, and sacred in some parts of India. Of course, within cultures individual attitudes also vary dramatically.

Many natural scenes, from a stunning mountain landscape to a majestic lion, evoke feelings of awe or even intense pleasure. In studies conducted in industrialized countries, when shown two landscapes, individuals invariably selected natural scenes as more beautiful than the urban ones. People also value species for their beauty, rarity, complexity, and variability. People are frequently attracted to natural areas for recreation or relaxation, or as a source of inspiration. Many hobbies reflect people’s fascination with nature, such as bird watching, hiking, gardening, scuba diving, or even watching nature shows.

Cultural Services: Tourism and recreation
Natural areas such as forests, lakes, mountains, and beaches provide venues for commercially valuable outdoor activities such as eco-tourism, bird watching, sport fishing, hunting, and hiking. The growing ecotourism industry generates an enormous amount of money and is fast becoming a lucrative industry for some developing nations. For example, in Costa Rica, tourism has expanded rapidly since the mid-1980s and is now the leading source of foreign revenue, surpassing the banana industry.

Cultural Services: Educational and scientific values

Biodiversity contributes to our knowledge in ways that are both informative and transformative. Knowledge about the components of biodiversity is valuable in stimulating technological innovation and in learning about human biology and ecology. Experiencing and increasing our knowledge about biodiversity transform our values and beliefs. Biodiversity has often served as an early-warning system that has foretold threats to human health before sufficient data had been collected to detect effects directly.

Types of Ecosystem Services Linked to Biodiversity

Atmospheric—Climatic

- Gaseous composition of the atmosphere
- Moderation of local and regional weather, including temperature and precipitation

Hydrological

- Water quality and quantity
- Stream-bank stability
- Control of severity of floods
- Stability of coastal zones (through presence of coastal communities, such as coral reefs, mangroves, or seagrass beds)

Biological and Chemical

- Biotransformation, detoxification, and dispersal of wastes
- Cycling of elements, particularly carbon, nitrogen, oxygen, and sulfur
- Buffering and moderation of the hydrological cycle
- Nutrient cycling and decay of organic matter
- Control of parasites and disease, pest control
- Maintenance of genetic library
- Habitat and food-chain support

Agricultural

- Crop production, timber and biomass energy production, pollination
- Stabilization of soils

Economic and Social

- Support of human cultures
- Aesthetic value and ecotourism