FUNDAMENTALS OF ECOLOGY AND ENVIRONMENT

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Fundamentals of

Ecology and Environment

Second edition

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Preface

Fundamentals of Ecology and Environment covers the basic concepts, ideas, major findings and current challenges. As knowledge and best practice in the ecology are constantly changing, the fundamentals are written in a sharply focused manner without overwhelming or excessive details. This book provides a balanced introduction to all major areas of the subject. It is designed to promote understanding of the basic principles and concepts of a subject rather than memorization of details.

We feel that understanding ecology and environment as a whole is far more important than merely identifying separate components of a natural community. With this in mind, the readers will come to understand some basic and underlying concepts, and we trust that, through an understanding and appreciation of these concepts, the overall environmental picture of the Earth will be more fully realized and admired for what it is.

Although the chapters of this book can be read independently of one another, they are arranged in a logical sequence. Our intention is to highlight only the essentials that are most relevant to understanding ecology and environment. The most significant feature of this book is its clear, up-to-date, accurate explanations of mechanisms, rather than the mere description of facts and events. This book has been conceived, designed and written in a manner to meet the aspirations of graduate and postgraduate students. We have tried to maintain a balance between describing the classic works and recent advances in ecology.

Each page is carefully laid out to place related text, figures and tables near one another, minimizing the need for page turning while reading a topic. Sincere efforts have been made to support textual clarifications and explanations with the help of figures and tables to make learning easy and convincing.

This book is intended to go beyond the traditional helping books. This book is divided into four parts– Basic ecology (The Environment, Ecosystem Ecology, Population Ecology and Community Ecology), Biodiversity, Pollution and Climate change. It is organized to provide an even, logical flow of concepts and to provide clear illustrations of the major ecological and environmental issues. It is our hope that this book will be utilized intensively by students and ecologists to gain a basic understanding of ecology.

This book is the result of the combined efforts of several persons. Several diligent and hardworking minds have come together to bring out this book in this complete form. During the prolonged period of writing this book, several of our students, took the time to read most of the chapters and make careful comments on them. For that I thank them. Special thanks to Aditya Arya who read and gave us feedback on all of the chapters as they were being written. This book is a team effort, and producing it would be impossible without the outstanding people of Pathfinder Publication. We acknowledge all the individuals whose special efforts went into this book. We wish to thanks especially to our students for their numerous comments and suggestions.

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Ecology as a science

Ecology is the scientific study of the relationships between organisms and their environment. These relationships are complex, varied and hierarchical. The word 'ecology' was first used by German biologist Ernst Haeckel in 1869. The word is derived from the Greek words, *oikos* (meaning 'house' or 'dwelling place') and *logos* (meaning the study of). Haeckel defined ecology as '*the study of the natural environment including the relations of organisms to one another and to their surroundings*'.

Ecology describes the relationships between living organisms and their environments, the interaction of organisms with each other and the pattern and cause of the abundance and distribution of organisms in nature. The *environment* includes everything (biotic as well as abiotic) that surrounds an organism. Thus, it is the science that attempts to answer questions about how the nature works. According to one of the most widely accepted definition,

'Ecology is the scientific study of the distribution and abundance of organisms and the interactions that determine distribution and abundance.'

Ecology is an interdisciplinary science

Ecology, as a unifying science, is integrating the knowledge of life on our planet. It has changed from a basic science to applied science. It has become an essential science in learning how life survive and grow. Several questions such as why do animals live in groups, what determines the distribution of a species, how does organism interact with biotic and abiotic components, behavioural aspects of animals often drive us to look into this subject. Ecology is not just biology but an interdisciplinary science that deals with the totality of living organisms and their relationship with the environment. Different kinds of physical, chemical and biological processes occurring within ecological systems involve complex interactions among different components of the system. To study these interactions, ecologists must involve other sciences like physiology, biochemistry, genetics, geology, hydrology and meteorology. Ecology has turned into more experimental rather than philosophical subject. With increasing scientific informations, this science also involves complex mathematical modeling and algorithms – a true interdisciplinary sciences.

Chapter 1

The Environment

Organisms and their environments are dynamic and interdependent. The term 'environment' etymologically means *surroundings*. Thus, the *environment* includes everything (biotic as well as abiotic) that surrounds an organism. Any factor, abiotic or biotic, that influences living organisms is called **environmental factor** (or *ecological factor* or *ecofactor*). Abiotic factors include ambient temperature, amount of sunlight, pH of the water, soil in which an organism lives and many other factors. Biotic factors include the availability of prey, competitors, predators and parasites.

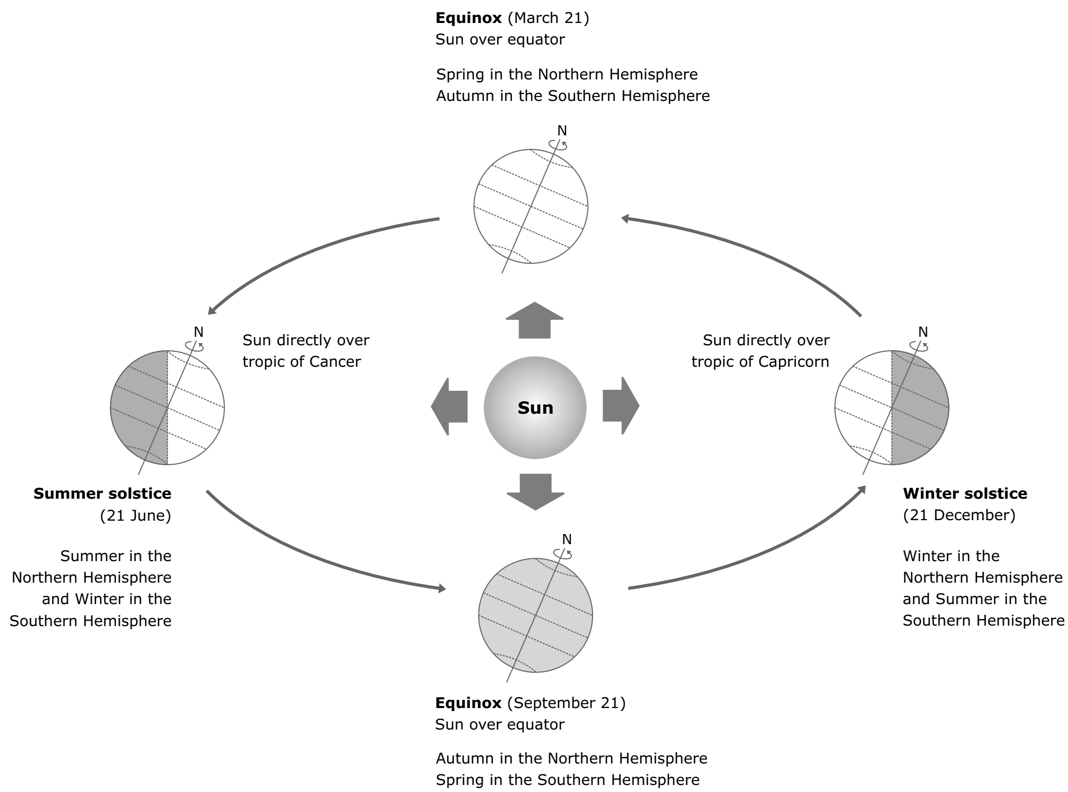
1.1 Physical environment

Soil

Soil is the uppermost weathered layer of the earth's crust. It is a mixture of weathered mineral rock particles, organic matter (i.e. both living and dead), water and air. Soil is a biologically active matrix and home of diverse organisms. The study of soil is called **pedology**.

Weathering and soil formation

The process of soil formation includes the formation of unconsolidated materials by the weathering process and the soil profile development. Weathering refers to the *physical disintegration* and *chemical decomposition* of the rocks and minerals contained in them. Physical disintegration breaks down rock into smaller fragments and eventually into sand and silt particles that are commonly made up of individual minerals. Simultaneously, the minerals decompose chemically, releasing soluble materials and synthesizing new minerals. New minerals form either by minor chemical alterations or by a complete chemical breakdown of the original mineral and resynthesis of new minerals. Based on the location of soil mineral particles formation and deposition, the soils are classified as *residual soil* and *transported soil*. If the soil mineral particles have been formed in place from the bedrock below, it is called **residual soil**. If the soil mineral particles have been carried from some other location by wind, water, gravity or ice then it is termed as **transported soil**. The transported soil can be classified into **colluvium** (transported by gravity), **alluvium** (transported by the movement of water), **glacial soil** (transported by the movement of glaciers) and **eolian soil** (transported by wind).



Since a large portion of the Northern Hemisphere is getting light from the sun, it is *summer* in the regions north of the equator. The longest day and the shortest night at these places occur on 21st June. At this time in the Southern Hemisphere, all these conditions are reversed. It is winter season there. The nights are longer than the days. This position of the earth is called the **Summer Solstice**. The combination of more direct rays of sunlight and more hours of daylight causes the hemisphere tilted toward the sun to receive more solar radiation and to have warmer temperatures.

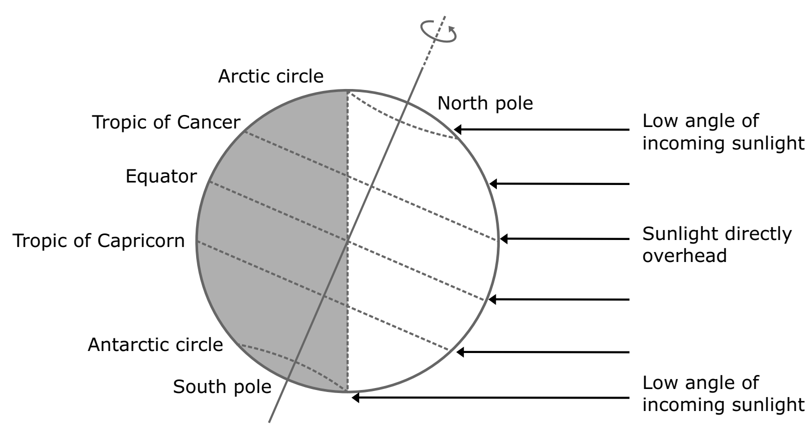


Figure 1.5 Inclination of the sun at Summer Solstice. The Sun is directly (90°) over the Tropic of Cancer and is at 66.5° over the equator. At this time, the area above the Arctic Circle is in light 24 hours a day, while the area below the Antarctic Circle is in darkness 24 hours a day.

When the incoming solar radiation is nearly perpendicular, the solar radiation is concentrated over a smaller surface area, causing high temperatures. At higher latitudes, the angle of solar radiation is smaller, causing solar radiation to spread over a larger surface area, causing lower

Poikilothermic (Greek *poikilos* – various, and *therme* – heat) animals like reptiles, fishes and amphibians are not able to maintain their body temperature at a constant level. In these organisms, the body temperature fluctuates with changes in the environmental temperature.

Poikilotherms have low metabolic rates and high thermal conductance. Environmental temperatures control their rates of metabolism. Poikilotherms have an upper and lower thermal limit that they can tolerate. The range of body temperatures at which poikilotherms carry out their daily activities is the *operative temperature range.* Upper and lower limits of tolerance to temperature vary among the poikilotherm species. To maintain a tolerable and fairly constant body temperature during active periods, terrestrial and amphibious poikilotherms rely on behavioral thermoregulation such as changing position or location.

To escape the long, cold winters, many terrestrial poikilotherms go into a long, seasonal torpor called **hibernation**. Torpor is a state of decreased physiological activity in an animal. Hibernation is characterized by physiological changes such as slow breathing and heart rate and low metabolic rate.

We also distinguish between **endothermic** (in Greek *endo* means 'within' and *therme* means 'heat') animals that produce sufficient metabolic heat to maintain a high body temperature and **ectothermic** (in Greek *ecto* means 'outside' and *therme* means 'heat') animals, which obtain much of their heat from the environment. *Endotherms* regulate their temperature by the production of heat within their own bodies, and *ectotherms* rely on external sources of heat.

Although it is true that many homeotherms are endotherms and many poikilotherms are ectotherms, we should not use the terms *endothermy* and *homeothermy* (or *ectothermy* and *poikilothermy*) synonymously. *Ectotherm* and *endotherm* emphasize the mechanisms that determine body temperature. The other two terms, *homeotherm* and *poikilotherm,* represent the nature of body temperature (either constant or variable).

The influence of temperature is size dependent. Small animals have relatively more surface area and relatively less metabolically active tissue to generate heat. Therefore, a small animal, when challenged with cold, lose heat more rapidly than a larger animal. If such an animal attempted to generate heat to offset the heat loss and maintain *body temperature*, it would require a relatively higher rate of energy generation. On the other hand, large animals have relatively small surface areas and cool slowly if placed in a cold environment.

A number of *rules* generalize the adaptive response of organisms to temperature. As with many other generalizations, exceptions to these rules exist. Among the best known is **Bergmann's rule**, which relates body size in endothermic vertebrates to average environmental temperature. Bergmann's rule states that individuals of species in cooler climates tend to be larger than those in warmer climates. This relationship derives primarily because bodies with larger volumes have small surface area-to-volume ratio. Because heat loss relates to surface area, larger bodies can retain heat more efficiently in cooler climates, whereas smaller bodies (large surface area-to-volume ratio) can eliminate heat more efficiently in warmer climates. An extension of Bergmann's rule is **Allen's rule** which states that endothermic animals from colder climates tend to have shorter extremities or appendages (e.g. ears and tail) than closely related species from warmer climates (*shorter extremities dissipate less heat*).

Another extension of Bergmann's rule is **Hesse's rule** (also known as the *heart–weight rule*) which states that species inhabiting colder climates have a larger heart in relation to body weight than closely related species inhabiting warmer climates.

1.3 Ecotype and Ecads

Many populations show a series of phenotypic variations as a result of environmental variations. These phenotypic variations usually remain even if the organisms are put in a different environment, and are inherited by their offspring, indicating that the characters are genetically rather than environmentally determined. A Swedish ecologist Turesson (1925) studied a plant species which showed some genetically fixed phenotypic variations between populations of the *Campanula rotundifolia*. He found that mountain populations were shorter and flowered earlier than the lowland forms. This suited their growth in short mountain turf and their adaptation for rapid flowering and seed production in the shorter growing season in high altitude mountain habitats. Turesson called these phenotypically different forms **ecotypes**.

An *ecotype* describes a genetically different population (subspecies) within a species which is adapted to specific environmental conditions. In ecotypes, adaptations become irreversible or genetically fixed. The different ecotypes of a particular species may differ in their edaphic, biotic or microclimatic requirements. Thus, ecotypes are genetically adapted local population. However, they are able to reproduce with other ecotypes of the same species and produce fertile offspring. Ecotypes can be classified and grouped together. A unit of classification which contains one or more ecotypes of a species is termed **ecospecies**. The term ecospecies has been proposed by Turesson. It is a unit of classification which contains one or more ecotypes, which although interfertile but do not cross or at least do not produce viable offsprings if crossed with ecotypes of other ecospecies.

A species with a continuous distribution cannot be divided at any one point into two ecotypes. For this pattern of distribution, the term **ecocline** has been applied. Ecocline represents the continuous variation or gradual change in plant phenotype, and associated genotype along an environmental gradient.

An **ecad** (also known as *ecophene)* is a plant species is a population of individuals which although belong to the same genetic stock, but differ markedly in phenotypes such as size, shape and number of leaves, etc. These variations are environmentally induced, and thus are temporary or reversible, i.e. one type of ecad may change into another with a change in its habitat. So, if different ecads are transplanted in the same habitat, all would become similar in appearance. Thus, ecads show **phenotypic plasticity** i.e. environmentally induced phenotypic variation. The phenotypic plasticity is the capacity of a single genotype to exhibit variable phenotypes in different environments. It is considered one of the major means by which plants can cope with environmental factor variability.

1.4 Metabolic rate and size of individuals

The *metabolic rate* of an organism is the amount of energy it needs per unit time. It is often estimated by measuring the rate at which oxygen is consumed. The most important factor affecting the metabolic rate of an individual is its size (mass). The study of the relationship of body size to shape, anatomy and physiology is called **allometry**. It can be defined broadly as 'the study of size and its consequences'.

An *allometric* relationship is one in which a physical or physiological property of an organism alters relative to the size of the organism.

Metabolic rate varies with body mass. However, rates are not directly proportional to body mass. The metabolic rate per unit of body mass in very small organisms is immensely higher than

Chapter 2

Ecosystem Ecology

An **ecosystem** (or *ecological system*) is a functional unit comprising all the organisms in a particular place interacting with one another and with their physical environment and interconnected by an ongoing flow of energy and a cycling of materials.

The concept of an ecosystem was first formally proposed by the English botanist Arthur Tansley in 1935. The term **biogeocoenosis** (proposed in the 1940s by the Soviet ecologist V. N. Sukachev) frequently used in Russian literature is roughly equivalent to the ecosystem. Its literal meaning is '*life and earth functioning together*'.

A key advance in the adoption of the ecosystem concept occurred after the appearance of a popular textbook by Eugene Odum. Odum's textbook was organized around the ecosystem concept. After Odum's textbook, a famous article in Science by Francis Evans (1956) mentioned the ecosystem as '*the basic unit in ecology*'. In the broadest sense, *an ecosystem is the interacting system made up of all the living and non-living objects in a physically defined space.*

Ecosystems ecology deals with the flow of energy and cycling of nutrients among organisms within a community and between organisms and the environment.

According to this simple definition, the size, location and timescale at which ecosystems are defined can therefore precisely match the question that the scientist is trying to answer. An ecosystem could be of any size depending on the communities to be studied and its boundaries can be either real or arbitrary. An ecosystem may be as small as a single tree or as large as the entire Earth and can be studied for time periods as long as millions of years.

An ecosystem can be visualized as a functional unit of nature. It has all components: biological and physical, necessary for survival. Accordingly, it is the basic unit around which theories and experiments of ecology are organized.

A *thermodynamic system* (or simply 'system') is a definite macroscopic region or space in the universe, in which one or more thermodynamic processes take place. Everything external to a thermodynamic system is called *surroundings*. System and surroundings are separated by a definite border called *boundary*.

All ecosystems are *open systems* in the sense that energy and matter are exchanged with their surroundings. It might be theoretically possible to define particular examples of ecosystems that are *closed systems*, not exchanging matters with their surroundings, but nearly all ecosystems do exchanges of energy and matters with their surroundings.

Ecosystems change through time. These changes may be gradual and subtle (losses of minerals from a weathering soil) or fast and dramatic (a fire sweeping through a forest). Both external forces (changes in climate or nutrient inputs) and internal dynamics (accumulation or depletion of materials in a soil or a lake) are important in driving temporal changes in ecosystems. In some cases, changes are directional and predictable (e.g. soil weathering, the filling of a lake basin), while in other cases changes may be specific and difficult to predict (e.g. the arrival of an invasive species).

Autecology is the study of the interaction between organisms and their environments at the level of an individual, a population or an entire species.

Synecology is the study of an ecological community. It is also called *community ecology*. It is the synecology which describes the ecological community as a whole, especially the links between organisms.

Box 2.1	**Levels of organization**

To study how organisms interact with each other and with their physical environments, several hierarchical levels of the organization have been recognized. Ecological patterns and processes vary as a function of the level of organization at which they operate.

Ecologists have identified four fundamental levels of the organization to study the interactions between organisms and their environment. These levels of organization include *individual organism, population, community* and *ecosystem*. Therefore, ecology ranges in scale from the study of an individual organism through the study of populations to the study of communities and ecosystems.

The most basic level of the ecological organization starts with the **individual** (a single plant, insect or bird). At the level of the organism, ecology deals with how individual organisms are affected by (and how they affect) their environment. *Organismal ecology* gives focus on the individual organisms' behaviour, physiology, morphology, etc. in response to the environment.

The next level of organization is the **population**. The term *population* has many uses and meanings in other fields of study. In ecology, a population is a group of individuals of the same species that occupy a given area. The *population ecology* deals with population growth and how and why a population changes over time.

Populations of different species in an area do not function independently of each other. They interact with each other. Hence, the next, more complex level of organization of the interacting population of different species form is the **community**. *Ecological communities* are made up of interacting populations of different species within some defined geographical area. *Community ecology* deals with the composition and organization of ecological communities and community development. Communities occur on a wide variety of scales from small pond communities to huge tropical rainforests. At the largest scales, these communities are known as 'biomes'. A **biome** is a distinct ecological community of plants and animals living together in a particular climate (for example, tropical rainforests, coniferous forests, savannas). It is characterized by distinctive vegetation distributed over a wide geographical area and defined largely by regional climatic conditions.

An **ecosystem** (or *ecological system*) is the interacting system made up of all the living and non-living components in a physically defined space. Because an ecosystem is a system, it has boundaries. All systems that encompass interacting biotic and abiotic components may be considered as an ecosystem. Ecosystems are complex, open, hierarchically organized, self-organizing and self-regulated systems. Ecosystems ecology deals with the flow of energy and cycling of nutrients among organisms within a community and between organisms and the environment. The highest level of organization for the ecological study is the **biosphere**. It is an ultimate ecosystem. It includes all ecosystems present on the Earth. In a strict sense, the biosphere represents all the living organisms of the Earth. But in ecology, the biosphere (also known as the **ecosphere**) is a functional concept which emphasizes the interrelationship between all living organisms and their environment on a planetary scale.

Although many ecologists have recognized 'ecosystem' as the fourth level of organization for an understanding of ecological phenomena. Some ecologists are considering the use of 'ecosystem' as the fourth level of organization is inappropriate because it does not include any new biological organization. Some have argued that the term 'landscape' would be a suitable term for a level of organization defined as an ecological system containing more than one community type.

Food chains

A classic paper by Lindeman (1942) laid the foundations of ecological energetics. He attempted to quantify the concept of food chains by considering the efficiency of energy transfer between trophic levels. The first trophic level belongs to the primary producers, the second level to the herbivores (primary consumers), and the higher levels of the carnivores (secondary consumers). Some consumers occupy a single trophic level, but many others, such as omnivores, occupy more than one trophic level. The relationship between one trophic level and adjacent trophic levels may be described by a food chain.

'The transfer of food energy from producers (plants) through a series of organisms that consume and are consumed is termed as a ***food chain****.'* A food chain shows the movement of energy through a system by indicating the path of food from a producer to a final consumer.

In general, food chains have 3 to 5 trophic links with 15 to 20 species. The length of food chain also may reflect the physical characteristics of a particular ecosystem. A harsh arctic landscape has a much shorter food chain than a temperate or tropical one.

Why are food chains relatively short? There are two main hypotheses. One, the **energetic hypothesis**, suggests that the length of a food chain is limited by the inefficiency of energy transfer along the chain. As we know, only about 10% of the energy stored in the organic matter of each trophic level is converted to organic matter at the next trophic level. At each transfer, a proportion (often as high as 80% to 90%) of the potential energy is lost as heat. Therefore, the shorter the food chain — or the nearer the organism to the first trophic level — the greater the energy available to that population. The second hypothesis, the **dynamic stability hypothesis**, proposes that long food chains are less stable than short chains. Population fluctuations at lower trophic levels are magnified at higher levels, potentially causing the local extinction of top predators. This hypothesis predicts that food chains should be shorter in unpredictable environments. Most of the data available support the energetic hypothesis.

Types of food chains

Within any ecosystem, there are two major food chains: the **grazing food chain** and the **detritus food chain**. The distinction between these two food chains is the source of energy for primary consumers. In the grazing food chain, the source of energy is living plant biomass (or net primary production). In the detrital food chain, the source of energy is dead organic matter or detritus.

Grazing food chains begin with photosynthetic plants (primary producers). Primary consumers (or herbivores) form the second link in the grazing food chain. They gain their energy by consuming primary producers. Secondary consumers (or primary carnivores), the third link in the chain, gain their energy by consuming herbivores. Tertiary consumers (or secondary carnivores) are animals that receive their energy by consuming primary carnivores.

Producer	→	Herbivore	→	Primary carnivore	→	Secondary carnivore
e.g. Grass		*e.g. Insect*		*e.g. Frog*		*e.g. Snake*

More often than not, such simple food chains are oversimplified versions of the reality of feeding relationships. Instead, there are often multiple and interconnecting pathways, as well as numbers of different species involved at each trophic level. These complex pathways

Autotroph and detritus-based ecosystem

The *autotroph based ecosystems* depend directly on the influx of solar radiation. They are characterized by a dependence on energy capture by photosynthetic autotrophs and secondarily by the movement of that captured energy through the system via herbivory and carnivory. A large number of ecosystems function in this way and numerous herbivores, carnivores and omnivores are dependent on such autotrophic ecosystems.

Some ecosystems depend less on direct solar energy incorporation and more on the influx of dead organic material, or detritus, produced in another ecosystem. Ecosystems, such as caves, are independent of direct solar energy and are dependent on the influx of detritus for energy. These ecosystems are regarded as *detritus-based ecosystems*.

Ecological efficiencies

In ecosystems, living organisms are linked together by feeding relationships. Producers (or autotrophs) have the ability to fix carbon through photosynthesis *via* chlorophylls in their leaves. Herbivores are the primary consumers of organic molecules fixed by the producers. Carnivores are secondary consumers, living on the organic molecules of the herbivores. There may be several levels of carnivores in any one ecosystem; in such cases, the ultimate level will be occupied by the top carnivore. The final groups of organisms in an ecosystem are decomposers, bacteria and fungi which can break down the complex organic chemicals of dead materials and waste products. *The amount of energy reaching each trophic level is determined by the NPP and the efficiencies with which food energy is converted to biomass energy within each trophic level.*

Percentage of energy in the biomass produced by one trophic level that is incorporated into the biomass produced by the next higher trophic level is called **ecological efficiency** (also called as *transfer efficiency* or *Lindeman's efficiency*)**.**

The proportions of net primary production that flow along each of the possible energy pathways depend on transfer efficiencies in the way energy is used and passed from one step to the next. A knowledge of three categories of transfer efficiency is required to predict the pattern of energy flow. These are *consumption efficiency* (CE), *assimilation efficiency* (AE) and *production efficiency* (PE).

Consumption efficiency (or *exploitation efficiency*) is the percentage of total productivity available at one trophic level (P_{n-1}) that is actually consumed (i.e. ingested) by a trophic compartment one level up (I_n).

$$\text{Consumption efficiency (CE)} = \frac{I_n}{P_{n-1}} \times 100$$

Ingestion
Ingestion is the process by which food is taken into the alimentary canal.

Assimilation
Assimilation is the process by which digested foods are taken into the cells of the alimentary canal.

In the case of secondary consumers, it is the percentage of herbivore productivity eaten by carnivores. Consumption efficiencies of herbivores are typically low in most ecosystems dominated by vascular plants, which are in many cases well defended against herbivores. For example, herbivores consume less than 10% of primary production in most terrestrial ecosystems. Herbivory in aquatic ecosystems is generally greater than in terrestrial ecosystems especially for algal-based ecosystems where herbivores often consume more than 50% of primary production. Similarly, in terrestrial forests, consumption efficiencies of herbivores are less as compared to grasslands where most plants are nonwoody.

Nutrient cycling

The Earth is essentially a *closed system* with respect to matter and *all matter on the Earth cycles*. Every matter that is used by living organisms passes between the biotic and abiotic components of the Earth. By 'matter' we mean *elements* (such as carbon, nitrogen, oxygen) or *molecules* (water). *Nutrient cycling* (or more precisely *element cycling*) is the movement of elements through both the biotic and abiotic components of the Earth. It is the transport and transformation of elements within and among ecosystems. It involves the incorporation of elements by living organisms and their subsequent release back into the environment via decomposition. It links biotic and abiotic parts of ecosystems. The movement of elements through atmosphere, hydrosphere, lithosphere and biosphere is generally termed as a **biogeochemical cycle**. An element's specific route through a biogeochemical cycle depends on the nature of element. All elements occurring in organisms are part of biogeochemical cycles. In addition to being a part of living organisms, these elements also cycle through abiotic components of ecosystems.

There are two basic types of biogeochemical cycles: *gaseous* and *sedimentary*. This classification is based on the primary source of element input to the ecosystem. In **gaseous cycles**, the *atmosphere* acts as a major reservoir of the element. Such cycles show little or no permanent change in the distribution and abundance of the element. Carbon and nitrogen are prime representatives of biogeochemical cycles with a prominent gaseous phase. In **sedimentary cycle**, the major reservoir is the lithosphere from which the elements are released largely by weathering. The sedimentary cycles, exemplified by phosphorus, sulfur and most of the other biologically important elements, have a tendency to stagnate. In such cycles, a portion of the supply may accumulate in large quantities, as in the deep ocean sediment, and thereby become inaccessible to organisms and to continual cycling. Some of the elements that are characterized by sedimentary cycles do have a gaseous phase, sulfur and iodine being among them, but these phases are insignificant in that there is no large gaseous reservoir.

An element's specific route through a biogeochemical cycle varies with the particular element. Based on spatial scale, there are, however, two general categories of biogeochemical cycles: *global* and *local cycle.* In **local cycles** such as the phosphorus cycle, there are no mechanisms for long distance transfer of elements; whereas **global cycles** such as nitrogen cycle, involve atmosphere for long distance transfer of elements. Global cycles unite the Earth into one giant interconnected ecosystem. Gaseous forms of carbon, oxygen, sulfur and nitrogen occur in the atmosphere, and cycles of these elements are essentially global. Other, less mobile elements, including phosphorus, potassium and calcium, generally cycle on a more localized scale, at least over the short term. Lithosphere is the main abiotic reservoir of elements performing local cycle.

Lithosphere
The lithosphere is composed of all the solid land mass comprising Earth's crust and upper mantle.

Biosphere
All the living things in the planet are categorized under the biosphere. In this view, the biosphere includes all the biotic components of the Earth.

Atmosphere
The atmosphere is the body of gases that surrounds our planet. Most of our atmosphere is located close to the Earth's surface.

Hydrosphere
The hydrosphere includes all the gaseous, liquid and solid forms of water of the Earth.

General model of nutrient cycling

Although the nutrient cycling of the various elements differ in detail, from the perspective of the ecosystem all nutrient cycles have a common pattern. A general model of nutrient cycling includes the main reservoirs of elements and the processes that transfer elements between reservoirs. Each reservoir is defined by two characteristics: whether it contains organic or inorganic materials and whether or not the materials are directly available for use by organisms. The nutrients in living organisms and in detritus are available to other organisms when

Nitrogen fixation

Natural processes of nitrogen fixation are of two types – *Biological nitrogen fixation* and *Nonbiological nitrogen fixation* (including nitrogen fixation by lightning and photochemical reactions). Approximately 90% of nitrogen fixation is biological nitrogen fixation, in which prokaryotic organisms fix molecular nitrogen into ammonia. It is a reductive biosynthetic process. Few prokaryotic organisms (termed as nitrogen-fixing organisms or **diazotroph**) are capable of biological nitrogen fixation only. Eukaryotic organisms are unable to fix nitrogen. The biological reaction of nitrogen fixation generates at least one mole of H_2 in addition to two moles of NH_3 for each mole of nitrogen molecule. Hence, total eight electrons are required in the reduction of one mole of nitrogen to two moles of NH_3.

$$N_2 \xrightleftharpoons{8e^- + 8H^+} 2NH_3 + H_2$$

Ammonification

Most of the nitrogen in the soil exists in organic forms. When organic nitrogen is converted into ammonium ions by bacteria and fungi, it is called *ammonification* or *mineralization.* Mineralization is a general term used for a process in which organically bound nutrient is released in an inorganic form.

Nitrification

The oxidation of ammonium ions to nitrite and subsequent oxidation of nitrite to nitrate is called *nitrification*. It is carried out exclusively by bacteria. There are two distinct steps of nitrification that are carried out by distinct types of bacteria. The first step in nitrification is the oxidation of ammonium ions to nitrite. This step is carried out by nitrifying bacteria (known as *ammonia-oxidizers*) of genera *Nitrosomonas*, *Nitrosospira* and *Nitrosococcus*.

The second step in nitrification is the oxidation of nitrite to nitrate. This step is carried out by nitrifying bacteria (known as *nitrite - oxidizers*) of genera *Nitrospira*, *Nitrobacter* and *Nitrococcus*.

$$2NH_4^+ + 3O_2 \longrightarrow 2NO_2^- + 4H^+ + 2H_2O$$

$$2NO_2^- + O_2 \longrightarrow 2NO_3^-$$

Denitrification

The process of conversion of NO_3^- into N_2 by anaerobic denitrifying bacteria is called *denitrification*. These bacteria use nitrate rather than oxygen as an electron acceptor during respiration. This causes nitrate to be reduced, producing in turn NO_2^-, NO, N_2O and finally N_2. Denitrification can only be performed under anaerobic conditions.

The process is performed primarily by heterotrophic denitrifying bacteria (such as *Paracoccus denitrificans* and various pseudomonads), although autotrophic denitrifiers have also been identified (e.g. *Thiobacillus denitrificans*).

$$2NO_3^- \longrightarrow 2NO_2^- \longrightarrow 2NO \longrightarrow N_2O \longrightarrow N_2$$

Anammox

Anammox (an abbreviation for ANaerobic AMMonium OXidation) is a recently discovered bacterial process which involves the anaerobic oxidation of ammonium to molecular nitrogen using nitrite as electron acceptor. Therefore, this process couples the oxidation of ammonium concentrations of some nutrients in the soil of tropical rainforests result from a faster nutrient cycling rate. In temperate forests, where decomposition is much slower, the soil may contain a large amount of the dead organic matter in the forest. Decomposition on land is also slower when conditions are either too dry for decomposers to thrive or too wet to supply them with enough oxygen.

2.2 Ecosystem services

Ecosystem services are '*the benefits which people obtain from ecosystems*'. According to IPCC (Intergovernmental Panel on Climate Change), ecosystem services are ecological processes or functions which have value to individuals or society. For example, forest ecosystems purify air and water, mitigate droughts and floods, cycle nutrients, generate fertile soils, provide wildlife habitat, maintain biodiversity, pollinate crops, provide storage site for carbon and also provide aesthetic, cultural and spiritual values.

Ecosystem services are grouped into four broad categories. All of these services are provided by complex chemical, physical, and biological processes, powered by the Sun, and operate at different temporal and spatial scales.

Provisioning, such as the production of food and water;

Regulating, such as the control of climate and disease;

Supporting, such as nutrient cycles and crop pollination; and

Cultural, such as spiritual and recreational benefits.

Provisioning services Products obtained from ecosystem.	**Regulating services** Benefits obtained from regulation of ecosystem processes.	**Cultural services** Non-material benefits obtained from ecosystem.	**Supporting services** Services necessary for the production of all other from ecosystem.
• Food	• Climate regulation	• Spiritual and religious	• Soil formation
• Fresh-water	• Disease regulation	• Recreation and ecotourism	• Nutrient cycling
• Fuelwood	• Water regulation	• Aesthetic	• Primary production
• Fiber	• Water purification	• Inspirational	
• Biochemicals	• Pollination	• Educational	
• Genetic resources		• Sense of place	
		• Cultural heritage	

2.2.1 Control of trophic structure: top–down versus bottom–up control

We have learned about how materials and energy flow through ecosystems. Now, we can address the question of 'what controls the trophic structure'? The control of tropic structure i.e. the partitioning of biomass between trophic levels is broadly divided into two categories. The first of these categories, **bottom-up control**, emphasizes the energy inputs into the primary producers and the subsequent efficiency of energy transfer between trophic levels in determining the biomass accumulation at each trophic level. The second category, **top-down control**, emphasizes the importance of predation in influencing patterns of biomass accumulation at different trophic levels.

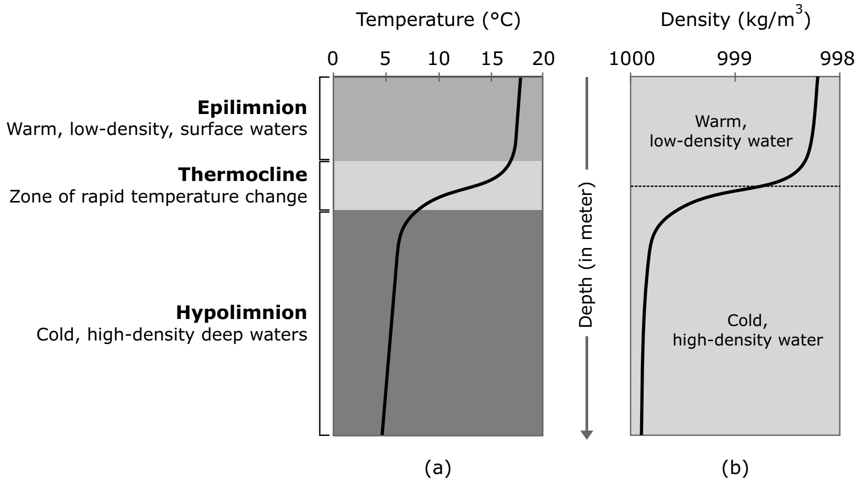


Figure 2.17 Temperature and density profiles with water depth for a temperate lake during summer. (a) The region of the vertical depth profile where the temperature declines most rapidly is called the thermocline. The thermocline is located between an upper layer of warm, less dense water called the epilimnion and a deeper layer of cold, denser water called the hypolimnion. (b) The rapid decline in temperature in the thermocline results in a distinct difference in water density in the warmer epilimnion as compared to the cooler waters of the hypolimnion, leading to a two-layer density profile—warm, low-density surface water and cold, high-density deep water.

Seasonal changes in water temperature

The temperature profile of a deep-water lake of *temperate region* changes from one season to the next and creates a cyclic pattern. Due to seasonal variation in the input of solar radiation to the water surface give rise to seasonal changes in the vertical profile of temperature.

Let us begin with spring season. After the ice melts on a lake, the lake water is generally has the same temperature from the surface to the bottom. It allows circulation and mixing of the lake water. Surface water can be pushed to the lake bottom and bottom water can rise to the surface. This circulation pattern allows large amounts of oxygen to reach the bottom of the lake. The mixing of the lake water at this time of year is called **spring overturn**.

As air temperature rises in summer, heat from the Sun begins to warm the lake. The layer of warm water at the surface of the lake is called the *epilimnion*. The cold layer below the epilimnion is called the *hypolimnion*. These two layers are separated by a layer of water which rapidly changes temperature with depth. This is called the *thermocline* (or *metalimnion*). Stratification during the summer acts as a deterrent to complete lake mixing. Wind circulates the surface water, but the warm water of the epilimnion is unable to move through the cold, dense water of the hypolimnion. As a result, the water is only mixed in the epilimnion.

As autumn (fall) approaches and temperature decreases, the epilimnion begins to decrease in depth. Eventually, the epilimnion gets so shallow that it can no longer be maintained as a separate layer and the lake loses its stratification. Thus, as in the spring, the lake water in the autumn has generally uniform temperatures and wind can once again thoroughly mix the lake water. In addition, surface water, which is in direct contact with the cold air, gets cooled faster than the water below. This cold, dense water sinks and further helps to mix the lake, and again more oxygen and nutrients are replenished throughout the lake. This process is called **autumn overturn**.

Box 2.4	Ramsar Convention

The Ramsar Convention (also known as the Convention on Wetlands) is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. It is named after the city of Ramsar in Iran, where the Convention was signed in 1971. The 2nd of February each year is **World Wetlands Day**, marking the date of the adoption of the Convention on Wetlands on 2 February 1971.

There are presently 169 Contracting Parties to the Convention. India is also a signatory to the Ramsar Convention on Wetlands. The 'Ramsar List' (list of wetlands of international importance) has 2,282 Ramsar Sites (wetlands of international importance) in March 2016. The country with the highest number of Ramsar Sites is the United Kingdom with 170; India currently has 26 Ramsar Sites.

Terrestrial ecosystem

Terrestrial ecosystems are those that are found only on land. The key to the meaning of terrestrial ecosystems lies in the word 'terrestrial', which generally means anything occurring on land. Therefore, terrestrial ecosystem refers to the interacting system made up of living organisms and non-living objects occurring on land. Only 28 percent of the Earth's surface belongs to terrestrial ecosystems.

Forest ecosystem

A **forest** is a complex ecosystem which is predominantly composed of trees and shrubs. It is defined as 'a land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent' (UN FAO). It does not include land that is predominantly under agricultural or urban land use. Forests are the dominant terrestrial ecosystem of Earth and are distributed across the globe. Forests account for 75% of the gross primary productivity of the Earth's biosphere and contain 80% of the Earth's plant biomass. Based on canopy cover, forest can be *very dense forest* (all lands with tree cover of canopy density of 70% and above), *moderately-dense forest* (all lands with tree cover of canopy density between 40% and 70% above) and *open forest* (all lands with tree cover of canopy density between 10% and 40%). Forest types differ widely, determined by factors including latitude, altitude, temperature, rainfall patterns and soil composition. Climate (temperature and rainfall), soil types and topography are the main factors that determine the type of forest. There are three major types of forest – taiga forest, temperate forests and tropical forests

Taiga forest (*coniferous forest* or *boreal forest*) is located at higher latitudes, close to the polar region and is dominated by needle-leaved, drought tolerant, evergreen trees. The taiga or boreal forest has a subarctic climate. Winter is long and very cold and summer is short and cool. Precipitation occurs primarily in the form of snow, 40–100 cm annually.

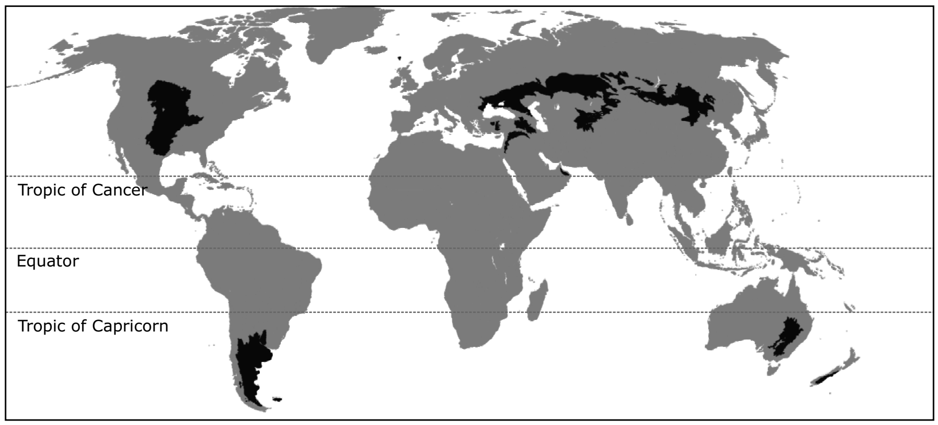
The UNFCCC defines 'a *forest* as an area of land 0.05–1 hectare in size, of which more than 10–30% is covered by tree canopy. Trees must also have the potential to reach a minimum height of 2-5 metres'.

Temperate forests are found in the temperate climatic zone (between the tropics and boreal regions) in both the Northern and Southern Hemisphere. They may also be called 'four-season forests' because these forests experience four distinct seasons. In the temperate region, winters are mild and rainfall is moderate. Temperate forests are a mix of deciduous, broad-leaved and coniferous evergreen trees. They are simpler in structure than tropical forests and support a lesser number of tree species. Temperate forests can be further distinguished by weather

Temperate grasslands are known as the *veldts* of South Africa, the *puszta* of Hungary, the *pampas* of Argentina and Uruguay, the *steppes* of the former Soviet Union and the *plains* and *prairies* of central North America.

Temperate grasslands

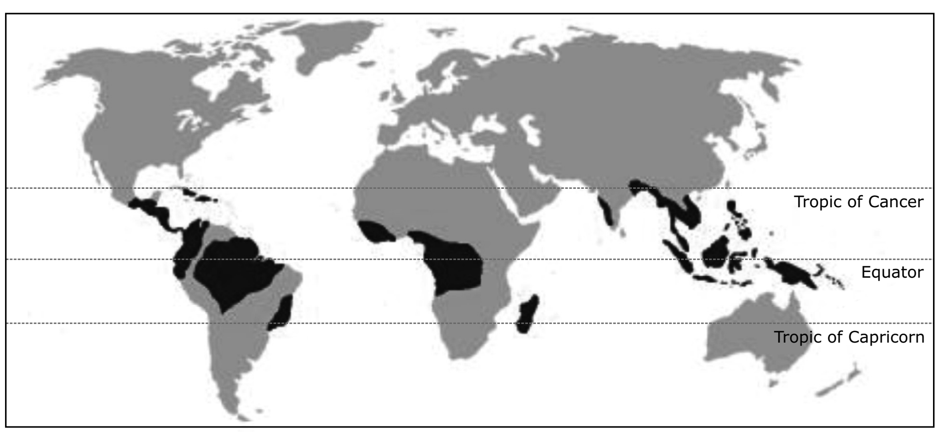
Temperate grasslands are characterized as having grasses as the dominant vegetation. Trees and large shrubs are absent. Temperate grasslands have hot summers and cold winters and the amount of rainfall (25 to 75 cm) is less than in savannas. As in the savanna, seasonal drought and occasional fires are very important to maintain biodiversity. However, their effects aren't as dramatic in temperate grasslands as they are in savannas. The type of grassland community that develops, and the productivity of grasslands, depends strongly upon precipitation. Higher precipitation leads to tall grasses with a high biodiversity of grasses. Temperate grasslands can be further subdivided. *Prairies* are grasslands with tall grasses while *steppes* are grasslands with short grasses.



Temperate grassland biome

Tropical rainforests

Tropical rainforests occur at low altitude zones near the equator (found within 23.5° latitude of the equator) and are characterized by a high temperature, high rainfall and greatest diversity of species. The average temperature is between 20–25°C and varies little throughout the year. Winter is absent. Annual rainfall exceeds 200 cm. Although, the climate of tropical rainforest regions varies geographically but is typically characterized by a mean temperature of all months exceeding 18°C and minimum monthly precipitation above 6 cm. Warm and moist conditions promote strong chemical weathering and rapid leaching of soluble materials.



Tropical Rainforests

References

Barrett GW, Likens GE and Odum EP (2002), *Pioneer of ecosystem ecology*. BioScience, 52: 1047-1048.

Begon M, Townsend CR, Harper JL (2006), *Ecology: From individuals to ecosystems*, 4th ed. Blackwell Publishing.

Bormann FH and Likens GE (1967), *Nutrient cycling*. Science, 155:424-429.

Campbell NA et al. (2005), *Biology*, 7th ed. San Francisco CA: Pearson.

Carpenter SR and Kitchell JF (1988), *Consumer control of lake productivity*. BioScience, 38:764-769.

Chapin FS, Matson PA and Vitousek PM (2011), *Principles of Terrestrial Ecosystem Ecology*, 2nd ed. Springer.

Chapman JL and Reiss MJ (2010), *Ecology: Principles and Applications*, 2nd ed. Cambridge University Press.

Dodson SI, Arnott SE and Cottingham KL (2000), *The relationship in lake communities between primary productivity and species richness*. Ecology, 81, 2662–2679.

Field CB, Behrenfield MJ, Randerson JT and Falkowski PG (1998), *Primary production of the biosphere: integrating terrestrial and oceanic components*. Science, 281, 237–240.

Jorgensen SE (1997), *Integration of ecosystem theories: A pattern*. Dordrecht: Kluwer.

Knight TM et al. (2005), *Trophic cascades across ecosystems*. Nature, 437, 880-883.

Kormondy EJ (1996), *Concepts of Ecology*, 4th ed. W.H. Prentice-Hall.

Krebs CJ (2009), *Ecology*, 6th ed. San Francisco CA: Pearson Benjamin Cummings.

Lidicker WZ (2008), *Levels of organization in biology: on the nature and nomenclature of ecology's fourth level*. Biol Rev Camb Philos Soc.

Melillo JM et al. (1993), *Global climate-change and terrestrial net primary production*. Nature, 363, 234–240.

Molles MC Jr. (2010), *Ecology*: *Concepts and Applications*, 5th ed. McGraw-Hill Higher Education, NY.

Naveh Z and Lieberman AS (1984), *Landscape ecology: Theory and application*. New York: Springer Verlag.

Odum EP (1969), *The Strategy of Ecosystem Development*. Science, 164, 262-270.

Odum EP and Barrett GW (2004), *Fundamentals of Ecology*, 5th ed. Cengage Learning.

Ricklefs RE (1990), *Ecology*, 3rd ed. W.H. Freeman and Company, New York.

Roy J et al. (2001), *Terrestrial Global Productivity*. San Diego, CA: Academic Press.

Schlesinger WH (1997), *Biogeochemistry: An analysis of global change*. San Diego, CA: Academic Press.

Smith TM and Smith RL (2009), *Elements of Ecology*, 7th ed. San Francisco CA: Pearson Benjamin Cummings.

Stiling P (2015), *Ecology: Global insights and investigations*, 2nd ed. McGraw-Hill Education.

Whittaker RH and Likens GE (1973), The primary production of the biosphere. Human Ecology, 1:301-369.

Chapter 3

Population Ecology

Each species in an ecosystem exist as a population. A **population** is a group of individuals of the same species that live together in a region. Members of a population rely on the same resources, are influenced by similar environmental factors and are bred with one another. In other words, a population (synonymous with *biological population*) consists of a group of interbreeding or potentially interbreeding organisms found in the same space or area at the same time. The study of populations (especially population abundance) and how they change over time is called **population ecology**. It studies the spatial and temporal patterns in the abundance and distribution of organisms and of the mechanisms that produce those patterns. The study of population ecology includes understanding, explanation and prediction of population growth, regulation and dynamics or demography.

Multicellular organisms are of two kinds, unitary organisms and modular organisms. Most animal populations are made up of **unitary organisms**. In unitary organisms, the form is highly determinate consisting usually of a strictly defined number of parts (such as legs or wings) established only during embryogenesis. Their pattern of development and final form are predictable. For example, all dogs have four legs, all squid have two eyes, etc. In **modular organisms**, on the other hand, neither timing nor form is predictable. These organisms grow by the repeated iteration of modules, usually to yield a branching pattern. Examples of modular organisms include plants and many sessile benthic invertebrates. In modular organisms, a single genetic individual (or *genet*) can consist of many modules (or *ramets*) capable of existence as individuals. In plants, a **genet** is an individual that has arisen from a seed. A **ramet** is a new plant which has arisen through vegetative propagation and is now a completely independent plant with its own roots and shoots. For example, a population of grasses may consist of several genets, each of which has several ramets.

3.1 Population characteristics

A population has several characteristics or attributes which are a function of the whole group and not of the individual. Different populations can be compared by measuring these attributes. These attributes are population density, natality, mortality, distributions, etc. The study of the group characteristics of a population, their changes over time and prediction of future changes is known as **demography**.

Population density

The size of the population is represented by its fundamental property called *density*. It is generally expressed as the number of individuals or the population biomass per unit area or volume. Two types of densities are described – *crude density* and *specific* (or ecological) *density.* **Crude density** is the density per unit of total space. Generally, populations do not occupy all the space as whole because all area may not be habitable. Hence, density per unit of habitable space is called **specific density**. It includes only that portion of total space that can actually be colonized by the population.

Determining population size

Population size (or abundance) is a function of population density and the area that is occupied (geographic distribution). Usually, population size is estimated by counting all the individuals from a smaller sample area, then extrapolated over a larger area. When the individuals are not mobile - their population size may be estimated by counting individuals within a specified area. When individuals are very mobile and frequently move from one area to another then we can count the number by applying a common method called a **mark-recapture method**. Using this method, a small random sample of the population is captured, marked, then released to disperse within the general population. The marked individuals mix freely with unmarked individuals and within a short time are randomly mixed within the population. The population is resampled and the numbers of marked and unmarked individuals are recorded. We then assume that the ratio of marked to unmarked individuals in the second sample taken is the same as the ratio of marked to unmarked individuals in the first sample. We can use a simple formula for estimating total population size (N):

$$N = \frac{\text{Total individuals marked in first sample} \times \text{Size of second sample}}{\text{Number of marked individuals recaptured in second sample}}$$

This expression is known as the **Lincoln-Peterson index** to population size.

Let’s take an example to understand mark-recapture method. Suppose, we catch 50 fish (*Labeo rohita*) in a lake and mark (color) them. After that, we release all marked fishes immediately as close as possible to the collection site. A week later (after giving sufficient time to mix randomly with the whole population) we catch 40 fish (a second sample) and 5 of them are previously marked fish. If we assume no immigration or emigration has occurred, which is quite likely in a closed system like a lake, and we assume there have been no births or deaths of fish, then the total population size of fish is 400 (50×40/5).

Natality

Natality refers to the birth of individuals in a population. The natality rate (or birth rate) is expressed as the number of individuals produced per female per unit time. To describe ‘rate’, we must specify time interval (such as one year or one month) and a base population. Two bases are commonly used – *Per capita or per individual* (it is equivalent to the number of births per individual per unit of time) or *Per 1000 individuals*.

Natality may be *maximum natality* or *ecological* natality. **Maximum natality** (sometimes called *absolute* or *physiological natality*) is the theoretical maximum number of individuals produced under ideal environmental conditions (i.e. no ecological limiting factors) and is a constant for a given population. **Ecological** or **realized natality** refers to the number of individuals produced

Exponential growth

A population shows *exponential growth* if there is no limitation on growth i.e. in an idealized unlimited environment. Under an ideal unlimited environment, the per capita rate of increase (the number of offspring born per individual) is maximum. During exponential growth, the number increases in the geometric progression 2^0, 2^1, 2^2, 2^3,…. In *geometric growth*, the rate of increase is expressed as a constant fraction or an exponent by which a particular population is multiplied (like 2, 4, 8, 16…). By contrast, a pattern of growth that increases at a constant amount per unit of time (i.e. 1, 2, 3, 4 or 1, 3, 5, 7…) is called *arithmetic growth*. The *exponential* form of growth may be represented by the simple model based on the exponential equation:

$$\frac{dN}{dt} = rN \quad \text{or,} \quad \frac{dN}{dt} \times \frac{1}{N} = r$$

Where, *N* is the *population size* and *r* is the *intrinsic rate of increase*.

During exponential population growth under an ideal unlimited environment, per capita rate of increase is maximum and is called the **intrinsic rate of increase**. The maximum value of *r* is often referred by the less specific but widely used expression **biotic potential** (or *reproductive potential*). It is the maximum per capita growth rate in the absence of *environmental resistance.* The sum total of all environmental factors that together act to limit the biotic potential of an organism from being realized is called *environmental resistance*. It includes both biotic factors such as predation, competition, parasitism and abiotic factors such as drought, fire, flood etc. Biotic potential differs from one species to another e.g. deer populations can grow faster than a population of elephants.

In a *closed* population, *r* is defined as the *per capita birth rate* (b) minus the *per capita death rate* (d).

$$\frac{dN}{dt} = (b - d)N \qquad \text{where, } r = b - d$$

When per capita birth rate exceeds per capita death rate (b > d), the population is increasing and *r* is *positive*; when death rate exceeds birth rate (d > b), then *r* is *negative* and the population is decreasing.

The integral form of the exponential growth equation is:

$$N_t = N_0 e^{rt}$$

Where, N_t = Population size after time t,

N_0 = Population size at time zero,

r = Intrinsic rate of increase and

e = Exponent, a mathematical constant

$$\frac{N_t}{N_0} = e^{rt}$$

By taking the natural log of both sides,

$$\ln N_t - \ln N_0 = rt$$

When resources (food and space) in a habitat are unlimited, all members of a species have the ability to grow exponentially. The population size that increases exponentially at a constant rate, results in a *J-shaped growth curve* when population size (N) is plotted over time (t).

3.4 Population regulation

Are populations regulated? If so, how? What does population regulation really mean? Population ecologists have identified a number of mechanisms by which populations could be regulated. Broadly speaking, factors regulating population growth are either density-dependent or density-independent.

Density-dependent factors affect population growth as a *function of the population density*. These factors include disease, competition for resources and predation. For example, a population of rabbits may increase exponentially until competitive intraspecific interactions cause either the birth rate to decrease or the death rate to increase, leading to a net decline in reproductive rate and subsequent decrease in population density. Density-dependent factors often include resources that are in limited supply such as space, water and nutrients.

Density-dependent factors can have either a positive or a negative correlation to population size. As population size increases, either birth rate declines or mortality rate increases or both. It is a *negative feedback*. However, not always density-dependent factors are negatively related to population size. In some cases, growth rate increases with population size. This phenomenon is referred to as the **Allee effect** (after W. Allee, who first described it) and is an example of *positive feedback.* A positive relationship between fitness and population size can be caused by a variety of mechanisms that affect reproduction and survival. A well-established reason of Allee effect is the *mate limitation*. Because sexual reproduction requires contact between male and female gametes, mate limitation reduces reproduction in small population. Second reason is the increased vulnerability to predators. The per capita risk of predation is less in large prey populations than small prey populations. Finally, genetic mechanisms may give rise to Allee effects. For many organisms, when population size is small, inbreeding depression can cause an Allee effect by reducing average fitness as population size declines.

Density-independent factors affect population growth, irrespective of the density of the population. These factors are usually associated with abiotic events – changes in the physical environment – that either promote or repress population growth, but their effects are *independent of population density*. Density-independent factors may include natural catastrophes such as hurricanes, floods, and seasonal variation in weather patterns.

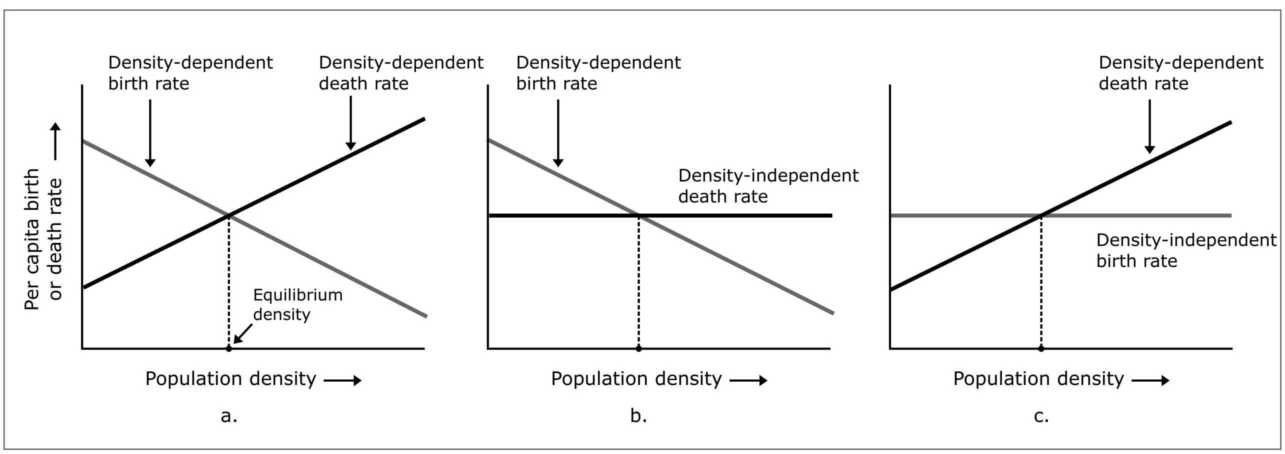


Figure 3.7 Determining equilibrium for population density. This simple model considers only birth and death rates. a. Both birth rate and death rate change with population density. b. Birth rate changes with population density while death rate is constant. c. Death rate changes with population density while birth rate is constant

References

Begon M, Harper JL and Townsend CL (1986), *Ecology*: *Individuals, Populations and Communities*. Sinauer Associates, Sunderland, MA.

Blackburn TM, Cassey P and Gaston KJ (2006), *Variations on a theme*: *Sources of heterogeneity in the interspecific relationship between abundance and distribution*. Journal of Animal Ecology, 75, 1426–1439.

Campbell NA et al. (2005), *Biology*, 7th ed. San Francisco CA: Pearson.

Chapman JL and Reiss MJ (2010), *Ecology, Principles and Applications*, 2nd ed. Cambridge University Press.

Hanski IA (1989), *Metapopulation dynamics: Does it help to have more of the same?* Trends in Ecology and Evolution, 4:113-114.

Kenyon C (2010), *The genetics of ageing*. Nature, 464, 504–512.

Kormondy EJ (1996), *Concepts of Ecology*, 4th ed. W.H. Prentice-Hall.

Miller GT and Spoolman SE (2009), *Essentials of Ecology*, 5th ed. Brooks/Cole, Cengage Learning.

Murdoch WW (1994), *Population regulation in theory and practice*. Ecology, 75:271–287.

Odum EP and Barrett GW (2004), *Fundamentals of Ecology*, 5th ed. Cengage Learning.

Pianka ER (1970), *r- and K-selection*. American Naturalist, 102: 592–597.

Ranta E, Lundberg P and Kaitala V (2006), *Ecology of Populations*, Cambridge University Press.

Raven PH, Johnson GB, Mason KA, Losos JB, and Singer SR (2011), Biology, 9th ed. McGraw-Hill.

Ricklefs RE (1990), *Ecology*, 3rd ed. W.H. Freeman and Company, New York.

Rockwood LL (2006), *Introduction to Population Ecology*, Blackwell Publishing.

Smith TM and Smith RL (2009), *Elements of Ecology*, 7th ed. San Francisco CA: Pearson Benjamin Cummings.

Stiling P (2015), *Ecology*: *Global insights and investigations*, 2nd ed. McGraw-Hill Education.

Wauters LA and Lens L (1995), *Effects of food availability and density on red squirrel* (*Sciurus vulgaris*) *reproduction*. Ecology, 76, 2460–2469.

Young TP (1981), *A general model of comparative fecundity for semelparous and iteroparous life histories*. American Naturalist, 118, 27–36.

Chapter 4

Community Ecology

An **ecological community** is a group of species that coexist in a space and time and interact with one another directly or indirectly. The term 'community' means different things to different ecologists. Most definitions of ecological communities include the idea of a collection of species found in a particular place. For instance, Robert Whittaker (1975) defined ecological community as,

'...an assemblage of populations of plants, animals, bacteria and fungi that live in an environment and interact with one another, forming together a distinctive living system with its own composition, structure, environmental relations, development and function.'

Simply, an ecological community is a group of interacting species that inhabit a particular location at a particular time. Most communities are extraordinarily complex. However, main features of ecological communities include:

Firstly, a community represents the biotic or a living component of the ecosystem. Organisms within a community include primary producers, consumers and decomposers. In terrestrial communities, the community structure is largely defined by the vegetation.

Secondly, considering the functional aspect, communities are made up of organisms with interlocking food chains and each species depends on many other species in a community which are taxonomically unrelated.

Thirdly, a community may be of any size. It can range from small pond communities to huge tropical rain forests.

Community ecology is a field that examines the effects of abiotic and biotic features on community or assemblage structure. Community ecologists study the number of species and their relative abundance in a particular location and ask why the number of species and their abundance changes over time. They also do study communities in different locations and differences in the species diversity with location. In a broad sense, the goal of community ecology is to understand the origin, maintenance and consequences of biological diversity within communities.

Community is a group of interacting populations of different species occurring together in space whereas *assemblage* is a taxonomically related group of species populations that occur together in space.

There are two contrasting concepts of the community – *organismal* and *individualistic concepts*. The **organismal concept** of communities (put forward by Clements, 1916) views the community as a unit, an association of species, in which each species is representing an interacting, integrated component of the whole and development of the community through

4.1.2 Species diversity

Species diversity is one of the most important and basic characteristic of a community. The number of species and their relative abundance define *species diversity* of a community. It includes the number of species in a community (i.e. **richness**) and the relative abundance of each species (i.e. **evenness**). Species richness is simply the number of species in a community. But, among the array of species that make up the community, not all are equally abundant. We can find the *relative abundance* by counting all the individuals of each species within a community and determining what percentage each species contributes to the total number of individuals of all species. Communities in which the species are all more or less equal in abundance exhibit *evenness,* whereas communities with one or a few abundant species (i.e. present in large numbers) show *dominance*. Species evenness is highest when all species in a sample have the same abundance. Abundance patterns in communities can be examined by numbers of individuals per species, biomass per species, or percent cover per species.

Species diversity

Species Richness
The number of different species present.

Community 1	*Community 2*
Dog	Dog
Frog	Squirrel
Elephant	Elephant
Lion	Tiger
Horse	Bear
	Leopard
	Gorilla
Number of species: Five	Number of species: Seven
Species richness: Low	Species richness: High

Species Evenness
The abundance of each species in a community.

Community 1		*Community 2*	
Dog	30	Dog	20
Frog	48	Squirrel	15
Elephant	03	Elephant	20
Lion	09	Tiger	25
Horse	20	Bear	18
Number of species: Five		Number of species: Five	
Species evenness: Low		Species evenness: High	

Both number of species (*species richness*) and their relative abundance (*species evenness*)define species diversity. In table 4.1, two hypothetical communities– 1 and 2 – both have 5 species and 50 individuals. Species richness is the same in both communities. But the community–2

Table 4.1 Comparison of species richness and species evenness

Species	*Individuals per species*	
	Community 1	*Community 2*
Dog	10	05
Frog	10	05
Elephant	10	05
Lion	10	05
Horse	10	30
Total individuals	50	50
Total number of species	05	05

the x-axis. Thus, the most abundant species is plotted first along the x-axis, with the corresponding value on the y-axis being the value of relative abundance. This process is continued until all species are plotted. The resulting graph is called a **rank-abundance diagram**. It is a graphical plot of numbers of individuals per species against the rank of species commonness in the community. A rank abundance diagram can be drawn for the number of individuals in a community, biomass of individuals, ground area covered by plants and other variables all plotted against rank abundance.

4.1.3 Diversity index

A *diversity index* is a mathematical measure of species diversity in a community. It is a measure of the number of species in an area and the relative abundance of individuals among those species. That is, it takes into account the number of species present (*species richness*) as well as the abundance of each species (*species evenness*). A variety of indices have been used to estimate species diversity. We can divide them into two broad categories: *dominance indices* and *information statistic indices*. Dominance indices are more influenced by the abundance of common or dominant species. A widely used dominance index is *Simpson's diversity index*. Information statistic indices are more influenced by the numbers of rare species. Most commonly used information statistic index is the *Shannon diversity index*.

Simpson's diversity index

Simpson's diversity index is a simple mathematical measure that characterizes species diversity in a community. The term *Simpson's diversity index* can actually refer to any one of two closely related indices – *Simpson's index* and *Simpson's index of diversity*.

Simpson's index (D) is a measure of the species diversity of an ecosystem based on the concept of dominance. It measures the probability that two individuals randomly selected from a sample will belong to the same species. It is actually a measurement of dominance. There are two versions of the formula for calculating D.

$$D = \sum P_i^2 = \sum \left(\frac{n}{N}\right)^2$$

where, P_i = the relative abundance of each species (n/N).

n = total number of individuals of a particular species in the sample.

N = total number of individuals of all species present in the sample.

For a finite community, this is

$$D = \frac{\sum n(n-1)}{N(N-1)}$$

D is a measure of dominance, so as D increases, diversity (in the sense of evenness) decreases. The value of D ranges between 0 and 1. With this index, 0 represents an infinite diversity and 1, no diversity. That is, the bigger the value of D, the lower the diversity.

Simpson's index is usually reported as its complement 1-D called **Simpson's index of diversity**. The value of this index also ranges between 0 and 1, but now, the greater the value, the greater the sample diversity. In this case, the index represents the probability that two individuals randomly selected from a sample will belong to different species.

Positive interaction

Mutualism

Mutualism is a symbiotic relationship between members of two different species in which both members of the association benefited. On the basis of this relationship, individuals of both species enhance their survival, growth, or reproduction. Mutualistic relationships involve diverse interactions. Mutualisms can be characterized by the degree of dependency, the kinds of benefits received, the degree of specificity and duration of the interactions.

Mutualisms can vary in the degree of dependency between mutualists. Based on this, mutualisms can be *obligate* or *facultative*. In **obligate mutualism**, both organisms benefit by living in close association, and the relationship is obligatory (i.e. neither can survive without each other). Obligate mutualists cannot survive or reproduce without the mutualistic interaction. In **facultative mutualism** (also called **protocooperation**), mutualists benefit by living in close association, but the relationship is not obligatory. The cooperating species do not depend on each other for survival. One good example is the mutualistic association between a coelenterate, sea anemone — *Adamsia palliata* and a hermit crab – *Pagurus prideaux*. The sea anemone is carried by the crab to fresh feeding sites and crab in turn is said to be protected from its enemies by sea anemone.

The term **symbiosis** is sometimes used in the same sense as mutualism. 'Symbiosis' (termed used by de Barry in 1879) simply means *living together*. In narrowest sense, it is used to describe an association in which two species are deriving mutual benefit. However, now this term is used in a broad sense to describe all types of interactions (positive**,** negative or neutral). So, symbiosis is a close ecological relationship between the individuals of two (or more) different species.

The duration of intimacy among mutualistic interactions and also the degree of specificity of mutualistic interactions varies from one interaction to another. The mutualistic interactions can range from one-to-one, species-specific associations (termed *specialists*) to association with a wide diversity of mutualistic partners (*generalists*). Mutualisms can also be subdivided according to the services provided, regardless of whether the participants are obligate or facultative mutualists. Based on the nature of service involved, mutualisms can be *dispersive*, *defensive* and *resource-based mutualism.* **Dispersive mutualism** involves mutualistic association in which one partner species distributing pollens or seeds of another species and in return receives resources for growth. **Defensive mutualism** involves mutualistic association in which one partner provides protection to other partner against herbivores or parasites in exchange for a place to live or for nutrients needed for growth. **Resource-based mutualism** involves interactions where resources (such as nutrients) obtained by one mutualist is made available to another.

There are many classic examples of mutualistic associations in nature. Reef-forming corals of the tropical waters provide an excellent example of *resource-based mutualism*. **Coral reefs** are a special subtype of ocean floor ecosystem. One fascinating feature of shallow water, reef-building corals is their mutualistic relationship with photosynthetic algae called **zooxanthellae**, which live in their tissues. The coral provides the algae with a protected environment and the compounds they need for photosynthesis. In return, the algae produce oxygen and help the coral to remove wastes.

Box 4.2 **Host-parasite coevolution**

Coevolution is the process by which ecologically interacting species, evolve in tandem by exerting selection pressures on each other. It involves an evolutionary change in a trait of the individuals in one population in response to a trait of the individuals in a second population, followed by an evolutionary response by the second population to the change in the first. Examples of coevolutionary systems include host and parasites, predators and prey, and mutualistic or symbiotic interactions. Coevolution in parasites and hosts is antagonistic, unlike the mutualistic coevolution of ants and caterpillars or of flowering plants and pollinators.

Coevolution that is driven by antagonistic interactions, so-called 'antagonistic coevolution' can be defined as 'reciprocal adaptation and counter-adaptation of two interacting species for which fitness is negatively correlated'. In other words, an adaptation that increases fitness in one species will decrease the fitness of the other species. Theoretical and empirical studies of antagonistic coevolution have generally focused on two distinct mechanisms, one driven by negative frequency-dependent selection and the other by positive directional selection. These two mechanisms are expected to have fundamentally different influences on important evolutionary phenomena (e.g. the maintenance of genetic variation and sex).

Negative frequency–dependent selection: Red Queen coevolution

Frequency-dependent selection is defined as a situation where fitness is dependent upon the frequency of a phenotype or genotype in a population. In case of *negative frequency-dependent selection*, the fitness of a phenotype or genotype increases as its frequency in a population decreases. On the other hand, in case of *positive frequency-dependent selection*, the fitness of a phenotype or genotype increases as its frequency in a population increases.

Negative frequency-dependent selection is believed to be a primary driver of coevolution between biological antagonists. According to this selection, the parasite should adapt to the most common host genotype, because it can then infect a large number of hosts. In turn, a rare host genotype may then be favoured by selection, its frequency will increase and eventually it becomes common. Subsequently, the parasite should adapt to the former infrequent genotype. Coevolution determined by negative frequency-dependent selection is rapid. It maintains high genetic diversity by favouring uncommon alleles. Negative frequency-dependent selection is considered by many evolutionary biologists to be a particularly important and interesting form of natural selection because, unlike directional and stabilizing selection, negative frequency-dependent selection favours rare genotypes and can thus maintain high levels of genetic diversity.

Positive directional selection: Arms race coevolution

If an allele provides a fitness benefit, its frequency will increase within a population – the selection is a *positive directional selection*. Under positive directional selection, relative fitness increases as the value of a trait increases. Dawkins and Krebs (1970) suggested that reciprocal positive directional selection exerted by coevolving hosts and parasites could lead to a situation where hosts continually become more resistant to parasitism while parasites respond by becoming more virulent or evolving new mechanisms of evading host immunity (i.e. *Arms race coevolution*). 'Arms race' is a specific form of coevolution that is characterized by increased levels of defense and counterdefense in antagonistic interactions. The process is considered to be slower in comparison to negative frequency-dependent selection. In contrast to Arms race coevolution, Red Queen coevolution, synonymous with *negative frequency-dependent selection*, occur when rare host genotypes have a selective advantage over common ones.

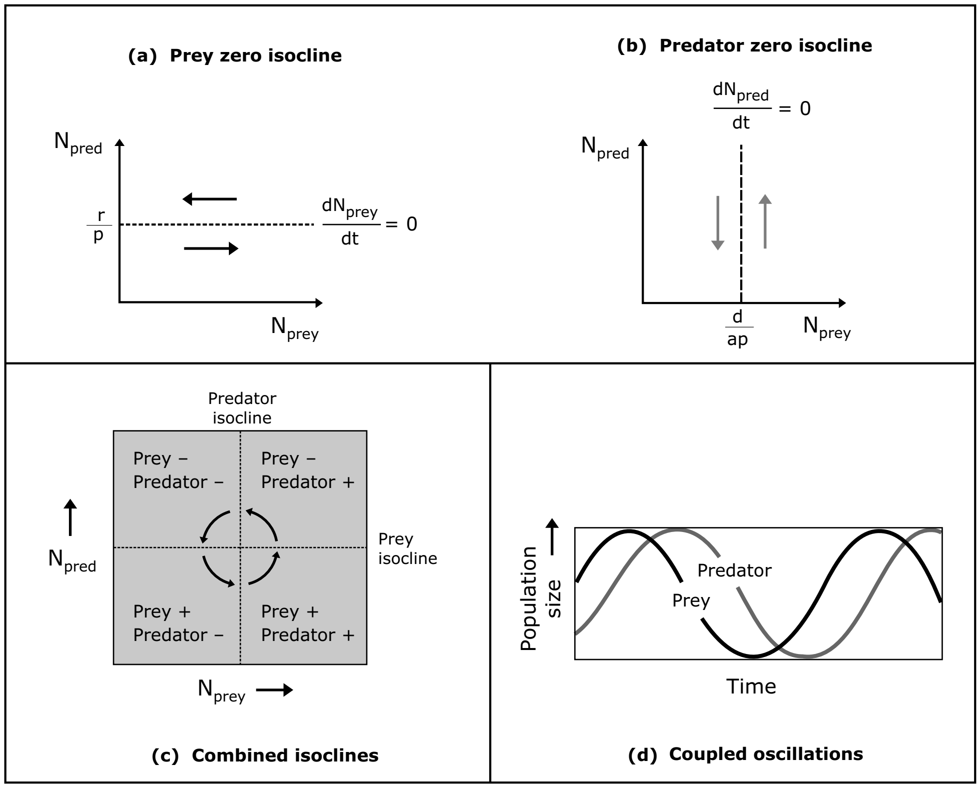


Figure 4.7 The basic Lotka-Volterra predator-prey model. (a and b) Zero isoclines (dN/dt = 0) for the prey and predator populations. Note that the zero isocline for the prey population is defined by a fixed number of predators, and the zero isocline for the predator population is defined by a fixed number of prey. Arrows show the direction of change in population size relative to the isoclines. The prey zero isocline: The number of prey increases at low predator densities and decrease at high predator densities. The predator zero isocline: The number of predators increases when prey numbers are high and decreases when prey numbers are low. (c) When prey and predator isoclines are combined, coupled oscillations result. When the zero isoclines are combined, the arrows can also be combined, and these joint arrows progress in anticlockwise circles. A minus sign indicates population decline, and a plus sign indicates population increase. This trajectory shows the cyclic nature of the predator–prey interaction. (d) By plotting the changes in size for both the predator and prey populations through time, we can see that the two populations continuously cycle out of phase with each other, and the density of predators lags behind that of prey. Adapted from Begon, et al., 1996.

Odum (1959) defined the ecological niche as ‘the position or status of an organism within its community and ecosystem resulting from the organism's structural adaptations, physiological responses, and specific behavior (inherited and/or learned).’ He emphasized that ‘the ecological niche of an organism depends not only on where it lives but also on what it does.’ The place an organism lives, or where one would go to find it, is its habitat. For Odum the habitat is the organism's ‘address,’ whereas the niche is its ‘profession.’

4.8 Ecological niche

Organisms do not live in isolation. They interact with other organisms, inhabit particular environment and coevolve with other organisms and with changing environment. *Niche* represents the place where members of a species live, the ways in which the environmental resources are used and interactions with other individuals of their own or of other species. Thus, the niche concept expresses the relationship of the individuals to all aspect of its environment.

The term ‘niche’ was used for the first time by Grinnell is frequently misunderstood and misused. It is often used loosely to describe the sort of place in which an organism lives. Strictly, however, the place in which a particular organism lives is its **habitat**. Niche is different from habitat. It is not simply a place where organism lives. *It is the sum total of all the ecological requisites and activities of a species.* It includes not only the physical space occupied by an

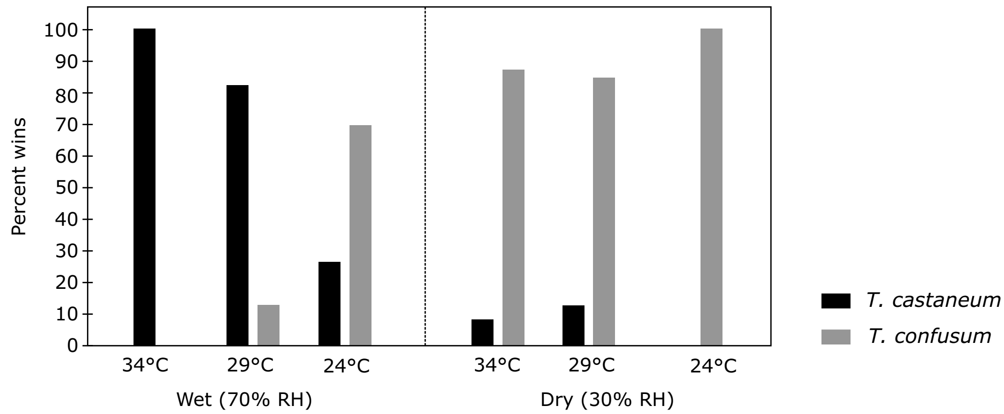


Figure 4.11 Competitive ability can be influenced by the abiotic environment. Biologist Thomas Park cultured two different species of flour beetles, *Tribolium castaneum* and *Tribolium confusum*, together at varied temperature and moisture. Results of competition between two flour beetles show that each species usually performs better in a given habitat; for example, *T. confusum* does better in dry conditions.

Competitive exclusion and coexistence

The species coexistence is rooted in the competitive exclusion principle, which states that two species competing for the same resource cannot coexist. The species that is better at gaining the limiting resource will eventually eliminate the inferior competitor. If a superior and an inferior competitor are placed into a habitat at initially equal abundance, the former will inevitably eliminate the latter. Differences between species in their competitive ability drive the superior to dominance and the inferior to exclusion. If complete competitors drive one another to local extinction, then how two very related species will coexist?

One answer to reduce interspecific competition between species and thus competitive exclusion of inferior species is the *niche differentiation*. For example, the niche differences of the two rodent species may include differences in the size of seeds consumed – one rodent tends to consume larger seeds and other smaller seeds. By niche differentiation two rodent species can reduce competition for food and coexist.

Resource partitioning

Niche differentiation may take a variety of forms, of which *resource partitioning* is most common. Because the degree of competition is assumed to depend upon the degree of niche overlap, hence, some species evolve to reduce niche overlap through resource partitioning. The term ‘resource partitioning’ describes the niche differentiation, both in space and time that enables similar species to coexist in a community. It refers to the state of reduced overlap in resource use between coexisting species. By consuming slightly different forms of a limiting resource or using the same limiting resource at a different place, individuals of different species compete less with one another (interspecific competition). Through resource partitioning in temporal scale, species also able to manage to coexist by using the same limiting resources at different times. The assumption is that competition among species that are active at different times would be less intense than if the same set of species all attempted to use the same resource at the same time. Resource partitioning is often viewed as a product of the coevolution of characteristics that function to reduce competition.

Chapter 5

Biodiversity

Biodiversity, short for **biological diversity**, refers to the sum total of all the variety and variability of life in a defined area. In contrast to the more specific term *species diversity*, the term *biodiversity* was coined to emphasize the many complex kinds of variations that exist within and among organisms at different levels of organization. It refers to the totality of genes, species and ecosystems of a region. United Nations Earth Summit defined biological diversity as:

'*Biological diversity means the variability among living organisms from all sources including, inter alia (among other things), terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems*.'

Convention on Biological Diversity, 1992

5.1 Levels of biodiversity

Biodiversity includes three hierarchical levels: Genetic, species and ecosystem diversity

Genetic diversity

Genetic diversity refers to the variation in the genetic composition of individuals within or among species. The genetic diversity enables the population to adapt to its environment and respond to natural selection. The amount of genetic variation is the basis of speciation. Genetic diversity occurs at several levels of organization such as among higher taxonomic categories such as kingdoms phyla and families, among species and among populations. Most genetic diversity one can see between organisms of two kingdoms (such as plants versus animals), between phyla (such as arthropods versus chordates), between classes (such as birds versus reptiles) and so on.

Species diversity

According to *biological species concept*, species are groups of actually or potentially interbreeding natural populations, which are reproductively isolated from other such groups. Simply, species diversity refers to the variety of species within a region i.e. species richness. However, in the broad sense, species diversity includes species richness, species evenness as well as taxonomic (or phylogenetic) diversity. Taxonomic or phylogenetic diversity describes the genetic relationship between different groups of species. A more taxonomically diverse community is therefore considered richer compared to the less taxonomically diverse community.

Species richness and evenness

The simplest measure of species diversity is species richness, i.e. the number of species present in per unit area. Species richness is only one aspect of diversity. Not all species exist in equal numbers: some are rare, some are common but not numerous, and others are very abundant. Imagine two forests, both of which contain a total of 100 individuals belonging to 5 different species. In one forest, there are 20 individuals of each species. In the other, one species has 60 individuals, while each of the other four species has 10 individuals. These two samples differ in a property called *evenness*. The first, in which the species are represented by the same number of individuals, is more even, and thus, has high overall species diversity. Thus, the species diversity of a community depends on both its richness as well as evenness: higher species numbers, with the individuals more evenly distributed among them, contribute to higher community diversity.

Ecosystem diversity

Ecosystems include all the species, plus all the abiotic factors characteristic of a region. For example, a desert ecosystem has soil, temperature, rainfall patterns, and solar radiation that affect not only what species occur there, but also the morphology, behaviour and the interactions among those species. Ecosystem diversity describes the number of niches, trophic levels and various ecological processes that sustain energy flow, food webs and the recycling of nutrients.

5.2 Gradients and Magnitude of biodiversity

Gradients of biodiversity

Biodiversity varies with changes in latitude or altitude. As we move from the poles to the equator, the biodiversity increases, and vice versa. The increase in species richness or biodiversity that occurs from the poles to the tropics often referred to as the *latitudinal gradient* in species diversity, is one of the most widely recognized patterns in ecology.

In general, species diversity decreases as we move away from the equator towards the poles. With very few exceptions, tropics (latitudinal range of 23.5° N to 23.5° S) harbour more species than temperate or polar areas. For example, Colombia located near the equator has nearly 1,400 species of birds while New York at 41° N has about 105 species and Greenland at 71° N only about 56 species. India, with much of its land area in the tropical latitudes, has more than 1,200 species of birds. The tropical Amazon rain forest in South America has the greatest biodiversity on the Earth – it is home to more than 40,000 species of plants.

The two key factors in latitudinal gradients of species richness are probably *evolutionary history* and *climate*. Over the course of evolutionary time, species diversity may increase in a community as more speciation events occur. Tropical communities are generally older than temperate or polar communities. In effect, speciation events occur about five times as fast in the tropics as near the poles. Climate is another important reason of the latitudinal gradient in biodiversity. In terrestrial communities, the two main climatic factors correlated with biodiversity are solar energy input and water availability, both of which are relatively high in the tropics.

Just like latitudinal variation, *altitudinal variation* also causes changes in the biodiversity. A decrease in species diversity occurs from lower to higher altitudes on a mountain. A 1000 m increase in altitude results in a temperature drop of about 6.5°C. The drop in temperature and greater seasonal variability at higher altitudes are major factors that reduce biodiversity.

Critically endangered

A species is critically endangered when it is facing an extremely high risk of extinction in the wild in the immediate future. To be defined as critically endangered, a species must meet any of the following criteria.

- Population reduction: ≥80-90% population decline
- Geographic range

  Extent of occurrence: <100 km^2

  Area of occupancy: <10 km^2
- Population size: <250 mature individuals
- Extinction probability (in the wild): at least 50% within 10 years or 3 generations.

Example: Gharial, Great Indian bustard, Ganges shark, Pygmy hog.

Reduction of population size causes loss of genetic diversity due to loss of some alleles from the species. It also increases the chance of inbreeding and homozygosity. Increased homozygosity increases mortality of young, and inbreeding depression leads to reduced offspring fitness.

Endangered

A species, whose numbers are so small that the species is at risk of extinction. To be defined as endangered, a species must meet any of the following criteria.

- Population reduction: 50-70% population decline
- Geographic range

  Extent of occurrence: <5,000 km^2

  Area of occupancy: <500 km^2
- Population size: <2,500 mature individuals
- Extinction probability (in the wild): at least 20% within 20 years or 5 generations.

Example: Red panda, Snow leopard, Bengal Tiger and One horned rhinoceros and Black buck.

Vulnerable

A species is vulnerable when it is not critically endangered or endangered, but is facing a high risk of becoming endangered in the near future.

- Population reduction: ≥30-50% population decline
- Geographic range

  Extent of occurrence: <20,000 km^2

  Area of occupancy: <2,000 km^2
- Population size: <10,000 mature individuals
- Extinction probability (in the wild): at least 10% within 100 years.

Of the 47,677 species in the International Union for Conservation of Nature (IUCN) Red List of Threatened Species of 2009, 17,291 are deemed to be at serious risk. The list reveals that 21 percent of all known mammals, 30 percent of all known amphibians, 12 percent of all known birds, 28 percent of reptiles, 37 percent of freshwater fishes, 70 percent of plants and 35 percent of invertebrates assessed so far, are under threat.

Near threatened

A category on the IUCN Red List of threatened species which indicates that a taxon has been evaluated against the Red List criteria does not qualify for critically endangered, endangered and vulnerable status now but it is close to qualify or likely to qualify for a threatened category in the near future. Polar bears, giraffes, and white rhinos are listed as Near Threatened species because their survival depends on conservation programs.

Experts on Biological Diversity in November 1988. The Convention was opened for signature at the Earth Summit in Rio de Janeiro on 5 June 1992 and entered into force on 29 December 1993. It has three main objectives:

- The conservation of biological diversity.
- The sustainable use of the components of biological diversity.
- The fair and equitable sharing of the benefits arising out of the utilization of genetic resources.

CITES

CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora), also known as the **Washington Convention**, is an international agreement to protect endangered plants and animals. It was drafted as a result of a resolution adopted in 1963 at a meeting of members of the International Union for Conservation of Nature (IUCN). The convention was opened for signature in 1973 and CITES entered into force on 1 July 1975. Its aim is to ensure that international trade in specimens of wild animals and plants does not threaten the survival of the species in the wild, and it accords varying degrees of protection to more than 35,000 species of animals and plants. India become party to CITES in 1976.

World Heritage Convention (WHC)

The convention concerning the protection of the world cultural and natural heritage commonly known as the 'World Heritage Convention', is an international treaty, adopted in 1972. The convention recognizes the way in which people interact with nature, and the fundamental need to preserve the balance between the two. The convention sets out the duties of states parties in identifying potential sites and their role in protecting and preserving them. By signing the convention, each country pledges to conserve not only the World Heritage sites situated on its territory, but also to protect its national heritage.

World Heritage sites are places on Earth that are of Outstanding Universal Value (OUV) to humanity and therefore, have been inscribed on the World Heritage List to be protected for future generations. Places as diverse and unique as the Great Barrier Reef in Australia, Galapagos Islands in Ecuador and the Grand Canyon in the USA are examples of places inscribed on the World Heritage List. The World Heritage Convention 1, which has been ratified by 191 countries, was adopted by United Nations Educational, Scientific and Cultural Organization's (UNESCO) General Conference in 1972, and came into force in 1975, for the identification, protection, conservation, presentation and transmission to future generations of the world cultural and natural heritage. The secretariat to the World Heritage Convention is the UNESCO World Heritage Centre, whilst three organisations: International Council on Monuments and Sites (ICOMOS), International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM) and the International Union for Conservation of Nature (IUCN) act as its Advisory Bodies. The Advisory Body on natural heritage is IUCN.

Convention on the Conservation of Migratory Species of Wild Animals

The CMS, or the *Bonn Convention* aims to conserve terrestrial, marine and avian migratory species throughout their range. Parties to the CMS work together to conserve migratory species and their habitats by providing strict protection for the most endangered migratory species, by concluding regional multilateral agreements for the conservation and management

Chapter 6

Pollution

Pollution is any undesirable change in the physical, chemical, or biological characteristics of the air, water and land that can harmfully affect the living organisms and the ecosystem as a whole. Any substance introduced into the environment that adversely affects the physical, chemical or biological properties of the environment that have a harmful effect on the ecosystem as a whole is termed as **pollutant**. There are three major types of environmental pollution: air pollution, water pollution and soil pollution.

6.1 Air pollution

Air pollution may be defined as any atmospheric condition in which *substances* are present at concentrations above their normal permissible levels to produce a *measurable effect* on man, animals, vegetation or materials. Substances mean any natural or anthropogenic (man-made) chemical compounds capable of being airborne. They may exist in the atmosphere as gases, liquid drops or solid particles.

According to Air (prevention and control) act, 1981, an *air pollutant* is any solid, liquid or gaseous substance (including noise) present in the atmosphere in such concentration as may be or tend to be injurious to human being or other living creatures or plants or property or environment.

6.1.1 Composition of air

Air is a heterogenous mixture of different gases that makes the atmosphere. *Atmosphere* is the gaseous mass or envelope surrounding the Earth and retained by the Earth's gravitational field. The troposphere is the lowest portion of Earth's atmosphere. It contains approximately 80% of the atmosphere's mass. By volume, dry air contains 78.08% nitrogen, 20.9% oxygen, 0.9% argon, 0.033% carbon dioxide, and small amounts of other gases. There are two common ways by which one can represent the composition of air – *percentage of gas by volume* or *percentage of the gas by mass.* It is important to note that, the composition of different gases (in dry air) by mass is a fixed one whereas the percentage composition of the gases by volume or mass in wet air (i.e. air containing moisture) is dependent on humidity or the moisture in the air.

Table 6.1 Composition of clean, dry air (expressed in volume)

Constituent	*Percent by volume*	*In ppm*
Nitrogen	78.084%	780840
Oxygen	20.9%	209440
Argon	0.93%	9340
Carbon dioxide	0.0355%	355 (Year 1990)
Others	0.065%	650

6.1.2 Sources of air pollution

There are two main sources of air pollution:

Natural sources – such as wind-blown dust, wildfires and volcanoes

Man-made (or anthropogenic) **sources**

Man-made sources can be mobile or stationary in nature.

Mobile sources: These sources account for most of the air pollution and the primary mobile source of air pollution is the automobile.

Stationary sources: Air pollution sources that do not move from location to location. It can be either point source or area source.

Point sources include pollution from power plants, oil refineries, emit large amounts of pollution from a single location.

Area sources include emissions from many smaller stationary sources present in an industrial, commercial and residential area.

6.1.3 Types of air pollutants

Air pollutant can be of natural origin or man-made. It can be classified on the following basis:

- the physical state of the pollutant
- the basis of origin
- the occurrence and nature of the threat

Classification based on the physical state of the pollutant

According to the physical state of pollutant, pollutants may be gaseous and particulate in nature.

Gaseous pollutants include carbon dioxide, sulfur oxides, oxides of nitrogen, carbon monoxide, volatile organic compounds, chlorofluorocarbons, ammonia and other gases.

Particulate matters are tiny solid or liquid particles suspended in air.

Aerosol
An aerosol is a colloid of fine solid particles or liquid droplets, in gas. A *colloid* is a broad category of mixtures, and is defined as one phase suspended in another. Aerosol can be *liquid aerosol* (*liquid* suspended in gas) and *solid aerosol* (*solid* suspended in gas).

Classification based on origin

Air pollutants can also be classified as either *primary* or *secondary,* based on origin.

Primary air pollutants are substances which are directly emitted into the atmosphere from natural and anthropogenic sources, such as SO_2 from a volcanic eruption and the carbon monoxide gas from motor vehicles.

6.5 Bioremediation

Bioremediation is a biological process whereby organic wastes are biologically degraded under controlled conditions. The process involves the use of living organisms, primarily microorganisms, to degrade the environmental contaminants. In this process, contaminant compounds are transformed by living organisms through reactions that take place as a part of their metabolic processes. For bioremediation to be effective, microorganisms must enzymatically attack the contaminants and convert them to harmless products. Hence it is effective only where environmental conditions permit microbial growth and activity. Thus, its application involves the manipulation of environmental parameters to allow microbial growth and degradation to proceed at a faster rate. The control and optimization of bioremediation processes is a complex phenomenon. Various factors influence this process. These factors include: the existence of a microbial population capable of degrading the pollutants; the availability of contaminants to the microbial population; the environment factors (type of soil, temperature, pH, the presence of oxygen or other electron acceptors and nutrients).

Bioremediation strategies

Bioremediation strategies can be *in-situ* or *ex-situ*. *In situ bioremediation* involves treating the contaminated material at the site while *ex-situ bioremediation* involves the removal of the contaminated material to be treated elsewhere. *In-situ* bioremediation techniques are generally the most desirable option due to lower cost and less disturbance since they provide the treatment at a site avoiding excavation and transport of contaminants. *Ex-situ* bioremediation requires transport of the contaminated water or excavation of contaminated soil prior to remediation treatments.

In-situ and *ex-situ* strategies involve different technologies such as bioventing, biosparging, bioreactor, composting, landfarming, bioaugmentation and biostimulation.

Bioventing is an *in-situ* bioremediation technology that uses microorganisms to biodegrade organic constituents adsorbed on soils in the *unsaturated zone* (extends from the top of the ground surface to the water table). Bioventing enhances the activity of indigenous bacteria and stimulates the natural *in-situ* biodegradation of contaminated materials in soil by inducing air or oxygen flow into the unsaturated zone and, if necessary, by adding nutrients.

Biosparging is also an *in-situ* bioremediation technology that uses indigenous microorganisms to biodegrade organic constituents in the *saturated zone*. In biosparging, air (or oxygen) and nutrients (if needed) are injected into the saturated zone to increase the biological activity of the indigenous microorganisms.

Biostimulation involves the modification of the environment to stimulate the existing bacteria capable of bioremediation. This can be done by the addition of various forms of rate limiting nutrients and electron acceptors, such as phosphorus, nitrogen, oxygen, or carbon (e.g. in the form of molasses).

Bioaugmentation is a process where selected, standardized bacteria (microbes) are added to an area that has been contaminated with an unwanted substance. These bacteria cause breakdown of contaminants.

Composting is a controlled decomposition of organic matters. It involves mixing of contaminated soil with non-hazardous organic materials such as manure or agricultural wastes. The presence of these organic materials supports the development of a rich microbial population, which causes decomposition of organic contaminants.

Chapter 7

Climate Change

Climate is the long-term pattern of weather in a locality, region or even over the entire globe. It is the statistics of weather, usually over a 30-year interval. It is measured by assessing the patterns of variation in temperature, humidity, atmospheric pressure, wind, precipitation and other meteorological variables in a given region over long periods of time.

'*Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system*.'

Intergovernmental Panel on Climate Change (IPCC), 2001

The terms climate and weather have different meanings. **Weather** is the short-term properties (such as temperature, pressure, moisture) of atmospheric conditions for a specific place and time. Weather differs both spatially and temporally. Two of the most important factors determining an area's climate are air temperature and precipitation. The climate of a region will determine which plants will grow there and which animals will inhabit it.

7.1 Climate change

Climate science is a process of collective learning that relies on the careful gathering and analyses of data, the formulation of hypotheses, the development of models to study key processes and make predictions, and the combined use of observations and models to test scientific understanding.

Climate change is a large-scale, long-term shift in the planet's weather patterns. According to Intergovernmental Panel on Climate Change (IPCC),

'*Climate change refers to a change in the state of the climate that can be identified* (*e.g. by using statistical tests*) *by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use*'.

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as, 'a change of climate that is attributed directly or indirectly to human activity that alters

IPCC
The Intergovernmental Panel on Climate Change (IPCC) is the international body for assessing the science related to climate change. The IPCC was set up in 1988 by the World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation. The IPCC produces reports that support the United Nations Framework Convention on Climate Change (UNFCCC), which is the main international treaty on climate change.

Box 7.1 ***Scientific consensus***

'Climate change is real. There will always be uncertainty in understanding a system as complex as the world's climate. However, there is now strong evidence that significant global warming is occurring. The evidence comes from direct measurements of rising surface air temperatures and subsurface ocean temperatures and from phenomena such as increases in average global sea levels, retreating glaciers, and changes to many physical and biological systems. It is likely that most of the warming in recent decades can be attributed to human activities'.

Joint science academies' statement: Global response to climate change (2005)

7.2 Greenhouse effect

The Earth receives energy from the Sun in the form of solar radiation. Various gases in the atmosphere absorb incoming solar radiation. The ability of atmospheric gases to absorb radiation varies with the wavelength. All of the incoming solar radiation with wavelengths less than 0.3 μm is absorbed by oxygen and ozone. This absorption occurs mainly in the stratosphere. Most of the solar radiation passes through the atmosphere without being absorbed. A large fraction of this radiation is absorbed by land and oceans. This absorbed energy is then re-radiated upward from the Earth's surface in the form of longwave infrared radiation.

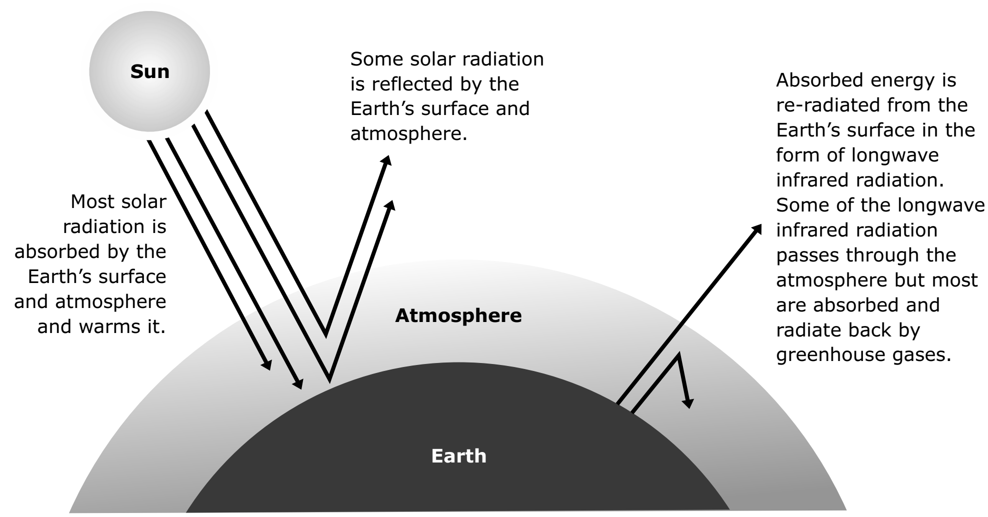


Figure 7.1 Incoming shortwave solar radiations (ultraviolet, visible and a limited portion of infrared energy) from the Sun drive the Earth's climate system. Some of this incoming radiation is reflected by the atmosphere and the Earth's surface whereas some is absorbed by the atmosphere and the Earth's surface. The heat generated by this absorption is emitted as longwave infrared radiation. Some of which radiates out into space but most of the Earth's emitted longwave infrared radiation is absorbed by greenhouse gases present in the atmosphere, which heats the lower atmosphere.

Most of these longwave infrared radiation (greater than 4 μm) re-radiated by the Earth's surface is absorbed by atmospheric gases, most importantly water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Radiatively active gases that absorb wavelengths longer than 4 μm are called **greenhouse gases**. This absorption heats the atmosphere, which in turn, radiates energy back to the Earth. Thus, the greenhouse gases act as a thermal blanket around the Earth, raising the Earth's temperature. This effect is known as **greenhouse effect**.

$$O_2 \xrightarrow{<242\ nm} O + O$$

The atomic oxygen, in turn, reacts with molecular oxygen to form ozone,

$$O + O_2 \xrightarrow{M} O_3 + M$$

Where M represents a third body (N_2 or O_2) necessary to carry away the energy released in the reaction. The ozone that is formed in this process is also dissociated by solar radiation to form an oxygen atom and an oxygen molecule. Ozone absorbs UV radiation in the 200 to 320 nm wavelength region and generates molecular oxygen as a result of photodissociation.

$$O_3 \longrightarrow O_2 + O$$

This cyclic process leads to a natural steady-state concentration of stratospheric ozone. These three reactions are called the **Chapman cycle**, after the person who discovered them.

Levels of ozone in the stratosphere are measured in **Dobson Units** (D.U.). The average amount of stratospheric ozone throughout the world is about 300 D.U (equivalent to a layer 3 millimeters thick if it is compressed into a single layer). Ozone concentrations over Antarctica during the period of greatest depletion usually fall well below 200 D.U.

Box 7.3 Dobson Unit

The Dobson Unit (D.U.) is the most common unit for measuring ozone concentration. Instead of measuring the amount of ozone at a particular height, the Dobson Unit measures the total amount of ozone in a column extending vertically from Earth's surface to the top of the atmosphere. A column of air with an ozone concentration of 1 Dobson Unit would contain about 2.69×10^{16} ozone molecules for every square centimeter of area at the base of the column. The number of molecules of ozone present in one Dobson Unit would form a layer of 0.01 millimeters thick layer at the base of the column if it were compressed into a single layer at a temperature of 0°C and a pressure of 1 atmosphere. 100 Dobson Unit of ozone would form a layer only 1 millimeter thick if it were compressed into a single layer.

Ozone layer thickness is expressed in terms of Dobson units, which measure what its physical thickness would be if compressed in the Earth's atmosphere. Over the Earth's surface, the ozone layer's average thickness is about 300 Dobson Units or a layer that is 3 millimeters thick.

Stratospheric ozone depletion

Ozone is continuously being synthesized from molecular oxygen in the stratosphere by the absorption of short-wavelength ultraviolet (UV) radiation, while at the same time it is continuously being removed by various chemical reactions that convert it back to molecular oxygen. The rates of synthesis and destruction at any given time determine the concentration of ozone in the stratosphere. This balance is being affected by increasing stratospheric concentrations of chlorine and bromine, which increase the destruction process. One chlorine atom can destroy over 100,000 ozone molecules before it is removed from the stratosphere. *Bromine atom is believed to be 40 times more destructive than chlorine molecules.*

Some compounds release chlorine or bromine when they are exposed to intense UV light in the stratosphere. The chlorine and bromine containing compounds that cause significant depletion of the ozone layer are chlorofluorocarbons, carbon tetrachloride, methyl chloroform, hydrochlorofluorocarbons, hydrobromoflurocarbons and halons. These compounds contribute to

Biological Diversity Act, 2002

An act to provide for the conservation of biological diversity, sustainable use of its components and fair and equitable sharing of the benefits arising out of the use of biological resources and knowledge associated with it.

Scheduled Tribes & other Traditional forest Dwellers (Recognition of Forest Rights) Act, 2006

To address the adverse living conditions of many tribal families living in forests was on account of non-recognition and vesting of pre-existing rights, a landmark legislation viz. Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006, has been enacted to recognize and vest the forest rights and occupation of forest land in forest dwelling Scheduled Tribes and other traditional forest dwellers, who have been residing in such forests for generations, but whose rights could not be recorded.

Environment and Pollution

Water (Prevention and Control of Pollution) Act, 1974

Establishes an institutional structure for preventing and abating water pollution. It establishes standards for water quality and effluent. Polluting industries must seek permission to discharge waste into water bodies. The CPCB was constituted under this act. This act has been last amended in 1988.

Water (Prevention and Control of Pollution) Cess Act, 1977

An act to provide for the levy and collection of cess or fees on water consuming industries and local authorities. This act has been last amended in 2003.

Air (Prevention and Control of Pollution) Act, 1981

An act to provide for the prevention, control and abatement of air pollution. It entrusts the power of enforcing this act to the central board or state board. This act has been last amended in 1987.

Environment (Protection) Act, 1986

Authorizes the central government to protect and improve environmental quality, control and reduce pollution from all sources and prohibit or restrict the setting and/or operation of any industrial facility on environmental grounds. The EPA (Environment Protection Act), 1986 came into force soon after the Bhopal gas tragedy. This act has been last amended in 1991.

Manufacture, Storage and Import of Hazardous Chemical Rules, 1989

Define the terms used in this context, and sets up an authority to inspect, once a year, the industrial activity connected with hazardous chemicals and isolated storage facilities. These rules have been last amended in 2000. These rules were notified under the Environment (Protection) Act, 1986.

Public Liability Insurance Act, 1991

An Act to provide for public liability- insurance for the purpose of providing immediate relief to the persons affected by accident occurring while handling any hazardous substance and for matters connected therewith or incidental thereto. This act has been last amended in 1992.

all greenhouse gases in one standard unit. The 'equivalent' means that the footprint is made up of a number of different greenhouse gases, which have been converted into the equivalent quantity of carbon dioxide in order to show all emissions in a single number.

A carbon footprint is made up of the sum of two parts, the primary footprint and the secondary footprint. The primary footprint is a measure of our direct emissions of carbon dioxide from the burning of fossil fuels including domestic energy consumption and transportation (e.g. car and plane). The secondary footprint is a measure of the indirect carbon dioxide emissions from the whole lifecycle of products we use – those associated with their manufacture and eventual breakdown.

Why carry out a carbon footprint?

Carbon footprints are useful for a number of purposes:

1. For publicly reporting greenhouse gas emissions.
2. For setting a target for reducing emissions (in order to set a reduction target it is necessary to know what current emissions are).
3. To identify which activities contribute the most to a footprint (in order to identify the important areas for reduction efforts).
4. In order to measure changes in emissions over time and to monitor the effectiveness of reduction activities.
5. To offset emissions (in order to offset emissions it is necessary to know how many reductions credits to purchase).

The Economics of Ecosystems and Biodiversity (TEEB) for National and International Policy Makers 2009, noted different types of carbon emissions as colors of carbon:

Brown carbon
Industrial emissions of greenhouse gases that affect the climate.

Green carbon
Carbon incorporated into plant biomass and the soils below.

Blue carbon
Blue carbon is the term for carbon captured by the world's ocean and coastal ecosystems.

Black carbon
Formed through incomplete combustion of fuels.

Nitrogen footprint

Nitrogen is an important component in air, land and water. While necessary to life, reactive nitrogen (all forms of the nitrogen except N_2) can be detrimental to both ecosystem and human health when present in excessive amounts. Different forms of reactive nitrogen contribute to smog and reduced air quality, acid deposition, eutrophication, reduced drinking water quality, biodiversity loss, global warming and more.

The nitrogen footprint is a measurement of the amount of reactive nitrogen released into the environment as a result of human activities. It mainly includes NOx, N_2O, NO_3^-, and NH_3 emission. The two main pathways through which we release reactive nitrogen to the environment are fossil fuel combustion and food production. When a fossil fuel is burned, reactive nitrogen is emitted to the atmosphere as a waste product. The use of nitrogen in food production, on the other hand, is intentional. Nitrogen is a key nutrient for food production and is contained in fertilizers. The nitrogen footprint includes nitrogen contained in consumed food, plus nitrogen released during the whole chain of production, distribution and preparation of the food. The other component of the nitrogen footprint determines the amount of nitrogen (as NOx emissions) released from the burning of fossil fuels related to energy use in housing (e.g. cooking, heating, cooling); transport (e.g. use of private or public transport) and the energy used to produce goods and provide services.

Water footprint

The 'water footprint' concept was introduced by Hoekstra in 2002. It is defined as the total volume of freshwater used to produce the goods and services consumed by the individual or producer. It accounts for both the direct (domestic water use) and indirect (water required

Fundamentals of

Ecology and Environment

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