



Hierarchy of Life (Biological Organisation)

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Introduction

Hierarchy of life, is the hierarchy of complex biological structures and systems that define life using a reductionistic approach. The traditional hierarchy, as detailed below, extends from atoms (or lower) to biospheres. The higher levels of this scheme are often referred to as **ecological organisation**.

Each level in the hierarchy represents an increase in organisational complexity, with each "object" being primarily composed of the previous level's basic unit. The basic principle behind the organisation is the concept of *emergence*—the properties and functions found at a hierarchical level are not present and irrelevant at the lower levels.

Organisation furthermore refers to the high degree of order of an organism (in comparison to general objects). Ideally, individual organisms of the same species have the same arrangement of the same structures. For example, the typical human has a torso with two legs at the bottom and two arms on the sides and a head on top. It is extremely rare (and usually impossible, due to physiological and biomechanical factors) to find a human that has all of these structures but in a different arrangement.

The biological organisation of life is a fundamental premise for numerous areas of scientific research, particularly in the medical sciences. Without this necessary degree of organisation, it would be much more difficult—and likely impossible—to apply the study of the effects of various physical and chemical phenomena to diseases and body function. For example, fields such as cognitive and behavioural neuroscience could not exist if the brain was not composed of specific types of cells, and the basic concepts of pharmacology could not exist if it was not known that a change at the cellular level can affect an entire organism. These applications extend into the ecological levels as well. For example, DDT's direct effect occurs at the subcellular level, but affects higher levels up to and including multiple ecosystems. Theoretically, a change in one atom could change the entire biosphere.

Levels

The simple standard biological organization scheme, from the lowest level to the highest level, is as follows:

<i>A-cellular level</i>	* The atom
<i>and</i>	
<i>Pre-cellular level</i>	* The molecule, a grouping of atoms
<i>Sub-cellular level</i>	* The organelle, a functional grouping of biomolecules; biochemical reactions and interactions
<i>Cellular level</i>	* The cell, the basic unit of all life and the grouping of organelles
<i>Super-cellular level</i> <i>(Multicellular level)</i>	<ul style="list-style-type: none"> * The tissue, a functional grouping of cells * The organ, a functional grouping of tissues * The organ system, a functional grouping of organs * The organism, the basic living system, a functional grouping of the lower-level components, including at least one cell * The population, a grouping of organisms of the same species * The biocoenosis or community, an interspecific grouping of populations * The ecosystem, a grouping of organisms from all biological domains in conjunction with the physical (abiotic) environment * The biosphere, the complete set of ecosystems

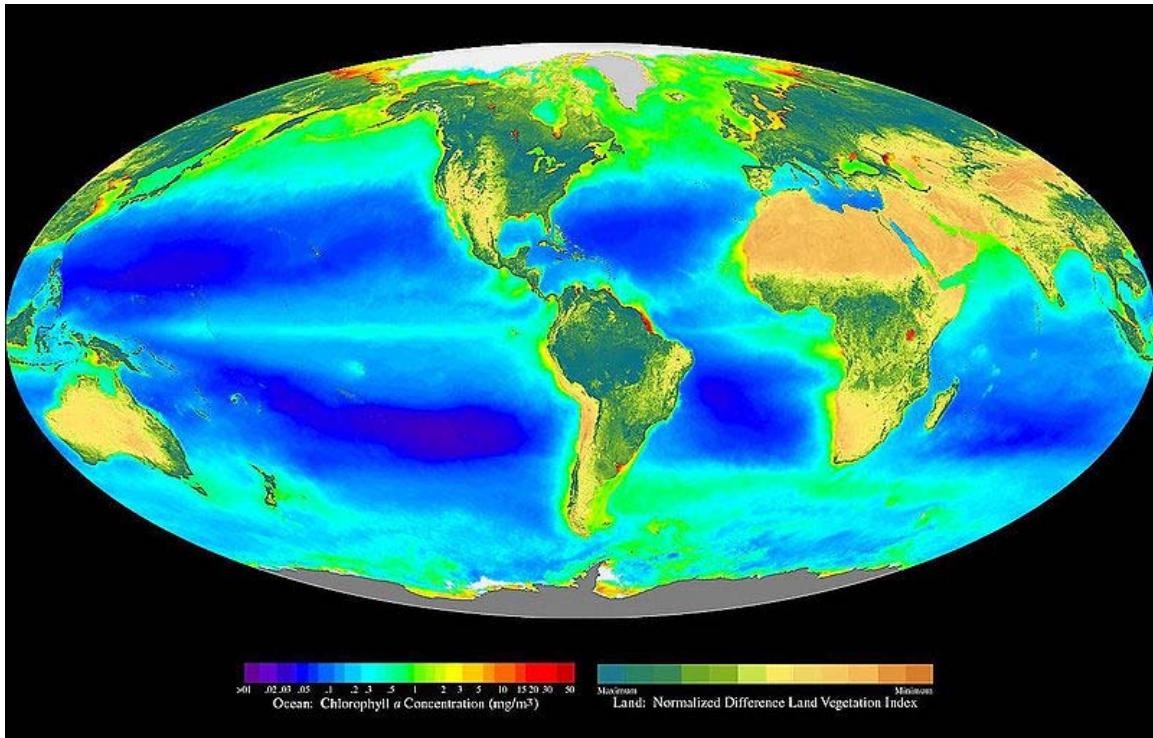
More complex schemes incorporate many more levels. For example, a molecule can be viewed as a grouping of elements, and an atom can be further divided into subatomic particles (these levels are outside the scope of biological organisation). Each level can also be broken down into its own hierarchy, and specific types of these biological objects can have their own hierarchical scheme. For example, genomes can be further subdivided into a hierarchy of genes.

Each level in the hierarchy can be described by its lower levels. For example, the organism may be described at any of its component levels, including the atomic, molecular, cellular, histological (tissue), organ and organ system levels. Furthermore, at every level of the hierarchy, new functions necessary for the control of life appear. These new roles are not functions that the lower level components are capable of and are thus referred to as *emergent properties*.

Every organism is organised, though not necessarily to the same degree. An organism can not be organised at the histological (tissue) level if it is not composed of tissues in the first place.

Chapter 1

Biosphere



A false-color composite of global oceanic and terrestrial photoautotroph abundance, from September 1997 to August 2000. Provided by the SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE.

Our **biosphere** is the global sum of all ecosystems. It can also be called the zone of life on Earth, a closed (apart from solar and cosmic radiation) and self-regulating system. From the broadest biophysiological point of view, the biosphere is the global ecological system integrating all living beings and their relationships, including their interaction with the elements of the lithosphere, hydrosphere and atmosphere. The biosphere is

postulated to have evolved, beginning through a process of biogenesis or biopoesis, at least some 3.5 billion years ago.

In a broader sense; biospheres are any closed, self-regulating systems containing ecosystems; including artificial ones such as Biosphere 2 and BIOS-3; and, potentially, ones on other planets or moons.

Origin and use of the term

The term "biosphere" was coined by geologist Eduard Sues in 1875, which he defined as:

"The place on Earth's surface where life dwells."

While this concept has a geological origin, it is an indication of the impact of both Darwin and Maury on the earth sciences. The biosphere's ecological context comes from the 1920s, preceding the 1935 introduction of the term "ecosystem" by Sir Arthur Tansley. Vernadsky defined ecology as the science of the biosphere. It is an interdisciplinary concept for integrating astronomy, geophysics, meteorology, biogeography, evolution, geology, geochemistry, hydrology and, generally speaking, all life and earth sciences.

Narrow definition



A familiar scene on Earth which simultaneously shows the lithosphere, hydrosphere and atmosphere.

Some life scientists and earth scientists use *biosphere* in a more limited sense. For example, geochemists define the biosphere as being the total sum of living organisms (the "biomass" or "biota" as referred to by biologists and ecologists). In this sense, the biosphere is but one of four separate components of the geochemical model, the other three being *lithosphere*, *hydrosphere*, and *atmosphere*. The narrow meaning used by geochemists is one of the consequences of specialization in modern science. Some might prefer the word *ecosphere*, coined in the 1960s, as all encompassing of both biological and physical components of the planet.

The Second International Conference on Closed Life Systems defined *biospherics* as the science and technology of analogs and models of Earth's biosphere; i.e., artificial Earth-like biospheres. Others may include the creation of artificial non-Earth biospheres—for example, human-centered biospheres or a native Martian biosphere—in the field of biospherics.

Gaia hypothesis

The concept that the biosphere is itself a living organism, either actually or metaphorically, is known as the Gaia hypothesis.

James Lovelock, an atmospheric scientist from the United Kingdom, proposed the Gaia hypothesis to explain how biotic and abiotic factors interact in the biosphere. This hypothesis considers Earth itself a kind of living organism. Its atmosphere, geosphere, and hydrosphere are cooperating systems that yield a biosphere full of life. In the early 1970s, Lynn Margulis, a microbiologist from the United States, added to the hypothesis, specifically noting the ties between the biosphere and other Earth systems. For example, when carbon dioxide levels increase in the atmosphere, plants grow more quickly. As their growth continues, they remove more and more carbon dioxide from the atmosphere.

Many scientists are now involved in new fields of study that examine interactions between biotic and abiotic factors in the biosphere, such as geobiology and geomicrobiology.

Ecosystems occur when communities and their physical environment work together as a system. The difference between this and a biosphere is simple, the biosphere is everything in general terms.

Extent of Earth's biosphere



Water covers 71% of the Earth's surface. Image is the Earth photographed from Apollo 17.

Every part of the planet, from the polar ice caps to the Equator, supports life of some kind. Recent advances in microbiology have demonstrated that microbes live deep beneath the Earth's terrestrial surface, and that the total mass of microbial life in so-called "uninhabitable zones" may, in biomass, exceed all animal and plant life on the surface. The actual thickness of the biosphere on earth is difficult to measure. Birds typically fly at altitudes of 650 to 1,800 meters, and fish that live deep underwater can be found down to -8,372 meters in the Puerto Rico Trench.

There are more extreme examples for life on the planet: Rüppell's Vulture has been found at altitudes of 11,300 meters; Bar-headed Geese migrate at altitudes of at least 8,300

meters (over Mount Everest); Yaks live at elevations between 3,200 to 5,400 meters above sea level; mountain goats live up to 3,050 meters. Herbivorous animals at these elevations depend on lichens, grasses, and herbs.

Microscopic organisms live at such extremes that, taking them into consideration puts the thickness of the biosphere much greater. Culturable microbes have been found in the Earth's upper atmosphere as high as 41 km (25 mi) (Wainwright et al., 2003, in FEMS Microbiology Letters). It is unlikely, however, that microbes are active at such altitudes, where temperatures and air pressure are extremely low and ultraviolet radiation very high. More likely these microbes were brought into the upper atmosphere by winds or possibly volcanic eruptions. Barophilic marine microbes have been found at more than 10 km (6 mi) depth in the Marianas Trench (Takamia et al., 1997, in FEMS Microbiology Letters). Microbes are not limited to the air, water or the Earth's surface. Culturable thermophilic microbes have been extracted from cores drilled more than 5 km (3 mi) into the Earth's crust in Sweden (Gold, 1992, and Szewzyk, 1994, both in PNAS), from rocks between 65-75 °C. Temperature increases with increasing depth into the Earth's crust. The speed at which the temperature increases depends on many factors, including type of crust (continental vs. oceanic), rock type, geographic location, etc. The upper known limit of temperature at which microbial life can exist is 122 °C (*Methanopyrus kandleri* Strain 116), and it is likely that the limit of life in the "deep biosphere" is defined by temperature rather than absolute depth.

Our biosphere is divided into a number of biomes, inhabited by broadly similar flora and fauna. On land, biomes are separated primarily by latitude. Terrestrial biomes lying within the Arctic and Antarctic Circles are relatively barren of plant and animal life, while most of the more populous biomes lie near the equator. Terrestrial organisms in temperate and Arctic biomes have relatively small amounts of total biomass, smaller energy budgets, and display prominent adaptations to cold, including world-spanning migrations, social adaptations, homeothermy, estivation and multiple layers of insulation.

Specific biospheres

When the word is followed by a number, it is usually referring to a specific system or number. Thus:

- Biosphere 1, the planet Earth
- Biosphere 2, a laboratory in Arizona which contains 3.15 acres (13,000 m²) of closed ecosystem.
- BIOS-3, a closed ecosystem at the Institute of Biophysics in Krasnoyarsk, Siberia, in what was then the Soviet Union.
- Biosphere J (CEEF, Closed Ecology Experiment Facilities), an experiment in Japan.

Chapter 2

Ecosystem



Coral reefs are an example of a marine ecosystem.



Rainforests often have a great deal of biodiversity with many plant and animal species. This is the Gambia River in Senegal's Niokolo-Koba National Park.

An **ecosystem** is a biological environment consisting of all the organisms living in a particular area, as well as all the nonliving, physical components of the environment with which the organisms interact, such as air, soil, water and sunlight. It is all the organisms in a given area, along with the nonliving (abiotic) factors with which they interact; a biological community and its physical environment.

Overview

The entire array of organisms inhabiting a particular ecosystem is called a community. In a typical ecosystem, plants and other photosynthetic organisms are the producers that provide the food. Ecosystems can be permanent or temporary. Ecosystems usually form a number of food webs.

Ecosystems are functional units consisting of living things in a given area, non-living chemical and physical factors of their environment, linked together through nutrient cycle and energy flow.

1. Natural
 1. Terrestrial ecosystem
 2. Aquatic ecosystem
 1. Lentic, the ecosystem of a lake, pond or swamp.
 2. Lotic, the ecosystem of a river, stream or spring.

2. Artificial, ecosystems created by humans.

Central to the ecosystem concept is the idea that living organisms interact with every other element in their local environment. Eugene Odum, a founder of ecology, stated: "Any unit that includes all of the organisms (ie: the "community") in a given area interacting with the physical environment so that a flow of energy leads to clearly defined trophic structure, biotic diversity, and material cycles (i.e.: exchange of materials between living and nonliving parts) within the system is an ecosystem."

Etymology

The term ecosystem was coined in 1930 by Roy Clapham to mean the combined physical and biological components of an environment. British ecologist Arthur Tansley later refined the term, describing it as "The whole system, ... including not only the organism-complex, but also the whole complex of physical factors forming what we call the environment". Tansley regarded ecosystems not simply as natural units, but as mental isolates. Tansley later defined the spatial extent of ecosystems using the term ecotope.

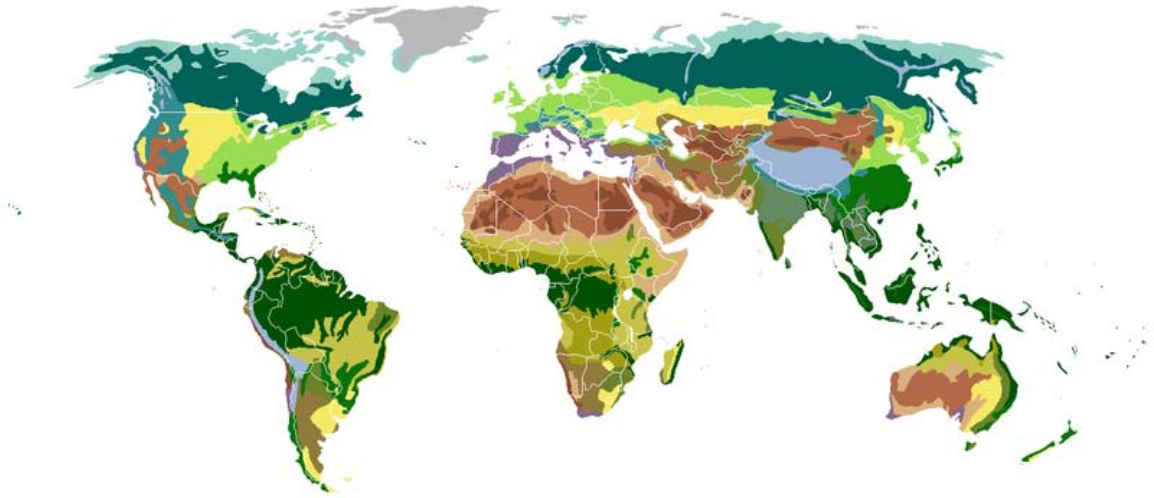
Examples of ecosystems

- agro-ecosystems
- Agroecosystem
- Aquatic ecosystem
- Chaparral
- Coral reef
- Desert
- Forest
- Greater Yellowstone Ecosystem
- Human ecosystem
- Large marine ecosystem
- Littoral zone
- Lotic
- Marine ecosystem
- Pond Ecosystem
- Prairie
- Rainforest
- Riparian zone
- Savanna
- Steppe
- Subsurface Lithoautotrophic Microbial Ecosystem
- Taiga
- Tundra
- Urban ecosystem



A freshwater ecosystem in Gran Canaria, an island of the Canary Islands.

Biomes



Map of Terrestrial biomes classified by vegetation.

Biomes are a classification of globally similar areas, including ecosystems, such as ecological communities of plants and animals, soil organisms and climatic conditions. Biomes are in part defined based on factors such as plant structures (such as trees, shrubs and grasses), leaf types (such as broadleaf and needleleaf), plant spacing (forest, woodland, savanna) and climate. Unlike ecozones, biomes are not defined by genetic, taxonomic or historical similarities. Biomes are often identified with particular patterns of ecological succession and climax vegetation.

A fundamental classification of biomes is:

1. Terrestrial (land) biomes.
2. Freshwater biomes.
3. Marine biomes.

Classification



Summer field in Belgium (Hamois). The blue flower is *Centaurea cyanus* and the red one a *Papaver rhoeas*.



The High Peaks Wilderness Area in the 6,000,000-acre (2,400,000 ha) Adirondack Park is an example of a diverse ecosystem.



Flora of Baja California Desert, Cataviña region, Mexico.

Ecosystems have become particularly important politically, since the Convention on Biological Diversity (CBD) - ratified by 192 countries - defines "the protection of ecosystems, natural habitats and the maintenance of viable populations of species in natural surroundings" as a commitment of ratifying countries. This has created the political necessity to spatially identify ecosystems and somehow distinguish among them. The CBD defines an "ecosystem" as a "dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit".

With the need of protecting ecosystems, the political need arose to describe and identify them efficiently. Vreugdenhil et al. argued that this could be achieved most effectively by using a physiognomic-ecological classification system, as ecosystems are easily recognizable in the field as well as on satellite images. They argued that the structure and seasonality of the associated vegetation, or flora, complemented with ecological data (such as elevation, humidity, and drainage), are each determining modifiers that separate partially distinct sets of species. This is true not only for plant species, but also for species of animals, fungi and bacteria. The degree of ecosystem distinction is subject to the physiognomic modifiers that can be identified on an image and/or in the field. Where

necessary, specific fauna elements can be added, such as seasonal concentrations of animals and the distribution of coral reefs.

Several physiognomic-ecological classification systems are available:

- Physiognomic-Ecological Classification of Plant Formations of the Earth: a system based on the 1974 work of Mueller-Dombois and Heinz Ellenberg, and developed by UNESCO. This classification "describes the above-ground or underwater vegetation structures and cover as observed in the field, described as plant life forms. This classification is fundamentally a species-independent physiognomic, hierarchical vegetation classification system which also takes into account ecological factors such as climate, elevation, human influences such as grazing, hydric regimes and survival strategies such as seasonality. The system was expanded with a basic classification for open water formations".
- Land Cover Classification System (LCCS), developed by the Food and Agriculture Organization (FAO).
- Forest-Range Environmental Study Ecosystems (FRES) developed by the United States Forest Service for use in the United States.

Several aquatic classification systems are available, and an effort is being made by the United States Geological Survey (USGS) and the Inter-American Biodiversity Information Network (IABIN) to design a complete ecosystem classification system that will cover both terrestrial and aquatic ecosystems.

From a philosophy of science perspective, ecosystems are not discrete units of nature that simply can be identified using the most "correct" type of classification approach. In agreement with the definition by Tansley ("mental isolates"), any attempt to delineate or classify ecosystems should be explicit about the observer/analyst input in the classification including its normative rationale.



Two Giant Sequoias, Sequoia National Park. Note the large fire scar at the base of the right-hand tree; fires do not kill the trees but do remove competing thin-barked species, and aid Giant Sequoia regeneration.

Ecosystem services

Ecosystem services are “fundamental life-support services upon which human civilization depends,”¹ and can be direct or indirect. Examples of direct ecosystem services are: pollination, wood and erosion prevention. Indirect services could be considered climate moderation, nutrient cycles and detoxifying natural substances.

The services and goods an ecosystem provides are often undervalued as many of them are without market value. Broad examples include:

- regulating (climate, floods, nutrient balance, water filtration)
- provisioning (food, medicine, fur)
- cultural (science, spiritual, ceremonial, recreation, aesthetic)
- supporting (nutrient cycling, photosynthesis, soil formation).

Ecosystem legal rights

Ecuador's new constitution of 2008 is the first in the world to recognize legally enforceable Rights of Nature, or ecosystem rights.

The borough of Tamaqua, Pennsylvania passed a law giving ecosystems legal rights. The ordinance establishes that the municipal government or any Tamaqua resident can file a lawsuit on behalf of the local ecosystem. Other townships, such as Rush, followed suit and passed their own laws.

This is part of a growing body of legal opinion proposing 'wild law'. Wild law, a term coined by Cormac Cullinan (a lawyer based in South Africa), would cover birds and animals, rivers and deserts.

Function and biodiversity



Savanna at Ngorongoro Conservation Area, Tanzania.



The side of a tide pool showing sea stars (*Dermasterias*), sea anemones (*Anthopleura*) and sea sponges in Santa Cruz, California.

From an anthropocentric point of view, some people perceive ecosystems as production units that produce goods and services, such as wood by forest ecosystems and grass for cattle by natural grasslands. Meat from wild animals, often referred to as bush meat in Africa, has proven to be extremely successful under well-controlled management schemes in South Africa and Kenya. Much less successful has been the discovery and commercialization of substances of wild organism for pharmaceutical purposes. Services derived from ecosystems are referred to as ecosystem services. They may include

1. facilitating the enjoyment of nature, which may generate many forms of income and employment in the tourism sector, often referred to as eco-tourisms,
2. water retention, thus facilitating a more evenly distributed release of water,
3. soil protection, open-air laboratory for scientific research, etc.

A greater degree of species or biological diversity - commonly referred to as Biodiversity - of an ecosystem may contribute to greater resilience of an ecosystem, because there are more species present at a location to respond to change and thus "absorb" or reduce its effects. "Some theories predict that biodiversity will promote ecosystem integrity in changing climates, because high diversity ensures that functional groups will retain at least one species able to tolerate altered condition." This reduces the effect before the ecosystem's structure is fundamentally changed to a different state. One hypothesis about this is the Rivet Poper Hypothesis. According to Paul and Anne Ehrlich "the diversity of life is something like the rivets on an airplane. Each species plays a small but significant

role in the working of the whole, and the loss of any rivet weakens the plane by a small but measurable amount. Pop too many rivets and the plane will crash that is, some vital function will collapse." They are saying if too many species die out then some sort of vital function of the ecosystem such as a food web would collapse causing the ecosystem to fail. When thinking about species as rivets the smaller species would actually be the larger rivet though because of their importance to the ecosystem. Without the smaller species the ecosystem there to produce, the rest would not survive. This is not universally the case and there is no proven relationship between the species diversity of an ecosystem and its ability to provide goods and services on a sustainable level: Humid tropical forests produce very few goods and direct services and are extremely vulnerable to change, while many temperate forests readily grow back to their previous state of development within a lifetime after felling or a forest fire. Some grasslands have been sustainably exploited for thousands of years (Mongolia, Africa, European peat and moorland communities).

The study of ecosystems



Forest on San Juan Island

Ecosystem dynamics



Loch Lomond in Scotland forms a relatively isolated ecosystem. The fish community of this lake has remained unchanged over a very long period of time.

Introduction of new elements, whether biotic or abiotic, into an ecosystem tend to have a disruptive effect. In some cases, this can lead to ecological collapse or "trophic cascading" and the death of many species within the ecosystem. Under this deterministic vision, the abstract notion of ecological health attempts to measure the robustness and recovery capacity for an ecosystem; i.e. how far the ecosystem is away from its steady state.

Often, however, ecosystems have the ability to rebound from a disruptive agent. The difference between collapse or a gentle rebound is determined by two factors—the toxicity of the introduced element and the resiliency of the original ecosystem.

Ecosystems are primarily governed by stochastic (chance) events, the reactions these events provoke on non-living materials and the responses by organisms to the conditions surrounding them. Thus, an ecosystem results from the sum of individual responses of organisms to stimuli from elements in the environment. The presence or absence of populations merely depends on reproductive and dispersal success, and population levels fluctuate in response to stochastic events. As the number of species in an ecosystem is higher, the number of stimuli is also higher. Since the beginning of life organisms have

survived continuous change through natural selection of successful feeding, reproductive and dispersal behavior. Through natural selection the planet's species have continuously adapted to change through variation in their biological composition and distribution. Mathematically it can be demonstrated that greater numbers of different interacting factors tend to dampen fluctuations in each of the individual factors.



Spiny forest at Ifaty, Madagascar, featuring various *Adansonia* (baobab) species, *Alluaudia procera* (Madagascar ocotillo) and other vegetation.

Given the great diversity among organisms on earth, most ecosystems only changed very gradually, as some species would disappear while others would move in. Locally, sub-populations continuously go extinct, to be replaced later through dispersal of other sub-populations. Stochastists do recognize that certain intrinsic regulating mechanisms occur in nature. Feedback and response mechanisms at the species level regulate population levels, most notably through territorial behaviour. Andrewatha and Birch suggest that territorial behaviour tends to keep populations at levels where food supply is not a limiting factor. Hence, stochastists see territorial behaviour as a regulatory mechanism at the species level but not at the ecosystem level. Thus, in their vision, ecosystems are not regulated by feedback and response mechanisms from the ecosystem itself and there is no such thing as a balance of nature.

If ecosystems are governed primarily by stochastic processes, through which its subsequent state would be determined by both predictable and random actions, they may be more resilient to sudden change than each species individually. In the absence of a balance of nature, the species composition of ecosystems would undergo shifts that

would depend on the nature of the change, but entire ecological collapse would probably be infrequent events.



Arctic tundra on Wrangel Island, Russia.

The theoretical ecologist Robert Ulanowicz has used information theory tools to describe the structure of ecosystems, emphasizing mutual information (correlations) in studied systems. Drawing on this methodology and prior observations of complex ecosystems, Ulanowicz depicts approaches to determining the stress levels on ecosystems and predicting system reactions to defined types of alteration in their settings (such as increased or reduced energy flow, and eutrophication).

In addition, Eric Sanderson has developed the Muir web, based on experience on the Mannahatta project. This graphical schematic shows how different species are connected to each other, not only regarding their position in the food chain, but also regarding other services, i.e. provisioning of shelter.

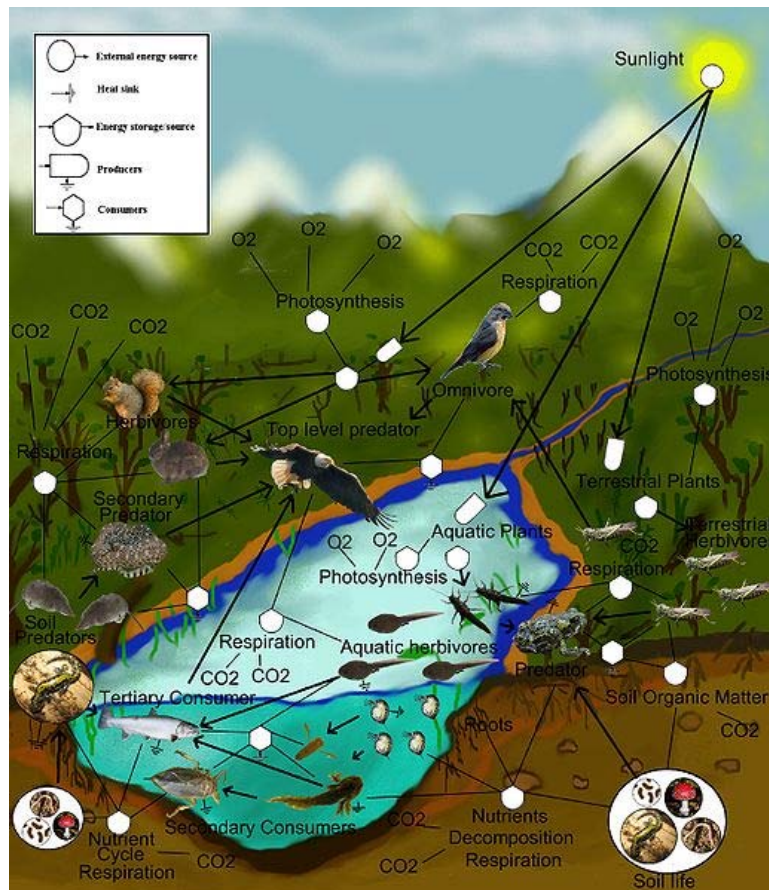
Ecosystem ecology

Ecosystem ecology is the integrated study of biotic and abiotic components of ecosystems and their interactions within an ecosystem framework. This science examines how ecosystems work and relates this to their components such as chemicals, bedrock, soil, plants, and animals. Ecosystem ecology examines physical and biological structure and examines how these ecosystem characteristics interact.

Chapter 3

Biocoenosis and Population

Biocoenosis



A freshwater aquatic and terrestrial food web.

A **biocoenosis** (alternatively, **biocoenose** or **biocenose**), termed by Karl Möbius in 1877, describes all the interacting organisms living together in a specific habitat (or biotope).

Biotic community, biological community, and **ecological community** are more common synonyms of biocenosis, all of which represent the same concepts.

Three related descriptors within an ecosystem are:

- zoocoenosis for the faunal community,
- phytocoenosis for the floral community,
- microbiocoenosis for the microbial community.

The extent or geographical area of a biocenose is limited only by the requirement of a more or less uniform species composition.

Ecosystems

An ecosystem, as originally defined by Tansley (1935), is a biotic community (or biocoenosis) along with its physical environment (or *biotope* as defined by many known ecologists).

The importance of the biocoenosis concept in ecology is its emphasis on the interrelationships among species in a geographical area. These interactions are as important as the physical factors to which each species is adapted and responding. In a very real sense, it is the specific biological community or biocoenosis that is adapted to conditions that prevail in a given place.

Biotic communities

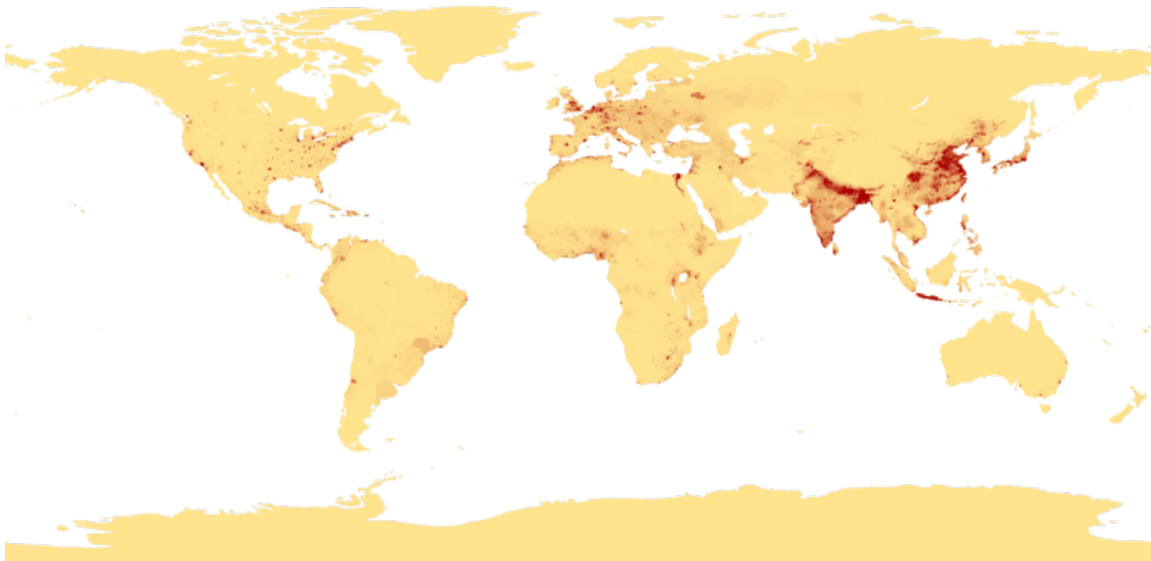


The side of a tide pool showing sea stars (*Dermasterias*), sea anemones (*Anthopleura*) and sea sponges in Santa Cruz, California.

Biotic communities may be of varying sizes, and larger ones may contain smaller ones. The interactions between species are especially evident in food or feeding relationships. Therefore, a practical method of delineating biotic communities is to map the food network to identify which species feed upon which others and then determine the system boundary as the one that can be drawn through the fewest consumption links relative to the number of species within the boundary.

Mapping biotic communities is particularly important when identifying sites in need of environmental protection such as the British Site of Special Scientific Interest (SSSIs). The Australian Department of the Environment and Heritage maintains a register of *Threatened Species and Threatened Ecological Communities* under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).

Population



Distribution of world population in 1994.

A **population** is all the organisms that both belong to the same species and live in the same geographical area. The area that is used to define the population is such that interbreeding is possible between any pair within the area and more probable than crossbreeding with individuals from other areas. Normally breeding is substantially more common within the area than across the border.

In sociology, population refers to a collection of human beings. Demography is a sociological discipline which entails the statistical study of human populations.

Population genetics

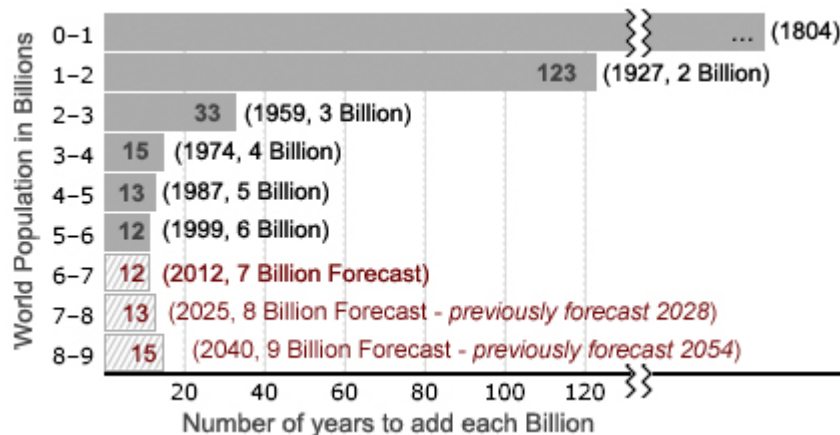
In population genetics a population is a set of organisms in which any pair of members can breed together. This implies that all members belong to the same species and live near each other. .

World human population

As of 28 March 2011, the world population is estimated by the United States Census Bureau to be 6.908 billion.

According to papers published by the United States Census Bureau, the world population hit 6.5 billion (6,500,000,000) on 24 February 2006. The United Nations Population Fund designated 12 October 1999 as the approximate day on which world population reached 6 billion. This was about 12 years after world population reached 5 billion in 1987, and 6 years after world population reached 5.5 billion in 1993. The population of some countries, such as Nigeria and China is not even known to the nearest million, so there is a considerable margin of error in such estimates.

Growth



Time taken for each billion people to be added to the world's population (including future estimates).

Population growth increased significantly as the Industrial Revolution gathered pace from 1700 onwards. The last 50 years have seen a yet more rapid increase in the rate of population growth due to medical advances and substantial increases in agricultural productivity, particularly beginning in the 1960s, made by the Green Revolution. In 2007 the United Nations Population Division projected that the world's population will likely surpass 10 billion in 2055. In the future, world population has been expected to reach a peak of growth, from there it will decline due to economic reasons, health concerns, land exhaustion and environmental hazards. There is around an 85% chance that the world's population will stop growing before the end of the century. There is a 60% probability that the world's population will not exceed 10 billion people before 2100, and around a

15% probability that the world's population at the end of the century will be lower than it is today. For different regions, the date and size of the peak population will vary considerably.

The population pattern of less-developed regions of the world in recent years has been marked by gradually declining birth rates following an earlier sharp reduction in death rates. This transition from high birth and death rates to low birth and death rates is often referred to as the demographic transition.

Control

Human population control is the practice of artificially altering the rate of growth of a human population. Historically, human population control has been implemented by limiting the population's birth rate, usually by government mandate, and has been undertaken as a response to factors including high or increasing levels of poverty, environmental concerns, religious reasons, and overpopulation. While population control can involve measures that improve people's lives by giving them greater control of their reproduction, some programs have exposed them to exploitation.

Worldwide, the population control movement was active throughout the 1960s and 1970s, driving many reproductive health and family planning programs. In the 1980s, tension grew between population control advocates and women's health activists who advanced women's reproductive rights as part of a human rights-based approach. Growing opposition to the narrow population control focus led to a significant change in population control policies in the early 1990s.

Chapter 4

Organism



A polypore mushroom has parasitic relationship with its host



An ericoid mycorrhizal fungus

In biology, an **organism** is any contiguous living system (such as animal, plant, fungus, or micro-organism). In at least some form, all organisms are capable of response to stimuli, reproduction, growth and development, and maintenance of homeostasis as a stable whole. An organism may either be unicellular (single-celled) or be composed of, as in humans, many trillions of cells grouped into specialized tissues and organs. The term *multicellular* (many-celled) describes any organism made up of more than one cell.

The term "organism" first appeared in the English language in 1701 and took on its current definition by 1834 (Oxford English Dictionary). It is directly related to the term "organization". There is a long tradition of defining organisms as self-organizing beings.

There has been a great deal of recent controversy about the best way to define the organism and indeed about whether or not such a definition is necessary. Several contributions are responses to the suggestion that the category of "organism" may well not be adequate in biology.

Scientific classification in biology considers organisms synonymous with "life on Earth". Based on cell type, organisms may be divided into the prokaryotic and eukaryotic groups. The prokaryotes represent two separate domains, the Bacteria and Archaea. Eukaryotic organisms, with a membrane-bounded cell nucleus, also contain organelles, namely

mitochondria and (in plants) plastids, generally considered to be derived from endosymbiotic bacteria. Fungi, animals and plants are examples of species that are eukaryotes.

More recently a clade, Neomura, has been proposed, which groups together the Archaea and Eukarya. Neomura is thought to have evolved from Bacteria, more specifically from Actinobacteria.

Semantics

The word *organism* may broadly be defined as an assembly of molecules functioning as a more or less stable whole which exhibits the properties of life. However, many sources propose definitions that exclude viruses and theoretically possible man-made non-organic life forms. Viruses are dependent on the biochemical machinery of a host cell for reproduction.

Chambers Online Reference provides a broad definition: "any living structure, such as a plant, animal, fungus or bacterium, capable of growth and reproduction".

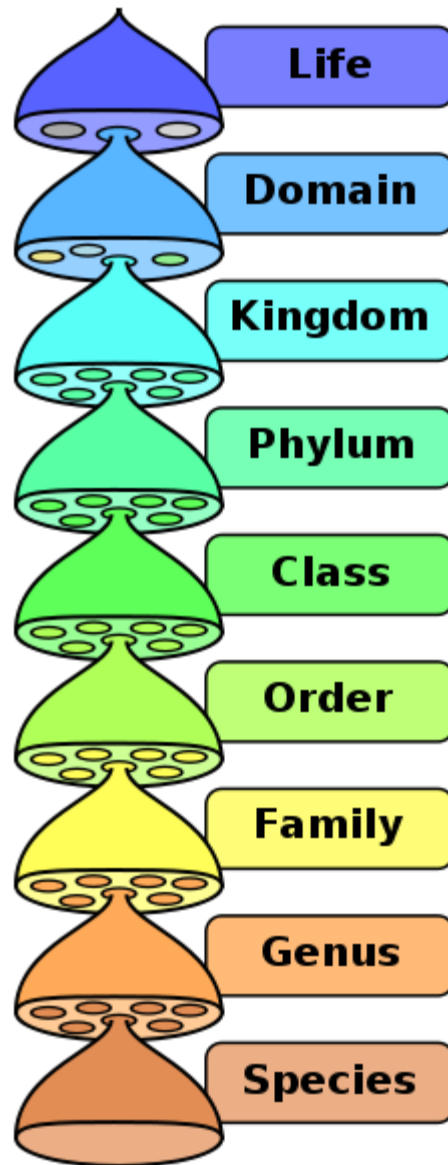
In multicellular terms, "organism" usually describes the whole hierarchical assemblage of systems (for example circulatory, digestive, or reproductive) themselves collections of organs; these are, in turn, collections of tissues, which are themselves made of cells. In some plants and the nematode *Caenorhabditis elegans*, individual cells are totipotent.

A superorganism is an organism consisting of many individuals working together as a single functional or social unit.

Viruses

Viruses are not typically considered to be organisms because they are incapable of "independent" or autonomous reproduction or metabolism. This controversy is problematic because some cellular organisms are also incapable of independent survival (but not of independent metabolism and procreation) and live as obligatory intracellular parasites. Although viruses have a few enzymes and molecules characteristic of living organisms, they have no metabolism of their own and cannot synthesize and organize the organic compounds that form them. Naturally, this rules out autonomous reproduction and they can only be passively replicated by the machinery of the host cell. In this sense they are similar to inanimate matter. While viruses sustain no independent metabolism, and thus are usually not accounted organisms, they do have their own genes and they do evolve by similar mechanisms by which organisms evolve.

Organizational terminology



The hierarchy of biological classification's eight major taxonomic ranks, which is an example of definition by genus and differentia. Intermediate minor rankings are not shown.

All organisms are classified by the science of alpha taxonomy into either taxa or clades.

Taxa are ranked groups of organisms, which run from the general (domain) to the specific (species). A broad scheme of ranks in hierarchical order is:

1. Domain
2. Kingdom
3. Phylum

4. Class
5. Order
6. Family
7. Genus
8. Species

To give an example, *Homo sapiens* is the Latin binomial equating to modern humans. All members of the species *sapiens* are, at least in theory, genetically able to interbreed. Several species may belong to a genus, but the members of different species within a genus are unable to interbreed to produce fertile offspring. *Homo*, however, only has one surviving species (*sapiens*), *Homo erectus*, *Homo neanderthalensis*, etc. having become extinct thousands of years ago. Several genera belong to the same family and so on up the hierarchy. Eventually, the relevant kingdom (Animalia, in the case of humans) is placed into one of the three domains depending upon certain genetic and structural characteristics.

All living organisms known to science are given classification by this system such that the species within a particular family are more closely related and genetically similar than the species within a particular phylum.

Chemistry

Organisms are complex chemical systems, organized in ways that promote reproduction and some measure of sustainability or survival. The molecular phenomena of chemistry are fundamental in understanding organisms, but it is a philosophical error (reductionism) to reduce organismal biology to mere chemistry. It is generally the phenomena of entire organisms that determine their fitness to an environment and therefore the survivability of their DNA-based genes.

Organisms clearly owe their origin, metabolism, and many other internal functions to chemical phenomena, especially the chemistry of large organic molecules. Organisms are complex systems of chemical compounds that, through interaction and environment, play a wide variety of roles.

Organisms are semi-closed chemical systems. Although they are individual units of life (as the definition requires) they are not closed to the environment around them. To operate they constantly take in and release energy. Autotrophs produce usable energy (in the form of organic compounds) using light from the sun or inorganic compounds while heterotrophs take in organic compounds from the environment.

The primary chemical element in these compounds is carbon. The physical properties of this element such as its great affinity for bonding with other small atoms, including other carbon atoms, and its small size making it capable of forming multiple bonds, make it ideal as the basis of organic life. It is able to form small three-atom compounds (such as carbon dioxide), as well as large chains of many thousands of atoms that can store data (nucleic acids), hold cells together, and transmit information (protein).

Macromolecules

Compounds that make up organisms may be divided into macromolecules and other, smaller molecules. The four groups of macromolecule are nucleic acids, proteins, carbohydrates and lipids. Nucleic acids (specifically deoxyribonucleic acid, or DNA) store genetic data as a sequence of nucleotides. The particular sequence of the four different types of nucleotides (adenine, cytosine, guanine, and thymine) dictate the many characteristics that constitute the organism. The sequence is divided up into codons, each of which is a particular sequence of three nucleotides and corresponds to a particular amino acid. Thus a sequence of DNA codes for a particular protein that, due to the chemical properties of the amino acids it is made from, folds in a particular manner and so performs a particular function.

These protein functions have been recognized:

1. Enzymes, which catalyze all of the reactions of metabolism
2. Structural proteins, such as tubulin, or collagen
3. Regulatory proteins, such as transcription factors or cyclins that regulate the cell cycle
4. Signaling molecules or their receptors such as some hormones and their receptors
5. Defensive proteins, which can include everything from antibodies of the immune system, to toxins (e.g., dendrotoxins of snakes), to proteins that include unusual amino acids like canavanine

Lipids make up the membrane of cells that constitutes a barrier, containing everything within the cell and preventing compounds from freely passing into, and out of, the cell. In some multicellular organisms they serve to store energy and mediate communication between cells. Carbohydrates also store and transport energy in some organisms, but are more easily broken down than lipids.

Structure

All organisms consist of monomeric units called cells; some contain a single cell (unicellular) and others contain many units (multicellular). Multicellular organisms are able to specialize cells to perform specific functions. A group of such cells is a tissue, the four basic types of which are epithelium, nervous tissue, muscle tissue, and connective tissue. Several types of tissue work together in the form of an organ to produce a particular function (such as the pumping of the blood by the heart, or as a barrier to the environment as the skin). This pattern continues to a higher level with several organs functioning as an organ system to allow for reproduction, digestion, etc. Many multicelled organisms consist of several organ systems, which coordinate to allow for life.

The cell

The cell theory, first developed in 1839 by Schleiden and Schwann, states that all organisms are composed of one or more cells; all cells come from preexisting cells; all vital functions of an organism occur within cells, and cells contain the hereditary information necessary for regulating cell functions and for transmitting information to the next generation of cells.

There are two types of cells, eukaryotic and prokaryotic. Prokaryotic cells are usually singletons, while eukaryotic cells are usually found in multicellular organisms. Prokaryotic cells lack a nuclear membrane so DNA is unbound within the cell, eukaryotic cells have nuclear membranes.

All cells, whether prokaryotic or eukaryotic, have a membrane, which envelops the cell, separates its interior from its environment, regulates what moves in and out, and maintains the electric potential of the cell. Inside the membrane, a salty cytoplasm takes up most of the cell volume. All cells possess DNA, the hereditary material of genes, and RNA, containing the information necessary to build various proteins such as enzymes, the cell's primary machinery. There are also other kinds of biomolecules in cells.

All cells share several abilities:

- Reproduction by cell division (binary fission, mitosis or meiosis).
- Use of enzymes and other proteins coded for by DNA genes and made via messenger RNA intermediates and ribosomes.
- Metabolism, including taking in raw materials, building cell components, converting energy, molecules and releasing by-products. The functioning of a cell depends upon its ability to extract and use chemical energy stored in organic molecules. This energy is derived from metabolic pathways.
- Response to external and internal stimuli such as changes in temperature, pH or nutrient levels.
- Cell contents are contained within a cell surface membrane that contains proteins and a lipid bilayer.

Life span

One of the basic parameters of an organism is its life span. Some organisms live as short as one day, while some plants can live thousands of years. Aging is important when determining the life span of most organisms, bacterium, a virus or even a prion.

Evolution

In biology, the theory of universal common descent proposes that all organisms on Earth are descended from a common ancestor or ancestral gene pool. Evidence for common descent may be found in traits shared between all living organisms. In Darwin's day, the

evidence of shared traits was based solely on visible observation of morphologic similarities, such as the fact that all birds have wings, even those that do not fly.

Today, there is debate over whether or not all organisms descended from a common ancestor, or a "last universal ancestor" (LUA), also called the "last universal common ancestor" (LUCA). The universality of genetic coding suggests common ancestry. For example, every living cell makes use of nucleic acids as its genetic material, and uses the same twenty amino acids as the building blocks for proteins, although exceptions to the basic twenty amino acids have been found. However, throughout history groupings based on appearance or function of species have sometimes been polyphyletic due to convergent evolution.

The "last universal ancestor" (LUA), or "last universal common ancestor" (LUCA), is the name given to the hypothetical unicellular organism or single cell that gave rise to all life on Earth 3.5 to 3.8 billion years ago; however, this hypothesis has since been refuted on many grounds. For example, it was once thought that the genetic code was universal (see: Universal genetic code), but many variations have been discovered including various alternative mitochondrial codes. Back in the early 1970s, evolutionary biologists thought that a given piece of DNA specified the same protein subunit in every living thing, and that the genetic code was thus universal. This was interpreted as evidence that every organism had inherited its genetic code from a single common ancestor, aka, an LUCA. In 1979, however, exceptions to the code were found in mitochondria, the tiny energy factories inside cells. Researchers studying human mitochondrial genes discovered that they used an alternative code, and many slight variants have been discovered since, including various alternative mitochondrial codes, as well as small variants such as *Mycoplasma* translating the codon UGA as tryptophan. Biologists subsequently found exceptions in bacteria and in the nuclei of algae and single-celled animals. For example, certain proteins may use alternative initiation (start) codons not normally used by that species. In certain proteins, non-standard amino acids are substituted for standard stop codons, depending upon associated signal sequences in the messenger RNA: UGA can code for selenocysteine and UAG can code for pyrrolysine. Selenocysteine is now viewed as the 21st amino acid, and pyrrolysine is viewed as the 22nd. A detailed description of variations in the genetic code can be found at the NCBI web site.

Information about the early development of life includes input from many different fields, including geology and planetary science. These sciences provide information about the history of the Earth and the changes produced by life. However, a great deal of information about the early Earth has been destroyed by geological processes over the course of time.

History of life

The chemical evolution from self-catalytic chemical reactions to life is not a part of biological evolution, but it is unclear at which point such increasingly complex sets of reactions became what we would consider, today, to be living organisms.



Precambrian stromatolites in the Siyeh Formation, Glacier National Park. In 2002, William Schopf of UCLA published a controversial paper in the journal *Nature* arguing that formations such as this possess 3.5 billion year old fossilized algae microbes. If true, they would be the earliest known life on earth.

Not much is known about the earliest developments in life. However, all existing organisms share certain traits, including cellular structure and genetic code. Most scientists interpret this to mean all existing organisms share a common ancestor, which had already developed the most fundamental cellular processes, but there is no scientific consensus on the relationship of the three domains of life (Archaea, Bacteria, Eukaryota) or the origin of life. Attempts to shed light on the earliest history of life generally focus on the behavior of macromolecules, particularly RNA, and the behavior of complex systems.

The emergence of oxygenic photosynthesis (around 3 billion years ago) and the subsequent emergence of an oxygen-rich, non-reducing atmosphere can be traced through the formation of banded iron deposits, and later red beds of iron oxides. This was a necessary prerequisite for the development of aerobic cellular respiration, believed to have emerged around 2 billion years ago.

In the last billion years, simple multicellular plants and animals began to appear in the oceans. Soon after the emergence of the first animals, the Cambrian explosion (a period of unrivaled and remarkable, but brief, organismal diversity documented in the fossils found at the Burgess Shale) saw the creation of all the major body plans, or phyla, of modern animals. This event is now believed to have been triggered by the development

of the Hox genes. About 500 million years ago, plants and fungi colonized the land, and were soon followed by arthropods and other animals, leading to the development of today's land ecosystems.

The evolutionary process may be exceedingly slow. Fossil evidence indicates that the diversity and complexity of modern life has developed over much of the history of the earth. Geological evidence indicates that the Earth is approximately 4.6 billion years old. Studies on guppies by David Reznick at the University of California, Riverside, however, have shown that the rate of evolution through natural selection can proceed 10 thousand to 10 million times faster than what is indicated in the fossil record. Such comparative studies however are invariably biased by disparities in the time scales over which evolutionary change is measured in the laboratory, field experiments, and the fossil record.

Horizontal gene transfer

The ancestry of living organisms has traditionally been reconstructed from morphology, but is increasingly supplemented with phylogenetics—the reconstruction of phylogenies by the comparison of genetic (DNA) sequence.

Sequence comparisons suggest recent horizontal transfer of many genes among diverse species including across the boundaries of phylogenetic "domains". Thus determining the phylogenetic history of a species can not be done conclusively by determining evolutionary trees for single genes.

Biologist Gogarten suggests "the original metaphor of a tree no longer fits the data from recent genome research", therefore "biologists [should] use the metaphor of a mosaic to describe the different histories combined in individual genomes and use [the] metaphor of a net to visualize the rich exchange and cooperative effects of HGT among microbes."

Future of life (cloning and synthetic organisms)

In modern terms, the category of organism cloning refers to the procedure of creating a new multicellular organism, genetically identical to another. However, cloning also has the potential of creating entirely new species of organisms. Organism cloning is the subject of much ethical debate.

The J. Craig Venter Institute has recently assembled a synthetic bacterial genome, *Mycoplasma genitalium*, by using recombination in yeast of 25 overlapping DNA fragments in a single step. "The use of yeast recombination greatly simplifies the assembly of large DNA molecules from both synthetic and natural fragments." Other companies, such as Synthetic Genomics, have already been formed to take advantage of the many commercial uses of custom designed genomes.

Chapter 5

Organ (Anatomy) and Tissue (Biology)

Organ (anatomy)

In biology and anatomy, an **organ** (Latin: *organum*, "instrument, tool", from Greek ὄργανον, *organon*, "organ, instrument, tool") is a collection of tissues joined in structural unit to serve a common function.

Usually there is a *main* tissue and *sporadic* tissues. The main tissue is the one that is unique for the specific organ. For example, main tissue in the heart is the myocardium, while sporadic are the nerves, blood, connective etc.. Functionally related organs often cooperate to form whole organ systems. Organs exist in all higher biological organisms, in particular they are not restricted to animals, but can also be identified in plants. An example of this is the bladder. In single-cell organisms like bacteria, the functional analogues of organs are called organelles.

A **hollow organ** is a visceral organ that is a hollow tube or pouch (as the stomach or intestine) or that includes a cavity (as of the heart or urinary bladder).

Organ systems

The functions of organ systems often share significant overlap. For instance, the nervous and endocrine system both operate via a shared organ, the hypothalamus. For this reason, the two systems are combined and studied as the neuroendocrine system. The same is true for the musculoskeletal system, which involves the relationship between the muscular and skeletal systems.

Plants



The flower is the angiosperm's reproductive organ. This *Hibiscus* flower is hermaphroditic, and it contains stamens and pistils.



Strobilus of *Equisetum telmateia*.

Organs of plants can be divided into vegetative and reproductive. Vegetative plant organs are root, stem and leaf. The reproductive organs are variable. In angiosperms, they are represented with the flower, seed and fruit. In conifers, the organ that bears the reproductive structures is called a cone. In other divisions of plants, the reproductive organs are called strobili (in *Lycopodiophyta*) or simply gametophores (in mosses).

The vegetative organs are essential for maintaining the life of a plant. There are 11 organ systems (they perform the vital functions, such as photosynthesis), while the reproductive organs are essential in reproduction. However, if there is asexual vegetative reproduction, the vegetative organs are those that create the new generation of plants.

The two main organ systems in vascular plants are the root system and the shoot system.

Animals

The organ level of organisation in animals can be first detected in flatworms and the more advanced phyla. The less-advanced taxons (like *Placozoa*, *Porifera* and *Radiata*) do not show consolidation of their tissues into organs.

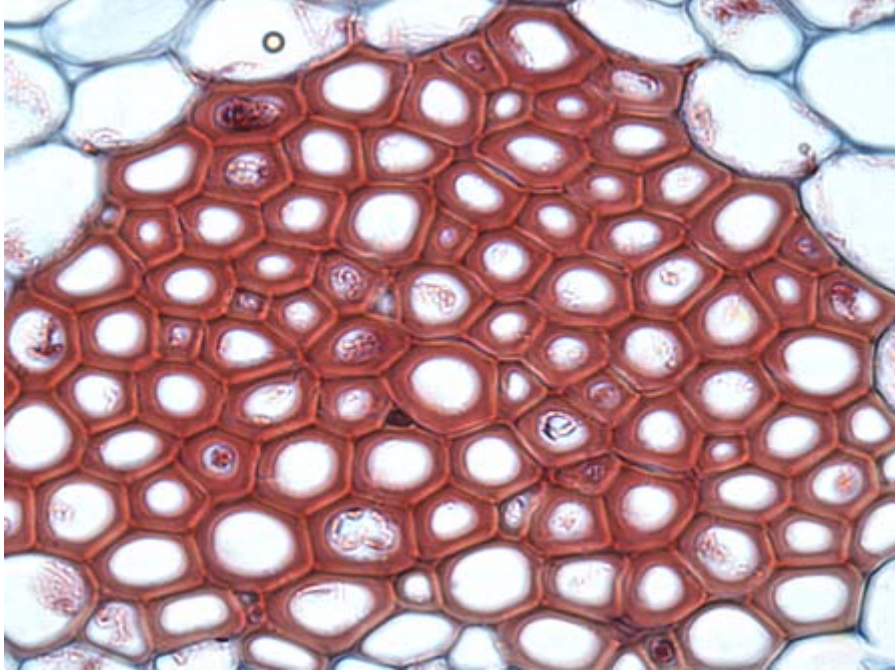
List of mammalian organ systems

There are eleven major organ systems found in mammals.

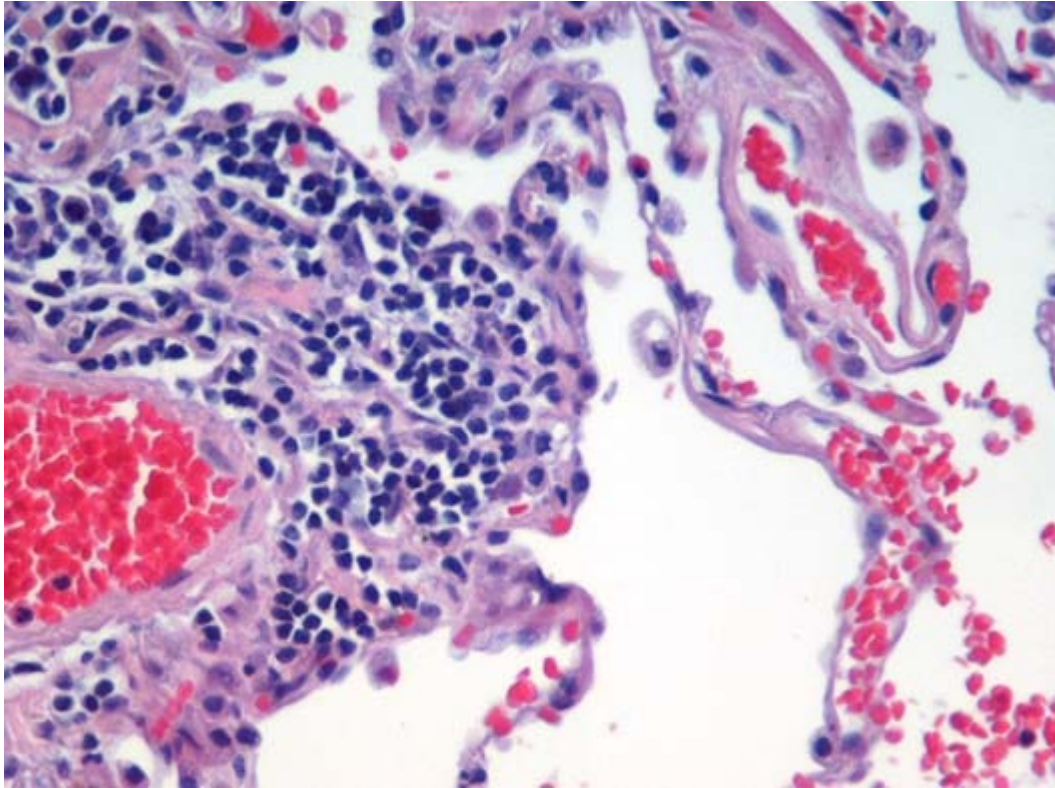
Mammals such as humans have a variety of organ systems. These specific systems are also widely studied in human anatomy.

- Circulatory system: pumping and channeling blood to and from the body and lungs with heart, blood and blood vessels.
- Digestive system: digestion and processing food with salivary glands, esophagus, stomach, liver, gallbladder, pancreas, intestines, colon, rectum and anus.
- Endocrine system: communication within the body using hormones made by endocrine glands such as the hypothalamus, pituitary or pituitary gland, pineal body or pineal gland, thyroid, parathyroids and adrenals, i.e., adrenal glands.
- Excretory system: kidneys, ureters, bladder and urethra involved in fluid balance, electrolyte balance and excretion of urine.
- Integumentary system: skin, hair and nails.
- Lymphatic system: structures involved in the transfer of lymph between tissues and the blood stream, the lymph and the nodes and vessels that transport it including the Immune system: defending against disease-causing agents with leukocytes, tonsils, adenoids, thymus and spleen.
- Muscular system: movement with muscles.
- Nervous system: collecting, transferring and processing information with brain, spinal cord, peripheral nerves and nerves.
- Reproductive system: the sex organs, such as ovaries, fallopian tubes, uterus, vagina, mammary glands, testes, vas deferens, seminal vesicles, prostate and penis.
- Respiratory system: the organs used for breathing, the pharynx, larynx, trachea, bronchi, lungs and diaphragm.
- Skeletal system: structural support and protection with bones, cartilage, ligaments and tendons.

Tissue (biology)



Cross section of sclerenchyma fibers in plant ground tissue

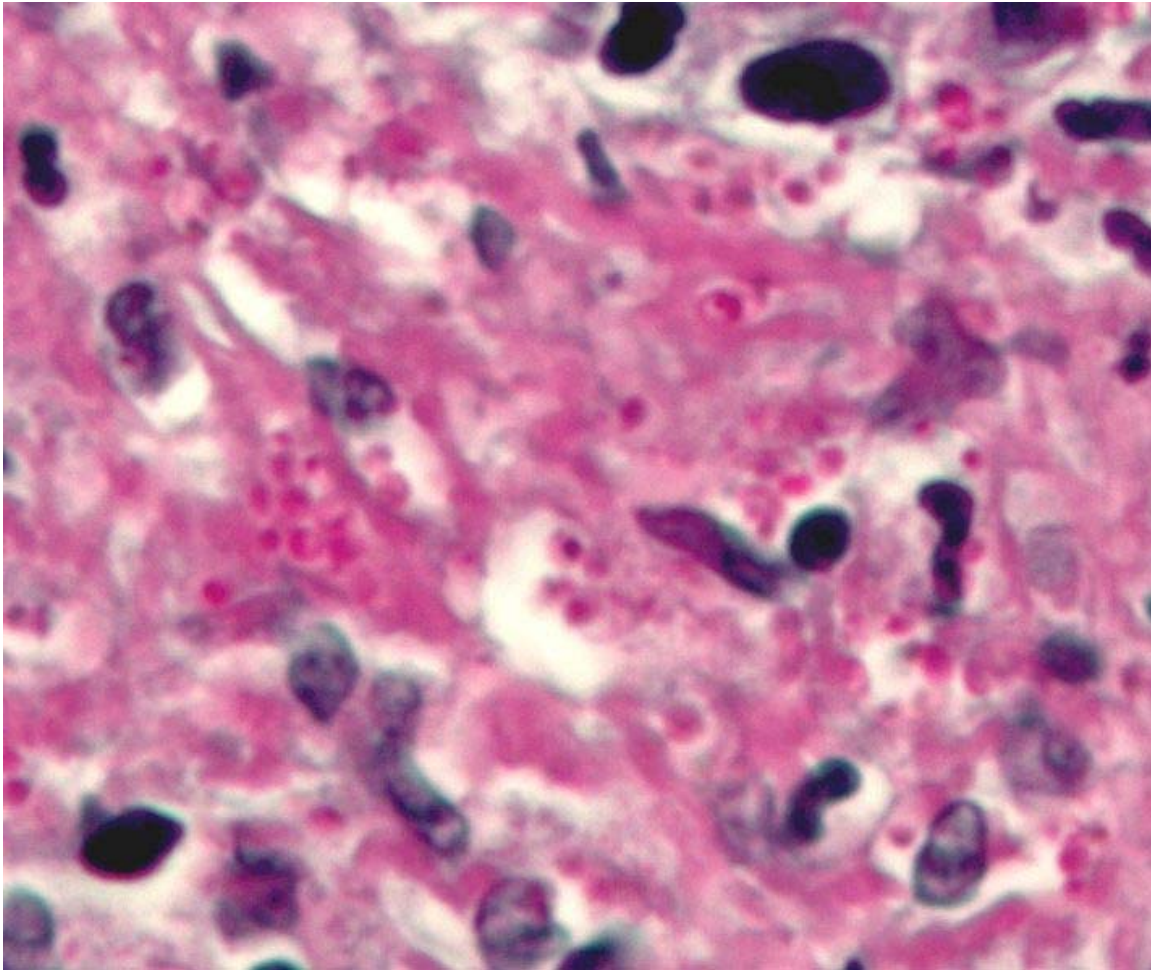


Microscopic view of a histologic specimen of human lung tissue stained with hematoxylin and eosin.

Tissue is a cellular organizational level intermediate between cells and a complete organism. A tissue is an ensemble of cells, not necessarily identical, but from the same origin, that together carry out a specific function. **Organs** are then formed by the functional grouping together of multiple tissues.

The study of tissue is known as histology or, in connection with disease, histopathology. The classical tools for studying tissues are the paraffin block in which tissue is embedded and then sectioned, the histological stain, and the optical microscope. In the last couple of decades, developments in electron microscopy, immunofluorescence, and the use of frozen tissue sections have enhanced the detail that can be observed in tissues. With these tools, the classical appearances of tissues can be examined in health and disease, enabling considerable refinement of clinical diagnosis and prognosis.

Animal tissues



PAS diastase showing the fungus Histoplasma.

Animal tissues can be grouped into four basic types: connective, muscle, nervous, and epithelial. Multiple tissue types comprise organs and body structures. While all animals can generally be considered to contain the four tissue types, the manifestation of these tissues can differ depending on the type of organism. For example, the origin of the cells comprising a particular tissue type may differ developmentally for different classifications of animals. The epithelium in all animals is derived from the ectoderm and endoderm with a small contribution from the mesoderm which forms the endothelium. By contrast, a true epithelial tissue is present only in a single layer of cells held together via occluding junctions called tight junctions, to create a selectively permeable barrier. This tissue covers all organismal surfaces that come in contact with the external environment such as the skin, the airways, and the digestive tract. It serves functions of protection, secretion, and absorption, and is separated from other tissues below by a basal lamina. Endothelium, which comprises the vasculature, is a specialized type of epithelium.

Connective tissue

Connective tissues are fibrous tissues. They are made up of cells separated by non-living material, which is called extracellular matrix. Connective tissue gives shape to organs and holds them in place. Both blood and bone are examples of connective tissue.

Muscle tissue

Muscle cells form the active contractile tissue of the body known as muscle tissue. Muscle tissue functions to produce force and cause motion, either locomotion or movement within internal organs. Muscle tissue is separated into three distinct categories: visceral or smooth muscle, which is found in the inner linings of organs; skeletal muscle, in which is found attached to bone providing for gross movement; and cardiac muscle which is found in the heart, allowing it to contract and pump blood throughout an organism.

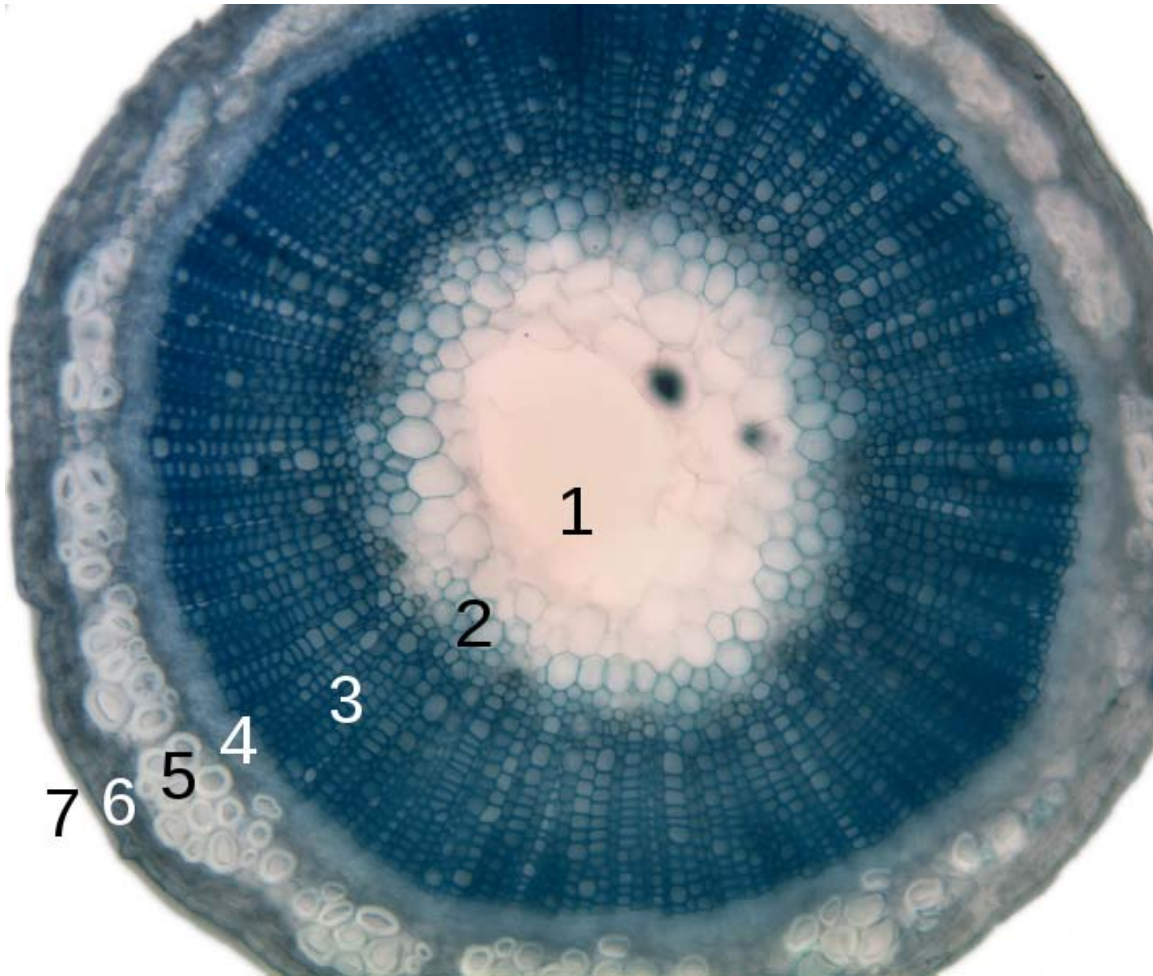
Nervous tissue

Cells comprising the central nervous system and peripheral nervous system are classified as neural tissue. In the central nervous system, neural tissue forms the brain and spinal cord and, in the peripheral nervous system forms the cranial nerves and spinal nerves, inclusive of the motor neurons. Transmits communications.

Epithelial tissue

The epithelial tissues are formed by cells that cover organ surfaces such as the surface of the skin, the airways, the reproductive tract, and the inner lining of the digestive tract. The cells comprising an epithelial layer are linked via semi-permeable, tight junctions; hence, this tissue provides a barrier between the external environment and the organ it covers. In addition to this protective function, epithelial tissue may also be specialized to function in secretion and absorption. Epithelial tissue helps to protect organisms from microorganisms, injury, and fluid loss.

Plant tissues



Cross-section of a flax plant stem with several layers of different tissue types:

1. Pith,
2. Protoxylem,
3. Xylem I,
4. Phloem I,
5. Sclerenchyma (bast fibre),
6. Cortex,
7. Epidermis

Examples of tissue in other multicellular organisms are vascular tissue in plants, such as xylem and phloem. Plant tissues are categorized broadly into three tissue systems: the epidermis, the ground tissue, and the vascular tissue. Together they are often referred to as biomass.

- **Epidermis** - Cells forming the outer surface of the leaves and of the young plant body.
- **Vascular tissue** - The primary components of vascular tissue are the xylem and phloem. These transport fluid and nutrients internally.

- **Ground tissue** - Ground tissue is less differentiated than other tissues. Ground tissue manufactures nutrients by photosynthesis and stores reserve nutrients.

Plant tissues can also be divided differently into two types:

1. Meristematic tissues
2. Permanent tissues

Meristematic tissues

Meristematic tissue consist of actively dividing cells this is found in regions such as the tips of stems or roots and lead to increase in length and thickness of the plant this cells are spherical oval polygonal and rectangular and have thin cells walls. The growth of plant occurs only in certain specific regions. At these regions, the meristematic tissues are present. New cells produced by meristem are initially those of meristem itself, but as they grow and mature, their characteristics slowly change and they become differentiated as components of other tissues. Depending on the region of occurrence of meristematic tissues they are classified as:

- a) **Apical Meristem** - It is present at the growing tips of stems and roots and increases the length of the stem and root. They form growing parts at the apices of roots and stems and are responsible for increase in length, also called primary growth. This meristem is responsible for the linear growth of an organ.
- b) **Lateral Meristem** - This meristem consist of cells which mainly divide in one plane and cause the organ to increase in diameter and growth. Lateral Meristem usually occurs beneath the bark of the tree in the form of Cork Cambium and in vascular bundles of dicots in the form of vascular cambium. The activity of this cambium results in the formation of secondary growth.
- c) **Intercalary Meristem** - This meristem is located in between permanent tissues. It is usually present at the base of node, inter node and on leaf base. They are responsible for growth in length of the plant. This adds growth in the girth of stem.

The cells of meristematic tissues are similar in structure and have thin and elastic primary cell wall made up of cellulose. They are compactly arranged without inter-cellular spaces between them. Each cell contains a dense cytoplasm and a prominent nucleus. Dense protoplasm of meristematic cells contains very few vacuoles. Normally the meristematic cells are oval, polygonal or rectangular in shape.

Meristematic tissue cells have a large nucleus with small or no vacuoles, they have no inter cellular spaces.

Permanent tissues

The meristematic tissues that take up a specific role lose the ability to divide. This process of taking up a permanent shape, size and a function is called cellular

differentiation. Cells of meristematic tissue differentiate to form different types of permanent tissue. There are 2 types of permanent tissues:

1. simple permanent tissues
2. complex permanent tissues

Simple permanent tissues

These tissues are called simple because they are composed of similar types of cells which have common origin and function. They are further classified into:

1. Parenchyma
2. Chlorenchyma
3. Aerenchyma
4. Collenchyma
5. Sclerenchyma
6. Epidermis

Parenchyma

Parenchyma is Greek word where "parn" means besides and "enchien" means to pour. Parenchyma is the most specialized primitive tissue. It mainly consist of thin-walled cells which have inter-cellular spaces between them. The cell wall is made up of cellulose. Each parenchymatous cell is iso-diametric, spherical, or oval in shape. It is widely distributed in various plant organs like root, stem, leaf, flowers and fruits. They mainly occur in the cortex epidermis, and pith, as well as in the mesophyll of leaves.

The main function of parenchymatous tissue is assimilation and storage of reserve food materials like starch, fats and proteins. They also store waste products such as gums, resins, and inorganic waste materials.

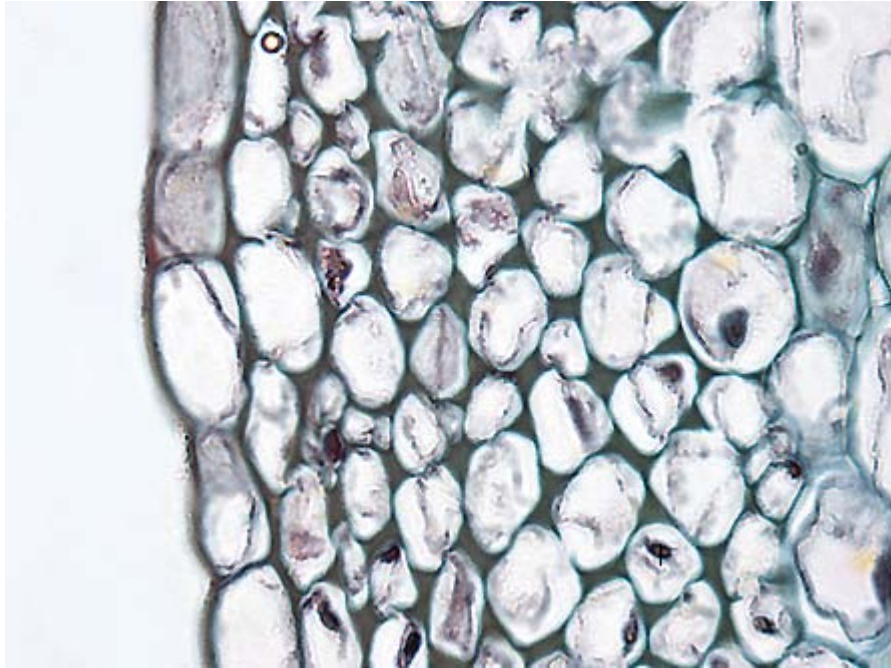
Chlorenchyma

The cells of this tissue are characterized by having chloroplasts (containing chlorophyll). It is found in the palisade and spongy tissues in the green leaves and the stem cortex of the herbs where photosynthesis occurs.

Aerenchyma

Aerenchyma is a type of parenchyma. In aquatic plants the intercellular spaces form large air cavities. They give buoyancy to the plant and help them float in water. Such parenchyma is called aerenchyma.

Collenchyma



Cross section of collenchyma cells

Collenchyma is Greek word where "Collen" means gum and "enchyma" means infusion. It is a living tissue of primary body like Parenchyma. Cells are thin-walled but possess thickening of cellulose and pectin substances at the corners where number of cells join together. This tissue gives a tensile strength to the plant and the cells are compactly arranged and do not have inter-cellular spaces. It occurs chiefly in hypodermis of stems and leaves. It is absent in monocots and in roots.

Collenchymatous tissue acts as a supporting tissue in stems of young plants. It provides mechanical support, elasticity, and tensile strength to the plant body. It helps in manufacturing sugar and storing it as starch. It is present in margin of leaves and resist tearing effect of the wind.

Sclerenchyma

Sclerenchyma is Greek word where "Sclrenes" means hard and "enchyma" means infusion. This tissue consists of thick-walled, dead cells. These cells have hard and extremely thick secondary walls due to uniform distribution of lignin. Lignin deposition is so thick that the cell walls become strong, rigid and impermeable to water. Sclerenchymatous cells are closely packed without inter-cellular spaces between them. Thus, they appear as hexagonal net in transverse section. The cells are cemented with the help of lamella. The middle lamella is a wall that lies between adjacent cells. Sclerenchymatous cells mainly occur in hypodermis, pericycle, secondary xylem and phloem. They also occur in endocarp of almond and coconut. It is made of pectin, lignin, protein. The cells of sclerenchymatous cells can be classified as :

1. Fibres- Fibres are long, elongated sclerenchymatous cells with pointed ends.
2. Sclerides- Sclerenchymatous cells which are short and possess extremely thick, lamellated, lignified walls with long singular piths. They are called sclerides.

The main function of Sclerenchymatous tissues is to give support to the plant.

Epidermis

The entire surface of the plant consists of a single layer of cells called epidermis or surface tissue. The entire surface of the plant has this outer layer of epidermis. Hence it is also called surface tissue. Most of the epidermal cells are relatively flat. The outer and lateral walls of the cell are often thicker than the inner walls. The cells form a continuous sheet without inter cellular spaces. It protects all parts of the plant.

Complex permanent tissue

A complex permanent tissue may be classified as a group of more than one type of tissue having a common origin and working together as a unit to perform a function. These tissues are concerned with transportation of water, mineral, nutrients and organic substances. The important complex tissues in vascular plants are xylem, phloem.

Xylem

Xylem is a chief, conducting tissue of vascular plants. It is responsible for conduction of water and mineral ions.

Xylem is an important plant tissue as it is part of the 'plumbing' of a plant. Think of bundles of pipes running along the main axis of stems and roots. It carries water and dissolved substances throughout and consists of a combination of parenchyma cells, fibers, vessels, tracheids and ray cells. Long tubes made up of individual cells are the vessels, while vessel members are open at each end. Internally, there may be bars of wall material extending across the open space. These cells are joined end to end to form long tubes. Vessel members and tracheids are dead at maturity. Tracheids have thick secondary cell walls and are tapered at the ends. They do not have end openings such as the vessels. The tracheids ends overlap with each other, with pairs of pits present. The pit pairs allow water to pass from cell to cell. While most conduction in the xylem is up and down, there is some side-to-side or lateral conduction via rays. Rays are horizontal rows of long-living parenchyma cells that arise out of the vascular cambium. In trees, and other woody plants, ray will radiate out from the center of stems and roots and in cross-section will look like the spokes of a wheel.

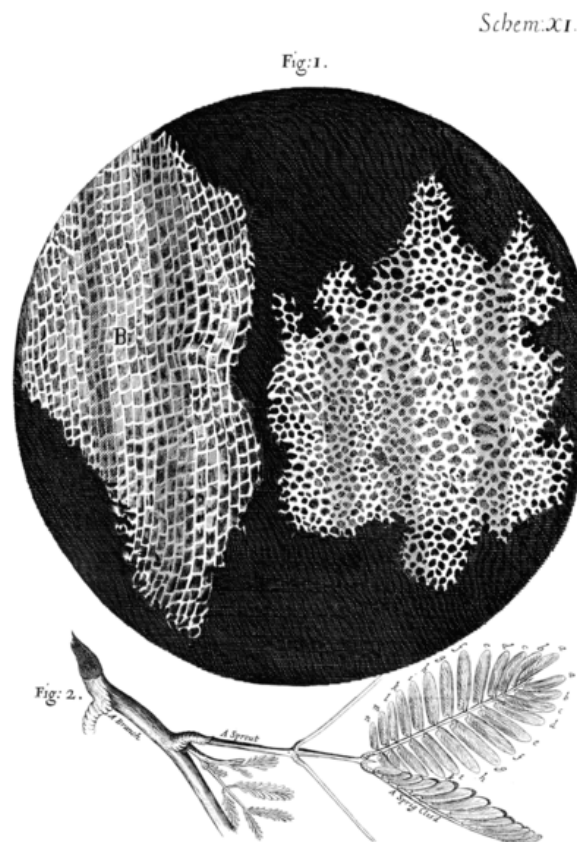
Phloem

Phloem is an equally important plant tissue as it also is part of the 'plumbing' of a plant. Primarily, phloem carries dissolved food substances throughout the plant. This conduction system is composed of sieve-tube member and companion cells, that are

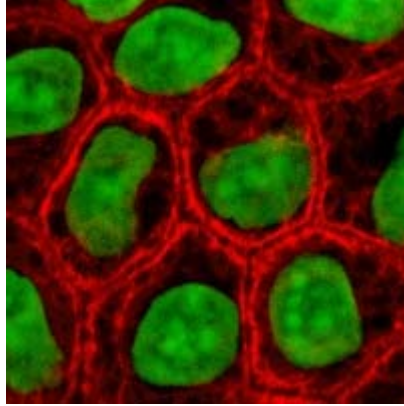
without secondary walls. The parent cells of the vascular cambium produce both xylem and phloem. This usually also includes fibers, parenchyma and ray cells. Sieve tubes are formed from sieve-tube members laid end to end. The end walls, unlike vessel members in xylem, do not have openings. The end walls, however, are full of small pores where cytoplasm extends from cell to cell. These porous connections are called sieve plates. In spite of the fact that their cytoplasm is actively involved in the conduction of food materials, sieve-tube members do not have nuclei at maturity. It is the companion cells that are nestled between sieve-tube members that function in some manner bringing about the conduction of food. Sieve-tube members that are alive contain a polymer called callose. Callose stays in solution as long as the cell contents are under pressure. As a repair mechanism, if an insect injures a cell and the pressure drops, the callose will precipitate. However, the callose and a phloem protein will be moved through the nearest sieve plate where they will form a plug. This prevents further leakage of sieve tube contents and the injury is not necessarily fatal to overall plant turgor pressure. Phloem transports food and materials in plants in upwards and downwards as required.

Chapter 6

Cell (Biology)



Drawing of the structure of cork as it appeared under the microscope to Robert Hooke from *Micrographia* which is the origin of the word "cell" being used to describe the smallest unit of a living organism



Cells in culture, stained for keratin (red) and DNA (green)

The **cell** is the functional basic unit of life. It was discovered by Robert Hooke and is the functional unit of all known living organisms. It is the smallest unit of life that is classified as a living thing, and is often called the building block of life. Some organisms, such as most bacteria, are unicellular (consist of a single cell). Other organisms, such as humans, are multicellular. Humans have about 100 trillion or 10^{14} cells; a typical cell size is $10\ \mu\text{m}$ and a typical cell mass is 1 nanogram. The largest cells are about $135\ \mu\text{m}$ in the anterior horn in the spinal cord while granule cells in the cerebellum, the smallest, can be some $4\ \mu\text{m}$ and the longest cell can reach from the toe to the lower brain stem (Pseudounipolar cells). The largest known cells are unfertilised ostrich egg cells which weigh 3.3 pounds.

In 1835, before the final cell theory was developed, Jan Evangelista Purkyně observed small "granules" while looking at the plant tissue through a microscope. The cell theory, first developed in 1839 by Matthias Jakob Schleiden and Theodor Schwann, states that all organisms are composed of one or more cells, that all cells come from preexisting cells, that vital functions of an organism occur within cells, and that all cells contain the hereditary information necessary for regulating cell functions and for transmitting information to the next generation of cells.

The word *cell* comes from the Latin *cellula*, meaning, a small room. The descriptive term for the smallest living biological structure was coined by Robert Hooke in a book he published in 1665 when he compared the cork cells he saw through his microscope to the small rooms monks lived in.

Anatomy

There are two types of cells: eukaryotic and prokaryotic. Prokaryotic cells are usually independent, while eukaryotic cells are often found in multicellular organisms.

Prokaryotic cells

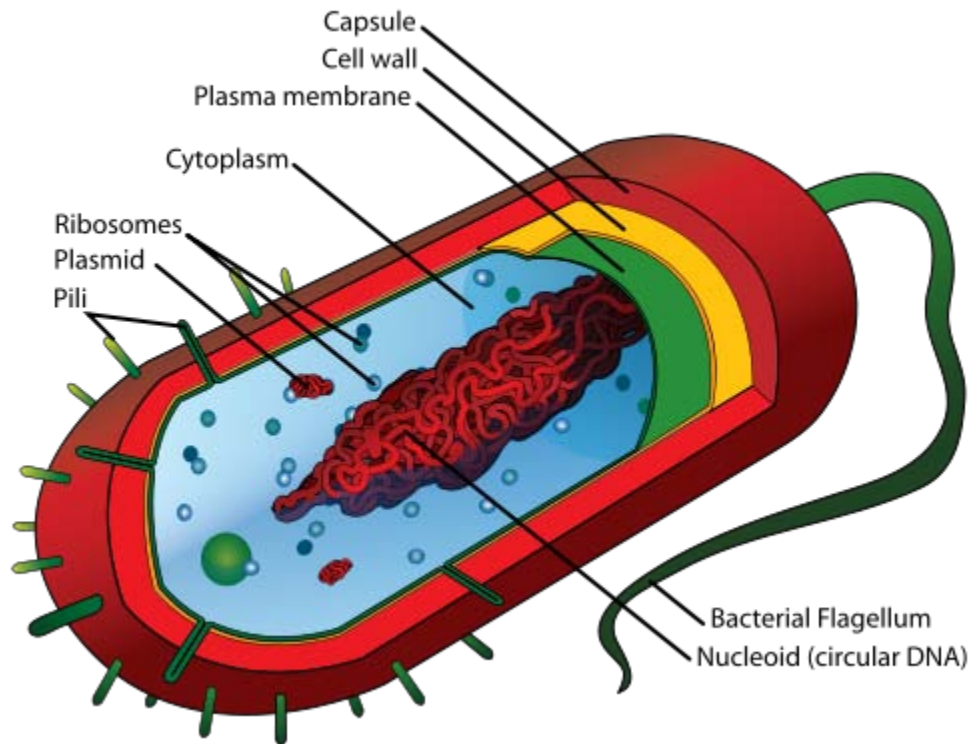


Diagram of a typical prokaryotic cell

The prokaryote cell is simpler, and therefore smaller, than a eukaryote cell, lacking a nucleus and most of the other organelles of eukaryotes. There are two kinds of prokaryotes: bacteria and archaea; these share a similar structure.

Nuclear material of prokaryotic cell consist of a single chromosome which is in direct contact with cytoplasm. Here the undefined nuclear region in the cytoplasm is called nucleoid.

A prokaryotic cell has three architectural regions:

- On the outside, flagella and pili project from the cell's surface. These are structures (not present in all prokaryotes) made of proteins that facilitate movement and communication between cells;
- Enclosing the cell is the cell envelope – generally consisting of a cell wall covering a plasma membrane though some bacteria also have a further covering layer called a capsule. The envelope gives rigidity to the cell and separates the interior of the cell from its environment, serving as a protective filter. Though most prokaryotes have a cell wall, there are exceptions such as *Mycoplasma* (bacteria) and *Thermoplasma* (archaea). The cell wall consists of *peptidoglycan* in bacteria, and acts as an additional barrier against exterior forces. It also prevents

the cell from expanding and finally bursting (cytolysis) from osmotic pressure against a hypotonic environment. Some eukaryote cells (plant cells and fungi cells) also have a cell wall;

- Inside the cell is the cytoplasmic region that contains the cell genome (DNA) and ribosomes and various sorts of inclusions. A prokaryotic chromosome is usually a circular molecule (an exception is that of the bacterium *Borrelia burgdorferi*, which causes Lyme disease). Though not forming a *nucleus*, the DNA is condensed in a *nucleoid*. Prokaryotes can carry extrachromosomal DNA elements called *plasmids*, which are usually circular. Plasmids enable additional functions, such as antibiotic resistance.

Eukaryotic cells

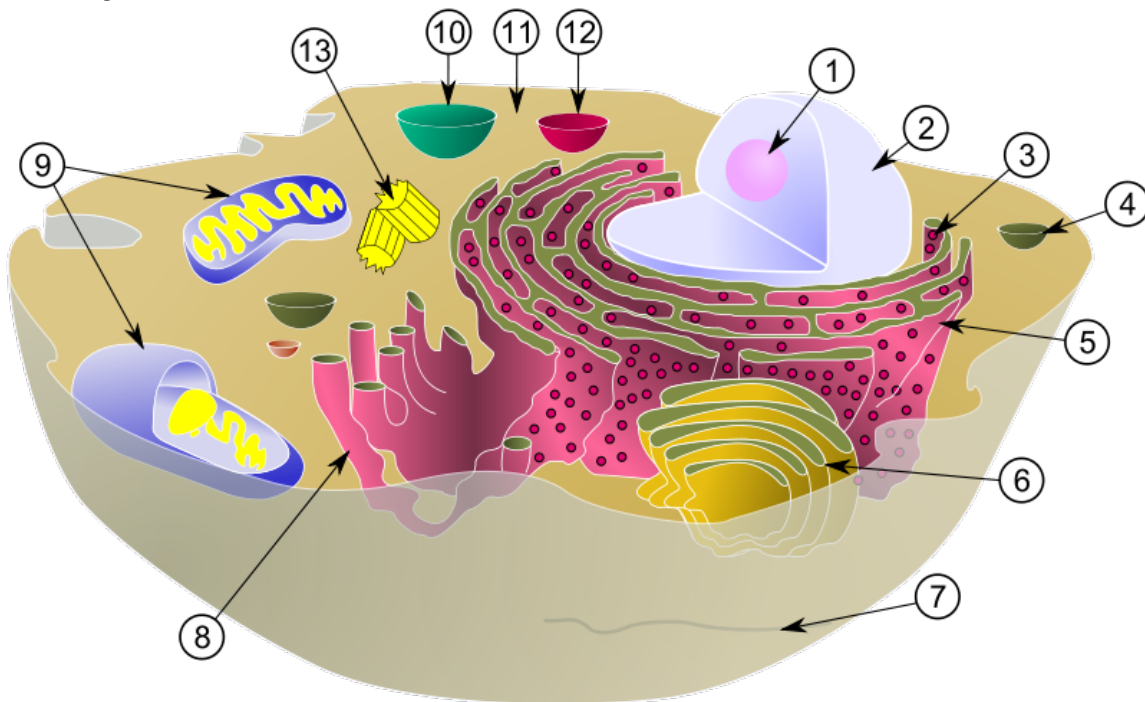


Diagram of a typical animal (eukaryotic) cell, showing subcellular components.

Organelles:

- (1) nucleolus
- (2) nucleus
- (3) ribosome
- (4) vesicle
- (5) rough endoplasmic reticulum (ER)
- (6) Golgi apparatus
- (7) Cytoskeleton
- (8) smooth endoplasmic reticulum
- (9) mitochondria
- (10) vacuole
- (11) cytoplasm

- (12) lysosome
- (13) centrioles within centrosome

Eukaryotic cells are about 15 times wider than a typical prokaryote and can be as much as 1000 times greater in volume. The major difference between prokaryotes and eukaryotes is that eukaryotic cells contain membrane-bound compartments in which specific metabolic activities take place. Most important among these is a cell nucleus, a membrane-delineated compartment that houses the eukaryotic cell's DNA. This nucleus gives the eukaryote its name, which means "true nucleus." Other differences include:

- The plasma membrane resembles that of prokaryotes in function, with minor differences in the setup. Cell walls may or may not be present.
- The eukaryotic DNA is organized in one or more linear molecules, called chromosomes, which are associated with histone proteins. All chromosomal DNA is stored in the *cell nucleus*, separated from the cytoplasm by a membrane. Some eukaryotic organelles such as mitochondria also contain some DNA.
- Many eukaryotic cells are ciliated with *primary cilia*. Primary cilia play important roles in chemosensation, mechanosensation, and thermosensation. Cilia may thus be "viewed as sensory cellular antennae that coordinate a large number of cellular signaling pathways, sometimes coupling the signaling to ciliary motility or alternatively to cell division and differentiation."
- Eukaryotes can move using *motile cilia* or *flagella*. The flagella are more complex than those of prokaryotes.

Table 1: Comparison of features of prokaryotic and eukaryotic cells

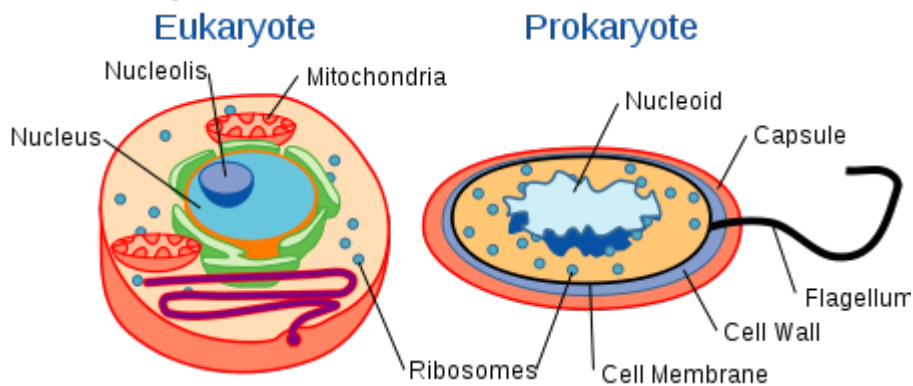
	Prokaryotes	Eukaryotes
Typical organisms	bacteria, archaea	protists, fungi, plants, animals
Typical size	~ 1–10 μm	~ 10–100 μm (sperm cells, apart from the tail, are smaller)
Type of nucleus	nucleoid region; no real nucleus	real nucleus with double membrane
DNA	circular (usually)	linear molecules (chromosomes) with histone proteins
RNA-/protein-synthesis	coupled in cytoplasm	RNA-synthesis inside the nucleus protein synthesis in cytoplasm
Ribosomes	50S+30S	60S+40S
Cytoplasmatic structure	very few structures	highly structured by endomembranes and a cytoskeleton
Cell movement	flagella made of flagellin	flagella and cilia containing microtubules; lamellipodia and filopodia containing actin
Mitochondria	none	one to several thousand (though some lack mitochondria)
Chloroplasts	none	in algae and plants
Organization	usually single cells	single cells, colonies, higher multicellular

		organisms with specialized cells
Cell division	Binary fission (simple division)	Mitosis (fission or budding) Meiosis

Table 2: Comparison of structures between animal and plant cells

	Typical animal cell	Typical plant cell
Organelles	<ul style="list-style-type: none"> • Nucleus <ul style="list-style-type: none"> ◦ Nucleolus (within nucleus) • Rough endoplasmic reticulum (ER) • Smooth ER • Ribosomes • Cytoskeleton • Golgi apparatus • Cytoplasm • Mitochondria • Vesicles • Lysosomes • Centrosome <ul style="list-style-type: none"> ◦ Centrioles 	<ul style="list-style-type: none"> • Nucleus <ul style="list-style-type: none"> ◦ Nucleolus (within nucleus) • Rough ER • Smooth ER • Ribosomes • Cytoskeleton • Golgi apparatus (dictyosomes) • Cytoplasm • Mitochondria • Plastids and its derivatives • Vacuole(s) • Cell wall

Subcellular components



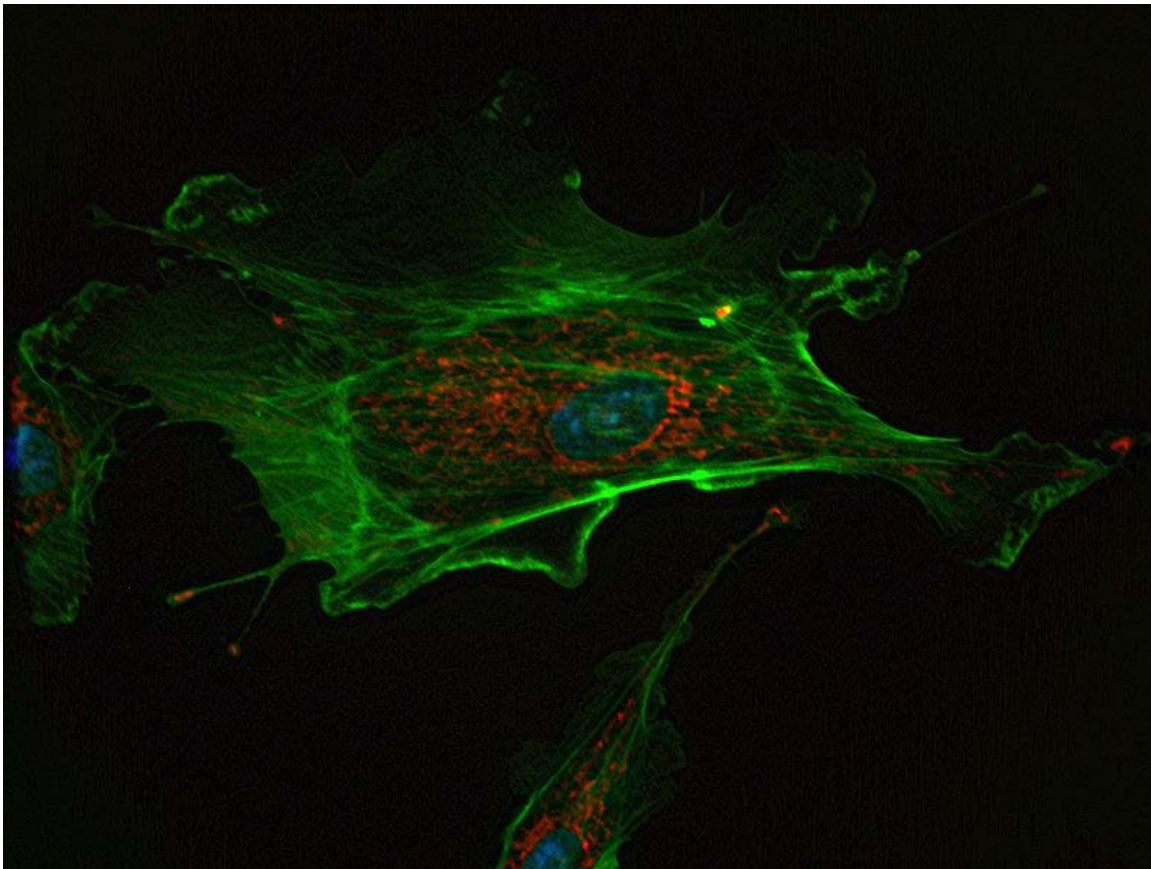
The cells of eukaryotes (left) and prokaryotes (right)

All cells, whether prokaryotic or eukaryotic, have a membrane that envelops the cell, separates its interior from its environment, regulates what moves in and out (selectively permeable), and maintains the electric potential of the cell. Inside the membrane, a salty cytoplasm takes up most of the cell volume. All cells possess DNA, the hereditary material of genes, and RNA, containing the information necessary to build various proteins such as enzymes, the cell's primary machinery. There are also other kinds of biomolecules in cells.

Membrane

The cytoplasm of a cell is surrounded by a cell membrane or *plasma membrane*. The plasma membrane in plants and prokaryotes is usually covered by a cell wall. This membrane serves to separate and protect a cell from its surrounding environment and is made mostly from a double layer of lipids (hydrophobic fat-like molecules) and hydrophilic phosphorus molecules. Hence, the layer is called a phospholipid bilayer. It may also be called a fluid mosaic membrane. Embedded within this membrane is a variety of protein molecules that act as channels and pumps that move different molecules into and out of the cell. The membrane is said to be 'semi-permeable', in that it can either let a substance (molecule or ion) pass through freely, pass through to a limited extent or not pass through at all. Cell surface membranes also contain receptor proteins that allow cells to detect external signaling molecules such as hormones.

Cytoskeleton



Bovine Pulmonary Artery Endothelial cell: nuclei stained blue, mitochondria stained red, and F-actin, an important component in microfilaments, stained green. Cell imaged on a fluorescent microscope.

The cytoskeleton acts to organize and maintain the cell's shape; anchors organelles in place; helps during endocytosis, the uptake of external materials by a cell, and cytokinesis, the separation of daughter cells after cell division; and moves parts of the

cell in processes of growth and mobility. The eukaryotic cytoskeleton is composed of microfilaments, intermediate filaments and microtubules. There is a great number of proteins associated with them, each controlling a cell's structure by directing, bundling, and aligning filaments. The prokaryotic cytoskeleton is less well-studied but is involved in the maintenance of cell shape, polarity and cytokinesis.

Genetic material

Two different kinds of genetic material exist: deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). Most organisms use DNA for their long-term information storage, but some viruses (e.g., retroviruses) have RNA as their genetic material. The biological information contained in an organism is encoded in its DNA or RNA sequence. RNA is also used for information transport (e.g., mRNA) and enzymatic functions (e.g., ribosomal RNA) in organisms that use DNA for the genetic code itself. Transfer RNA (tRNA) molecules are used to add amino acids during protein translation.

Prokaryotic genetic material is organized in a simple circular DNA molecule (the bacterial chromosome) in the nucleoid region of the cytoplasm. Eukaryotic genetic material is divided into different, linear molecules called chromosomes inside a discrete nucleus, usually with additional genetic material in some organelles like mitochondria and chloroplasts.

A human cell has genetic material contained in the cell nucleus (the nuclear genome) and in the mitochondria (the mitochondrial genome). In humans the nuclear genome is divided into 23 pairs of linear DNA molecules called chromosomes. The mitochondrial genome is a circular DNA molecule distinct from the nuclear DNA. Although the mitochondrial DNA is very small compared to nuclear chromosomes, it codes for 13 proteins involved in mitochondrial energy production and specific tRNAs.

Foreign genetic material (most commonly DNA) can also be artificially introduced into the cell by a process called transfection. This can be transient, if the DNA is not inserted into the cell's genome, or stable, if it is. Certain viruses also insert their genetic material into the genome.

Organelles

The human body contains many different organs, such as the heart, lung, and kidney, with each organ performing a different function. Cells also have a set of "little organs," called organelles, that are adapted and/or specialized for carrying out one or more vital functions. Both eukaryotic and prokaryotic cells have organelles but organelles in eukaryotes are generally more complex and may be membrane bound.

There are several types of organelles in a cell. Some (such as the nucleus and golgi apparatus) are typically solitary, while others (such as mitochondria, peroxisomes and lysosomes) can be numerous (hundreds to thousands). The cytosol is the gelatinous fluid that fills the cell and surrounds the organelles.

Cell nucleus – eukaryotes only - a cell's information center

The cell nucleus is the most conspicuous organelle found in a eukaryotic cell. It houses the cell's chromosomes, and is the place where almost all DNA replication and RNA synthesis (transcription) occur. The nucleus is spherical and separated from the cytoplasm by a double membrane called the nuclear envelope. The nuclear envelope isolates and protects a cell's DNA from various molecules that could accidentally damage its structure or interfere with its processing. During processing, DNA is transcribed, or copied into a special RNA, called messenger RNA (mRNA). This mRNA is then transported out of the nucleus, where it is translated into a specific protein molecule. The nucleolus is a specialized region within the nucleus where ribosome subunits are assembled. In prokaryotes, DNA processing takes place in the cytoplasm.

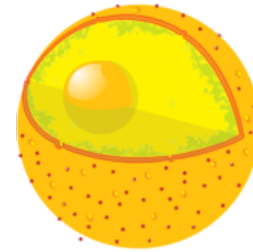


Diagram of a cell nucleus

Mitochondria and Chloroplasts – eukaryotes only - the power generators

Mitochondria are self-replicating organelles that occur in various numbers, shapes, and sizes in the cytoplasm of all eukaryotic cells. Mitochondria play a critical role in generating energy in the eukaryotic cell. Mitochondria generate the cell's energy by oxidative phosphorylation, using oxygen to release energy stored in cellular nutrients (typically pertaining to glucose) to generate ATP. Mitochondria multiply by splitting in two. Respiration occurs in the cell mitochondria. Organelles that are modified chloroplasts are broadly called plastids, and are involved in energy storage through photosynthesis, which uses solar energy to generate carbohydrates and oxygen from carbon dioxide and water. Mitochondria and chloroplasts each contain their own genome, which is separate and distinct from the nuclear genome of a cell. Both organelles contain this DNA in circular plasmids, much like prokaryotic cells, strongly supporting the evolutionary theory of endosymbiosis; since these organelles contain

their own genomes and have other similarities to prokaryotes, they are thought to have developed through a symbiotic relationship after being engulfed by a primitive cell.

Endoplasmic reticulum – eukaryotes only

The endoplasmic reticulum (ER) is the transport network for molecules targeted for certain modifications and specific destinations, as compared to molecules that will float freely in the cytoplasm. The ER has two forms: the rough ER, which has ribosomes on its surface and secretes proteins into the cytoplasm, and the smooth ER, which lacks them. Smooth ER plays a role in calcium sequestration and release.

Golgi apparatus – eukaryotes only

The primary function of the Golgi apparatus is to process and package the macromolecules such as proteins and lipids that are synthesized by the cell. It is particularly important in the processing of proteins for secretion. The Golgi apparatus forms a part of the endomembrane system of eukaryotic cells. Vesicles that enter the Golgi apparatus are processed in a cis to trans direction, meaning they coalesce on the cis side of the apparatus and after processing pinch off on the opposite (trans) side to form a new vesicle in the animal cell.



Diagram of an endomembrane system

Ribosomes

The ribosome is a large complex of RNA and protein molecules. They each consist of two subunits, and act as an assembly line where RNA from the nucleus is used to synthesise proteins from amino acids. Ribosomes can be found either floating freely or bound to a membrane (the rough endoplasmatic reticulum in eukaryotes, or the cell membrane in prokaryotes).

Lysosomes and Peroxisomes – eukaryotes only

Lysosomes contain digestive enzymes (acid hydrolases). They digest excess or worn-out organelles, food particles, and engulfed viruses or bacteria. Peroxisomes have enzymes that rid the cell of toxic peroxides. The cell could not house these destructive enzymes if they were not contained in a membrane-bound system. These organelles are often called a "suicide bag" because of their ability to detonate and destroy the cell.

Centrosome – the cytoskeleton organiser

The centrosome produces the microtubules of a cell – a key component of the cytoskeleton. It directs the transport through the ER and the Golgi apparatus. Centrosomes are composed of two centrioles, which separate during cell division and help in the formation of the mitotic spindle. A single centrosome is present in the animal cells. They are also found in some fungi and algae cells.

Vacuoles

Vacuoles store food and waste. Some vacuoles store extra water. They are often described as liquid filled space and are surrounded by a membrane. Some cells, most notably *Amoeba*, have contractile vacuoles, which can pump water out of the cell if there is too much water. The vacuoles of eukaryotic cells are usually larger in those of plants than animals.

Structures outside the cell wall

Capsule

A gelatinous capsule is present in some bacteria outside the cell wall. The capsule may be polysaccharide as in pneumococci, meningococci or polypeptide as *Bacillus anthracis* or hyaluronic acid as in streptococci. Capsules are not marked by ordinary stain and can be detected by special stain. The capsule is antigenic. The capsule has antiphagocytic function so it determines the virulence of many bacteria. It also plays a role in attachment of the organism to mucous membranes.

Flagella

Flagella are the organelles of cellular mobility. They arise from cytoplasm and extrude through the cell wall. They are long and thick thread-like appendages, protein in nature. Are most commonly found in bacteria cells but are found in animal cells as well.

Fimbriae (pili)

They are short and thin hair like filaments, formed of protein called pilin (antigenic). Fimbriae are responsible for attachment of bacteria to specific receptors of human cell (adherence). There are special types of pili called (sex pili) involved in conjugation.

Functions

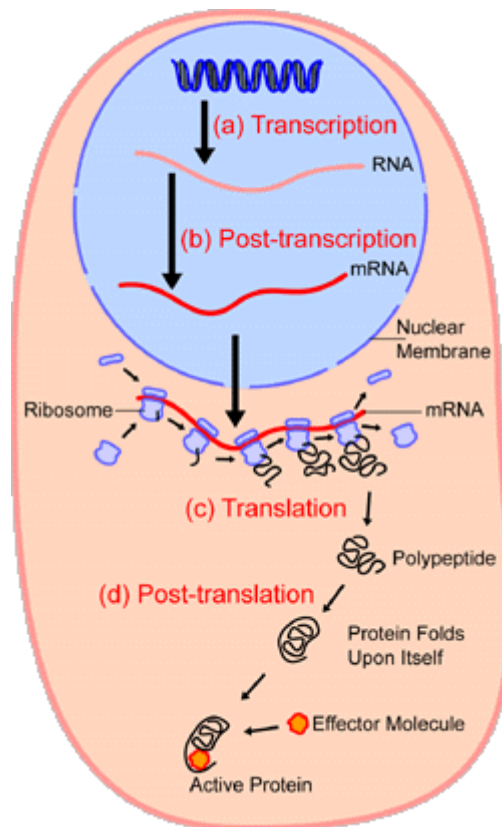
Growth and metabolism

Between successive cell divisions, cells grow through the functioning of cellular metabolism. Cell metabolism is the process by which individual cells process nutrient molecules. Metabolism has two distinct divisions: catabolism, in which the cell breaks

down complex molecules to produce energy and reducing power, and anabolism, in which the cell uses energy and reducing power to construct complex molecules and perform other biological functions. Complex sugars consumed by the organism can be broken down into a less chemically complex sugar molecule called glucose. Once inside the cell, glucose is broken down to make adenosine triphosphate (ATP), a form of energy, through two different pathways.

The first pathway, glycolysis, requires no oxygen and is referred to as anaerobic metabolism. Each reaction is designed to produce some hydrogen ions that can then be used to make energy packets (ATP). In prokaryotes, glycolysis is the only method used for converting energy.

The second pathway, called the Krebs cycle, or citric acid cycle, occurs inside the mitochondria and can generate enough ATP to run all the cell functions.



An overview of protein synthesis.

Within the nucleus of the cell (*light blue*), genes (DNA, *dark blue*) are transcribed into RNA. This RNA is then subject to post-transcriptional modification and control, resulting in a mature mRNA (*red*) that is then transported out of the nucleus and into the cytoplasm (*peach*), where it undergoes translation into a protein. mRNA is translated by ribosomes (*purple*) that match the three-base codons of the mRNA to the three-base anti-codons of

the appropriate tRNA. Newly synthesized proteins (*black*) are often further modified, such as by binding to an effector molecule (*orange*), to become fully active.

Creation

Cell division involves a single cell (called a *mother cell*) dividing into two daughter cells. This leads to growth in multicellular organisms (the growth of tissue) and to procreation (vegetative reproduction) in unicellular organisms.

Prokaryotic cells divide by binary fission. Eukaryotic cells usually undergo a process of nuclear division, called mitosis, followed by division of the cell, called cytokinesis. A diploid cell may also undergo meiosis to produce haploid cells, usually four. Haploid cells serve as gametes in multicellular organisms, fusing to form new diploid cells.

DNA replication, or the process of duplicating a cell's genome, is required every time a cell divides. Replication, like all cellular activities, requires specialized proteins for carrying out the job.

Protein synthesis

Cells are capable of synthesizing new proteins, which are essential for the modulation and maintenance of cellular activities. This process involves the formation of new protein molecules from amino acid building blocks based on information encoded in DNA/RNA. Protein synthesis generally consists of two major steps: transcription and translation.

Transcription is the process where genetic information in DNA is used to produce a complementary RNA strand. This RNA strand is then processed to give messenger RNA (mRNA), which is free to migrate through the cell. mRNA molecules bind to protein-RNA complexes called ribosomes located in the cytosol, where they are translated into polypeptide sequences. The ribosome mediates the formation of a polypeptide sequence based on the mRNA sequence. The mRNA sequence directly relates to the polypeptide sequence by binding to transfer RNA (tRNA) adapter molecules in binding pockets within the ribosome. The new polypeptide then folds into a functional three-dimensional protein molecule.

Movement or motility

Cells can move during many processes: such as wound healing, the immune response and cancer metastasis. For wound healing to occur, white blood cells and cells that ingest bacteria move to the wound site to kill the microorganisms that cause infection.

At the same time fibroblasts (connective tissue cells) move there to remodel damaged structures. In the case of tumor development, cells from a primary tumor move away and spread to other parts of the body. Cell motility involves many receptors, crosslinking, bundling, binding, adhesion, motor and other proteins. The process is divided into three steps – protrusion of the leading edge of the cell, adhesion of the leading edge and de-

adhesion at the cell body and rear, and cytoskeletal contraction to pull the cell forward. Each step is driven by physical forces generated by unique segments of the cytoskeleton.

Evolution

The origin of cells has to do with the origin of life, which began the history of life on Earth.

Origin of the first cell

There are several theories about the origin of small molecules that could lead to life in an early Earth. One is that they came from meteorites. Another is that they were created at deep-sea vents. A third is that they were synthesized by lightning in a reducing atmosphere; although it is not clear if Earth had such an atmosphere. There are essentially no experimental data defining what the first self-replicating forms were. RNA is generally assumed to be the earliest self-replicating molecule, as it is capable of both storing genetic information and catalyzing chemical reactions. But some other entity with the potential to self-replicate could have preceded RNA, like clay or peptide nucleic acid.

Cells emerged at least 4.0–4.3 billion years ago. The current belief is that these cells were heterotrophs. An important characteristic of cells is the cell membrane, composed of a bilayer of lipids. The early cell membranes were probably more simple and permeable than modern ones, with only a single fatty acid chain per lipid. Lipids are known to spontaneously form bilayered vesicles in water, and could have preceded RNA. But the first cell membranes could also have been produced by catalytic RNA, or even have required structural proteins before they could form.

Origin of eukaryotic cells

The eukaryotic cell seems to have evolved from a symbiotic community of prokaryotic cells. DNA-bearing organelles like the mitochondria and the chloroplasts are almost certainly what remains of ancient symbiotic oxygen-breathing proteobacteria and cyanobacteria, respectively, where the rest of the cell seems to be derived from an ancestral archaean prokaryote cell – a theory termed the endosymbiotic theory.

There is still considerable debate about whether organelles like the hydrogenosome predated the origin of mitochondria, or viceversa.

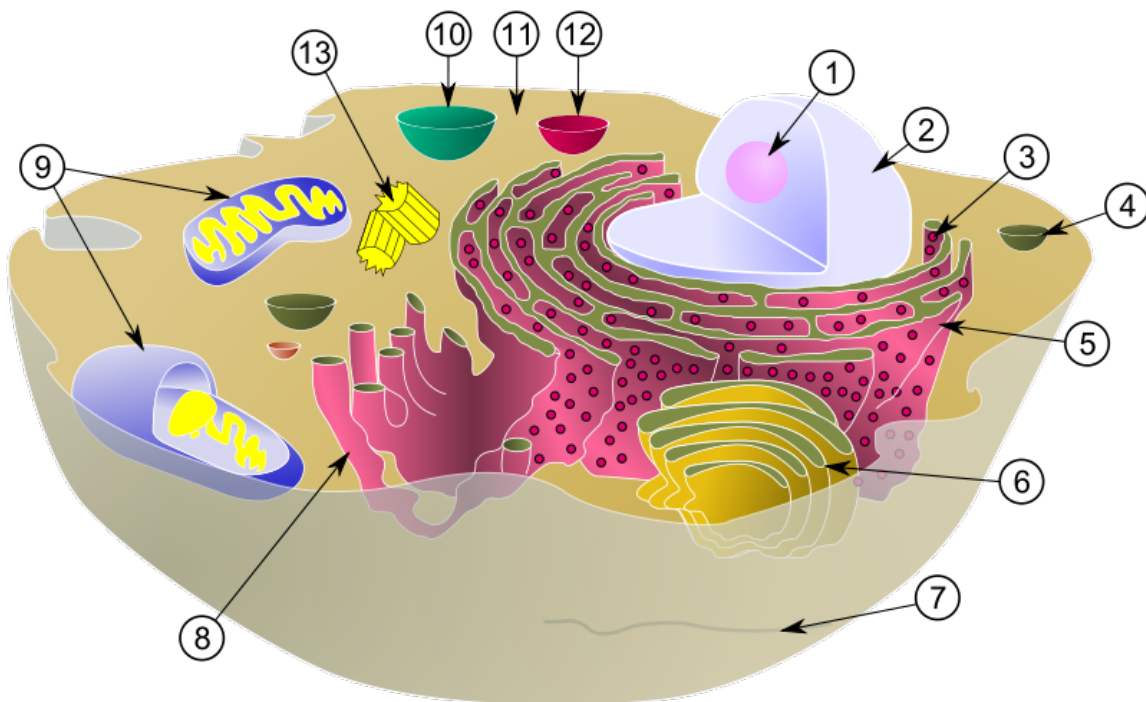
Sex, as the stereotyped choreography of meiosis and syngamy that persists in nearly all extant eukaryotes, may have played a role in the transition from prokaryotes to eukaryotes. An 'origin of sex as vaccination' theory suggests that the eukaryote genome accreted from prokaryotic parasite genomes in numerous rounds of lateral gene transfer. Sex-as-syngamy (fusion sex) arose when infected hosts began swapping nuclearized genomes containing co-evolved, vertically transmitted symbionts that conveyed protection against horizontal infection by more virulent symbionts.

History

- 1632–1723: Antonie van Leeuwenhoek teaches himself to grind lenses, builds a microscope and draws protozoa, such as *Vorticella* from rain water, and bacteria from his own mouth.
- 1665: Robert Hooke discovers cells in cork, then in living plant tissue using an early microscope.
- 1839: Theodor Schwann and Matthias Jakob Schleiden elucidate the principle that plants and animals are made of cells, concluding that cells are a common unit of structure and development, and thus founding the cell theory.
- The belief that life forms can occur spontaneously (*generatio spontanea*) is contradicted by Louis Pasteur (1822–1895) (although Francesco Redi had performed an experiment in 1668 that suggested the same conclusion).
- 1855: Rudolf Virchow states that cells always emerge from cell divisions (*omnis cellula ex cellula*).
- 1931: Ernst Ruska builds first transmission electron microscope (TEM) at the University of Berlin. By 1935, he has built an EM with twice the resolution of a light microscope, revealing previously unresolvable organelles.
- 1953: Watson and Crick made their first announcement on the double-helix structure for DNA on February 28.
- 1981: Lynn Margulis published *Symbiosis in Cell Evolution* detailing the endosymbiotic theory.

Chapter 7

Organelle



A typical animal cell. Within the cytoplasm, the major organelles and cellular structures include: (1) nucleolus (2) nucleus (3) ribosome (4) vesicle (5) rough endoplasmic reticulum (6) Golgi apparatus (7) cytoskeleton (8) smooth endoplasmic reticulum (9) mitochondria (10) vacuole (11) cytosol (12) lysosome (13) centriole.

In cell biology, an **organelle** is a specialized subunit within a cell that has a specific function, and is usually separately enclosed within its own lipid bilayer.

The name *organelle* comes from the idea that these structures are to cells what an organ is to the body (hence the name *organelle*, the suffix *-elle* being a diminutive). Organelles are identified by microscopy, and can also be purified by cell fractionation. There are many types of organelles, particularly in eukaryotic cells. Prokaryotes were once thought not to have organelles, but some examples have now been identified.

History and terminology

In biology, *organs* are defined as confined functional units within an organism. The analogy of bodily organs to microscopic cellular substructures is obvious, as from even early works, authors of respective textbooks rarely elaborate on the distinction between the two.

Credited as the first to use a diminutive of *organ* (*i.e.* little organ) for cellular structures was German zoologist Karl August Möbius (1884), who used the term "organula" (plural form of *organulum*, the diminutive of latin *organum*). From the context, it is clear that he referred to reproduction related structures of protists. In a footnote, which was published as a correction in the next issue of the journal, he justified his suggestion to call organs of unicellular organisms "organella" since they are only differently formed parts of one cell, in contrast to multicellular organs of multicellular organisms. Thus, the original definition was limited to structures of unicellular organisms.

It would take several years before *organulum*, or the later term *organelle*, became accepted and expanded in meaning to include subcellular structures in multicellular organisms. Books around 1900 from Valentin Häcker, Edmund Wilson and Oscar Hertwig still referred to cellular *organs*. Later, both terms came to be used side by side: Bengt Lidforss wrote 1915 (in German) about "Organs or Organells".

Around 1920, the term organelle was used to describe propulsion structures ("motor organelle complex", *i.e.*, flagella and their anchoring) and other protist structures, such as ciliates. Alfred Kühn wrote about centrioles as division organelles, although he stated that, for Vahlkampffias, the alternative 'organelle' or 'product of structural build-up' had not yet been decided, without explaining the difference between the alternatives.

In his 1953 textbook, Max Hartmann used the term for extracellular (pellicula, shells, cell walls) and intracellular skeletons of protists.

Later, the now-widely-used definition of organelle emerged, after which only cellular structures with surrounding membrane had been considered organelles. However, the more original definition of subcellular functional unit in general still coexists.

In 1978, Albert Frey-Wyssling suggested that the term organelle should refer only to structures that convert energy, such as centrosomes, ribosomes, and nucleoli. This new definition, however, did not win wide recognition.

Examples

While most cell biologists consider the term **organelle** to be synonymous with "cell compartment", other cell biologists choose to limit the term organelle to include only those that are DNA-containing, having originated from formerly-autonomous microscopic organisms acquired via endosymbiosis.

The most notable of these organelles having originated from endosymbiont bacteria are:

- mitochondria (in almost all eukaryotes)
- chloroplasts (in plants, algae and protists).

Other organelles are also suggested to have endosymbiotic origins, (notably the flagellum).

Under the more restricted definition of membrane-bound structures, some parts of the cell do not qualify as organelles. Nevertheless, the use of organelle to refer to non-membrane bound structures such as ribosomes is common. This has led some texts to delineate between membrane-bound and non-membrane bound organelles. These structures are large assemblies of macromolecules that carry out particular and specialized functions, but they lack membrane boundaries. Such cell structures include:

- ribosome
- cytoskeleton
- flagellum
- centriole and microtubule-organizing center (MTOC).

Eukaryotic organelles

Eukaryotes are one of the structurally complex cell type, and by definition are in part organized by smaller interior compartments, that are themselves enclosed by lipid membranes that resemble the outermost cell membrane. The larger organelles, such as the nucleus and vacuoles, are easily visible with the light microscope. They were among the first biological discoveries made after the invention of the microscope.

Not all eukaryotic cells have each of the organelles listed below. Exceptional organisms have cells which do not include some organelles that might otherwise be considered universal to eukaryotes (such as mitochondria). There are also occasional exceptions to the number of membranes surrounding organelles, listed in the tables below (e.g., some that are listed as double-membrane are sometimes found with single or triple membranes). In addition, the number of individual organelles of each type found in a given cell varies depending upon the function of that cell.

Major eukaryotic organelles

Organelle	Main function	Structure	Organisms	Notes
chloroplast (plastid)	photosynthesis, traps energy from sunlight	double-membrane compartment	plants, protists (rare kleptoplastic organisms)	has some genes; theorized to be engulfed by the ancestral eukaryotic cell (endosymbiosis)
endoplasmic reticulum	translation and folding of new	single-membrane	all eukaryotes	rough endoplasmic reticulum is covered

	proteins (rough endoplasmic reticulum), expression of lipids (smooth endoplasmic reticulum)	compartment		with ribosomes, has folds that are flat sacs; smooth endoplasmic reticulum has folds that are tubular
Golgi apparatus	sorting and modification of proteins	single-membrane compartment	all eukaryotes	cis-face (convex) nearest to rough endoplasmic reticulum; trans-face (concave) farthest from rough endoplasmic reticulum
mitochondria	energy production from the oxidation of food substances and the release of adenosine triphosphate	double-membrane compartment	most eukaryotes	has some DNA; theorized to be engulfed by an ancestral eukaryotic cell (endosymbiosis)
vacuole	storage, helps maintain homeostasis	single-membrane compartment	eukaryotes	
nucleus	DNA maintenance, controls all activities of the cell, RNA transcription	double-membrane compartment	all eukaryotes	contains bulk of genome

Mitochondria and chloroplasts, which have double-membranes and their own DNA, are believed to have originated from incompletely consumed or invading prokaryotic organisms, which were adopted as a part of the invaded cell. This idea is supported in the Endosymbiotic theory.

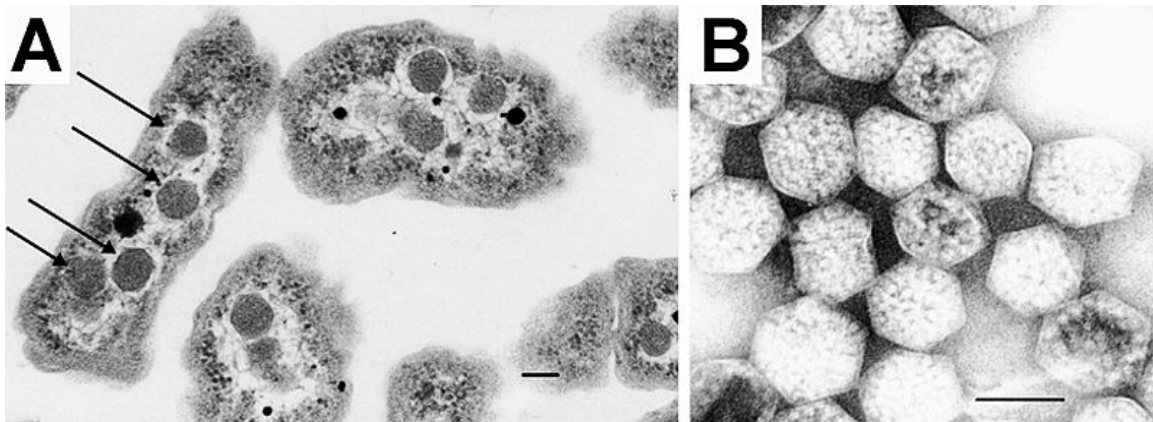
Minor eukaryotic organelles and cell components

Organelle/Macromolecule	Main function	Structure	Organisms
acrosome	helps spermatozoa fuse with ovum	single-membrane compartment	many animals
autophagosome	vesicle which sequesters cytoplasmic material and organelles for degradation	double-membrane compartment	all eukaryotic cells
centriole	anchor for cytoskeleton, helps in cell division by forming spindle fibres	Microtubule protein	animals

cilium	movement in or of external medium; "critical developmental signaling pathway".	Microtubule protein	animals, protists, few plants
eyespot apparatus	detects light, allowing phototaxis to take place		green algae and other unicellular photosynthetic organisms such as euglenids
glycosome	carries out glycolysis	single-membrane compartment	Some protozoa, such as <i>Trypanosomes</i> .
glyoxysome	conversion of fat into sugars	single-membrane compartment	plants
hydrogenosome	energy & hydrogen production	double-membrane compartment	a few unicellular eukaryotes
lysosome	breakdown of large molecules (e.g., proteins + polysaccharides)	single-membrane compartment	most eukaryotes
melanosome	pigment storage	single-membrane compartment	animals
mitosome	not characterized	double-membrane compartment	a few unicellular eukaryotes
myofibril	muscular contraction	bundled filaments	animals
nucleolus	ribosome production	protein-DNA-RNA	most eukaryotes
parenthesome	not characterized	not characterized	fungi
peroxisome	breakdown of metabolic hydrogen peroxide	single-membrane compartment	all eukaryotes
ribosome	translation of RNA into proteins	RNA-protein	eukaryotes, prokaryotes
vesicle	material transport	single-membrane compartment	all eukaryotes

Other related structures:

- cytosol
- endomembrane system
- nucleosome
- microtubule
- cell membrane



(A) Electron micrograph of *Halothiobacillus neapolitanus* cells, arrows highlight carboxysomes. (B) Image of intact carboxysomes isolated from *H. neapolitanus*. Scale bars are 100 nm.

Prokaryotic organelles

Prokaryotes are not as structurally complex as eukaryotes, and were once thought not to have any internal structures enclosed by lipid membranes. In the past, they were often viewed as having little internal organization; but, slowly, details are emerging about prokaryotic internal structures. An early false turn was the idea developed in the 1970s that bacteria might contain membrane folds termed mesosomes, but these were later shown to be artifacts produced by the chemicals used to prepare the cells for electron microscopy.

However, more recent research has revealed that at least some prokaryotes have microcompartments such as carboxysomes. These subcellular compartments are 100 - 200 nm in diameter and are enclosed by a shell of proteins. Even more striking is the description of membrane-bound magnetosomes in bacteria, as well as the nucleus-like structures of the *Planctomycetes* that are surrounded by lipid membranes.

Prokaryotic organelles and cell components

Organelle/Macromolecule	Main function	Structure	Organisms
carboxysome	carbon fixation	protein-shell compartment	some bacteria
chlorosome	photosynthesis	light harvesting	green sulfur

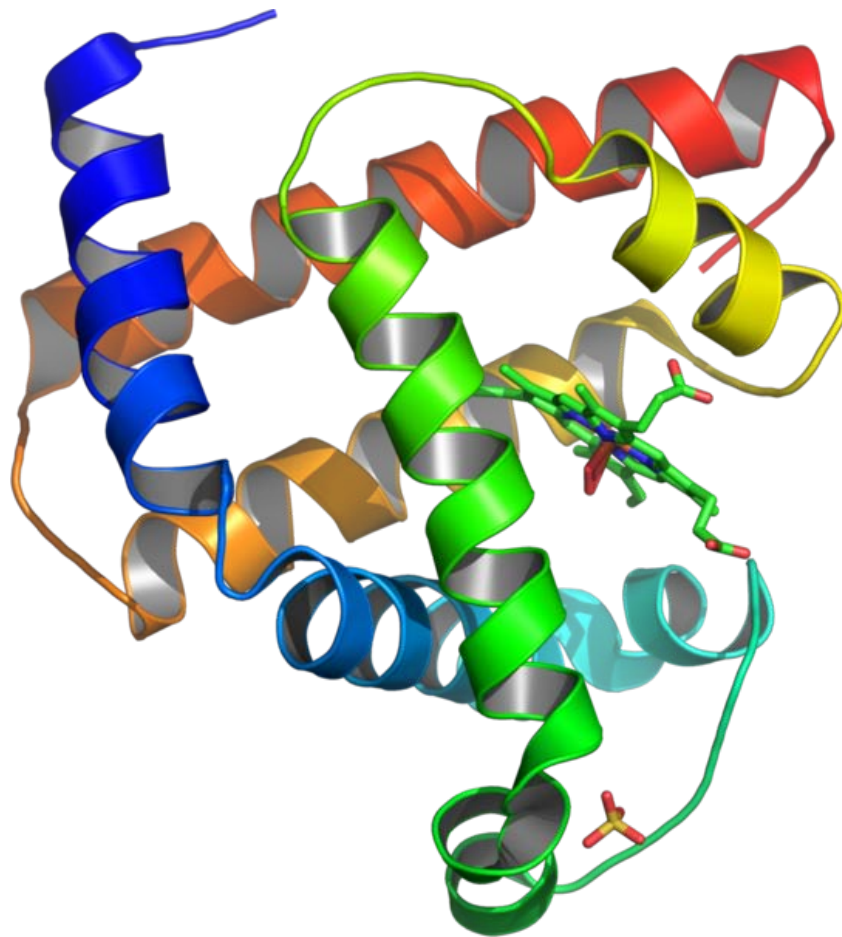
flagellum	movement in external medium	complex protein filament	bacteria some prokaryotes and eukaryotes
magnetosome	magnetic orientation	inorganic crystal, lipid membrane	magnetotactic bacteria
nucleoid	DNA maintenance, transcription to RNA	DNA-protein	prokaryotes
plasmid	DNA exchange	circular DNA	some bacteria
ribosome	translation of RNA into proteins	RNA-protein	eukaryotes, prokaryotes
thylakoid	photosynthesis	photosystem proteins and pigments	mostly cyanobacteria

Proteins and organelles

The function of a protein is closely correlated with the organelle in which it resides. Some methods were proposed for predicting the organelle in which an uncharacterized protein is located according to its amino acid composition and some methods were based on pseudo amino acid composition.

Chapter 8

Biomolecule



A representation of the 3D structure of myoglobin, showing coloured alpha helices. This protein was the first to have its structure solved by X-ray crystallography by Max Perutz and Sir John Cowdery Kendrew in 1958, for which they received a Nobel Prize in Chemistry.

A **biomolecule** is any molecule that is produced by a living organism, including large polymeric molecules such as proteins, polysaccharides, lipids, and nucleic acids as well as small molecules such as primary metabolites, secondary metabolites, and natural products. A more general name for this class of molecules is a biogenic substance.

Types of biomolecules

A diverse range of biomolecules exist, including:

- Small molecules:
 - Lipids, phospholipids, glycolipids, sterols, glycerolipids
 - Vitamins
 - Hormones, neurotransmitters
 - Metabolites

- Monomers, oligomers and polymers:

Biomonomers	Bio-oligomers	Biopolymers	Polymerization process	Covalent Bond name between monomers
Amino acids	Oligopeptides	Polypeptides, proteins (hemoglobin...)	Polycondensation	Peptide bond
Monosaccharides	Oligosaccharides	Polysaccharides (cellulose...)	Polycondensation	Glycosidic bond
Isoprene	Terpenes	Polyterpenes: cis-1,4-polyisoprene natural rubber and trans-1,4-polyisoprene gutta-percha	Polyaddition	
Nucleotides	Oligonucleotides	Polynucleotides, nucleic acids (DNA, RNA)		Phosphodiester bond

Nucleosides and nucleotides

Nucleosides are molecules formed by attaching a nucleobase to a ribose ring. Examples of these include cytidine, uridine, adenosine, guanosine, thymidine and inosine.

Nucleosides can be phosphorylated by specific kinases in the cell, producing nucleotides. Both DNA and RNA are polymers, consisting of long, linear molecules. The repeating structural units, or monomers, of the nucleic acids are called nucleotides.

Each nucleotide is made of an acyclic nitrogenous base, a pentose and one to three phosphate groups. They contain carbon, nitrogen, oxygen, hydrogen and phosphorus. They serve as sources of chemical energy (adenosine triphosphate and guanosine triphosphate), participate in cellular signaling (cyclic guanosine monophosphate and cyclic adenosine monophosphate), and are incorporated into important cofactors of enzymatic reactions (coenzyme A, flavin adenine dinucleotide, flavin mononucleotide, and nicotinamide adenine dinucleotide phosphate).

Saccharides

Monosaccharides are the simplest form of carbohydrates with only one simple sugar. They essentially contain an aldehyde or ketone group in their structure. The presence of an aldehyde group in a monosaccharide is indicated by the prefix *aldo-*. Similarly, a ketone group is denoted by the prefix *keto-*. Examples of monosaccharides are the hexoses glucose, fructose, and galactose and pentoses, ribose, and deoxyribose. Consumed fructose and glucose have different rates of gastric emptying, are differentially absorbed and have different metabolic fates, providing multiple opportunities for 2 different saccharides to differentially affect food intake.

Disaccharides are formed when two monosaccharides, or two single simple sugars, form a bond with removal of water. They can be hydrolyzed to yield their saccharin building blocks by boiling with dilute acid or reacting them with appropriate enzymes. Examples of disaccharides include sucrose, maltose, and lactose.

Polysaccharides are polymerized monosaccharides, complex, carbohydrates. They have multiple simple sugars. Examples are starch, cellulose, and glycogen. They are generally large and often have a complex branched connectivity. Because of their size, polysaccharides are not water-soluble, but their many hydroxy groups become hydrated individually when exposed to water, and some polysaccharides form thick colloidal dispersions when heated in water. Shorter polysaccharides, with 3 - 10 monomers, are called oligosaccharides. A fluorescent indicator-displacement molecular imprinting sensor was developed for discriminating saccharides. It successfully discriminated three brands of orange juice beverage. The change in fluorescence intensity of the sensing films resulting is directly related to the saccharide concentration.

Lignin

Lignin is a random polymer composed mainly of aromatic rings with short (up to three) aliphatic carbons chains connecting the rings. Lignin is the second most common biopolymer (after cellulose) and is one of the primary structural components of most plants. It contains subunits derived from *p*-coumaryl alcohol, coniferyl alcohol, and sinapyl alcohol and is unusual among biomolecules in that it is racemic i.e. it is not optically active. The lack of optical activity is because the polymerization of lignin occurs via free radical coupling reactions in which there is no preference for either configuration at a chiral center.

Lipids

Lipids are chiefly **fatty acid esters**, and are the basic building blocks of biological membranes. Another biological role is energy storage (e.g., triglycerides). Most lipids consist of a polar or hydrophilic head (typically glycerol) and one to three nonpolar or hydrophobic fatty acid tails, and therefore they are amphiphilic. Fatty acids consist of unbranched chains of carbon atoms that are connected by single bonds alone (**saturated** fatty acids) or by both single and double bonds (**unsaturated** fatty acids). The chains are usually 14-24 carbon groups long, but it is always an even number.

For lipids present in biological membranes, the hydrophilic head is from one of three classes:

- Glycolipids, whose heads contain an oligosaccharide with 1-15 saccharide residues.
- Phospholipids, whose heads contain a positively charged group that is linked to the tail by a negatively charged phosphate group.
- Sterols, whose heads contain a planar steroid ring, for example, cholesterol.

Other lipids include prostaglandins and leukotrienes which are both 20-carbon fatty acyl units synthesized from arachidonic acid. They are also known as fatty acids

Amino acids

Amino acids contain both amino and carboxylic acid functional groups. (In biochemistry, the term amino acid is used when referring to those amino acids in which the amino and carboxylate functionalities are attached to the same carbon, plus proline which is not actually an amino acid).

Amino acids are the building blocks of long polymer chains. With 2-10 amino acids such chains are called peptides, with 10-100 they are often called polypeptides, and longer chains are known as proteins. These protein structures have many structural and enzymatic roles in organisms.

There are twenty amino acids that are encoded by the standard genetic code, but there are more than 500 natural amino acids. When amino acids other than the set of twenty are observed in proteins, this is usually the result of modification after translation (protein synthesis). Only two amino acids other than the standard twenty are known to be incorporated into proteins during translation, in certain organisms:

- Selenocysteine is incorporated into some proteins at a UGA codon, which is normally a stop codon.
- Pyrrolysine is incorporated into some proteins at a UAG codon. For instance, in some methanogens in enzymes that are used to produce methane.

Besides those used in protein synthesis, other biologically important amino acids include carnitine (used in lipid transport within a cell), ornithine, GABA and taurine.

Protein structure

The particular series of amino acids that form a protein is known as that protein's primary structure. This sequence is determined by the genetic makeup of the individual. Proteins have several, well-classified, elements of local structure formed by intermolecular attraction, this forms the secondary structure of protein. They are broadly divided in two, alpha helix and beta sheet, also called beta pleated sheets. Alpha helices are formed of coiling of protein due to attraction between amine group of one amino acid with carboxylic acid group of other. The coil contains about 3.6 amino acids per turn and the alkyl group of amino acid lie outside the plane of coil. Beta pleated sheets are formed by strong continuous hydrogen bond over the length of protein chain. Bonding may be parallel or antiparallel in nature. Structurally, natural silk is formed of beta pleated sheets. Usually, a protein is formed by action of both these structures in variable ratios. Coiling may also be random. The overall 3D structure of a protein is termed its tertiary structure. It is formed as result of various forces like hydrogen bonding, disulfide bridges, hydrophobic interactions, hydrophilic interactions, van der Waals force etc. When two or more different polypeptide chains cluster to form a protein, quaternary structure of protein is formed. Quaternary structure is a unique attribute of polymeric and heteromeric proteins like hemoglobin, which consists of two alpha and two beta peptide chains.

Apoenzymes

An apoenzyme is the inactive storage and generally secretory form of a protein. This is required to protect the secretory cell from the activity of that protein. Apoenzymes becomes active enzyme on addition of a cofactor. Cofactors can be either inorganic (e.g., metal ions and iron-sulfur clusters) or organic compounds, (e.g., flavin and heme). Organic cofactors can be either prosthetic groups, which are tightly bound to an enzyme, or coenzymes, which are released from the enzyme's active site during the reaction.

Isoenzymes

Isoenzymes are enzymes with similar function but different structure. They are products of different genes. They are produced in different organs to perform the same function. LDH are examples of such enzymes. Their varied levels in blood are used to determine any deformity in the organ of secretion.

Vitamins

A vitamin is a compound that is generally not synthesized by a given organism but is nonetheless vital to its survival or health (for example coenzymes). These compounds must be absorbed, or eaten, but typically only in trace quantities. When originally proposed by Casimir Funk, a Polish biochemist, he believed them to all be basic and

therefore named them vital amines. The "l" was later dropped to form the word vitamins.

Chapter 9

Cell Membrane

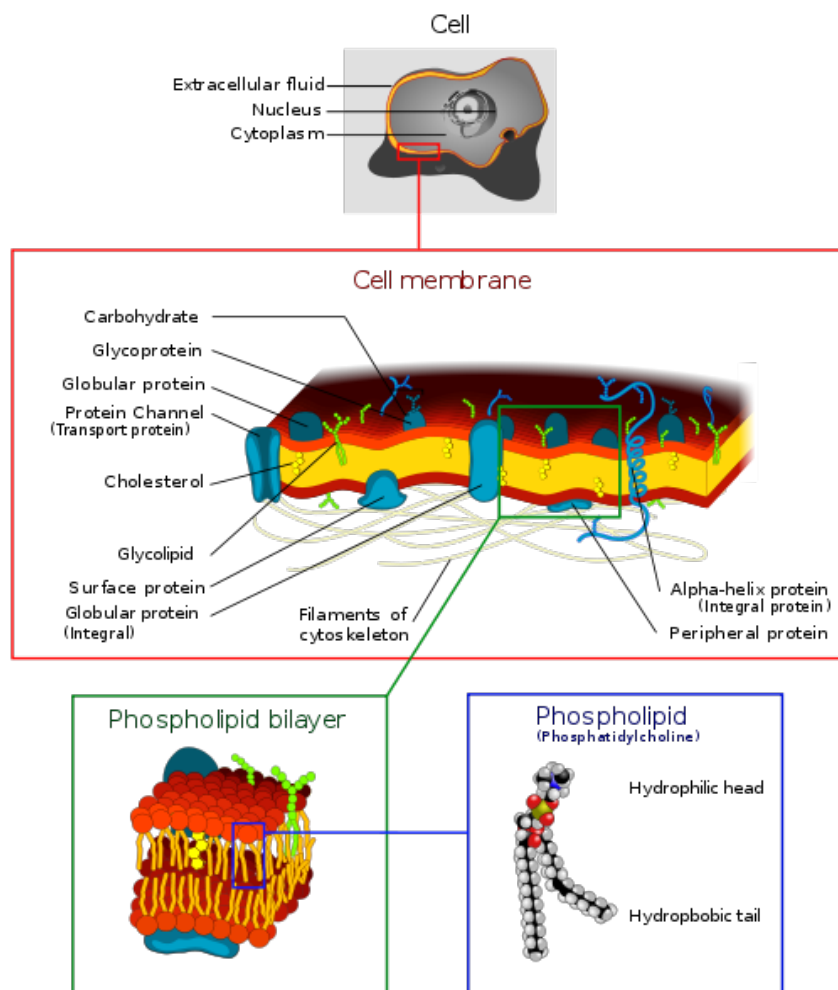


Illustration of a Eukaryotic cell membrane

The **cell membrane** is a biological membrane that separates the interior of all cells from the outside environment. The cell membrane is selectively-permeable to ions and organic molecules and controls the movement of substances in and out of cells. It consists of the phospholipid bilayer with embedded proteins. Cell membranes are involved in a variety

of cellular processes such as cell adhesion, ion conductivity and cell signaling and serve as the attachment surface for the extracellular glycocalyx and cell wall and intracellular cytoskeleton.

Function

The cell membrane surrounds the protoplasm of a cell and, in animal cells, physically separates the intracellular components from the extracellular environment. Fungi, bacteria and plants also have the cell wall which provides a mechanical support for the cell and precludes passage of the larger molecules. The cell membrane also plays a role in anchoring the cytoskeleton to provide shape to the cell, and in attaching to the extracellular matrix and other cells to help group cells together to form tissues.

The barrier is differentially permeable and able to regulate what enters and exits the cell, thus facilitating the transport of materials needed for survival. The movement of substances across the membrane can be either *passive*, occurring without the input of cellular energy, or active, requiring the cell to expend energy in moving it. The membrane also maintains the cell potential.

Prokaryotes

Gram-negative bacteria have plasma membrane and outer membrane separated by the periplasmic space. Other prokaryotic species have only plasma membrane. Prokaryotic cells are also surrounded by a cell wall.

Structure

Fluid mosaic model

According to the fluid mosaic model of S. J. Singer and Garth Nicolson 1972, the biological membranes can be considered as a two-dimensional liquid where all lipid and protein molecules diffuse more or less easily. This picture may be valid in the space scale of 10 nm. However, the plasma membranes contain different structures or domains that can be classified as: (a) protein-protein complexes; (b) lipid rafts, and (c) pickets and fences formed by the actin-based cytoskeleton.

Lipid bilayer

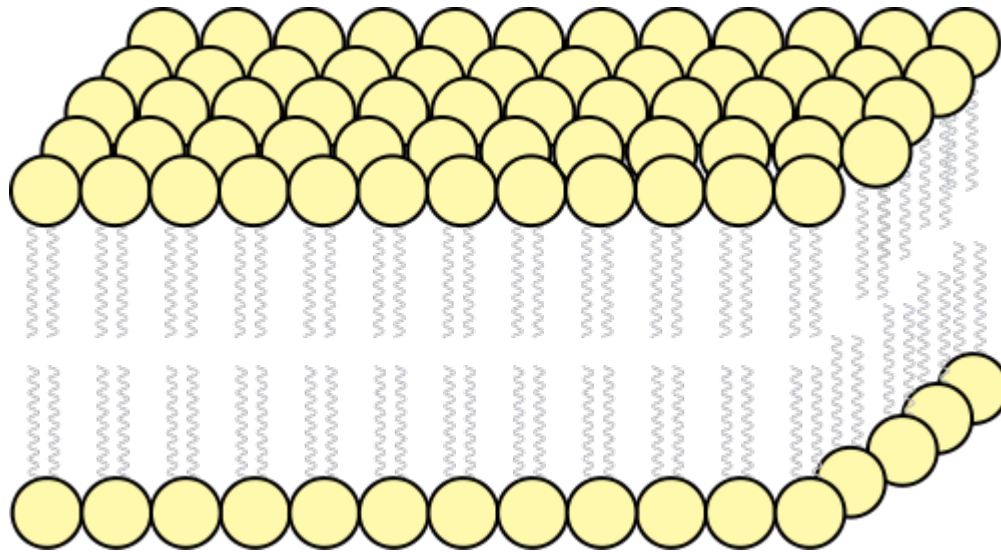


Diagram of the arrangement of amphipathic lipid molecules to form a lipid bilayer. The yellow polar head groups separate the grey hydrophobic tails from the aqueous cytosolic and extracellular environments.

Lipid bilayers go through a self assembly process in the formation of membranes. The cell membrane consists primarily of a thin layer of amphipathic phospholipids which spontaneously arrange so that the hydrophobic "tail" regions are shielded from the surrounding polar fluid, causing the more hydrophilic "head" regions to associate with the cytosolic and extracellular faces of the resulting bilayer. This forms a continuous, spherical lipid bilayer. Forces such as Van der Waal, electrostatic, hydrogen bonds, and noncovalent interactions, are all forces that contribute to the formation of the lipid bilayer. Overall, hydrophobic interactions are the major driving force in the formation of lipid bilayers.

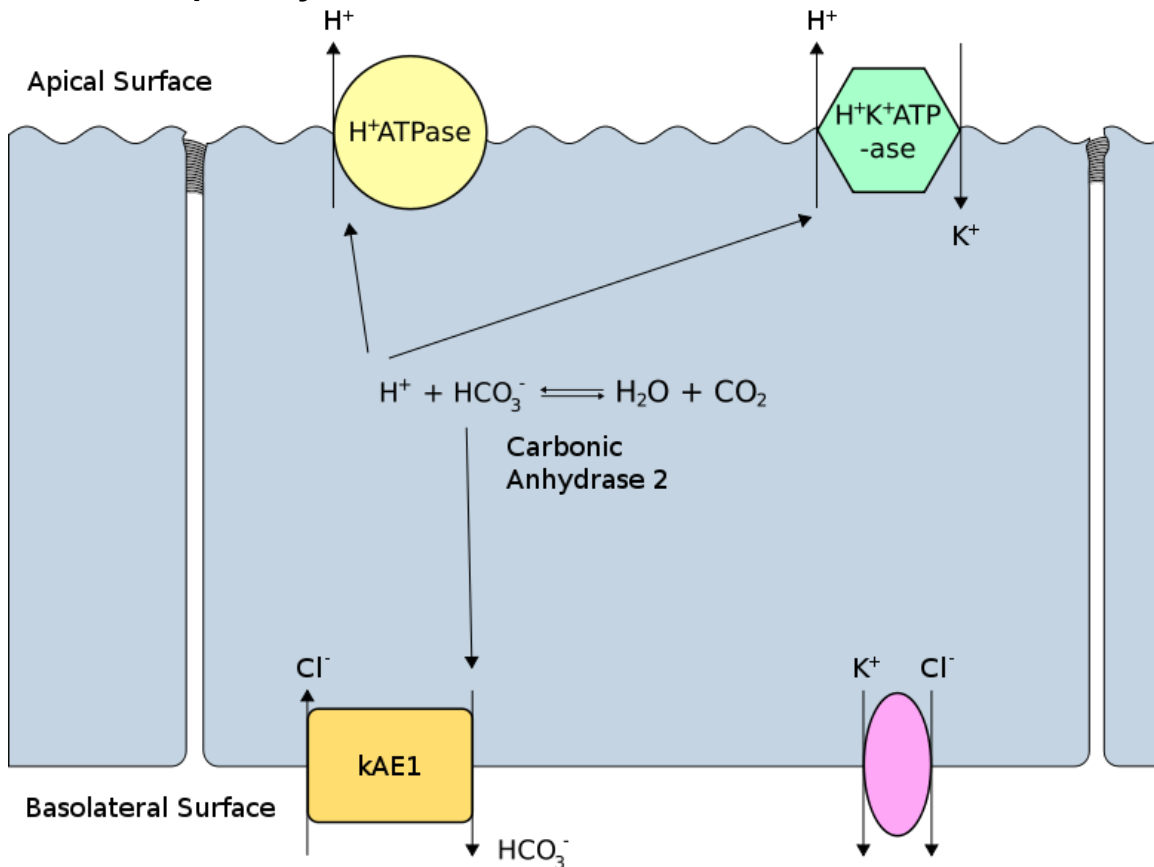
Lipid bilayers have very low permeability for ions and most polar molecules. The arrangement of hydrophilic heads and hydrophobic tails of the lipid bilayer prevent polar solutes (e.g. amino acids, nucleic acids, carbohydrates, proteins, and ions) from diffusing across the membrane, but generally allows for the passive diffusion of hydrophobic molecules. This affords the cell the ability to control the movement of these substances via transmembrane protein complexes such as pores and gates.

Flippases and Scramblases concentrate phosphatidyl serine, which carries a negative charge, on the inner membrane. Along with NANA, this creates an extra barrier to charged moieties moving through the membrane.

Membranes serve diverse functions in eukaryotic and prokaryotic cells. One important role is to regulate the movement of materials into and out of cells. The phospholipid bilayer structure (fluid mosaic model) with specific membrane proteins accounts for the selective permeability of the membrane and passive and active transport mechanisms. In

addition, membranes in prokaryotes and in the mitochondria and chloroplasts of eukaryotes facilitate the synthesis of ATP through chemiosmosis.

Membrane polarity



Alpha intercalated cell

The **apical membrane** of a polarized cell is the surface of the plasma membrane that faces the lumen. This is particularly evident in epithelial and endothelial cells, but also describes other polarized cells, such as neurons.

The **basolateral membrane** of a polarized cell is the surface of the plasma membrane that forms its basal and lateral surfaces. It faces towards the interstitium, and away from the lumen.

"Basolateral membrane" is a compound phrase referring to the terms *basal (base) membrane* and *lateral (side) membrane*, which, especially in epithelial cells, are identical in composition and activity. Proteins (such as ion channels and pumps) are free to move from the basal to the lateral surface of the cell or *vice versa* in accordance with the fluid mosaic model.

Tight junctions that join epithelial cells near their apical surface prevent the migration of proteins from the basolateral membrane to the apical membrane. The basal and lateral

surfaces thus remain roughly equivalent to one another, yet distinct from the apical surface.

Integral membrane proteins

The cell membrane contains many integral membrane proteins, which pepper the entire surface. These structures, which can be visualized by electron microscopy or fluorescence microscopy, can be found on the inside of the membrane, the outside, or membrane spanning. These may include integrins, cadherins, desmosomes, clathrin-coated pits, caveolae, and different structures involved in cell adhesion. Integral proteins are the most abundant type of protein to span the lipid bilayer. They interact widely with hydrocarbon chains of membrane lipids and can be released by agents that compete for the same nonpolar interactions.

Peripheral membrane proteins

Peripheral proteins are proteins that are bounded to the membrane by electrostatic interactions and hydrogen bonding with the hydrophilic phospholipid heads. Many of these proteins can be found bounded to the surfaces of integral proteins on either the cytoplasmic side of the cell or the extracellular side of the membrane. Some are anchored to the bilayer through covalent bond with a fatty acid.

Membrane skeleton

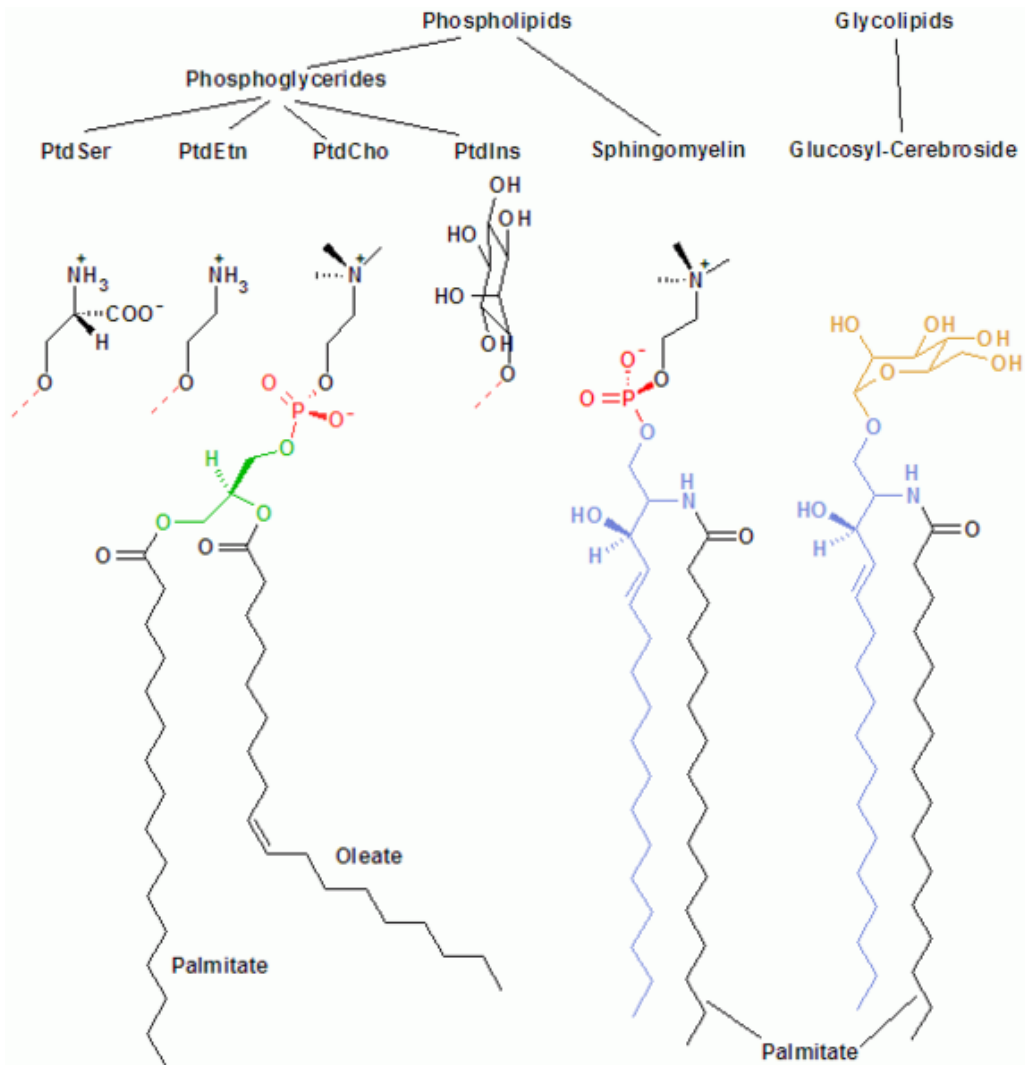
The cytoskeleton is found underlying the cell membrane in the cytoplasm and provides a scaffolding for membrane proteins to anchor to, as well as forming organelles that extend from the cell. Indeed, cytoskeletal elements interact extensively and intimately with the cell membrane. Anchoring proteins restricts them to a particular cell surface — for example, the *apical surface* of epithelial cells that line the vertebrate gut — and limits how far they may diffuse within the bilayer. The cytoskeleton is able to form appendage-like organelles, such as cilia, which are microtubule-based extensions covered by the cell membrane, and filopodia, which are actin-based extensions. These extensions are ensheathed in membrane and project from the surface of the cell in order to sense the external environment and/or make contact with the substrate or other cells. The apical surfaces of epithelial cells are dense with actin-based finger-like projections known as microvilli, which increase cell surface area and thereby increase the absorption rate of nutrients. Localized decoupling of the cytoskeleton and cell membrane results in formation of a bleb.

Composition

Cell membranes contain a variety of biological molecules, notably lipids and proteins. Material is incorporated into the membrane, or deleted from it, by a variety of mechanisms:

- Fusion of intracellular vesicles with the membrane (exocytosis) not only excretes the contents of the vesicle but also incorporates the vesicle membrane's components into the cell membrane. The membrane may form blebs around extracellular material that pinch off to become vesicles (endocytosis).
- If a membrane is continuous with a tubular structure made of membrane material, then material from the tube can be drawn into the membrane continuously.
- Although the concentration of membrane components in the aqueous phase is low (stable membrane components have low solubility in water), there is an exchange of molecules between the lipid and aqueous phases.

Lipids



Examples of the major membrane phospholipids and glycolipids: phosphatidylcholine (PtdCho), phosphatidylethanolamine (PtdEtn), phosphatidylinositol (PtdIns), phosphatidylserine (PtdSer).

The cell membrane consists of three classes of amphipathic lipids: phospholipids, glycolipids, and cholesterol. The amount of each depends upon the type of cell, but in the majority of cases phospholipids are the most abundant. In RBC studies, 30% of the plasma membrane is lipid.

The fatty chains in phospholipids and glycolipids usually contain an even number of carbon atoms, typically between 16 and 20. The 16- and 18-carbon fatty acids are the most common. Fatty acids may be saturated or unsaturated, with the configuration of the double bonds nearly always *cis*. The length and the degree of unsaturation of fatty acid chains have a profound effect on membrane fluidity as unsaturated lipids create a kink, preventing the fatty acids from packing together as tightly, thus decreasing the melting temperature (increasing the fluidity) of the membrane. The ability of some organisms to regulate the fluidity of their cell membranes by altering lipid composition is called homeoviscous adaptation.

The entire membrane is held together via non-covalent interaction of hydrophobic tails, however the structure is quite fluid and not fixed rigidly in place. Under physiological conditions phospholipid molecules in the cell membrane are in the liquid crystalline state. It means the lipid molecules are free to diffuse and exhibit rapid lateral diffusion along the layer in which they are present. However, the exchange of phospholipid molecules between intracellular and extracellular leaflets of the bilayer is a very slow process. Lipid rafts and caveolae are examples of cholesterol-enriched microdomains in the cell membrane.

In animal cells cholesterol is normally found dispersed in varying degrees throughout cell membranes, in the irregular spaces between the hydrophobic tails of the membrane lipids, where it confers a stiffening and strengthening effect on the membrane.

Phospholipids forming lipid vesicles

Lipid vesicles or liposomes are circular pockets that are enclosed by a lipid bilayer. These structures are used in laboratories to study the effects of chemicals in cells by delivering these chemicals directly to the cell, as well as getting more insight into cell membrane permeability. Lipid vesicles and liposomes are formed by first suspending a lipid in an aqueous solution then agitating the mixture through sonication, resulting in a uniformly circular vesicle. By measuring the rate of efflux from that of the inside of the vesicle to the ambient solution, allows researcher to better understand membrane permeability. Vesicles can be formed with molecules and ions inside the vesicle by forming the vesicle with the desired molecule or ion present in the solution. Proteins can also be embedded into the membrane through solubilizing the desired proteins in the presence of detergents and attaching them to the phospholipids in which the liposome is formed. These provide researchers with a tool to examine various membrane protein functions.

Carbohydrates

Plasma membranes also contain carbohydrates, predominantly glycoproteins, but with some glycolipids (cerebrosides and gangliosides). For the most part, no glycosylation occurs on membranes within the cell; rather generally glycosylation occurs on the extracellular surface of the plasma membrane.

The glycocalyx is an important feature in all cells, especially epithelia with microvilli. Recent data suggest the glycocalyx participates in cell adhesion, lymphocyte homing, and many others.

The penultimate sugar is galactose and the terminal sugar is sialic acid, as the sugar backbone is modified in the golgi apparatus. Sialic acid carries a negative charge, providing an external barrier to charged particles.

Proteins

Proteins within the membrane are key to the functioning of the overall membrane. These proteins mainly transport chemicals and information across the membrane. Every membrane has a varying degree of protein content. Proteins can be in the form of peripheral or integral.

Type	Description	Examples
Integral proteins or <i>transmembrane proteins</i>	Span the membrane and have a hydrophilic cytosolic domain, which interacts with internal molecules, a hydrophobic membrane-spanning domain that anchors it within the cell membrane, and a hydrophilic extracellular domain that interacts with external molecules. The hydrophobic domain consists of one, multiple, or a combination of α -helices and β sheet protein motifs.	Ion channels, proton pumps, G protein-coupled receptor
Lipid anchored proteins	Covalently-bound to single or multiple lipid molecules; hydrophobically insert into the cell membrane and anchor the protein. The protein itself is not in contact with the membrane.	G proteins
Peripheral proteins	Attached to integral membrane proteins, or associated with peripheral regions of the lipid bilayer. These proteins tend to have only temporary interactions with biological membranes, and, once reacted the molecule, dissociates to carry on its work in	Some enzymes, some hormones

the cytoplasm.

The cell membrane plays host to a large amount of protein that is responsible for its various activities. The amount of protein differs between species and according to function, however the typical amount in a cell membrane is 50%. These proteins are undoubtedly important to a cell: Approximately a third of the genes in yeast code specifically for them, and this number is even higher in multicellular organisms.

The cell membrane, being exposed to the outside environment, is an important site of cell-cell communication. As such, a large variety of protein receptors and identification proteins, such as antigens, are present on the surface of the membrane. Functions of membrane proteins can also include cell-cell contact, surface recognition, cytoskeleton contact, signaling, enzymatic activity, or transporting substances across the membrane.

Most membrane proteins must be inserted in some way into the membrane. For this to occur, an N-terminus "signal sequence" of amino acids directs proteins to the endoplasmic reticulum, which inserts the proteins into a lipid bilayer. Once inserted, the proteins are then transported to their final destination in vesicles, where the vesicle fuses with the target membrane.

Variation

The cell membrane has different lipid and protein compositions in distinct types of cells and may have therefore specific names for certain cell types:

- Sarcolemma in myocytes
- Oolemma in oocytes
- Historically, the plasma membrane was also referred to as the plasmalemma.

Permeability

The permeability of a membrane is the ease of molecules to pass through it. Permeability depends mainly on the electric charge of the molecule and to a lesser extent the molar mass of the molecule. Electrically neutral and small molecules pass the membrane easier than charged, large ones.

The inability of charged molecules to pass through the cell membrane results in pH partitioning of substances throughout the fluid compartments of the body.

Chapter 10

Biodiversity



Some of the biodiversity of a coral reef



Rainforests are an example of biodiversity on the planet, and typically possess a great deal of species diversity. This is the Gambia River in Senegal's Niokolo-Koba National Park.

Biodiversity is the degree of variation of life forms within a given ecosystem, biome, or an entire planet. Biodiversity is a measure of the health of ecosystems. Greater biodiversity implies greater health. Biodiversity is in part a function of climate. In terrestrial habitats, tropical regions are typically rich whereas polar regions support fewer species.

Rapid environmental changes typically cause extinctions. One estimate is that less than 1% of the species that have existed on Earth are extant.

Since life began on Earth, five major mass extinctions and several minor events have led to large and sudden drops in biodiversity. The Phanerozoic eon (the last 540 million years) marked a rapid growth in biodiversity via the Cambrian explosion—a period during which nearly every phylum of multicellular organisms first appeared. The next 400 million years included repeated, massive biodiversity losses classified as mass extinction events. In the Carboniferous, rainforest collapse led to a great loss of plant and animal life. The Permian–Triassic extinction event, 251 million years ago, was the worst; vertebrate recovery took 30 million years. The most recent, the Cretaceous–Tertiary extinction event, occurred 65 million years ago, and has often attracted more attention than others because it resulted in the extinction of the nonavian dinosaurs.

The period since the emergence of humans has displayed an ongoing biodiversity reduction and an accompanying loss of genetic diversity. Named the Holocene extinction, the reduction is caused primarily by human impacts, particularly habitat destruction. Biodiversity's impact on human health is a major international issue.

The United Nations designated 2010 as the International Year of Biodiversity.

Etymology

The term **biological diversity** was used first by wildlife scientist and conservationist Raymond F. Dasmann in the 1968 lay book *A Different Kind of Country* advocating conservation. The term was widely adopted only after more than a decade, when in the 1980s it came into common usage in science and environmental policy. Thomas Lovejoy, in the foreword to the book **Conservation Biology**, introduced the term to the scientific community. Until then the term "natural diversity" was common, introduced by The Science Division of The Nature Conservancy in an important 1975 study, "The Preservation of Natural Diversity." By the early 1980s TNC's Science program and its head, Robert E. Jenkins, Lovejoy and other leading conservation scientists at the time in America advocated the use of "biological diversity".

The term's contracted form **biodiversity** may have been coined by W.G. Rosen in 1985 while planning the 1986 *National Forum on Biological Diversity* organized by the National Research Council (NRC). It first appeared in a publication in 1988 when entomologist E. O. Wilson used it as the title of the proceedings of that forum.

Since this period the term has achieved widespread use among biologists, environmentalists, political leaders, and concerned citizens.

A similar term in the United States is "natural heritage." It predates the others and is more accepted by the wider audience interested in conservation. Broader than biodiversity, it includes geology and landforms (geodiversity).

Definitions



A Sampling of fungi collected during summer 2008 in Northern Saskatchewan mixed woods, near LaRonge is an example regarding the species diversity of fungi. In this photo, there are also leaf lichens and mosses.

"Biological diversity" or "biodiversity" can have many interpretations. It is most commonly used to replace the more clearly defined and long established terms, species diversity and species richness. Biologists most often define biodiversity as the "totality of genes, species, and ecosystems of a region". An advantage of this definition is that it seems to describe most circumstances and presents a unified view of the traditional three levels at which biological variety has been identified:

- species diversity

- ecosystem diversity
- genetic diversity

In 2003 Professor Anthony Campbell at Cardiff University, UK and the Darwin Centre, Pembrokeshire, defined a fourth level: Molecular Diversity.

This multilevel construct is consistent with Dasmann and Lovejoy. An explicit definition consistent with this interpretation was first given in a paper by Bruce A. Wilcox commissioned by the International Union for the Conservation of Nature and Natural Resources (IUCN) for the 1982 World National Parks Conference. Wilcox's definition was "Biological diversity is the variety of life forms...at all levels of biological systems (i.e., molecular, organismic, population, species and ecosystem)..." The 1992 United Nations Earth Summit defined "biological diversity" as "the variability among living organisms from all sources, including, 'inter alia', terrestrial, marine, and other aquatic ecosystems, and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems". This definition is used in the United Nations Convention on Biological Diversity.

One textbook's definition is "variation of life at all levels of biological organization".

Geneticists define it as the diversity of genes and organisms. They study processes such as mutations, gene transfer, and genome dynamics that generate evolution.

Linking biodiversity levels

Measuring diversity at one level in a group of organisms may not precisely correspond to diversity at other levels. However, tetrapod (terrestrial vertebrates) taxonomic and ecological diversity shows a very close correlation.

Distribution



A conifer forest in the Swiss Alps (National Park).

Selection bias amongst researchers may contribute to biased empirical research for modern estimates of biodiversity. In 1768 Rev. Gilbert White succinctly observed of his Selborne, Hampshire "all nature is so full, that that district produces the most variety which is the most examined."

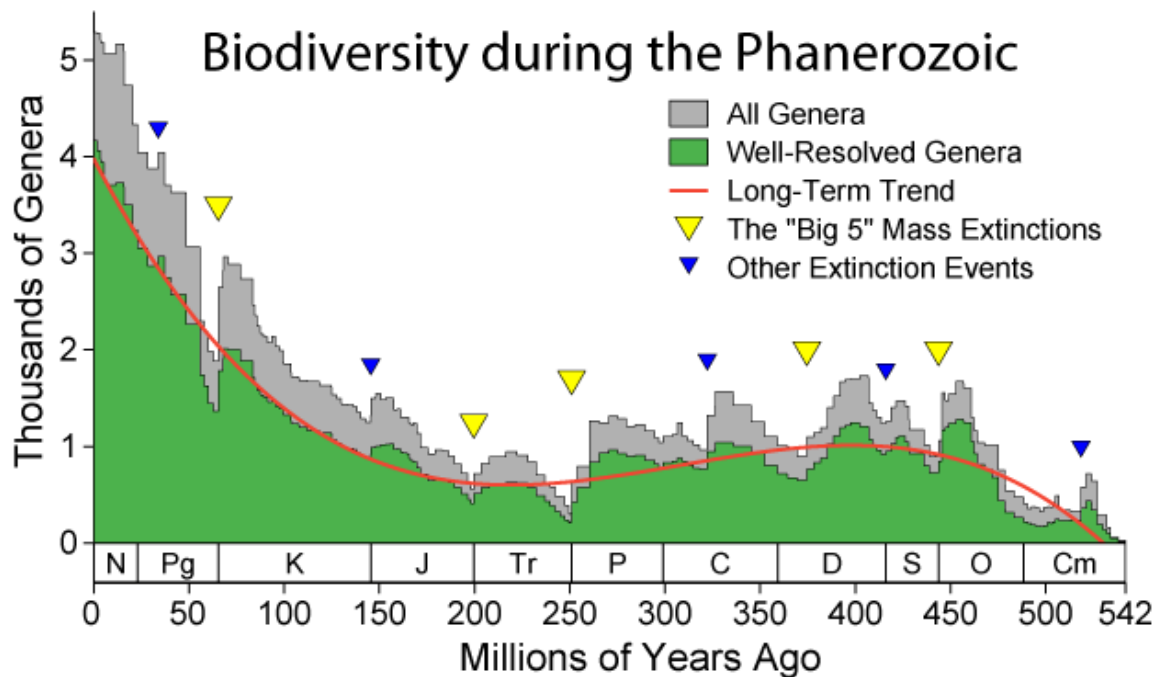
Biodiversity is not evenly distributed. Flora and fauna diversity depends on climate, altitude, soils and the presence of other species. Diversity consistently measures higher in the tropics and in other localized regions such as Cape Floristic Province and lower in polar regions generally. In 2006 many species were formally classified as rare or endangered or threatened; moreover, scientists have estimated that millions more species are at risk which have not been formally recognized. About 40 percent of the 40,177 species assessed using the IUCN Red List criteria are now listed as threatened with extinction—a total of 16,119.

Even though terrestrial biodiversity declines from the equator to the poles, this characteristic is unverified in aquatic ecosystems, especially in marine ecosystems. In addition, several assessments reveal tremendous diversity in higher latitudes. Generally terrestrial biodiversity is up to 25 times greater than ocean biodiversity.

A biodiversity hotspot is a region with a high level of endemic species. Hotspots were first named in 1988 by Dr. Norman Myers. Many hotspots have large nearby human populations. Most hotspots are located in the tropics and most of them are forests.

Brazil's Atlantic Forest is considered one such hotspot, containing roughly 20,000 plant species, 1,350 vertebrates, and millions of insects, about half of which occur nowhere else. The island of Madagascar, particularly the unique Madagascar dry deciduous forests and lowland rainforests, possess a high ratio of endemism. Since the island separated from mainland Africa 65 million years ago, many species and ecosystems have evolved independently. Indonesia's 17,000 islands cover 735,355 square miles (1,904,560 km²) contain 10% of the world's flowering plants, 12% of mammals and 17% of reptiles, amphibians and birds—along with nearly 240 million people. Many regions of high biodiversity and/or endemism arise from specialized habitats which require unusual adaptations, for example alpine environments in high mountains, or Northern European peat bogs.

Evolution



Apparent marine fossil diversity during the Phanerozoic

Biodiversity is the result of 3.5 billion years of evolution. The origin of life has not been definitely established by science, however some evidence suggests that life may already have been well-established only a few hundred million years after the formation of the Earth. Until approximately 600 million years ago, all life consisted of archaea, bacteria, protozoans and similar single-celled organisms.

The history of biodiversity during the Phanerozoic (the last 540 million years), starts with rapid growth during the Cambrian explosion—a period during which nearly every

phylum of multicellular organisms first appeared. Over the next 400 million years or so, global diversity showed little overall trend, but was marked by periodic, massive losses of diversity classified as mass extinction events. A significant loss occurred when rainforests collapsed in the carboniferous. The worst was the Permo-Triassic extinction, 251 million years ago. Vertebrates took 30 million years to recover from this event.

The fossil record suggests that the last few million years featured the greatest biodiversity in history. However, not all scientists support this view, since there is considerable uncertainty as to how strongly the fossil record is biased by the greater availability and preservation of recent geologic sections. Corrected for sampling artifacts, modern biodiversity may not be much different from biodiversity 300 million years ago. Estimates of the present global macroscopic species diversity vary from 2 million to 100 million, with a best estimate of somewhere near 13–14 million, the vast majority arthropods. Diversity appears to increase continually in the absence of natural selection.

Evolutionary diversification

The existence of a "global carrying capacity", limiting the amount of life that can live at once, is debated, as is the question of whether such a limit would also cap the number of species. While records of life in the sea shows a logistic pattern of growth, life on land (insects, plants and tetrapods) shows an exponential rise in diversity. As one author states, "Tetrapods have not yet invaded 64 per cent of potentially habitable modes, and it could be that without human influence the ecological and taxonomic diversity of tetrapods would continue to increase in an exponential fashion until most or all of the available ecospace is filled."

On the other hand, changes through the Phanerozoic correlate much better with the hyperbolic model (widely used in population biology, demography and macrosociology, as well as fossil biodiversity) than with exponential and logistic models. The latter models imply that changes in diversity are guided by a first-order positive feedback (more ancestors, more descendants) and/or a negative feedback arising from resource limitation. Hyperbolic model implies a second-order positive feedback. The hyperbolic pattern of the world population growth arises from a second-order positive feedback between the population size and the rate of technological growth. The hyperbolic character of biodiversity growth can be similarly accounted for by a feedback between diversity and community structure complexity. The similarity between the curves of biodiversity and human population probably comes from the fact that both are derived from the interference of the hyperbolic trend with cyclical and stochastic dynamics.

Most biologists agree however that the period since human emergence is part of a new mass extinction, named the Holocene extinction event, caused primarily by the impact humans are having on the environment. It has been argued that the present rate of extinction is sufficient to eliminate most species on the planet Earth within 100 years.

New species are regularly discovered (on average between 5–10,000 new species each year, most of them insects) and many, though discovered, are not yet classified (estimates

are that nearly 90% of all arthropods are not yet classified). Most of the terrestrial diversity is found in tropical forests.

Human benefits



Summer field in Belgium (Hamois). The blue flowers are *Centaurea cyanus* and the red are *Papaver rhoeas*.

Biodiversity supports ecosystem services including air quality, climate (e.g., CO₂ sequestration), water purification, pollination, and prevention of erosion.

Since the stone age, species loss has accelerated above the prior rate, driven by human activity. Estimates of species loss are at a rate 100-10,000 times as fast as is typical in the fossil record.

Non-material benefits include spiritual and aesthetic values, knowledge systems and the value of education.

Agriculture



Amazon Rainforest in Brazil.

The reservoir of genetic traits present in wild varieties and traditionally grown landraces is extremely important in improving crop performance. Important crops, such as potato, banana and coffee, are often derived from only a few genetic strains. Improvements in crop species over the last 250 years have been largely due to incorporating genes from wild varieties and species into cultivars. Crop breeding for beneficial traits has helped to more than double crop production in the last 50 years as a result of the Green Revolution. A biodiverse environment preserves the genome from which such productive genes are drawn.

Crop diversity aids recovery when the dominant cultivar is attacked by a disease or predator:

- The Irish potato blight of 1846 was a major factor in the deaths of one million people and the emigration of another million. It was the result of planting only two potato varieties, both vulnerable to the blight.
- When rice grassy stunt virus struck rice fields from Indonesia to India in the 1970s, 6,273 varieties were tested for resistance. Only one was resistant, an Indian variety, and known to science only since 1966. This variety formed a hybrid with other varieties and is now widely grown.
- Coffee rust attacked coffee plantations in Sri Lanka, Brazil, and Central America in 1970. A resistant variety was found in Ethiopia. Although the diseases are themselves a form of biodiversity.

Biodiversity's relevance to human health is becoming an international political issue, as scientific evidence builds on the global health implications of biodiversity loss. This issue is closely linked with the issue of climate change, as many of the anticipated health risks of climate change are associated with changes in biodiversity (e.g. changes in populations and distribution of disease vectors, scarcity of fresh water, impacts on agricultural biodiversity and food resources etc.) Some of the health issues influenced by biodiversity include dietary health and nutrition security, infectious disease, medical science and medicinal resources, social and psychological health. Biodiversity is also known to have an important role in reducing disaster risk, and in post-disaster relief and recovery efforts.

Biodiversity provides critical support for drug discovery and the availability of medicinal resources. A significant proportion of drugs are derived, directly or indirectly, from biological sources; At least 50% of the pharmaceutical compounds on the US market are derived from plants, animals, and microorganisms, while about 80% of the world population depends on medicines from nature (used in either modern or traditional medical practice) for primary healthcare. Only a tiny fraction of wild species has been investigated for medical potential. Biodiversity has been critical to advances throughout the field of bionics. Evidence from market analysis and biodiversity science indicates that the decline in output from the pharmaceutical sector since the mid-1980s can be attributed to a move away from natural product exploration ("bioprospecting") in favor of genomics and synthetic chemistry; meanwhile, natural products have a long history of supporting significant economic and health innovation. Marine ecosystems are particularly important, although inappropriate bioprospecting can increase biodiversity loss, as well as violating the laws of the communities and states from which the resources are taken.

Business and Industry



Agriculture production, pictured is a tractor and a chaser bin

Many industrial materials derive directly from biological sources. These include building materials, fibers, dyes, rubber and oil. Biodiversity is also important to the security of resources such as water, timber, paper, fiber, and food. As a result, biodiversity loss is a significant risk factor in business development and a threat to long term economic sustainability.

Leisure, cultural and aesthetic value

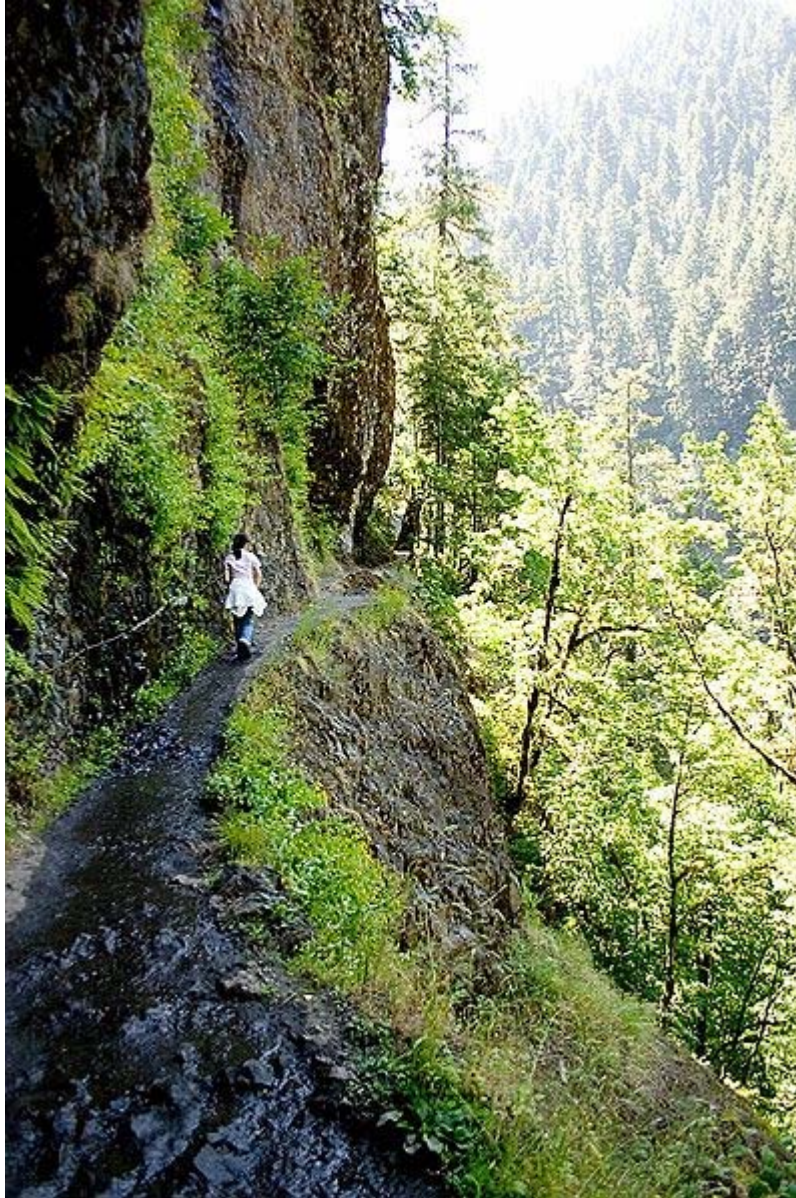
Biodiversity enriches leisure activities such as hiking, birdwatching or natural history study. Biodiversity inspires musicians, painters, sculptors, writers and other artists. Many cultures view themselves as an integral part of the natural world which requires them to respect other living organisms.

Popular activities such as gardening, fishkeeping and specimen collecting strongly depend on biodiversity. The number of species involved in such pursuits is in the tens of thousands, though the majority do not enter commerce.

The relationships between the original natural areas of these often exotic animals and plants and commercial collectors, suppliers, breeders, propagators and those who promote their understanding and enjoyment are complex and poorly understood. The general public responds well to exposure to rare and unusual organisms, reflecting their inherent value.

Philosophically it could be argued that biodiversity has intrinsic aesthetic and spiritual value to mankind *in and of itself*. This idea can be used as a counterweight to the notion that tropical forests and other ecological realms are only worthy of conservation because of the services they provide.

Other services



Eagle Creek, Oregon hiking

Biodiversity supports many ecosystem services that are often not readily visible. It plays a part in regulating the chemistry of our atmosphere and water supply. Biodiversity is directly involved in water purification, recycling nutrients and providing fertile soils. Experiments with controlled environments have shown that humans cannot easily build ecosystems to support human needs; for example insect pollination cannot be mimicked,

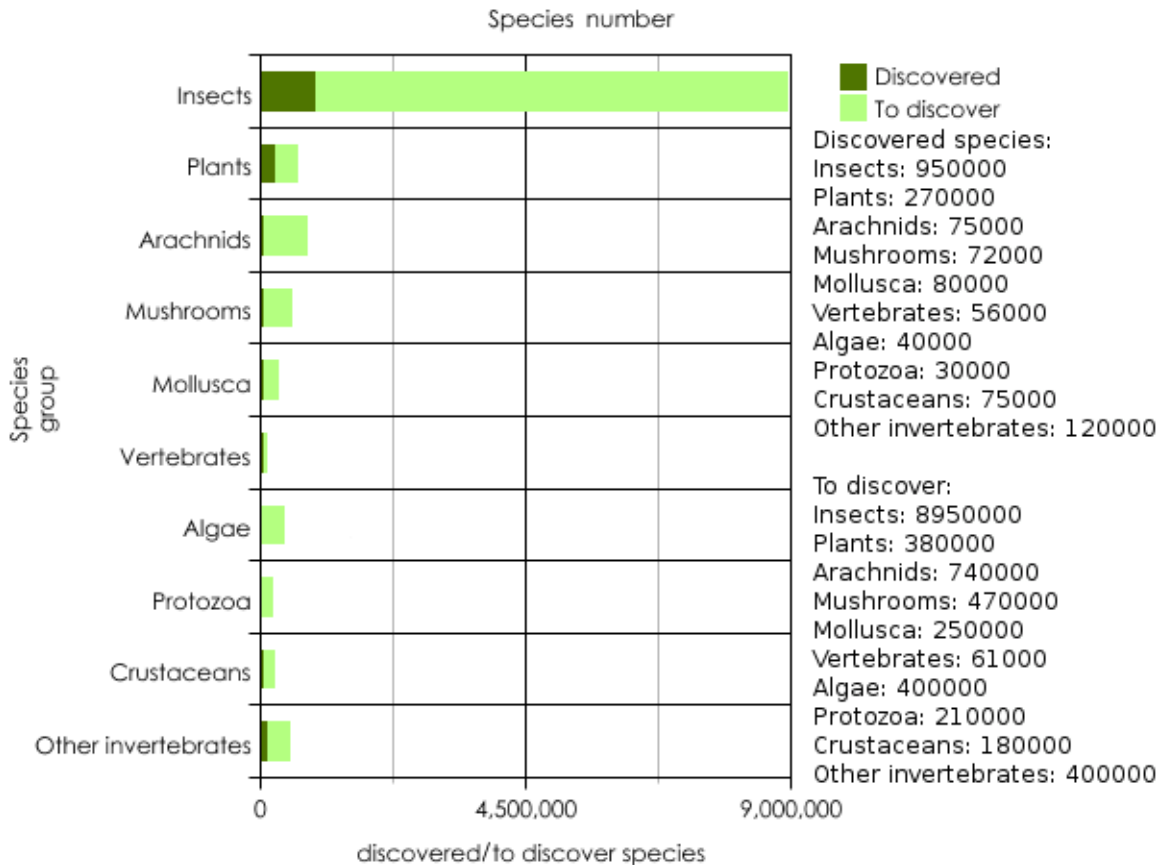
and that activity alone represents tens of billions of dollars in ecosystem services per year to humankind.

Ecosystem stability is also positively related to biodiversity, protecting against disruption by extreme weather or human exploitation.



Polar bears on the sea ice of the Arctic Ocean, near the North Pole.

Number of species



Undiscovered and discovered species

According to the Global Taxonomy Initiative and the European Distributed Institute of Taxonomy, the *total* number of species for some phyla may be much higher than what was known in 2010:

- 10–30 million insects; (of some 0,9 we know today)
- 5–10 million bacteria;
- 1.5 million fungi; (of some 0,4 million we know today)
- ~1 million mites
- The number of microbial species is not reliably known, but the Global Ocean Sampling Expedition dramatically increased the estimates of genetic diversity by identifying an enormous number of new genes from near-surface plankton samples at various marine locations, initially over the 2004-2006 period. The findings may eventually cause a significant change in the way science defines species and other taxonomic categories.

Since the rate of extinction has increased, many extant species may become extinct before they are described.

Species loss rates

During the last century, decreases in biodiversity have been increasingly observed. In 2007, German Federal Environment Minister Sigmar Gabriel cited estimates that up to 30% of all species will be extinct by 2050. Of these, about one eighth of known plant species are threatened with extinction. Estimates reach as high as 140,000 species per year (based on Species-area theory). This figure indicates unsustainable ecological practices, because few species emerge each year. Almost all scientists acknowledge that the rate of species loss is greater now than at any time in human history, with extinctions occurring at rates hundreds of times higher than background extinction rates.

Threats

Jared Diamond describes an "Evil Quartet" of habitat destruction, overkill, introduced species, and secondary extinctions. Edward O. Wilson prefers the acronym **HIPPO**, standing for **H**abitat destruction, **I**nvasive species, **P**ollution, **H**uman Over **P**opulation, and **O**verharvesting. The most authoritative classification in use today is IUCN's Classification of Direct Threats which has been adopted by major international conservation organizations such as the US Nature Conservancy, the World Wildlife Fund, Conservation International, and Birdlife International.

Habitat destruction



Deforestation and increased road-building in the Amazon Rainforest are a significant concern because of increased human encroachment upon wild areas, increased resource extraction and further threats to biodiversity.

Habitat destruction has played a key role in extinctions, especially related to tropical forest destruction. While most threatened species are not food species, their biomass is converted into human food when their habitat is transformed into pasture, cropland, and orchards. It is estimated that more than a third of the earth's biomass is tied up in humans, livestock and crop species. Factors contributing to habitat loss are: overpopulation, deforestation, pollution (air pollution, water pollution, soil contamination) and global warming or climate change.

Habitat size and numbers of species are systematically related. Physically larger species and those living at lower latitudes or in forests or oceans are more sensitive to reduction in habitat area. Conversion to "trivial" standardized ecosystems (e.g., monoculture following deforestation) effectively destroys habitat for the more diverse species that preceded the conversion. In some countries lack of property rights or lax law/regulatory enforcement necessarily leads to biodiversity loss (degradation costs having to be supported by the community).

A 2007 study conducted by the National Science Foundation found that biodiversity and genetic diversity are codependent—that diversity among species requires diversity within a species, and vice versa. "If any one type is removed from the system, the cycle can break down, and the community becomes dominated by a single species." At present, the most threatened ecosystems are found in fresh water, according to the Millennium Ecosystem Assessment 2005, which was confirmed by the "**Freshwater Animal Diversity Assessment**", organised by the biodiversity platform, and the French Institut de recherche pour le développement (MNHNP).

Co-extinctions are a form of habitat destruction. Co-extinction occurs when the extinction or decline in one accompanies the other, such as in plants and beetles.

Introduced and invasive species



Male *Lophura nycthemera* (Silver Pheasant), a native of East Asia that has been introduced into parts of Europe for ornamental reasons

Barriers such as large rivers, seas, oceans, mountains and deserts encourage diversity by enabling independent evolution on either side of the barrier. Invasive species occur when those barriers are blurred. Without barriers such species occupy new niches, substantially reducing diversity. Repeatedly humans have helped these species circumvent these barriers, introducing them for food and other purposes. This has occurred on a time scale much shorter than the eons that historically have been required for a species to extend its range.

Not all introduced species are invasive, nor all invasive species deliberately introduced. In cases such as the zebra mussel, invasion of US waterways was unintentional. In other cases, such as mongooses in Hawaii, the introduction is deliberate but ineffective (nocturnal rats were not vulnerable to the diurnal mongoose!). In other cases, such as oil

palms in Indonesia and Malaysia, the introduction produces substantial economic benefits, but the benefits are accompanied by costly unintended consequences.

Finally, an introduced species may unintentionally injure a species that depends on the species it replaces. In Belgium, *Prunus spinosa* from Eastern Europe leafs much sooner than its West European counterparts, disrupting the feeding habits of the *Thecla betulae* butterfly (which feeds on the leaves). Introducing new species often leaves endemic and other local species unable to compete with the exotic species and unable to survive. The exotic organisms may be predators, parasites, or may simply outcompete indigenous species for nutrients, water and light.

At present, several countries have already imported so many exotic species, particularly agricultural and ornamental plants, that the own indigenous fauna/flora may be outnumbered.

Genetic pollution

Endemic species can be threatened with extinction through the process of genetic pollution, i.e. uncontrolled hybridization, introgression and genetic swamping. Genetic pollution leads to homogenization or replacement of local genomes as a result of either a numerical and/or fitness advantage of an introduced species. Hybridization and introgression are side-effects of introduction and invasion. These phenomena can be especially detrimental to rare species that come into contact with more abundant ones. The abundant species can interbreed with the rare species, swamping its gene pool. This problem is not always apparent from morphological (outward appearance) observations alone. Some degree of gene flow is normal adaptation, and not all gene and genotype constellations can be preserved. However, hybridization with or without introgression may, nevertheless, threaten a rare species' existence.

Overexploitation

Overexploitation occurs when a resource is consumed at an unsustainable rate. This occurs on land in the form of overhunting, excessive logging, poor soil conservation in agriculture and the illegal wildlife trade. Joe Walston, director of the Wildlife Conservation Society's Asian programs, called the latter the "single largest threat" to biodiversity in Asia. The international trade of endangered species is second in size only to drug trafficking.

About 25% of world fisheries are now overfished to the point where their current biomass is less than the level that maximizes their sustainable yield.

The overkill hypothesis explains why earlier megafaunal extinctions occurred within a relatively short period of time. This can be connected with human migration.

Hybridization, genetic pollution/erosion and food security



The Yecoro wheat (right) cultivar is sensitive to salinity, plants resulting from a hybrid cross with cultivar W4910 (left) show greater tolerance to high salinity

In agriculture and animal husbandry, the Green Revolution popularized the use of conventional hybridization to increase yield. Often hybridized breeds originated in developed countries and were further hybridized with local varieties in the developing world to create high yield strains resistant to local climate and diseases. Local governments and industry have been pushing hybridization. Formerly huge gene pools of various wild and indigenous breeds have collapsed causing widespread genetic erosion and genetic pollution. This has resulted in loss of genetic diversity and biodiversity as a whole.

(GM organisms) have genetic material altered by genetic engineering procedures such as recombinant DNA technology. GM crops have become a common source for genetic pollution, not only of wild varieties but also of domesticated varieties derived from classical hybridization.

Genetic erosion coupled with genetic pollution may be destroying unique genotypes, thereby creating a hidden crisis which could result in a severe threat to our food security. Diverse genetic material could cease to exist which would impact our ability to further hybridize food crops and livestock against more resistant diseases and climatic changes.

Climate Change

Global warming is also considered to be a major threat to global biodiversity. For example coral reefs -which are biodiversity hotspots- will be lost in 20 to 40 years if global warming continues at the current trend.

In 2004, an international collaborative study on four continents estimated that 10 percent of species would become extinct by 2050 because of global warming. "We need to limit climate change or we wind up with a lot of species in trouble, possibly extinct," said Dr. Lee Hannah, a co-author of the paper and chief climate change biologist at the Center for Applied Biodiversity Science at Conservation International.

Overpopulation

From 1950 to 2005, world population increased from 2.5 billion to 6.5 billion and is forecast to reach a plateau of more than 9 billion during the 21st century. Sir David King, former chief scientific adviser to the UK government, told a parliamentary inquiry: "It is self-evident that the massive growth in the human population through the 20th century has had more impact on biodiversity than any other single factor."

The Holocene extinction

Rates of decline in biodiversity in this sixth mass extinction match or exceed rates of loss in the five previous mass extinction events in the fossil record. Loss of biodiversity results in the loss of natural capital that supplies ecosystem goods and services. The economic value of 17 ecosystem services for Earth's biosphere (calculated in 1997) has an estimated value of US\$ 33 trillion (3.3×10^{13}) per year.

Conservation



The retreat of Aletsch Glacier in the Swiss Alps (situation in 1979, 1991 and 2002), due to global warming.

Conservation biology matured in the mid-20th century as ecologists, naturalists, and other scientists began to research and address issues pertaining to global biodiversity declines.

The conservation ethic advocates management of natural resources for the purpose of sustaining biodiversity in species, ecosystems, the evolutionary process, and human culture and society.

Conservation biology is reforming around strategic plans to protect biodiversity. Preserving global biodiversity is a priority in strategic conservation plans that are designed to engage public policy and concerns affecting local, regional and global scales of communities, ecosystems, and cultures. Action plans identify ways of sustaining human well-being, employing natural capital, market capital, and ecosystem services.

Protection and restoration techniques

The most powerful technique is to preserve habitat.

Exotic species removal allows less competitive species to recover their ecological niches. Exotic species that have become a pest can be identified taxonomically (e.g. with Digital Automated Identification SYstem (DAISY), using the barcode of life. Removal is practical only given large groups of individuals due to the economic cost.

Once the preservation of the remaining native species in an area is assured. "missing" species can be identified and reintroduced using databases such as the *Encyclopedia of Life* and the Global Biodiversity Information Facility.

Other techniques include:

- Biodiversity banking places a monetary value on biodiversity. One example is the Australian Native Vegetation Management Framework.
- Gene banks are collections of specimens and genetic material. Some banks intend to reintroduce banked species to the ecosystem (e.g. via tree nurseries).
- Reducing and better targeting of pesticides allows more species to survive in agricultural and urbanized areas.
- Location-specific approaches are less useful for protecting migratory species. One approach is to create wildlife corridors that correspond to the animals' movements. National and other boundaries can complicate corridor creation.

Resource allocation

Focusing on limited areas of higher potential biodiversity promises greater immediate return on investment than spreading resources evenly or focusing on areas of little diversity but greater interest in biodiversity.

A second strategy focuses on areas that retain most of their original diversity, which typically require little or no restoration. These are typically non-urbanized, non-agricultural areas. Tropical areas often fit both criteria, given their natively high diversity and relative lack of development.

Legal status



A great deal of work is occurring to preserve the natural characteristics of Hopetoun Falls, Australia while continuing to allow visitor access.

Biodiversity is taken into account in some political and judicial decisions:

- The relationship between law and ecosystems is very ancient and has consequences for biodiversity. It is related to private and public property rights. It can define protection for threatened ecosystems, but also some rights and duties (for example, fishing and hunting rights).
- Law regarding species is more recent. It defines species that must be protected because they may be threatened by extinction. The U.S. Endangered Species Act is an example of an attempt to address the "law and species" issue.
- Laws regarding gene pools are only about a century old. Domestication and plant breeding methods are not new, but advances in genetic engineering has led to tighter laws covering distribution of genetically modified organisms, gene patents and process patents. Governments struggle to decide whether to focus on for example, genes, genomes, or organisms and species.

Global agreements such as the Convention on Biological Diversity), give **sovereign national rights over biological resources** (not property). The agreements commit countries to **conserve biodiversity, develop resources for sustainability and share the benefits** resulting from their use. Biodiverse countries that allow bioprospecting or collection of natural products, expect a share of the benefits rather than allowing the individual or institution that discovers/exploits the resource to capture them privately. Bioprospecting can become a type of biopiracy when such principles are not respected.

Sovereignty principles can rely upon what is better known as Access and Benefit Sharing Agreements (ABAs). The Convention on Biodiversity implies informed consent between the source country and the collector, to establish which resource will be used and for what, and to settle on a fair agreement on benefit sharing.

Uniform approval for use of biodiversity as a legal standard has not been achieved, however. Bosselman argues that biodiversity should not be used as a legal standard, claiming that the remaining areas of scientific uncertainty cause unacceptable administrative waste and increase litigation without promoting preservation goals.

Analytical limits

Taxonomic and size relationships

Less than 1% of all species that have been described have been studied beyond simply noting their existence. The vast majority of Earth's species are microbial. Contemporary biodiversity physics is "firmly fixated on the visible [macroscopic] world". For example, microbial life is metabolically and environmentally more diverse than multicellular life. "On the tree of life, based on analyses of small-subunit ribosomal RNA, visible life consists of barely noticeable twigs. The inverse relationship of size and population recurs higher on the evolutionary ladder—"to a first approximation, all multicellular species on Earth are insects". Insect extinction rates are high—supporting the Holocene extinction hypothesis.