FUNDAMENTALS OF ECOLOGY

University textbook for students of veterinary medicine

ĐURO HUBER

TOMISLAV GOMERČIĆ

JOSIP KUSAK

UNIVERSITY OF ZAGREB TEXTBOOKS

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Faculty of Veterinary Medicine
University of Zagreb
Zagreb, 2015

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University textbook in the field of ecology at the Faculty of Veterinary Medicine for the regular course Zoology of the study program Integrated Undergraduate and Graduate University Study of Veterinary Medicine at the University of Zagreb.

On the recommendation of the Committee for University and Course Literature, the Senate of the University of Zagreb, at the session held on 21 July 2015, reached a decision (reg.no.: 380-061/252-15-6) approving the use of the title university textbook (*Manualia universitatis studiorum Zagrabiensis*) for this textbook in Croatian language.

CIP data are available in the digital catalogue of the National and University Library in Zagreb under the number 000945828.

ISBN 978-953-8006-10-4

Foreword

This university textbook is intended for students in the course Zoology. The regular course Zoology is taught in the first year of the Integrated Undergraduate and Graduate University Study of Veterinary Medicine at the Faculty of Veterinary Medicine, University of Zagreb. Within the Zoology course, the textbook covers methodological units of basic knowledge in the field of ecology that are important for students of veterinary medicine and are included in the curricula. The authors took it upon themselves to explain the extensive and very complicated material in an acceptable and completely understandable manner, gradually introducing the student to the fundamentals of ecology and eventually to specific knowledge in the field.

The textbook allows the lecturer to almost fully achieve the objectives set by the framework curriculum for the course. The text encourages active learning and consideration of the essential science that can recognize the nature of global changes in the environment and at the same time single out the resources and measures that can lead to the neutralization and mitigation of consequences and to the reconstruction and recovery of natural ecosystems. The textbook opens up the possibility of productive learning in accordance with the cognitive abilities of first-year students. It asserts itself as a functional communicative tool in teaching and a textbook such as this one is the primary source of knowledge.

With their approachable style, the authors managed to present this sophisticated material to a wide audience of their fellow veterinarians, as well as students of undergraduate and postgraduate studies. On the other hand, the other lecturers and associates will receive a textbook that will facilitate their classes and practical exercises.

The book is primarily intended for veterinary medicine experts dealing with environmental issues. However, since biology, and especially the fundamentals of ecology, is associated with all areas of veterinary medicine, the book will be of significance for all types of undergraduate students, as well as postgraduate students in other areas of veterinary medicine. I highly recommend this book to all interested readers.

The reviewer of the university textbook
Prof Ksenija Vlahović, PhD

Contents

1 Introduction

The term ecology has been used for this scientific discipline since 1869 when it was defined and used by a German biologist Ernst Haeckel (1834 - 1919). It derives from the Greek word “oikos“ meaning house or home, here in the sense of shared living. The simplest possible definition of the term ecology is that it studies the interrelationships between organisms and their environment and the relationships of organisms with each other. The understanding that there are complex relationships between the inanimate and animate world, as well as among all types of living organisms, existed even before Haeckel gave the name to the discipline. A beautiful recorded example of experiential understanding of relationships in nature is a letter of the Native American Chief Seattle to the president of the United States of America (Figure 1) written in 1852.

Figure 1. Chief Seattle lived from around 1786 to 1866.
Source: (http://www.rozsavage.com/2010/02/16/chief-seattle/)

Letter of the Native American Chief Seattle

But how can you buy or sell the sky? The land? The idea is strange to us. If we do not own the freshness of the air and the sparkle of the water how can you buy them?

Every part of this earth is sacred to my people. Every shining pine needle, every sandy shore, every mist in the dark woods, every meadow, every humming insect. All are holy in the memory and experience of my people. The sap which courses through the trees carries the memories of the red man.

The white man's dead forget the country of their birth when they go to walk among the stars. Our dead never forget this beautiful earth, for it is the mother of the red man. We are part of the earth and it is part of us. The perfumed flowers are our sisters. The bear, the deer, the great eagle, these are our brothers. The rocky crests, the juices in the meadow, the body heat of a pony, and man, all belong to the same family.

So, when the Great Chief in Washington sends word that he wishes to buy land, he asks much of us. The Great Chief sends word he will reserve us a place so that we can live comfortably to ourselves. He will be our father and we will be his children. So we will consider your offer to buy our land. But it will not be easy. For this land is sacred to us. This shining water that moves in the streams and rivers is not just water but the blood of our ancestors. If we sell you land, you must remember that it is sacred, and you must teach your children that it is sacred and that each ghostly reflection in the clear water of the lakes tells of events and memories in the life of my people. The water's murmur is the voice of my father's father. The rivers are our brothers, they quench our thirst. The rivers carry our canoes, and feed our children. If we sell you our land, you must remember, and teach your children, that the rivers are our brothers, and yours, and you must henceforth give the rivers the kindness you would give any brother.

We know that the white man does not understand our ways. One portion of land is the same to him as the next, for he is a stranger who comes in the night and takes from the land whatever he needs. The earth is not his brother, but his enemy, and when he has conquered it, he moves on. He leaves his father's graves behind, and he does not care. He kidnaps the earth from his children, and he does not care. His father's grave, and his children's birth right, are forgotten. He treats his mother, the earth, and his brother, the sky, as things to be bought, plundered, sold like sheep or bright beads. His appetite will devour the earth and leave behind only a desert.

I do not know. Our ways are different from your ways. The sight of your cities pains the eyes of the red man. But perhaps it is because the red man is a savage and does not understand. There is no quiet place in the white man's cities. No place to hear the unfurling of leaves in spring, or the rustle of an insect's wings. But perhaps it is because I am a savage and do not understand. The clatter only seems to insult the ears. And what is there to life if a man cannot hear the lonely cry of the whip-poor-will or the arguments of the frogs around a pond at night? I am a red man and do not understand. The Indian prefers the soft sound of the wind darting over the face of a pond, and the smell of the wind itself, cleaned by a midday rain, or scented with the pinion pine. The air is precious to the red man, for all things share the same breath - the beast, the tree, the man, they all share the same breath. The white man does not seem to notice the air he breathes. Like a man dying for many days, he is numb to the stench. But if we sell you our land, you must remember that the air is precious to us, that the air shares its spirit with all the life it supports. The wind that gave our grandfather his first breath also receives his last sigh. And if we sell you our land, you must keep it apart and sacred, as a place where even the white man can go to taste the wind that is sweetened by the meadow's flowers.

So we will consider your offer to buy our land. If we decide to accept, I will make one condition: The white man must treat the beasts of this land as his brothers.

I am a savage and I do not understand any other way. I've seen a thousand rotting buffaloes on the prairie, left by the white man who shot them from a passing train. I am a savage and I do not understand how the smoking iron horse can be more important than the buffalo that we kill only to stay alive. What is man without the beasts? If all the beasts were gone, man would die from a great loneliness of spirit. For whatever happens to the beasts, soon happens to manual things are connected.

You must teach your children that the ground beneath their feet is the ashes of your grandfathers. So that they will respect the land, tell your children that the earth is rich with the lives of our kin. Teach your children what we have taught our children that the earth is our mother. Whatever befalls the earth befalls the sons of the earth. If men spit upon the ground, they spit upon themselves.

This we know: The earth does not belong to man; man belongs to the earth. This we know. All things are connected like the blood which unites one family. All things are connected.

Whatever befalls the earth befalls the sons of the earth. Man did not weave the web of life: he is merely a strand in it. Whatever he does to the web, he does to himself.

Even the white man, whose God walks and talks with him as friend to friend, cannot be exempt from the common destiny. We may be brothers after all. We shall see. One thing we know, which the white man may one day discover, our God is the same God. You may think now that you own Him as you wish to own our land; but you cannot. He is the God of man, and His compassion is equal for the red man and the white. This earth is precious to Him, and to harm the earth is to heap contempt on its Creator. The whites too shall pass; perhaps sooner than all other tribes. Contaminate your bed, and you will one night suffocate in your own waste.

But in your perishing you will shine brightly, fired by the strength of God who brought you to this land and for some special purpose gave you dominion over this land and over the red man. That destiny is a mystery to us, for we do not understand when the buffalo are all slaughtered, the wild horses are tamed, the secret corners of the forest heavy with scent of many men, and the view of the ripe hills blotted by talking wires. Where is the thicket? Gone. Where is the eagle? Gone. The end of living and the beginning of survival.

1.1 Ecology as one of the fields of biology

Biology or the science of life encompasses very different areas. In addition to the rough division, in terms of major taxonomic categories such as kingdoms, the specialization of approach may reach the level of an individual species. On the other hand, approach can be also be specialized based on scientific disciplines, so each group of organisms can be researched based on e.g. genetics, physiology, evolution or development (Figure 2). This also includes ecological research, with the distinction that it cannot refer only to certain species or groups of organisms but must encompass the entire community (biocenosis), as well as inanimate (abiotic) factors. This makes ecological research significantly more demanding and complex than research in other disciplines of biology. Today, computer technology enables simultaneous processing of large and continuously growing databases and new usable conclusions can be derived through modelling. Current examples are the efforts to predict the effects of climate change on plant and animal communities in each area.

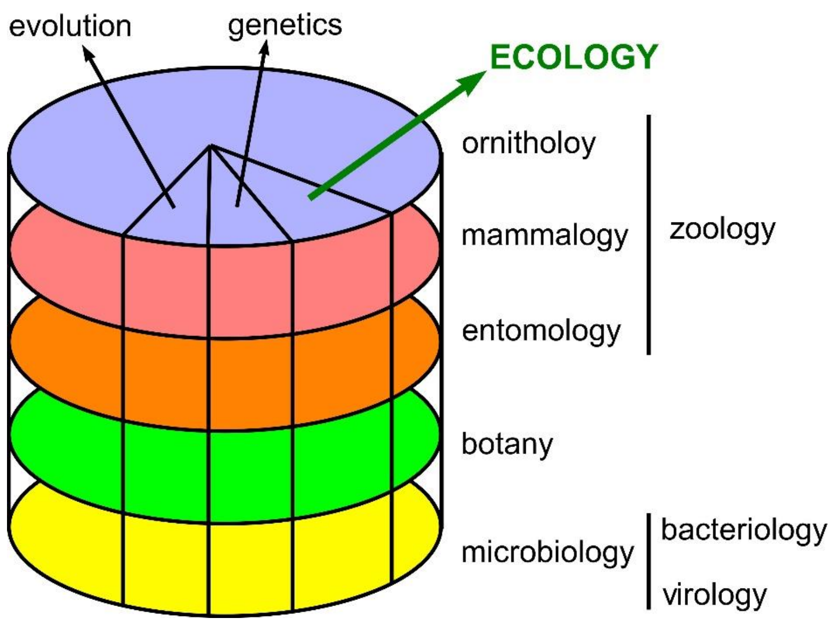


Figure 2. Ecology within biology shown as a multilayer cake. The specificity of biology is that it cannot address only certain segments. It must encompass all layers, including inanimate nature. Source: Authors

2 Definitions of basic concepts in ecology

Most of the below-defined terms will be elaborated in more detail in the textbook. Here, we only present the shortest possible definitions for the purposes of understanding the text.

Spatial categories listed from broader and larger to narrower and smaller:

Biome – a complex of a large number of communities in one climate region

Biocycle – the division of biomes into land (terrestrial) and water (aquatic) biocycles – marine and inland aquatic (freshwater) biocycles

Ecosystem – "geobiocenosis"; a fundamental functional unit in ecology in which the abiotic and biotic environment are functionally stable at a certain trophic level of matter circulation

Biotope (habitat) – an area with uniform environmental conditions and associated adapted organisms

Habitat – an external environment with conditions supporting life of some plant, animal or other type of organism

Microhabitat – immediate special environment of an organism

Biocenosis – a community of organisms in a biotope (zoocenosis and phytocenosis)

Functional categories:

Ecological niche – the location and status (role) of an organism in a biotic environment

Ecological amplitude (valence) – a relative tolerance to deviations from the optimum environmental conditions (limits of fluctuations of an individual ecological factor tolerable for the survival of a species)

Euryvalent organisms – organisms that tolerate a wide range of deviations of ecological parameters from optimal values (ubiquitous)

Stenovalent organisms – organisms that tolerate a narrow range of deviations of ecological parameters from optimal values

Examples of ecological amplitude for certain needs:

Euryphagic species eat a wide variety of food, while **stenophagic** species eat only certain types of food (Figure 3)

Eurythermal species tolerate a wide temperature range, while **stenothermal** species tolerate a narrow range

Euryecious species can live in different habitats (thus called “ubiquitous” or global), while **stenoecious** species live in only one type of habitat

Euryosmotic aquatic animal species tolerate a wide range of osmotic pressure values and can live in both seawater and freshwater, while **stenoosmotic** species live in only one of those aquatic habitats

Figure 3. Giant panda as an example of a stenophagic animal (bamboo shoots are its main food) Source: Authors

Life form – a set of all adaptive possibilities (adaptations) of a species and its developmental stages, in harmony with the conditions in an ecosystem

Ecosystem homeostasis – an equilibrium state of a biological system and its resistance to change in which production and decomposition are in dynamic equilibrium

Coevolution – the evolution of communities through mutual (reciprocal) selection of interdependent species close in the food chain

Biomass – the total living mass (or “weight” if expressed in kilogram-force) of organisms in an ecosystem, a habitat or biosphere

3 Biosphere

The area in which there is life on planet Earth is called biosphere, which means "zone of life". It consists of lithosphere or the hard Earth's crust, hydrosphere or the water layer of much of Earth's surface and atmosphere as the air layer (Figure 4).

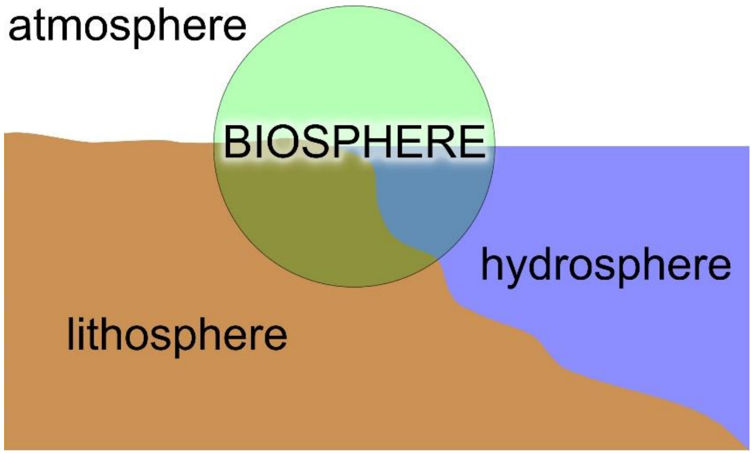


Figure 4. The biosphere as the meeting point at the borders of lithosphere, atmosphere and hydrosphere. Source: Authors

It should be noted that the "zone of life" for lithosphere beneath the surface of the ground reaches only the depth of the deepest roots of certain plants. The lithosphere at this depth also includes other types of organisms that belong to other kingdoms of living things, primarily some types of bacteria and fungi and some animal species. The exceptions are various heterotrophs in cave systems where they live in complete darkness and depend on the production of organic matter on the surface of the Earth. Life in the hydrosphere extends much deeper and can be found at the deepest depths of the ocean (10.911 m in the Mariana Trench) but there, as in the caves, it depends on the production of organic matter at the surface of the water system due to darkness. It can be said that life in the atmosphere extends from the surface of the land upwards only to the height of the highest trees. Many species that can fly (insects, birds) can rise significantly higher than the tallest trees, but this is only temporary "departure" from the biosphere because they inevitably must descend to the ground to perform most life functions (primarily for feeding and reproduction).

Therefore, there is in principle no life outside the biosphere. Thus, the concept of the "noosphere"" (or the "sphere of the mind") as an artificial environment created by man outside the biosphere was abandoned. The fact that people can live in artificial environments such as spaceships does not change this fact because all of life's needs there are met by using organic matter and gases transferred from the biosphere.

4 Production and decomposition of biomass

Biomass is constantly produced (P) and decomposed (D) in each ecosystem. At the level of the entire ecosystem, the two processes are in constant dynamic equilibrium (P≈D) (Figure 5). There are deviations in time, depending on the time of day (day or night), the seasons, and with respect to the micro-locality in the ecosystem (Figure 6).

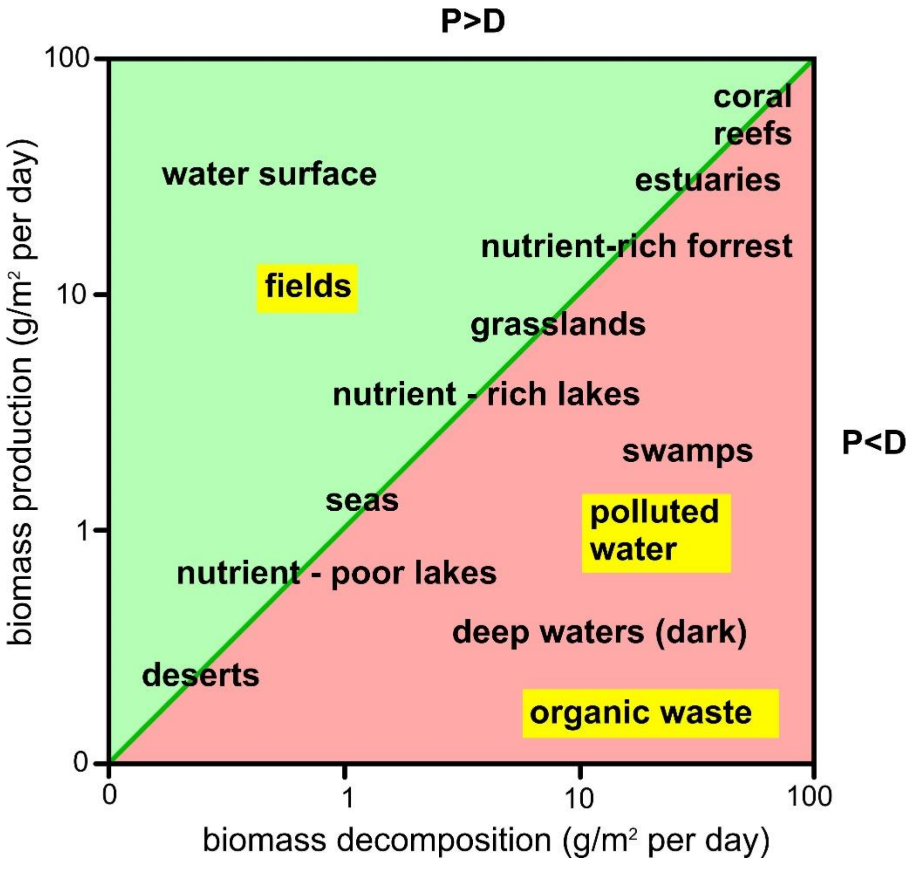


Figure 5. Hypothetical ecosystems (green square) with different productivity are orientationally arranged and named on the diagonal line. Above and below the diagonal line are examples of localities in which production is greater or lesser than decomposition (areas in yellow are under anthropogenic impact). Source: Authors

Figure 6. The river mouth (delta) of the river Po into the Adriatic Sea. Estuaries are characterized by great production and decomposition of biomass due to the nutrients from the river. Source: Authors

The amount of produced biomass in an area and over time primarily depends on the conditions of the non-living environment. Photosynthesis has the main role, followed by other steps of the food chain. It is important to understand that the overall size of the resulting biomass is not determined by factors that are in abundance, but precisely by the least present factor (Figure 7). The least present factor is called the constraining factor (“limiting factor”) and the described mechanism is called the “minimum rule“. This is the basic principle of functioning of every single organism and the entire ecosystem. The production results of all agricultural and animal production are based on the optimal satisfaction of constraining factors, i.e. adding what is missing.

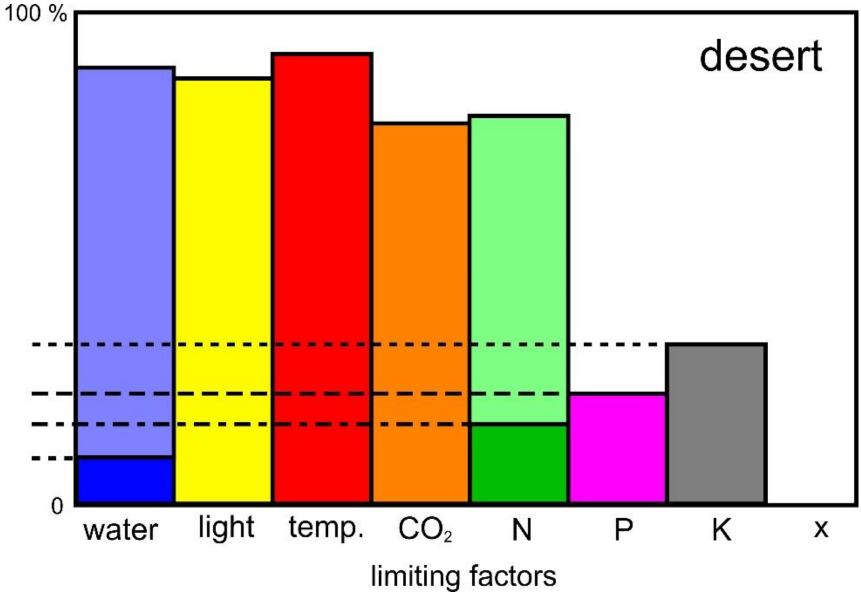


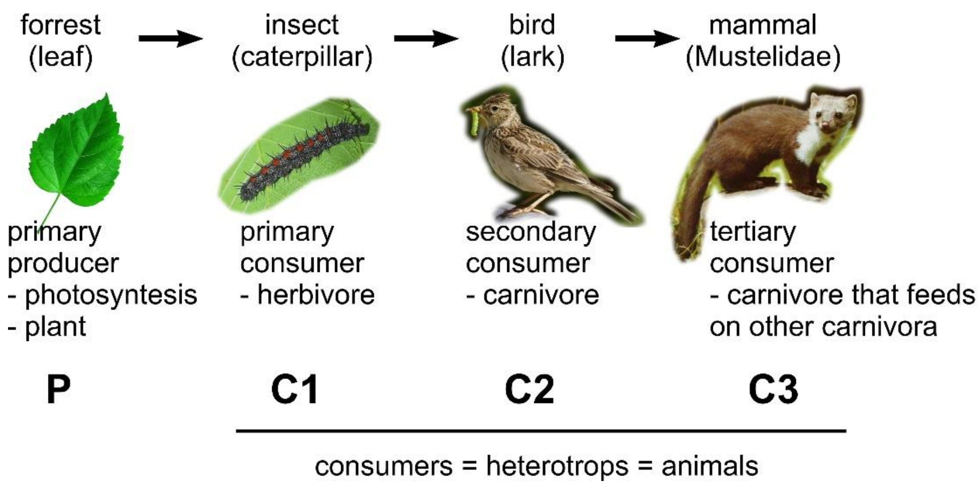
Figure 7. Constraining factors for biomass productivity. For example, if irrigation supplies plenty of water to a dry and warm ecosystem (such as the desert) where there is a lot of sunlight, heat and carbon dioxide, insufficient amounts of nitrogen, phosphorous, potassium or other substance may become the constraining factor for the total biomass produced. Source: Authors

5 Food chains and ecological pyramids

The food chain is a series of organisms through which matter circulates and energy flows (Figure 8). The links in the food chain:

- Producers (autotrophs) – green plants (P)
- Consumers (heterotrophs): primary consumers (plant-eaters or herbivores) (C1)
- Secondary consumers (primary carnivores or flesh-eaters) (C2)
- Tertiary consumers (secondary carnivores or carnivores that feed on other carnivores) (C3)
- Saprophytes (decomposers)

Figure 8. An example of a food chain. Source: Authors



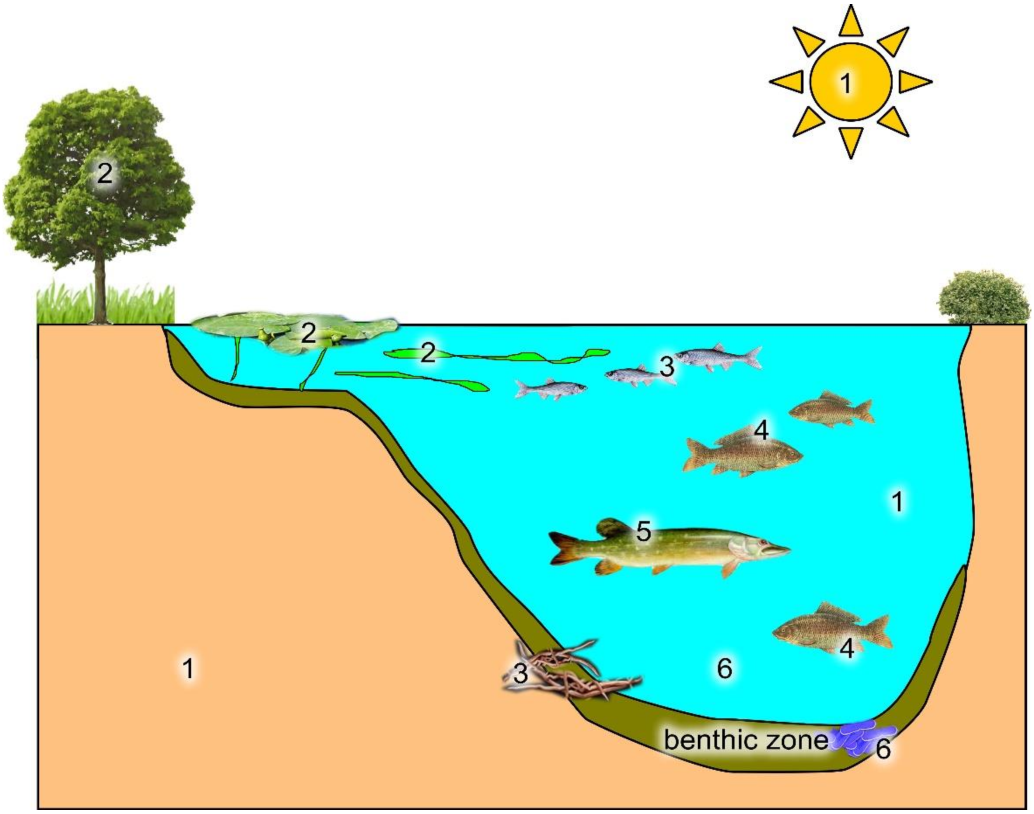


Figure 9. Lake as a model of an ecosystem. 1 – abiotic factors; 2 – primary producers; 3 – primary consumers; 4 – secondary consumers; 5 – tertiary consumers; 6 – decomposers (saprophytes): bacteria and fungi. Source: Authors

The comparison of biomass of certain categories of organisms in a water system (lake, Figure 9) and on land (grassland) shows that the current biomass for certain categories is equal, but also that several important groups have up to a hundred times more biomass on land (e.g. grass compared to phytoplankton). There is in total ten times more biomass on the grassland than in the lake in this example (Table 1). Here it is important to stress that processes in the lake occur up to 100 times faster than on land. For example, grass needs 100 days for the amount of biomass produced by phytoplankton in a day, so the total biomass turnover in water is approximately 10 times greater than on land. This indicates that the potential for food production in water (aquaculture) is approximately ten times greater than on land.

Table 1. Comparison of the amount of biomass in a lake and on grassland in a given moment. Given that the turnover is approximately 100 times faster in water, the total biomass production in water is approximately 10 times greater.

	Lake			Grassland		
	Group	N/m^2	g/m^2	Group	N/m^2	g/m^2
Producers	Phytoplankton	10^{10}	5.0	Grasses	10^3	500
Primary consumers	Zooplankton	10^7	0.5	Insects herbivores (Figure 10)	10^3	1.0
Secondary consumers	Insects, crustacean, gastropods	10^6	4.0	Spiders, carnivorous insects	10^6	4.0
Large consumers	Fish	1	15	Birds, mammals	0.01	0.3 - 15
Saprophages	Bacteria and fungi	10^{14}	10	Bacteria and fungi	10^{15}	100

Figure 10. Grasshopper as an example of a primary consumer. Source: Authors

Unidirectional food chains almost never exist in real ecosystems. The circulation of matter and flow of energy take place in more complex food webs in which each trophic level has several representatives of each individual category. The share of matter and/or energy at each trophic level is most often shown with "ecological pyramids" (Figures 11, 12 and 13). As a rule, values diminish in the direction of the chain of consumption (flow of matter and energy), starting at the wide base of the pyramid with primary producers (autotrophs) up to secondary carnivores at the top of the pyramid (heterotrophs). Pyramids showing organisms by their numbers (N), their biomass and their energy tied to the organic matter of that biomass are shown separately.

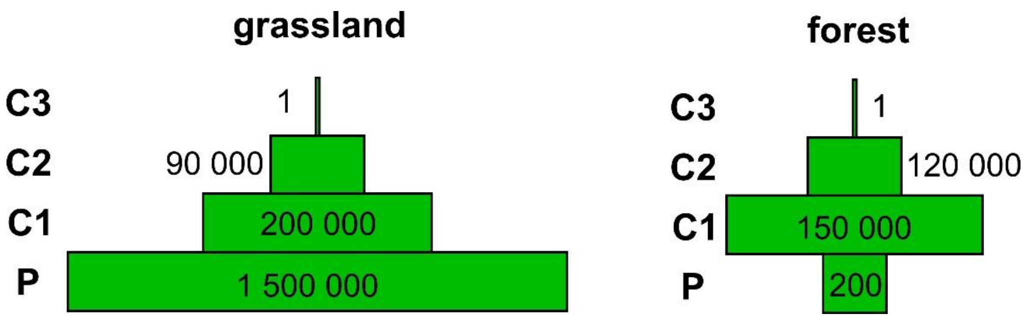


Figure 11. Numbers pyramid (no. of organisms per 0.1 ha). Grassland on the left and forest on the right. The number of organisms in the direction of the trophic chain generally decreases with the exception of large autotrophs such as trees in a forest. Source: Authors

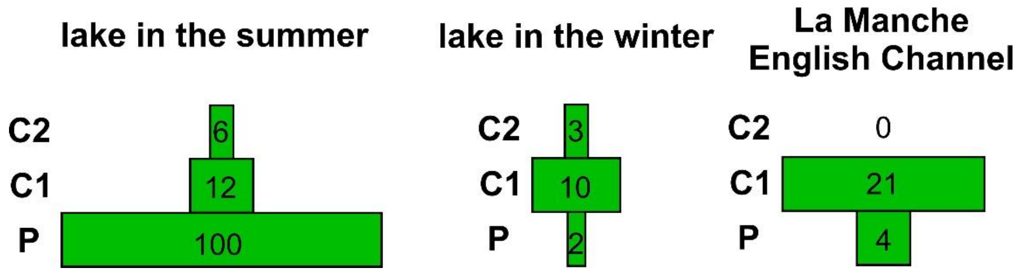


Figure 12. Biomass pyramid (g of dry matter /m^2). The biomass of the producers (autotrophs) is higher than the biomass of consumers (heterotrophs). The same lake in the winter when there are no phytoplankton (P) underneath the ice is shown as an exception. In the English Channel, the producer biomass production (P) is lower than the consumer biomass (C1), made possible by the Gulf Stream bringing in phytoplankton from distant warmer areas. Source: Authors

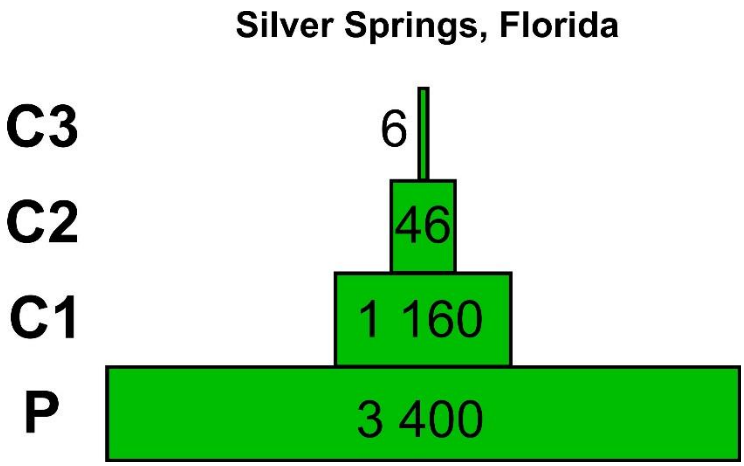


Figure 13. Energy pyramid (KJ/m^2). Energy is lost at every following trophic level as heat in accordance with the second law of thermodynamics (loss due to entropy). Source: Authors

The fact that the turnover of matter at each trophic level leads to great losses in biomass and energy as heat should be applied in human diet through the strategy of shortening the chain, i.e. using biomass closer to the base of the food pyramid. The optimum solution is to eat autotrophs (plants) and avoid those heterotrophs that are at the top of the pyramid (carnivores that feed on other carnivores).

Energy enters each system through sunlight which enables photosynthesis (Figure 14), but certain amounts of energy trapped in organic matter enter from neighbouring ecosystems, whether by their own movement or brought in by wind or water. Equal amounts of organic matter also leave the system in the same way, but the main output of energy is heat dissipation. Thermal energy is lost in each trophic step and part of the organic matter of each step is decomposed by decomposers (saprophytes) or it leaves the ecosystem directly. All of this leads to a reduction in biomass and remaining energy as you move up the ecological pyramid (Figure 15).

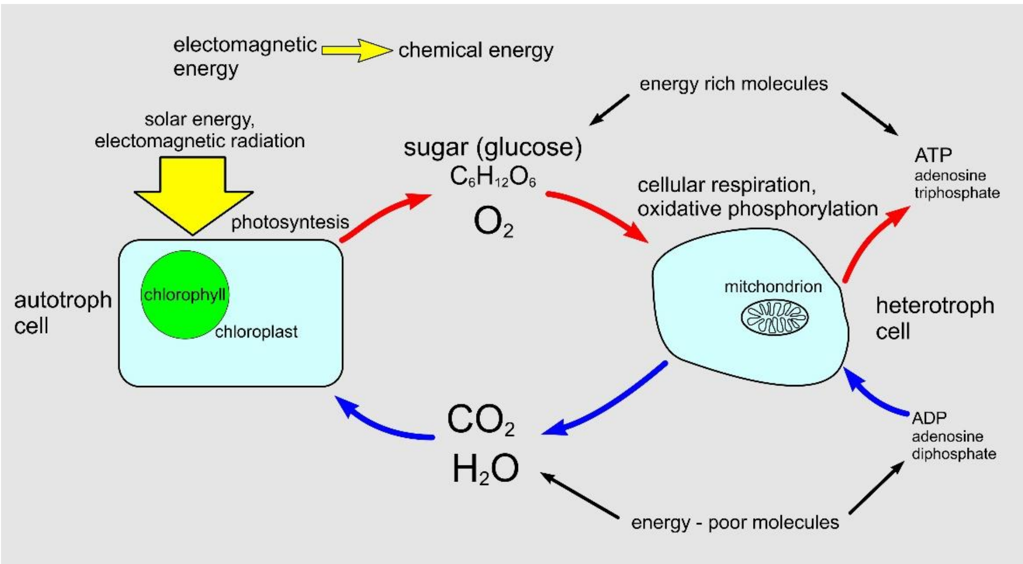


Figure 14. Transfer and transformation of energy in living organisms. Source: Authors

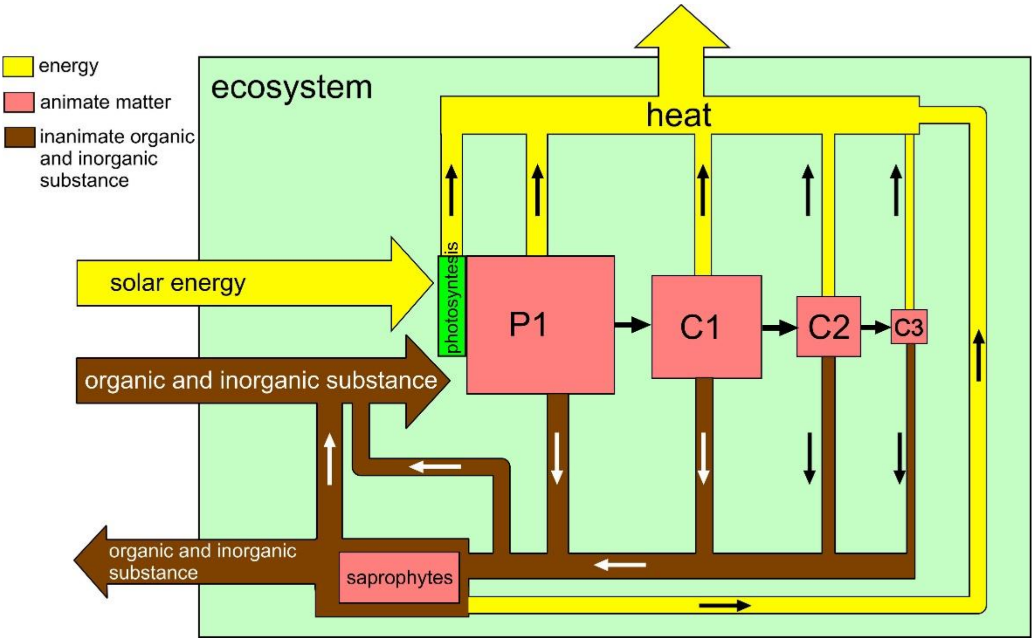


Figure 15. Energy flow and circulation of matter in an ecosystem. Source: Authors

6 Division and overview of ecological factors

Continuous circulation of matter and energy in an ecosystem is regulated by factors from the non-living (abiotic factors) and living world (biotic factors) (Table 2).

Abiotic factors include:

- **All inorganic matter**, i.e. any elements or compounds that exist or occur without the intervention of living organisms or that existed prior to the emergence of life on planet Earth
- **Organic matter found outside of living organisms** such as proteins, fats (lipids), hydrocarbons (carbohydrates) and nucleic acids (DNA and RNA), which are fewer in numbers and environmentally less important when outside living organisms
- **Physical factors** that directly determine the climate regime through parameters such as temperature, light, pressure and wind

Biotic factors include all living organisms which also represent the total biomass (the mass of all living organisms) of planet Earth. Given their ecological role, they are divided in the following way:

- **Producers** (autotrophs), green plants that produce organic matter from inorganic matter through photosynthesis (Figure 14) and thus directly turn inanimate matter into living organisms
- **Biophagous heterotrophs** that feed on living organisms. Those are macro-consumers that feed on plants (C1), the flesh of herbivores (C2) or the flesh of carnivores (C3)
- **Saprophagous heterotrophs** that feed on and decompose organic matter into inorganic matter. Those are micro-consumers amongst which dominate bacteria and fungi (Figure 16).

Table 2. Division of ecological factors into abiotic and biotic (matter and energy constantly circulate between those two groups of ecological factors)

ECOLOGICAL FACTORS	
ABIOTIC	BIOTIC
Inorganic matter C, N, CO_2, H_20	**Producers (autotrophs)** Green plants
Organic matter proteins, sugars (hydrocarbons), lipids	**Macroconsumers (biophagousheterotrophs)** They feed on living organisms of the first, second and third order
Climactic (physical) factors temperature, light, pressure, rainfall...	**Microconsumers (saprophagous heterotrophs)** They feed on organic matter (bacteria, fungi)
	BIOMASS

Figure 16. Decomposition of a bear by saprophytic bacteria. Source: Authors

6.1 Abiotic factors

The effect of many abiotic factors can be observed as part of the process of geochemical cycles of minerals (Figure 17).

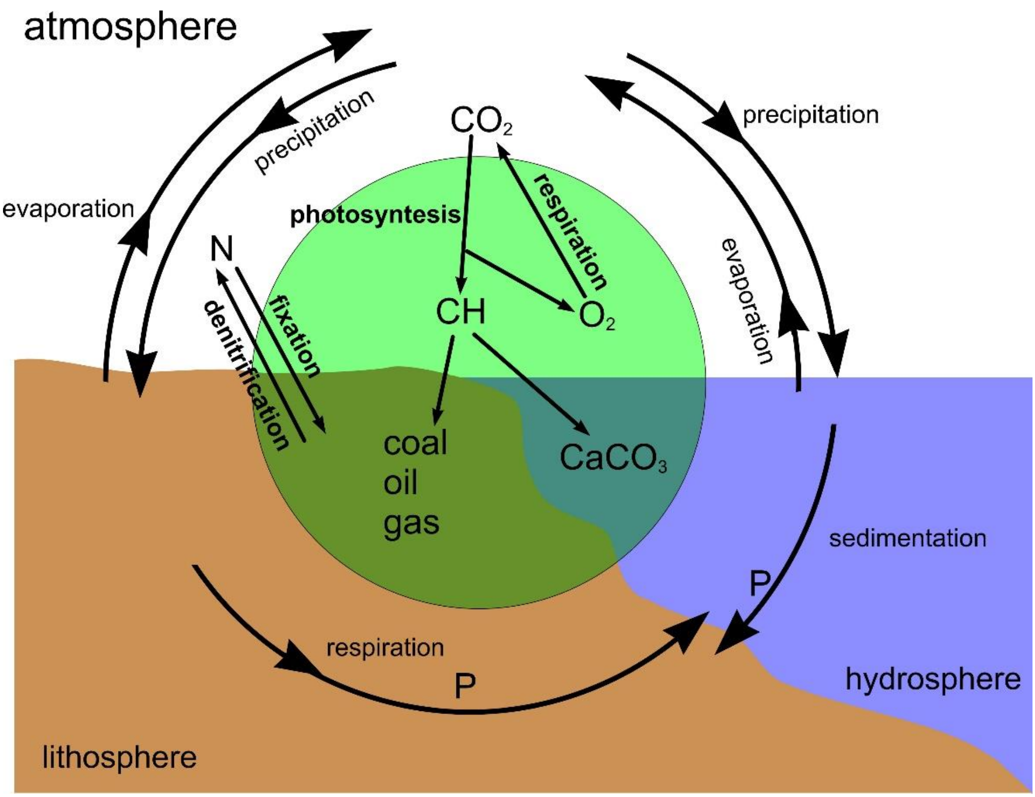


Figure 17. Overview of the entry of carbon, oxygen and hydrogen into the biosphere and their exit, i.e. the formation (photosynthesis) and decomposition (respiration) of hydrocarbon, water and carbon dioxide, as well as nitrogen and phosphorus pathways. Source: Authors

6.1.1 Carbon, oxygen, hydrogen

Carbon is present in the atmosphere as an inorganic compound with oxygen (CO_2) which combines with hydrogen in the process of photosynthesis and transforms into organic matter (hydrocarbons or sugars) with the simultaneous release of oxygen molecules (O_2). Through cell respiration (oxidation), heterotrophs release energy from hydrocarbons, wherein oxygen is consumed, and water (H_2O) and carbon dioxide (CO_2) are created. Part of unused hydrocarbons may be deposited in the form of fossil fuels (coal, oil and gas) or carbon can bind into calcium carbonate ($CaCO_2$), which are mainly sediments of shells and skeletons of marine organisms.

6.1.2 Nitrogen

Nitrogen is present in the atmosphere as gas with nearly 4/5 of its volume (78%) in the form of N_2. Despite its abundance in inorganic form, all living organisms invest continuous effort to reach organic nitrogen necessary for the formation of amino acids, proteins and nucleic acids. The only ecologically significant and natural way of binding (fixing) atmospheric nitrogen is by nitrifying bacterial species (Figure 18). Cyanobacteria are the most important bacteria for fixing atmospheric nitrogen in marine ecosystems, while the most important bacteria in terrestrial ecosystems are bacteria of the genus Rhizobium, and to a lesser extent other genera of bacteria, e.g. the terrestrial bacteria of the genus *Azobacter*. Those bacteria are the only organisms that can synthesize the enzyme nitrogenase which binds nitrogen with hydrogen into ammonium ion (NH_4+), i.e. the form plants can use for the formation of their amino acids and then proteins. Animals receive nitrogen in organic form by consuming plants. An important place in nature where bacteria of the genus *Rhizobium* can live are nodules on the root branches of legumes (clover) and this is where the process on which life on Earth depends takes place. Man found a way to use high temperature achieved by burning large amounts of fossil fuels (gas or oil) to artificially bind nitrogen with hydrogen and form urea through ammonia, which is an essential component of fertilizers. Organic nitrogen which animals obtained by consuming plants (or flesh for carnivores) is returned to nature through excretion (urine or uric acid excretion) or through decomposition of their bodies after death to ammonia (NH_3). This process is called “ammonification”. Ammonia is then decomposed by bacteria of the genus *Nitromonas* to nitrate (NO_3) and nitrite (NO_2) in a process called „nitrification”. At the same time, plants are trying to bind those organic forms of nitrogen for their needs and keep them within the biosphere. In the process of bacterial denitrification, nitrogen is separated from oxygen and is released into the atmosphere as liberated inorganic nitrogen (N_2) where it again represents inorganic matter (Figure 19).

Figure 18. Legume root nodules where bacteria of the genus Rhizobium live. Source: Authors

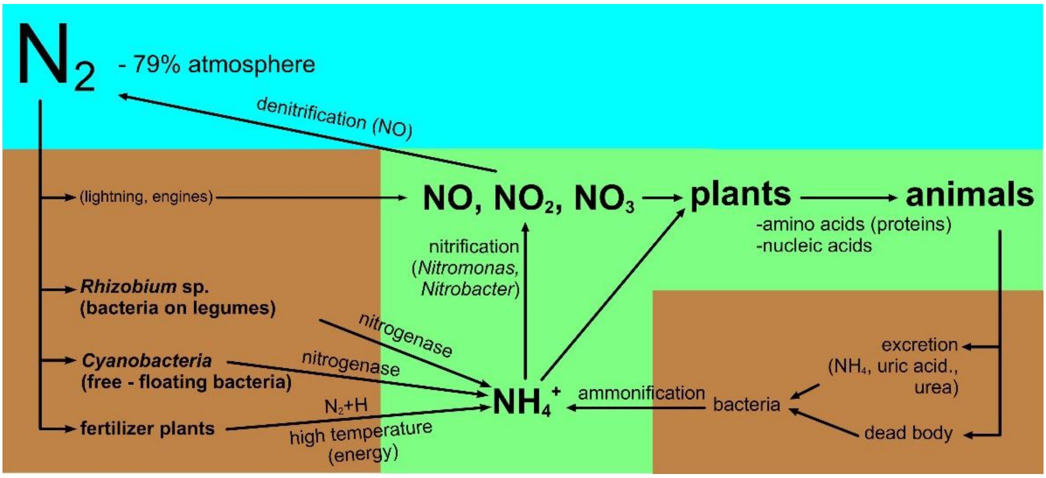


Figure 19. Schematic representation of the nitrogen cycle. Source: Authors

6.1.3 Phosphorus

Phosphorus moves from the lithosphere to hydrosphere through runoff because it is water soluble. There it embeds into organisms and in excess stimulates eutrophication of aquatic ecosystems which also manifests in the proliferation of algae growth. At the same time, there is a constant need for phosphorus on land and as such, it is one of the major limiting factors for biomass production.

6.1.4 Light

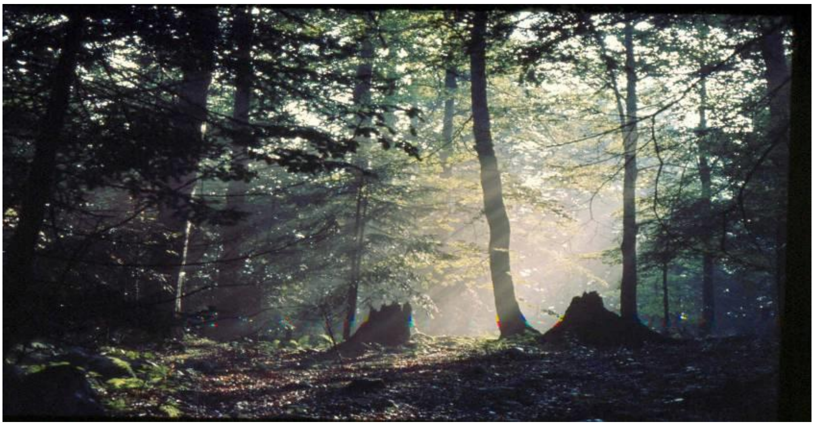


Figure 20. The visible part of the spectrum of solar radiation leads to photosynthesis on the green parts of plants. Source: Authors

Light comes from the visible part of solar radiation (Figure 20). Days and nights alternate due to the Earth's rotation, so light is a "primarily periodic abiotic factor". Due to the tilt of the Earth's rotational axis towards the Sun, the length of days and nights changes during the year. Likewise, due to the titled rotational axis of the Earth, different parts of the planet are tilted differently towards the Sun during its journey (orbit) around the Sun and this leads to the occurrence of different seasons.

Light energy (in the form of photons) has immediate effect on autotrophs and leads to photosynthesis - the most important biological process on Earth. In addition to the previously described process of atmospheric nitrogen fixation with the enzyme nitrogenase, photosynthesis is another important natural process for life on Earth. Less than 2% of the Sun's rays hitting the Earth reaches the green parts of the plants and is used in photosynthesis, and the majority of the process (approx. 90%) occurs in the sea.

Light energy is important for heterotrophs because it provides them with food through autotrophs, even those living in permanent darkness. In addition to that, light indirectly affects the life of heterotrophs, impacting various life phenomena. Here are a few examples:

Bird migration – birds select the starting day of migration south from our region in autumn, based on the length of day which quickly shortens at that time of year. They leave the place where they spent the summer and raised a new generation of birds while there is still enough food and the temperature is still not too low, but the shortening of days announces the upcoming change.

Egg-laying – the pond snail (*Limnea sp.*) starts laying eggs in the spring when the day starts to last 13.5 hours, 1.5 hours longer than the night. Such egg-laying may be induced with a simple experiment, by extending the length of day for snails to more than 13.5 hours, e.g. during winter.

Trout spawning – some edible species of trout spawn 90 days after the longest day, around September 20. In an artificial environment, the longest day can be simulated in March by artificial lighting and the day can then be shortened to cause spawning in June.

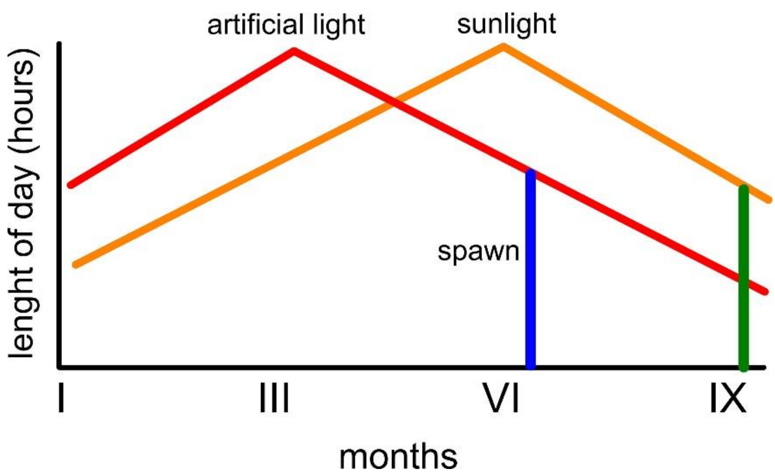


Figure 21. An artificial regime with the longest day in March (red line) can be used to induce spawning in June (blue vertical line) instead of natural spawning in September (green vertical line). Source: Authors

Crab moulting – crab occasionally have to change their chitinous exoskeleton in order to grow. The shedding of the exoskeleton is induced by neurosecretory glands. However, if we keep the crab in permanent darkness, the neurosecretion is constant and the crab continues moulting without growing in the meantime.

Sexual activity – the mating of deer in autumn, wolves in the winter or polecats in the spring. The strategy for reproduction success for each species must include the targeted time of offspring birth when climactic conditions are most favourable. With plenty of exceptions, the most favourable time for offspring is spring, when winter temperatures subside and plant food becomes abundant. It all starts by choosing the time of mating, a choice based on the duration of days and nights. Deer mating ("deer roaring") occurs in September when days get shorter. It is interesting that roe deer embryos in fertilized females (does) remain in the developmental blastocyst stage (delayed implantation) until mid-winter when embryonic development proceeds apace in order for birth to occur in April or May. In addition to birth occurring at optimum time, this process also helps deer avoid the efforts of mating in winter when males, who fertilize several females (harem) and fight other males, would have a hard time compensating for the loss of energy and surviving the winter. On the other hand, winter is the most favourable time for wolves to obtain food so they also mate in winter in order to have offspring in two months' time, in early spring. In polecats, pregnancy lasts only a month so they can both mate and have offspring in the spring.

Changing the colour of fur and feathers – hare, weasel, snowy owl (Figure 22). It is an advantage for some species of animals to have their body cover (fur or feathers) white in winter and to be less noticeable (mimicry), whether they are predators or potential victims (prey). The growth of white hair or feathers in autumn is prompted by the shortening of days. When days start to lengthen in spring, the cover again takes the colours that least disclose the position of the animal. Therefore, animals do not wait for the first snow to "turn white". However, snow can come late, causing the white animals to stand out in their environment for part of the winter.

Figure 22. The feathers of the snowy owl are almost entirely white in the winter (left) and turn darker in the summer (right). Source: Authors

Zooplankton photo-kinesis – zooplankton travel to the water surface at night. Unlike phytoplankton which need light energy for photosynthesis and which are attracted to the surface by daylight, zooplankton travel to the surface at night in search of food and hide from the light in the deeper layers during the day. Some species of zooplankton glow at night (bioluminescence) near the water surface.

The effect of light and darkness on overall activity. According to the pattern of activity during 24 hours, animal species can be divided into: (I) diurnal (active during the night), (II) nocturnal (active at night), (III) indifferent (equally active during the day and at night) and (IV) crepuscular (active during twilight). Given that twilight occurs in the morning and evening, those species have two activity peaks which is why we also call them bimodal or crepuscular (Table 3, Figure 23 and 24).

Table 3. Examples of some animal species with respect to their activity cycle during 24 hours

Type of activity	Example of species	Daytime activity	Night-time activity
Diurnal	domestic pig	88%	12%
	European ground squirrel (souslik)	98%	2%
Nocturnal	frog	15%	85%
	vole	16%	84%
	wood mouse	21%	79%
Indifferent	rodent (*Lagurus)*	40%	60%
	insect (*Basalus)*	54%	46%

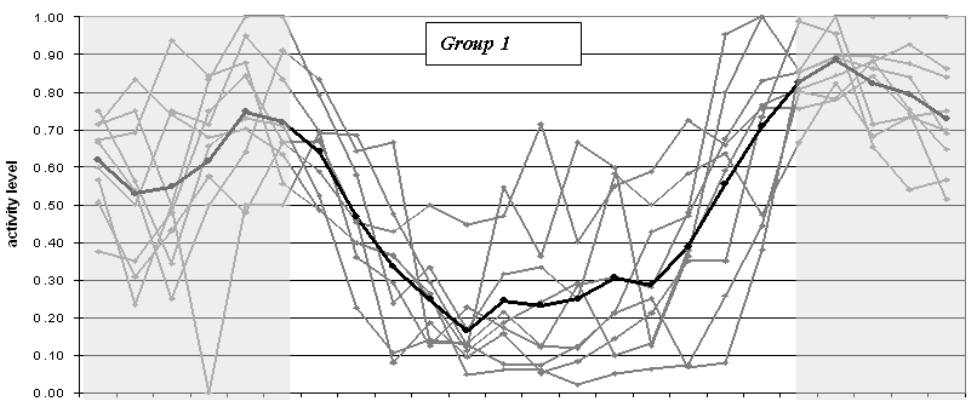


Figure 23. Activity patterns of bears tracked with the use of telemetry. Thin lines represent individual animals and the thicker line represents the mean value. Two activity peaks stand out, at dawn and at dusk. It is clear that the overall activity is greater at night than during the day, so bears are mostly nocturnal animals with a pronounced bimodal (crepuscular) rhythm. Source: Kaczensky, Petra; Huber, Đuro; Knauer, Felix; Roth, Hans; Wagner, Alex; Kusak, Josip.(2006) Activity patterns of brown bears in Slovenia and Croatia. Journal of Zoology 269:474-485.

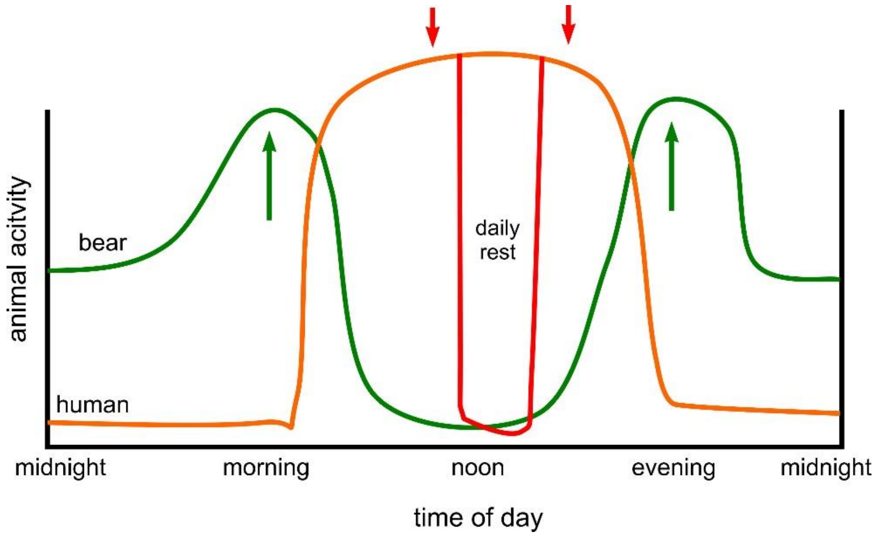


Figure 24. Schematic representation of two examples of the bimodal activity rhythm. The green line indicates bears that are mostly nocturnal with crepuscular peaks (at twilight). The orange line indicates a hypothetical man active during the day (diurnal) that becomes bimodal on those days when he takes an afternoon break. Source: Authors

6.1.5 Heat

Thermal radiation of the Sun is represented by 60% of rays and it is located on the infrared (IR) part of the spectrum of energy radiation with longer wavelengths in the form of photons (Figure 25). Earth receives almost all thermal energy essential for ecological processes from the Sun. The Earth's land surface, oceans and atmosphere absorb the thermal radiation of the Sun and reach a certain temperature. The hot core of the Earth manifests on the surface only as localised hot springs that support distinctive life forms, or as points of molten rock (lava) eruption which, in turn, destroys any form of life.

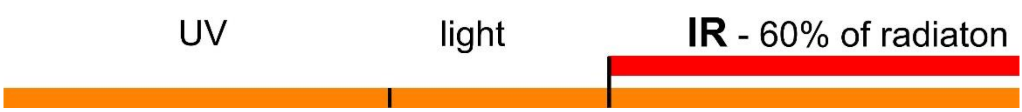


Figure 25. Position of infrared (IR) radiation in the solar spectrum. Source: Authors

Temperatures on the Earth's surface may vary significantly depending on the proximity of the equator or the poles, and with respect to elevation. The lowest temperatures have been measured in Antarctica (-88 °C) and the highest in tropical deserts (+56 °C). Springs of hot water (hot springs) may have temperatures near the boiling point (+90 °C).

The temperature range within their ecosystem is important for living organisms. In continental deserts, that range may be 40 °C in 24 hours. In contrast, in tropical moist forests temperatures may vary a very small range of only approximately 6 °C throughout the year. Naturally, the organisms' adaptations to such different temperature conditions are very particular. It is believed that the acceptable range for life as we know it on Earth is from 0 to 40 °C. Some of the species are capable of surviving certain periods outside that range, such as long winters, because of previously procured food supply or body fat. However, the cold period must be followed by more favourable weather when the growing season and the production of new organic matter start again.

Exceptions are always interesting. One species of fish from the group of cods (*Boreogadus sp*.) can live under the sea ice at a temperature of –2 °C due to cellular glycoproteins that prevent freezing (act as "antifreeze"). Interesting species at the other end of the temperature range are blue-green algae in hot springs in Yellowstone National Park that can withstand +86 °C.

It is important for every living organism to be able to regulate its own body temperature, i.e. to ensure thermoregulation. Most species are classified as (a) poikilothermic (ectothermic) organisms (all plants and 98% of animal species), and only the remaining 2% are (b) homeothermic (endothermic), and those are only birds and mammals.

Poikilothermic species allow for their body temperature to change to some extent under the influence of ambient temperature. However, they too use a number of opportunities to keep their body temperature as close to optimum as possible. Thus, (a) they select a microhabitat with favourable temperature (at sunrise, a lizard will expose itself to thermal radiation and later retreat to the shade), (b) they use their body colour to absorb or reflect thermal radiation (dark colours retain more heat rays), (c) with the shape of their body they can temporarily increase their surface (the back or neck folds of a lizard), (d) by physically waving their wings they aerate their microhabitats (bees in a beehive) or (e) they can enter the state of hibernation (lethargy) in winter, or aestivation in the summer.

Homeothermic species maintain a constant body temperature within a very narrow range, usually within one degree Celsius. They achieve this by regulating the bio-oxidation process in the body cell metabolism with simultaneous major energy consumption. It is estimated that homeothermic species spend approximately 90% of consumed energy just to maintain constant body temperature. This is why they have the ability to keep an almost unchanged level of activity in an environment with fluctuating temperatures; e.g. moving at night when it is colder. However, when temperature fluctuations (extremes) become too high, or when food needed for energy becomes unavailable, some animals may go into hibernation (winter sleep) in which they reduce metabolic functions and exceptionally allow their body temperature to drop below the thresholds for active periods, but always stay sufficiently above the freezing point. Besides that, homeothermic species also try to reduce energy expenditures to maintaining their body temperature. All cells in a body generate heat through metabolism and the number of cells in a body depends on the volume (mass) of the animal. Therefore, the amount of produced heat in the body depends on the volume of the animal. All bodies, including animal bodies, lose heat through the surface area of the body because this is the surface between the warm body and the often colder environment. The amount of heat in the body depends on the produced and released heat. The former depends on the volume (mass) of the body and the latter on its surface, which is why the ratio between the volume and the mass of an organism is important (Figure 26). In order to minimize heat loss, animals in colder areas have a somewhat smaller surface area of the body relative to volume compared to animals that live in warmer habitats. **Bergmann's rule** states that larger animals have a somewhat smaller surface area relative to the body's volume. This is the reason why animals in colder climates are larger than animals in warmer climates. For example, bottlenose dolphins in northern seas are larger than bottlenose dolphins in the Mediterranean Sea, and wolves in the polar region are larger than wolves from the temperate zone or subtropical zone. **Allen's rule** states that animals whose body shape resembles a ball have a somewhat smaller surface area relative to their volume. Thus, animals in colder regions have smaller protrusions from the trunk of the body, so their legs, snouts and ears are very small and short, and their shape resembles a ball (Figures 27 and 28). In contrast, animals in warmer climates have long legs, big ears, pointy snouts, etc.

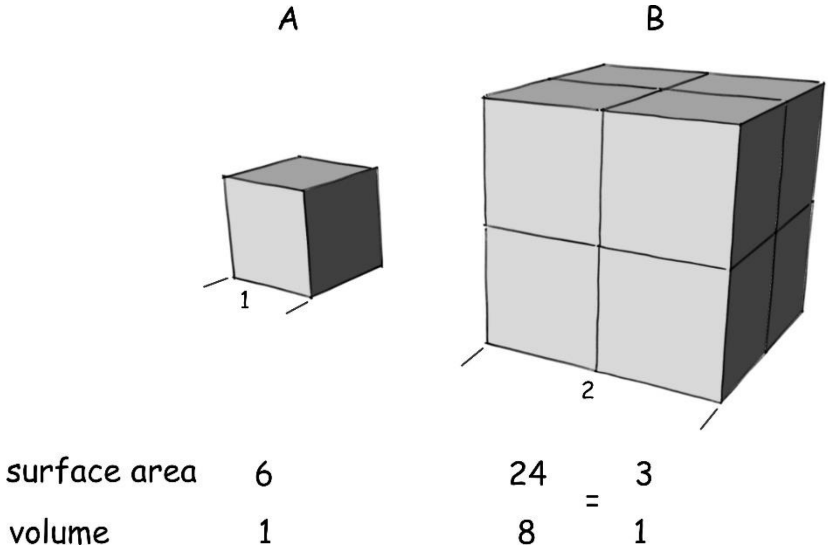


Figure 26. Bergmann's rule states that larger animals have a relatively smaller surface area relative to their volume. A body of the same shape but twice as big has relatively half the surface of the body relative to its volume. Source: Authors

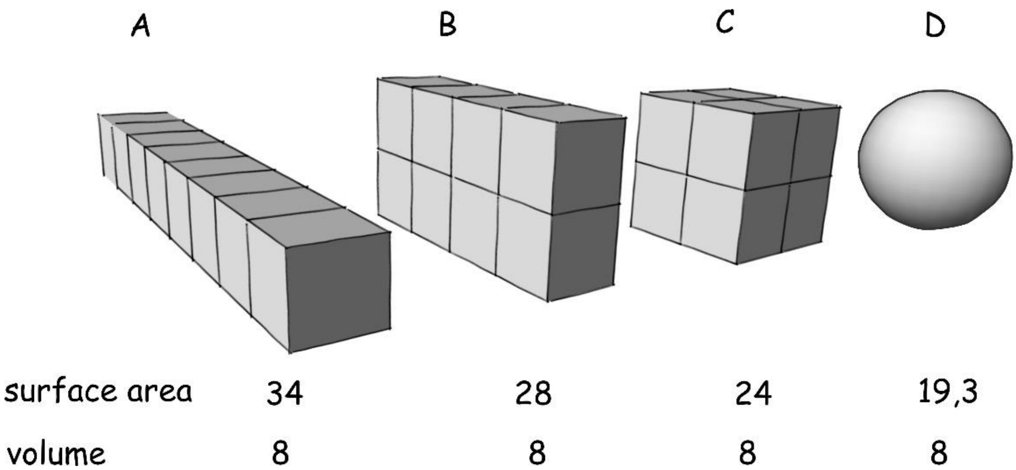


Figure 27. Allen's rule states that animals whose shape resembles the shape of a ball have a relatively smaller surface of the body relative to its volume. The figure shows different body shapes with the same volume (8 cubes) but with different surface areas. A ball is a geometrical object with the smallest surface area relative to volume. Source: Authors

Figure 28. The fennec fox (Vulpes zerda) (left) has big ears, a long snout, long legs and a long tail which increase its body surface, while the polar fox (Alopex lagopus) (right) has small ears, a short snout and short legs and tail which, according to Allen's rule, reduce its body surface and heat loss. Source: Authors

When it comes to poikilothermic animal species, the **Van't Hoff's rule** (Q10) applies, stating that all biological processes are accelerated two to three times with a temperature increase of approximately 10 °C, and that they are equally decelerated with a decrease in temperature. So for example, *Paramecia* will split once in 24 hours at 15 °C and twice in 24 hours at 20 °C. The embryonic development of the Atlantic herring takes 45 days at 0.5 °C and only seven days at 16 °C. It is clear that these organisms need certain heat to perform certain metabolic and life functions. This was the origin of the **thermal constant** concept which shows the total amount of thermal energy needed for the development of an organism, calculated as the sum of daily temperatures in a given period. For example, the development of an insect from an egg to an adult requires: (a) 77 Celsius degree-days for embryonic development in the egg, (b) 582 Celsius degree-days for the growth of a caterpillar, (c) 79 Celsius degree-days for the prepupa stage and (d) 262 Celsius degree-days for metamorphosis in a pupa. This is a total of 1000 Celsius degree-days of thermal energy. Naturally, within the acceptable limits of ecological amplitude. As for eurythermal animal species, an observed organism can accumulate the required 1000 Celsius degree-days, e.g. in 100 days with an average temperature of 10 °C or in 50 days with an average temperature of 20 °C. Depending on that, the number of generations an insect can produce in a season may range between one and three or four generations.

The temperature is distributed differently in water than in the atmosphere, especially in standing waters. There is no uniform mixing of water in the same way that the air mixes, proportionally and quickly. Instead, separate layers of different temperatures form below each other in the water so we talk about vertical layering or vertical stratification (Figure 29). For example, the surface layer of standing waters gets heated in the summer by the Sun's heat rays, and the warm surface layer is called an epilimnion. The depth of the epilimnion may vary from several meters to several tens of meters. Below is a thinner layer called metalimnion in which temperature drops rapidly, a phenomena called a temperature drop or a thermocline. The layer below that extends all the way to the bottom and it is called a hypolimnion. There, the water temperature is constant at approx. 4 °C, wherein the water is most dense. Despite stable temperature layers, there is a constant vertical circulation of dissolved gases and minerals which increases when the surface layer begins to cool. Oxygen and organic matter created at the surface travel down, while carbon dioxide and inorganic matter travel up. Those movements enable life in all layers of aquatic ecosystems. The situation changes when the water surface freezes in winter. The water is the same temperature under the ice (4 °C) all the way to the bottom, also known as isothermy. At that point, the described circulation of gases and other matter stops and conditions for the survival of living organisms become difficult.

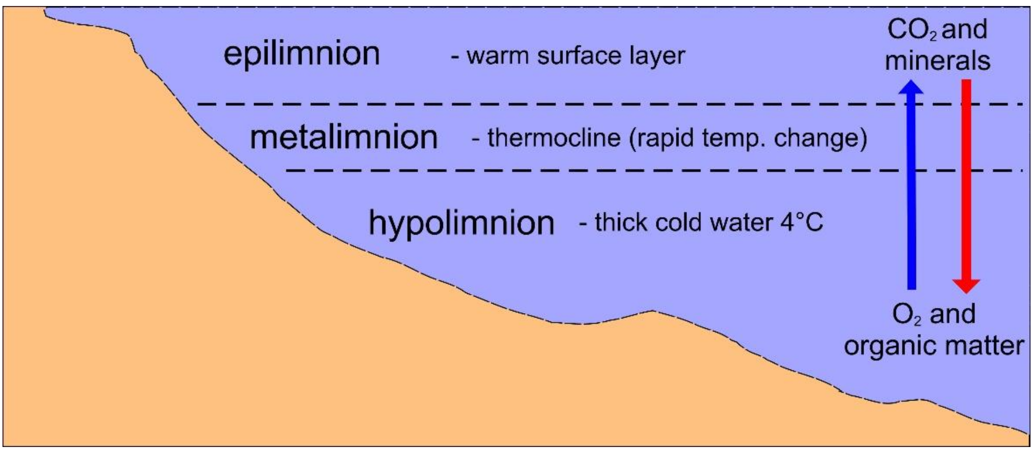


Figure 29. Vertical stratification of temperature layers in an aquatic ecosystem. Source: Authors

A common problem today is thermal pollution in parts of certain aquatic systems, i.e. "heat pollution" from various sources. The most common pollutant is hot water from the cooling systems of thermal power plants or other industrial facilities. The effects of the water temperature increase are in accordance with the Van't Hoff's rule – the metabolic processes of all poikilothermic organisms are accelerated, leading to an increase in their volume and number. At the same time, less oxygen dissolves in warm water. However, due to the increase in heterotrophs populating the water, more oxygen is required. This can eventually lead to mass deaths from suffocation. It is believed that temperatures from 30 °C to 35 °C are lethal for most species of fish, as well as any increase in water temperature over 3 to 5 °C.

6.1.6 Water

Water has the highest percentage in bodies of all living organisms. Thus, the body of a mammal (e.g., a human) consists of 2/3 (67%) of water and the "wettest" species, such as jellyfish, consist of 98% water (Figure 30). Even a seemingly dry animal, such as a moth, has 42% water. All the water in the body is in constant motion and thus maintains all cellular functions. At the same time, each living thing must constantly introduce fresh water from the environment into its body and excrete it from the body in different ways.

Figure 30. Jellyfish are approximately 98% water. Source: Authors

With regard to water intake needs, all terrestrial species can be divided into three categories:

Mesophilic species – these include most species; they need a medium amount of water for life, e.g. most land animals.

Hygrophilous species – these can only live in wetlands. They have not developed mechanisms for water conservation so they excrete much diluted urine and lose a substantial portion of water through moist skin or breathing (Figure 31).

Figure 31. Frog as an example of a hygrophilous species. Source: Authors

Xerophilic species – they live in arid areas. They have morphologically and physiologically adapted in order to conserve water, so they excrete concentrated urine, they do not have sweat glands and arthropods are, for example, protected against water loss by chitin.

For animal species living in water, the key life strategy is osmoregulation, i.e. maintaining optimum concentrations of ions and salts in the body. According to the laws of physics on the diffusion of liquids through a semipermeable membrane (every cell membrane is semipermeable), the water spontaneously (passively) passes from a medium with lower osmotic concentration (hypotonic) to a medium with higher osmotic concentration (hypertonic). The hypertonic medium is diluted and its osmotic concentration is reduced. When concentrations on both sides equalize, isotonicity is achieved and the passive flow of water is stopped. Aquatic animals are divided into two groups according to the way they regulate osmotic pressure:

Poikilosmotic animals – those are all marine invertebrates and cartilaginous fishes. The concentration of their bodily fluids is variable, i.e. it is equal to the osmotic concentration of water, so they achieve isotonicity with the surrounding seawater in which they live. This is due to sodium chloride (salt) dissolved in seawater.

Homeosmotic animals – all freshwater animals and marine bony fishes maintain constant osmotic pressure of their bodily fluids, above the osmotic pressure of fresh water in which they live, so they are hypertonic relative to the water that surrounds them. The hypotonic water around them constantly tries to enter their bodies by osmosis, so they have developed organ systems for expelling excess water (contractile vacuoles of protozoa, evolutionary forms of kidneys in metazoans - pronephros, mesonephros, metanephros - filter large amounts of diluted urine) and for preventing its entry (mucus, skin and scales). A delay in water expulsion would lead to swelling and rupture of individual cells and eventually the entire organism. Fighting against a hypotonic environment is an additional difficulty for sexual cells (gametes) and later for larvae outside the eggs. Eggs are protected by an amorphous mass that swells around them during spawning, and sperm must quickly reach the egg and penetrate it before they burst. Homeosmotic animals also include fish such as eel and salmon, which are euryhaline (euryvalent to different osmotic pressures) and which can also withstand sudden changes in osmotic pressure enabling them to migrate from seawater to fresh water and vice versa.

6.1.7 pH (hydrogen ion concentration)

In different habitats, the pH value of the medium of life can differ significantly. In principle, every kind of habitat is inhabited by organisms that have evolved to adapt to just such an environment and thus to those specific pH values. However, the pH value close to the neutral values suits most species; this value is around 7.0, which is the value of most fresh water. Acidic habitats may occur in peat-lands (pH 2.2 – 2.4) where there is a lot of organic matter. The sea can be slightly alkaline: up to 8.3 and around 7.5 in deep waters. The optimum pH value for most fish is from 7.2 to 8.6, and very few species tolerate pH under 7.0. Gastrointestinal parasites can tolerate relatively extreme concentrations of hydrogen ions. Some species of tapeworm can live in the stomach with pH 4.0 and others in the small intestine with pH 11.0.

Due to human influence, there are now frequent occurrences of precipitation known as "acid rain". Due to the emission of sulphur oxides and nitrogen oxides released by burning fossil fuels, sulphuric acid and nitric acid form in the atmosphere and through precipitation (rain, snow) reach the surface of the Earth with where they acidify water and soil in the root system of plants.

6.1.8 Pressure

All organisms on Earth are exposed to pressure which is the result of pressure from a column of air or water, depending on whether the organisms are terrestrial or aquatic. The column of air represents atmospheric pressure. It is lower at high altitudes, but it also changes everywhere depending on meteorological conditions. Sudden changes in altitude, for example in bird flight, require certain adaptations. People experience this during airplane flights or cable car rides. Significantly stronger pressure is caused by a column of water called hydrostatic pressure. Some species of fish and marine mammals can dive deep and return to surface, while for others such changes in pressure may be fatal. The swim bladder of many demersal fish will significantly increase and pop out of their mouths after they are suddenly pulled to the surface, due to the pressure drop. Underwater divers, regardless of the diving mode, need to constantly observe and take into account the changes in hydrostatic pressure.

6.2 Biotic factors

Ecological biotic factors are those affected by living organisms. They are described as characteristics of populations and the branch of ecology that explores them is called demecology. A population is defined as a summation of all organisms of the same species that live in a common area at the same time, and which are characterized by a limited exchange of organisms and genes with neighbouring populations of the same species. Here we will describe biotic factors classified into 10 groups.

6.2.1 Abundance (number, density, biomass) of organisms

The size of the population in a given unit of space (surface or volume) can be expressed as the number of individuals, as their biomass or as their density or abundance. This is one of the main initial parameters for almost every ecological study.

The most preferred manner of expressing abundance is in the form of an absolute number. This would require a total count which is virtually impossible in practice for wild animals in nature. Even states conduct human population censuses only once every ten years and the size of the population is estimated by modelling in the meantime. A somewhat simpler method is counting the total population in sample areas. If those areas are large enough and well chosen, the obtained numbers can be applied to the entire area (a process of extrapolation). Ecologists more often use relative indicators of abundance which can credibly determine population trends, with the correct application of methodology. In a given period, the trend can be stable, positive or negative. The resulting data may be sufficient for the successful management of a population without knowing its true size at any one time. The first step is to determine the population density index of the studied species. The index ranges from 1 to 5. Index “0” can be used if the species is not present, “1” can be used when a single individual is observed, and so on up to “5”, indicating that the habitat’s capacity has been reached. A clear procedure is needed in order to objectively determine the index, instead of determining it by subjective approximation. A common method is the transect method, i.e. counting occurrences of animals or their tracks (footprints, faeces, digging sites, bird nests or vocalisations) along a specific path or in a specific area. Observations can be made along a path with a specific (and always identical) length or from a specific location (e.g. a tree stand next to a grassland, lake or feeding area). An even more objective method is capturing the animals; after a successful capture, habitats, seasons and years are compared. This method can be supplemented with marking captured animals and releasing them. During the next capture in the same area, the number of recaptures of previously marked animals is recorded (Figure 32). The approximate total size of local population can be determined with the use of a simple Lincoln-Peterson index. Too much time should not pass between the two capture processes because some of the animals could be lost (natural death, emigration or hunting) and new ones could appear due to immigration or birth, individuals that have not been in the area during the first capturing, which is why they could not have been marked. Due to the probability of such cases, the index offers correction values (factors) to minimize errors. Today, computer technology offers numerous and complex models for similar procedures based on the “capture-mark-recapture” method.

Depending on the group of animals whose abundance is being determined, researchers use various trapping devices such as cages and other traps, nets, dredges or suction traps. Researchers also use non-invasive methods with which animals are only recorded in the appropriate manner, including the use of the thermal part of the radiation spectrum (infrared photography).

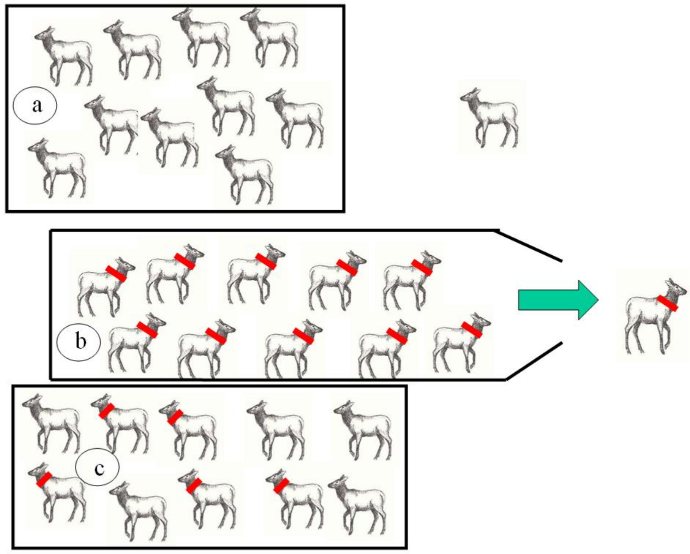


Figure 32. (a) Random capture in a wild population, e.g. N=10 animals, (b) all animals have been marked and released, (c) another 10 animals were captured during random recapture in a wild population, of which 50% were marked. This means that the entire population has approximately 20 individuals of that species. Source: Authors

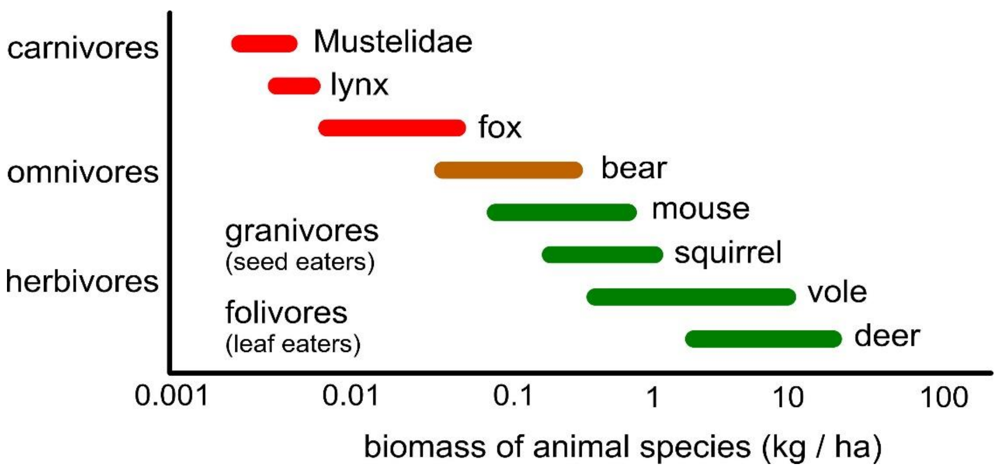


Figure 33. The biomass of animal species per unit of space exponentially decreases in the direction of the food chain. Even among herbivores, there are more of those that feed on grass and leaves than those that feed on seeds. Source: Authors

It should always be clear that abundance decreases with each trophic level (ecological pyramids) and that the differences are significant, but also natural and explicable (Figure 33).

The concepts of crude and ecological density of organisms should be distinguished. While crude density shows the average number of organisms per unit of total area assuming the even use of the entire area, ecological density shows the actual number of organisms in a particular used area, i.e. it accounts for the fact that some parts of the habitat are used less or not at all due to temporary or permanent lower quality or inaccessibility (Figure 34).

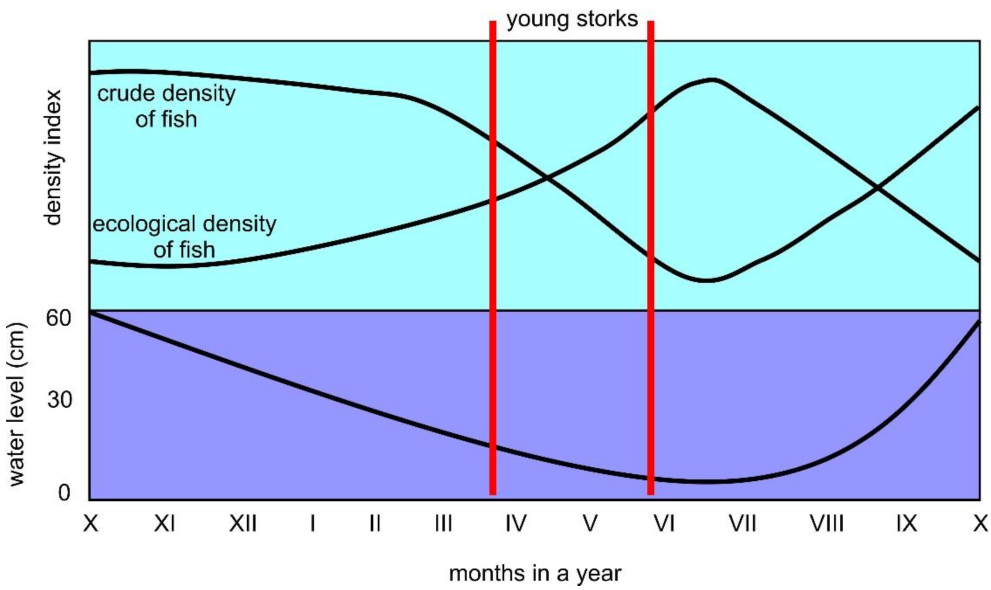


Figure 34. Ecological density of fish in a lake is multiplied manifold with a decrease in water level, even though the total number of fish and, thus, crude density decreases at that time. The figure indicates that storks bear offspring at the time when ecological density surpasses crude density, when it is the easiest for storks to obtain food for their offspring in the nest. Source: Authors

6.2.2 Spatial distribution (dominance, sociability and range)

The manner in which individuals of a certain species are distributed in an area in relation to members of other species and each other can be examined through categories of dominance, sociability and range.

6.2.2.1 Dominance

Dominance expresses the share of individuals of one species in a habitat in relation to the share of individuals of other species in the same area. It can be expressed as a percentage or the species can be ranked according to frequency. The most numerous species is called the dominant species and the entire community is usually named after it. This selection is most often based on the most common plants, therefore a forest with the most beech is called a beech forest. If two species are equally represented, they are called "co-dominant" species, e.g. the "beech-fir forest" dominant in the Dinara massif in Croatia. All other species in a habitat are called "accompanying" species. The ideal is to have a list of all present species from all taxonomic categories.

6.2.2.2 Sociability

The concept of sociability analyses the distribution of members of a single species in an area, and their use of that area. It shows us how much they tend to group or how much they avoid each other. There are three categories of this distribution: (I) even continuous, (II) uneven continuous and (III) discontinuous distribution (Figure 35).

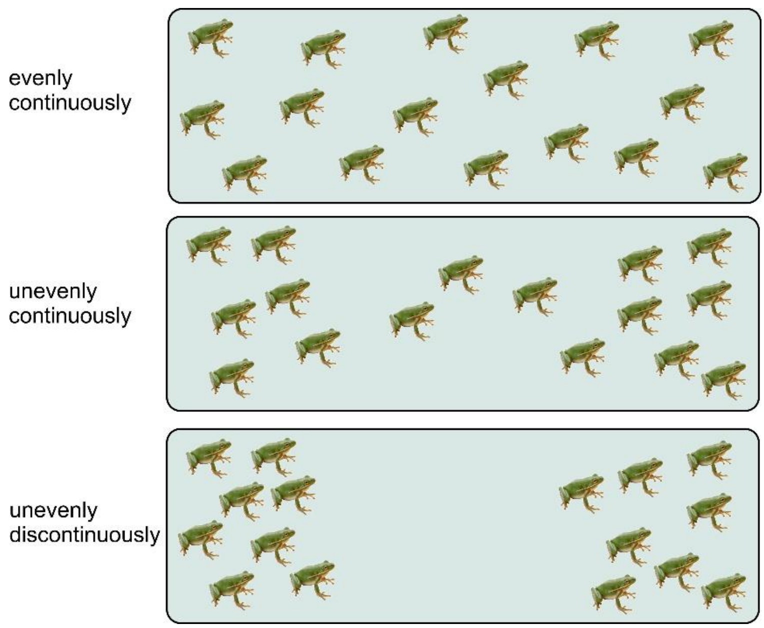


Figure 35. Three possibilities of intra-species distribution in a habitat. Source: Authors

The manner of distribution of a species in an area depends on the method of finding food, the mating strategy (monogamy, polygamy), offspring nurturing, and manner of alerting to danger or simply on their socialization.

6.2.2.3 Home range

Home range is defined as the area in which an individual or group of individuals of the same species meet all their needs. It can be a lifelong range or, according to species and situation, an annual, seasonal or day range.

Some species actively defend their range from other members of their species, which is then called territoriality. This can be an individual, e.g. the insect *Arax imperator,* whose male does not allow other males of its own species to enter the space 50 m above a part of a lake, or it can be a community, such as a pack of wolves (*Canis lupus*) (Figure 36). By defending their range, they secure their food sources and the conditions for reproduction. At the same time, this limits the growth of their own population, which is a nice example of population self-regulation. When an existing area no longer satisfies the needs of an individual or community, they can try to expand the area by conquering neighbouring areas (if the domicile individual or group is weak or if it disappeared), or new individuals created by reproduction must leave the territory. It is well-known that emigrant wolves ("dispersers") have difficulty finding and conquering new territories, as well as finding mating partners. It is believed that only approximately 10% of "dispersers" manage to survive a year after leaving the parental pack.

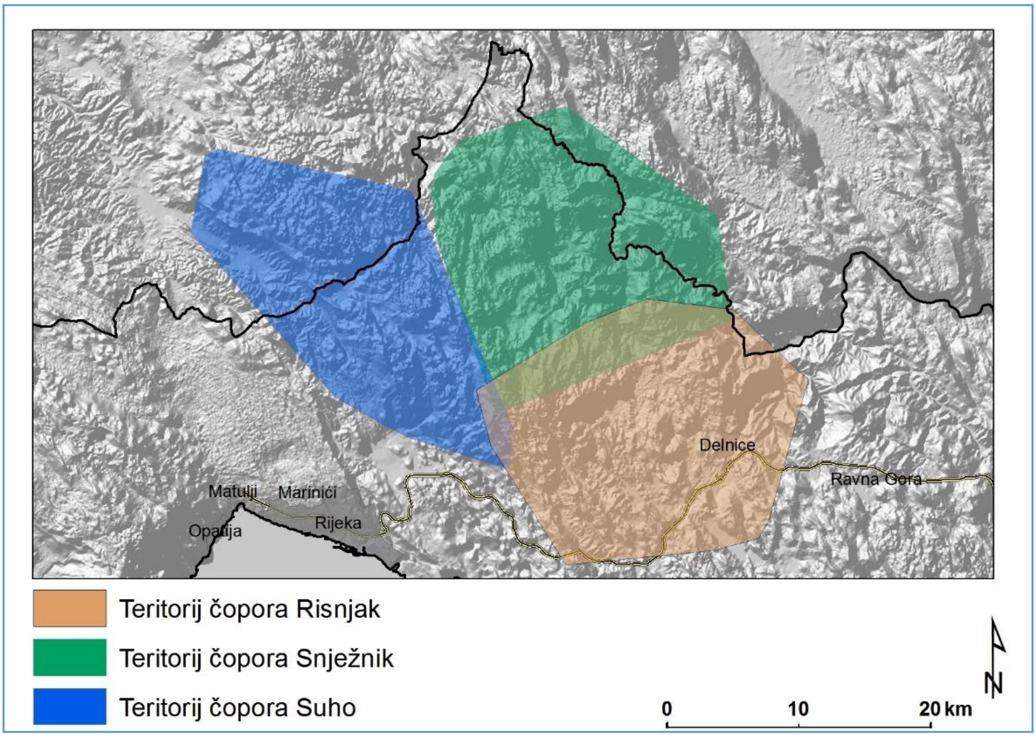


Figure 36. The territories of three wolf packs in Gorski kotar in Croatia determined by telemetric monitoring. Wolves defend the borders of their territories primarily by regularly marking it with urine and faeces, by scratching the soil and/or by howling. Source: Authors

Individuals of many species engage in migration during their lifetimes. Migrations can be periodic, which means that they occur regularly and include a departure and return to the natal area. Periodic migration usually refers to seasonal migration when animals avoid unfavourable climactic periods in their range and migrate to the most favourable area for reproduction. The direction of those migrations can be North-South, but also up-down in mountains. There are also migrations for life, e.g. sexually mature salmon returning from the sea and swimming up rivers to spawn in the natal area where they were born. Many species also migrate daily based on the rotation of days and nights (e.g. plankton).

There are also non-periodic migrations which can happen once or zero times in an individual's lifetime. Animals can permanently leave a habitat if there is an adverse change in conditions. Such departure is called emigration. If they settle in a new habitat in which the species has not been present, that is called immigration. A species immigrating to a new area must establish its ecological niche. If it is unsuccessful, it will become extinct; it can also escape the population control mechanisms and become an invasive species. In reality, this most often happens when humans inadvertently or with reckless intent transfer a species to an area where it does not belong.

6.2.3 Natality

Natality is a positive factor of population growth, when new individuals are recorded in a unit of time based on the species reproduction. The term natality implies birth when referring to placental mammals, hatching when referring to oviparous animals and cell division for unicellular organisms. In stable populations, natality is almost equal to mortality.

There is maximum (absolute) natality or the greatest possible biological reproduction of a species and ecological (realized) natality achieved under the effect of every limiting factor. Maximum natality can be achieved only in theory or in a shorter period of time when ideal conditions are created either in nature or in a laboratory. In practice, there is a huge difference between the possible and the realized natality. This can be illustrated by fecundity and fertility. Fecundity signifies the physiologically possible number of eggs produced by a female, while fertility indicates the possible number of offspring per female. The most obvious fact is that animals whose fertilization takes place outside the female's body have to produce infinitely more eggs than animals in which the male releases sperm into the female's body during copulation. In external fertilization, the vast majority of eggs remains unfertilized and decays. There are also situations in which a female must produce many eggs despite internal fertilization, e.g. (a) if only one female is sexually mature and can reproduce in the entire community, such as the queen bee or the termite queen, or (b) if the life cycle requires several hosts, as is the case for most parasitic species (tapeworms, trematoda), because only a very small number of developmental stages finds the next host in the life cycle. In any case, the evolutionary selective pressure led to the development of mechanisms enabling populations to stay in dynamic equilibrium when it comes to their numbers through both fecundity and subsequently achieved fertility (Figure 37, Table 4).

Figure 37. The female mouse has very high fertility among mammals. Source: Authors

Table 4. Comparison of fecundity for females of different species according to the place of fertilization. It should be noted that both the termite queen and the tapeworm need to produce many eggs despite internal fertilization because the termite queen is the mother of all offspring in the community and the tapeworm loses offspring that fail to complete the development cycle.

Species	Fecundity	Fertilization
Woman	400 in a lifetime	internal
Oyster	60 000 000 per season	external
Termite (queen)	100 000 000 in a lifetime	internal
Tape-worm (*Taenia sp.*)	14 000 per day	internal

Fertility rate is the number of born offspring. It is extremely small in homeothermic species (birds and mammals). Due to the internal fertilization of those animals, the share of fertilized eggs is significantly higher than in external fertilization, so fecundity can be lower. For placental mammals especially, the prospects of giving birth to a live offspring after fertilization are high. For example, a female elephant can give birth to no more than five or six offspring in her lifetime, but the number is more than enough to sustain the population.

6.2.4 Mortality

Mortality indicates the number of dead individuals in a population per unit of time and it represents a negative growth factor. In stable populations, mortality is almost equal to natality.

One should distinguish physiological mortality which is minimal under optimal conditions, i.e. each individual reaches the highest possible physiological age. This is possible only in theory. What is actually achieved is ecological mortality which depends on external circumstances, including any limiting factors. In practice, ecological mortality is much higher than physiological, i.e. the average age reached by an individual is much shorter than that which is physiologically possible.

The length of life can be observed through the survival rate which shows (usually as a percentage) which part of the population survived a unit of time. If the observed species lives for years, the important information is the percentage of the population that survives from one year to another. For example, a population of small rodents can have a survival rate of about 50% which means that approximately half of the individuals born last year are still alive this year. The distribution of mortality across age groups is especially important. In this respect, three life stages are analysed: (a) pre-reproduction, (b) reproduction and (c) post-reproduction (Figure 38). In populations of all animal species, great losses occur at a young age before individuals enter the reproduction cycle. Those losses are "provided for" by fertility and this is the evolution's major opportunity to select the most adapted individuals. The most vulnerable losses for a population are those that occur at the reproduction stage of individuals in a population. Losses are minimal at this stage because individuals are in the best shape of their life and because they have gained the experience of avoiding dangerous situations. The post-reproduction phase no longer has any ecological importance for a population, so losses at this stage are even desirable. The ratios of life stages in different animal groups are extremely varied; generally, the post-reproduction stage spans over approximately one third of life only in humans.

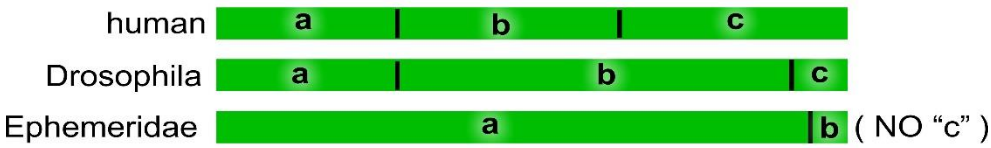


Figure 38. In mayflies (Epheremidae), the postreproduction (c) stage does not exist because they die immediately after mating and laying eggs ("a" pre-reproduction, "b" reproduction and "c" post-reproduction stage of life). Source: Authors

6.2.5 Age structure

The structure of age categories in a population is usually shown with an age pyramid (Figures 39 and 40). The pyramid shows the number of individuals in each age category (e.g. approximate age) from the youngest to the oldest. It is normal for the youngest group (pre-reproductive stage) to have the most individuals and for the number to gradually decrease with the possible duration of life. The pyramid also enables simultaneous and separate depiction of age categories according to sex. When and if an age pyramid can be made for a population, its further development can be completely predicted and it can be correctly managed.

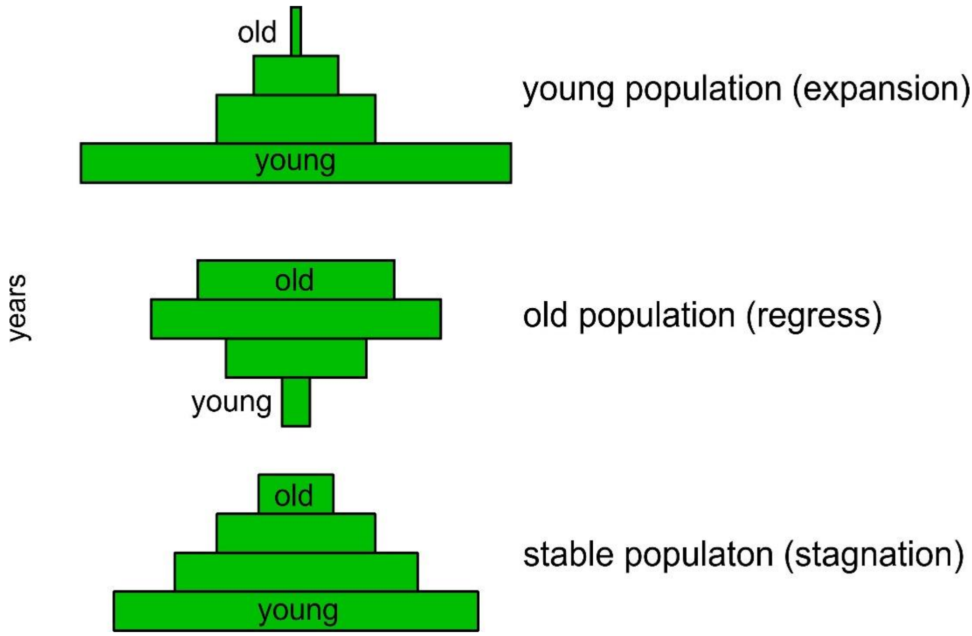


Figure 39. An example of different age pyramids for three populations of some animals (e.g. hares) that initially have the same number of animals (e.g.1000) and differ only in age structure. The young population in the top pyramid has the ability to double in the next two to three years and the old population in the middle pyramid could disappear in the same period. Only the stable population in the bottom pyramid will maintain its numbers. Source: Authors

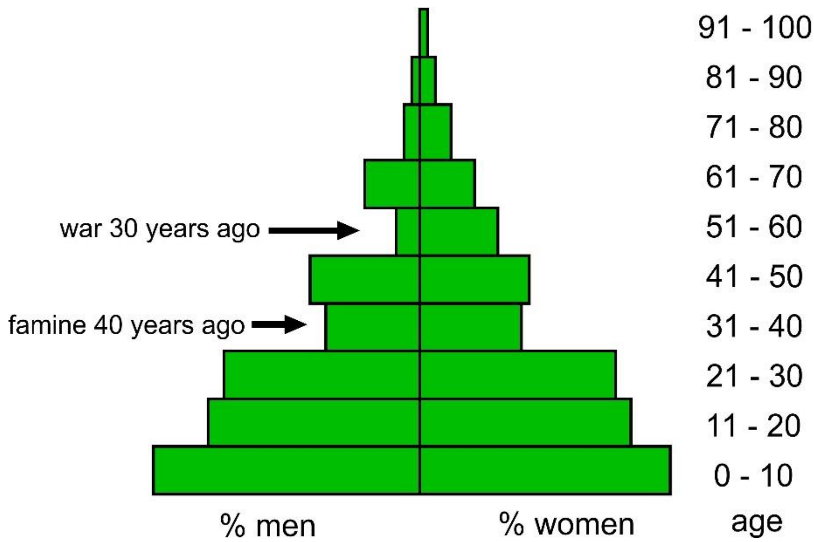


Figure 40. An imagined age pyramid of a human population with transferred "deficits" due to hunger in infancy and later due to war at the age of 21-30. Source: Authors

6.2.6 Biotic potential

Biotic potential stems from the size and ratio of the natality and mortality rate which allows the calculation of a hypothetical reproductive capacity of a species. The calculation assumes a 100% achievement of the potential under optimum conditions at the same time, with maximum natality and physiological mortality, so that each individual has the highest possible number of offspring and reaches the oldest possible age. Optimum conditions, if they occur in nature, never last long. Naturally, all of that is possible only in theory, because the reproductive capacity (the ability of the species) is restricted by environmental resistance. So only a small part of biotic potential is regularly achieved in any species, just enough to maintain a dynamically stable population size.

The following examples illustrate the vast difference between "the possible" and "the achieved" with environmental resistance:

- A pair of sparrows has the biotic potential based on which the number of 275,716,983,699 sparrows could be achieved in 10 years.
- A pair of elephants (as an extremely low-fertility species) could have 19,000,000 offspring in 750 years.

- A pair of domestic flies, if they achieved their biotic potential, would completely fill the Earth's biosphere in six years.

Given that the biotic potential is not achieved in nature, all of this shows that nature provides a great variety of options for evolutionary change over generations. It also shows that a species such as humans is actually offered plenty of surpluses for its own reasonable (renewable) exploitation. It is therefore surprising that humans managed to exterminate a large number of species.

6.2.7 Population dynamics

While on the one hand ecological relationships promote equilibrium in an ecosystem, one should always keep in mind that the balance is very dynamic, i.e. that it continues to oscillate around some average values and that it is occasionally thrown completely off balance with a change in environmental conditions, an emergence of a new population or an extinction of an existing one. The balance is then re-established, but on another level and possibly with other participants.

Sooner or later, every population goes through five stages of its existence (Figure 41):

1. **The stage of positive growth.** The number of individuals in a population doubles over a unit of time, which leads to an exponential curve of growth.

2. **The stagnation stage.** This stage starts when the number approaches the "carrying capacity of a habitat" (K) and ends when that capacity is reached, which takes the form of a sigmoid curve reaching the plateau of growth.

3. **The stage of oscillation.** The size of the population fluctuates around the habitat's capacity in such a way that it occasionally drops below the limit and occasionally goes beyond it. This stage lasts for the entire existence of a monitored population, theoretically for millions of years, even though it can sometimes be short if the entire existence of the population is short. In practice, and in most cases, we deal with a population precisely at the stage of its normal oscillating existence. Oscillations can be periodic and non-periodic.

- ***Periodic oscillations***. Intervals between two minima or two maxima are almost equal, as well as deviations from the habitat's capacity ("K"). There are several "classic" examples of periodic oscillations: (a) the laboratory experiment with a fly (*Lucidia cuprina*) (Figure 42), (b) the natural cycle of lemmings (*Lemmus lemmus*) (Figure 43) and (c) the population cycle of snowshoe hares and Canadian lynxes (Figure 44).

- ***Non-periodic oscillations.*** These oscillations happen at irregular and unpredictable intervals and with very different deviations from "K". Any extreme fluctuation can lead to the population's extinction. An example of a non-periodic oscillation that can be recreated in a laboratory is a host – parasite system, with a fly (*Musca domestica*) as the host and a wasp (*Nasonia vitropennis*) as the parasite (Figure 45). Numerous examples in nature are various natural disasters such as floods, fires, extreme droughts or long winters.

4. The stage of negative growth. Negative growth of a population starts when one of the oscillations towards a lower than average value is not followed by an equal oscillation towards a higher than average value. Negative growth can progress as a continuously dropping line or with oscillations which also result in a drop.

5. The stage of population extinction. This is the moment when the life of the last individual in a population ends. In some cases, this may represent the extinction of an entire species.

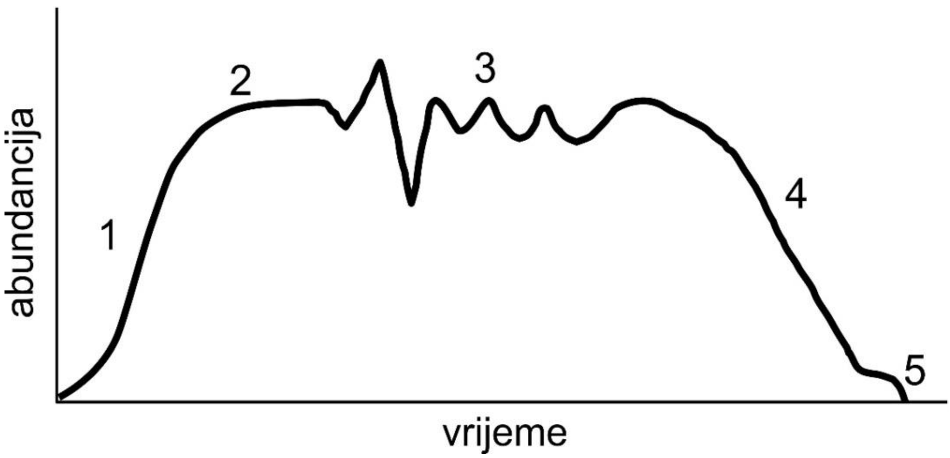


Figure 41. (1) The stage of positive growth (exponential curve), (2) the stage of stagnation (sigmoid curve) – when K (habitat's capacity) is reached, (3) the stage of oscillation – most permanent fluctuations (periodic and non-periodic), (4) the stage of negative growth and (5) the stage of population extinction. Source: Authors

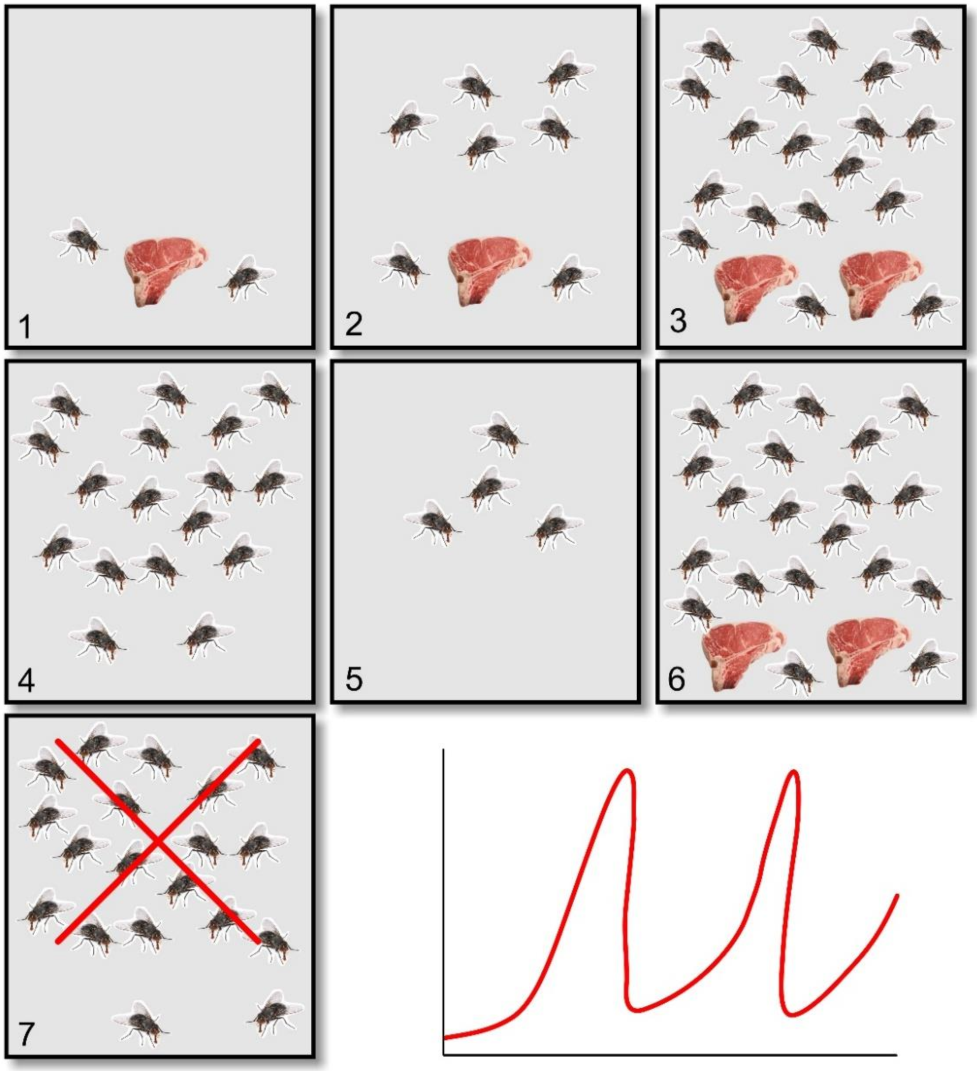


Figure 42. A laboratory experiment with flies (Lucidia cuprina) kept in constant conditions and fed with identical amounts in identical intervals (e.g.10 grams of meat every 10 days) irrespective of the fluctuations in the number of flies. The initial pair of flies pictured with their first meal (Figure 1) reproduces (Figure 2), experiences the second meal and the second generation of offspring (Figure 3) that eat all of the food before the third meal (Figure 4) which leads to death from starvation (Figure 5), after which the population grows again with the following meals (Figure 6), followed by new deaths from starvation (Figure 7). The graphical representation of oscillations in population depicts exponential growth and then a sudden drop every time. In such simple conditions, a population is unable to stabilize its numbers near the habitat's capacity (K) and instead experiences permanent large oscillations. Source: Authors

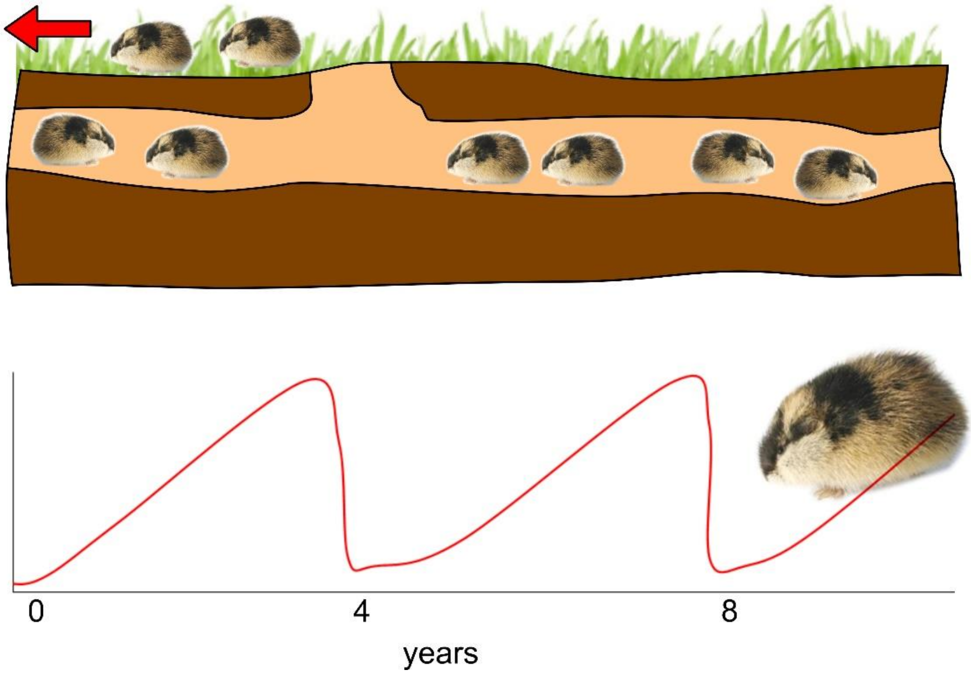


Figure 43. The natural cycle of a small rodent lemming (Lemmus lemmus) that lives in the ground and in underground tunnels of tundra. The population has a growth trend until it exceeds the habitat's capacity (K). At that point, stress and hunger increase, causing large migrations of lemmings in search of a new habitat. There is sudden drop in population in a four-year cycle. The oscillations also affect their main predators – snowy owls and polar foxes, which are significantly more successful in raising their offspring in the years when the lemming population is at its peak. Source: Authors

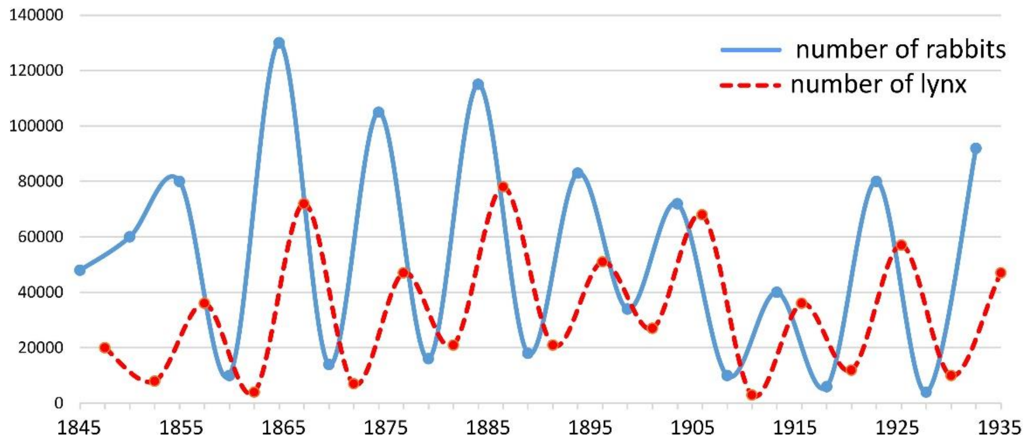


Figure 44. The population cycle of the snowshoe hare (Lepus americanus) and the Canadian lynx (Lynx canadensis) according to the purchase of fur by the Hudson Bay Company. It is clear that the number of hares drops before the lynx population peaks, which means that the main reasons for the drop are food shortages, stress and diseases and only after that lynx predation. On the other hand, the lynx population follows the growth of the hare population (with a lag of one to two years), because the abundance of prey allows them to successfully nurse offspring. Conversely, the disappearance of hares directly causes a drop in the lynx population. In this example, the predator does not regulate the population of its prey but the abundance of prey regulates the number of predators. Graphical representation was made based on the data of the Hudson Bay Company. Elton, C., M. Nicholson (1942): The ten-year cycle in numbers of the lynx in Canada. Journal of Animal Ecology 11: 215-244.

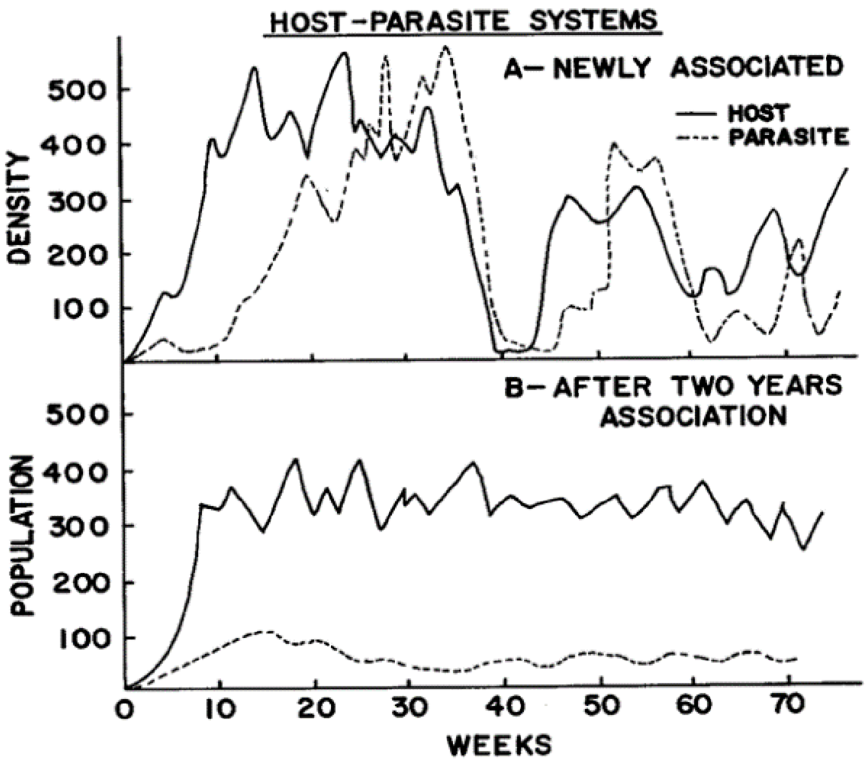


Figure 45. Laboratory non-periodic oscillations in the host – parasite system. The fly (Musca domestica) as the host, after the invasion of the parasitic wasp (Nasonia vitropennis), experiences a sudden drop in population along with its parasite. After several cycles of strong oscillations, the system stabilizes itself after two years at new levels of equilibrium. Source: Pimentel, D., F. Stone (1968): Evolution and population ecology of parasite–host systems. The Canadian Entomologist 100: 655-662.

Factors affecting population fluctuations can be divided into physical and biological.

Physical causes are usually associated with climate events: extreme temperatures (ice, heat, and fire), extreme humidity variations (drought, floods) or severe storms. They are regularly non-periodic and it is also ecologically important that they do not depend on the density of the observed population, i.e. they equally affect populations with only a few individuals and those that are very numerous. Such fluctuations dominate in monotonous systems, the example for this in nature being tundra, while large surfaces with crops of the same species (monocultures) are an example of vulnerable artificial systems. There, fluctuations are more frequent, stronger and have more severe consequences.

Biological causes for fluctuations depend on the numerical relationships between species that share a habitat, i.e. their effect depends on density so it changes directly proportional to the feedback reaction. So the population growth of species “a” can reduce the population of species “b”, but also the decrease in numbers of species “a” encourages the growth of species “b”. The more species there are in a habitat, the lesser the fluctuations, so biological regulation dominates in more diverse systems, such as rich forests.

Each individual has a sex drive and adaptations to be as successful as possible at reproduction, i.e. to spread as many of its genes through the population as possible. However, there is usually no hyper-population because self-regulation mechanisms exist and have an effect at the population level. Hyper-population is not in the interest of any population.

6.2.8 Interactions (intraspecific and interspecific)

Interactions between individuals of the same species are intraspecific interactions, while those between individuals of different species are interspecific interactions. Intraspecific competitions spread the range of a species to peripheral areas and interspecific competition narrows it to the optimal zone (Figure 46).

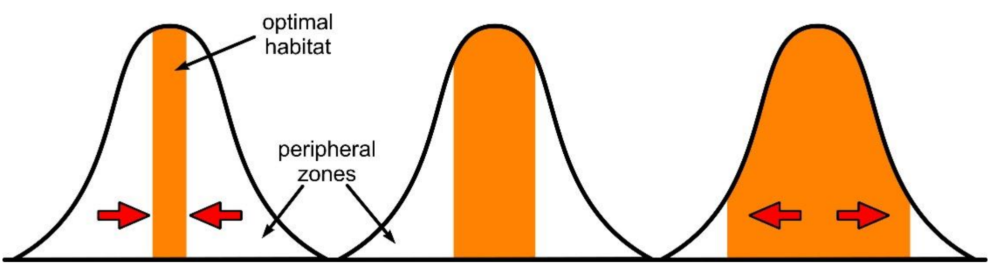


Figure 46. Competition with other species (interspecific) pushes members of the observed species to the habitat’s optimal zone (left) and competition within the species (intraspecific) spreads it towards peripheral zones of the habitat (right). Source: Authors

When it comes to competition for range, its increase in intraspecific relationships (growth of own population) spreads the range of the species to peripheral areas of the available habitat, while interspecific competition narrows the range to the optimal zone for each observed species. The growth of a competing species reduces every species to the optimal zone of their habitats (Figure 47).

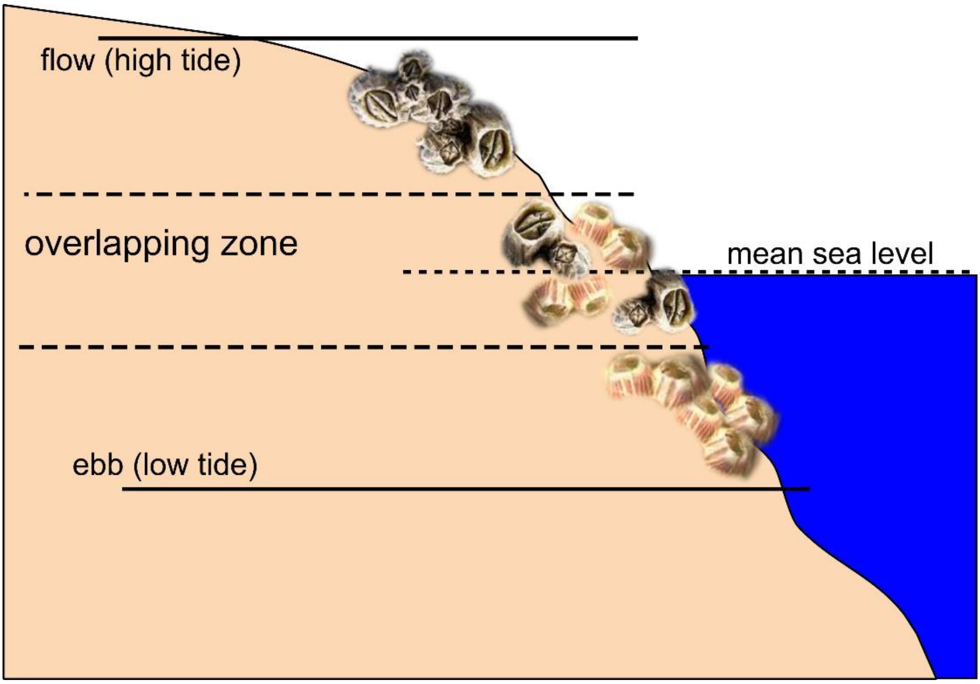


Figure 47. An example of interspecific competition between barnacles on a rocky seashore. Both species (A and B) can live in the zone from the lowest ebb to the highest flow, but the part that is dry for the longer part of the day is more suitable for species A and the part that is under water for the longer part of the day is more suitable for species B. The complete overlap of niche is around the mean sea level where both species will be more represented in the fight for space. Source: Authors

6.2.8.1 The division of interspecific interactions

The relationship between members of different species can be: positive or stimulating (+), negative or inhibiting (-) or without effect (0) (Table 5). By combining those three signs, we can differentiate a total of nine different types of relationships between different species. In three cases, even with the same effect signs (-:-, +:- and +:+), we can distinguish between different relationships. So we distinguish between active and passive competition (-:-). Active competition is when species in a relationship try to directly suppress each other, e.g. a parasite from the group of roundworms (nematodes) that first inhabited the digestive tract of the host secretes toxins preventing a competing parasite from the group of thorny-headed worms (acanthocephalans) to settle in the same desirable place. In the same way, the so-called “ring grass” in American prairies secretes substances that prevent the growth of other species of grass in a circle around it. In passive competition, parties to the relationship do not affect each other directly but merely spend the same resources (food or water) until they are exhausted (they “eat from the same pot”). In a situation of conflicting positive (+) and negative (-) relationships, we can distinguish between the parasite:host relationship and the predator:prey relationship. A parasite is typically small and seeks to exploit its host as long as possible, while a predator is larger than its prey which it kills and eats as fast as possible. Even though the parasite’s host and the predator’s prey are at a loss (“minus”) as individuals in these relations, it is important to understand that ecological relationships are positive for both sides at the level of populations and species. Through evolutionary pressure, parasites and predators maintain the populations of its hosts and prey at the optimum level for the stability of entire ecosystems. The third situation is marked by two positive signs (+:+) where the two types of relationships can be identified as mutualisms or communion. Proto-cooperation is an optional relationship from which both parties benefit, but can live separately. In symbiosis, the species are so interdependent that they can no longer live without each other.

Table 5. An overview of interspecific interactions in which species "A" and "B" can have a positive (+), negative (-) or neutral (0) effect.

	Species A	Species B	**Interspecific relationship**	
	0	0	neutralism	species that belong to different ecological niches
	-	-	competition, active	e.g. roundworms and thorny-headed worms (Figure 48)
	-	-	competition, passive	about food, water, etc.
	-	0	amensalism	e.g. individuals of large and small species
	+	-	parasitism	more lasting, a difference in size (Figure 50)
	+	-	predation	short, predator is bigger or similar to prey (Figure 49)
	+	0	commensalism	e.g. orange clownfish and anemone
mutualism, communion	+	+	Proto-cooperation	optional, pr. hermit crab and sea anemone
	+	+	symbiosis	obligatory, e.g. ruminants and microorganisms in their reticulorumens

Figure 48. Ring grass in American prairies, in active competition with other species of grass, secretes toxins to prevent their grown in a circle around it. Source: Authors

Figure 49. Cheetah as the predator and rabbit as the prey. Source: Authors

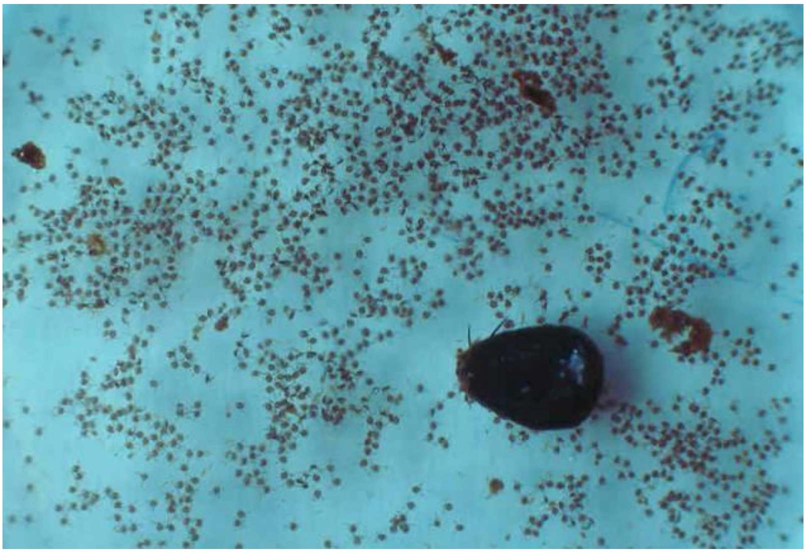


Figure 50. A female tick (parasite) with offspring. Source: Authors

7 Biocenotic succession

In every ecosystem, populations of all living organisms alternate in order to reach a final, stable phase known as the climax (Figure 51). Biocenotic successions can be primary and secondary. Primary succession occurs on the ground where there is no life. It rarely happens in nature, a typical good example being the island of Anak Krakatau, which emerged following a volcano eruption in 1883 (Figures 52 and 53). Secondary succession is a process occurring on any ground where there has been a regression in the sequence of succession to one of the earlier stages. While this can happen in natural conditions, e.g. when a fire or flood destroys existing living communities, humans regularly cause the process, for example, by deforestation or soil cultivation.

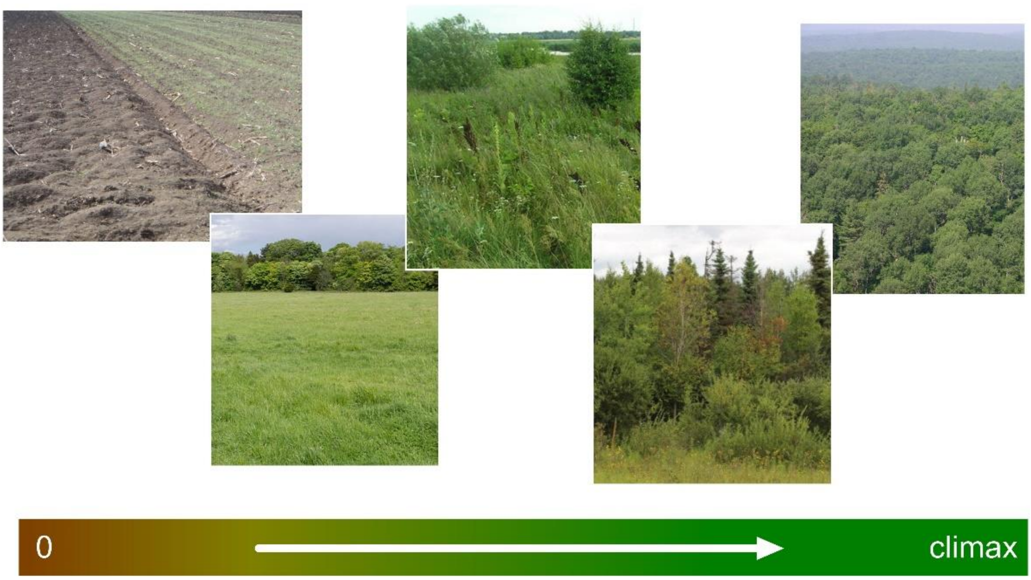


Figure 51. An example of secondary succession in a temperate zone habitat, in which the deciduous forest represents the climax. The sequence begins from a piece of plough-land (year 0), proceeding through grassland or sown grains (year 1–2) and various stages of shrubland (year 3–10) to a forest which remains young for over 10 years, finally followed by the mature forest in 40–60 years. Source: Authors

Successions may be progressive and regressive. Progressive successions move towards the climax, simultaneously generating a new substrate – soil. On average, 1 mm of soil can be generated in one year. This means that it takes 250 years to generate around 250 mm of soil, which is a minimum required for any agricultural purposes (Figure 54).

Regressive succession follows the opposite direction, returning the population sequence towards the initial stages (Figure 55). It is often accompanied by soil erosion or loss, which are often prompted by deforestation, overgrazing or ploughing. In those conditions, soil that took 250 or more years to form may be lost in a very short period.

Climax is a final and stable community maintaining its own balance and resisting change. There is a dynamic equilibrium between the production (P) and decomposition (D) of the organic matter.

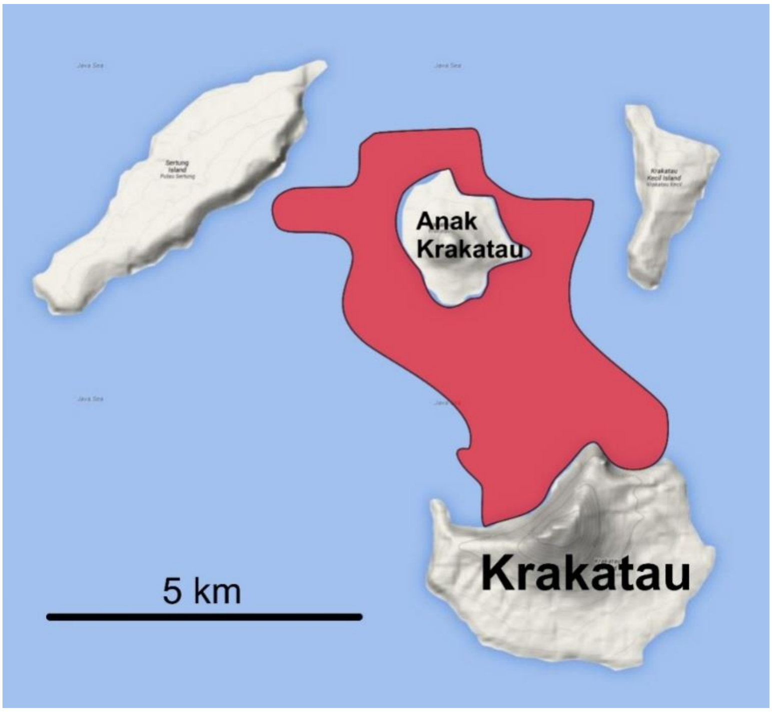


Figure 52. A volcano eruption on the Indonesian island of Krakatau in 1883 as an example of primary biocenotic succession. The eruption instantly destroyed 2/3 of the island (marked in red), but following its subsequent phases, a new island was formed from the volcanic ash: Anak Krakatau ("the Son of Krakatau"). The ash cooled rapidly, its composition being favourable (nutritious) for the growth of vegetation, but there were no life forms at the beginning. It was found that mosses appeared after three years; phytophagous insects, birds, trees and hymenoptera feeding on nectar after 10 years; while it took 50 years for a coconut forest to grow, equal to the one in the climax stage on an island 18 km away. While there were 0 species in 1883, there were 202 plant and animal species in 1908, 621 species in 1921 and finally, 880 species in 1933. Source: Authors

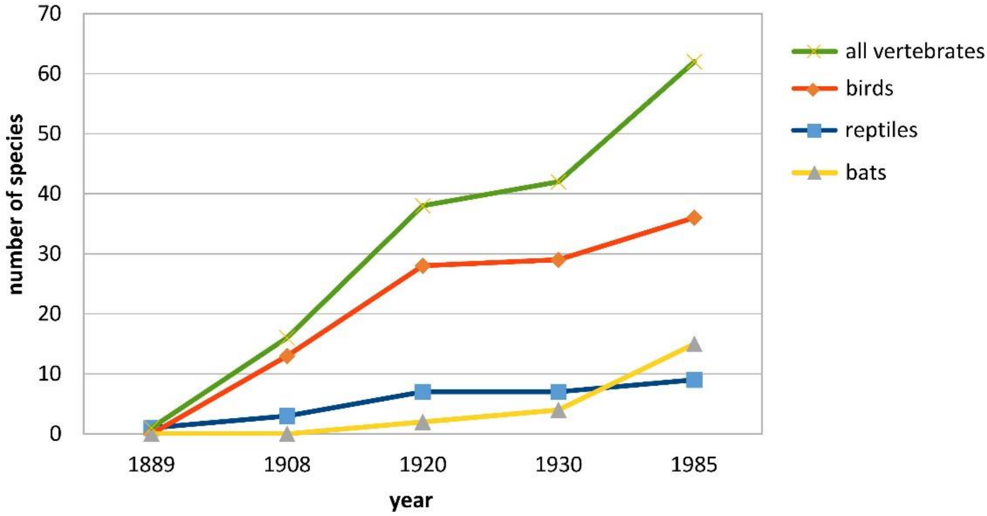


Figure 53. The emergence of various types of animals following the volcano eruption on the island of Krakatau, 1883. Source:Prepared according to the data in Thornton, I. W. B., R. A. Zann, P. A. Rawlinson, C. R. Tidemann, A. S. Adikerana, A. H. T. Widjoya (1988): Colonization of the Krakatau Islands by vertebrates: Equilibrium, succession, and possible delayed extinction. Proc. Nati. Acad. Sci. 85:515-518

Figure 54. During a progressive succession, a 25 cm layer of soil may be formed in around 250 years. Source: Authors

Climate is the most common determinant of a community representing the climax in an area. This is referred to as climatic climax. Observing only the parameters such as temperature and humidity, extremely different biomes can be distinguished: (a) tropical moist forest with temperatures constantly above 20 °C and a lot of rain (over 1500 mm) throughout the entire year, (b) temperate deciduous forest with warm summers and cold winters and at least 700 mm of precipitation per year (including snow in the winter), (c) prairie grassland with similar temperatures as in the deciduous forest biome, but with less than 700 mm of precipitation per year (too dry for a forest), or (d) deserts, where the amount of precipitation (below 250 mm) is insufficient even for grass, regardless of the temperature. In some places, the type of soil (substrate) determines the extent to which the communities can be developed, which is known as edaphic climax. Examples are areas in which the soil is very salty, acidic, alkaline or, in turn, stony on steep hills, where it is impossible to retain soil. Nowadays, large areas of Earth are in the climax generated by humans, which is known as anthropogenic climax. The most prominent example is agriculture, where people usually grow crops in one-year cycles, harvesting them every year and returning to the initial stage of succession by ploughing (Figure 56). In many areas, the succession is interrupted by vineyards, coffee or tea plantations (equivalent to the shrubland stage) or orchards (equivalent to forests). Additionally, the majority of forests are under a management regime, not reaching their development climax.

Figure 55. Fire as a natural cause of regressive succession in a coniferous forest (left) in the first year after the fire and (right) a few years after the fire.(Riding Mountains, Canada). Source: Authors

Figure 56. Regular mowing interrupts the biocenotic succession. Source: Authors

8 Biomes

Biosphere is divided into two biocycles: water or aquatic and land or terrestrial. Land biomes are complexes of a large number of communities in a wider climate zone; therefore, climate is a major determinant for the classification of eight biomes. In addition to temperature, the chemical composition, depth and size of water are important in aquatic systems.

8.1 Aquatic systems

Salt waters include oceans and seas containing 98.5% of water on the planet. Fresh waters are divided into standing waters (lakes) and flowing waters (fast and lowland waters or streams and rivers). Large river mouths extending into the sea (estuary) and ground-waters (flowing and standing) comprise a special category.

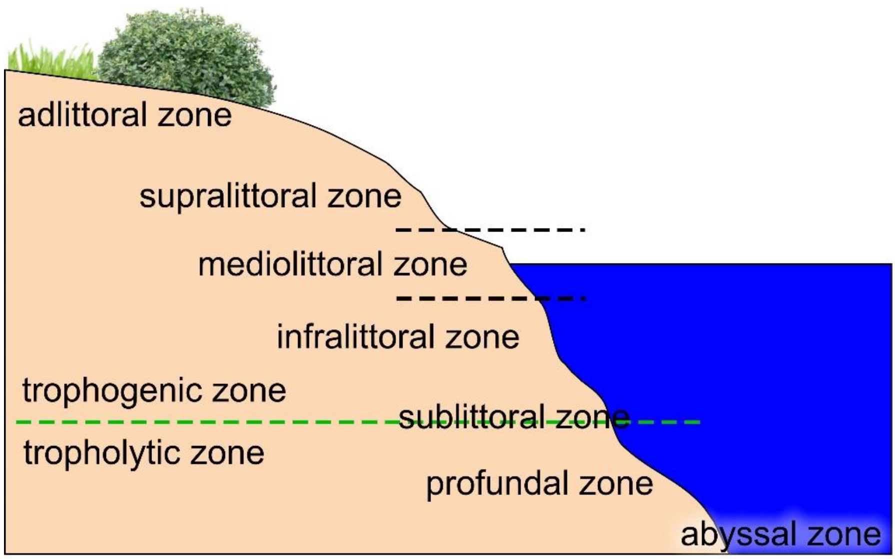


Figure 57. Life zones in a (marine) aquatic system. The figure shows the adlittoral, first land zone, supralittoral is the wave splash zone, midlittoral is the range between the flow and ebb, infralittoral is the underwater zone extending down to the depth reached by sufficient sunlight for photosynthesis (trophogenic zone), sublittoral is the twilight zone, and profundal is the dark zone (tropholitic zone). The abyssal zone includes ocean depths outside the continental shelfs. Source: Authors

Figure 58. Rocky coast on the Brijuni Islands and on Lastovo: dark rocks classify as midlittoral, white ones as supralittoral, while the vegetation grows in the adlittoral. The infralittoral is under the water. Source: Authors

The types of living communities inhabiting particular parts of aquatic systems depend on (a) the composition of minerals, (b) depth, (c) light, (d) temperature and (e) water movement (Table 6).

Sodium chloride (NaCl) content is the essential component of minerals. Sea water contains about 3.5% of salt, making the osmoregulation processes much different (simpler) than in fresh water, which is hypotonic for all living organisms and must be constantly released from their bodies. For this reason, such organisms have to be homeosmotic.

The depth affects the hydrostatic pressure which increases by approximately 1 bar for every 10 m depth, and presses the submerged organisms from all sides. Although the majority of organisms are adjusted to living under a certain pressure, only some species are able to tolerate major changes, or move up to the surface and back into the depth. Additionally, the amount of light in the water decreases with increase in depth (Figures 57 and 58).

Light in the water is important for photosynthesis. The amount of sunlight penetrating the water surface depends on water depth and transparency. Water transparency is mostly influenced by suspended particles retaining some light. So, while some red algae, discovered near the island of Jabuka in the clear Adriatic Sea, perform photosynthesis even at a depth of 200 m, in the murky Baltic Sea, there is already complete darkness at a depth of 10 to 15 m.

While some seas have a temperature of around or above 25 °C throughout the entire year, enabling the growth of coral reefs, others freeze on the surface in the winter, water temperature below the ice being around 4 °C.

Water movements significantly determine which locations are suitable for the life of specific organisms and what adaptations are required for such conditions. Water movements include river and sea currents, waves, as well as ebb and flow (Figure 59).

Figure 59. Large tidal range occurring in a single day, at the same location – the Bay of Biscay in the Atlantic Ocean, near the city of Gijón (Spain). Source: Authors

Table 6. Common nomenclature for living communities in aquatic systems

<table>
<tr><td></td><td>Sea-water</td><td>Fresh water</td><td></td><td>light</td><td>darkness</td></tr>
<tr><td rowspan="2">free water</td><td rowspan="2">pelagic zone</td><td rowspan="2">limnetic zone</td><td>plankton – floating passively</td><td rowspan="4">trophogenic layer</td><td rowspan="4">tropholitic layer</td></tr>
<tr><td>nekton – swimming actively</td></tr>
<tr><td rowspan="2">bottom</td><td rowspan="2">benthos (benthic zone)</td><td rowspan="2">pedon</td><td>littoral (light zone)</td></tr>
<tr><td>profundal (dark zone)</td></tr>
</table>

Evolution finds ways to populate each possible habitat with as diverse forms of life as possible. The largest number of different phyla of living organisms lives in the sea. There are no echinoderms, cephalopods or tunicates in fresh waters, only a few cnidarians and sponges.

8.2 Terrestrial biomes

8.2.1 Tropical moist forests

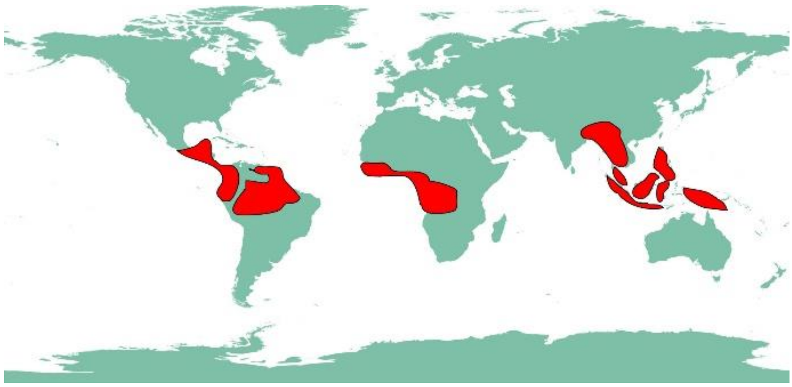


Figure 60. Tropical moist forests are found in South America, in the basins of the Amazon and Orinoco Rivers, in Central America, in Africa, in the basins of the Congo and Niger, on the Malay Peninsula in Southeast Asia, on the islands of Borneo and New Guinea, and on many other islands between Asia and Australia. Source: Authors

All tropical moist forests are found in tropical regions, but not all tropical regions are moist. In total, they occupy only 7% of the most productive land on Earth and comprise about 80% of all terrestrial biomass (Figure 60).

All these areas have over 1500 mm of precipitation per year, while the temperature is constantly above 20 °C. All the species inhabiting the area are hygrophilous. The diversity of species can be illustrated by the fact that there are more than 2500 species of trees there. Fauna is very diverse, particularly among insects. The largest number of still undescribed animal species on Earth inhabits these areas. For example, in one research project, as many as 20 new species of amphibians and two new species of fish were found in the epiphytic flowers growing on the trees along the river 12 meters above the ground, which retain some water. Organic transformation is rapid. Organic matter found outside of a living organism rejoins the biomass rapidly. Measurements in which radioactive caesium was used to mark a branch that had fallen of a tree have shown that the branch was already decomposed within 24 hours, absorbed through the root system and the same caesium could be found at the top of the crown on the following day. A dead animal the size of a bear is scavenged to the bone within 24 hours, and faeces "disappear" within an hour. All of this points to a very sensitive climax state. After deforestation, it is difficult to once again reach climax, and the whole system loses balance. Unfortunately, the terrestrial system of tropical moist forests is most endangered by humans: on a global scale, 3 hectares per minute are irreversibly destroyed, 24 hours a day.

8.2.2 Temperate moist deciduous forests

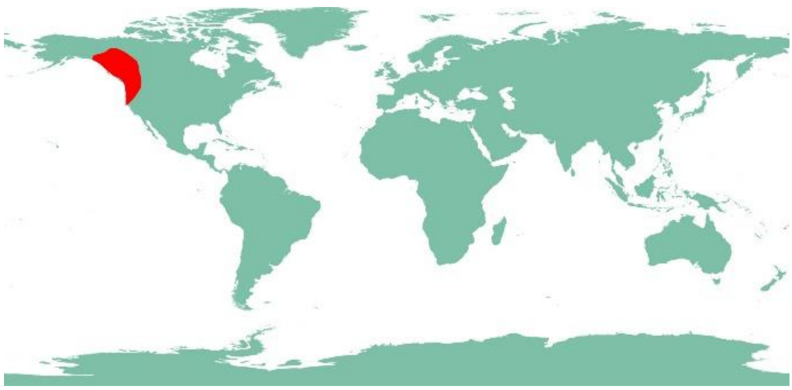


Figure 61. Temperate moist broadleaf forests along the Pacific coast in North America. Source: Authors

While moist broadleaf forests receive large amounts of precipitation, just like tropical moist forests, they are located in the temperate zone, with severe, snowy winters. An example is a forest along the coast of the northern Pacific Ocean in the US state of Washington, the location of Olympic National Park. Abundant precipitation encourages the growth of dense vegetation, including many epiphytes. This is accompanied by a corresponding fauna.

8.2.3 Temperate deciduous forests

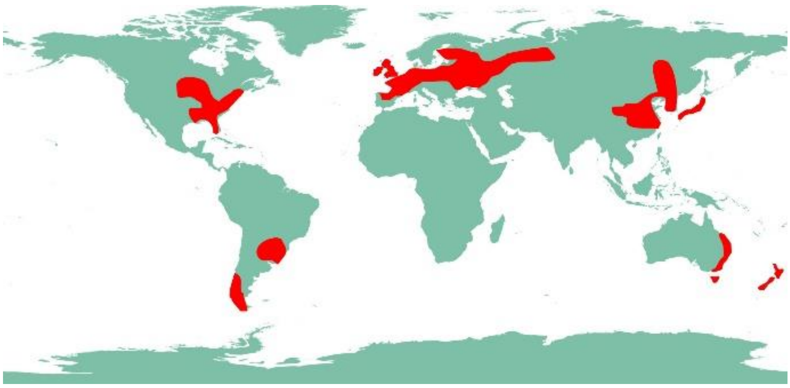


Figure 62. Temperate deciduous forests occupy a large part of Europe, eastern part of North America, southern part of South America, part of Japan and Australia and New Zealand. Source: Authors

Deciduous forests growing in the temperate zone are also known as broadleaf forests. Since they are mainly found in the areas of millennial "civilization", they are largely destroyed due to urbanization or conversion into agricultural land, or markedly transformed by exploitation and planting foreign (allochthonous) species (Figure 62).

Climatic features include hot summers and cold winters with 700–1500 mm of annual precipitation, occurring in the form of snow during the winter. Forests shed leaves in autumn to survive winter, while the young leaves develop relatively late in springtime, during April and May. In the spring, the Sun's rays pass through bare crowns to the soil, melting the snow and stimulating the growth of terrestrial vegetation. The soil is soon covered with well-developed green undergrowth (Figure 63). This is favourable for herbivores that are hungry after the winter, and soon need to bear offspring. When crowns become green by the end of May, the undergrowth plants have already completed their annual cycle of growth, flowering and reproduction. In the autumn, animals will feed on the forest's fruit and seeds (acorns, beechnuts, chestnuts) (Figure 69).

Figure 63. (a) Well-developed undergrowth in a temperate deciduous forest in springtime, before the leaves develop in the crowns of broadleaf trees. (b) Forest soil in the summer, when the crowns are full of leaves and the undergrowth has completed its vegetation stage. (c) Deciduous forest in the winter, during the period of vegetation rest (Risnjak). Source: Authors

8.2.4 Taiga (northern coniferous forest)

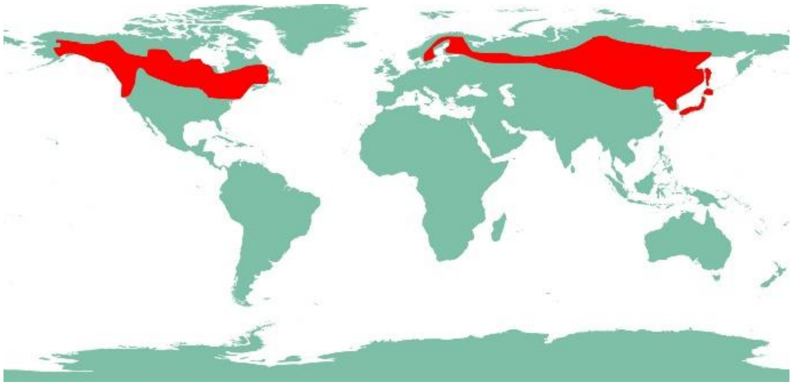


Figure 64. Taiga is located in the northern part of North America and northern Eurasia. Mountain taiga biomes are also found at certain altitudes in mountain areas elsewhere in the world. Source: Authors

The climate sustaining the taiga biome is characterized by long and cold winters and short, moderately warm summers with long days (Figure 64). The majority of trees are needle-leaved and evergreen, meaning that the trees retain green needles throughout the year, changing them constantly and gradually. The main groups of trees are different types of pine, spruce and fir (Figures 65 and 69). Unlike the broadleaf forests, in these forests the Sun's rays do not penetrate to the forest soil in springtime, neither do they stimulate the growth of terrestrial vegetation. The soil receives relatively little light and is covered with dry needles, resulting in scarce vegetation (Figure 66). There are lichens and mosses. This means that little food is being provided for large herbivores, so their biomass is lower than in the deciduous forests.

Figure 65. Alpine taiga biome in the highest part of Risnjak in Croatia. Source: Authors

Figure 66. The soil of a dense coniferous forest, covered with needles and poorly lit, resulting in scarce ground vegetation (undergrowth). Source: Authors

8.2.5 Tundra

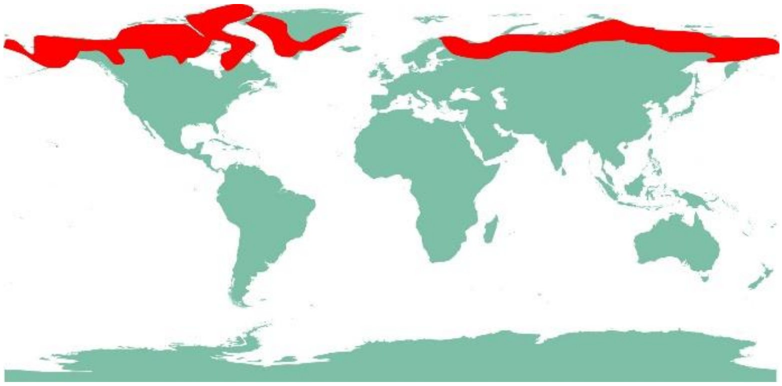


Figure 67. Tundra is located in circumpolar areas along the Arctic in North America, Europe and Asia, to the north of the taiga zone. High mountains are distinguished by the "alpine tundra" located at altitudes surpassing the zone of tree growth. Source: Authors

Figure 68. Tundra biome in Iceland and the peninsula of Labrador. Source: Authors

The area is strongly affected by constraining factors: temperature and light (Figure 67). Interseasonal fluctuations are extreme due to the inclination of the Earth's rotation axis relative to the Sun. During the winter, the Sun does not rise for an average of 60 days (1 to 182 days at the Pole itself) in the areas to the north of the polar circle (67^{th} degree). During that period, the temperatures can drop below -60° C in some places. In contrast; in summertime, the Sun does not set for an equal number of days. That is the period of intensive growth occurring in 24-hour daylight. While the snow and ice on the surface melt, the layers beneath the ground surface remain permanently frozen, which is called permafrost. Underground ice prevents plants from developing deeper roots. On the other hand, lichens, grasses and low shrubs grow rapidly and abundantly (Figure 68). There is an explosive growth of insect populations. All of these provide plenty of food for other animals migrating to the area at that period from southern taiga regions, and for those few species (lemming, musk ox) managing to survive the winter in tundra. Large reindeer herds arrive followed by predators – wolves. Particularly numerous are migratory birds, which breed in these areas during that period, just like mammals. With plenty of food, the offspring progress rapidly. They have to grow before the end of the summer, occurring at the end of August, to be able to migrate southward or survive the upcoming winter in these areas.

Figure 69. *Altitude differences set clear boundaries between the zones of temperate deciduous forests, alpine taiga (coniferous forest) and alpine tundra (mountain pastures) in the Pyrenees (France). Source: Authors*

8.2.6 Grasslands

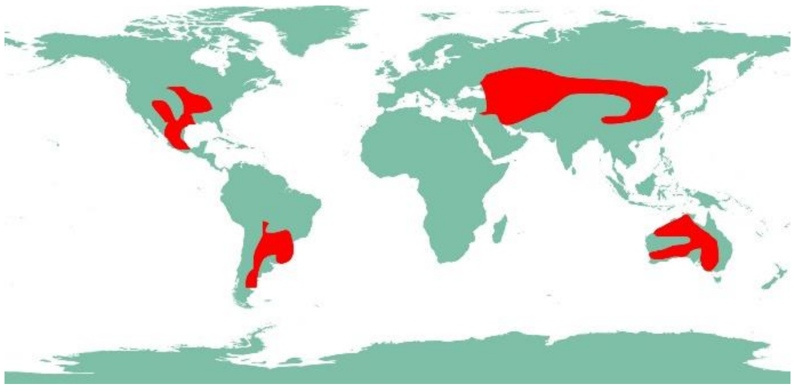


Figure 70. Temperate grasslands: prairies (North America), pampas (South America) or steppes (Eastern Europe, Central Asia and Australia). Source: Authors

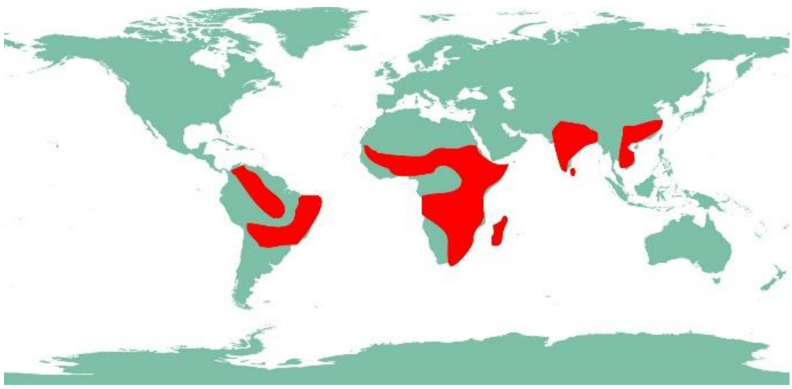


Figure 71. Tropical savanna grasslands in Africa, India, part of East Asia and South America. Source: Authors

In general, grassland biomes lack sufficient precipitation for a forest to grow. However, the precipitation regime and the position in different temperature zones are precisely the features distinguishing two basic types of grasslands (according to some classifications, they are regarded as separate biomes). Temperate grasslands are known as prairies in North America (Figure 70), pampas in South America and steppes in Eastern Europe and western Central Asia (Figure 71). Tropical grasslands are referred to as savannas in Africa and India and llanos in the tropical part of South America.

Figure 72. Prairie biome in Utah (USA). Source: Authors

Figure 73. Steppe biome in Hustai National Park in Mongolia. Source: Authors

Receiving 250–700 mm of annual precipitation (Figure 72), the temperate zone is the environment suitable for grass growth. If an area has annual precipitation of less than 250 mm, which cannot even sustain the grass, it is referred to as a desert. In order for a forest to grow, there must be over 750 mm of precipitation per year. Grasses of very different heights grow within the range from 250 to 750 mm. The grass is a generous source of food for ruminants and other herbivores from the superorder of odd-toed ungulates (Figure 73). Nowadays, large parts of temperate grasslands are used for agricultural purposes, mainly for grain cultivation. Therefore, wild herbivores and their predators have largely disappeared from those grasslands. An example is the extermination of the buffalo in the American prairies. They were replaced by domestic ruminants.

Figure 74. In addition to grass, savannas are home to individual trees of baobab and acacia (Serengeti, Tanzania). Source: Authors

In the tropical zone with savanna grasslands, annual rainfall reaches as much as 1000 mm, which is above the lower limit required for forest growth. Although individual trees (such as baobab or acacia) do grow there, there are no forests (Figure 74). The reason for this is the long dry season, and an uneven distribution of precipitation during the year. Dry seasons are characterized by regular fires which can only be tolerated by specific trees. Wild herbivores undertake regular annual mass migrations in search of water and food (Figure 74).

8.2.7 Chaparral

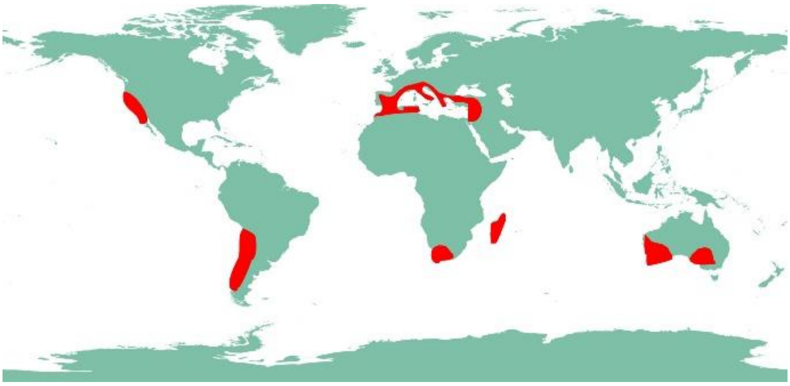


Figure 75. The chaparral biome occupies the entire coast of the Mediterranean Sea, California, Chile, South America, Madagascar and part of West Australia. Source: Authors

The chaparral is located in the warmer part of the temperate zone where the winters are mild with plenty of rainfall, while the summers are hot and dry (Figure 75). The typical vegetation includes evergreen shrubs and plenty of other plants that are dry in the summer, since they complete flowering and reproduction by springtime (Figure 76). The fauna consists of plenty of reptiles, smaller mammals and various birds. Fires often break out in the summer as a natural occurrence, and a new climax is reached after 20 years.

Figure 76. Chaparral during the climax of development (Lastovo and Mljet). Source: Authors

8.2.8 Deserts

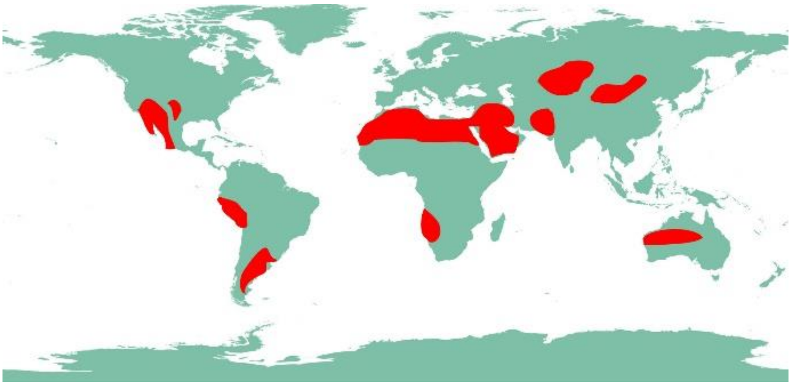


Figure 77. Deserts are present on all continents except Europe. The largest ones are the Sahara and Namibia in Africa, Sonora in North America, Atacama and Patagonia in South America, Gobi, Taklimakan, and Arabia in Asia, and the Central Desert in Australia. Source: Authors

The main feature of deserts is that they receive less than 250 mm of precipitation annually (Figure 77). This is usually accompanied by poor soil (sand and stone). In order to sustain life in such conditions, organisms must be adapted to saving water; such organisms are xerophilous. The most widespread form of plants are succulents (e.g. cactus), shrubs with small leafs and plants with a short reproduction cycle, which is performed after a single occurrence of rain (Figures 78 and 79). When it comes to animals, deserts are populated by reptiles, insects and several species of mammals (e.g. desert gerbil).

Figure 78. Succulent vegetation in the Mojave Desert in Arizona (USA).
Source: Authors

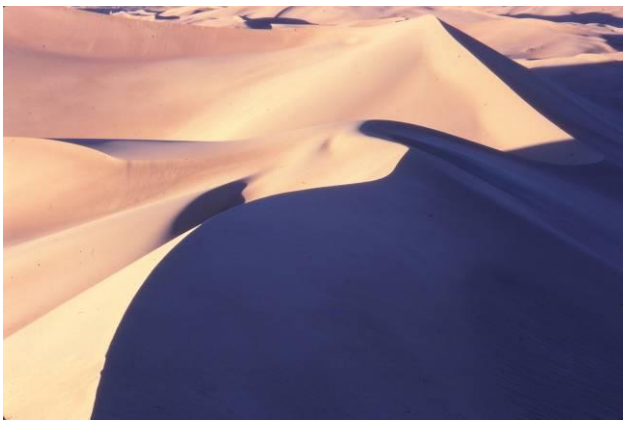


Figure 79. Sand desert Great Sand Dunes in Colorado (USA). Source: Authors

8.2.9 Ecotone areas

An ecotone is not a specific kind of biome, it is only a zone of transition from one biome to another. Certainly, there are no clear boundaries between biomes in nature, but one biome gradually shifts to another. The forests in the mountain ranges in Croatia are a good example of overlap between the temperate deciduous forests and mountainous coniferous forests (taiga) (Figure 80). Aside from the deciduous forests in the lowlands and the highest peaks covered in dwarf mountain pine, almost all other forests in Croatia are actually an ecotone between deciduous and coniferous forests (e.g. beech and fir forest). These forests are said to be co-dominated by beech and fir. The narrower ecotone, i.e. the line of demarcation, is usually located between terrestrial and aquatic systems. In total, ecotone areas make up a large part of the land area on Earth.

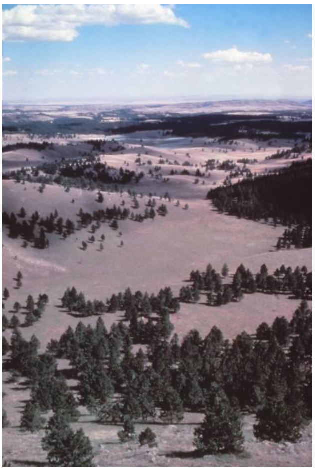


Figure 80. Example of a transition area (ecotone): (a) between a deciduous forest and grassland in Montana (USA) and (b) between a deciduous forest and coniferous forest in a beech and fir forest at Plitvice Lakes. Source: Authors

9 Methods of ecological research

The methodology of ecological research is a very complicated subject that encompasses a lot of aspects. Indications of specific methods are mentioned in the chapter on abundance. Here we shall only outline the types of ecological research.

9.1 Qualitative methods

In qualitative ecological research the main expected result is the list of all species present, preferably from all taxonomical categories. Neither their biomass nor number is measured, so there is no measure of quantity (abundance), only that of quality. However, in addition to the list itself, consistently conducted qualitative ecological research will also show:

- Characteristic (inherent) species in the habitat (domination or co-domination)
- Abundance (e.g. with a point evaluation from 1 to 5)
- Sociability (in one of the three types described)
- Demarcation of biocenoses (the coefficient of "habitat similarity" can be calculated)
- A comparison of several areas or characteristics of an area at different times
- Population size trend

9.2 Quantitative methods

Quantitative ecological research presupposes that qualitative research was performed beforehand (list of species), but it must also provide quantitative (numerical) data.

The total counting and/or weighing of all species and individual organisms may be performed on test surfaces or transects, and by using different indices (some are mentioned in the section on abundance).

For a quantitative determination, it is important to collect research samples without a selective loss. The list of methods includes various nets, dredges and other traps, photography techniques (including IR photography), telemetry and radioactive isotopes.

10 Human impact on ecological balance

Humans are a species with high demands on the environment, with regard to its numbers (biomass) and its need to exploit the environment. With their intellectual abilities, humans compensate for their physical inferiority in relation to other species. Due to their limited ability to adapt to their own environment, humans, as no other species in the history of planet Earth, adapt the environment to themselves. To that end, human beings consume vast quantities of fossil fuels, make permanent changes to the appearance and functioning of the Earth's surface for production of their own food, housing, transport connections, and industry. All of that has a strong impact on the natural ecological balance. Human impact can be divided into direct and indirect impact.

10.1 Direct human impact

Every time humans change the properties of a habitat, an ecosystem or an entire biome, this has a direct impact on the ecological balance. Most of direct human impact is related to the exploitation of natural resources, i.e. taking more from nature than can be renewed during the same time period with the processes of biomass production. It is especially important to take into account that many of the natural resources humans exploit are non-renewable, which means those organic materials are not produced any more. The main example are fossil fuels (petroleum, coal and natural gas), as well as many types of mineral raw materials. At the same time, every surface, which is for instance covered with concrete or asphalt, is permanently changed, and the ecological relations present prior to such an interference are no longer possible. General examples of direct impact are:

- Deforestation, as well as tree planting
- Hunting and fishing, as well as game and fish breeding
- Agricultural tillage, including livestock breeding
- All types of urbanization (construction)
- Irrigation by building dams or drainage (melioration)

In most cases, a change in habitat conditions does not mean there is no habitat left for the "wild" (unbred) species, and it especially does not mean that the quality of human habitat is diminished or spoiled. Humans generally raise their own quality of life, but it is at the expense of altering the original natural balance. In doing so, many species lose their own habitat or become directly extinct. It is estimated that humans today permanently exterminate at least four species per hour and that it is the highest recorded rate of extinction in the history of this planet. In addition to that, with their direct (and indirect) impact, humans change some areas to such an extent that those areas are no longer habitable even for them.

10.2 Indirect human impact - pollution

Practically all indirect human impact on the ecological balance can be regarded as pollution.

"Pollution" is an internationally accepted term for a concept which in Croatian stands for two different terms that translate as "pollution" (zagađivanje) and "contamination" (onečišćenje). Possible discrepancies between these two terms in Croatian are linguistic in nature, and are therefore not going to be analysed here, but all terms are given equal significance. Often, the word "pollution" is used for signifying a higher degree of pollution, while "contamination" is used to signify a lower degree of pollution.

Pollution can be defined as an undesirable change in physical, chemical and/or biological properties of air, soil and/or water. Therefore, change is viewed in a negative sense.

The substance with which we pollute is called a pollutant. Pollutants are residues of the substances humans produce, use and discard. For example, to produce an object (e.g. a car), a certain amount of water is often contaminated and a certain quantity of various types of gases is released into the atmosphere (with the consumption of natural resources). When this object is used, it continues to release various substances (and it generally consumes energy), and when it is disposed at the end of its service life, it continues to additionally pollute the environment. This problem seems to be ever increasing due to the growth of human population on Earth, and especially per capita. In each new decade, people have an even greater need for industrial (and other) products and their service life continues to shorten.

The damage resulting from pollution can be categorized in many different ways. This is one of them:

- Expenditure of raw materials through wasteful exploitation
- High inspection and clean-up costs (damage control)

- Human health (as well as the health of animals); increase in malignant diseases

All forms of pollution can be classified in the following nine categories:

10.2.1 High molecular organic compounds

In this sense, high molecular organic compounds represent organic matter: carbohydrates, fats and proteins. While they are present in living organisms, these materials constitute the biomass generated in continuous production processes: primarily by photosynthesis (P), and then by the metabolism of herbivores (C1), carnivores (C2) and carnivores that feed on other carnivores (C3). After becoming waste from living organisms, this biomass becomes organic matter as an abiotic factor, which is considered to be the environment's "self-load" (auto-load). Decomposition ("auto purification") takes place at the same time, which is in dynamic and approximate equilibrium with production at the ecosystem level (Figure 81). Also, an important fact is that organic matter is the only food all heterotrophs need for their survival (consumers C1, C2 and C3), is always desirable and generally insufficient. Then how can such a valuable food source be a pollutant? The problem occurs when the quantity of organic matter found outside of living organisms exceeds the quantities heterotrophs are able to consume. This happens when humans release additional (waste) organic matter into the system. The first reaction to the excessive quantities of food is an increase in numbers and biomass of heterotrophs, including saprotrophs (saprophytes). Heterotrophs need oxygen to survive, and the increase in their abundance also leads to an increase in their need for oxygen. There is a decrease in available oxygen (microaerobic conditions), and even a complete depletion of oxygen (anaerobic conditions). A great number of heterotrophs die, and the processes that take place without oxygen lead to increased emissions of the gases CH_4, H_2S, and CO_2, in which case we talk about pollution. Here, the hydrogen sulphide (H_2S) can be recognized by its unpleasant odour signifying the breakdown of organic matter due to the absence of oxygen. The entire composition of species is changed and only microaerobic and anaerobic organisms survive. One example is the extinction of jellyfish in the northern Adriatic. Once, 44 registered species inhabited that area, while today there are only seven, which means 37 species have gone extinct. The reasons behind their extinction are the nearly anaerobic conditions at the bottom of the sea, where a part of the life cycle (the polyp, hydra stages) of most species of jellyfish takes place. The surviving species of jellyfish are the ones whose entire life cycle takes place at the surface of the sea, where there is enough oxygen.

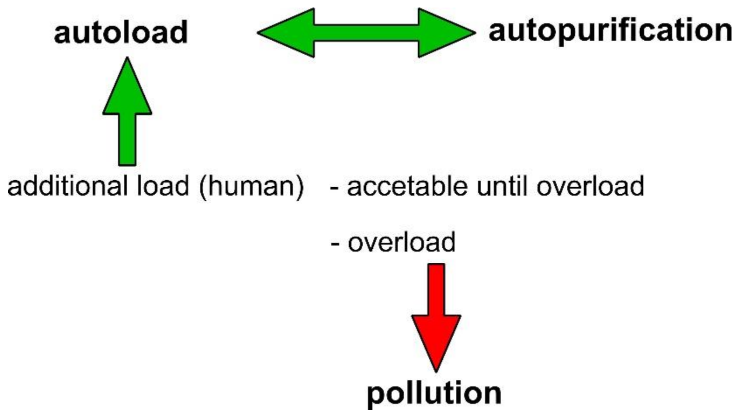


Figure 81. A diagram of the process in which the additional organic matter becomes too much for the system to process and this ﬁverload"then becomes ﬂollution" due to the lack of oxygen. Source: Authors

The consequences of the excess organic matter are easily noticeable in aquatic systems. That is why categories of water are determined according to the degree of load/contamination by organic matter. There are 4 types of water according to the degree of contamination:

I (o) oligosaprobic waters. The cleanest water with virtually no organic matter. Examples of this type of water are mountain streams where the water is shallow and the Sun's rays reach the bottom of the stream, so photosynthesis is possible at all levels. Also, rapid currents with numerous waterfalls and cascades promote saturation of water with oxygen (Figure 82).

II (β) beta-mesosaprobic waters. These are lowland rivers with a degree of contamination free of human impact (water's natural state). The water contains minimally 6 mg of O_2/l. These waters support rich biocoenoses (Figure 83).

III (ά) alpha-mesosaprobic waters. In nature, these can be river arms where water deposits leaves, branches and other organic material. In fish ponds, people purposely keep the quality of water at such a level by fish feeding. Oxygen levels range from 3 to 6 mg/l, and it is important to sustain the oxygen levels at or above 3 mg/l, because lower levels would cause the fish to suffocate. In seeking a compromise between giving as much food as possible to the fish and maintaining adequate oxygen levels, summer proves to be a particularly difficult season when there is a general drop in water levels and the water is warmer, which makes it difficult for oxygen to dissolve. In alpha-mesosaprobic waters, there are around 100,000 bacteria per mm^3 of water. This kind of environment is favourable for blue-green algae, diatoms and leeches.

IV (p) polysaprobic waters. As a rule, these are channels and slurries with a high load of organic matter. Oxygen levels range from 0 to 3 mg/l, and there are >1,000,000 bacteria per mm^3. There are no fish in these waters, and the only species that can survive there are facultative anaerobes, nitrifying bacteria, bacteriophagous protozoa, and insect larvae of the genus Tubifex and Chironomus (Figure 84).

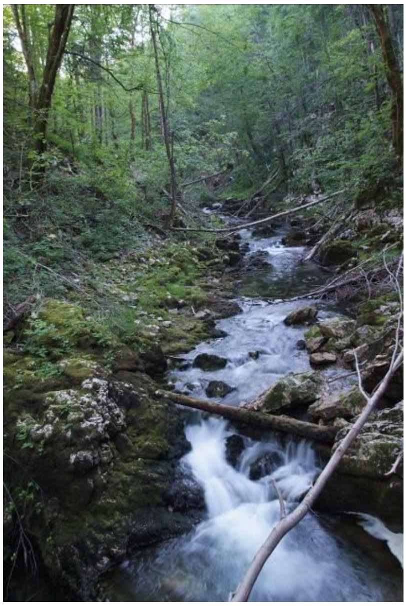


Figure 82. A mountain stream as an example of oligosaprobic water (Kamačnik). Source: Authors

Figure 83. A lowland river as an example of the beta-mesosaprobic water, which turns into alpha-mesosaprobic water when polluted with additional organic matter (Sava near Zagreb). Source: Authors

Figure 84. A slurry channel as an example of a polysaprobic water. Source: Authors

10.2.2 Inorganic matter

All organisms living on Earth today have evolutionarily adapted to the concentration of inorganic matter present in the environment. On the one hand, organisms need most of these substances, but at the same time, an increase of the quantities already present in the environment can have a harmful effect. The range between the minimum quantities required and the maximum tolerable quantities is often very limited. It is extremely rare that an increase in concentration of certain inorganic substances has a stimulative effect on certain species and populations, as opposed to the effect of the limited addition of organic substances into the environment as described in the previous section. Among the inorganic substances considered to be pollutants, we include heavy metals, acids, lyes, salts, insecticides, herbicides. In simple terms, it can be concluded that any amount of these substances, when added by man, has a harmful effect.

10.2.3 Suspended particles

Suspend particles are different substances scattered like dust. The particles are inherently non-toxic (although some may be toxic), but their harmful effects are mechanical. Their amount changes the surface on which they accumulate. If they accumulate on body parts of living beings, they typically reduce the respiratory surface, such as the lungs or gills, and on the leaves of plants they close the stomata thus reducing photosynthesis. Among these we include substances such as ash, coal dust and stone dust. People who work in mines and breathe in coal dust tend to suffer from anthracnose, and people who work in the quarries suffer of silicosis. Working with asbestos causes asbestosis, and it can lead to mechanical and carcinogenic effects. Suspended particles can also change habitats, so for example, they reduce the transparency of water, and at the bottom they create a muddy sediment. During the last century, when the coal mine Trbovlje was still active, 1,000 tons of coal dust was rinsed into the Sava River every day, so the water was only transparent up to a depth of 35 cm, and there was no visibility below that depth. The layer of sludge formed by the dust that settles on the bottom of a water system prevents life for all species that need a different type of substrate.

10.2.4 Radioactive matter

In addition to direct harmful effects of different types of radiation in the ecological sense, it is important to consider the problem of radioactive isotope accumulation in the food chain. From low concentrations in soil through those in lichens, fungi and plants to meat, fats and milk of large herbivores, and especially carnivores, radioactive radiation can range from 1 to 1000. One of the specific problems of our time is the matter of radioactive waste disposal. All of that potentiates a long half-life of a large number of radioisotopes, so it is necessary to think far into the future.

10.2.5 Thermal pollution

Thermal pollution can prove to be a problem at a local level, but it is particularly serious because it also occurred on a global scale.

Local thermal pollution: Usually, thermal pollution refers to a temperature rise in an aquatic ecosystem (bay, lake, river) caused by the discharge of industrial hot water. Here we refer to clean warm water (for example, water from the cooling systems of thermal power plants), but such water may contain certain contaminants, which then poses an additional problem. Heat contributes to the rate of biological processes, and for poikilothermic organisms it is specified by Van't Hoffs rule, which says that an increase in temperature of about 10 °C accelerates all biological processes two to three times. As in case of pollution with organic matter, the problem is the shortage of oxygen. On the one hand, more heterotrophs are present due to warmer water (and they consume oxygen), but on the other hand, the warmer the water the less oxygen can be dissolved in it. It is believed that an abrupt change in temperature of 5 °C kills the more sensitive fish, and that a summer temperature of 28 °C is lethal for most species of fish. International regulations allow an increase in water temperature of up to 3 °C.

The air temperature can locally be higher than the environment if in a certain area (for example, above a town or an industrial area) a dome of smog is formed, causing a greenhouse effect (Figure 85).

Figure 85. A layer of smog above Zagreb has a greenhouse effect. Source: Authors

Global thermal pollution: The air temperature is rising globally due to the greenhouse effect caused by the increase in carbon dioxide (CO2), methane (CH_4) and some other gases in the atmosphere (Figures 86, 87, 88 and 89). The most significant is carbon dioxide additionally produced by burning fossil fuels. In the last one hundred years, due to human influence, the concentration of CO_2 in the atmosphere has continually increased, and in July 2014 it reached 399.00 ppm (parts per million). Before that, throughout the history of planet Earth the highest CO_2 levels were between 275 and 300 ppm, and that was more than a 100,000 years ago. The greenhouse effect is a process in which thermal radiation reaches the Earth's surface through the atmosphere, but it is only partially reflected back into the upper layers of the atmosphere. Air and water temperatures have been monitored worldwide since 1880. Measurements have shown that 2013 (alongside 2010) was the warmest year since the measurements have started. The average increase in air temperature in relation to the average value in the past 100 years is 0.99 °C, while the average increase in ocean temperatures is 0.48 °C. These seemingly small changes in temperature cause very noticeable climate changes. There are numerous examples of glacier recession, the shortening of periods when the surface of the sea is frozen (which poses a serious problem for polar bears), the degradation of coral reefs (the sea is more acidic due to an increase in CO_2 levels), as well as more frequent storms and floods.

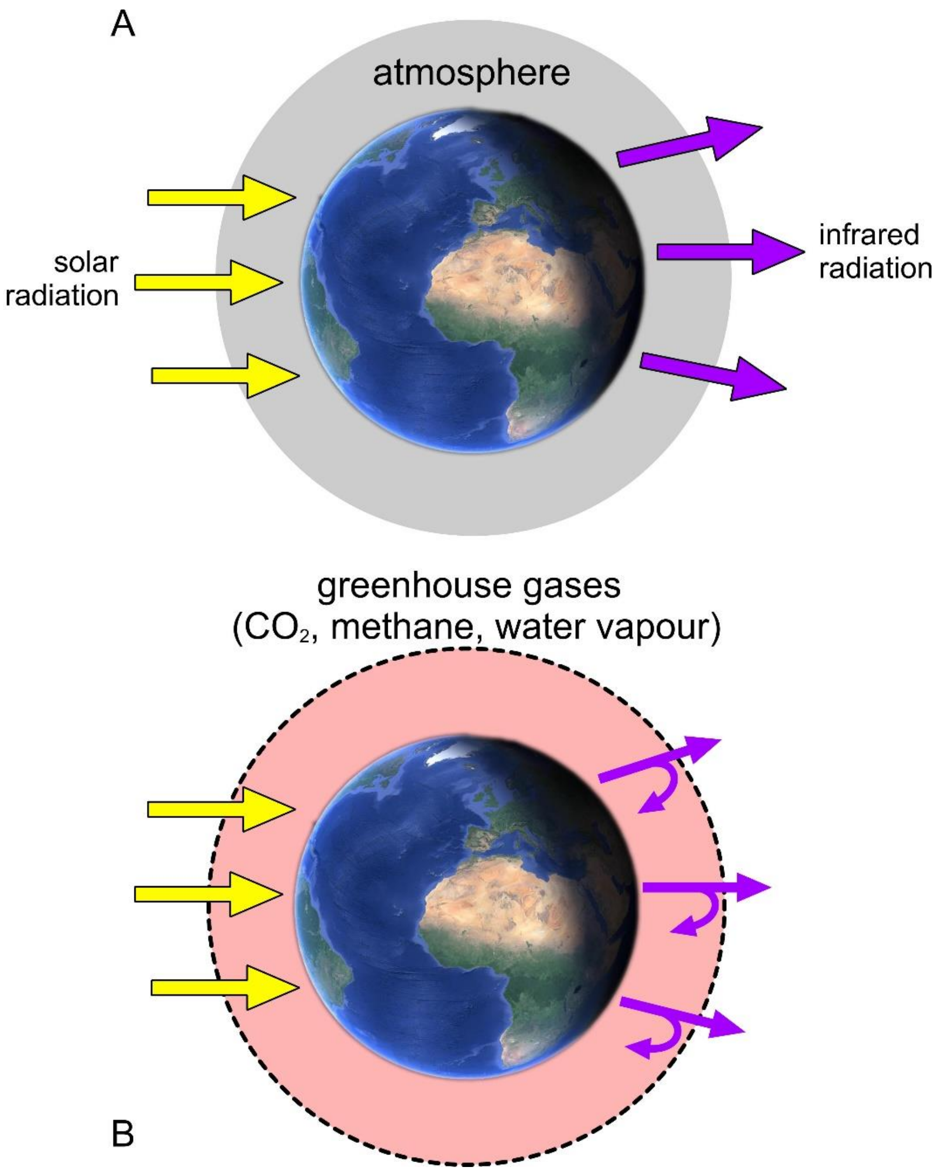


Figure 86. Global warming due to the greenhouse effect. (A) A whole spectrum of the Sun's electromagnetic radiation heats planet Earth. The Earth cools down by radiating heat through infrared radiation.(B) The increased concentration of greenhouse gases in the atmosphere causes absorption and impermeability of energy radiation within the infrared spectrum, thus preventing the cooling of the Earth. Greenhouse gases allow solar radiation to pass through the atmosphere and continue to heat up the Earth. Source: Authors

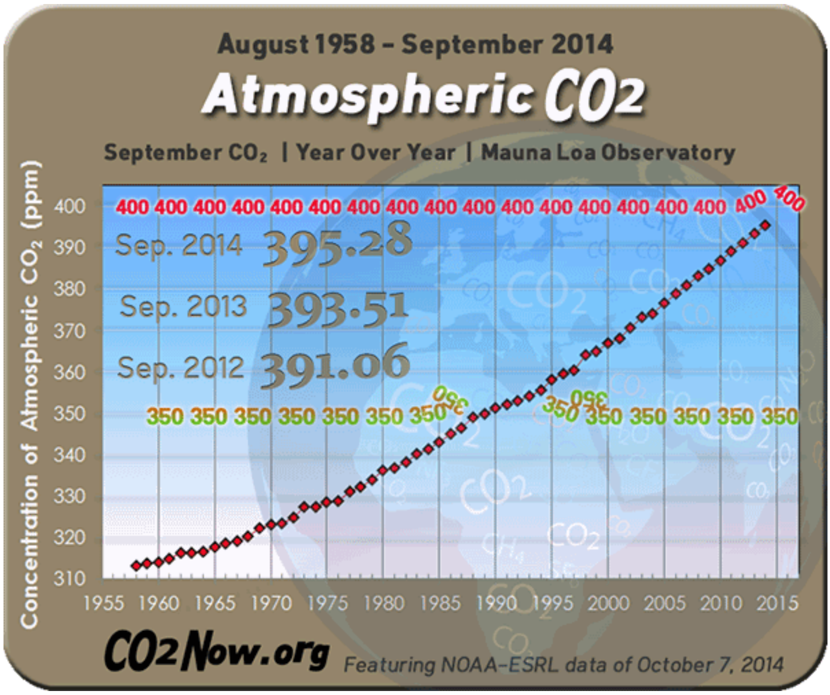


Figure 87. The growth curve of CO_2 concentration in the atmosphere. Source: http://co2now.org/

Figure 88. The mouth of the glacier into the sea (Greenland). Source: Authors

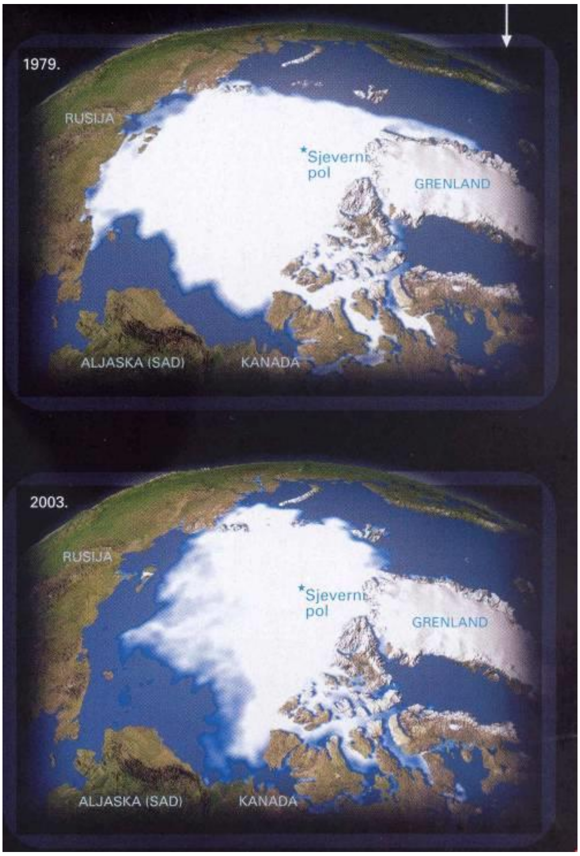


Figure 89. The reduction of the ice cap around the North Pole from 1979 to 2003. Source: National Geographic 2003.

10.2.6 Acid rains

The reason why different forms of atmospheric precipitation are often acidic is the result of emissions of sulphur oxides (SO_x) and nitrogen oxides (NO_x) into the atmosphere, which causes the formation of sulphuric acid (H_2SO_4) and nitric acid (HNO_3). These gases are increasingly released into the atmosphere primarily by burning fossil fuels. Coal and petroleum, which have higher sulphur content, are particularly harmful. Acid rains and acid snow affect various ecosystems. When certain aquatic ecosystems (usually lakes) become acidified, fish start to have breathing problems because there is an excess of aluminium oxide which clogs their gills. Invertebrates with shells also face problems because their calcium carbonate ($CaCO_3$) shells dissolve. Plants primarily get damaged by the acid on the leaves, which damages the stomata, and in the root system the acid disrupts the transmission of minerals, leading to a lack of magnesium and a surplus of aluminium. The most vulnerable are firs, but other trees are also at risk (Figures 90 and 91).

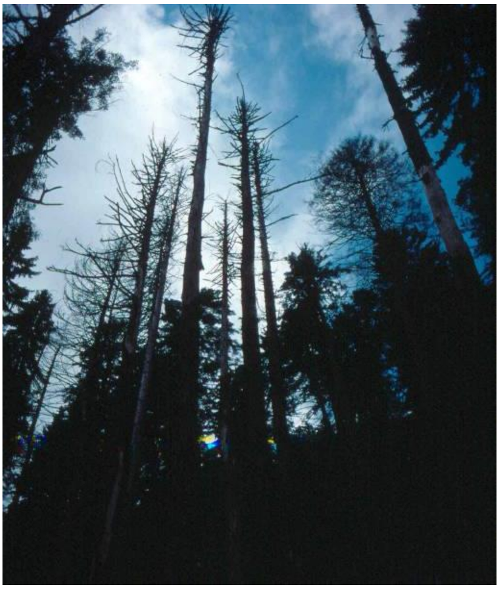


Figure 90. Dried silver fir trees in Gorski kotar. Source: Authors

Figure 91. A view above the clouds penetrated by columns of smoke from factory chimneys. Source: Authors

10.2.7 Ozone holes

The deficiency, i.e. the decrease in the ozone (O_3) share in the stratosphere is referred to as an “ozone hole”. Normally, only one three-atom oxygen compound can be found in 10 million air molecules or 0.6 ppm in the air. Ozone is formed by the action of solar ultraviolet radiation and atmospheric electrical discharges on oxygen molecules. The formation and decomposition of ozone are in dynamic equilibrium in normal conditions. The depletion of ozone is caused by the pollution of the higher layers of the atmosphere with chlorofluorocarbons (CFC compounds) that act as catalysts in the destruction of O_3 and its transformation into O_2. Humans release these gases mainly in the form of freons, because they are used as propellant gases in a variety of devices: all kinds of spray bottles, including fire extinguishers, in cooling systems, and even in jet motor fuels. When this gas was discovered in 1928, it seemed that it possessed only positive qualities, because it is, among other things, non-toxic, non-flammable, non-corrosive and stable. The negative consequences of widespread use were observed only around 1980, when an unexpected discovery showed that CFCs destroy ozone. Through the thinned ozone layer, larger amounts of ultraviolet (UV) rays coming from the invisible part of the solar radiation spectrum penetrate to the Earth's surface. With increased concentration, these rays have a mutagenic effect. The effects are more common skin cancers (melanoma), and a general weakening of the immune system, cataracts, and a decrease in vegetable crop production. Since 1995, the use of CFC compounds has been prohibited, but it is estimated that it will take decades for the ozone layer to spontaneously regenerate.

10.2.8 Light pollution

Through evolution, all living organisms have adapted to the regular alternation of day and night related to the rotation of the Earth around its axis. Humans have produces a great number of artificial light sources, which allow a variety of activities during the night. When this light penetrates into natural ecosystems at night, living conditions are altered, and we can observe different disorders. For example, the introduction of light in some caverns to allow visitation leads to the growth of certain plants (algae, mosses, and even trees), which can photosynthesize in such conditions. Plants in city parks also have an altered photosynthesis regime. Night lights have a strong effect on many animal species. Insects are attracted to lamp posts where they are easily accessible to bats and birds that would normally be inactive at night, and that leads to increased mortality in many species. This poses a particular problem for young sea turtles during their hatching season on a strip of beach, because they need to find their way to the sea which should be brighter than land due to the reflection of the stars and the moon. Urban lights are often brighter than the reflection of the night sky on the sea surface, so many of them start moving towards those lights and get killed on the roads or die before they find the sea.

In January 2012, the Republic of Croatia passed the Light Pollution Protection Act. The Act proscribes the requirements that public lighting and other sources of night lighting need to meet.

10.2.9 Noise

Hearing is a vital sense and sounds play a vital role in the lives of most animals. Human-produced sound waves have not been present for a long enough time for animals to fully adapt to them. Noise sources in a natural ecosystem usually drive animals to flea the source zone. One of the examples is traffic noise on motorways that cuts through forest ecosystems, where there is 70% less animal activity in the 500 meter range on each side of the road. Careful avoidance of unnecessary noise is also important for livestock living in intense breeding facilities. Various devices for ventilation, food supply and cleaning can increase the occurrence of stress related diseases (for example bleeding in the digestion system) and consequentially lead to a decrease in production.

11 Further reading

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We thank the companies that supported the printing of this textbook.