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Ecology

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Abstract:
Ecology is a science that studies the mutual interactions between organisms and their environment. The fundamental subject of interest in ecology is the individual. Topics of interest to ecologists include the diversity, distribution and number of particular organisms, as well as cooperation and competition between organisms, both within and among ecosystems. Today, ecology is a multidisciplinary science. This is particularly true when the subject of interest is the ecosystem or biosphere, which requires the knowledge and input of biologists, chemists, physicists, geologists, geographists, climatologists, hydrologists and many other experts. Ecology is applied in a science of restoration, repairing disturbed sites through human intervention, in natural resource management, and in environmental impact assessments.

Keywords: elements of ecology, environment, habitat, biodiversity

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1 Introduction

The phrase ecology is used often today and has a wide meaning. Ecology is referred to as a science, ecology as nature, ecology as an idea and ecology as a movement. In this chapter, ecology is used to refer to ecology as a science that studies the mutual interactions between organisms and their environment. For practical reasons, ecology is typically divided into plant ecology, animal ecology and human ecology. One of the first to describe the significance of ecological observations was renowned natural historian Charles Darwin, in his book *On the Origin of the Species* [1]. Darwin explained numerous examples of evolution (adaptation, natural selection, fighting for survival and extinction of the species) which included an entire range of mutual relations between organisms and their interactions with the conditions of their environment. The word ecology (Greek: *oikos* = house, home, habitat; *logos* = study of, knowledge) was first coined by the German biologist Ernst Haeckel in his book *Generelle Morphologie der Organismen* [2].

The fundamental subject of interest in ecology is the individual, the plant or animal organism. Individuals of plants or animals do not live isolated, but are typically grouped, and such groups of similar individuals are called species. Though biologists have not agreed on a single definition of the species, most accept that species are groups of individuals that share similar morphological and genetic traits, and individuals of a species are able to reproduce with one another and create fertile offspring. Today, ecology is a multidisciplinary science: in order to provide answers to many of the questions this field of science deals with, cooperation is needed from many different fields. This is particularly true when the subject of interest is the ecosystem or biosphere, which requires the knowledge and input of biologist, chemists, physicists, geologists, geographists, climatologists, hydrologists and many other experts.

Humans, in addition to consuming massive amounts of energy, have polluted nature with industrial waste, harmful gases, pesticides, heavy metals and organic compounds, thereby drastically reducing the diversity of plant and animal species, which has started to change the ecological balance. The altered environment negatively impacts human health and is even gradually threatening human survival (climate change, greenhouse effect, destruction of the Earth’s ozone layer). Industry – the foundation for global prosperity – has created significant global threats to humankind’s opportunities for continued survival. Therefore, future development should be based on protecting the environment, in the form of sustainable development and management. This implies that the use of natural resources must be tolerable, allowing those resources to regenerate and remain in ecological balance. If we master the fundamental principles of ecology, we will be more easily able to create the conditions for the rational use of natural resources of the biosphere, and to improve relations between humans and their natural environment.

Ivancica Ternjej is the corresponding author.

2 Conditions for life

Many factors influence the distribution and survival of species. Generally, they can be divided into factors of the non-living environment – abiotic – and factors of the living environment – biotic factors. The habitat, or biotope, as the area where a given species lives, is characterised by a specific complex set of ecological factors. None of these factors acts alone, and so organisms are distributed only in those areas where the gradients of specific factors in play overlap in a suitable way. The range of fluctuation of a single ecological factor, within which the life of a certain organism is possible, is called ecological valence (Shelford's law of tolerance) (Figure 1). However, the effect of one ecological factor may not be within the limits of the ecological valence, and organism could not survive. For each ecological factor, there is an optimal range, and a minimum and maximum. At both the minimum and maximum, the intensity of ecological factor corresponds to the stress zone, or area pessimum (from lat. pessimus – very bad). Optimum is that quantity or intensity of the ecological factor whose intensity is most suitable for the organism and the consequence is his maximal growth and development. The concept of the limiting effect of an ecological factor was introduced in ecology by V. E. Shelford [3], and it is valid for all ecological factors and for all organisms.

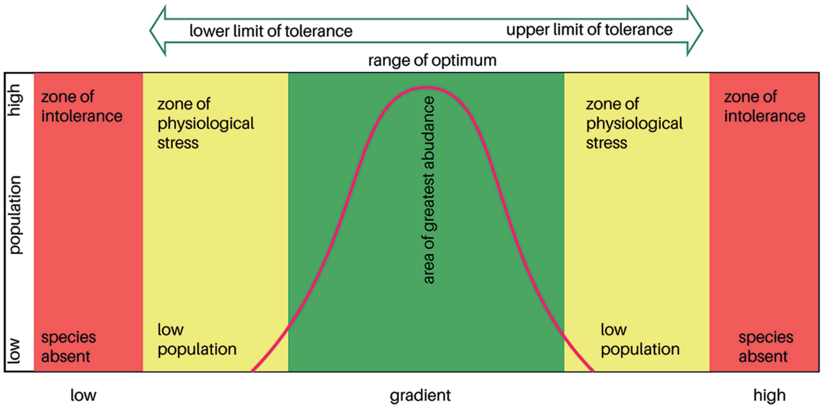

Figure 1: A schematic representation of the ecological valence [inspired by [4].

Organisms with a wide range of tolerance for an ecological factor are called eurivalent species, while organisms with a narrow range of tolerance for an ecological factor are called stenovalent species. What is interesting is that one single life factor at a minimum can exclude a certain species from a given habitat, regardless of the fact that all other factors may be at optimum ranges.

2.1 Abiotic factors

Temperature and moisture are key ecological factors that determine the distribution and development of plants, and based on these factors, we can differentiate different vegetation zones on Earth. For animals, vegetation is an important factor as shelter and a source of food. In areas where ecological conditions are unfavourable, and the plant cover is poorly developed, the diversity and abundance of animals is also lower, due to the scarcity of suitable shelters and available food. Many animals are distributed only with certain temperature limits that are suitable for their survival, and the very distribution of climate areas on Earth becomes a barrier to their broader dispersal. Monkeys and parrots are primarily distributed in the tropical and subtropical zones; the polar bear, walrus and some diving birds are distributed in the polar regions. Another important ecological factor is light. The rhythmic change of light is a dependent factor for many of the daily and seasonal phenomena and activities in plants and animals. Day length is a factor that determines when leaves begin to fall in many deciduous tree species in moderate climate zones. There are long- and short-day organisms. For example, barley is a long-day plant and blooms under long-day light, while in tobacco, long days prevent blooming. Constant daylight is a reason why plants in the tropics bloom year round, and why polar plants fail to thrive in other parts of the world, as they are adapted for long days. Trout spawns at a temperature of 6 – 7 °C (winter), though spawning can be achieved experimentally in periods of higher temperature (summer) just by reducing the amount of daylight. Shortening daylight also stimulates migrating birds to fly south. How organisms react to the rhythmic changes in the intensity of light – day, night – is of particular ecological importance. Among mammals in temperate forests 30–40 % are active during the day and 60–70 % are active during the night. The distribution of animals also depends on light. For example, in Norway, the wood mouse (*Apodemus sylvaticus*) reaches the maximum latitude of 62°N. The reason for this is the duration of the summer nights, which in that part of the world lasts only 5 hours. Since the wood mouse is a nocturnal animal (active and feeds at night), a shorter night is one of the main reasons why this animal cannot disperse further north, as during such short nights, this animal simply cannot feed enough to ensure its survival.

Specific behaviour patterns are also tied to changes in photoperiod and temperature, such as bird migrations. In aquatic ecosystems, primary producers (phytoplankton, macrophytes and sea grasses) are limited to the depth of light penetration, water temperature and the quantity of available nutrients, while for animals, the quantity of metabolic gases (oxygen and carbon dioxide), salinity and pressure (in the sea) are important factors.

2.2 Biotic relationships

Population

The living area of a species consists of a multitude of intertwining abiotic factors that affect the organism. However, organisms of the same species, and those of other species, also come into contact and affect one another. A population is a group of individuals of the same species in a given area. Each population has their own dynamics and properties: a size of the population, spatial distribution, age structure, sex ratio, birth, death, immigration and emigration rates. The spatial distribution of individuals in the environment could be caused by the distribution of resources or by social relationships among the individuals.

Mutual interactions and relationships between individuals of the same species are called intraspecific relations. If a certain resource essential for the life of the population is limited, this will result in competition among the population members (intraspecific competition), which can limit the population size. When ecologists investigate endangered species, the size of the surviving population is of crucial importance in the design of proper management. Population size also depends on other population characteristics: natality, mortality, survivorship, reproduction potential and dispersion. Populations are increased through the birth of new individuals (natality) and the arrival of new individuals (immigration), while they are reduced through death (mortality) and those leaving the population (emigration).

Population growth can be exponential or logistic. Exponential population growth is characteristic in invertebrates and some vertebrates (rodents) while colonising new habitats, when the two most important resources – space and food – are not yet limiting (Figure 2). But no real population can for long continue increasing exponentially and are instead stabilised at a certain level.

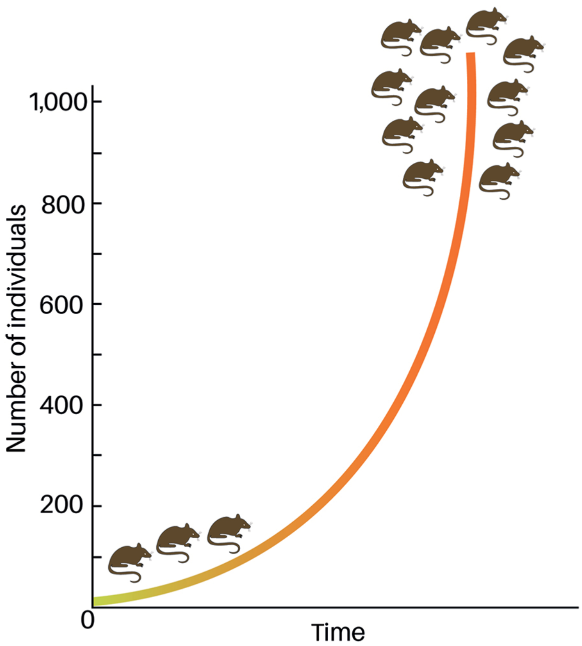

Figure 2: The exponential growth curve [inspired by [5].

Logistic growth is caused by the limitation of resources in the habitat. It is characterised by the carrying capacity (K) of the environment, which indicates the maximum population size that the habitat can support with its resources. For example, sheep brought to the Australian island of Tasmania in 1800 experienced a rapid population expansion to almost two million individuals. The result was massive competition for food and by 1885, their numbers had declined and stabilised, to the level of about 1.6 million individuals (Figure 3).

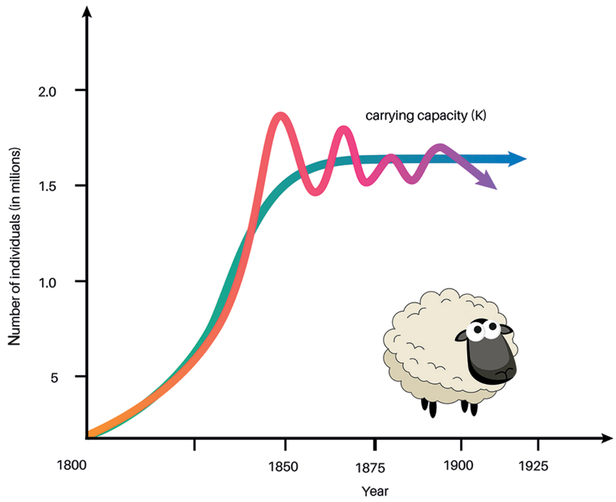

Figure 3: The logistic growth curve. When the carrying capacity is reached, there is no further increase in density [inspired by [5].

The terms r-selection and K-selection have been used by ecologists to describe the growth and reproductive strategies of various organisms. The r and K classification was originally proposed by R. McArthur and O.E. Wilson [6]. R-selected species live in variable, unstable habitats, while K-selected species reside in stable environments. Small body size, early reproductive maturity, high fecundity and low parental investment are main characteristics of the r-selection species. Flies and most invertebrates are an example of an r-selected species. The extreme opposite is K-selection species with low fecundity and high parental investment. Most mammals are examples of K-selected species.

2.2.1 Interspecific relationships

Relationships between different species (populations) are called interspecific relationships and imply an entire series of mutual influences, such as competition, predation, parasitism, mutualism and commensalism. For example, one species may feed on another, and is, therefore, dependent on it.

Competition

Species can compete for the same food source or space, and thus they are in competition. An interesting example is the barnacles *Chthalamus stellatus* and *Balanus balanoides*. Both species inhabit the tidal zone, though *Chthalamus* always is found in higher areas and *Balanus* in lower areas of that zone. Connell [7] conducted experiments with these barnacles: he moved the rocks housing *Chthalamus* to lower areas and those housing *Balanus* to higher areas, and he physically removed the *Balanus* from the rocks in the lower areas and *Chthalamus* from the rocks in the higher areas. Connell found that *Chthalamus* was able to survive normally in the lower level on the rocks he had placed there. However, *Balanus* did not fare well on the rocks in the higher zone, as this species is less tolerant to drying out. It is interesting that Connell also took photographs of larvae of both species equally colonising the lower zone. However, as *Balanus* individuals grow, their base expands more rapidly and they literally expel the *Chthalamus* larvae from the rocks. On the one hand, the ecological factors act on the vertical distribution of these species; while on the other hand, during colonisation of rocks the acting factor is competition.

Competition can be so great that one species completely expels another from a habitat. This is called competitive exclusion. Many allochthonous (alien) species can also expel autochthonous (indigenous) species through this process of competitive exclusion. In many clean rivers still in a relatively natural state, the introduction of rainbow trout (*Oncorhynchus mykiss*) has resulted in significant reductions of populations of the native brook trout (*Salmo trutta*). The introduction of alien and invasive species has particularly impacted the Dinaric karst rivers of the Adriatic basin, which abound in endemic species [8]. Another example is the introduction of the American grey squirrel (*Sciurus carolinensis*) in Great Britain between 1876 and continued to 1915 or later. By the mid-1920s, the population of the native red squirrel (*Sciurus vulgaris*) had declined drastically due to disease. The spread of introduced species co-occurred with the declining population of the indigenous species. It has been confirmed that the grey squirrel spread in those habitats not inhabited by the domestic red squirrel, and also into those where the domestic squirrel population was in decline due to disease. The introduced species was stronger in competition for food sources and habitat, and also more resistant to disease, and therefore drove out the native species in a great part of Britain. The domestic red squirrel has maintained large populations only in certain isolated localities, which had not been exposed to the epidemic (e. g. on the Isle of Wight off the south-east coast of Great Britain) [9].

There are countless examples of competition. However, most species having the same needs often share the same habitat. This is considered coexistence, indicating that they have somehow succeeded in overcoming or reducing the competition between them. One way different species use the resource is to use it at different times. In forests, predator bird species, such as falcons and buzzards, hunt by day, while owls hunt by night. Both groups feed on small mammals. The macrozooplankton of Visovac Lake in Krka National Park (Croatia) consists of four species of water fleas. Of these, two species are in direct competition for food, and both belong to the same order of water fleas (*Daphnia*) [10]. The species *Daphnia longispina* is small and feeds primarily on algae from 15–20 µm in size. The second water flea species, *Daphnia cucullata*, feeds on green algae of the same size. However, unlike the first species, this species can also feed on slightly larger amounts of small organic particles. The annual cycle of these two crustacean species is shown in Figure 4.

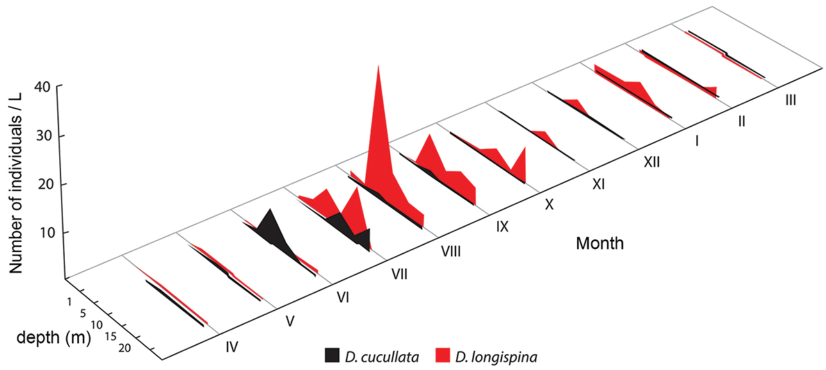

Figure 4: Niche separation in space and time between two *Daphnia* species in Visovac Lake.

In this case, the spatial and temporal distribution of these species is primarily determined by food sources. It can be noted that *D. cucullata* develops the densest populations in June, when the species *D. longispina* is not present yet in the macrozooplankton. Namely, this species begins to appear in July, and when it does, it slowly forces out the first species. During July, their populations are separated spatially: *D. cucullata* is found at depths of 10 and 20 m, while *D. longispina* is found at depths of 5 and 15 m. However, for the remainder of the year, only *D. longispina* is present in the macrozooplankton.

As explained in these examples, different species can coexist by separating their ecological niches, either spatially or temporally. Most often, the term ecological niche implies the position of a species in the community in terms of food, which can be considered its microhabitat. It could be said that the habitat of a species is its "address," while its niche is its "profession"! In that way, species living at the same "address" need not have the same "profession." However, this understanding of the ecological niche has been gradually evolving over the past 30 years. Today, many biologists feel that the ecological niche is not determined only by the feeding methods, but also by all the other ecological factors to which a species has adapted.

There is yet another way to avoid competition. In Asia Minor, the distribution ranges of two passerine bird species overlap: the western rock nuthatch (*Sitta neumayer*) and the eastern rock nuthatch (*Sitta tephronata*). Both species feed on insects in the soil. The size of the beak of each species determines the size of prey it can catch. Both nuthatches have a beak 26 mm in length, and therefore, it could be assumed that they will feed on insects of the same size, and that they will be in direct competition with one another. However, this is not the case in nature. In those areas where their distribution ranges overlap, the western rock hatch develops a beak 24 mm in length, while the beak of the eastern rock nuthatch grows to 29 mm! In areas where they do not overlap, and where they are not in competition, both species have a beak 26 mm in length [11]. This phenomenon is called character displacement. It is seen in the fact that species that come into competition in overlapping range areas will change those characteristics that create the competition between them.

Is there competition among plants? Plants resolve possible competitors through allelopathy. This is a phenomenon in which some plants secrete chemical compounds into the soil to inhibit the growth of other plants. For example, walnut or sage secretes compounds into the soil that will disable the group of other plant species to with a radius of several metres from the plant.

Predation

Another important biotic factor that can influence the distribution of a given species is predation. This is the relationship in which one organism, the predator, consumes another, the prey. The prey is alive when the predator first attacks! Predators can overhunt and completely eliminate prey species from a certain area, or they can disable range expansion and colonisation of new areas by potential prey. Though there is theoretical support for such a possibility, there is no actual proof that this occurs in nature. Such extreme events are only known to occur in cases of introductions of species that are not native to an area.

The influence of a predator on the prey population is evidently detrimental. However, predator effects on a prey population are not always easily predictable. There are two reasons for this: prey individuals that are killed or damaged do not always correspond to the random pattern of the entire prey population. Predators tend to select the prey that is easiest to catch: the young (and naïve), the old (and weak) and the sick (and helpless). Second, predation can impact the growth, survival and reproduction of prey. In other words, while predation is harmful to the prey individuals that are captured and consumed, it can be favourable to those individuals not captured. The case of the Kaibab deer is well known [12]. The initial population of 4,000 of these animals on the Kaibab Plateau, located in northern Arizona in the United States along the northern border of the Grand Canyon, grew to 100,000 in just 20 years (1905–1924), as humans hunted and eliminated their natural predators (the cougar and coyotes), Figure 5. This massive population growth resulted in great competition, primarily for food resources, and within the next 15 years, the population declined to 10,000 individuals. Therefore, it could be concluded that the relationship between predator and prey is what maintains the natural balance!

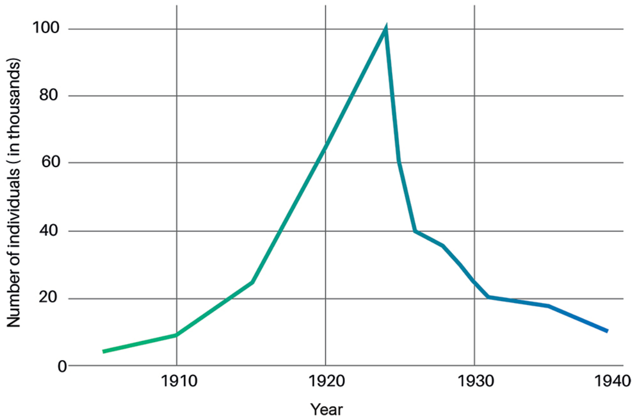

Figure 5: Changes in abundance of Kaibab deer after elimination of natural predators [inspired by www.biologycorner.com/worksheets/kaibab_key.html, Keeton Biological science].

It is also important to note which prey individuals are under the effect of predators and during which life stage. Young individuals cannot yet contribute reproductively to the population, and therefore the effects of predation of this segment of the prey population are less than if the predator catches a reproductively mature individual. The impact of a predator on prey is not constant, and is instead limited to certain time periods. For example, the boa constrictor (*Boa constrictor*) will rest for a while after eating its prey, while it digests. The success rate of hunting prey is not always 100 %, as prey may escape. Also, some predators take the time to learn how to hunt, and their efficacy will change with age: the young tiger or lion are less experienced and effective than adult individuals.

Parasitism

Parasitism is a relationship that is similar to predation. It could be said that parasitism is a special form of predation, in which the predator is most often much smaller than its prey (host). Unlike "classical" predators, the parasite typically does not kill its prey. This is a relationship in which the parasite has a benefit, while the host typically experiences more or less damage. As in predation, parasites are one means of regulating the natural balance. They maintain their host populations to a certain level, to ensure that they will not be left without a food source. However, introduced parasites can cause significant changes in the distribution of potential host populations. Lake trout (*Salvelinus namayscush*) is a widely distributed species throughout northern North America, but it is not adapted to the presence of parasitic lampreys (*Petromyzon* and *Entopshenus*). These lampreys attach to fish and feed off their tissue and bodily fluids. Niagara Falls is a natural barrier preventing the entry of these parasites into the Great Lakes, where large populations of lake trout thrived. However, with the construction of the Welland Canal, connecting Lakes Ontario and Erie, the lampreys spread throughout all the Great Lakes and caused substantial declines in the lake trout populations [13].

A similar effect was seen following the introduction of the parasite that causes malaria in birds (*Plasmodium*) to the Hawaiian Islands. The endemic bird fauna of these islands suffered significant population declines of some species, range contractions and even extinctions [14].

Mutualism

Mutualism is a relationship in which both species benefit. This relationship can imply a close physical interaction between members. Typically, one member of such a pair becomes completely dependent on the other, and for this species, this mutualism is obligatory. In extreme cases, in their interactions, these organisms begin to function as a single individual, as in the case of fungi and algae in lichens. One such example of obligate mutualism is the protozoans and bacteria in the digestive tracts of certain animals, such as ruminants or termites. Protozoans in the digestive tract of termites break down wood into compounds the host can digest further. Neither of these organisms would be able to survive on their own. Mycorrhiza is another form of mutualism. This is a symbiosis between the roots of a vascular plant (tree) and fungi. The fungi supply the tree with nutrients, while the plant supplies the fungi with carbon. However, mutualism may also be facultative (not obligatory), in which mutualists can survive normally without one another. The most common example of this form of mutualism is the hermit crabs and certain sessile anemones. The hermit crab settles in an empty snail shell, upon which one or more anemones can settle. The anemones defend the crab with their stinging cells, and since they are sessile organisms, the crab serves as their "means of transport." However, both of these organisms can survive without the other.

A special form of mutualism can also be seen in the relationship between certain plants and insects (or birds) as pollinators. Coevolution has gone very far here, as can be witnessed in the form of flowers, colouration and special mechanisms developed by plants and their pollinators. The most unusual examples of mutualism can be seen in the relationship between ants and certain plants. The South American species of acacia (*Acacia*) have thorns in which some ant species of the genus *Pseudomyrmex* built their nests [15]. The plant contains the protein-rich Beltian bodies (resembling berries) and the sweet fluids that the ants feed on. In return, they protect the plant from attack by other herbivorous insects and vertebrates. They also eliminate the surrounding vegetation, thus reducing competition with other plants. This specialisation has resulted in identical distribution ranges for these two species.

Commensalism

Commensalism is a relationship in which one species benefits, and the second neither benefits nor suffers. The Adriatic Sea is home to small soft-bodied crabs of the family Pinnotheridae, which are in commensal relations with numerous bivalves, ascidians and the pipes of the polychaete worms (Polychaeta). Among the many genera and species, the most common are the crabs that inhabit the noble pen shell and the crabs that inhabit oyster and mussel shells. The bivalves are not disturbed by these small crabs, which are seeking shelter from predators. Another example of commensalism is epiphytic plants. These are mostly tropical plants characteristic as living on the branches of other plants. They use only space on which organic material and water has collected, and have no other impact on the host plant.

2.3 Community

No organism in nature lives in complete isolation. A collection of organisms interacting directly or indirectly in a habitat is a community. The concept of community is based on the efforts of botanists to group certain plant formations. In the early twentieth century, American scientist Frederic Clements [16] proposed that the plant units, which he called the "*association*," are strictly determined and fixed for a long period of time. Today, the term "*community*" involves a group of all living organisms in the same habitat where among them there are relations of mutual dependence and biological connections. Their interaction is important for the functioning of the community.

2.3.1 Community structure

The community is characterised not only by a mixture of species, but also by physical features. On land, the vertical structure of the community is mostly determined by plants. Their height, branching and the amount of leaves, determine temperature, moisture and light vertical gradient (Figure 6). Plants make the framework of the community in which animal species are adapted to. A well-developed forest ecosystem contains several layers of vegetation. There are the canopy layer, the understory, the shrub layer, ground layer and the forest floor. The most important role in the fixation of sun energy has a canopy. Aquatic systems, like lakes and oceans, are also vertically stratified primarily by penetration of light.

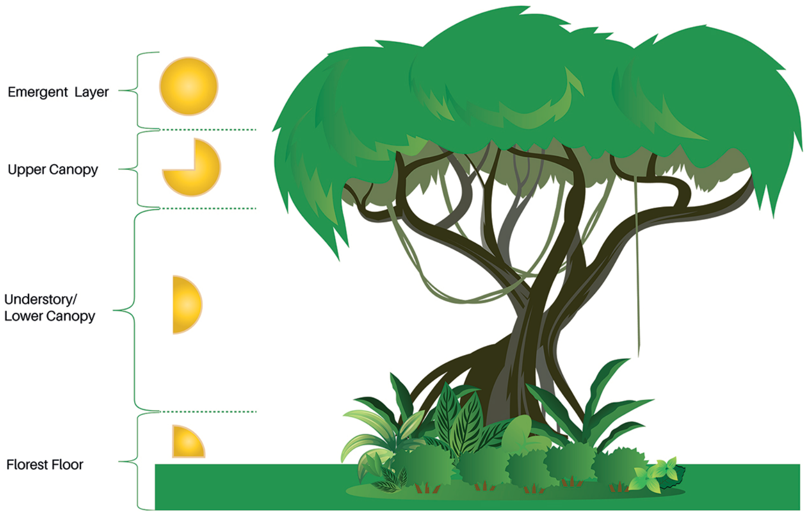

Figure 6: Forest vertical structure and light vertical gradient.

The horizontal pattern of community in space is variable. Usually, it includes differences due to latitude and altitude. Increasing latitude and altitude means more extreme conditions, and therefore the composition and appearance of the community changes.

2.3.2 Community sustainability

In the early twentieth century, two American scientists, Frederic Clements and Henry Gleason, prompted the question of community sustainability (equilibria).

Clements [16, 17] developed an "*organism concept of community*." In the concept, each species in the community representing an interacting component of the whole. The main processes shaping the community are mutualism and coevolution (predator–prey or competition interactions). On the other hand, Gleason [18, 19] supported "*the individualistic continuum concept*." The community very rarely (almost never) reaches a state of equilibrium. Communities, therefore, are not highly regulated species groups, but rather random populations of plants and animals, in which each individual responds to changes in the environment specifically. Biological factors, such as competition and predation, have no significant impact on community sustainability or equilibria.

Many studies have been conducted in order to prove one of these theories in the last 50 years. Some have shown that predation and competition play an important role in regulating the community. Rapid change in the physical environment can strongly affect the composition and structure of the community. Climate change, weather or natural disasters can also affect communities significantly.

2.3.3 Biodiversity

Biological diversity (biodiversity) is the variability of life on Earth. It includes genetic variation, ecosystem variation and species variation [20] within an area, biome or the whole planet.

Diversity is estimated on the basis of species richness (number of species) and species abundance (the number of individuals per species). For estimation of biodiversity, many indexes are used, the most common is Shanon index:

$$H = -\sum_{i=1}^{s} (p_i)\left(\log_2 p_i\right)$$

where H is a diversity of species, S is the number of species, and p_i is the proportion of individuals in total sample belonging to the ith species.

The number of species is changing over time (Figure 7). The oscillations of diversity and extinction rates are a consequence of changes in a number of factors: biotic and abiotic. It is believed that the biggest impact has a climate change [21]. Human activities disrupt the natural balance. This caused the extinction of many organisms, especially in the last century.

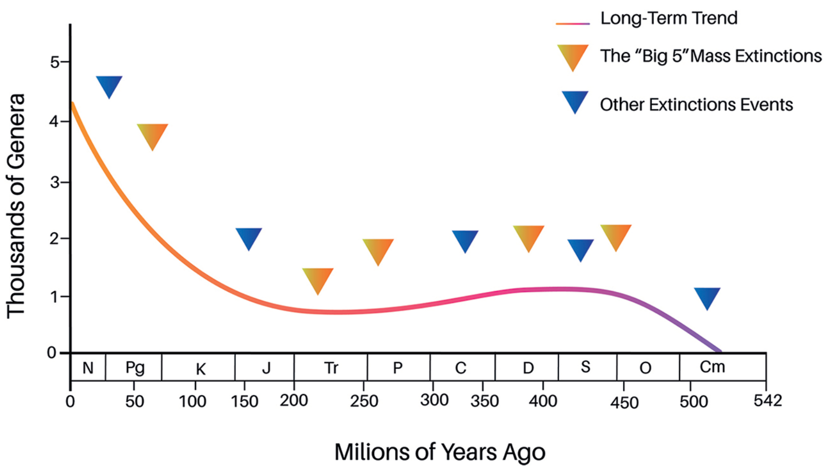

Figure 7: Apparent marine fossil diversity during the Phanerozoic; N – Neogene, P – Paleogene, K – Cretaceous, J – Jurassic, Tr – Triassic, P – Permian, C – Carboniferus, D – Devonian S – Silurian, O – Ordovician, Cm – Cambrian, inspired by [22].

2.4 Ecosystem

The concept of the community includes only living organisms in a habitat but ignores the physical environment: nutrients and energy that allow living organisms survival. The ecosystem is a spatial or organisational unit of organisms and their physical environment. The environment is consisting of biotic and abiotic components linked together through nutrient cycles and energy flow. Simply said, all ecosystems (terrestrial and aquatic) have three important parts: producers, consumers and the non-living environment (Figure 8).

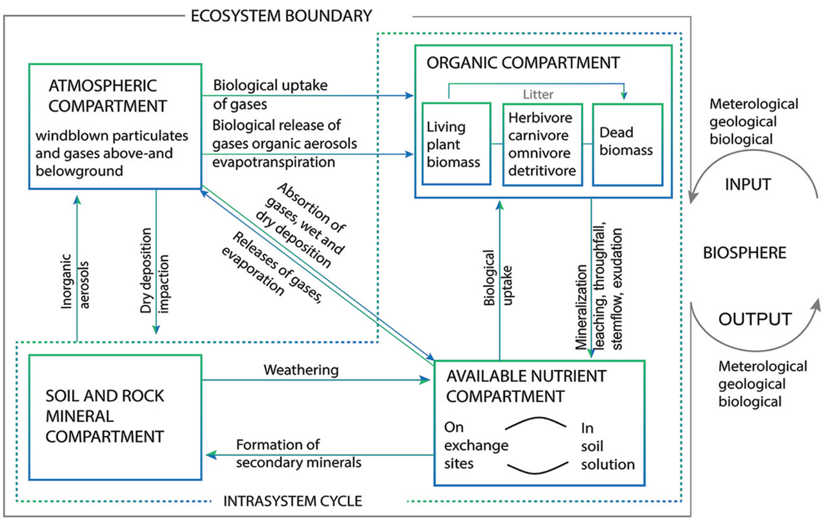

Figure 8: Schematic representation of the ecosystem; inspired by [23].

The energy that flows through ecosystems is obtained primarily from the sun. It generally enters the system through the process of photosynthesis. The energy accumulated in the process is called primary production. Total annual primary production on Earth is 162.41 × 10^9 t. Approximately 1/3 of it occurs in the sea, and the rest on the land. Among the most productive ecosystems in the world are wetlands; however, their share in global production is small because they cover a very small part of the earth's surface.

In terrestrial systems, production is determined by temperature and precipitation, because those directly affect the level of photosynthesis. In the oceans, production is limited by the penetration of light. The phytoplankton (and plants) are located mainly in the surface layers of aquatic ecosystems, where there is enough light. However, the primary production also depends on the amount of nutrients: nutrients from deeper parts must be transported in the surface layers.

The energy stored in plants is going through ecosystem in series of steps called food chains. A food chain shows how the organisms are related to each other by the food they eat. Each level of a food chain represents a different trophic level, but all of them starting from producer organisms (plants) and ending at apex predator species (carnivore). One kind of plant can be a source of food for many herbivores, but also many carnivores can hunt the same prey. So actually, in the ecosystem, many food chains interconnected in food webs.

Organisms in the food chain can be grouped according to the type of food they consume, in trophic levels. In general, all organisms that feed on other organisms are called consumers or secondary producer. Consumers can be divided into subgroups, each of which represents a single trophic level: those which feed on plants (primary producers) are called herbivores or primary consumers. Carnivorous (meat-eating) or predators feed on herbivores (plant eaters) and are called secondary consumers. Almost every habitat, including freshwater ecosystems, includes consumers who do not fit entirely into this simple scheme of trophic levels. These are consumers – decomposers or detritivores, they feed on dead remains of other organisms (detritus). Their role may at first glance do not seem so important, but they are an important link in the flow of energy and nutrient circulation in the ecosystem. Decomposers are involved in the degradation of dead plants and animals, returning nutrients in the cycle and thus allowing growth and development of primary producers.

The amount of energy that is transferred from one trophic level to another is very difficult to determine. When summed, biomass, or energy on each trophic level, constructs an ecological pyramid. It is also called Elton's pyramid, according to Elton [24]. In general, biomass and energy of producers must be greater than the biomass and energy of secondary producer: base of the pyramid determines the size of each of the next trophic level (Figure 9).

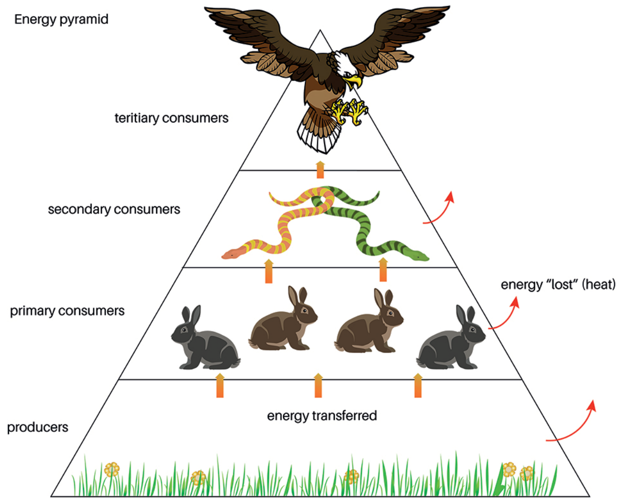

Figure 9: Energy pyramid.

According to the second law of thermodynamics, as energy transfers between different trophic levels, there is a loss in the form of heat which limits the number of links in the chain. Highly productive systems do not support long food chains; however, they have a lot of species. This means that their food web is very complex. It is also known that ecosystems which are subject to rapid changes in abiotic factors have shorter food chains in relation to those stable. Highly stratified systems such as forests or pelagic ocean food chains are longer than those less stratified (meadows, tundra, benthal of a stream).

2.4.1 Biogeochemical cycles

All nutrients are transported through the ecosystem from the non-living to the living components in cyclic paths called biogeochemical cycles. The most important biogenic elements such as carbon, nitrogen, phosphorus and sulfur are bound in living organisms in the food chains and, through the process of decomposition of dead organisms, again returned to the lithosphere. Then the whole cycle begins again (Figure 10(a)). The main driver of all is the solar energy and is unusually important role for all biogenic elements has a water cycle (Figure 10(b)).

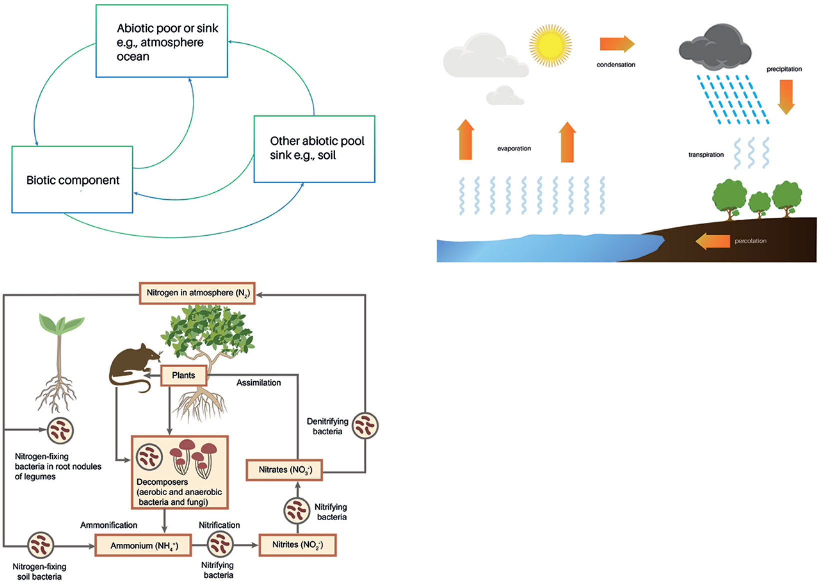

Figure 10: (a) nutrients cycle; (b) water cycle; (c) nitrogen cycle.

Carbon, hydrogen, oxygen, nitrogen, phosphorus and sulfur make 95 % of the biomass on Earth and are called macroelements. Macroelements together with calcium, silicon, magnesium, sodium, potassium, chlorine and iron (micro elements) consist 99 % of the dry weight of living organisms. Other biogenic elements (manganese, molybdenum, copper, vanadium, nickel) appear in much lower concentrations and a group of trace elements.

2.4.2 Ecosystem biodiversity and stability

One of the basic questions in ecology is: how many species is necessary for the normal functioning of the ecosystem? Is there a minimum or, if they are redundant species in the system? If there are redundant species: which species are necessary for the maintenance of the ecosystem?

If we assume that all species are essential for the functioning of the ecosystem, then the loss of any causes imbalance: leads to degradation or collapse of the whole system (Figure 11). Maybe a diversity of species in ecosystem has no influence on its function, so the loss of any species causes random and unpredictable consequences.

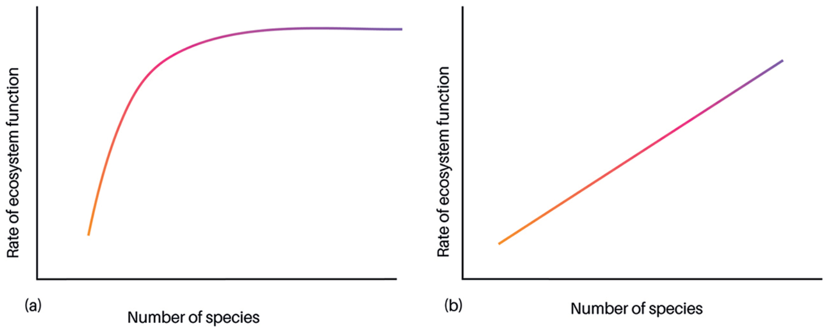

Figure 11: The potential relationship between the number of species in the ecosystem and its functioning (primary production, decomposition, circulation of materials); (a) redundant species hypothesis; (b) hypothesis dependent species [25].

These models were tested in the laboratory and *in situ*. The first laboratory research on this subject was conducted by John Lawton with a group of researchers at the Imperial College in London [26]. They found that ecosystems with a large number of species have more efficient primary production and developed a complex plant cover, but also accumulate more nutrients. Their results support the second hypothesis: that the reduction of biodiversity causes poorer functioning ecosystem. However, it is possible that further addition of species in a system causes a certain saturation point so that this experiment does not answer the question posed at the beginning. In any case, this research demonstrates that we can reject the third hypothesis: the functioning of the ecosystem is not random in relation to biodiversity.

The group of authors from the University of Minnesota conducted similar studies [27]. Their results were similar to Lawton's research: greater biodiversity – a better functioning of the ecosystem. However, they found that all species in the system are not equally valuable. The value indicates how much the loss of a certain species impacts the entire ecosystem, but also that some species depend on each other. For example, plants belonging to family (Fabaceae) legumes are very important for the nutrient cycling in the ecosystem, since their roots have symbiotic bacteria that can bind elementary nitrogen. Circulation of nitrogen is one of the basic biogenic cycles that is important for all organisms. By fixing nitrogen, these plants provide more nutrients in the soil, which in turn results in greater production of other plants, and animals, which are connected to them in the food chain. Therefore, the loss of legume species can have a major impact on the production of the entire system. These species are often called and "keystone species," in terms of their importance to the functioning of a system.

Another issue is of extraordinary importance when it comes to biodiversity and ecosystem function: whether biodiversity influences the stability of the ecosystem?

British ecologist Charles Elton during the 1950s observed that more complex and richer types of systems are less susceptible to the influence of sudden changes. However, the development of mathematical modelling and the use of simulation in the population ecology did not to reach the same results. Models showed that the populations of some species even in diverse ecosystems are subject to fluctuations caused by external factors (disease, drought, etc.). It is possible that regardless of variations in individual species, the functioning of the entire ecosystem remains unchanged. So, the population of a certain species may fall or rise, but ecosystem survives because there are a lot of other populations that still maintain the function of the system.

2.5 Succession

Communities in an ecosystem are changing over time. Such changes are called succession. Actually, it would be more accurate to say that the succession is a series of changes in communities within a certain time period. Succession occurs in both terrestrial and aquatic systems. We distinguish between so-called primary and secondary successions. Primary succession takes place on previously completely bare surfaces (without life). Secondary succession happens to already populated habitats after a disturbance.

On August 28, 1883, at 10:02 pm there was an extraordinary disaster. The Indonesian island of Krakatoa exploded in one of the largest volcanic eruptions in recent history. Most of the island was blown off in the explosion. At the site of the former island of Krakatau was born two smaller islets: Anak Krakatau and Rakata. The island of Rakata was completely sterilised: the entire island was covered with a layer of lava 30–60 m thick, and all life on it was destroyed. The first expedition came to Rakata 8 months after the explosion and found only one living creature on the island: one spider! Scientists continue to explore settlement of animals and plants on this completely bare area. After 3 years, the first living organisms were observed on the island: the blue-green algae inhabited areas of cooled volcanic ash. Along came mosses, they are the pioneer species that first colonists of a habitat.

Pioneer species created the basis for the settlement of other organisms. After 25 years, the tropical forest appeared and with it the characteristic fauna of birds, snails, butterflies, bats, etc. In 1983, scientists counted a total of 420 taxa on Inland Rakata (Figure 12). During the colonisation of the island Rakata, several communities replaced one after another. In succession, plants are always preceded the animals, creating a habitat for them.

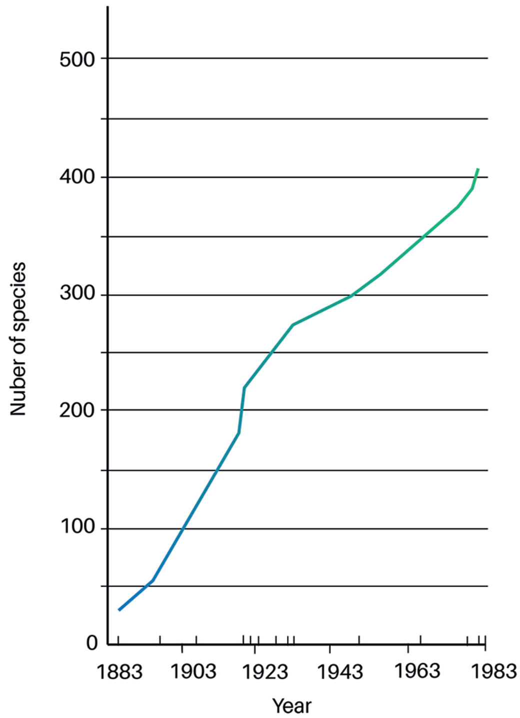

Figure 12: The number of species on Rakata in time, after Krakatau explosion; inspired by [28].

2.5.1 Climax

According to the classical ecological theory, succession ceases when species of late successional stages become dominant. At this point, the community has achieved stability, and any disturbance cannot significantly change the system. This final point of succession is called the climax.

Community climax theoretically has certain characteristics: community achieved the balance between total primary production and total respiration; energy obtained from sunlight and decomposition; between the consumption of nutrients and nutrients returned by a process of decomposition. Each individual in the stage of climax is replaced after the death with another individual of the same species; species composition is actually in a state of equilibrium.

Many communities that seemingly appear balanced actually undergo successive changes a lot more often than we perceive. Tropical forests in Central America are exposed to frequent natural disasters. Tropical storms and hurricanes occur very often in this area and have a great impact on the communities. According to some calculations, tropical storms affect the same area (community) every 60 years, leaving behind devastation: broken trees or full or partial defoliation of vegetation. Destruction of vegetation cover, of course, affects the wildlife causing also a different composition and distribution of animal habitats. Therefore, climax should be considered as a dynamic equilibrium of the community. Even “old” and apparently stable community is constantly in the process of dynamic change.

2.6 Biomes

Climate largely determines plant formations and life in them. These formations are called biomes. There are several major terrestrial biomes: tundra, grassland, desert, taiga, forest temperate zone, Mediterranean vegetation and tropical rainforest. They are further divided into types depending on the climate and altitude. (Figure 13).

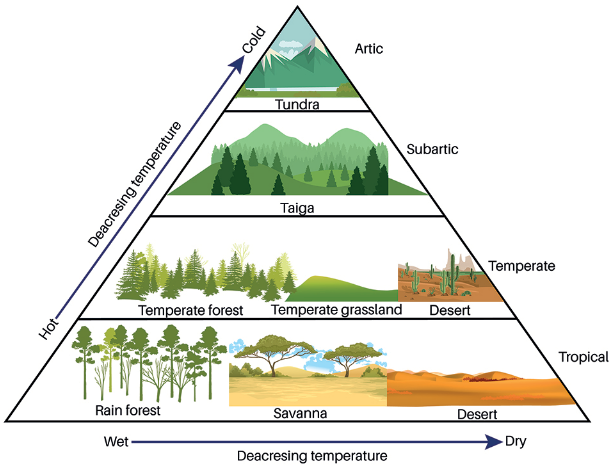

Figure 13: Biomes; inspired by [29].

Although inland water (freshwaters) account just a little bit over 0.5 % of all water on Earth, its importance is very high. It is used as drinking water, in industry and agriculture. Inland waters are groundwaters and surface waters. Surface waters are running waters like rivers and streams and standing waters like pools, ponds and lakes.

Seas and oceans cover more than 70 % of the Earth's surface and are inhabited by living organisms from the surface to bottom. The chemical composition of sea water is very stable, more than 85 % of the total amount consists NaCl. Temperature fluctuations of the surface layer depend on the geographical location. In addition to temperature, pressure has a significant impact on life in the sea. Pressure increases with depth. Deep layers have a constant temperature, while in the surface layers (up to 200 m) temperature varies. There are two main habitats in the sea: bottom and water column. The sea bottom is very diverse habitat it is inhabited by benthic organisms. Plankton and nekton organisms live in the water column.

2.7 Global changes

Today, human activities cause environmental changes that disturb the normal functioning of the biosphere. Major changes are greenhouse effect that causes the global warming, ozone depletion, acid rains and the destruction of habitats.

2.7.1 Greenhouse effect

In the last 100 years, the concentration of CO_2 in the atmosphere has increased about 25 % particularly due to a greater exploitation and use of fossil fuels. Excessive amounts of CO_2 in the Earth's atmosphere are causing the greenhouse effect. The earth's surface absorbs solar radiation and then transmits it as longwave radiation or thermal energy. CO_2 traps longwave, thus heating up the Earth's atmosphere. This effect is called the greenhouse effect and causes global warming. According to some predictions, by the year 2100, the average temperature on Earth will increase in about 2 °C. The consequences could be climate change that can lead to drastic changes in the distribution of individual plant and animal species, which in turn can lead to problems in food production, and transmission of various diseases (malaria, influenza and yellow fever).

2.7.2 Acid rains

Precipitation such as rain and snow have naturally slightly acidic pH: between 5 and 5.6 (due to a certain amount of CO_2 in the air). Acid rain is any precipitation with pH lower than 5. Such acidic precipitation is caused by higher amounts of various air pollutants particularly sulfur dioxide (SO_2) and nitrogen oxides (NOx). Precipitation with low pH damages plants, causes acidification of lakes and rivers and directly influences the living world in them. Acid rain may also cause acidification of soil. The consequences of this are heavy metal leeching in terrestrial and aquatic ecosystems. Heavy metals are toxic to living organisms: in vertebrates, they are deposited in the liver and brain and can cause serious damage to these organs.

2.7.3 Ozone depletion

Ozone, O_3, is a form of elemental oxygen that is important for the absorption of ultraviolet radiation in the stratosphere. It absorbs 99 % of UV radiation which can cause severe damage to DNA. The depletion of the ozone layer can be caused by freons (a number of halocarbon products which have typically been used as refrigerants and as aerosol propellants), the detonation of nuclear weapons and the exhaust gases over large urban centres.

2.7.4 Habitat fragmentation

We already at the beginning of this chapter emphasised that the human's impact on nature is great. One of the global environmental problems is the destruction of habitats. Construction of roads, railways, power lines, expansion of settlements and agricultural land use caused the destruction of natural habitats and/or their fragmentation. Such fragments of natural habitat are often insufficient to maintain populations. One of the major problems of habitat destruction is certainly deforestation, particularly in the tropics. In addition to degradation of the forest community, it also causes a drastic climate change.

2.8 Applied ecology

2.8.1 Constructed wetlands

Constructed wetlands are treatment systems designed for the purpose of improvement of water quality. They use natural processes involving wetland vegetation, soils and associated microbial assemblages in treating anthropogenic discharge such as municipal or industrial wastewater or storm water runoff.

Constructed wetlands can be designed to emulate the features of natural wetlands, such as acting as biofilters for removing sediments and pollutants from the water. Some constructed wetlands may also serve as a habitat for native and migratory wildlife, although that is usually not their main purpose.

Vegetation in a constructed wetland provides a substrate (roots, stems and leaves) upon which microorganisms can grow as they break down organic materials (Figure 14 and Figure 15). The plants remove about 7–10% of pollutants and act as a carbon source for the microbes which are responsible for approximately 90 % of pollutant removal.

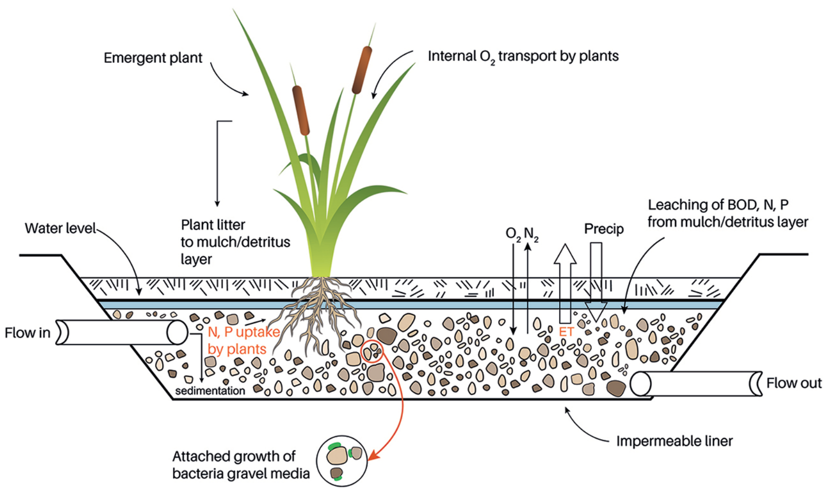

Figure 14: Constructed wetland; inspired by [30].

Figure 15: Constructed wetland in location Hruščica near Zagreb; photo by Renata Horvat.

2.8.2 Water framework directive

Freshwater ecosystems are among the most degraded on the planet. Numerous human activities impact water quality, including agriculture, industry, urbanisation, disposal of human waste, mining and climate change. In 2000, the European Union established its framework for the protection, improvement and sustainable use of Europe's water resources by launching the Water Framework Directive (WFD) [31]. The WFD is considered to be pioneering because it champions the ecosystem approach, that is, the integrated consideration of chemical and ecological status in defining water quality [32]. Although the Directive requires the assessment of hydromorphological and physico-chemical elements, a biological assessment is given priority. The assessment of the ecological status establishes the analysis of the structure of biological communities of macroinvertebrates, fish, macrophytes, phytobenthos and phytoplankton. Figure 16 illustrates how these various elements are combined and how the "one-out, all-out" principle is applied.

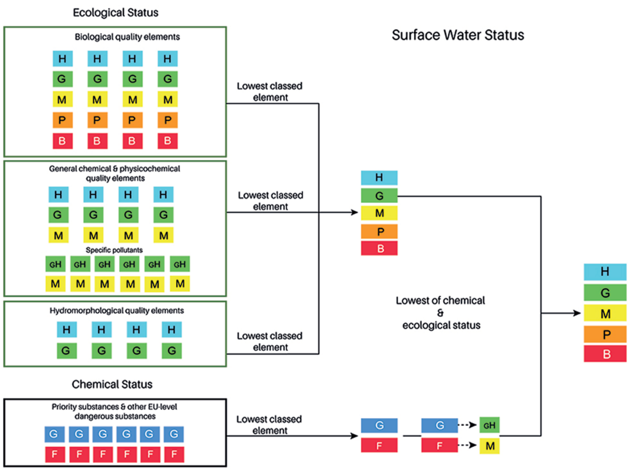

Figure 16: Classification scheme of surface water status using "one-out, all-out" principle; H – high status, G – good status, M – moderate status, P – poor status, B – bad status.

Measuring ecological status makes it possible to evaluate the effect of human activity on water ecosystems, and it will be an essential tool for the sustainable management of water resources. The legislation requires the periodic assessment of all water bodies, including rivers, lakes, estuaries, coastal waters and groundwaters. The first and basic step in the implementation of the WFD in the segment of surface waters is their typification, so that a type-specific approach to estimation water quality could be applied [33]. Water types are then assigned to a classification system that grades their deviation from reference state (high, good, moderate, poor and bad), with no, or very minor, disturbance from human activities. In Croatia, 19 river types were identified and large river types were intercalibrated at EU level. The WFD requires the EU Member States to develop classification systems to describe the ecological status of a given water body at a given time. The main objective of the WFD is to implement measures to achieve "good ecological status" of all natural water bodies. The emphasis given by the WFD to ecological elements has been widely welcomed by scientists and environmental managers as it focuses risk management efforts on restoring those impacted ecosystems that are classified as being of less than "good ecological status."

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Study questions

1: What do several different populations living together make?
A) a biosphere; B) an organism; C) a community; D) an ecosystem

2: When there is a lot of pollution, rain can be acidic, harming plants and animals. What is this an example of?

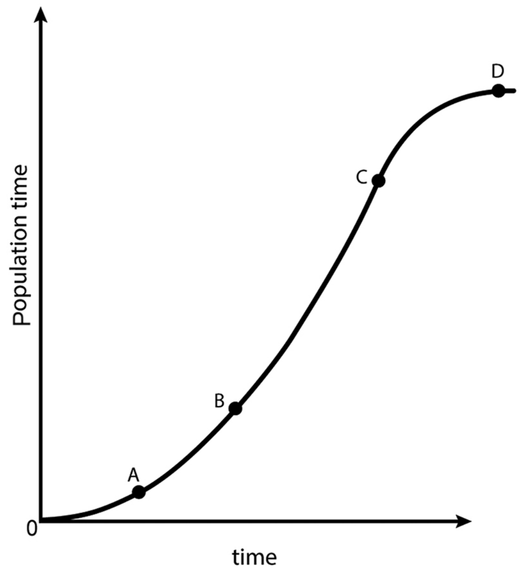
A) competition between a population and a community; B) a mutualistic type of symbiosis; C) an abiotic factor affecting an ecosystem; D) an individual affecting a community

3: Bears eat fruits such as berries and animals such as fish. They hibernate in the winter. Which of these terms applies to bears?

A) they have a mutualistic relationship with berries; B) they are at the bottom of the energy pyramid; C) they are decomposers; D) they are consumers.

4: The carrying capacity of the environment, for the population shown in the diagram, is the best represented by a point on the curve marked with a letter:

A) A; B) B; C) C; D) D.



5: In a simple ecosystem, a census of the populations in four successive trophic levels was taken as shown in the Table 1. If Level 1 is composed of photosynthetic autotrophs, then the trophic level with 823 individuals will most likely represent?

Table 1: Population density.

Level	Population
1	53
2	361
3	823
4	6283

A) primary consumers; B) secondary consumers; C) decomposers; D) producers.

6: What effect does biodiversity have on a community?

A) it makes destruction by insects impossible; B) it makes primary succession more likely; C) it enables species to survive in a desert; D) it enables the community to withstand changes.

7: Precipitation and evaporation are important components of the

A) nitrogen cycle; B) water cycle; C) carbon cycle; D) phosphorus cycle.

8: Match each item with the correct statement:

A. the populations in an ecosystem 1) food web
B. made up of interconnected food chains 2) abiotic
C. the model that shows feeding relationships 3) food chain
D. living things in an ecosystem 4) biotic

E. non-living things in an ecosystem 5) community

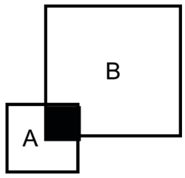
9: A certain area in north-west Europe (peatlands) store 30 million tonnes of carbon. In pristine condition, these peatlands can store an additional 15,000 tonnes of carbon per year.

A) Given this rate of productivity, how long would it take for the peatlands to sequester this much carbon?

B) One prediction of climate change models is a reduction in rainfall in this part of Europe. This would transform the peatlands into a carbon source, emitting up to 462,000 tonnes of carbon per year. How many years would it take to respire all the carbon stored in the peatland?

C) What is the effective residence time of the carbon that makes it into long-term storage in the peatland if there is no disturbance in the ecosystem? (Note: it is not a calculating problem!)

10: Base your answer to the following question on the diagram below. A pair of wild goat, A, lives on 1 square kilometre of land. A second pair, B, lives on 4 square kilometres of land, in which 0.25 of the 4 square kilometres overlaps the territory of the first pair.



Both pairs A and B are members of the same species. Which of the following explains why area B is larger than area A?

A) Pair B is bigger; B) Pair B has less food in its area; C) Pair A has fewer offspring

D) Pair B has more available resources.

Solutions:

1. C; **2**. C; **3**. D; **4**. B; **5**. B; **6**. D; **7**. B; **10**. B;

8. A) the populations in an ecosystem 5) community

B) made up of interconnected food chains 1) food web

C) model that shows feeding relationships 3) food chain

D) living things in an ecosystem 4) biotic

E) non-living things in an ecosystem 2) abiotic

9. A) 30,000,000 tonnes C / 15,000 tonnes C yr-1 = 2000 years;

B) 30,000,000 tonnes C / 462,000 tonnes C yr-1 = 64,9 years;

C) Theoretically, infinite: the net community productivity is stored in peat indefinitely.