**DISTRIBUTION OF MICROORGANISMS IN AQUATIC ENVIRONMENT**

**30.1 Introduction**

Water occurring in nature contains dissolved salts and gases, especially sea and mineral waters. Water covers 70% of the earth's surface, and thus, it is the most essential habitat of life. The overall volume of inland waters is estimated at 7.5 x105 km3, of seas and oceans at 1.4 x 109 km3, and of glaciers and continental glaciers at 1.8 x 107km. Water makes up the most crucial component of living organisms (70-90% of cell mass) and fulfils a purpose in taking part in various biological reactions and processes.

**30.2 Types of Waters Inhabited by Microorganisms**

The biotopes of water microorganisms may be underground and/or surface waters as well as bottom sediments.

* The underground waters (mineral and thermal springs, ground waters) - due to their oligotrophic character (nutrient - deficient) are usually inhabited by a sparse microflora that is represented by a low number of species with almost a complete lack of higher plants or animals.
* The surface waters such as streams, rivers, lakes and sea waters are inhabited by a diverse flora and fauna. Microorganisms in those waters are a largely varied group. Next to the typical water species, other microorganisms from soil habitats and sewage derived from living and industrial pollution occur.
* Bottom sediments are a transient type of habitat i.e. the soil-water habitat that is almost always typically oxygen-free in which the processes of anaerobic decomposition by microorganisms cause the release of hydrogen sulphide and methane into water. In the bottom sediment, anaerobic putrefying microflora, cellulolytic bacteria and the anaerobic chemoautotrophs develop.

**30.3 Groups of Water Organisms**

Microorganisms occupy surface waters in all of the zones; they may be suspended in water (plankton), cover stationary underwater objects, plants etc. (periphyton), or live in bottom sediments (benthos).

**30.3.1 Plankton**

The group of organisms that passively float in water not being able to resist the movement and the flow of water mass is called plankton or bioseston. These are of following types:

***30.3.1.1 Phytoplankton***

Phytoplankton are mainly microscopic algae and blue-green algae. It is a varied community in terms of the systematics and mainly composed of forms smaller than 50 μm. Sea phytoplankton are dominated by diatoms and dinophyta, whereas fresh water phytoplankton are dominated one by cryptophytes, diatoms, green algae, and blue-green algae.

***30.3.1.2 Zooplankton***

Zooplankton are small water animals that occur in plankton. There are three systematic groups that occur in fresh waters: rotifers, branchiopods and copepods. The sea water plankton is composed of copepods, ctenophores, urochordata, arrow-worms as well as some species of snails. Most of them are filtrators (condense suspended particles) or predators.

***30.3.1.3 Protozoa plankton***

Protozoa plankton consists of protozoa which occupy the open water zones like flagellates and ciliates. They are the main consumers of bacteria. Moreover, most ciliates feed upon flagellates, algae and smaller ciliates. The protozoa itself feeds the zooplankton.

***30.3.1.4 The heterotrophic bacteria plankton***

The heterotrophic bacteria plankton occupy waters which are abundant in organic compounds. The amount of bacteria in open waters varies between 105-107 cells/ml.

***30.3.1.5 Virus plankton***

Virus plankton is composed of viruses which are the smallest element of plankton. Their numbers may be very high (from 108 in 1ml) in various fresh and sea water habitats. Viruses are, next to the protozoa, a crucial factor in bacteria mortality.
 **30.3.2 Periphyton**

Periphyton occupy the shore line zones. They are a group of organisms that create outgrowths upon various objects and underwater plants. Most of the time, they usually consist of small algae - diatoms, green algae and bacteria. Moreover, various settled or semi-settled protozoa, eelwarms, oligochaetes, insect larva, and even crustaceans make up the periphyton biocenosis. Periphyton has a characteristic complex biocenosis and many ecological relationships can be observed between its components.
**30.3.3 Benthos**

The bottom habitat is occupied by a group of organisms called the benthos. The muddy bottom contains an abundance of organic compounds that are created as a result of dead matter decomposition (fallen parts of plants and animals). At great depths the bottom is free from any plants which, due to a lack of light cannot grow. However, the absence of oxygen supports the development of, among others, an oxygen-free putrid microflora. Among the benthos microflora the most numerous are bacteria and fungi (decomposers) as well as some animals (detritophages). Both of the above groups are responsible for decomposition of the organic matter. Benthos of shallow reservoirs may also contain some algae.

**30.4 Factors Affecting Growth of Microorganisms in Water**

The development of microorganisms in water is influenced by a large number of chemical and physical factors which, in various ways, interact or oppose each other. They have an influence on the size, species and composition of the microbial biocenosis as well as on their appearance and life processes. Within water ecosystems two groups of factors that have a crucial influence on the quantitative and qualitative relationships between microorganisms may be distinguished:

* Abiotic factors - light and thermal energy, water reaction, water flow, climate and the compounds dissolved and suspended in water (dead organic matter, non-organic compounds and gasses such as oxygen, carbon dioxide, methane and others).
* Biotic factors - all water living organisms such as plants, animals, microorganisms and the relationship between them.

**30.4.1 Abiotic factors

*30.4.1.1 Light energy***

Light plays a major role in the process of photosynthesis. The amount of light penetrating different layers of water strictly depends on the position of the sun, transparency, colour and depth of water. The lesser the incidence angle the smaller the loss of sun rays due to reflection. Depending on the level of insolation and water turbidity, the biologically active sun rays usually penetrate water somewhere between 10-150 m. Undoubtedly, sea waters are clearer and less polluted than inland waters, thus light can penetrate much further down through these waters. Sun rays penetrate sea waters down to about 150 m creating the so called photic zone where photosynthesis takes place. Due to different light conditions the development of photoautotrophs isn't identical throughout the entire water mass. The indicator of the illumination quantity is often the lower boundary (limit) of algae occurrence – their greatest development takes place at a depth of 0.5-2 m. Most algae possess an ability to change and adapt their colouring to the light conditions. Light is harmful to those microorganisms which are deprived of any pigments. Both the ultraviolet and the longer wavelength may have a negative effect. For instance, blue light (wave length 366-436 nm) inhibits the process of nitrite oxidation by Nitrobacter vinogradskyi. Light also has an influence upon water fungi development. Blue and green rays have a greater impact than red rays.

***30.4.1.2 Temperature***

The amount of thermal energy depends, just as in the case of light energy, on the incidence angle (the position of the sun in relation to the water surface). Therefore, it varies with time of day, seasons and latitude. Lotic waters such as rivers have a steady temperature throughout their mass due to constant mixing by the water flow. However, such a water habitat is characterised by daily temperature fluctuations especially in shallow rivers. In lentic (stagnant) waters such as lakes, where the water current is very weak or nonexistent, the temperature fluctuates during the annual cycle. Lakes, especially deep ones, are characterized by vertical stratification (the formation of layers that vary according to their composition and temperature). Illuminated warm and near-surface waters have a lower density than the dark and cold waters from below. The difference in density prevents mixing of the layers. The warm water layer is called the epilimnion. The cooler layers from below form a thermocline or metalimnion and become cooler with depth. The temperature falls by 1°C with each meter. In the lowest layer - hypolimnion – the water is at 4°C and has the highest density.

The thermocline works as a barrier between the epi- and hypolimnion. The upper waters do not mix throughout the year due to their different density. Water is only moved within the epilimnion layer by the wind. The biogenes present near the bottom are not available for the organisms living in the upper layers thus, in late summer; the top layer has a deficit of trophic substances. In the autumn the surface waters begin to cool down, slowly falling while pushing the warmer waters upwards, which also cool down. As the waters continue to exchange (autumn circulation) and are mixed by the wind they oxygenate and at the same time lose CO2 by releasing it to the atmosphere especially from the bottom waters. A slight inversion of temperature occurs in the winter since the water at less than 4°C has a lower density than the 4°C water and it rises towards the surface. Different circulation occurs in the spring as the surface waters warm up. Then, the entire body of water is rich in oxygen and biogenes. The mixing of water also causes organisms to move.

***30.4.1.3 Water movement***

Mixing of water is of great importance to both the temperature distribution and for the balance of the chemical composition (gasses, nutrients, substances that equalize the osmotic pressure, water pH etc.). The movement of water is caused by the following:

* variations in density caused by different temperatures and contents of soluble
* suspended compounds
* winds
* difference in the levels at the bottom (lotic waters)
* specific hydraulic engineering processes.

***30.4.1.4 Pressure***

Pressure is an important ecological factor that strongly influences the life of microorganisms among other things by affecting the activity of the cells enzymatic systems. In water the hydrostatic pressure gradually increases with depth at 1 atm per 10 m. Thus, in large oceans and some deep lakes the pressure is quite high - in most seas it's at about 100 atm and in some Pacific trenches it may reach even 1100 atm. The group of abyssal microorganisms, which occur at depths of 10,000 m, are called barophilic. They grow and develop not only under great pressures, but also at very low temperature (3 -5°C) but their growth is very slow. Most fresh water and soil bacteria do not develop when the pressure exceeds 200 atm (barophobic microorganisms).

***30.4.1.5 pH of water***

An optimal pH for water-bacteria is between 6.5 and 8.5. The pH of most lakes is 7.0, rivers - 7.5, and the surface layer of the seas 8.2. Because of the high content of carbonates and their buffer properties, the pH of water does not usually fluctuate significantly. But when there is a rapid growth of photosynthesising organisms the pH may increase rather considerably. Some mineral springs and inland waters with a high content of humus compounds may be acidic. In such conditions the number of acidophilic fungi increases. Relatively large changes in pH can be observed in eutrophic lakes where the pH varies between 7-10, which has an obvious influence on the populations of bacteria and fungi.

***30.4.1.6 Salinity***

Most microorganisms that live in clean rivers and lakes are halophobic and in natural conditions do not live in waters in which the salinity exceeds 10%. There aren't many halophilic organisms which may grow in waters of higher salinity. Due to the salinity, sea is thought of as a separate (distinct) biotope; the predominant number of bacteria and fungi living in seas are halophilic. Their life processes depend on a specific concentration of NaCl thus, most of the organisms living in such habitats cannot survive anywhere else. The major mass of salt (99%) is composed of the following elements: Cl, Na, S, Mg, Ca and K. The concentration of salt in sea water is on average 35%. The optimal salinity range for most halophilic bacteria and fungi varies between 25-40%. In the oceans is on average 32-38%, however in closed seas (salty lakes) the range is much greater. For instance, the Caspian Sea contains a low level of salt (1.1-1.3%), whereas the Dead Sea's salinity ranges up to 28%. An increase in salinity has an influence on the generation cycle of bacteria and fungi, and on their morphological and physiological properties. Lakes with a high concentration of salts are extreme biotopes and their biotic groups are low in species variation (the main microorganisms are the bacteria, blue-green algae, flagellates).

***30.4.1.7 Other non-organic substances***

The life cycle of water microorganisms is also dependent on non-organic substances other than NaCl, among which phosphorus and nitrogen compounds play a major role.

Besides free nitrogen, many mineral compounds of this element, such as nitrates, nitrites and ammonium salts, occur in surface waters. Algae and heterotrophic bacteria most often use nitrates and ammonium salts. The maximum amounts of nitrogen which are tolerated by various algae species are different. For instance, diatoms (such as Asterionella) may reproduce at high concentrations – even at 100 μg N/l, whereas the maximum level for Pediastrum algae is only 2 μg N/l. It is similar for the bacteria - the maximum amount is different for various species. The most important element which limits the development of algae is phosphorus. Its content in water is rather low (0.01-0.1 mg P2O5/l). Mineral phosphorus occurs in waters in diluted forms (orthophosphate) and in the form of insoluble salts - calcium phosphate, magnesium phosphate etc. Algae may store phosphorus in their cells in amounts exceeding their requirement. The influence of an increasing phosphate concentration by the introduction of pollutants is a reason for water blooming. In oligotrophic lakes as well as in seas that are nutrient-deficient, it is difficult to detect any presence of ammonium ions, nitrites, nitrates and phosphates since these elements are utilized by phytoplankton immediately after their production. Within the photic zones of many tropical seas the deficiencies in nitrogen and phosphorus compounds last throughout the year, whereas in temperate zones it undergoes seasonal changes.

On the other hand, in the deep waters of some large lakes and seas the accumulation of nitrates and phosphates occurs as a result of heterotrophic microorganism activities.

Ammonium ions and nitrites are the energy substrates for the nitrification bacteria whereas, oxygen combined in nitrates may be utilized by a number of denitrifying bacteria to oxidize the organic substances in anaerobic conditions. Other life essential salts are the compounds of S, Mg, Ca, K, Fe and Si. They are utilized by microorganisms to build cell structures and for the activation of enzymes.

***30.4.1.8 Gases-In water reservoirs***

Gases-In water reservoirs, besides salts and organic substances, small quantities of diluted gas can be found. Water possesses an ability to dilute gases but the solubility decreases as the temperature and salinity increase; it is lower in sea waters than in the fresh water basins. It mainly concerns oxygen, carbon dioxide and nitrogen. The main source of the above gases is the atmosphere from which gases diffuse into the upper layers of water until a state of saturation is obtained. In addition, gases diluted in water and sediments may be created during biochemical processes. In this way oxygen is released by green plants as a result of photosynthesis, CO2during respiration, free nitrogen during denitrification, hydrogen sulphide as a result of desulfurication, and hydrocarbons as a result of fermentation processes.

***30.4.1.9 Organic substances***

Organic substances are either secreted by living cells or the products of their autolysis. However, the greatest amounts of organic compounds are introduced into water by sewage. Organic compounds occur in water in the form of solutions or as suspended matter. First of all they serve as food for heterotrophic bacteria and fungi. Microorganisms that often occur on the surface of the suspensions, especially upon the particles of the detritus which absorb the organic substances from water, enjoy favourable feeding conditions. The development and metabolic changes of microorganisms are influenced, more by the content of readily available organic compounds (such as carbohydrates, organic acids, proteins and lipids) rather than the amount of the organic substances in general. Their depletion from water occurs rather quickly. When there is a lack of organic substances bacteria do not reach their proper size and their cell division is slowed down.

***30.4.1.10 Trophicity of surface waters***

Trophicity is the water's abundance of biogenic elements and soluble simple organic compounds. Trophicity determines the primary production rate and the size of the biomass. Major indicators of water trophicity are: phosphorus and nitrogen concentration, chlorophyll concentration, water transparency and oxygen conditions near the bottom. With reference to the water trophicity, the following kinds of water reservoirs may be distinguished: oligotrophic (low nutrient concentration), mesotrophic (medium nutrient concentration), eutrophic (rich in nutrients/fertile), and hypertrophic (very rich in nutrients). The abundance of nutrients in water reservoirs changes with time.

This process of water fertility increases from oligothrophic through mesotrophic to eutrophic waters in a process called eutrophication. When the above process is moderate and its effects are beneficial, then it is considered to be a fertilization process.

However when the process is excessive and its effects aren't beneficial, then it is considered to be biogenic substance pollution. Nutrient deficient low-fertile waters are those which have a low content of phosphorus and nitrogen – it is these two elements that are the most crucial. Therefore the waters contain low numbers of phyto- and zooplankton organisms and they are clean and clear. In waters which contain a low amount of plankton very little dead matter falls to the bottom. Therefore, its decomposition does not deplete the oxygen reserves near the bottom. Up to a certain level, the increase in water fertility in turn causes an increase in the number of most organisms in water and consequently an intensification of life manifestations. When the level of nutrients is too high the organic matter produced disturbs the ecosystem's homeostasis. Some enzymes released by bacteria cause decomposition of the other bacteria and algae. Owing to a release of organic substances the plankton microorganisms grow abundantly. The increased use of oxygen causes a deficit of oxygen in deeper waters and consequently, the development of anaerobic microorganisms and the appearance of methane and hydrogen sulphide. Thus, high vitality means increased production in water basins, biomass development of phytoplankton and at the same time lower oxygen concentration in deeper layers. Water blooming is a consequence of eutrophication and it is caused by the reproduction of algae in the upper layers of water. The above process causes changes in water colour, its turbidity, water quality deteriorates, and toxic compounds are produced. The process of natural eutrophication proceeds very slowly – it takes up to a few thousand years. Accelerated eutrophication, however, is caused by human activities. As a result, excess amounts of nitrogen and phosphorus get into waters from various sources such as industrial and municipal wastes, as well as fields that have been fertilized with phosphorus and nitrogen fertilizers. Such activities greatly increase the concentration of biogenes creating favourable conditions for algae reproduction. In such polluted waters, faecal and pathogenic bacteria may survive for a longer period of time. Precipitation in highly industrial and polluted areas has also had an influence upon eutrophication.

**30.4.2 Biotic factors**

Mutual interactions exist between individual members of the biocenosis that inhabit surface waters. As a result, the organisms may support each other (synergism) or inhibit each other (antagonism).

***30.4.2.1 Competition for food***

The organisms which most efficiently find and take in food may have an advantage over others. For a given habitat with a typical supply of nutrients, the number of microorganisms quickly increases. However, in many cases, the abundant production of products of metabolism (inhibitors) decreases the number of competitors, sometimes eliminating them entirely. Such situations occur, for instance, when the pH is significantly altered by acidification or alkalization, and when antibiotic substances are released.

***30.4.2.2 Co-operation***

In feeding and growth processes, co-operation between the microorganisms is often observed. It allows quicker development of mixed microorganism cultures. Biodegradation is a multistage process when consecutive reactions are conducted by different specialized microorganisms. The process prevents the accumulation of the metabolism by-products. Owing to this co-operation, the biodegradation of persistent organic compounds (ligninocellulose) becomes possible.

***30.4.2.3 Predation***

Bacteria and fungi are food for lower animals. This is why in some water reservoirs their numbers may vary a lot. Most protozoa feed on bacteria. It has been confirmed that their biomass increases along with the increase in bacterial numbers. Numerous multi-cellular organisms also utilize bacteria as their food. These mainly include filtrating animals such as sponges. In bottom sediments many animals feed upon fungi. Blue-green algae which are a part of the benthos are often eaten by turbellarians, nematodes, crustaceans and insect larva. Blue-green algae are eaten by zooplankton, without the latter water blooming and release of toxic substances would occur.

***30.4.2.4 Parasitism***

Water microorganisms are attacked and destroyed by viruses, bacteria and fungi. The presence of bacteriophages has been affirmed in inland and sea waters. They are especially numerous in sewage and are probably the reason for a quick depletion of bacteria in rivers, lakes and in inshore waters that were polluted with sewage. Another reason for the limitation of bacterial numbers is the presence of the Vibrio bacteria which belong to Bdellovibrio genera and lead a parasitic existence. They attach themselves to host cells and reproduce utilizing their energy and consequently digest the cells content. After lysing the host's cell wall, they free themselves and infect further bacteria.