EVOLUTION AND FUNCTION OF EARTH'S BIOMES: AQUATIC SYSTEMS

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Summary

In this article the different aquatic ecosystems of the earth are briefly described. In principle, there are two different groups of aquatic ecosystems, the very stable oceans filled with salty water and the more or less unstable rivers and lakes with either salty or fresh water, which tend to exist only for a shorter time-span. It is in the oceans that life is presumed to have originated, and the first steps of evolution took place in the oceans, which were less salty at that period of time. Autotrophic lower plants became typical of oceans. These plants are monocellular or consist of a colony of less specialized cells of similar function, which can be found either in the plankton or in the benthos. The oceans also contain heterotrophic animals feeding on autotrophic plants. The biodiversity of oceans did not grow as remarkably as on the land since geographical isolation only rarely contributed to the formation of separate species. The development of life in general was influenced by very different selection processes, which related to the growing concentrations of salts in the oceans through ages, to the changing availability of oxygen in the water, and to the better availability of oxygen on the land, where plants became able to survive only after the development of roots which allowed them to take up water and nutrients from the soil instead of the environs of the green plant parts, as is

the case in the oceans.

1. Introduction: Different Biomes

Water has several peculiarities which influence the character of aquatic ecosystems. Below 0°C, H_2O is solid ice; above 0°C, its melting point, it is fluid water. H_2O has its highest density at a temperature of about 4°C (changing slightly according to the salinity of the water), which means that ice (with the lower density) floats on water (with the higher density). Under an ice cover, water is maintained at a temperature of about 4°C because it is unable to expand. Furthermore, the formation of an ice cover results in perfect isolation of the water body underneath from the atmosphere. The weight and pressure of the ice cover do not allow expansion of the water and therefore a lowering of its temperature, so that organisms can survive under the ice in water of a temperature of about 4°C.

Different gases from the atmosphere and numerous different salts can be dissolved and diluted in water, but the solubility of these compounds is influenced by the temperature. The melting point of ice is affected by the content of different salts in the water. The temperature of water stabilizes the temperature of its environs. In the vicinity of relatively warm water the temperature is stabilized at a relatively high level, whereas alterations in temperature over the course of days and seasons are higher further away from water. Ice keeps the temperature at a low level in its environs, and in order to melt ice high amounts of solar energy are required which therefore cannot be used for warming land and water instead.

Water temperatures and their periodicity through the years are crucial to life in the water, as is the availability of nutrients in the water, which is partly also influenced by its temperature. Organisms in the water can only live if special temperature requirements are fulfilled and if all nutrients essential to their life are available from the water.

The salts dissolved in the water are not exclusively nutrients, but can also be poisonous, so that they destroy organisms. Many salts are hygroscopic, which means that these salts attract water and withdraw water from organisms. Organisms can therefore die of thirst if they are surrounded by salty water and are not adapted to it. 96-98% of the Earth's water is salty at present, and salt can be found in all oceans and seas. Water running from land to sea transports different kinds of salt, which are dissolved from bedrock and sediments. The content of salts in the ocean water therefore increases over time. The salt contents of oceans and seas are not equal, especially in flat seas, which can be regarded as great bays of the oceans. The salt content of the Mediterranean Sea is high because evaporation is great in the subtropical belt. The salt content of the boreal Baltic Sea is lower, as many rivers contribute to this sea and evaporation is much lower in this cool region.

Salty water can also be found in salt lakes in the inner parts of continents, especially in subtropical regions where the evaporation rate is high. Important examples of salt lakes exist in the inner parts of North America (Salt Lake City) and in the Near East (Dead Sea). In subtropical regions evaporation can be so high that the water from a lake evaporates completely while the salt remains in the lake basin. If this salt is covered by other sediments a salt layer can be formed which can be subject to lithification and orogenesis (mountain formation) afterwards, so that stone salt is formed. Stone salt is never pure, as during its formation dead organisms and other sediments are also deposited at the bottom of the lake. Stone salt can be dissolved again by water and transported to the oceans. Alternatively, salt water springs and lakes may be formed at a place where stone salt is dissolved by water, e.g. in Central Germany.

Only 2-4% of the Earth's water is fresh water, which can be found in clouds and, after rain, in lakes, rivers and caves. This water also contains salts, but in very low percentages, so that the salts cannot be tasted. Fresh water can serve as a nutrient to land and fresh water plants and animals without being hygroscopic and attracting water from these organisms. Still water and running water form different ecosystems. A typical lamination of water can exist in still water lakes, but not in rivers and creeks where water flows at different speeds which influence the plants and animals in an ecosystem more or less mechanically. The oxygen content is higher in cold and, especially, rapidly flowing water and can be lower in warm lakes where many organisms require oxygen. Still and running water ecosystems are not strictly separated from each other. In the course of a river or creek the running speed of water is not constant but varies greatly from meter to meter, so that some patches of a river can be regarded more as areas of running, others more of still water. Lake Constance (Bodensee) in Central Europe is a part of the course of the river Rhine, but is nevertheless a lake in spite of the fact that all running water from the Rhine penetrates the lake. The same is true of most other lakes of the world: water flows from a contributing river into the lake, and leaves the lake via another river.

Sediments from fresh water, arising mainly in lakes, contain only low amounts of salt but higher quantities of chalk and lime from dead organisms. They also contain sand or loam which have been transported by river to lakes, where the transport power of water is low so that mineral components cannot be carried further but are deposited on the bottom of the lake.

A strict separation between fresh and salty water does not exist as water in principle (if it is not distilled) contains more or less salt. Very important ecosystems are developed in regions where the water is brackish, which means that there is a certain amount of salt from the oceans, but a lot of fresh water also reaches these ecosystems transported by rivers. These ecosystems are called estuaries.

2. The Circulation of Water and Minerals

The circulation of water connects all water ecosystems of the Earth. Water evaporates from the surfaces of the oceans, lakes and also to a certain extent from the land, especially in regions where insolation and therefore the air and water temperatures are high, as they are in the tropical and subtropical belts of the world. This process forms clouds of fresh water. They are driven by wind to the continents, where rainfall is caused, so that fresh water reaches the Earth's surface. Part of the water is retained by the soil, part is used and retained by organisms. Water can also be collected in lake basins and river valleys. Basins and valleys are permanently formed and changed by water erosion, and sediments are deposited where the streaming speed of water is lowered.

Water permanently flows downwards from the site where it is precipitated to the river mouths and the oceans, transporting dissolved salts, sand, loam, and gravel according to its speed of flow. These compounds are either dissolved in the water or suspended or mechanically driven by the force of running water. Sediments are deposited at the river mouths, forming deltas. These sediments can also be transported by ocean streams, which are influenced by different temperatures of the water in oceans and by the Earth's rotation and magnetic influences from the Earth's space. Tides are generated in the oceans by the positions of the moon and sun: they are high at new and full moon and lower at half-moon. The tides particularly influence the ecosystems at flat coasts at continental shelves, as in the European North Sea, and give them an amphibian character.

Flowing water erodes the coasts, so that both bedrock and sediments are always being destroyed by water. The eroded material, together with materials from the deltas and estuaries, is transported to places where different water streams come together and the speed of flow is lowered so that the force of the water is not high enough to transport any kind of sediments further. Sand banks are formed from coarser materials and marshes from fine materials. Sand banks can be connected, forming a barrier, if the tides are relatively low. A good example of this process is the Lido do Jesolo near Venice on the Mediterranean coast. Barrier islands such as the West and East Frisian Islands in the southern North Sea are formed if the tides are higher, and if there are rather high tides, sand plates alone are deposited, as in the mouths of the rivers Elbe and Weser. All these sediments can be transported further if there is a higher flow speed of the water at any time, so that ecosystems developing there are not stable but of an amphibian character.

There is, therefore, not only a circulation of water between sea and land, but other means of circulation also exist. Salt can be deposited on the bottom of a lake which was separated from an ocean in an arid climate, later forming stone salt as a sediment and then being dissolved by water again. Sediments transported by water are also deposited and susbsequently eroded, so that land is first formed and then destroyed again by water.

In oceans, on amphibian stands at the coast and in estuaries, in rivers, lakes and their banks different types of ecosystems have developed through time. On the one hand, there are organisms which are strictly bound to one or another ecosystem with constant conditions of salt content, temperature etc.; on the other hand, there are organisms which can thrive in different water ecosystems. For the development of water ecosystems, waterfowl and fish which can link different water ecosystems are important, as will be outlined later. In connection with them a further type of circulation arises in water ecosystems, a circulation of organisms from ecosystems to ecosystems which otherwise would be strictly separated.

In the following paragraphs the main ecological conditions in water biomes of the earth will be briefly outlined.

3. Water Biomes

3.1. Oceans

All the oceans of the world are linked together to form one ecosystem. This is an important difference from land ecosystems, which are not linked together. For the development of life on the continents, separation between the ecosystems of different continents, islands and in mountainous regions was very important. Separation could not play a role for the development of life in the oceans: all organisms in the ocean can in principle either actively swim or passively drift from any part of the ocean to another. Sedentary plants can also be distributed to any location in the ocean through the drift of their seeds and fruits and through transport with waterfowl. Differences in ecosystems result from different water temperatures and the differing availability of sunlight and sun rays in different layers of the ocean. These differences are less strict than the differences between land ecosystems, because the mobility of water causes a permanent mixture of otherwise more strictly separated ecosystems. Boundaries between different types of ocean water are only given by definition, and are never strict.

Besides the water, all other nutrients required by autotrophic organisms are also available in the ocean water. Water itself is a very important nutrient to autotrophic organisms, as is CO_2. By photosynthesis, carbohydrates can be formed from water and CO_2. Several other elements such as phosphorus, sulfur and nitrogen are necessary to form living organisms, together with trace elements, all of which are available from the ocean water. Autotrophic organisms which form carbohydrates by photosynthesis mainly live near the water surface, where the highest amounts of solar rays are available as a precondition for successful photosynthesis. As a result of the high salt content of ocean water, the transport of water from cell to cell in an autotrophic plant is impeded. Therefore monocellular organisms are frequent, along with those which are able to absorb water into every cell through each cell wall, as is the case with lower plants. More highly developed plants forming a cormus with roots, stems and leaves are rare in the oceans: it is complicated to build up gradients of different salt concentrations in the cells to transport water from cell to cell, given the hygroscopic pressure which is built up by the salt in the water outside the plant. Typical plants living in the oceans are phototrophic algae, which are either monocellular or form cell colonies such as *Fucus*.

In deeper layers of the water there occur bacteria which synthesize organic compounds by chemosynthesis; they are chemoautotrophic as they also build up organic compounds from inorganic materials. They do not require sunlight, but use chemical reactions to receive energy which is essential for the synthesis of carbohydrates from inorganic compounds.

Autotrophic microorganisms and plants, monocellular or forming cell colonies as in the case of the *Fucus* algae, occur in two forms. Most of them occur in the plankton. This is formed by floating organisms which ideally thrive near the water surface where a maximum of sun rays is available. They can drift to any part of the world's oceans but die when transported to a place where living conditions are unfavorable for them, such as estuaries where the salt contents of the water are lower than in any other part of the ocean, or areas where the temperature is too low or too high. Different species of organisms can therefore be found in the plankton of tropical and arctic oceans. However, they have less sharp boundaries between them than ecosystems on land. Instead, there are very smooth gradients between them as a consequence of only slight differences in the water temperatures. Furthermore, the water streams between all parts of the oceanic system account for the formation of mixtures of plankton organisms in each area. Land bridges such as in Central America can act as barriers which separate tropical parts of the oceanic system to a very high extent, but not completely since an exchange of organisms is possible e.g. through transport by animals across the land bridge.

Apart from the planktonic autotrophic organisms there are also communities of benthic autotrophic organisms living sedentarily in the benthos. They are not important in the open ocean as they only have the chance to receive enough sunlight in water which is always very flat; this situation only rarely occurs, but is more frequent at coastal sites and at coral reefs. Benthic ecosystems will be described along with the other coastal ecosystems.

Other organisms are heterotrophic, which means that they have to uptake organic compounds by eating and digesting autotrophic organisms. Some small heterotrophic organisms, such as some *Crustacea*, float in the water as part of the plankton. But most animals swim actively although they also passively use the flow of the water as this is easier than swimming against the flow. Other animals try to maintain a permanent position for a period of time or live sedentarily, so that plankton organisms are brought to them by passive transport in the water stream. Many animals, like fish, feed on monocellular algae. Compounds like cellulose are rare in algae so that the problem of cellulose digestion does not arise. This is also important to many land animals, which are not able to digest cellulose as the main part of their plant diet; cellulose is frequent in cormophytes occurring on land. The animals feeding on algae can digest the greater part of their substance. Benthic animals also feed on monocellular algae, such as corals which only occur in reefs in tropical oceans, as they can only thrive at high water temperatures. Coral reefs grow through time as the corals forming the reef produce lime. Sedentary animals like corals in the benthos produce a streaming of water using tentacles or similar organs to transport plankton to them, but they also use the water flow to receive their diet.

In the food chain there are also predators feeding on other animals. They either swim actively or live in the benthos as sedentary organisms.

The network of the Earth's oceans has always been situated partly in the warm, partly in the cold parts of the world. But the precise situations of the oceans and the continents have not been constant through time: an ocean has existed at times between India and the Himalayas, and the Atlantic Ocean between Europe, Africa and America arose relatively late in time. The size of the oceans contributed to the formation of ocean streams which lead water from colder to warmer parts of the sea, because the density of cold water (4°C) is higher than the density of the much warmer water in the tropical belt whose temperature can reach more than 20°C. If there is a water stream from the arctic to the tropical belt, there must also be another stream which transports water back in the opposite direction. In the North Atlantic Ocean a water stream runs southwards along the coast of North America, and another stream runs northwards from the tropical waters between the Western Indian Archipelago across the center of the ocean leading in the direction of Europe. This Gulf Stream causes relatively high temperatures in Western Europe, whereas the water and the climate along the eastern coast of North America are remarkably cooler. Similar stream systems can be found along the western coasts of America, in southern Africa and in eastern Asia, bringing cold water in the direction of the equator and warm water in the direction of the poles. Both streams form a water circulation system in each ocean, and the circulation of water in the oceans is responsible for the fact that all the water in the oceans can be exchanged between all the world's oceans within a short period of time. The history of the streams inside the oceans is of great importance for the character of the climate in the neighboring continents and of the world in total; it also accounts for the development of biodiversity in the oceans themselves and outside the oceans on the continents.

The history of the oceans underwent remarkable influences during the Ice Ages. During a cold phase, ice was accumulated in the polar regions and the neighboring temperate zones. The accumulation of ice led to a draining in other parts of the oceans, which resulted in the lowering of water tables in the oceans by more than 100 meters. Coastlines were therefore remarkably altered, especially in regions of flat parts of the oceans and seas, above all the shelf seas of the continents. The North Sea, being in parts less than 100 meters deep during the present warm period, did not exist during the glaciation phases; nor did the British Channel, which is also less than 100 meters deep. This means that during the Ice Ages a part of the Gulf Stream did not penetrate to the shelf seas in Western Europe, especially into the North Sea, so that the warming influence of this stream did not affect Western Europe. The speed of flow of the Western Atlantic Stream along the North American coast may also have been influenced by this factor.

Some seas did not exist as part of the oceanic network either, e.g. the Baltic and the Black Sea. They were fresh water lakes at some periods, and their salinity changed dramatically from time to time as their water bodies and their heights were influenced sometimes by ocean water and sometimes by running fresh water from the rivers and melting glaciers.

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Bibliography

Beazley M., ed., (1977). The Atlas of the Oceans, 208 pp. London, Great Britain: Mitchell Beazley Publishers Ltd. [An atlas demonstrating oceanic ecosystems in great detail; it is translated into several languages.]

Grabherr G. (1997). Farbatlas Oekosysteme der Erde, 364 pp. Stuttgart, Germany: Eugen Ulmer. [A comprehensive book written in German with short descriptions and typical photographs of all the important biomes of the world.]

Rahmann H. (1972). Die Entstehung des Lebendigen, 126 pp. Stuttgart, Germany: Gustav Fischer. [A comprehensive book written in German in which the early evolution of life in the ocean is concisely described.]

Biographical Sketch

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Selected publications:

Geschichte der Landschaft in Mitteleuropa. Von der Eiszeit bis zur Gegenwart. München 1995. - Transhumance and the use of (semi-)natural pastures. In: Michel Colardelle (Hrsg.), L'Homme et la Nature au Moyen Age. Paléoenvironnement des Sociétés Occidentales. Paris (Editions Errance) 1996, 118-121. - Auswirkungen von Klimaschwankungen und menschlicher Landschaftsnutzung auf die Arealverschiebung von Pflanzen und die Ausbildung mitteleuropäischer Wälder. Forstwissenschaftliches Centralblatt 115, 1996, 301-320. - The role of farming in the postglacial expansion of beech and hornbeam in the oak woodlands of central Europe. The Holocene 7 (2), 1997, 239-242. - Pb and Cd concentrations in a Southern Bavarian bog profile and the history of vegetation as recorded by pollen analysis (with K.-E. Rehfuess). Water, Air, and Soil Pollution 100, 1997, 379-386. - Geschichte des Waldes. Von der Urzeit bis zur Gegenwart. München 1998.