EVOLUTION AND FUNCTION OF EARTH'S BIOMES: TERRESTRIAL SYSTEMS

Kuester H.
University of Hannover, Germany

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Summary

In this article the different terrestrial biomes of Earth are briefly described. The reasons for the characteristic differences are explained by giving a short introduction to terrestrial ecology, particularly with respect to the relations between organisms, climates, and substrates and to the fact that the resulting ecosystems cannot be regarded as completely separate and stable units. An outline is given of why biomes are not stable, why populations of organisms tend to enlarge their areas, and how this is changed by evolution. Human interference, which is present and has grown over the millennia, influenced and still influences the development of some biomes more intensively than others. Natural and human influences together cause characteristic biomes which should be protected or developed with special care.

1. Introduction: Different Biomes

On Earth's continents several biomes can be distinguished.

In the vicinity of the equator, tropical rain forests can be found with generally high temperatures and high precipitation rates throughout the year, and no seasons. There is, however, a periodicity of weather conditions during the days, with a hot, sunny morning and noon, when intensive evaporation of water takes place and clouds are formed, followed by a thunderstorm in the afternoon with heavy rain. In the late afternoon sunny weather conditions again prevail. Frosts never occur in the tropics. Typical ecosystems of the tropics are the tropical rain forests which are well developed in the Amazon basin in Brazil, in central Africa, south India, and the Malaya archipelago.

Outside the inner tropics, there are two outer tropical and subtropical belts to the north and to the south. Seasons occur in these belts, including a rain period when the sun rises up to the zenith, and a season of drought, in which the sun is somewhat further away, but temperatures are normally high. According to the precipitation rates and the temperatures, either woodlands or savannas prevail. Further away from the equator very dry regions can be found where rainfall only occurs once in many years, but frost can occur during clear nights. Very few plants can grow in these regions, and deserts such as the Sahara, the Kalahari, the Mexican deserts, and the inner parts of Australia predominate.

In the vicinity of coasts in the subtropical belt a so-called etesien climate occurs, with rains in winter and a period of drought in summer which is not very severe. Frosts can sometimes occur and harm evergreen plants. Typical etesien climates can be found in the Mediterranean area and in California.

Further to the north and south, temperate regions can be found, such as in Europe north of the Alps, in China and Japan, and in North America. In the southern part of the globe, temperate regions are restricted to some small areas of south Australia, New Zealand, and Chile. There a marked seasonality of climate is typical, with warm and rainy summers and cold, damp winters with regularly occurring frost periods. Broad-leaved deciduous trees, which are green only during summer, prevail.

In the inner parts of the continents, where the climate is more continental, and further to the north in the northern hemisphere, boreal woodlands grow, with predominant conifers such as spruce, pine and larch. Boreal woodlands (also called taigas) cover great parts of Canada, Scandinavia, Russia, and Siberia. In the southern hemisphere, no land is found in the area where boreal woodlands could occur.

Near to the North and South Poles, which are covered by permanent ice, arctic vegetation types without trees and shrubs can be found. Herbs and grasses which can grow and develop during very short summers, and are covered by snow during a long winter season, prevail in these regions.

The closer the proximity to the equator, the more equal are the lengths of the days year-round. The closer the proximity to the poles, the more the day lengths differ through the year. Winter days are very short, and north and south of the polar circles the sun does not shine at all in winter. In summer, by contrast, days are very long, and between the poles and the polar circles the sun shines all day round at midsummer.

Biomes, ecosystems, and plant and animal communities must be understood as types, which are defined so as to describe them in a brief and readily understandable way. However, they are not restricted in any simple way that can be deduced from vegetation and ecosystem maps, which can only give an overview of the ecosystem types.

In mountainous areas, a zonation of biomes can be found which is very similar to (although not exactly the same as) the zonation according to latitude: there are deciduous woodlands in the lower belts, conifers in higher elevations, a timberline and a belt of alpine vegetation which is similar to the arctic vegetation. Differences between arctic and alpine stands are caused by the different lengths of the days in the two areas.

Whereas the biomes which exist in accordance with the climatic belt can be categorized as being zonal, many stands in the mountains are extrazonal. This means, for instance, that an ecosystem which is similar to an arctic ecosystem can be found inside the temperate zone, which makes it extrazonal. Other extrazonal ecosystems or plant communities can be recognized on steep slopes. Slopes exposed to the sun may be covered by plants which normally grow in warmer areas than those of the zonal stands nearby. On slopes in the shade, plants can be found which normally occur in ecosystems which zonally correspond to colder regions. Further extrazonal stands are dry regions inside the tropical belt which may owe their existence to a mountain chain which avoids the circulation of tropical cyclones. Extrazonal stands in the etesien belt are mountains with higher precipitation rates such as the Zagros and Tauros mountains and the Lebanon in the Near East, where climatic conditions can be found which are in some respects similar to the temperate zones.

Aside from zonal and extrazonal ecosystems, azonal ecosystems also develop. In these, special ecological parameters are, so to speak, stronger than climatic conditions and form similar ecosystems in several vegetation zones. Azonal ecosystems are, for instance, fens and bogs, lake and sea shores, and river banks.

2. The Reasons for the Differences

2.1. The Preconditions for Photosynthesis of Autotrophic Plants

In some parts of the Earth, life continues year-round, while in other areas phases of life development are interrupted by regular phases of rest which occur every year. Rest can be caused by drought, cold temperatures, or by a combination of both.

High activity of life only occurs if plants, autotrophic organisms, are growing. This means that photosynthesis must be able to proceed so that primary production of carbohydrates or organic materials from inorganic compounds can take place. The products of photosynthesis (the carbohydrates) can be transformed into very many different organic compounds. In plants, mainly cellulose is formed, the building material of plant cell walls. Only if cellulose is built up can the plant grow. The woody parts of plants are characterized by lignin intrusions into the cell walls.

Photosynthesis in the green parts of plants can only take place if certain preconditions are fulfilled: water, CO_2, and solar energy must be available. Whereas CO_2 is always available in the atmosphere, the presence of water and solar energy varies according to the weather conditions. Water is available in humid phases of the year, but not in dry phases, and also not during phases of frost, when the water is frozen and therefore unavailable for photosynthesis just as in dry phases. But the availability of water is not only affected by climatic conditions. Water can be delivered by rivers (such as the Nile, the Indus, the Ganges, the Euphrates, and the Tigris); on the other hand, water can be tightly held by the soils so that it is not available to plants. The availability of solar energy varies according to the seasons, especially in high latitudes. It is well known that plants develop according to the lengths of the day: plants at high latitudes flower in the season when days become longer, which happens before a warm period during which seeds and fruits can develop; plants at low latitudes flower when days become shorter, which happens before a season with moister conditions which are also appropriate for seed development. See ***Photosynthesis, Water Cycle***. See ***Water Cycle***.

2.2. The Availability of Trace Elements

For the favorable development of plants, nitrogen (either in the form of nitrates or as ammonium) must also be available: it is essential for the formation of amino acids and of the DNA bases. Sulfur is also necessary for the biosynthesis of amino acids, the parts of proteins or enzymes which are essential for all enzymatically controlled biosyntheses inside organisms. Phosphorus (in the form of phosphates) is necessary for the formation of some compounds transferring energy in living beings and also for the formation of parts of DNA. Some trace elements, such as iron and potassium, must also be available for optimal plant growth. All these elements are taken up from the soils (N also from the atmosphere by some organisms), where they are available in different concentrations. The concentrations of trace elements are partly determined by the geological substrates, but also by the pH-values, as they are only set free from clay minerals at special grades of soil acidity. Soil acidity depends on the development of humic acids from decayed organic material and is also influenced by the character of the geological substrates. See ***Trace Elements***.

Some plant species form a symbiosis with fungi called mycorrhiza. Fungi are not autotrophic, but rather heterotrophic organisms without the capacity for photosynthesis. They receive carbohydrates from plants, and they deliver additional water and trace elements to the green plants. It is likely that very many green plants can only grow in combination with fungi. Other plant species live in a symbiosis with bacteria which can fixate nitrogen from the atmosphere; this is especially characteristic of legumes.

Some trace elements are more frequent in limestone, others in silicates. However, the availability of trace elements depends also on the more recent Earth history of the substrates of different stands. Some areas of the Earth, notably the tropical belt, were relatively stable during the Ice Age. The woodlands were much more limited in area than at the present time, but the region was not glaciated, and severe frosts did not occur as often and regularly as in other parts of the world, so that severe frost erosion, transport of coarse and fine materials and sedimentation did not take place. Severe frost erosion due to crushing of stones took place both in the glaciated areas and in the vicinity of the glacier fronts. Stones were further crushed by melting water, which sometimes streamed with great strength and in abundance from the glacier fronts to the oceans. Coarse materials remained in the river beds, whereas fine sediments were transported to the estuaries and coasts where they were deposited as loamy and fertile substrates. Other fine materials were blown out of the river beds when they fell dry during winter and deposited as loess and cover loam on the denuded rocks of the mountains where only sparse vegetation of herbs and grasses could be found. These fine sediments contain very many different trace elements and form the most fertile stands for plants on the earth. In the tropical belt, fine loam and loess were not distributed during the Ice Age, which is one reason why tropical soils are poorer in minerogenic nutrients.

2.3. The Different Life Conditions for Consumers

Consumers are heterotrophic organisms which are not able to synthesize organic compounds from inorganic materials. They must take up organic materials by nutrition. Organic material must be taken up by eating autotrophic organisms or parts of them, or by eating other consumer organisms. Consumers are a few higher plants (such as some orchids), fungi, heterotrophic microorganisms, and all animals.

Most or all animals (it is not established with certainty which) are not able to feed on cellulose, a main component of plants, because they lack enzymes called cellulases which control the decay of cellulose. But there are several other possibilities for nutrition:

- Animals can feed on plant organs which contain relatively small amounts of cellulose, such as fruits, seeds, bulbs and other store tissues, and young shoots in which a secondary length growth has not taken place so that high amounts of cellulose have not formed. This is the case with young shoots of grass, asparagus, and sprouts.
- Other animal species live in a symbiosis with microorganisms, mainly bacteria, which can crack cellulose with the aid of their cellulases. During assimilation, they build up other organic compounds which can serve as nutrition for the animals. In the case of ruminants, this process takes place in the rumen. Ruminants are therefore able to feed on green shoots and leaves of plants which consist mainly of cellulose. Insects feeding on green plant parts also live in a symbiosis with bacteria.
- A third group of animals does not feed on plant materials at all, but is carnivorous, which means that other animals are predated and digested afterwards. For assimilation, only organic compounds which are similar to those of the organism itself must be decomposed, in order to build up other organic compounds so that the consumer's own body can grow and survive.

According to the different methods of nutrition, different food chains are formed which always begin with the producers, i.e., the green plants, which are able to form organic compounds by photosynthesis. Primary consumers feed on these plants: the primary consumers are animals in cases where, e.g., seeds and fruits are eaten and microorganisms in the symbioses of ruminants. The ruminants in reality are not primary consumers but secondary consumers inside the food chain. Carnivorous animals are also secondary consumers, but they can additionally be tertiary consumers if they feed on ruminants or on other carnivores.

There are also omnivores, which feed on both meat and plant material, such as humans, rats, and pigs. But in these cases the only plant materials which are taken up are those containing only small quantities of cellulose, such as seeds and fruits.

Some animals are active throughout the year, which means that they must be able to withstand hard weather conditions such as drought and frost in unfavorable regions of the world. Other animals rest in periods when conditions for living and foraging are not favorable. There are also animals which move over great distances according to the seasons, the climatic conditions, and the availability of nutrients, such as the large mammals of the savannas, some grasshoppers and other insects, and migrant birds.

Normally, the numbers of animal populations are controlled by the availability of plants or animals as their nourishment. Only as many individuals of a species can survive as can feed on their specific nutrients. If the number of individuals becomes greater than the number which can find enough nutrients, a reduction of nutrients or famine results. Only those individuals which are able to find nutrients survive; others starve. In some animal species, mainly insects, the numbers of individuals vary enormously from year to year; this is for instance the case with subtropical migrant grasshoppers. A phase in which large populations of grasshoppers occur can cause severe damage to plant populations serving as their nutrition. A restriction of population sizes of these plant species is followed by restrictions in the animal species, which becomes rare through the following years, so that the populations of the damaged plant species can increase again.

In agriculture, monocultures of plants are normally formed, so that the nutrition conditions for some animal species become extremely favorable. Cultivation of potatoes thus gives rise to very favorable conditions for the growth of populations of the Colorado beetle, and cultivating and storing cereals causes the growth of populations of rats, mice and some beetles which feed on cereal grains, which serve also as nutrition for humans. See ***Macronutrients, Micronutrients***.

2.4. Decomposers

So-called decomposers function as the next step in a food chain. They decay organic compounds to form mineral inorganic compounds; this process is called mineralization and takes place in soils. Through this process nitrates, ammonium, phosphates, and trace elements become available in the soils. They may be retained in clay minerals, but they can also serve again as essential nutrients to plants, which are primary producers of organic material. Decomposers decay secretion products such as feces and also dead plant and animal material from which compost is formed. Dung and compost serve as valuable manure because of their high contents of nutrients for plants as primary producers. Harvesting crops and hay-making must be compensated for by manuring because organic material, including trace elements, is removed from the stands during harvest: the nutrients are not available on the stands through natural decay because this is avoided by man through the harvest of crops and animal fodder.

Decomposers are only active if the soil is not frozen or too acid, and if enough water and oxygen are available to them. Decay of organic materials proceeds best if the pH values are neutral or slightly basic, if no frosts occur, and if water is available all the time but the groundwater table is not too far from the earth's surface. Life conditions for decomposers are very favorable in the tropical belt, but less favorable in cold areas, bogs, and deserts. In the tropical rain forest a very rapid turnover of nutrients takes place after decay so that new plant material is formed with the aid of the decayed material as quickly as possible; the decayed material is not stored in the soils. In the temperate zones, decomposers cannot decay organic material all year round, but they also work rather effectively due to the almost permanent availability of water and oxygen. Inorganic compounds can be stored by the clay elements in the soils, which takes place in tropical soils to a much lesser extent. See ***Weathering***.

Food chains are formed as rotation systems, which vary according to the climate, the availability of water and inorganic nutrients which are available in different ways and in different amounts from the geological substrates. The conditions for agriculture, cattle breeding, forestry, and nature conservation are therefore very different in each part of the world, and only bear partial comparison with each other. See ***Food Chain***.

3. Stability and Dynamics of Ecosystems

3.1. General Remarks

When discussing Earth's biomes, it must not be overlooked that they are only types which are and can be defined for the purpose of describing the Earth's nature, as mentioned above. This is also the case with plant communities, ecosystems, landscapes (in a geographical sense), and their units. Types are ideals, designed by man. Looking at types one must be aware that they sum up individual landscapes or ecosystems which are unique in the world. Certainly, there are similarities between the tropical rain forests in Africa, Southeast Asia, and South America, but also large and important differences. The same is true for the temperate zones of the world. The temperate broad-leaved woodlands in North America, Europe, and East Asia are similar, and they can be regarded as a type, as one biome. However, there are also differences which are partly caused by slightly different ecological parameters, but in particular by the different plant, animal and microorganism species which live in the specific ecosystems and form them. See ***Ecosystems***.

In designing a map of the earth's biomes (as well as the landscape units, the ecosystems, or plant communities), it is very important to designate the boundaries between the single units or types of nature which can be classified. These boundaries are only important for the map: they do not exist in nature. Biomes as well as landscape units, ecosystems, and plant communities do not have boundaries in reality but only on the map, in an abstract "world". In reality, sometimes gradients between different biomes or ecosystems can be defined, but even these gradients do not have fixed boundaries.

The boundaries of a map of landscape and nature units also give a misleading impression in another way. They tell the user of a map that the boundaries, and the units they separate, are stable. However, this is not the case either, as the plant and animal populations forming the biomes in which they live always tend to enlarge the areas in which they occur, a tendency which is sometimes avoided by climatic and other abiotic influences, but permanently hindered by members of other plant and animal populations.

A further compelling reason not to regard these basic processes of ecology as stable is that the stands of plants change, partly under the influence of the beings themselves, but mainly because the genetic constitution of all living beings changes through time by the mechanisms of evolution, including genetic mutations, selections of populations, and the (mainly geographic) isolations. At any point in time, new populations of beings can arise which behave in new ways in the course of the important processes of competition which function as the basis of enlarging or restricting areas in which plant, animal, and microorganism species occur.

One must be aware that, when dealing with structures of life, one can develop models with fixed terms (which might be "species" or "biomes"), but this contrasts with living structures which are not stable in the sense that they could be computerized so that the past, present and future states of life or aspects of it can be determined by computer. This is nevertheless attempted intensively throughout the world with enormous effort, yet it is increasingly forgotten that life itself is rather incompletely understood if an endeavor like this is undertaken with the claim to lead nature sciences to a new horizon. The development of computerized models of the future of nature is interesting, but biologists must recognize that the computerized simulation of nature's development has little to do with the real development of nature and its structures or units, which are also not real, but rather defined by man.

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Biographical Sketch

Professor Dr. Hansjörg Kuester: Born 1956 in Frankfurt/Main, Germany. Studied Biology at the University of Stuttgart-Hohenheim 1975–1981. 1985 Dr.rer.nat. in Biology at the University of Stuttgart-Hohenheim. 1981–1998 coordination of the work group for vegetation history at the Institute for Pre- and Protohistory at the University of München/Munich. 1992 Dr.rer.silv.habil. at the Faculty of Forestry Sciences of the University of Munich. Further teaching experiences at the Universities of Potsdam, Würzburg, Regensburg, and Freiburg. Since 1998, Professor for Plant Ecology at the University of Hannover.

Fields of interest: Plant ecology, Vegetation history, Landscape history, Archaeobotany.

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