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International post-graduate course in ecological approaches to resources development, land management and impact assessment in developing countries

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INTERNATIONAL POSTGRADUATE COURSE IN ECOLOGICAL APPROACHES TO RESOURCES DEVELOPMENT, LAND MANAGEMENT AND IMPACT ASSESSMENT IN DEVELOPING COUNTRIES (EMA)

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United Nations Educational, Scientific and Cultural Organization (UNESCO) and the United Nations Environment Programme (UNEP)	Centre for Protection and Improvement of Environment (Berlin) of the Ministry of Environmental Protection and Water Management of the German Democratic Republic in cooperation with the Technical University Dresden

Subject II: Ecological fundamentals of production systems

STUDY MATERIAL

elaborated by a team of authors under W. Bassus

Volume One

II. 1. Biological fundamentals of production

- Basic problems of the ecology of terrestrial ecosystems
- Basic problems of the ecology of aquatic ecosystems
- Fundamentals of primary production
- Production of useable biomass and strategies for its utilization
- Influencing the productivity of ecosystems

Volume Two

II. 2. Soil as production factor

- Soil genesis
- Soil types and soil classification
- Site characteristics
- Soil fertility

Volume Three

II. 3. Water as production factor

- Climate and hydrological cycle
- Groundwater
- Surface water
- Interrelations soil-water-plant
- Irrigation and drainage
- Water quality, water treatment, drinking water supply

Volume Four

II. 4. Stability and protection of ecosystems

- Economic, social and hygienic influences
- Conditions for the regeneration and stability of ecosystems
- Measures for the maintenance of stability
- Management of nature and landscape protection, biosphere reserves and rational utilization and protection of natural resources

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Volume One

II.1. Biological fundamentals of production

Introduction

To have knowledge of the biological and ecological foundations of life on earth is a necessary prerequisite, if any management and preservation of ecosystems is to be effective.

Section II.1. which deals with the "Biological fundamentals of production" provides basic knowledge on terrestrial and aquatic ecosystems, primary production and factors which may affect the productivity of ecosystems.

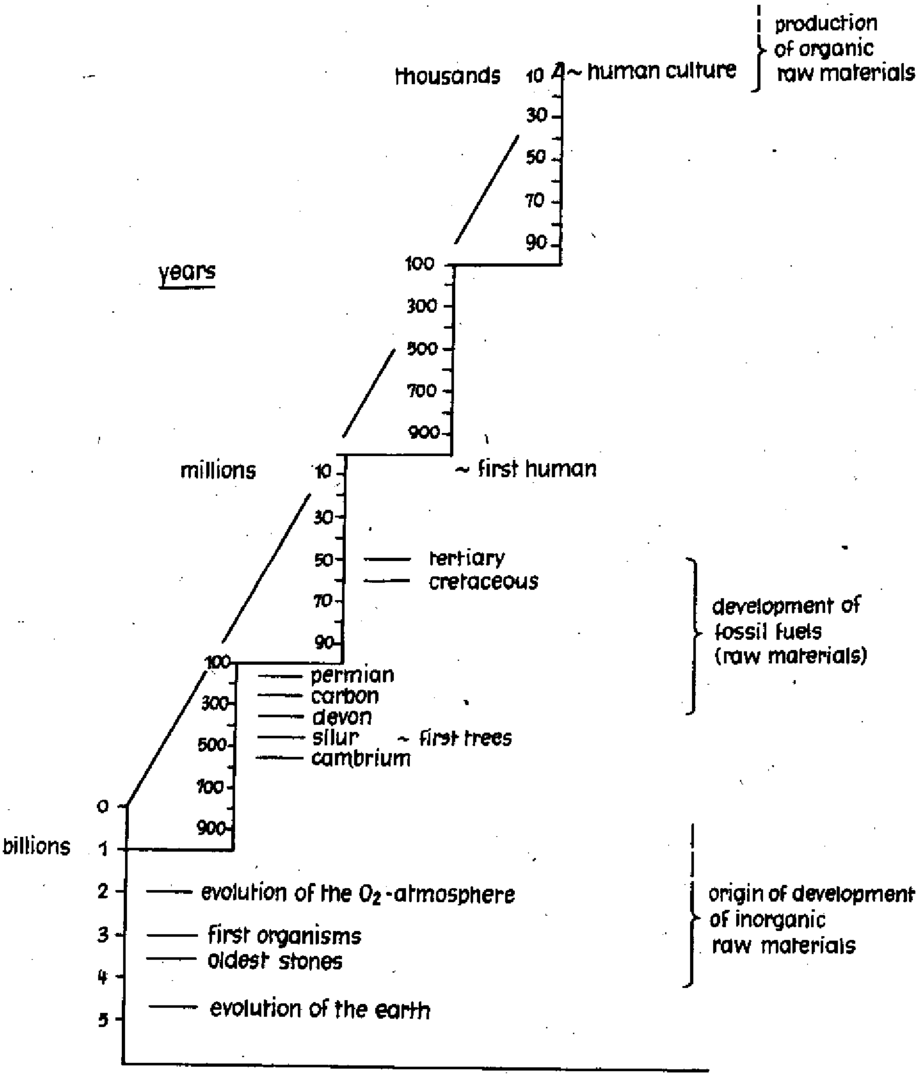
Readers shall be enabled to

- understand ordering principles and regulating mechanisms of nature;
- understand biological and ecological processes of the productivity of ecosystems and their underlying laws, and
- familiarize themselves with a number of methodological fundamentals for ecosystem analyses and ecosystem assessments.

This knowledge is absolutely necessary, if an understanding is to be acquired of the management (use and maintenance) of agricultural, forestal and aquaric ecosystems.

The earth is about 4.5 billion years old. It has been inhabited by living creatures for some three billion years and by man for about 3 million years.

Figure II.1.-1 Geo-biological evolution and development of natural ressources



When the earth was formed, this process was accompanied by the formation of its crust structure and the emergence of the inorganic matter. These were processes of geological evolution. Many of the inorganic unrenewable natural substances (such as stones, minerals and ores), which cannot be manufactured industrially, came into existence during that time.

That was the period of the development of the geosphere, if the process is seen from an ecological point of view.

The geosphere is the entire earth, but with no living creatures on it.

The geosphere can be subdivided into three other distinct spheres:

- lithosphere: the sphere of the solid and loose rocks
- hydrosphere: the sphere of the liquid water
- atmosphere: the sphere of gaseous air.

Lithosphere

The lithosphere is the earth's solid crust. It is subdivided into the SIAL, an outer layer of 10 to 40 km, and, below it, the SIMA which is 20 to 40 km.

The important process of soil formation happens at the surface of the lithosphere, with living creatures being involved in this process of paramount importance to plants, animals and man. Topic II.1.2. "Soil as a production factor" will deal with this process in more detail. In ecological terms, the soil itself is sometimes called the "pedosphere".

In addition to the inorganic and unrenewable natural substances, the lithosphere contains also organic unrenewable (fossil) natural substances of primarily plant origin: hard coal, soft coal, petroleum and natural gas. So far, the lithosphere had been considered to constitute the "unexhaustable source of a large number of elements which the organisms need for the buildup of their body substance" (LARCHER, 1980).

This definition may still apply to the organisms of plants and animals, which need these elements only "temporarily" for the buildup of their body substances, and from which they are recycled to the pedosphere after their death.

But the deposits are limited for man, as he converts many of these ores or minerals into technological products or burns organic fossil raw materials for the generation of energy, so that they will be lost for ever.

Hydrosphere

The hydrosphere does not only include the oceans and seas (which account for 71 per cent of the earth's surface), but also the streams, rivers, lakes and ponds and the ground and dammed-up water in the soil. Its depth may be three to four kilometres in the open ocean and more than 11 km in the oceanic deeps. As the hydrosphere contains considerable amounts of elements, it is a major source of inorganic natural substances. However, the hydrosphere assumes much more important with regard to the number of aquatic organisms living in it.

Atmosphere

The atmosphere contains the air of the earth. It can be subdivided into three other spheres:

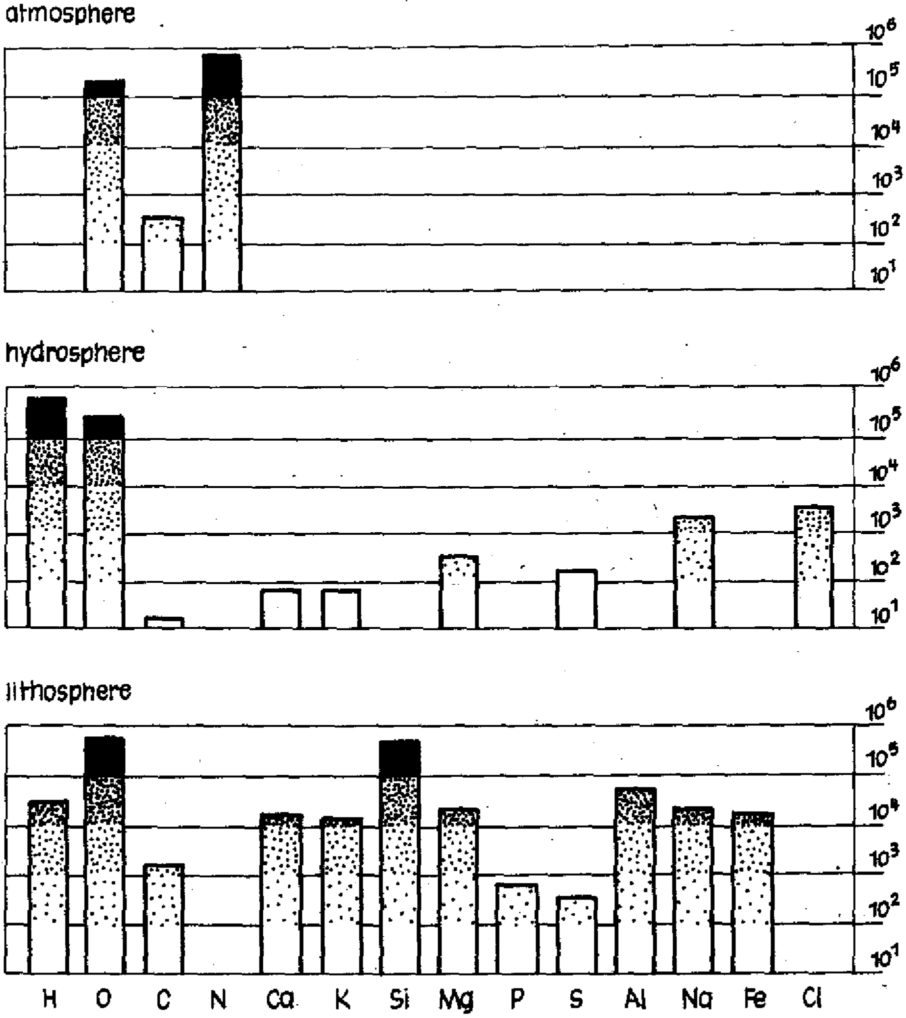
- troposphere: it extends from the ground level to an altitude of about 15 km. Living beings usually have contact only with this layer, which is also the zone where the weather is generated.
- stratosphere: it extends to an altitude of about 100 km. It contains an ozon belt at an altitude of about 20 - 60 km, which shields the organisms from the dangerous cosmic radiation, whereas the solar radiation of a wavelength between 0.29 μm and 3 μm passes the belt.
- ionosphere: it is the conducting layer of the atmosphere, which extends up to an altitude of 500 km.

In addition to the chemical elements shown in Fig. II.1.-2., the air contains also noble gases. All living beings living on the solid surface of the earth are markedly adapted to the composition of the air.

Depending on its concentration and length of occurrence, a pollution of the air constitutes usually a threat to their life. Fig. II.1.-2 shows the proportions of the chemical elements (the number of atoms, not percentage by weight).

Fig. II. 1.-2

Chemical elements (numbers of atoms, not weight-amounts) in the atmosphere, hydrosphere and lithosphere



source: Larcher 1980

The lithosphere, hydrosphere and atmosphere constitute the nonbiotic (abiotic) environment for any living being. For more than three billion years, an immense number of different living beings have developed in the abiotic environment. (There are an estimated 200,000 species of higher plants, among them about 40,000 or 50,000 tree species, some 80,000 Or 100,000 species of fungi and about 1,260,000 animal species, including about 854,000 insect and 42,000 vertebrate species.)

They are all interrelated in some way or another, be it as food for another species (nutrition chain), as a symbiont or in the host - parasite relation, or as competitors for food and space. The interrelations between the living beings are their biotic environment.

Accordingly, environment is the entirety of the abiotic and biotic conditions under which a living being or a community of organisms exists.

In a several million years' process of evolution, the organisms presently in existence have adapted themselves to the conditions of their environment. Owing to their adaptability, they have conquered waters and the solid earth's surface as their habitats and some have even penetrated into the troposphere or deep into the lithosphere. Birds may rise up to 2 km above ground level and microorganisms, insects, spores, pollens and seeds may be transported through air currents even into the troposphere. Anaerobic unicells (bacteria) were found up to 3 km deep in the earth's crust and up to 10 km deep in the oceans.

Abundant life, however, exists only in the layer near the earth's surface; i.e., about 100 m (trees) above and 10 m (roots) below the earth's surface or up to 100 m below sea level in waters penetrated by light.

The part of the geosphere which is able to support life is called biosphere.

While the development of the geosphere involved maninly the formation of inorganic unrenewable substances, the development of microbial, plant and animal organisms in the biosphere provided the basis for the formation of organic substances and soils. The formation of organic substances is a process which is underway also in the present time and whose basis is the conversion of carbon dioxide and water into carbohydrates and other organic substances by the green plants by means of the energy of the sunlight.

It is thanks to this photosynthesis, whose evolution started more than 2 billion years ago, that the atmosphere contains oxygen and that vegetative and - through the nutrition chain - also animal biomass is formed both in the past and at present. It is thanks to this process that immense, though not inexhaustible deposits of fossil organic natural resources such as hardcoal, soft coal, petroleum and natural gas have been formed. A large proportion of these deposists is attributable to trees whose evolution started some 450 million years ago. And this process of photosynthesis is also responsible for a constant re-formation of biomass, i.e., the constant formation of organic reproducible substances which serve man's nutrition and are used by him as raw materials.

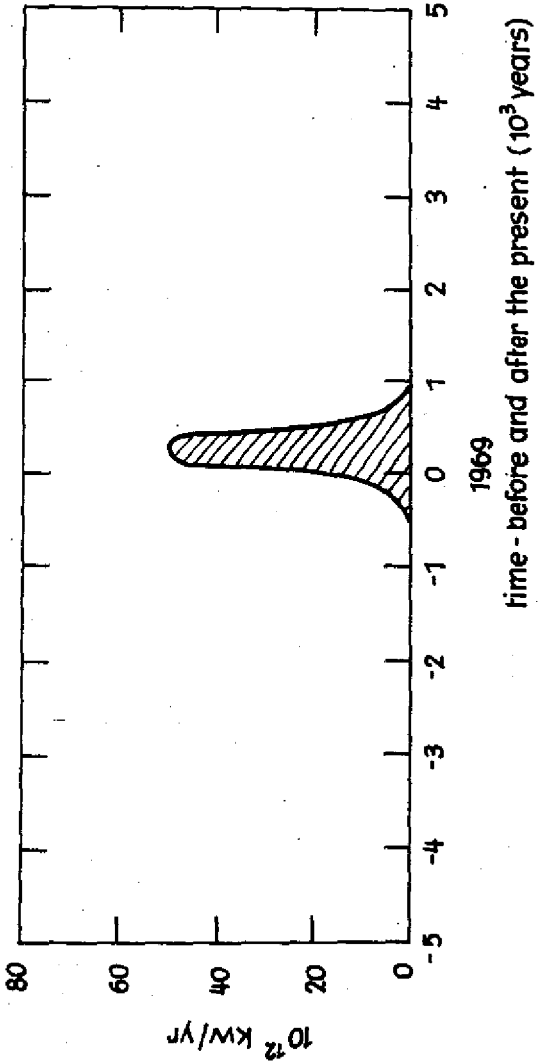
The evolution of man is impossible, unless <u>organic, renewable natural substances</u> are constantly formed. In prehistoric times, the food gathers and hunters used them, when civilization came into being they were used by the farmers and cattle rearers and they are being used in an ever more intensive manner as sources of food, energy and raw materials today. They are the basis of any production in ecosystems.

The use of <u>organic unrenewable</u> (fossil) natural resources started relatively late in history, if compared with the use of plants, animals and microorganisms. Fig. II.1.-3 shows that fossil natural resources such as coal, petroleum and natural gas have been used for about 500 years now, with this use climaxing during the period of industrialization.

It is impossible to exactly predict when the fossil raw materials will be exhausted. Preston (1969) gave a fairly optimistic estimate of about 1,000 years, whereas pessimistic approaches (Meadows et al., 1973) predict that they will last no longer than for another 150 years.

Fig. II.1.-3

Exploitation of fossil fuels in the past, present and future



source: Preston, C. 1969

II. 1.1. Basic problems of the ecology of terrestrial ecosystems

Ecology is the study of the relations between the organism and its environment.

The term ecology was derived from the Greek "oikos" meaning "household" or "theory of housekeeping". It was first used by Ernst Haeckel in 1866 in his "General Morphology of the Organisms" to denote the "theory of the household of nature".

Haeckel considered ecology to be mainly a biological discipline.

Biologists, however, are not able to study the entirety of relations between organisms and their environment. That is why it is common today for geologists, chemists, physicists, mathematicians and other scientists to work together with biologists on ecological problems. UNESCO's "Man and the biosphere" research programme which, in existence since 1975, has given particular emphasis to the involvement of man as a biosocial being in ecological studies, calls for the cooperation of sociologists, philosophers and other social scientists, too.

Ecological studies may investigate the relations between the organism and its environment in relation to the entire biosphere (global ecology) or in relation to smaller ecological units.

Such "smaller ecological units" can be regarded as subsystems of the biosphere. Their delimination is more or less random and fuzzy, and it may depend upon the scientific discipline conducting the study or the objectives of the study.

The system of ecological relations existing in bodies of water is called aquatic subsystem of the biosphere and that existing onthe mainland is called terrestrial subsystem of the biosphere.

The research into the relations between the organisms and their environment in bodies of water is called aquatic ecology.

The research into these relations on the mainland is called terrestrial ecology.

However, more ecological subsystems exist in both bodies of water and on the mainland: e.g., ocean, lake, river or wood, field, meadow, desert. Their common feature is that they all are composed of a large number of structural and functional components which are interlaced. Energy and substances must be consumed by them for their very existence, while other substances and entropy (mainly heat) are discharged to their environment.

In thermodynamic terms, they constitute open-end systems just like all living beings and any individual cell.

They are called ecosystems and their definition reads as follows:

> "An ecosystem is a structured and functional system in space and time which includes any community of living things and their environment."

Tab. II.1.-1 shows some of the essential structural and functional components of ecosystems.

Such structural and functional components were individually investigated in the past and this approach is still frequent today, but such studies will not provide an understanding of the ecosystem in its entirety just as an analysis of individual cells does not provide an understanding of the structure and function of higher developed living beings (animals or plants) in their complexity.

This shows that ecosystems like all other scientific objects to which we have access form entities into which other less highly organized systems which in themselves again form entities are integrated.

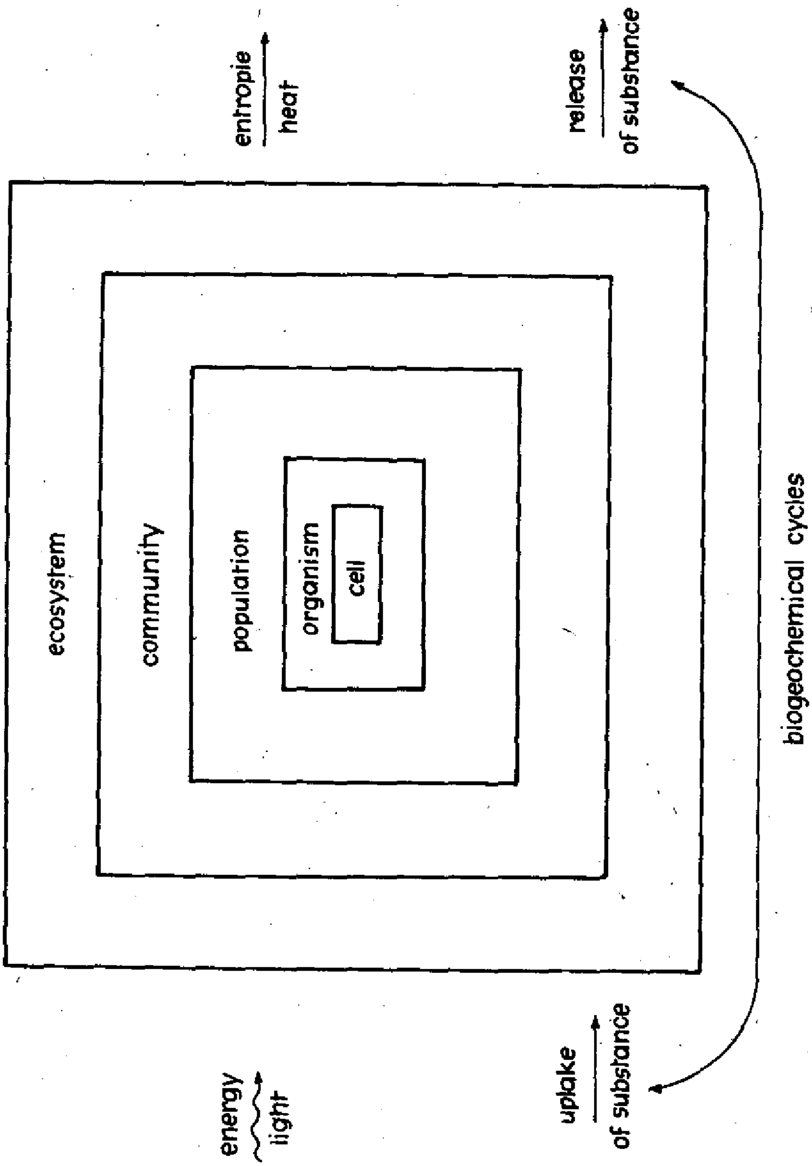
Tab. II.1-1

Selected structural and functional components of ecosystems

Structural components	Functional components
Biological components	- Energy flow
(Biocoenoses, biomes)	. radiation
- Communities	. biochemical energy
. Phytocoenoses	- Change of entropy
. Zoocoenoses	. heat
. Microbiocoenoses	
- Populations	- Food chains
. plants	. trophic chain
. animals	. trophic web
. microbes	- Biogeochemical cycles
- Individuals	(nutrient cycles)
. plants = primary producers	. cycle of water
. animals = consumers	. cycle of carbon dioxide
. microbes = reducers (destruents)	. cycle of minerals
- Diversity patterns in	- Information and transfer of information
time and space	- Control and regulating mechanism
Abiotic components	. adaption
(Biotope, ecotope)	
- Climatope	- Development and
. temperature	evolution
. light	- Stability
. air	- Productivity
. moisture	
- Edaphotope	
- Chemical components	
. oxygen	
. carbon dioxide	
. nitrogen	
. minerals	
. water	

However, these superior entities involve always more than the sum of the entities integrated into them.

Fig. II.1.- 4 Ecosystem and integrated biological systems



This statement does not forego the possibility that the structural and functional components listed in Tab. II.1.-1 are investigated separately and by scientists of different disciplines, but the individual investigations must be followed by a mathematical and statistical processing of the data obtained as well as by modelling, if the ecosystem is to be covered in its entirety.

It is also important for any researcher or user of ecological conditions to have a precise knowledge of the variety of individual structural and functional components and their interrelations. A somewhat closer look at them is provided in the following. An ecosystem can be subdivided into the two large subdivisions of the biocoenose and the biotope.

The biocoenoses are the communities of living beings plus all their biological relations.

The biotope (ecotope) comprises all the abiotic conditions of the environment which affect the ecosystem or the biocoenose. Subdivisions of the biotope are the climatope and the edaphotope.

In the biocoenose, the organisms as individuals (plants, animals or microbes) form the smallest and structurally and functionally important ecological entities.

Depending upon their functional and ecological importance they are called:

A. primary producers.	Organisms which, through photosynthesis (seldom by chemosynthesis), accumulate potential energy in the form of organic meterial fashioned from minerals derived from the abiotic environment, C autotrophic, photosynthetically active green organisms.
B. consumers.	Organisms which get their nourishment directly or indirectly from the organic materials made by the primary producers;

C-heterotrophic organisms which cannot carry on photosynthesis.

Other subdivisions are:

B.a. primary consumers. Herbivores, phytophagous organisms and plant parasites.
They feed directly on living plants, that is, on the organic substances formed by the primary producers. They constitute a nourishment and energy source for other consumers.

B.b. secondary consumers. carnivores.
They feed on the organic substance of the primary consumers, e.g., as carnivores which eat herbivores.

B.c. tertiary consumers. Carnivores which get nourishment from carnivores.
They feed on the organic substance of the secondary consumers.

B.d. carrion eaters (scavengers)
They feed on the corpses of the preceding consumers or the prey abandoned by carnivores.

C reducers (decomposers or destruents) are also C-heterotrophic organisms which decompose dead organic substance down to the stage of inorganic substance. Reducers assure the progressive mineralization of organic material and its return to the inorganic world.

It is a complex group of organisms which should be further subdivided.
They include: insects, fungi, coprophagous bacteria, which feed on corpses not eaten by scavengers.

In addition, there is the immense population of fungi and saprophytic bacteria which convert organic material in the soil into CO_2 and H_2O (respiration of soil), thus assuring the continuity of the nitrogen cycle in mineralization and the fixing of atmospheric nitrogen. Finally, they restore to the soil the cations and anions needed by living beings.

Although this classification into producers, consumers and reducers provides a general idea of the major food chains and the flow of energy, it should not be regarded as a rigid and unchangeable system. Apart from the herbivores and carnivores there exist omnivores such as pigs. Reducers on the other hand, need not necessarily be the final link in a food chain, but may rather provide nutritive substances for other organisms, such as fungi do for snails.

It is, however, important to know that in a stable natural ecosystem producers, consumers and reducers are in equilibrium.

A collection of individuals of the same species in a given area at a given moment is a population.

Populations are characterized by their own specific structural and functional parameters such as: density of population, birth rate (natality), mortality, age structure, population dynamics, etc.

Populations are thus clearly distinguishable from individuals, so that they form their own entities. As such, they are integral parts of the next higher entirety: the community.

A community is an assembly of different species populations (thus of individuals belonging to different species) in a given area at a given moment.

Separate investigations of communities by botanists, zoologists, microbiologists etc. have led to their further subdivision into:

phytocoenosis: plant communities
zoocoenosis: animal communities
microbocoenosis: communities of microbes
parasitocoenosis: parasite and symbiont communities.

While the terms phytocoenosis and zoocoenosis are widespread and commonly used (as a result of the history of research), the terms microbocoenoses and parasitocoenoses are still unconventional and questionable. They are not clearly defined and partly superimposed by other terms. Just to give an example: in the case of microorganisms in the influence sphere of plant roots the term rhizosphere, and in the influence sphere of leaves the term phyllosphere is used instead of microbocoenosis.

The relations (interaction) between the various parts of biocoenoses are determined by the functional (physiological, biochemical, informatory) performances of the species of organisms, which are possible under the influence of their biotope. In addition, these specific performances of one species in the ecosystem depend upon both the influence of the biotope and the relations with the other species.

The term "ecological niche" has been introduced to denote the variety of trophic and spatial relations of an organism in the ecosystem. An ecological niche is the total of functional and spatial aspects in a biotope, which apply to one population; in an ecosystem in equilibrium, there is only one theoretical niche for each species population as a consequence of adaptations in the struggle for existence.

The following is a brief outline of the most important functional components of ecosystems.

Energy flow

A continuous supply of energy is absolutely necessary, if the living systems (single cells and also ecosystems) are to continue to live and develop on this earth.

The access to free energy is the central question for the survival of any living system, but energy can neither be generated nor destroyed in the interior of the systems. It is only the flow of energy in the individual and the ecosystem that leads to changes of their internal energy.

Primary energy is available in an apparently unlimited amount in the form of <u>solar radiation</u>.

The sun incessantly transmits radiation energy derived from the conversion of hydrogen atoms into helium. The sun radiates an amount of energy of 4×10^{26} J sec^{-1}, with approximately 1.39 kJ m^{-2} sec^{-1} reaching the outer limits of the earth's atmosphere. This value is called "solar constant".

As the solar radiation penetrates the atmosphere, much of it is absorbed, reflected or scattered so that no more than 47 per cent of the solar radiation which has reached the outer limits of the atmosphere actually reach the earth's surface. Depending on a place's geographical location, terrain, altitude above sea-level, etc., different amounts of radiation energy are available there in the course of a day. At sea-level, a plain area in medium latitudes gets about 900 J m^{-2} s^{-1} (LARCHER, 1980).

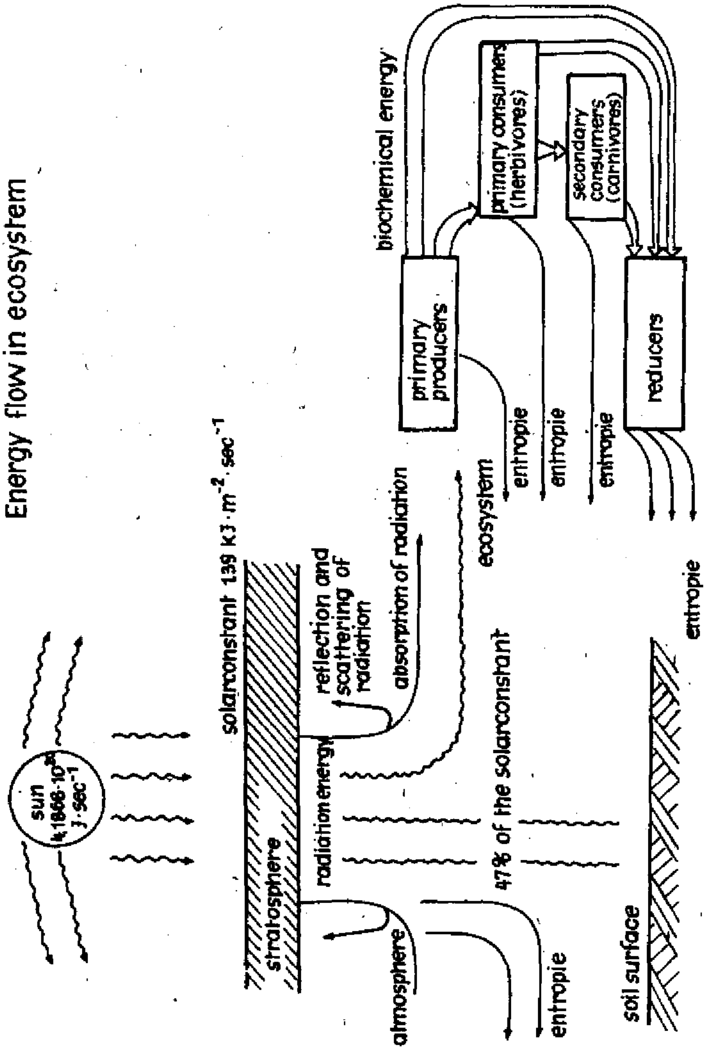
Only a relatively small percentage of the incident radiation energy (wavelengths between 380 and 710 µm) is used by the photosynthetic process of the green plants.

The abbreviation of this <u>ph</u>otosynthetic <u>a</u>ctive <u>r</u>adiation is PHAR. During photosynthesis, the radiation energy is converted into biochemical energy in the chloroplasts of the green plants (the primary producers). This is accompanied by an assimilation of organic substances.

As a result, organic substances rich in energy are formed, which can be stored by the plants and are available as sources of food and energy to other organisms.

A flow of energy is brought about as the stored biochemical energy of the primary producers passes to the consumers and other parts of the food chain. This flow divides into numerous smaller flows, in which part of the biochemical energy consumed is always used for a renewed production of substances, whereas another part of it is discharged to the environment in the form of heat (entropy) and is lost for ever. (Fig. II.1.-5)

Fig. II. 1.- 5
Energy flow in ecosystem



The part of the radiation energy which cannot be made accessible to the ecosystems through primary producers serves to heat up the earth's surface and the waters, and to bring about evaporation. Thus, solar radiation has been and continues to be the energy source for the production of organic matter, for the thermal regime as well as the water regime of the earth. It is part and parcel of the abiotic environment and creates the conditions of an environment, which enable vital processes to take place.

It was through solar radiation that the organisms developed from which mineral oil originated, and the forests of the Carboniferous and Tertiary, which turned into hard coal and lignite. Man, too, uses this energy transformed by green plants and stored by them as "chemical energy", for himself and for shaping his external living conditions, especially for technological purposes.

But, it is a well-known fact that organic, unreproducible raw materials, i.e. fossil fuels, used for direct energy generation are not available in unlimited quantities. For this reason, new ways of energy generation will have to be found, if mankind is to survive without being reduced in numbers, while maintaining its present standards of living.

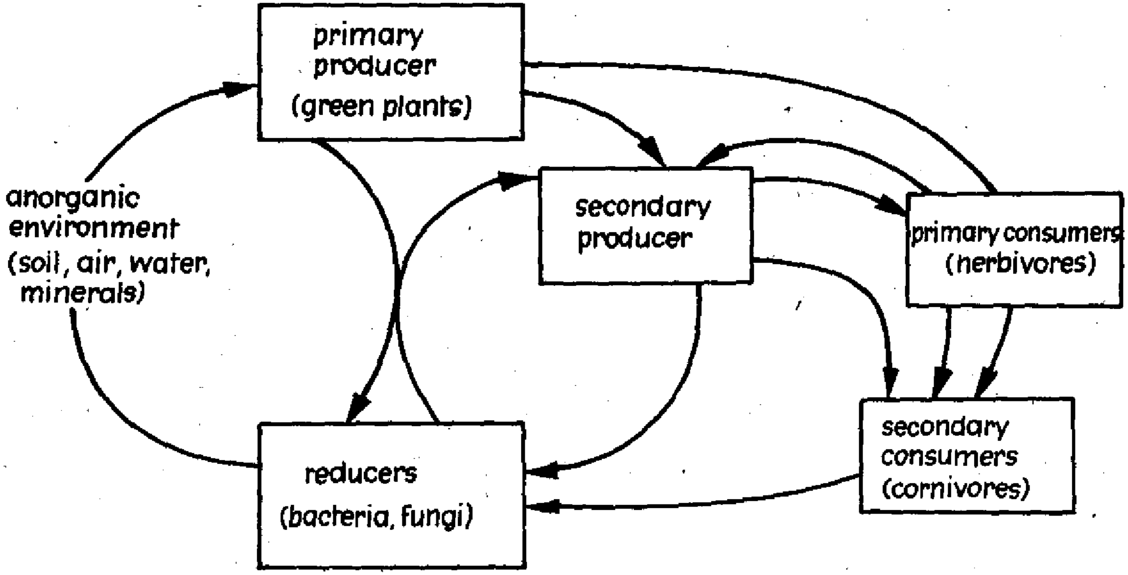
Such new ways are the use of nuclear fission, wind energy, tidal energy, the temperature of the earth's interior, biogas production, biomass for production of ethanol, and the direct technical use of solar energy (or indirect hydrogen).

Food chains

The description of the primary producers, consumers and destruents has already provided an indication of how substance can be transformed in an ecosystem.

It is a chain starting with the uptake and production of substances by the primary producers and continued by the conversion of substances by consumers and the decomposition of substances by the reducers. This is what is called a food chain. Fig. II.1-6

Fig. II. 1.- 6 Food chains in ecosystems



It is closely related with the flow energy in the ecosystem, without which it is unable to exist.

However, it is only in the simpliest of cases that a food chain exists directly from the primary producers to the primary and secondary consumers and the destruents.

Such a food chain is fairly obvious in agricultural ecosystems. They involve a systematic production of plants by man, which will be either used as fodder or be directly consumed by man. The flesh of the primary consumers is also consumed by man. Any wastes and corpses are finally mineralized by the reducers. There seems to be a clear food chain extending from the primary producers (plants) to the consumers (animals and man) and reducers (microbes). A closer look at this process reveals that this chain may be affected by a number of organisms. Wildlife herbivores such as seed eaters, or insects and microorganisms may cause serious losses among the plants cultivated, or wildlife carnivores and excitants of disease may decimate the animals kept.

The trophic chains in a natural ecosystem are even much more complicated.
There, the same producer can serve as food for different kind of herbivores or the same herbivore can feed many producers. These herbivores can in turn be eaten by various carnivores. This results in a multiplicity of trophic chains which anastomose in a <u>trophic web</u>.

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<u>The biogeochemical cycles of substances</u>

It has been shown that the energy of the biosphere flows only in one direction: sun - primary producers - consumers - destruents. Absorbed energy can only be used once by the same organism.

One quantum of radiant energy absorbed by the plant, transformed into thermal energy and restored to the atmosphere cannot be absorbed as thermal energy a second time.

However, inorganic substances important to life (bioelements) have the capability of forming a cycle.

These cycles take place in three dimensional spheres:
in the single organism, the ecosystem and the biosphere. The single organism takes up substances, which are then assimilated and precipitated.

The nutrition chains in the ecosystem are active. They are connected with the organic matter supplied to the biosphere by means of primary producers and destruents.

There are three basic types of biogeochemical cycles in the biosphere:

A. The "gaseous type" - the cycles of carbon, oxygen and water. The atmosphere and the hydrosphere are its reservoirs.

B. The "sedimentation type" - the cycles of the mineral bioelements. The pedosphere and the lithosphere are its reservoirs.

C. The "nitrogen type" is in an intermediate position between the "gaseous type" and the "sedimentation type", insofar as the air is its main reservoir (it contains 78 per cent of N by volume), but the primary producers are unable to absorb it from the air and are instead taking it from the soil (where only 0.05 per cent of the biosphere exist).

<u>The carbon cycle</u>

According to LARCHER (1973), the total store of carbon compounds on the earth is estimated at 26 x 10^{15} t C, which only appr. 0.05 % are bonded organically. The largest part of carbon compounds inorganically bonded is in coal, petroleum (mineral oil) and rock. In ecosystems, forests possess by far most of the organically bonded carbon.

75 per cent of C fixed in plants on the soil occurs in trees.

In the biosphere, carbon compounds are found in different states:

- solid: in the pedosphere and lithosphere,
- dissolved: within the cell sap, the water of organisms and the hydrosphere,
- *gaseous*: in the intercellular tissues of plants, in the pores of the soil and the atmosphere.

Green plants containing chlorophyll take carbon in form of CO_2 from the atmosphere through photosynthesis and convert it into carbohydrates by means of reduction. As a carbohydrate, it can be stored and enter the nutrition chains of the ecosystems or be fully perspired and get again on a short way into the atmosphere in the form of CO_2.

If carbon would enter the nutrition chains of the ecosystems, its exchange would last days or decades or even as long as centuries. Every year, about 6 - 7 per cent of CO_2 existing in the atmosphere or hydrosphere are fixed or bound by the green plants organically.

About 33 per cent are perspired by the phytomass, the rest serving as a nutrition base for consumers and destruents. Respiration, fermentation, decay or decomposition fill up again the CO_2 store of the atmosphere. In comparison with this biological cycle of CO_2, the release of CO_2 from volcanos, fires and industry is still very small at present. The total quantity of released CO_2 is annually somewhat more than 10 per cent of the CO_2 content of the biosphere.

All over the world, the average CO_2 content of the atmosphere is about 300 ppm, that is about 700×10^9 t of carbon in the whole atmosphere. There are, however, differences seasonally as well as regionally. In the northern hemisphere, the CO_2 content of the air is 8 ppm less during the vegetation period than in winter; in the southern hemisphere, the CO_2 content is 2 ppm less. In industrial districts, a maximum CO_2 content of 500 ppm was measured. This increase in the CO_2 content of the atmosphere not dangerous as long as there is a large photosynthetical active stock of plants (meadows, fields and woods) which are able to offset the increased content of CO_2 by raising their CO_2 assimilation.

The oxygen cycle

The average content of oxygen in the atmosphere is 21 per cent. Estimations based on single measurements and calculations of the absolute oxygen content of the atmosphere vary between $1.23 \cdot 10^{12}$t (BRÜNIG, 1971) and $1.2 \cdot 10^{15}$t (LARCHER, 1973). It is estimated that the total phytomass of the earth releases $70 \cdot 10^{9}$t of 0 to the atmosphere every year (LARCHER, 1973). This quantity, however, is largely consumed by the respiration of plants, man and microorganisms.

Since all processes of combustion consume oxygen, the store of oxygen of the earth, which, at first sight seems to be enormous, is by no means inexhaustible.

Its biological half life is estimated at 5,000 years (MOHR, 1969). At present and in the near future there will be enough oxygen available. A shortage of oxygen may, however, arise in the soil (pedosphere) and in water (hydrosphere), as the supply by diffusion and the water solubility of oxygen are relatively small.

The oxygen consumption by consumers and destruents can be very high, especially if the availability of nutrients is increased beyond the normal average (eutrophication).

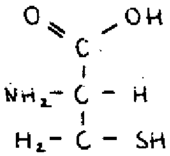
In addition, the circulation of the layers of water is very important to the supply of oxygen to the water. So the fact remains that the atmosphere is the main source of oxygen for all organisms.

The sulphur cycle

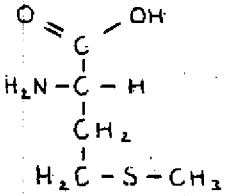
The cycles of the mineral bioelements can be explained by the example of sulphur.

Sulphur is an indispensable element for all organisms. As SH group, it is an essential part of the amino acids (e.g. cysteine and methionine)

cysteine

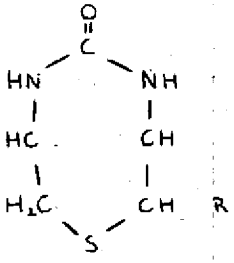


methionine



and proteins. Sulphur is also contained in vitamins (biotin and thiamine),

biotin



hormones (vasopressin), lipids of the nerve tissue and antibiotics (penicillin). Almost all plants and numerous microorganisms are autotrophic with regard to sulphur. Microorganisms can assimilate inorganic sulphur in form of elementary sulphur as sulphide, sulphate and thiosulphate

Sulphides (SH_2)

Pyrit	FeS_2	(pyrite)
Copper sulphide	CuS_2	
	PbS	(lead glance)
	ZnS	(sphalerite)

Plants can only do this as sulphate

Sulphates (SO_4^{2-})

calcium sulphate	$CaSO_4 \cdot 2 H_2O$	(gypsum)
magnesium sulphate	$M_gSO_4 \cdot 7 H_2O$	(bitter salt)
sodium sulphate	$NaSO_4 \cdot 10 H_2O$	(glauber salt)
barium sulphate	$BaSO_4$	(baryte)

The metabolism of the sulphate assimilation by C-autotrophic plants takes place from SO_4^- over adenosine - 5 - phosphosulphate (APS) SO_3^- $-SH_2$ to L-cysteine protein. It is a sulphate reduction.

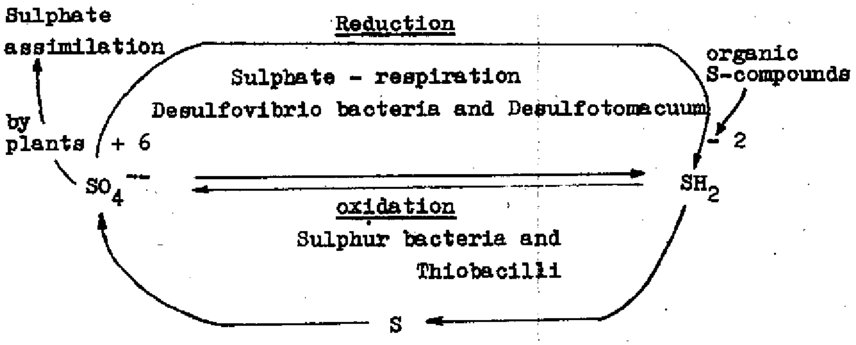
A number of microbe species are also S-autotrophic. They convert sulphureous inorganic and organic compounds in a variety of ways.

<u>Conversion of elementary S and S-compounds by microorganisms</u>

$SH_2 \longrightarrow S \longrightarrow SO_4$	Sulphur bacteria (colourless, green and purple) aerobic and anaerobic C-heterotrophic microorganisms
$SO_4 \longrightarrow SH_2$	Desulfovibrio bacteria Desulfotomacuum (anaerobic, sulphate reduction)
$SH_2 \longrightarrow SO_4$	Thiobacilli bacteria (Beggiatoa) Thiospirillium (aerobic sulphide oxidizers)
organic S-compounds $\downarrow$ SH_2	Decomposers (Reducers)

They form a specific S cycle.

Microbial S cycle



Desulfovibrio and Desulfotomacuum are "specialists" amongst the S-autotrophic microorganisms. They absorb SO_4 for the purpose of energy generation (release), i.e., they respire oxygen, oxidize SO_4 and eliminate SH. They are "desulfuricants". The process of sulphate respiration is strictly anaerobic and only takes place in the sapropel (sludge), (decomposed and mouldering mud), with a poor oxygen content on the bottom of lakes. SH can combine there with iron and sedimentate to form pyrite. This possibility of sedimentation within this kind of biogeochemical cycle has been called "sedimentation type".

There live also microorganisms in water (e.g. Beggiatoa) which oxidize SH_2 into SO_4^{--}. This process results in a dissolution of SO_4^{--} which, in turn, can be used as a source of sulphur for other S-autotrophic microorganisms and water plants.

Both animals and man are S-heterotrophic, depend on organic sulphur compounds, i.e., sulphur compounds from plants or microorganisms.

Sulphur - an indispensable component of plants - is also contained in very large quantities in fossil fuel material (coal, crude petroleum). By industrial combustion processes, sulphur - in the form of SO_2 - is released into the atmosphere as a waste product. This sulphur dioxide can - in small concentrations and under certain conditions - be also assimilated by plants. Long-time concentrations of 0.05 ppm or more may have a toxic effect on plants. This concentration occurs in industrial districts. This is a typical example of how man has misdirected the cycle of a substance. Instead of the hydrosphere or pedosphere the cycle is directed into the atmosphere.

The nitrogen cycle

As previously mentioned, the nitrogen cycle has a position in between the "gaseous type" and the "sedimentation type" cycles. With 78 per cent of the N in the air, the largest amount of nitrogen is in the air. In the pedo and lithospheres are only about 0.03 per cent of nitrogen. Nitrogen occurring in the upper part of the soil - which is much more accessible by plants - is much more abundant.

It makes up 0.1 to 0.4 per cent of the dry matter of the soil.
The distribution of N in the biosphere is as follows:

Resources

atmosphere	78 % N
pedo and lithospheres	0.03 % N

Biosphere - N - Cycle

99.4 %	in the atmosphere	= $3,8 \cdot 10^{18}$t
0.5 %	in the hydrosphere	
0.05 %	in the pedosphere	
0,0005 %	in biomass	

Green plants and numerous microorganisms are capable of using the inorganic nitrogen of the soil. They are N autotrophic. Animals and man need organic nitrogen compounds for building up their natural substances of their bodies, they are N heterotrophic. But there are also some "specialists" amongst the microorganisms which are ecologically of very great importance. These include the bacteria of the soil Clostridium pasteurianum and Azotobacter croococcum, the Blue-green algae Nostoc sp., Anabaena spec., and Calothryx spec., and symbiotic bacteria from the kind of Rhizobium which can absorb the elementary nitrogen of the air.

The great number of microorganisms are of ecological importance, which liberate nitrogen out of the waste products of the producers and consumers. According to the utilization of the different valencies and oxidation steps a distinction must be made between

- Ammonificants, i.e., microorganisms which liberate ammonia during the degradation of protein,
- Nitrificants, they oxidize NH_3 or NH_4^+ over nitrite to nitrate, and
- Denitrificants, they release molecular nitrogen and nitrogen oxide.

As the production of substance of plants is highly dependent on the nitrogen deposit in the soil - beside the capacity of the photosynthesis - the nitrogen contained in the soil plays an important part with regard to the production of biomass. Nitrogen fertilizing is therefore a very problem.

An example for a cycle misdirected by man is the release of NH_3 from large-scale animal farms.

NH_3 can be absorbed in small concentrations by plants from the atmosphere and converted into amides. An amide is an ammonia detoxicating product and a nitrogen reserve for plants. In strong concentrations, however, (more than 10^{-3} moles) NH_3 acts like a photosynthetic poison (LOSADA and ARNON, 1963) and leads to heavy damages to plants, which even can cause their death. Such concentrations may occur near large-scale animal farms.

Information and transfer of information

Just like the flow of energy and the food chains, the ability of informing is a characteristic of all living beings. Living systems would not have evolved, had there been no evolution of systems for the storage and transfer of information.

The modern concept of "information" comes from the field of cybernetics. The "bit" (binary digit) is the quantity by which information is measured. One "bit" gives the decision possibilities contained in a message. A message has a one-bit decision content, if a decision of only between "yes" or "no" can be made (KREEB, 1979).

In the field of biology, the term "information" means the organisms' ability to receive, process, store and transfer information.

The genes (DNA) and neurons are the most important biological systems capable of storing and processing information, so that a distinction can be made between genetic and neuron-borne information. The systems of genetic and neuron-borne information are best developed in man.

"One person has more than 10^{10} bits of genetic information and more than 10^{13} bits of information in his brain and nervous system." (EBELING and FEISTEL, 1982)

Relatively few findings have been made with regard to the storage and transfer of information in ecosystems. Accordingly, the term "information" has a variety of meanings.

As an example, STUGREN (1978) uses the term "information" for the characterization of the diversity of an ecosystem, whereas LARCHER (1980) presents concrete examples of a transfer of information in phytocoenoses.

It seems that in the fields of molecular biology and genetics much more has been done to explain the information system (of the DNA) at the subcellular, cellular and organisms' level than to explain the information system at the level above organisms, i.e., populations, communities and ecosystems.

It may be assumed that the genes or the DNA of the individual organisms are the main information memories also above the level of organisms.

But it may be likely assumed that a variety of specific, physical, chemical and acoustic information carriers and acceptors are available in populations, communities and ecosystems to perform the communication and transfer of information. Examples are the interrelations triggered of between organisms and phytocoenoses through the exudation of gaseous and liquid chemical substances.

Higher plants release ethylene which affects the activities of phytohormones in other plants, and they exudate carbohydrates from roots, which activate the growth of microorganisms in the soil.

Interrelations (transfer of information) are known to exist for specific species in zoocoenoses, with acoustic transfer of information playing also a role.

The intra and interspecific information in ecosystems constitute an important basis for control and regulating mechanisms.

II. 1.2. Basic Problems of Ecology of Aquatic Ecosystems

Aquatic ecosystems are subject to the same laws as terrestrial and marine ecosystems. However, the importance of the input quantities is somewhat different.

The dominant input quantities of terrestrial ecosystems are those factors which are dealt with in the soil section. Chemical factors such as CO_2 and O_2 play a minor role as system input quantities of terrestrial ecosystems. In comparison to aquatic ecosystems, a markedly discontinuous change between horizontal layers typifies terrestrial ecosystems. This applies to the tropical rain forest, where the upper layers include, in case of a high saturation deficit of the atmosphere, xeromorphic plant structures (e.g. xeromorphosis of tropical epiphytic orchids and bromeliacea) and the soil layer contains hygromorphic plant structures (e.g. selaginellacia).

Hydrobiology is concerned with the explanation of interrelations, i.e., structural and functional relations between water organisms and their environment. The following system input quantities are of importance to hydric ecosystems. Among the chemical factors, O_2 , CO_2 and HCO_3 (apart from nitrogen compounds and phosphorous compounds) play the most important role. Among the abiotic input quantities (environmental factors), the factors light, temperature and velocity of flow play the dominant role for ecosystems.

The visual depth (or visual range) provides essential information about the light penetration of a body of water. The SECCI- disc, a white-painted disc with a diameter of 0.25 m and three-point suspension, is used to determine the visual depth of a body of water, with the visual depth being defined as the depth where the observer is still able to see the disc. The visual depth can be used for a classification of waters. The visual depth is best in clear water bodies which are poor in nutrients.
Some examples for this from UHLMANN (1982):

waters	visual depth (in m)
tropical oceans	50
Lake Baikal, USSR	40
lakes in the Alps	20...25
lakes in the Northern part of the GDR	0.5...10
drinking water reservoirs in the GDR	2...11
waste water ponds	0.1

The light factor and its importance to aquatic ecosystems requires a more detailed explanation. Radiation is absorbed, when it penetrates into water. But absorption is different for different wavelengths. The decrease of light intensity with depth corresponds, in all regions of the spectrum, to an exponential decay curve

$$I = I_0 \cdot e^{(-\varepsilon \cdot z)}$$

I = intensity of a certain region of the spectrum at a water depth (in m)

I_0 = intensity of a certain region of the spectrum at the water surface

ε = extinction coefficient: a proportionality factor for the region of the spectrum concerned.

values in per metre of water depth

If I is plotted on the water depth at logarithmic scale in a linear diagram, it is possible to determine the extinction coefficient with the aid of the equation:

$$\varepsilon = \frac{2.3\,(\lg I_0 - \lg I)}{z}$$

For transparency, which is an important characteristic of the light factor in aquatic ecosystem, the following relation is valid:

$$T = \left(\frac{I}{I_o}\right)$$

I_o = intensity of incident light (incident radiation)
I = transmitted amount of light (intensity of radiation transmitted)

Extinction E is defined as a negative logarithm of T

$$E = -\ln\left(\frac{I}{I_o}\right)$$

According to Lambert-Beer's Law, the following relation exists:

$$E = \varepsilon \cdot s \cdot c$$

ε = extinction coefficient
s = layer thickness of a coloured solution, which is filled with light
c = concentration of dissolved particles

The transparency of water bodies is always lower than that of destilled water. This is due to the substances contained in waters, which cause a colouring or dimming. The colouring of water is mainly caused by humic substances and fulvic acids from industrial waste water, which result in the absorption of short wave radiation from the visible region of the spectrum. The dimming of water is caused by inorganic or organic suspended matter. Dimming of water by phytoplankton has to be included here. As a result of this the extinction coefficient consists of the two componenets g (extinction coefficient for solute substances) and p (extinction coefficient for particles):

$$\varepsilon = \varepsilon g + \varepsilon p$$

In reference to the total unlimited day light which is effective at the water surface, photosynthesis is even possible, if the illumination intensity (relative light supply) is about 1 per cent of the surface intensity.

$$L = \frac{Lh}{L_{vt}} \quad 100\ \%$$

L_h = light intensity in the examined water horizon

L_{vt} = light intensity of total unlimited day light at the water surface at the same moment of time. This value is supposed to be 100 per cent.

An $L_{0.35}$ - value of 15 per cent is the critical limit value for the growth of higher water plants in slowly flowing waters at the representative water depth of 0.35 m. At a $L_{0.35}$ = 15 % an overgrowing of rivers occurs (Jorga, Heym, Weise 1982). 3,000 lux is the lower critical value of photosythesis. PEUKERT (1972) determined the photosynthesis limit of a heavily polluted water body in the southern GDR at a radiation of 1 cal $cm^{-2}\ h^{-1}$ = 4.18 J $cm^{-2}\ h^{-1}$.

The vertical gradient of the light intensity is used to subdivide deep waters into two floors or layers. The upper layer is the illuminated <u>production layer</u>, where the conditions for photosynthesis exist:

$$6\ CO_2 + 6\ H_2O + \Delta G^{o\,\prime} = C_6H_{12}O_6 + 6O_2$$

$$\Delta G^{o\,\prime} = 686 kcal/mol\ glucose$$

(the positive sign characterizes the photosynthesis as an endergonic process)

As a result of the ongoing photosynthesis, there is biogenous oxygen input in the <u>euphotic</u> layer and the formation of organic matter under consumption of CO_2 or $HCO_3^{\prime -}$ Here the bicarbonate is changed photosynthetically by organisms using bicarbonate as a C- source, as by pondweeds of the genus Potamogeton in the following way:

$$HCO_3^- \dashrightarrow CO_2 + OH^-$$

The CO_2 is bound by the acceptor ribulose- 1.5- diphosphate and fittes into the pentose cycle, so that CO_2 is continuously extracted from the above mentioned equilibrium. The result of this process is a pH increase in the water. In case of high NH_4^+- stresses (e.g. as a consequence of fecal pollution) this causes an emission of NH_3 as an heavy cell poison.

The euphotic layer lies over the depth as a decomposition layer without light, where the decomposition of organic matter goes on under O_2- consumption and formation of CO_2. These processes reflect the vertical distribution of O_2 and CO_2, which, typically in deep waters, is parallel to the illumination.

The part of the radiation, which penetrates into the water, is decisive for photosynthesis. In destilled water, the infrared part of the radiation (warm radiation) is nearly totally "swallowed" in a layer of no more than 1 m. In comparison to this, the transmission of ultraviolet and blue light is very high. Natural waters absorb the short wave part of the spectrum (ultraviolet and blue) and transform it into heat because of their content of fulvic acids. It may theoretically be assumed that the temperature of water body decreases exponentially with depth. In practice this is not true, because of the turbulent mixing at least of the upper layers of the water body. Theoretically, 99 per cent of the long-wave radiation should be absorbed in the upper 10 m of a water body. In big lakes there is no temperature gradient to be found in this layer. This can be explained by help of the "turbulence" which includes at least the "upper floor" in the warming up process during summer. This upper floor (epilimnion) contrasts with the "lower floor" (hypolimnion) with a constant water temperature of 4 °C. At this temperature water reaches its highest density. This is also an explanation for the relatively high stability of the thermally caused stratification of the water body. Between the epilimnion and the hypolimnion is the layer with the highest temperature gradient. It reaches high values with ≥ 1 °C/m.

Under the conditions of moderate climates, this results in a characteristic <u>stratification</u> which is determined by the annual temperature curve.

<u>Spring</u>: Total circulation: The whole body of water has the same temperature of 4 °C. Because vertical gradients are lacking totally the whole water body is circulating. The extent of the circulation is determined by the air movement (wind).

<u>Summer</u>: Summer stagnation: Because of increasing radiation and warming up the temperature of the upper water layer increases and becomes specifically lighter. Now, this layer is over the specifically heavier hypolimnion with its constant water temperature of 4 °C ("cold, heavy deep water")!

<u>Autumn</u>: The result of decreasing day length and radiation is a cooling of the air, which leads to a loss of the epilimnion radiation. As a consequence, the temperature of the epilimnion adjusts to that of the cold hypolimnion. When all differences in density which were caused by different temperatures are equalized and the whole water body has the temperature of 4 °C the new total circulation is reached, determined and influenced by air movement (wind).

<u>Winter</u>: Winter stagnation: Further cooling of the surface water causes a "decrease of weight" in comparison to the hypolimnion.

This "inverse" stratification in winter generally is not very lasting, because the differences of density of the water are small in a temperature region of +1 °C - +4 °C. A cover of ice has a stabilizing effect.

The amount of mechanical work, which has to be done in order to destroy an existing density stratification marks the "<u>stability of the stratification</u>". The work is necessary to overcome the hight difference between the centre of gravity of the thermally stratified water body (S_2) and the (higher) centre of gravity of a totally mixed water body (S_1) by mechanical work (e.g. application of pressurized air).

The vertical distribution of the gradients of the environmental factors O_2 on the one hand and CH_4 and H_2S on the other in a thermally and thus chemically stratified deep lake, causes a characteristic vertical distribution of the microbial activity. For the biomass production of methane-oxidizing bacteria (figures in mg C/l x d) a sufficient amount of CH_4 is necessary which is emitted from the soil sludge in an anaerobic way as well as oxygen. Because of this, the region of high microbial activitiy of these "chemosynthetic agents" is to be found in deeper water layers. It is marked by high CH_4- and O_2- gradients.

The velocity of flow is another important exogenous factor of aquatic ecosystems. It leads to characteristic adjustments of organisms. In flowing waters there exist marked longitudinal gradients of ecosystem input quantities. The velocity of flow and the correlated carrying power of the water decrease upstream to downstream nearly parallel to the atmospheric aeration. On the other hand, there is an upstream to downstream temperature rise. The same is true for sludge sedimentation and thus the biological and chemical oxygen demand, because organic sludge is imported and sedimented downstream. But the changes are not so sudden here. Sludge movement by flowing waters starts at flow velocities of 0.5 m/s; sludge sedimentation generally starts at velocities of 0.3 m/s. Ecosystems of flowing waters are characterized by a constant movement of the water. Freely suspended biomass occurs here (phytoplankton, zooplankton) which is transported by the flowing wave. In addition to this there exists settled biomass of the bank region and the river bottom: Organisms which are living on the bottom of the water body or which form the periphyton. The balance equation for the settled biomass x of the periphyton is:

$$\frac{dx}{dt} = \mu^{x} + D \cdot x' - (R+G) \cdot x$$

μ = growth rate
D = renewal rate of the water body in a certain segment (d^{-1})
x' = free suspended biomass, which is transported by water and sticks to the periphyton

R = loss of velocity because of detachment of materials by transport of detritus and shearing forces (d^{-1})

G = loss of velocity caused by eating activities of animals (d^{-1})

The influence of high flow velocities (and resultant high turbulence) on water organisms is especially clearly to be seen under the aspect of O_2- and nutrient supply. A thin stick to which a microorganism has been fixed serves as a model. Around the microorganism "diffusion shells" form. These shells are few in case of high turbulence and relatively thick in case of low turbulence. For the sake of simplicity, the differences in the thickness of the diffusion shells, which normally occur as a result of the flow, have been neglected (these "shells" are thinner on the sides which face the flow.) The metabolic activity of water microorganisms rises in proportion to the removal of diffusion barriers. This happens at high flow velocities where the "diffusion shells" are small and, thus, PRANDTL's barrier layer is reduced. Thick diffusion shells are diffusion barriers which are difficult for the microorganism to overcome. They can be overcome over a long period of time by means of diffusion. This process goes on according to:

$$S_x = S_o \quad X$$

S_o = distance which has been overcome in a period of time

S_x = distance which has been overcome in x time units

x = time units

Water organisms are marked by <u>adaptation to the velocity of flow</u>, what provides them with specific ecological niches. Examples are:

- growth on hard soils (blocks, debris, gravel) of the upstream region: thin biological film, periphyton; flattening of the body; development of suction organs for improving the adhesive power; increase of the specific weight by formation of shells; absence of limbs. Organisms which have not adapted themselves in this way live in a gap system under the river bed (organisms of the hyporheon which is sufficiently provided with organic substrate: soil bacteria, fine earth, rests of plants; and oxygen) or in the bunches of water plants, thus protected from the power of water,

- growth on soft soils (grit, sand, sludge), typical for the downstream region- the lower the flow velocity the higher the similarity to the settlements on soft soils of stagnant water: In the narrow gap system of sand grow mainly small animals the body size of which corresponds to the pore diameter of the substrate. The aeration of sludge and clay soils is so low that only tube-forming animals with their own ventilation system (lateral appendages of the body) live there. A certain species of larvae of ephemerides build tubes into clay soils which are up to 20 cm deep. This ecological performance of the soft-soil organisms is of importance to the waters' self-purification potential. Tubificides and chironomides play an important role in the sludge water contact zone cycle of organically polluted flowing waters. The confirmation of organic substances in the sediment by eating probably is higher than the amount of aerobic microbial decomposition of soil sediments. The growth density of tubificides is $>$ 400,000 individuals per m^2, under extreme conditions even $>$ 1.5 million individuals per m^2. In the latter case, the biomass of tubificides was $>$ 2.5 kg of fresh mass per m^2. According to statements by UHLMANN (1982) the dry mass of sludge which is eaten by such a dense population can be assumed to be about 350...750 g/m^2 d. If one considers that the organic part (OS) of such sludges is about 30 per cent and that the tubifex take about 50 per cent of the eaten OS for its metabolism,this results in a reaction of 53...113 g OS m^{-2} d^{-1}. This value exceeds the highest possible photosynthetic value for matter production per area and is much higher than the organic stress per area of oxidation ponds. The ventilation mechanisms of the soft-soil organisms are a positive factor for the self-purification process in flowing water. Because of constant pumping of water through fine networks of tubes in the sludge these organisms cause a sludge oxidation to a depth of 4-8 cm. But a negative factor is the oxygen consumption of 10...20 g O_2 m^{-2} d^{-1} by respiration and sludge decomposition. A positive effect is the stabilization of the sludge by living activities of these organisms. This stabilization of sludge caused by animals (counteracting whirling) goes on in the following way (*UHLMANN*, 1982):

- conversion of the sludge into particles of higher grain size and density (crumb structure") by secretion in form of excrements,

- increase of the inner coherence of the sludge sediments by coating the tubes of chironomides larvae with a tissue of self-made silk-fibres.

Organisms form populations also in aquatic ecosystems.

Populations are "natural populations" which are always marked by a certain ± number of individuals. The individuals which live in a population are marked by their similarities, in an ecological sense of the word. In the normal case the organisms of one species (because of the same living requirements) form such a population as reproduction communities. According to another interpretation, organisms with a common position in the nutrient chain, too, can be called a population. In this way peaceful fish and fish of pray are different populations. A pond, a reservoir, and a body of flowing water form, as they are living communities (biocenoses) with their living space (biotop), each an ecosystem in terms of systems theory. Abstraction is necessary for the analyses and comparison of ecosystems. The formation of compartments of different populations and environmental factors with the same function - e.g. their position in the material balance of the whole system - is such an abstraction.

The compartment of producers of aquatic ecosystems is formed by autotroph organisms (phytoplankton, water plants) and chemo-autotroph bacteria (e.g. sulphur, nitrite, iron bateria) which use the energy coming from oxidation processes of inorganic compounds for the "assimilation" of CO_2 and its conversion primarily into carbohydrates. The organisms of the zooplankton as a whole can be called the compartment of primary consumers. In the nutrition chain the consumers are zooplankton-eating fish and - another compartment - fish of pray (see Fig. II 1-7). The destruents (heterotroph bacteria and fungi) are responsible for the biological decomposition of dead organic matter, which is continuously produced in the above-mentioned compartments and they are the final element in the material cycle in the ecosystem through the mineralization process.

Self-reproduction is a property of biological systems. This can be done on a constant level or - as extended self-reproduction - by growth of population (increase of biomass). Growth of population is the quantitative increase of a component in a system at the cost of another component as an expression of the law of maintenance of mass and energy. Criteria for growth processes can be:

- discrete variables (number of individuals N)
- continuous variable (biomass x, net production, substrate consumption dS/dt; energy consumption dU/dt)" (BAUMERT, 1983)

The laws of the growth of populations can be best explained for small water organisms (e.g. for bacteria, flagellates), which are generally marked by high time constants. This is a biological regularity. For details see the explanation given by UHLMANN (1983). The time constant is the number of generations per day (d). With a generation period of 0.1 d (baterial) the time constant is 10. (If one thinks of a generation period of 25 years for human beings, the time constant is 5 orders of magnitude smaller.)

In the following example a simplification was made to the extent that the dynamics of an investigated population in relation to the environmental factors is investigated in the biosystem. If the growth rate dx/dt is related to the size of the population x this results in the growth rate:

$$\mu = \frac{dx}{dt\,x}$$

Thus the growth rate determines the intensity of growth processes in a biomass unit. It is related to an hour (h^{-1}), day (d^{-1}) or year (a^{-1}). The increase of the size of population is proportional to the decomposition of the substrate.

$$\frac{dx}{dt} = - Y \frac{ds}{dt}$$

The yield constant Y is defined as

$$Y = \frac{dx}{ds}$$

The growth of a stock of water microorganisms, which form a population is - in case of enough nutrients and no limitating effects of other environmental factors - proportional to the already existing stock (see Fig. II. 1-8)

$$\frac{dx}{dt} = \mu \cdot x$$

x = biomass
t = time
μ = growth rate

But, in the reality of nature , nutrients are never unlimited. Because of this the "unlimited" population growth changes into a "limited" population growth - also because of increasing competition - after a certain time. The growth curve of a sigmoid form moves towards a maximum value of organisms which is not exceeded. Its level is determined by the environmental conditions. After the inflection point which finishes the phase of unlimited population growth the increase of population goes on very slowly, till the maximum is reached (x_m, K) (see Fig. II. 1-9). The change of a population in time results from the relation:

$$\frac{dx}{dt} = \mu \cdot x \; \frac{x_m - x}{x_m} \text{, or}$$

$$\frac{dx}{dt} = \mu \; x \; \frac{(K-N)}{K}$$

x = biomass
t = time
μ = specific growth rate
x_m = possible maximum of population under given conditions
N = number of individuals
K = possible maximum of individuals of a population under given conditions (upper maximum limit)

In case of "overshoot" of the population growth ($K < N$) the term

$$\frac{K - N}{N}$$

is negative. Consequently, the reduction of the overshoot-reaction follows until $K > N$, and after this a population growth starts again, which is moving towards the limit value K.

The growth rates μ vary for some species by several orders of magnitude. For cultures of bacteria these are 50^{-1}, for daphnia 0.3 d^{-1} (some figures for comparison: fish 0.3 a^{-1}, mixed deceduousforests of moderate regions up to 0.02 a^{-1}).

Growth rates are impressive characteristics of distribution possibilities of a population and possibilities of a renewal of damaged ecosystems. Fast-growing small organisms (high growth rates) are able to develop high densities and thus large populations within a short time. In case of high loads of degradable organic substances discharged into flowing waters, there is a sudden development of bacteria (fungus forcing).

High O_2 content and a very low content of degradable organic substance are typical features of oligosaprobe flowing waters. Bacteria play an absolutely subordinate role. When degradable organic substances are discharged, the oxygen content decreases because of the beginning chemical oxidation process. After a short time a strong population of bacteria develops which carries on the biogradation (decomposition of substrate). Consequently, the substrate concentration decreases gradually. The increase of biomass and the substrate consumption per time unit decrease until the establishment of a stationary phase in the open system. This phase is the criterion for the steady state, with an biomass increase of $dx/dt = 0$. When the nutrients have run out, the size of population (density) of bacteria decreases (like in the closed system) until its total breakdown. The dying biomass of bacteria serves as substrate basis for the then beginning population growth of the bacteria and mud eaters. Because of their filtering effect the light conditions in the water improve gradually. Thus, green plants can grow again at the end of such self-purification chains. The ecosystems' variety of species and information increases with continuing biological self-purification. (see Figs. II. 1-10,11,12)

The "one-sidedness" of the system is overcome by the processing of "waste water". A reflection of this is the fact that, under extreme conditions, only a few species (in the theoretical extreme case only one) find their living conditions there. These species are able to develop high numbers of individuals because of the inexistent competition with other populations. An example of this is the process of fungus forcing in heavily polluted flowing waters.

Because of its genetic structure every species contains "collections of biochemical programmes" for specific reactions of decomposition. The number of species in the system increases with the advance of the biological self-purification, because thus the one-sidedness of the substrate is overcome. So, with increasing numbers of species the <u>biological diversity</u> increases because of an increase in the content of "biological information" present in all species. On the other hand the increasing competition between the species limits the number of individuals and size of population in systems with high biological diversity. The simpliest approach to the recording of biological diversity is the index of biological diversity, suggested by **MARGALEF** (1958):

$$d = \frac{M-1}{\ln N}$$

d = diversity index
M = total number of species
N = total number of existing individuals

The registration of the index of lacking species according to KOTHE (1962) rests on the same basis as the density of species and diversity. For this it is necessary to determine numbers of species from comparable water samples. As can be expected, the numbers of species in non-polluted water sections (s_1 = standard of species) is higher than in those ecosystems which are organically polluted (s_x). The resulting difference of number of species is brought into relation with the standard of species which is 100 per cent:

$$\text{Index of lacking species} = \left(\frac{s_1 - s}{s_1} \right) \cdot 100 \ (\%)$$

The criteria density of species, diversity and index of lacking species are signs of changes in a living community of a body of water (MÄDLER 1983). These criteria are well suited, in the sense of bioindication, for the control and monitoring of ecosystems.

The knowledge of the interrelations between the various parts of the nutrition chain in an ecosystem serves as basis for the modelling of ecosystems. Detailed analyses of the structural and functional relations are necessary and the important causal connections have to be derived from them. The quality of ecosystem modelling is decisively depending on it.

The "one-way route" of potential chemical energy (ecoenergetics) (see Fig. II. 1-7) is the basic law also in water ecosystems. It results from the fact that the small crayfish (together they form the compartment of zooplankton) eat the phytoplankton organisms (and bacteria) which live in the water. The crayfish are eaten by peaceful fish and these are eaten by the fishes of pray (peak consumers). Here it has to be noted that in each step of the nutrition chain up to 90 per cent of the energy taken up is lost by respiration processes and in form of wastes.

It can be said that the total loss of potential chemical energy is increasing linearily with the number of steps in the nutrition chain. Because of the "energy losses" from one stage to another of the ecosystem, the production of fish in the second step of the nutrition chain by use of plant eating fishes (e.g. Amur-carp) is much more economical than in the third or even fourth steps.

In contrast to the one-way route of energy the material balance in the ecosystem is a ± closed cycle. This holds true especially for plant nutrients in stagnant waters and the ocean. But, as a precondition, the exchange with the atmosphere has to be zero (e.g. phosphorous compounds) or limited (e.g. nitrogen compounds, free and bonded CO_2).

According to ODUM there exist characteristic equivalents for energy produced from the decomposition of organic substances:

1g ash-free dry mass of plants $\hat{=}$ 4 kcal = 16.72 kJ
1g ash-free dry mass of animals $\hat{=}$ 5 kcal = 20.90 kJ
1g ash-free dry mass of seeds $\hat{=}$ 7...8 kcal

The amount of energy obtained through respiration of organic substances is used for growth, propagation, movement, guarantee of development, maintenance of the individual life by supplying the necessary energy for the metabolism of life.

To provide a clear overview, a model of the matter and energy transport in a nutrition chain is shown in the following (see Fig. II. 1-13). A through arrow and a dotted arrow mean transport of biomass; matter and energy transport at the same time. The four compartments are:

Phytoplankton	P (No. 1)
Zooplankton	Z (No. 2)
Fish	F (No. 3)
Bacteria	B (No. 4)

Compartment No. 0 is the complex of factors which represent the direct (not living) surroundings of the ecosystem considered. The velocity values of matter and/or energy transport from the compartments i to j are represented by kji. The scheme taken from UHLMANN (1982) explains the most important connections.

A precondition for the flow equilibrium of the ecosystem is the continuous energy supply from the surroundings (compartment 0). The arrow k10 marks this energy input. The net primary production of phytoplankton flows to the zooplankton (biomass transport as combined transport of energy and matter; k21) whose secondary net production serves as a nutrient basis for compartment 3 (transport of biomass k32). In addition to such biomass transports there are a lot of <u>backflows of nutrients</u> (recycling of nutrients). They realise an essential stabilization of the ecosystem. The k12, k13, k14 arrows show such processes. The "occupation" of the compartments with the resulting functional relations" matter transport", "energy transport", "transport of biomass" stabilize the ecosystem.

The highest "inner" stability is reached, when the matter reactions in the ecosystem are cycles. This holds true for the assumed water ecosystem. In case of CO_2 this means that CO_2 produced by respiration of producers, consumers and destruents is used photosynthetically by producers. Non-respirated biomass is mineralized by the destruents (bacteria). The developing CO_2 as well as the released nutriant salts are used by the producers.

The situation is quiet different in an waste water pond, which is a highly "one-sided" ecosystem. This is proven by analyses of the biological structure.

Characteristic curves will be obtained if the density of individuals or dry mass of individuals (for periphyton organisms) per m^2 is logarithmically related to the "sequence of species" of investigated biotopes, where the most frequently represented species take position 1. (LANGE and BAHR 1983) Extreme biotopes like waste water ponds have steep declining curves in such a semilogarithmic graph. On the other hand, "equalized" environmental conditions cause flat curves as an expression of high diversity of species and moderate population sizes. These reflect the limiting effect of the competition between species having a large number of "biocoenological connections". This means, there is a high degree of intermashing of structural and functional relations between the elements.

Waste water ponds do not have the compartment of the producers, so that they are "dependent biocoenoses" requiring a continuous supply of nutrients from outside, which are used and decomposited by the consumers immediately. The biomass which is not respirated by the consumers will be mineralized by the destruents. The CO_2 continously formed by respiration cannot be re-used in this "incomplete" ecosystem because the producers for this are lacking. The fact that this ecosystem is dependent on the continuous supply of organic nutrients from outside is proof of its low "inner stability". The zooplankton reaches very high numbers of individuals, because fishes which feed on zooplankton are not there. The reason for this is the oxygen content, which, sometimes, is very low (UHLMANN 1982, p. 55)

Carps in ponds, especially at high temperatures, decimate the zooplankton to such an extent that the grazing pressure on the phytoplankton is reduced. This causes a massive development of phytoplankton. This process leads to an accumulation of phytoplankton which is an "intermediate product", because not all of it is eaten or processed by the zooplankton organisms. Thus, fish block their own nutrient production. A fertilization of carp ponds for the final product "fish" will be economical under such conditions.

In drinking water reservoirs the filtering effect of the zooplankton should be as high as possible in order to maintain a good water quality. Here perches are one species of zooplankton-eating fish. If their number becomes too high the grazing pressure on the zooplankton increases and the zooplankton as a whole is decimated considerably. A result of this might be a too high increase of phytoplankton organisms. Water treatment facilities will then require increased technical and financial inputs. A correction of the ecosystem is possible through biomanipulation, by controlled use of fish of pray which limit the number of young perches.

The graph structure shown in the "well-balanced" fresh-water ecosystem diagram can also be explained as a system of differential equations. On the basis of an analysis of matter and energy flows it is possible to predict the amount produced by an investigated compartment of the system. The following equation is obtained for the temporal change of the zooplankton-biomass concentration. It is chosen because of the central position of the zooplankton compartment in the ecosystem which results from the high number of interrelations of energy, matter and biomass transport: On the basis of a technological model of an ecosystem the zooplankton would hold the same position as heavy industry (STUGREN 1978)

$$\frac{dz}{dt} = \underbrace{2K.21P.Z + {}_{2}K.24B.Z}_{\text{increment}} - \underbrace{{}_{1}K.02.Z}_{\text{respir-ation}} - \underbrace{{}_{1}K42.Z}_{\text{bacteriol. decomp.}} - \underbrace{{}_{2}K.32\ F.Z}_{\text{zooplankton eaten by fish}}$$

P = phytoplankton
Z = zooplankton
B = bacteria
F = fish

${}_{1}K$ = velocity value for reaction of first order
${}_{2}K$ = velocity value for reaction of second order

Similar differential equations can be established for the other compartments. The question, whether such a simple approach will lead to a useful mathematical model, which is a mainly correct reflection of the behaviour of an ecosystem by using empirical constants and initial values, can be answered with the aid of a computer (UHLMANN 1982). A test of adequateness of the mathematical model is necessary. After the necessary quality of the model is reached, the mathematical ecosystem model proves to be an excellent basis for the treatment, control and monitoring of ecosystems, last but not least for forecasts for water ecosystems still to be established, like planned dams and reservoirs. For details see BENNDORF and RECKNAGEL (1983), BENNDORF and UHLMANN (1983) and RECKNAGEL and BENNDORF (1983).

Fig. II.1-7 Ecoenergetics: The one-way-track of energy (After ODUM)

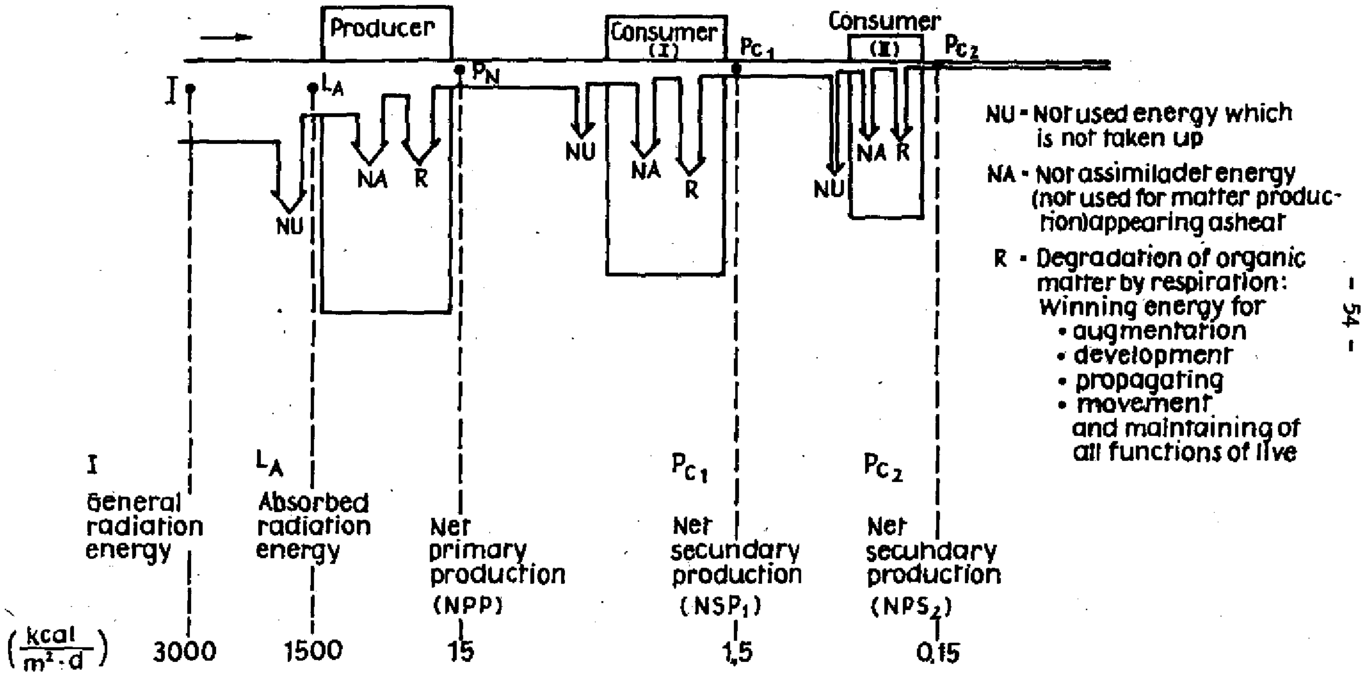


Fig. II.1-8 Population Dynamics I
unhindered (unlimited) population growth

Plotting the function | $N_t = N_0 \cdot e^{k \cdot t}$

Growth of biomass (x) in dt:

$$\frac{dx}{dt} = \mu \cdot x$$

Augmentation of the number of individuals (N) in dt:

$$\frac{dN}{dt} = r \cdot N$$

e = base of natural logarithms

k = species- and strain-specific population growth-constant
(k = r = a + b:

birth rate $a = \frac{dN_b}{dt \cdot N}$;

mortal rate $b = \frac{dN_m}{dt \cdot N}$;

N_b = Number of born individuals
N_m = Number of died individuals)

t = elapsed time

Application: The successful beginning of any population growth,

μ = specific growth rate
x = biomass
N = Number of individuals of the population

Fig. II. 1-9 Population Dynamics (II). Regulated population growth (VERHULST - PEARL)

$$N_t = \frac{N^*}{1+e\,(a-k\cdot t)}$$

$$N_t = \frac{K}{1+e\,(a-k\cdot t)}$$

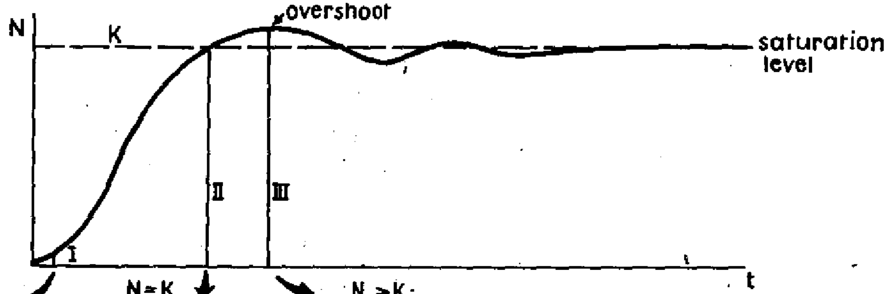
Growth of biomass (x) in dt:

$$\frac{dx}{dt} = \mu\cdot x\left(\frac{x_m - x}{x_m}\right)$$

Growth of the number of individuals (N) in dt:

$$\frac{dN}{dt} = r\cdot N\left(\frac{K-N}{K}\right)$$

N = Number of individuals
$N^* = K$ = The maximum upper limit of individuals of the population
N_t = Number of individuals in the time point t'
e = Base of natural logarithms
$r = k$ = Species- and strain specific population growth constant (further explanations see figure Population Dynamics (I)
a = Restraint constant: $a = e\cdot\log.\frac{N^* - N_0}{N_0}$; N_0 = number of individuals in the time point t_0
x = Biomass
x_m = The maximum upper limit of biomass
μ = Specific growth rate
t = Elapsed time



$N \ll K$; $\left(\frac{K-N}{K}\right) \approx 1$
→ Exponential growth of the population

$N = K$ $\left(\frac{K-N}{K}\right) = 0$
$\frac{dN}{dt} = 0$
Saturation level is reached

$N > K$; $\left(\frac{K-N}{K}\right) < 0$
→ Negative growth of the population till the approach to the saturation level is reached again

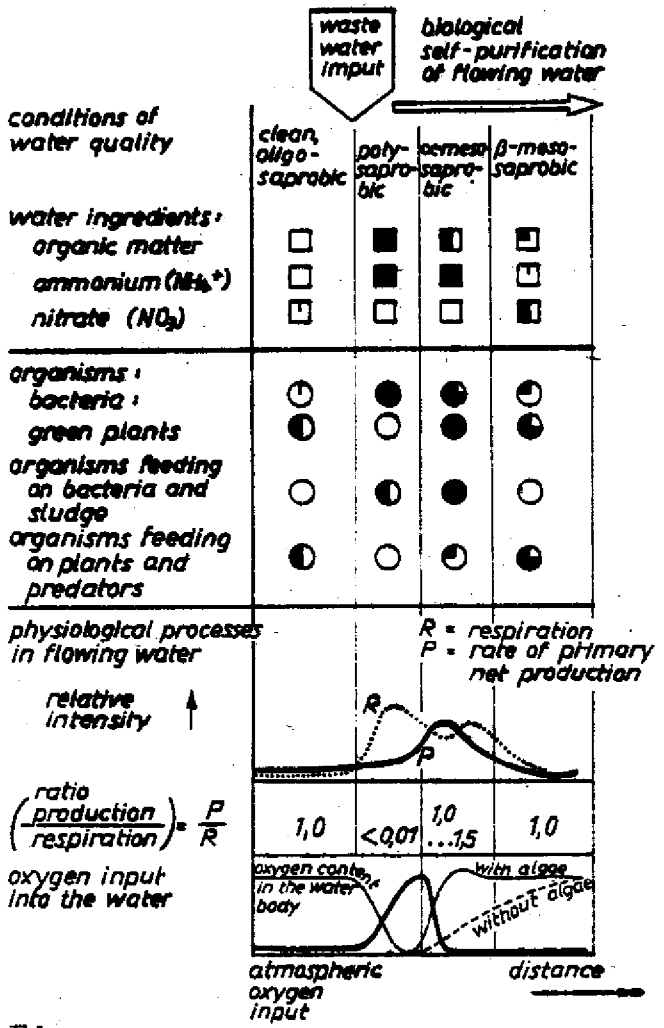


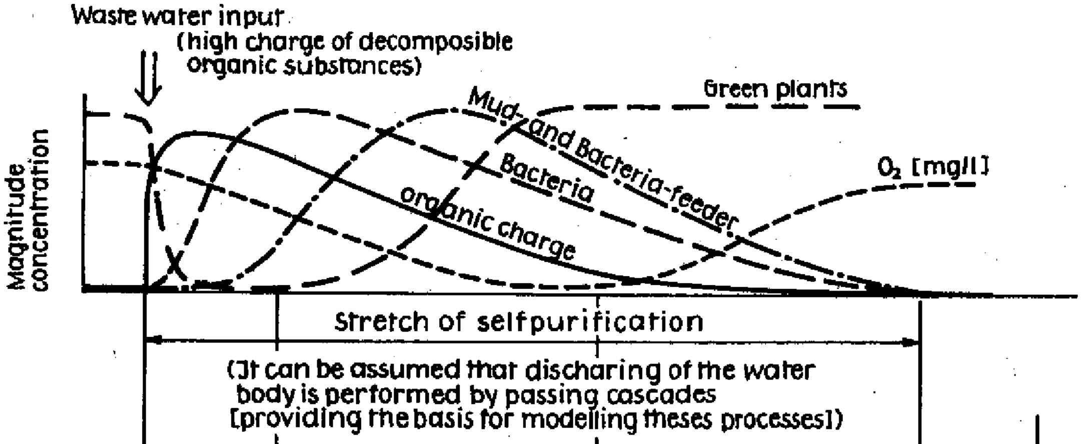
Fig. II.1-10 Dynamics of self-purification processes in flowing water (after D. UHLMANN)

nomenclature:

☐ low
⋮
■ high concentration of water ingredients

○ low
⋮
● high number of organisms

Fig.II.1 - 11 Scheme of self-purification processes in a slowly running water



□	■	◧	◰	□	Content of decomposible organic matter
◧	□	◲	◧	◧	Green plants
○	●	◕	◔	○	Bacteria
○	◕	●	◑	○	Mud- and Bacteria-feeder
1	<0,01	1... 1,5	1	1	Relative values of the ratio $\frac{\text{Production}}{\text{Respiration}} = \frac{P}{R}$
oligo-saprobic	poly-saprobic	α-mesosaprobic	β-mesosaprobic	oligo-saprobic	Type of Water Quality

Fig.II. 1-12 Scheme of succession after MARGALEF

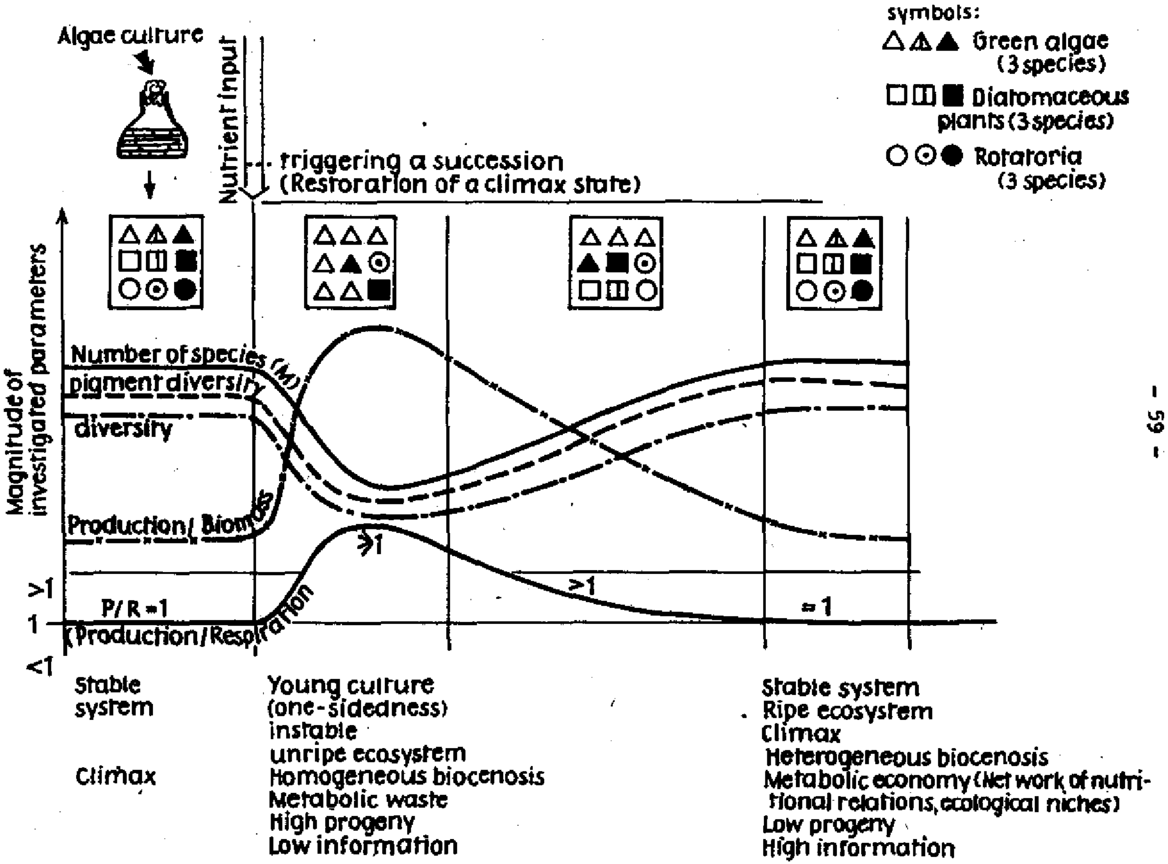
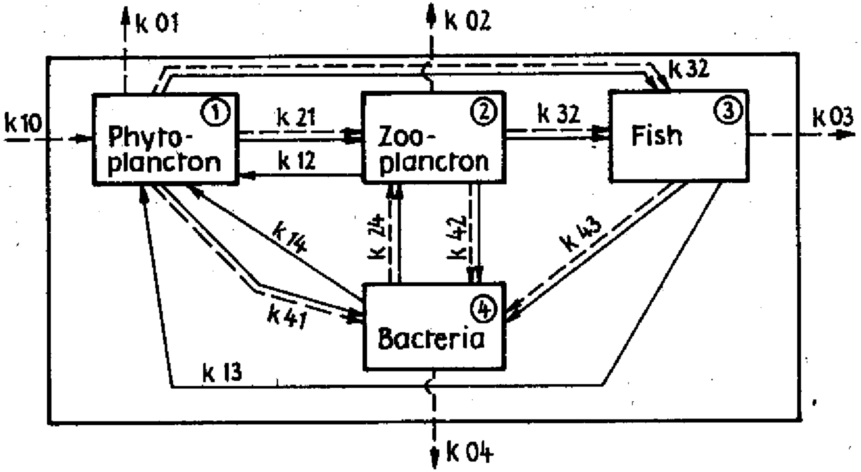


Fig.II. 1-13 Model of an aquatic Ecosystem
(A fresh water ecosystem as a cycling system)
After D. UHLMANN



Compartments:

① Phytoplancton

② Zooplancton

③ Fish

④ Bacteria

0 Compartment of influences out of ecosystem being considered

←—— matter transport

←– – energy transport

⇐== transport of biomass

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II. 1.3. Fundamentals of primary production

Primary production is the total mass of dry matter produced by green plants on a given area. It is calculated in kg of dry plant substance per ha or in g . m^{-2}, sometimes also in assimilated energy: J . m^{-2}. Consequently, primary production is much more then the yield intended by man in the cultivation of certain plants.

It comprises dry matter produced above as well as below ground, i.e., root mass as well as leave, trunk and branch mass.

The total mass of dry matter produced by plants is frequently called plant biomass, although a better term to use would be phytomass. Plant biomass and phytomass are synonymous. Foresters use the term dendromass for total dry matter of trees, although for the timber industry only the stem mass of trees is of interest.

Biomass is the total mass of dry matter produced by all organisms of an ecosystem, including plant, animal and microorganism biomass.

It is necessary to make a distinction between primary production and primary productivity.

Primary productivity, or also called productive performance, indicates the amount of dry matter produced on a given area in a given time unit. Its dimensions are: g . m^{-2} . day^{-1} or kg . ha^{-1} . $year^{-1}$ etc.

The fundamentals of primary production and of primary productivity are the photosynthetic capacity of plants and the climatic and edaphic factors of a given ecosystem.

Photosynthesis

The significance of phytosynthesis consists not only in producing organic matter from carbon dioxide, light and water, but also in binding extra-terrestrial energy on the earth and in releasing molecular oxygen, on which the majority of all organisms depend for the generation of energy from organic compounds in the process of respiration. The photosynthesis is the foundation of all life on earth. It is the basis of human and animal nutrition and the intensive exploitation of its products, and along with the technical and medical progress it has enabled mankind to reach the present world population figure.

Primary productivity is of fundamental importance to man. Primary productivity contains the portion of solar energy that can support the life of all components of the biosphere. The largest portion of human food is provided by the productivity of plant life on land. Terrestrial plant production also supplies the single most important substance for construction and manufacturing - wood - and a host of other products.

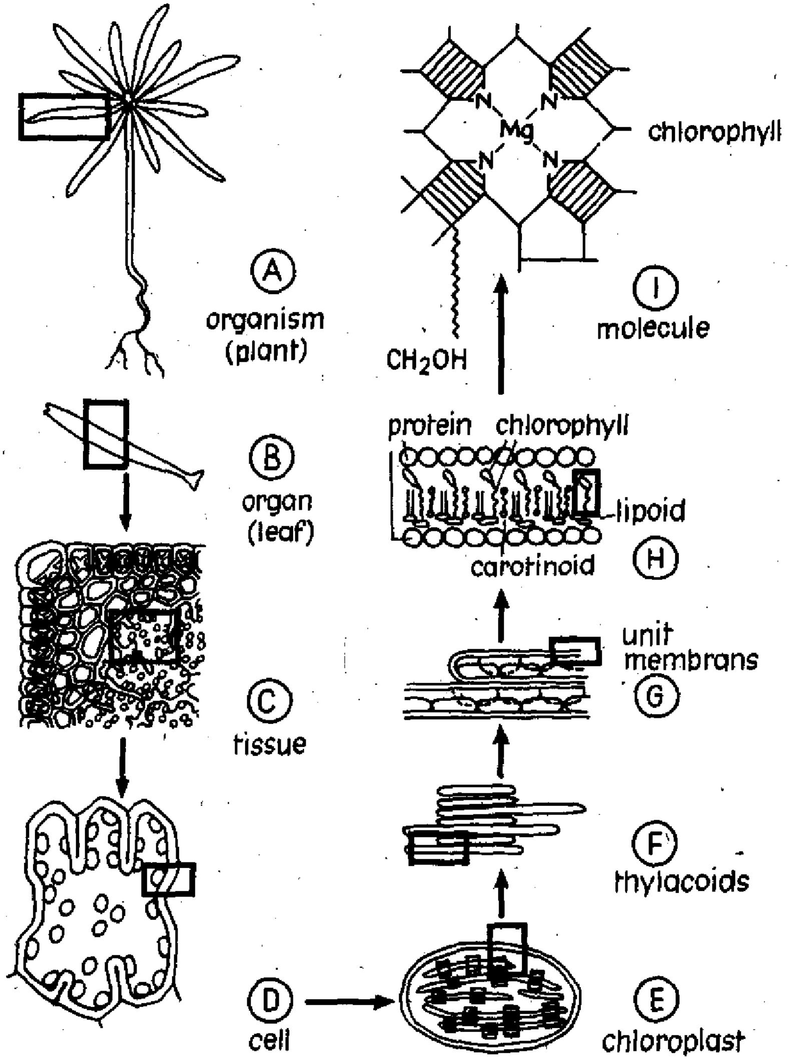
In the following, photosynthesis will be explained only to a degree considered necessary for the understanding of ecological processes.

The photosynthetic processes take place in the "photosynthetic apparatus" of plants. This apparatus is the green chloroplast. Chloroplasts are cell compartments delimitated, but not separated from the cytoplasms by a double-unit membrane. Such unit membranes extend also through the interior of the chloroplasts as thylakoids. (See Fig. II. 1-14)
If arranged individually and therefore hardly differing from the basic substance, i.e. the matrix or stroma, they are called stromathylakoids. If they are arranged in the form of piles they are called granathylakoids.

In the thylakoids, the pigments involved in photosynthesis, (e.g. chlorophyll) and the enzymes controlling the chemism of the reaction to light are located. In them the processes of water decomposition, electron transport and energy transformation seem to take place as well.

However, carbohydrate formation proper, which begins with the carboxylation of ribulose-1,5-diphosphate, takes place in the stroma.

Fig. II. 1.-14 Plant and „photosynthetic apparatus"



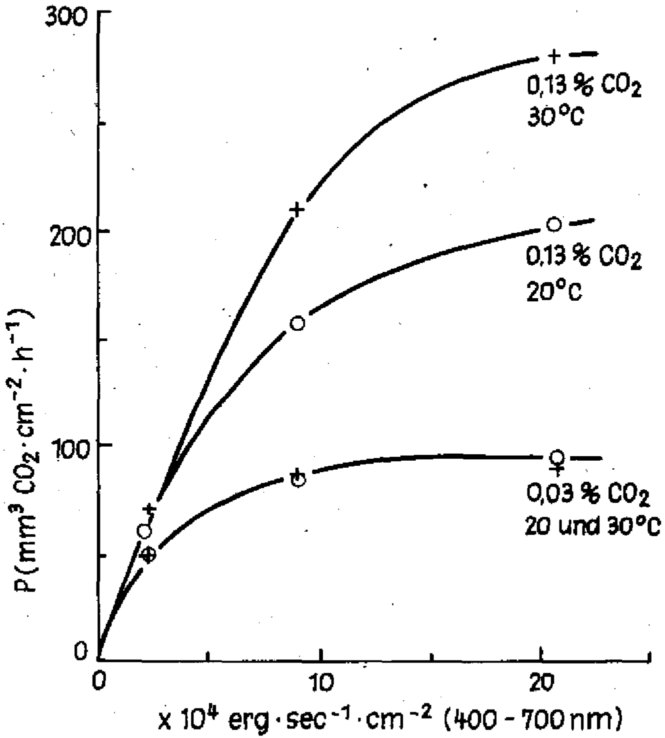


Fig. II. 1.-15 Photosynthesis of Cucumis sativus in Dependence of light, temperature and CO_2-Concentration
Abscissa - Intensity of radiation

Source: KREEB, 1974

The reactions of photosynthesis can be subdivided into three phases:

a) physical and biochemical reaction in the presence of light
light-dependent decomposition of water (photolysis) with simultaneous reduction of nicotinamide dinucleotide phosphate ($NADP^+$ into $NADPH + H^+$ and the release of oxygen);

b) biochemical reaction in the light
light-dependent synthesis of adenosine triphosphate (ATP) from adenosine (ADP) and inorganic phosphate (Pa), called photophosphorylation. In this process radiation energy is transformed into chemical energy and stored temporarily as ATP;

c) biochemical reaction in the dark
reductive incorporation of inorganic CO_2 from the air into carbohydrates by means of $NADPH + H^+$ and ATP.

Comments on item a):

The photochemical process begins with the absorption of PhAR by the chloroplasts. Their energy must overcome the potential difference of 1.14 V between the electron donor water ($E^{o'} = + 0.82$ V) and the electron acceptor in the plant, i.e., $NADP^+ / NADPH^+ + H^+$ ($E^{o'} = - 0.32$ V). Two pigment systems or photosystems (I and II) are available for this purpose. Photosystem I consists of chlorophyll a and other pigments. It has an absorption peak for radiation energy of 700 nm. Photosystem II also consists of chlorophyll a and accessory pigments. It has an absorption peak of 680 nm. On stimulation by radiation energy, photosystem I splits off electrons which can be used for the reduction of $NADP^+$. Electrons required for the re-reduction of chlorophyll are provided by the photolysis of water. The photolysis of water is also named HILL reaction after its discoverer. The oxygen released during the photosynthesis is released by the plant to the atmosphere. Photosystem II transports the electrons released from the water to photosystem I.

Comments on item b):

Electrons are always transported in line with the degree to which they are released in the process. This energy is used for ATP production, i.e., it is stored as chemical energy. This process is called photophosphorylation. There are two photophosphorylation reactions:

- cyclic photophosphorylation which takes place when electrons are split off from photosystem I. However, these electrons are not used for $NADP^+$ reduction, they are returned to the oxidized chlorophyll molecule through several redox systems. In this process ATP is produced;
- non-cyclic photophosphorylation which is directly linked with the electron transport of water through photosystem II and photosystem I to $NADP^+$. Hence, no electron is returned to the electron donor (as in cyclic photophosphorylation) in a cycle.
  ATP is produced in this case as well.

Comments on item c):

C_3 cycle

The energy obtained from radiation during the reactions of photophosphorylation is used as a reducing force to incorporate carbon dioxide into carbohydrates. This reaction does not require light; it can also take place in darkness. In most plants ribulose-1,5-diphosphate, a compound containing 5 C atoms serves as the acceptor for the CO_2 to be incorporated. The 6-carbon product resulting from the reductive CO_2 incorporation, disintegrates immediately into 2 molecules of 3-carbon compound phosphoglyceric acid. Therefore, this way of carbon assimilation is called the C_3 cycle.

In the further process, some of the resulting carbohydrate compounds are used to produce sugar (fructose and glucose). These enable the chloroplasts to enter the metabolism of the plants. Some remain in the chloroplasts where they help to regenerate the CO_2 acceptor ribulose-1,5 diphosphate.

The processes involved in carbohydrate synthesis were largely clarified by CALVIN et. al. in the fifties of this century. That is why they are often called "CALVIN Cycle", the more accurate term being, however, "reductive pentose phosphate cycle".

C_4 cycle

In 1970 HATCH and SLACK as well as KORTSCHAK found another way of CO_2 fixation in high-yield cultivated plants of the tropics (sugar cane, maize, millet). In a closed room these plants take CO_2 from the air until there are no more than about 10 ppm. C_3 plants cease to absorb CO_2, if the CO_2 content of the air has dropped to about 50 ppm. C_4 plants are better able to use CO_2 by means of an enzyme having a high affinity to CO_2, namely phosphoenolpyruvic carboxylase (PEP carboxylase) and phosphoenolpyruvate (PEP) as CO_2 acceptor.

The product resulting from the carboxylation of PEP is oxaloacetic acid, which is reduced to malate. Both oxaloacetic acid and malic acid are 4-carbon acids. And that is why this CO_2 assimilation is called C_4 cycle. Plants with the C_4 cycle are often briefly called C_4 plants. It is worth mentioning in this context that the malate of C_4 plants remains neither in the chloroplasts nor in the cells where it is produced, but moves into adjacent cells which have apparently specialized in its utilization. Anatomically, they are bundle sheath cells in which malate is decomposed into CO_2 and pyruvate. It is also in the bundle sheath cells that CO_2 is introduced into the CALVIN cycle and that pyruvate is returned to the mesophyll cells of the C_4 acid cycle to regenerate PEP. C_4 plants thus have the advantage of using CO_2 in an optimum way. Other peculiarities of photosynthesis in a number of different plants shall be mentioned only briefly.

Many of the C_3-group succulents belonging to the liliaceae, bromeliacea, orchidaceae, cactaceae, crassulaceae, mesembryanthemaceae and asclepiadaceae families absorb CO_2 through their widely opened stomata during the night, bind it to

PEP and transform it into malate. It is only on the following day that they convert it into carbohydrates via the C_3 cycle. Plants are thus capable of performing, in a number of ways, the photosynthetic process which is so vital for life on earth.

Photosynthesis which is the basis of any primary productivity by plants is dependent upon a number of factors.

These factors can be classified into those acting from within the plants and those acting from outside the plants.
The internal factors are specific to the individual species and they are regulated by the genetic potential of the plants. They include:

- structure of the leaf,
- structure and position of the chloroplasts,
- chlorophyll content.

Numerous abiotic and biotic features constitute the external factors. They become obvious when their concentrations are either too high or too low.

They include:

- light
- temperature
- water
- CO_2 concentration
- mineral matter.

It is not always easy to distinguish between the action of the individual factors, because they interact or influence the photosynthesis through a combination of factors. The amount of light available gives rise to the formation of shadow and sun leaves, which have different light saturation curves.

The rate of photosynthesis varies in accordance with the minimum availability of one of the following factors: light, temperature and CO_2 concentration.

Fig. II. 1.-15 shows that the rate of photosynthesis, irrespective of the CO_2 concentration and the temperature, is minimal, when the radiation is minimal. CO_2 concentration becomes a limiting factor, when the amount of light available rises (the rate of photosynthesis cannot be increased by rising temperatures, if the CO_2 content is 0.03 per cent). It is only when sufficient CO_2 concentrations occur that the rate of photosynthesis can be increased by a rise in temperature. But the rate of photosynthesis can be increased through a higher CO_2 content, if the temperature is optimal. (Fig. II. 1-16)

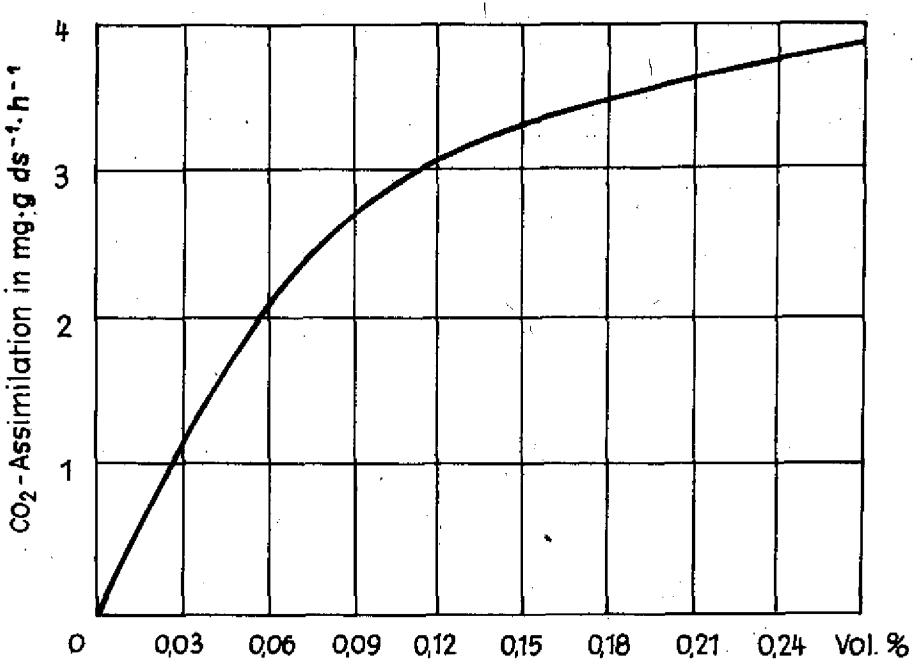


Fig. II. 1 - 16 Dependence of the Netto-photosynthesis of the CO_2-Concentration of the air (needles of Pinus silvestris)

Source: KREEB, 1974

This is especially important, because the CO_2 content of the atmosphere is 0.03 per cent by volume, so that an increase in the CO_2 concentration would be tantamount to a "CO_2 fertilizing". Accordingly, the 0.04 per cent of CO_2 concentration by volume caused by industry and the use of automobiles are not harmful to photosynthesis, they even promote it. However, climatic changes in the biosphere might be brought about, which may be tantamount to the "greenhouse" effect and have a considerable impact.

The terms "photosynthetic capacity" and "potential photosynthetic capacity" have been introduced to determine the individual factors' effects on photosynthesis.

Photosynthetic capacity (ability): The rate of photosynthesis attained when all external factors are at or above optimum with the exception of the CO_2 concentration, which is at the natural level (about 0.032 %).

Potential photosynthetic capacity: The rate of photosynthesis attained when all factors, including the CO_2 concentration, are at or above optimum.

Water has a direct effect on the rate of photosynthesis, because it is involved in the biochemical reactions of photosynthesis and because the overall water balance regulates the movement of the stomata and the exchange of carbon dioxide, oxygen and vapour (exchange of gases).
Many mineral substances have an effect on the production of substances (nitrogen, iron, magnesium and sulphur), although this effect is indirect via photosynthesis. This shows that photosynthesis is an essential but not the only prerequisite for phytomass production which is influenced, in addition to photosynthesis, by substance intake, transport and storage processes.

These processes have not yet been investigated to the extent the process of photosynthesis has been clarified.

That is why ROSS had to put a number of question marks behind his substance production model, especially where the conversion of photosynthetic products into stored or secondary substances is coupled with growth and differentiation processes.

But even when these physiological foundations of phytomass production should be largely known for a "standard plant", the phytomass production processes may still be influenced by:

- type and variety of plant,
- age and development stage of plant,
- position of plant in the phytocoenosis (or the managed stand of plants),
- competition and adaptability
- water supply,
- supply of nutrients - soil fertility,
- availability of energy, etc.,
- temperature.

Although these limitations exist, efforts continue to identify the capacity of local and global phytomass production. Justus von Liebig was one of the first researchers to investigate this problem (1862).

He calculated CO_2 fixation in the phytomass to be 5,000 kg ha^{-1} a^{-1}. LIETH (1973) reports that this would be equal to 230 - 240^{-9} metric tons a year globally.

LIETH himself, evaluating the results of other authors from the 1960s and 1970s, prepared the first few world models of primary production and published them as computer models. Tab. II. 1-2 provides an overview of his results.

More recently, he has updated the data obtained through the inclusion of water balance factors (evapotranspiration) and soil fertility (TEMPLIN model, LIETH, 1983).

Table II. 1-2 Net primary productivity and energy fixation in the world (around 1950)[a]

	Net primary productivity					Annual energy fixation	
Vegetation unit	Area (10^6 km^2)	Range (g.m.$^{-2}$.yr^{-1})	Approximate mean	Total for area (10^9 tons)	Combustion value (kcal/g)	Mean (10^6cal/m^2)	By area (10^{18}cal)
1	2	3	4	5	6	7	8
Forest	50.0		1290	64.5			277.0
Tropical rainforest	17.0	1000 - 3500	2000	34.0	4.1	8.2	139.4
Raingreen forest	7.5	600 - 3500	1500	11.3	4.2	6.3	47.2
Summergreen forest	7.0	400 - 2500	1000	7.0	4.6	4.6	32.2
Chaparral	1.5	250 - 1500	800	1.2	4.9	3.9	5.9
Warm temperate mixed forest	5.0	600 - 2500	1000	5.0	4.7	4.7	23.5
Boreal forest	12.0	200 - 1500	500	5.0	4.8	2.4	28.8
Woodland	7.0	200 - 1000	600	4.2	4.6	2.8	19.6
Dwarf and open scrub	26.0		90	2.4			10.2
Tundra	8.0	100 - 400	140	1.1	4.5	0.6	4.8
Desert scrub	18.0	10 - 250	70	1.3	4.5	0.3	5.4
Grassland	24.0		600	15.0			60.0
Trop. grassland	15.0	200 - 2000	700	10.5	4.0	2.8	42.0
Temp. grassland	9.0	100 - 1500	500	4.5	4.0	2.0	18.0
Desert	24.0		1	-			0.1
Dry desert	8.5	0 - 10	3	-	4.5	-	0.1
Ice desert	15.5	0 - 1	0	-	-	-	-

1	2	3	4	5	6	7	8
Cultivated land	14.0	100 - 4000	650	9.1	4.1	2.7	37.8
Freshwater	4.0		1250	5.0			21.4
Swamp and marsh	2.0	800 - 4000	2000	4.0	4.2	8.4	16.8
Lakes and rivers	2.0	100 - 1500	500	1.0	4.5	2.3	4.6
Total for continents	149.0		669	100.2			426.1

Table II. 1-2 presents the following data in column 1: the vegetation unit; in column 2: the area covered by this vegetation type; in columns 3 and 4: the rate of primary productivity; and in column 5: the total annual dry matter production for the vegetation type. The sum total for the earth amounts to 55.2 x 10^9 tons for the oceans and 100,2 x 10^9 tons for the continental areas. A separate estimation for the annual energy fixation of the same vegetation units is given in columns 6 - 8 of Table 1-2. Column 6 gives the averaged figures for the combustion values of the vegetation type, considering actual composition of vegetation samples as described by LIETH and PFLANZ (1968). This is converted into calories fixed per m^2 in column 7 by multiplying the figure of column 6 by the figure of column 4. Column 8 evaluates the total estimate of energy fixation for the entire vegetation unit. The total for the land surface is 426 x 10^{18} cal/year. Estimating marine primary productivity at 55 x 10^9 tons/year, with the caloric equivalents in the footnote to Table 1-2, 261 x 10^{18} cal/year is obtained for the oceans and a total net primary productivity for the world of 687 x 10^{18} cal/year is calculated. If 510 x 10^{18} kcal is accepted as the total annual solar radiation received by the earth, the total energy fixation averages 0.13 per cent, on the basis of 0.07 per cent, for the ocean and 0.3 per cent for the land surfaces.

The world total of 687 x 10^{18} cal/year, calculated on the basis of the figures in Table 1, coincides well with GOLLEY's (1972) figure of 652 x 10^{18} cal/year. The two assessments reinforce each other, since my estimates are based, for the most part, on a different data pool, which overlap in the two calculations only in the tropical regions.

GOLLEY relied heavily on a compilation by CUMMINS and WUYCHECK (1971) which was then available only in mimeographed form, and which was published after I had assembled my Table 1.

My own listing relied heavily on European data already available and several hundred checks made during the years 1962 - 1966 (one thesis by PFLANZ, 1964, and reports by VELEMIS, POWELL, and VAASMA, mostly unpublished except LIETH, 1965a, and LIETH and PFLANZ, 1968).

Comparison of the energy figures in Table 1 leads to the observation that among the forest types, caloric contents are correlated with climate and taxonomic group. Caloric values are, in general, higher in temperate than in tropical forests and higher in gymnosperms than in angiosperms. At the extremes of these two trends, the combustion values in (angiosperm) tropical rainforests are 20 - 25 per cent lower than in (gymnosperm) boreal forests.

This leads to a hypothesis on the success of the angiosperms over the gymnosperms during the last 60 million years (LIETH, 1972, cf. JORDAN, 1971b). One notes how the gymnosperms, in most temperate areas, have been pushed to environments that are marginal (because of aridity, or cold, or soil infertility) for tree growth while they have been essentially wiped out of the lowland tropics.

II. 1.4. Production of usable biomass and strategies for its utilization

Productivity is the organisms' ability to produce substances on a given area in a given time unit.

Abiotic and biotic enviromental factors limit the productivity of individual species in natural ecosystems. There is no need for individual species in natural ecosystems to produce maximum amounts of substances. Consequently, selection was not productivity-based in the course of evolution, but it took place with regard to stability.

A purposeful selection of plants, animals and microorganisms for the production of usable biomass did not take place until man settled in certain places some 10,000 years ago.

Man purposefully chose those plants and animals which were useful to him with regard to the provision of food, clothing and manufacture of implements. At the same time, he used them as sources of energy (work), thus providing protection for them. Unknowingly, man promoted also the growth of microorganisms which are suitable for the conservation or conversion of natural products (e.g. fermentation organisms).

By doing all this, man provided himself with one of the prerequisites for his own productivity and stability. Man, comprising four billion individuals and a dry weight of some 100 million tons (= $6 \cdot 10^{14}$ kcal = $2.5 \cdot 10^{15}$ kJ) at present, constitutes the largest biomass of all species of organisms (HABER 1978). The global 2 per cent population growth rate requires a constant increase in the production of usable biomass, if hunger and shortages of raw materials are to be abolished.

These aims can be achieved through:
- selection and breeding of useful organisms,
- use of the resources available,
- maintenance and improvement of the conditions for useful organisms,

- keeping away pests and other harmful factors.

The use of energy (in various forms) is an absolute must, if the production of usable biomass is to be increased.

The use of energy varies at the different systems levels. An agrarian ecosystem cultivating mainly annual plants requires an energy input which differs from that of a forest ecosystem with trees of more than 100 years.

Freshwater ecosystems differ from amrine ecosystems with regard to the energy input required for phytomass production. But it should be noted that phytomass production is no priority for many freshwater ecosystems, because the water is intended to be used as potable water.

Microorganisms are also able to produce usable biomass, and modern biotechnical techniques make it possible to produce protein from waste products with the aid of microorganisms. The following subjects provide a more detailed insight into the production of usable biomass and strategies for its utilization:

III. Agro-ecosystems
IV. Animal husbandry
V. Forest resources, and
VI. Management of aquatic ecosystems.

Accordingly, the following will be restricted to primary production, i.e. the production of usable phytomass (plant biomass) in managed ecosystems.

Table II. 1-2 shows that, in natural ecosystems, the productivity of individual natural vegetation units (phytocoenoses) may be as high as 3,500 g m^{-2} a^{-1} (i.e. 35 t ha^{-1} a^{-1}), whereas the average is about 22 t ha^{-1} a^{-1}.

But the bulk of crops and foods of plant origin is produced by man in agro or forest ecosystems (managed ecosystems, sometimes also called artificial ecosystems), e.g. pastures, corn fields, rise fields, fruit plantations, forests, etc. Their yields often exceed by far the primary production in natural ecosystems.

Provided that favourable environmental conditions prevail, 70 - 80 t . ha^{-1} . yr^{-1} can be achieved by high-yield varieties of sugar cane in tropical countries (see Table II 1-3).

Table II. 1-3

Maximum production of phytomass in cultivated ecosystems.

Plants		Phytomass t . ha^{-1} . $year^{-1}$
C_4 - grasses		
sugar cane		70 - 80
maize	(subtropics and tropics)	30
maize	(temperate zone)	15
C_3 - grasses		
wheat		18 - 30
rice		22
barley		15
rye		10
orchard grass		10
other crops		
soybeans		30
manioc		40
sugar beet		30
potato		20
trees in fast growing plantations (energy farming)		
eucalyptus		55
willow		52
poplar hybrids		35 - 40

Source: LARCHER 1980

If cultivated plants are to reach such high yields, all yield and stability-influencing factors must be optimal. This applies particularly to the following factors:

A. Preservation and use of the biological potential
- selecting suitable plants
- breeding high-yield varieties
- preserving the genetic potential of wild plants and high-yield varieties

B. Preservation and use of the natural resources
- water balance
- soil and its fertility
- nutrient supply
- clean air

C. Use of low or non-polluting techniques
- fertilizing
- stabilizing
- pest control
- cultivation methods
- harvesting methods

Comments on A:
Searching for plants whose biochemical, physiological and productive features can be used, man has always discovered new plants which had hardly been given any attention before or been considered even as weed. That is why it is necessary to preserve all plants (all organisms anyhow) and keep them from extinction.

This is even the more urgent as many of the wild plants are endangered by a highly mechanized agriculture and forestry. But certain varieties of cultivated plants, too, are superseded by more productive and better usable ones.

Both, the extinction of wild plants and the supersession of cultivated plants "no longer needed" requires active measures and strategies to be employed to preserve the genetic potential of the plant kingdom.

The International Board for Plant Genetic Resources (IBPGR) organizes and coordinates the steps taken to preserve the genetic reservoir of plants.

The International Board for Plant Genetic Resources (IBPGR) is an autonomous, international, scientific organization under the aegis of the Consultative Group on International Agricultural Research (CGIAR). The IBPGR was established by the CGIAR in 1974 and its Executive Secretariat is provided by the Food and Agriculture Organization of the United Nations. The basic function of the IBPGR, as defined by the Consultative Group, is to promote an international network of genetic resources centres to further the collection, conservation, documentation, evaluation and use of plant germ plasms and thereby contribute to raising the standard of living and welfare of people throughout the world. The Consultative Group mobilizes financial support from its members to meet the budgetary requirements of the Board.

In 1981, the following priorities were established for the preservation of the genetic potential of cultivated plants (IBPGR 1981) Table II. 1-4):

Table II. 1-4 Global crop priorities

Crop	Global Priority 1		Global Priority 2 •	High Regional Priority ■
Cereals	Wheat	*Sorghum *Finger millet *Barley	*Pearl millet *Foxtail millet *Rice	Maize Quinoza
Food legumes	Phaseolus beans	*Groundnut *Soybean *Cowpea *Yardlong bean *Winged bean	*Chickpea *Vigna radiata *V. mungo V. aconitifolia V. umbellata	Vicia faba Lentil Lupin
Roots and tubers	Cassava Sweet potato	Potato		Yam Taro and Aroids Minor S. American tuber
Oil crops		Oil palm (Elais melanococca) *Coconut *Oilseed brassicas		
Fibres		Cotton		

Crop	Global Priority 1	Global Priority 2	High Regional Priority
Starchy fruits		*Starchy banana and Plantain	Breadfruit and Jackfruit
Sugar crops		*Beet *Sugar cane	
Beverages	Coffee	Cocoa*(Criollo varieties)	
Subtropical and Tropical fruits		*Dessert banana *Citrus *Mango	Avocado Peach palm Lansium Durian Annona Rambutan Passiflora
Temperate fruits		*Apple *Pear and Quince Peach and Nectarine	
Vegetables	Tomato	*Amaranth *Brassica *Curcubits *Eggplant *Okra *Onion *Chilli *Radish Bitter gourd Globe artichoke Cucumis	Sechium Kangkong Spinacia

Crop	Global Priority 1	Global Priority 2	High Regional Priority
Trees		Trees for fuelwood and environmental stabilization	

= a first priority in at least one region
Although having a lower global priority these crops all have a first priority in at least one region.

Comments on Ba: water balance

Water, in shortage or excess, is one of the most common limiting factors in production.

Therefore, it is necessary to have an exact knowledge of the water demand of plants. This demand cannot simply be derived from the plants' water content. Investigations into the water uptake and discharge and production by the plants have to be conducted.

The following table provides a survey of the approximate water demand of a number of cultivated plants (Tab. II. 1-5).

Table II. 1-5

Water demand of plants to produce 1 kg of phytomass

name	Latin name	water demand (litres)
wheat	Triticum sp.	520
maize	Zea mays	361
rice	Oryza sativa	682
rye	Secale cereale	634
potato	Solanum tuberosa	575 - 636
sunflower	Helianthus annuus	577
bean	Phaseolus vulgaris	695
sugar beet	Beta vulgaris var. altissima	377
millet	Panicum miliaceum	259
soybean	Glycine soja	715
cucumber	Cucurbita pepo	802

The above figures make a rough estimate of the plants' water balance possible. However, it should be noted that the required amount of water should be continuously available during the whole vegetation period, in particular during critical development stages such as flower formation, fructification, filling of the storing organs, etc. Additional watering (irrigation) is required where droughts occur during the vegetation period. Any kind of irrigation requires the input of energy.

The following stategies are recommended to preserve and use water as a natural resource:

- investigations into the consumption of water by cultivated plants;
- selection of low-water-demand plants;
- efficient maintenance of a high soil water contents for maximum plant production;
- methods of forecasting crop water requirements and timing of irrigation;

- technologies for environmental modification, including drought protection.

Comments on Bb: soil and fertility

Topic 2 reports about soil and soil fertility. In this section, a few remarks will be made about the area available for phytomass production worldwide and its current use.

The total area of potentially arable land on earth, estimated at 3.2 billion hectares, is more than twice the area cultivated at some time during the last few decades.

About 44 per cent of this area is cultivated, while the land actually harvested during any particular year is about 30 per cent. However, the bulk of potentially arable land is not where the world population concentrates. (See Table II. 1-6)

- 11 per cent of the total area requires irrigation for even one crop (JACKSON and coworkers, 1975);
- every year, a portion of the potentially arable land is used for the construction of houses, roads and industrial plants;
- improper use of arable land by sophistocated agricultural methods may lead to a drop in soil fertility.

Accordingly, the following urgent strategies should be adopted to ensure future phytomass production:

- reclamation of potentially arable land, in particular in the developing countries;
- preservation of the potentially arable land for agricultural use, and
- preservation of soil fertility.

Table II. 1-6 Present population and cultivated[1] land on each continent, compared with potentially arable land

Continent	Population in 1982 millions of persons	Area in billions of hectares			Hectares of cultivated land per person	Ratio of cultivated to potentially arable land (per cent)
		Total	Potentially arable	Cultivated		
Africa	470	3.02	0.73	0.16	0.34	22
Asia	2,500	2.74	0.63	0.52	0.21	83
Australia and New Zealand	22	0.82	0.15	0.02	0.91	2
Europe	750	0.48	0.17	0.15	0.20	88
North America	371	2.11	0.46	0.24	0.65	51
South America	242	1.75	0.68	0.08	0.33	11
U.S.S.R.	262	2.23	0.36	0.23	0.88	64
Total	4,617	13.15	3.18	2.87	0.42	44

---

[1] Our "cultivated area" is called "Arable land and land under permanent crops" by the FAO. It includes land under crops, temporary fallow, temporary meadows, for mowing or pasture market and kitchen gardens, fruit trees, vines, shrubs, and rubber plantations. Within this definition there are said to be wide variations among reporting countries. The land actually harvested during any particular year is about one-half to two thirds of the total cultivated land.

Comments on Bc: mineral nutrition

Justus von Liebig was the first to discover that the yields of plants can be considerably increased through mineral-substance fertilizing. This applies in particular to the supply of nitrogen whose content in the pedosphere is no more than 0.03 per cent, while it is 78 per cent in the atmosphere. Plants, however, are unable to use the nitrogen contained in the atmosphere. Only their roots are able to take the nitrogen from the soil. Fertilizing inorganic N compounds, which has been the customary practice for decades now, is accompanied by one major drawback: microorganisms contained in the soil nitrify part of the mineral fertilizers. As the nitrate can easily be washed out, it is transported into the ground and surface water, where it enriches the lakes and reservoirs with N and results in a eutrophication of bodies of water.

That is why new strategies are necessary for the supply of mineral substances, particularly nitrogen.

They include:

- increased use of biological fertilizers (humus);
- development of N fertilizers with a long-term effect, with are more difficult to nitrify by microorganisms and, consequently do not wash out so easily;
- use of chemical substances which inhibit the activity of nitrifying microorganisms (nitrification inhibitors). Some concern about the use of such inhibitors must be voiced, because side-effects upon useful organisms in the soil are to be expected.
- development (breeding, cultivation by means of genetic engineering) of plants which, analogous to the leguminoseae, have atmospheric-nitrogen-binding symbiont microorganisms in their roots, thus being able of "self-supplying" nitrogen from the atmosphere.

Any newly developed technique must also bring about a saving of energy in the manufacture of mineral fertilizers (see Table II. 1-7).

Table II. 1-7

Energy demand of various products cultivated in California: Energy contained in the produce and conversion ratio (yield/input)

	Fuel or electricity input (1,000 kcal/t)	Calorie content of the crop (1,000 kcal/t)	Ratio
Field plants:			
barley	479.0	3166.1	6.6
wheat	563.3	3020.9	5.4
maize	1027.3	3338.4	3.3
rice	1289.3	3293.1	2.6
grain-millet	1188.8	3011.8	2.6
average			4.1
raw plant mass and fruits:			
potatoes	325.4	689.5	2.1
apples	401.1	508.0	1.3
grapes	576.9	607.8	1.1
carrots	359.8	381.0	1.1
tomatoes	262.2	199.6	0.8
pears	964.2	553.3	0.6
French beans	2058.0	1115.8	0.5
grapefruit	1165.5	371.9	0.3
lettuce	484.3	163.3	0.3
broccoli	1178.6	290.3	0.2
cauliflower	986.4	244.9	0.2
average			0.8

Source: BRUWER et al., 1980

Comments on Bd: air cleanness

It is primarily due to its content of carbon dioxide and oxygen that the air is a vital natural resource for plants and their productivity.

Though an increase in the CO_2 content of the air has no adverse effect on photosynthesis and phytomass production, air polluted by gaseous or solid substances such as SO_2, dust etc. poses a real danger to the plants' productivity and stability. It seems to be rather pointless to breed plants with a higher air pollution resistance, as there is no absolute resistance (immunity) to SO_2 and other substances, and higher-resistance plants usually have the disadvantage of a lower productivity. As an example, Picea pungens var. glauca is more SO_2 resistant than Picea abies, but the latter's growth is faster.

Polluted air may also pose a great risk to man (diseases, sickness, or death), when heavy metals concentrate in plants and enter the body via the food chain.

Strategies to preserve the air as a natural resource and production factor call for the abolition of any kind of emissions from industrial plants, cars, towns etc. through modern techniques (filter, absorption).

Comments on C:

The use of low-polluting cultivation and harvesting techniques depends upon the individual plant varieties and the standard of economic development in the countries and regions where these plants are cultivated.

So far, the highest yields have been recorded in those countries where an intensive-type of agriculture and forestry exists along with a high input of mineral fertilizers and chemicals for pest control and plant stabilization and the use of modern farm machinery.

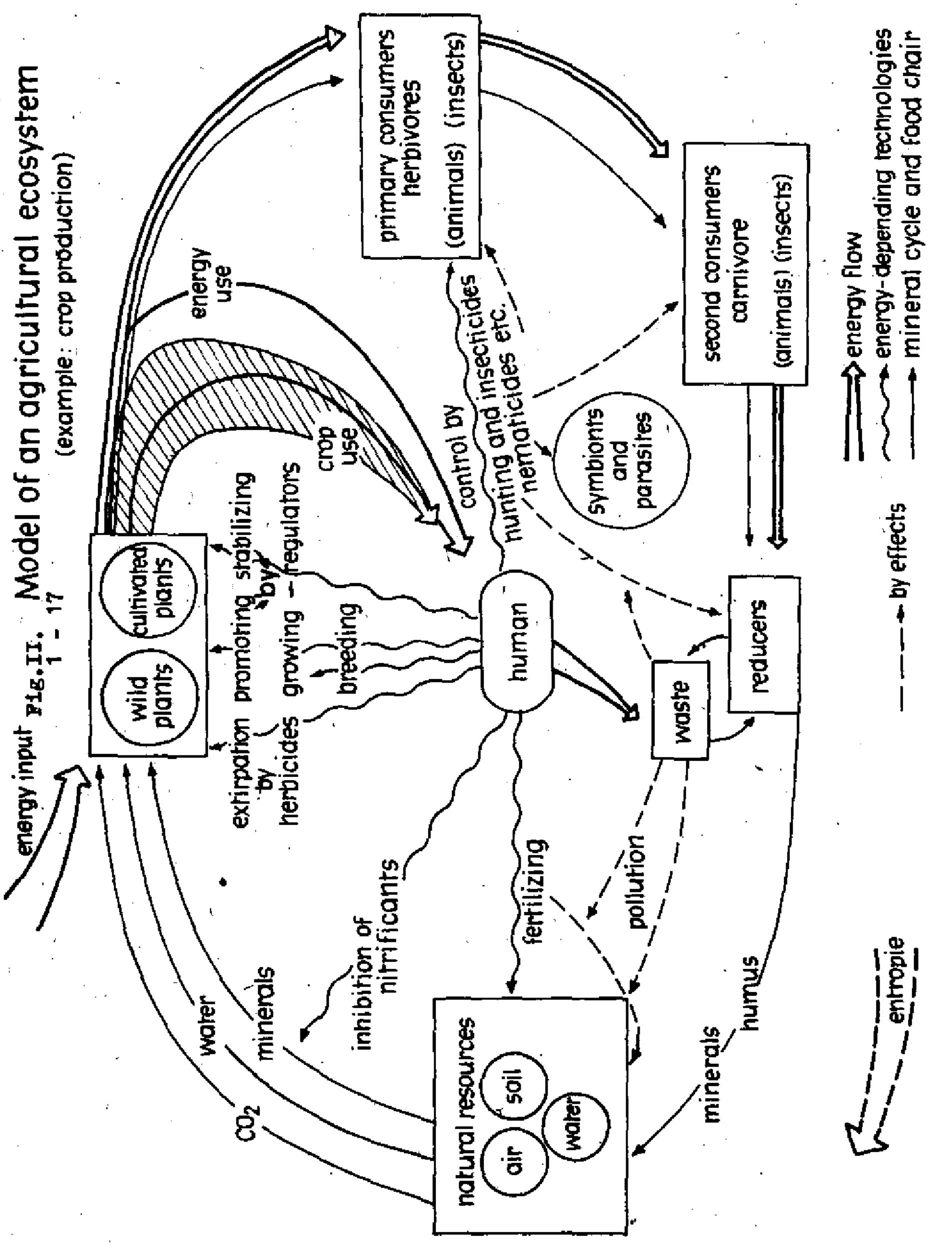
As can be seen from Fig. II. 1-17, many of the modern agricultural methods are very energy-intensive and have ecologically harmful effects.

That is why new techniques have to be introduced for the production of usable biomass, which, as has been shown by the example of nitrogen fertilizing, are both low-pollutant and energy-saving. Any cultivation energy input which is higher than the biochemical energy produced by the plants results in a reduction of fossil and more recent energy deposits and, accordingly, to an energy deficit.

That is why ecological, economic and energetic problems have to be included in an integrated approach to usable biomass production. They must be viewed as forming a unity together with the production target envisaged, as they constitute the most important strategy.

Fig.II. 1 - 17 Model of an agricultural ecosystem

(example: crop production)



II. 1.5 Influencing the productivity of ecosystems

The productivity of ecosystems can be influenced by a great number of abiotic and biotic factors, which may become effective individually or in complex form. (See Table II. 1-8)

Many of them act in every ecosystem as the environmental components (e.g. climatic factors) and are, under normal circumstances, of vital importance to a prosperous development of the biological system. They are considered to be disturbing factors when there have been unnatural changes of their values (concentration, dosage, density of infection, etc.).

Other such factors result from man's activity and they are introduced into the ecosystem either knowingly or unknowingly. Their action depends upon concentration, but mostly they are of vital importance in low concentrations.

On the level of organs, organisms and ecosystems, the effects of these factors act until harmful symptoms become visible, after that only when the border of organisms resistance is exceeded and damages or illnesses are evident. The whole system loses its stability then. On the cellular or subcellular levels, the effects remain mostly invisible for the observer, but they can be made visible by means of physiological, biochemical, molecular-biological or other methods. These invisible effects are today commonly called stress, if they are inreversible and do not indicate some illness (LEVITT 1972). In 1978, we proposed the following definition, which differs from other definitions (e.g. KREEB 1971) by inclusion of the time factor:

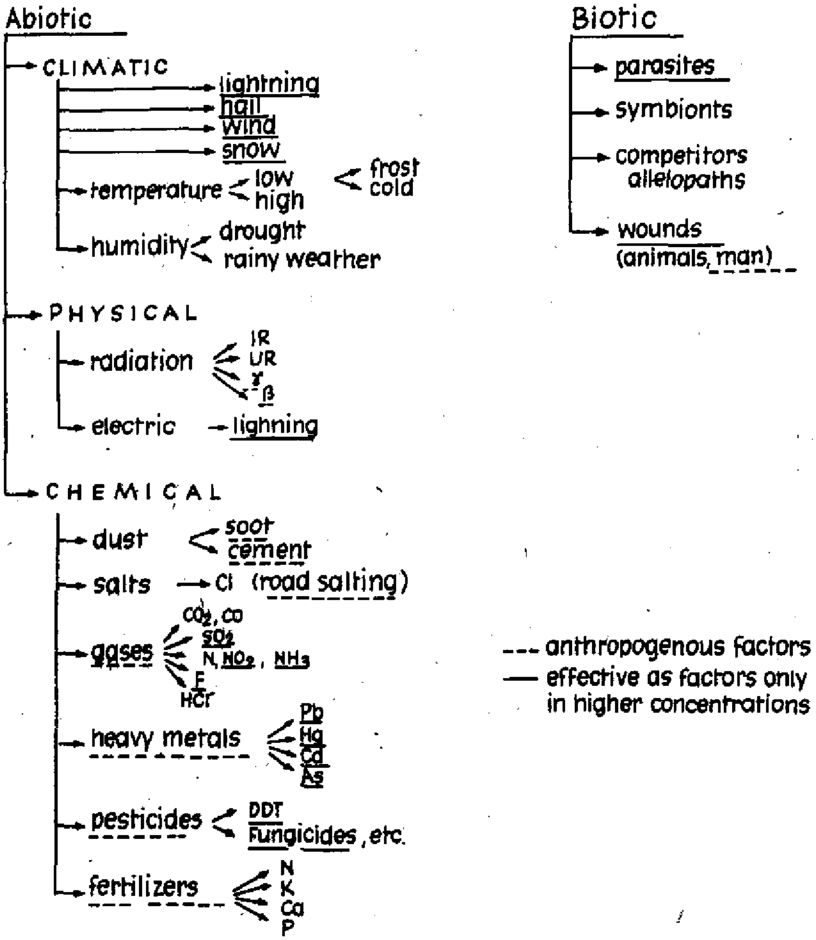
Stress is an extraordinary load limited in time, which does not lead to any visible or irreversible damages.

The following will explain the content and definition of the terms of vitality, stress and illness.

It follows from the above definition that all living organisms are in the relation of steady exchange with their environment,

Tab. II. 1.- 8

Some selected factors which influence the productivity of ecosystems (plants)



that their life is always dependent on the complex of the favourable components of the environment, and that they are contingent upon a dynamic equilibrium with their environment. This dynamic equilibrium is called stability.

All organisms in the stability state react more or less intensively to the changes in the environmental components and the impact of disturbing factors. They are in the state of being able (to some extent) to adapt themselves to the changed environmental conditions.

This response to normal environmental changes - adaptability - is genetically fixed and should be designated as the measure of response, which is characteristic of the organisms' vitality.

During changes of environmental components, which exceed the normal extent and the measure of response of an organism, an extraordinary load is exerted on the organism. The environmental components have become disturbing factors. The regulation mechanisms in the organism - active resistance reactions to preserve the organism's stability - must begin to act to lessen the organism's damage. This results in stress, during which the organism reaches, under the circumstances prevailing, its resistance border: the region of resistance to disturbing factors. In this state the vitality is weakened. In such situations it depends than on the magnitude of the disturbing stress, i.e. on the magnitude of the load and its duration and if the impact of the disturbing factors remain in the region of stress, whether or not this situation results in an illness.
Four examples are given: (Fig. II. 1-18)

Possible effects of environmental factors on plants

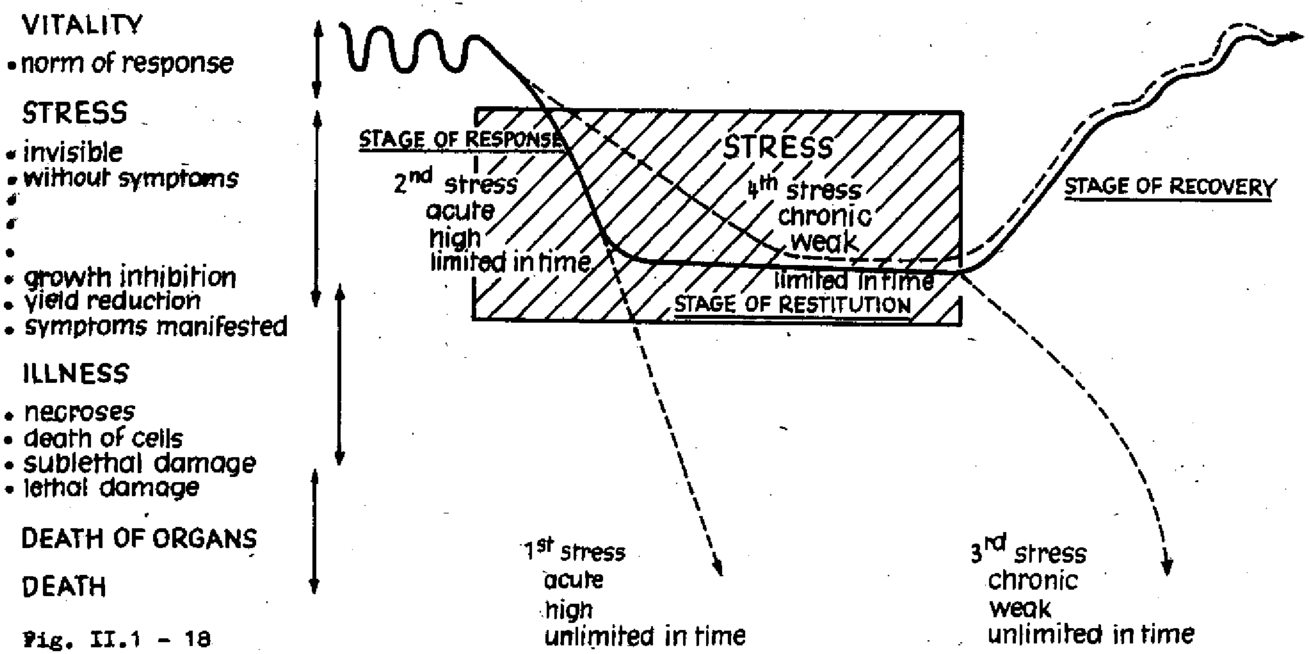


Fig. II.1 - 18

Example 1:

The high load acts on the organism acutely, i.e. suddenly and in rapidity.

The high load is unlimited in time.

Result: After the phase of "encountering the disturbing factor" (the phase of reaction according to STOCKER (1956)), the organism will be in the state of stress for a short while, but soon the symptoms of illness will appear and individual organs or the whole organism may die.

Example 2:

The high, acute but still endurable load is limited in time.

Result: The organism is under stress for a limited time, it can react and recover. The action is reversible. The symptoms of illness do not appear.

Example 3:

The weak load acts on the organism chronically, i.e., slowly and latently.

It is unlimited in time.

Result: The organism will react to the stress for shorter or longer time periods in a way specific to its species. The load, however, becomes severe with time, and the stress will result in an illness, which may lead to death.

Example 4:

The weak, chronic load is limited in time.

Result: The organism remains in the stress region during the time of load but it can react and recover after the stress has gone (called the phase of recovery by STOCKER 1956).

A number of problems are neglected in this approach:

- changes of the measure of response and resistance, caused by site-factors and the biorhythm,
- changes of predisposition as a result of stress,
- complex function of stress factors,

- species-dependent regeneration abilities of affected organisms,
- consequences of endured stress for the system (e.g. growing old as a consequence of stress).

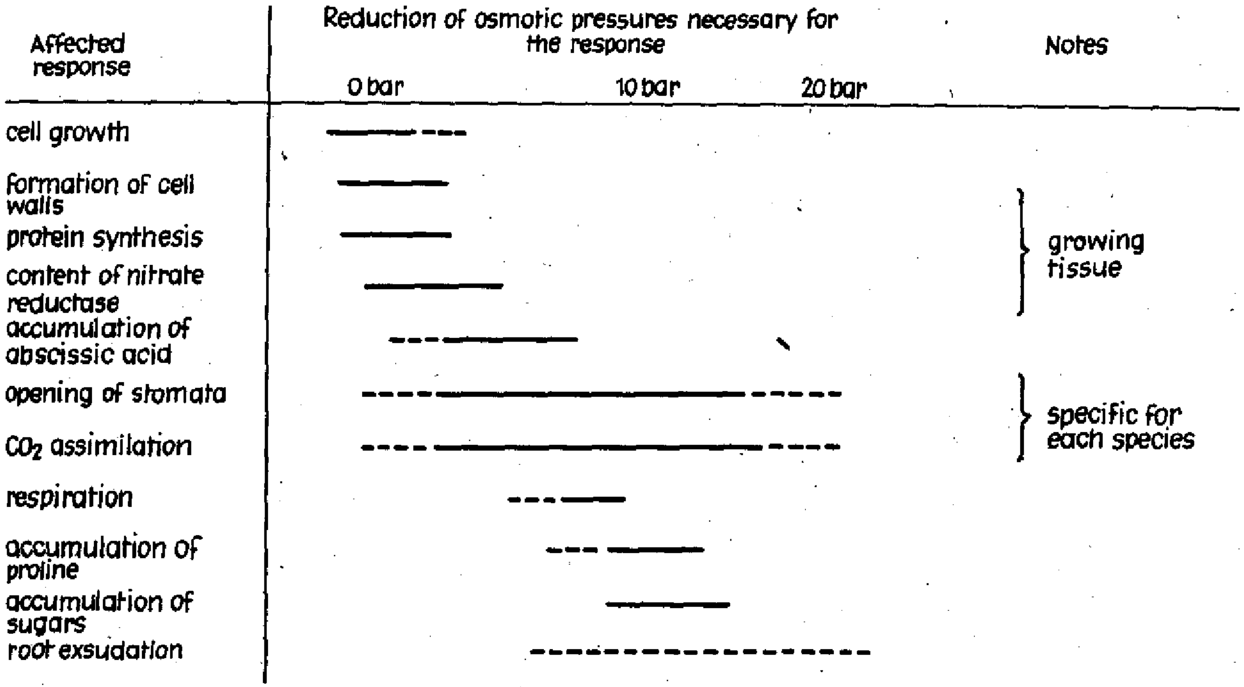
Two of them are very important for the further explanation and should be explained in more details.

1. Resistance changes resulting from the biophythm.
   These are resistance changes in the course of the year or the ontogenesis, etc. As an example, the different frost-resistance of plants during the year can be cited.
2. Predisposition.
   By predisposition we understand the exogenous modification of susceptibility to illness (Braun 1965), i.e. the temporary changed reversible predisposition to illness, caused by environmental factors.

In forestry, agriculture and horticulture, any attempt to understand the impact of disturbing factors before damage symptoms occur has not only scientific importance, but it is particularly useful for practical purposes.

Depending on the stress analysis in the sense of an early diagnosis, it is possible to eliminate the harmful factors or to protect plants before the damages to plants or their stands occur. This means that it would be possible to stabilize the plants or their stands in good time or preserve their stability. Therefore, much emphasis is placed on analyses of the reactions of plants to environmental stress and the discovery of specific stress indicators. At present, it is possible to do such analyses on the levels of cells, organs and organisms, from which conclusions for whole ecosystems can be derived.

Fig. II. 1.- 19 Response of plants to a drought stress



The length of lines expresses the first response to stress effects
Full lines require further studies

Source: HSIAO, 1973

The survey of the possibilities of indication of a stress function was compiled by HSIAO and ACEVEDO (1974) by the example of drought stress. (See Fig. II. 1-19) We have completed this survey by the "root exudation". It is still incomplete and new research results are added constantly. So, the following plant reactions to the drought stress were published by Dilley et al. (1975):

- reduction of uptake of nutrients,
- reduction of content of the growth regulators, such as gibberellin and cytokinin,
- release of ethylene, and
- influences on the root growth.

As far as we know, such surveys have not been compiled for other stress functions.

To get an understanding of the stability of biological systems against harmful factors it is necessary to understand the action of harmful factors and the reaction of systems to these disturbing factors before the onset of damage symptoms, i.e. in the region of stress. The analysis of stress factors requires a choice of suitable stress indicators.

The suitable indicators for stress acting from SO_2, frost and drought proved to be

- accumulation of proline in plants,
- exudation of metabolites from roots, and
- electrical conductivity of diffusates.

All three, of course, are nonspecific stress indicators. Further investigations in this field will contribute to improving the knowledge of when critical lead values are reached in trees or ecosystems, so that stability-preserving measures can be taken or systems be established which result in the desired final stability.

Significance of stress reactions

For the understanding of ecological relationships in phytocoenoses, those reactions of plants to stress actions are of special significance in which metabolites are formed and/or transmitted to the environment (VISSER 1964).

In the case of dought stress this holds true for ethylene production and all root exudations. The metabolites, which are produced in greater amounts or newly formed under stress, become environmental factors if being exuded by plants. As such they act as ecosystem regulators outside the donor plant.

The effect of ethylene as a significant component of the volatile substances of ripe apples, on numerous reactions of other plants has been known for some 40 years now. Lately, tests have been made on the mechanisms of action of ethylene on ferments and growth substances of sprouting cotton seeds and on the lignification of cotton sprouts, the latter being inhibited by ethylene.

Carbohydrate exudations from roots are expected to affect mainly soil microorganisms such as mycorrhiza fungi. But it is also a well-known fact that after drought periods, the highly phytopathogenous fungus Armillaria mellea fructifies particularly well, probably as a result of a fructification stimulation by tree root exudates during drought stress. In addition, root activity of other higher plants may be promoted by carbohydrates exuded under stress.

On the whole, the chemical interactions between plants developing in this manner still provide a broad field for further research work.

The following imperatives for further research can be derived from the present knowledge of the effects of stress on plants:

a) Further clarification of physiological reactions of plants under stress. These include:
   - exact analysis of processes in plants at the onset of stress,
   - further analysis of metabolic reactions during stress situations and
   - clarification of metabolic mechanisms contributing to drought resistance.

b) Further clarification of the relations between structure and function of individual plant organs under stress, especially clarification of interactions between the structure and functions of organs for uptake, transport and discharge of metabolites during stress situations.

c) Investigations into chemical, allelopathic interrelations in an ecosystem which are intensified or brought about by stress action, e.g.
   - investigations into the effect of exuded metabolites on useful or pathogenic microorganisms of the soil, the rhizosphere and the phyllosphere,
   - investigations into the effect of exuded products on other higher plants,
   - analysis of the chemical structure of exuded metabolites, and
   - analysis of primary causes of the exudation of substances taking place under stress.

d) Preparation of methods for the genetic manipulation of plants, and of technologies for an effective management of plant cultures under stress situations. These include:
   - biological engineering manipulations of the hereditary substance aimed at increasing resistance while stabilizing and/or creating additional resistance factors,
     - technologies to stabilize and increase yields under stress, and
     - development of management practics to enhance the effective exploitation of available resources.

An increase of the productivity of ecosystems may be achieved mainly by practical measures. The basic processes of photosynthesis cannot be influenced by human activities and conditions in tropical climates are limited by water supply. However, the different cycles in photosynthesis, expressed by the terms C_3 - C_4 - cycle should be considered, because the C_4 - mechanism may provide higher biomass under less favourable environmental conditions. Some highly productive tropical plants (maize, sugar-cane etc.) are tropical representatives of this C_4-mechanism.

Another important aspect for the increase of productivity are scientifically based breeding programmes to improve the genetical potential of plants for high yield crops or such crops with high protein content or other favourable properties.

Practical measures are mainly directed at the intensification of actual agricultural practices like increased fertilizer and pesticide application, irrigation and drainage, proper cultivation methods and several other factors which are treated in detail in Chapters III, IV and V.

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