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Conceptual aspects of ecological studies: the role of the energy- and mass- exchange

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RESUMEN

La existencia de la vida sobre la Tierra es posible sólo bajo condiciones de ciclos biogeoquímicos globales al nivel $(P^+ - P^-)/P^+ \equiv \chi \sim 10^{-4}$, en donde P^+ and P^- son flujos de síntesis (+) y descomposición (-) de substancias orgánicas. Debido a que existen altas correlaciones entre las comunidades locales que forman ecosistemas de tamaños finitos, se puede alcanzar una igualdad aproximada (con una precisión del orden de 10^{-4}) de P^+ y P^-. La estabilidad de estos ecosistemas locales se apoya en la selección de Darwin. Las fluctuaciones de escala pequeña de P^+ y P^- en un ecosistema local garantizan la transferencia de flujos básicos de materia y energía a través de partes no correlacionadas de tamaños microscópicos. La porción de consumo de energía por los organismos mayores no excede de 1%. Por otra parte, el consumo actual de la producción primaria de energía por el hombre ha alcanzado cerca del 25%. Lo anterior ha producido un rompimiento de los ciclos de las substancias hasta un porcentaje bajo, verificado por los datos del ciclo global del carbón.

PALABRAS CLAVE: Ecología; intercambio energía y masa.

ABSTRACT

The stable existence of life on Earth is only possible under conditions of closed global biogeochemical cycles at the level $(P^+ - P^-)/P^+ \equiv \chi \sim 10^{-4}$, where P^+ and P^- are fluxes of synthesis (+) and decomposition (-) of organic substances. An equality of P^+ and P^-, with an accuracy of the order of 10^{-4}, may be reached due to high correlations between the communities that form local ecological systems of finite sizes. Small-scale fluctuations of P^+ and P^- in a local ecosystem guarantee the transfer of basic fluxes of energy and matter through the uncorrelated parts of microscopic sizes. The share of energy consumption by large organisms does not exceed 1%. The present-day consumption by men has reached about 10% of the primary production on land. This has led to breaking of the cycles of substances up to the level of a few per cent, which is verified by the data on global carbon cycle.

KEY WORDS: Ecology; energy-and mass-exchange.

INTRODUCTION

A major objective of ecological studies is to substantiate the ways of providing healthy working and living conditions for both present and future generations in conditions of intensive (but not extensive) socioeconomic development (Kondratyev and Rostopshin, 1987). The preservation of natural environmental conditions is a major aspect of ecological safety. It follows, in particular, that the problem of the optimal density of global population must be solved in accordance with this condition but not based on the requirement of food supply only.

The steady state of the environment and the biosphere is mainly determined by the energy- and mass-exchange. For instance, unique conditions for the appearance and existence of life on Earth are known to result from its location in the solar system, which provides (due to the respective incoming solar radiation) the existing climate (Marchuk *et al.*, 1988; Kondratyev, 1987). The annual mean energy balance of the Earth is zero (the solar radiation absorbed by the planet is equalized by the heat lost to space due to thermal emission). Of special interest is the problem of closeness of global biogeochemical cycles (Gorshkov, 1987) (see Appendix 1).

THE CLOSENESS OF THE CYCLES OF SUBSTANCES IN THE ENVIRONMENT AND IN THE BIOSPHERE.

The environment includes a region of direct functioning of life. It is characterized by certain concentrations of chemical compounds consumed by life. The environmental changes result from physico-chemical reactions which transform some chemical compounds into other compounds and transport these compounds, but the whole content of chemical elements on Earth does not change.

Processes in the biota are reduced to the synthesis and decomposition of highly regular organic substances. People have added the synthesis and decomposition of industrial products to these processes. Besides, the environment can vary as a result of other processes - volcanic eruptions, filtration of substances from the mantle, and accumulation of sediments.

The relationships between these processes are well known: the fluxes of organic synthesis of the biospheric components (primary production) by mass-exchange exceed 10 times the industrial production and 10 thousand times the geophysical fluxes of matter (Degens *et al.*, 1984; Budyko *et al.*, 1985).

The masses (concentrations) and the rates of their variations for chemical substances involved in the biogeochemical cycles can be characterized by the masses and rates of changes in organic and inorganic carbon. The mass-exchange of the remaining elements can be evaluated from the mass-exchange of carbon, based on their constant ratios typical of biota (Ajtay *et al.*, 1979). The synthesis/decomposition of 1 kg of organic carbon per year (1 kg C/yr) would be equivalent to 1.3 W of absorption/release of energy. The stores of biologically active organic and inorganic carbon in the environment coincide in the order of magnitude and exceed the annual primary production about 10 times (Degens *et al.*, 1984; Ajtay *et al.*, 1979; Whittaker and Likens, 1975). Hence, with only the synthesis or decomposition of organic matter (*i.e.*, with the complete openness of global cycles) these stores will be spent during a period of about ten years. Then, all vital processes will stop. One has to emphasize in this connection that the present anthropogenic processes can destroy the environment during hundreds of years, while geophysical processes can do that during hundreds of thousands years (Budyko *et al.*, 1985; Vitousek *et al.*, 1987).

The chemical composition of the environment can remain constant, first of all, under conditions of strict equality of the fluxes of synthesis and decomposition of organic matter. The condition of secondary significance is the use of wasteless production technologies. It is obvious, however, that the development and application of wasteless technologies remain of principal importance. Without anthropogenic disturbances the fluxes of synthesis and decomposition of organic substances by natural biota coincide to an accuracy of four significant digits, which would stabilize the environment during the geological time periods (Gorshkov, 1987).

LE CHATELIER'S PRINCIPLE AND THE ENVIRONMENTAL STABILITY

Being the most powerful natural force of the environmental transformation, biota is able to form the environment, *i.e.*, to provide concentrations of biologically active chemical compounds, most favorable for biotic functioning. For instance, it is well known that the soil chemistry is completely formed and controlled by native biota (Zavarzin, 1984). There are important reasons to believe that the concentrations of biologically active substances of the globally mixed media - the atmosphere and the surface layer of the ocean - are also controlled by the biota. At present, this statement has been formulated in scientific literature as "Gaia hypothesis" (Margulis and Lovelock, 1974; Borisenkov and Kondratyev, 1988).

The concentrations of all dissolved inorganic biogenic compounds in the open ocean change several times from the surface down to several hundred meters deep. The concentrations of C, N, P grow with increasing depth, and the concentration of O_2 decreases. This is connected with the fact that photosynthesis of organic substances takes place in the surface layer, where the light penetrates. The decomposition of organic substances can occur at any depth. As a result, middle depths, at which both synthesis and decomposition take place, differ. In the zone of synthesis near the ocean surface, organic substances form that sink deep into the water and decompose into inorganic constituents in the oxidation zone hundreds of meters apart from the zone of synthesis. The reversed flux of inorganic compounds is provided by diffusion caused by the difference of their concentrations between deep and surface waters. Oxygen diffuses from the surface to the zone of oxidation, and C, N, P diffuse from the zone of oxidation to the zone of synthesis.

The concentration of dissolved carbon dioxide (CO_2) in deep waters is approximately three-fold higher than near the surface (Takahashi *et al.*, 1981). The surface concentration of CO_2 is in balance with the atmospheric one. Ceasing life in the ocean, all the concentrations both in deep waters and near the surface will equalize. Hence, CO_2 concentrations in the surface layer and in the atmosphere will triple. This can lead to catastrophic changes in the greenhouse effect and climate during decades. Hence, the oceanic biota maintains the atmospheric concentration of CO_2 at a level acceptable for life.

Slow variations in the environment during the geological time periods as a result of geophysical processes can be compensated with biological processes. For instance, the net flux of inorganic carbon from the ground to the environment is compensated with the flux promoting an accumulation in sediments of organic carbon dropping out from the biotic cycle (Degens *et al.*, 1984; Budyko *et al.*, 1985). The latter is equal to the difference between the synthesis and decomposition. The organic carbon mass in sediments is 3 to 4 orders of magnitude larger than the carbon mass in biota and in the environment (Ajtay *et al*, 1979; Whittaker and Likens, 1975). Hence, a pure flux of inorganic carbon from the ground to the environment coincides with an average flux of organic carbon to the sediments to an accuracy of 3 to 4 significant digits. The occasional coincidence with such an accuracy is impossible. On the whole the biota controls the fluxes of synthesis and decomposition of organic substances to an accuracy of 7 to 8 significant digits (Fig. 1) (Degens *et al.*, 1984; Whittaker and Likens, 1975). This is a strong argument in favor of the Gaia hypothesis, which has not been noted previously.

To maintain a definite chemical composition of the environment, the biota must follow Le Chatelier's principle: with the appearance of external disturbances of the environment, processes must happen in the biota

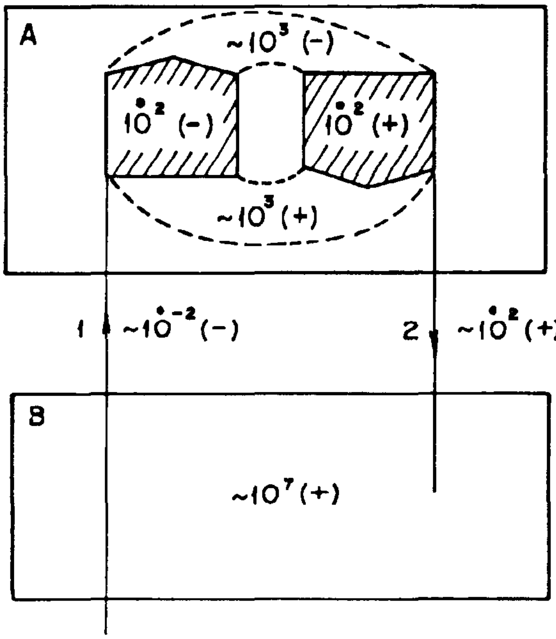

Fig. 1. The fluxes and stores of carbon in the biosphere and the environment, including sedimented rocks (Degens *et al.*, 1984; Vitousek *et al.*, 1987) A - the biosphere and the environment; B - sedimented rocks. Figures are carbon stores in GtC/year (Gigatons of carbon); figures with dots are carbon fluxes in GtC/year; "+" is the store or production (synthesis from non-organics) of organic carbon; "-" is the store or production (decomposition of organics) of inorganic carbon. The store of organic compounds in the environment (A) is maintained to be 4 orders of magnitude less than in sedimented rocks (B). It follows that the flux of inorganic carbon to the environment (1) coincides with the flux of organic carbon from the environment (2) with a relative accuracy of about 10^{-4}.

which compensate for this disturbance. The compensation of the environmental disturbances by the biota can take place at the expense of directed variations in the relationship between the synthesis and decomposition of organic substances (see Appendix 2). For instance, as the CO_2 content in the atmosphere increases, the biota can stimulate the synthesis of organic substances, transforming an excess inorganic carbon in the atmosphere into the bound low-active forms of organic carbon (for example, soil carbon and dissolved organic carbon in the ocean). On the contrary, with a decreasing CO_2 content in the atmosphere, the biota can compensate the concentration of atmospheric CO_2 by accelerating the decomposition of these low-active forms of organic carbon. The detection of such compensating processes (feedbacks) and studies of their mechanisms in natural biota should be considered one of the fundamental problems of ecology.

Along with regulating the content of natural chemical substances in the environment, the biota can also remove from it the products of anthropogenic releases, transforming them into less active forms. The facts demonstrating the ability of biota to self-cleaning (to certain limits) are well known (Yu Odum, 1986).

VIOLATION OF LE CHATELIER'S PRINCIPLE IN THE PRESENT-DAY BIOTA

The very large values of organic synthesis and decomposition fluxes due to natural biota, that surpass average geophysical perturbations by four orders of magnitude, are needed to rapidly compensate all possible fluctuations due to such perturbations (catastrophic volcanic eruptions, falls of gigantic meteorites, etc.). But at the same time, the strongly perturbed biota can change the environment during a very short time of an order of ten years.

It is well known that the carbon dioxide concentration in the atmosphere is now increasing. The world ocean (according to Le Chatelier principle) absorbs carbon dioxide from the atmosphere. But the land biota, seriously damaged by man impact, has lost its ability to compensate for the perturbations suffered by the atmosphere and has also become one of the principal sources of CO_2 released to the atmosphere (Borisenkov and Kondratyev, 1988; Gorshkov *et al.*, 1989). The quantitative violation of Le Chatelier principle for land biota may be assessed

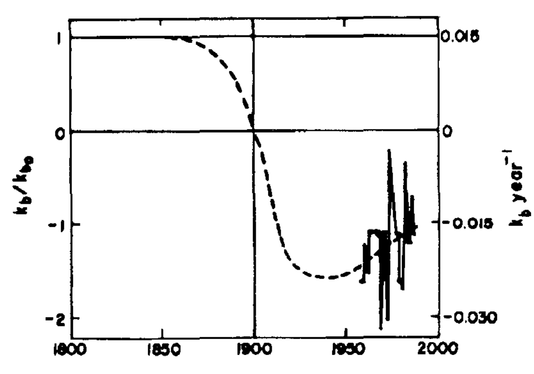

Fig. 2. Violation of the Le Chatelier principle for land biota. The response of the biota to a perturbation in the environment is assessed from the equation $\dot{M}_b = k_b \Delta M_a$, where $\dot{M}_b$ is the rate of the change of land organic carbon, ΔM_a the variation in the mass of atmospheric carbon. The Le Chatelier principle is satisfied in the case when the condition $k_b > 0$ is met; ΔM_a has been observed directly starting from 1958 (Gorshkov *et al.*, 1989); $\dot{M}_b$ is obtained from the law of conservation of matter. The solid line is drawn through empirical points for 1959-1986 (CO_2: Mauna Loa, fossil fuel combustion; $^{13}C/^{12}C$ and $^{14}C/^{12}C$ ratios in the atmosphere, ocean and biota, constant preindustial atmospheric CO_2 concentration). The dashed line is drawn using the conditions: $\Delta M_a=0$, $k_b=k_{b0}$ for $t< 1860$, the first time derivative $\dot{k}_b=0$ for 1860 and the second time derivative $\ddot{k}_b$ integrated over the whole period 1860-1986 is at a minimum (for detail see Gorshkov *et al.*, 1989) .

from the analysis of rare carbon isotope content in the atmosphere, ocean and biota (Gorshkov *et al.*, 1989). The conclusion can be drawn from this analysis that the land biota had failed to function in accordance with Le Chatelier principle by the beginning of the current century, Fig. 2 (Gorshkov *et al.*, 1989).

Direct estimates (Whittaker and Likens, 1975; Vitousek , *et al.*,1987 and Gorshkov, 1986) show that the consumption by man of the primary production by the biota (in the form of food, fodder, wood, etc.) did not exceed 1% of the total primary production by land biota before the beginning of the current century. So, we may accept this value as the threshold of violation of Le Chatelier principle.

NATURAL BIOTIC COMMUNITIES

The synthesis and decomposition of organic substances are realized by different kinds of living organisms practically in the whole global-scale biota. The coincidence of four and the control of seven significant digits in the seasonally averaged oscillations of the fluxes of synthesis and decomposition of organic substances cannot be occasional. Only those species and their communities that can provide it had been selected in the process of evolution during millions of years. These communities of species, together with the environmental components formed by these species constitute the Earth's biosphere (Gorshkov, 1987; Yu. Odum, 1986).

The impact of the environment and the biosphere can only be compensated by either undisturbed or weakly disturbed biota. For instance, when the biota biomass is destroyed, the synthesis and decomposition of organic substances cease. With the substitution of natural biota by cultivated species, the latter always looses the ability not only to compensate the external impacts but also to compensate, with the needed accuracy, for the losses of different substances in the absence of disturbances (Gorshkov, 1987; Schlesinger, 1986; Woodwell, 1986). The cycles of the substances of the agricultural crops of plough-land, pasture, as well as re-forested areas are closed within 2-3 orders of magnitude worse than those of natural communities: they can maintain the coincidence only of the first and sometimes the second significant digits in the fluxes of synthesis and decomposition (Gorshkov, 1987; Whittaker and Likens, 1975) and cannot maintain the functioning of Le Chatelier principle. The impact on the biosphere through the realization of the existing practices of agricultural production, the exploitation of pastures, and the deforestation can completely destroy the biosphere during a lapse of the order of one hundred years (Gorshkov, 1987; Houghton, 1986; Woodwell, 1986). Such a lapse of environmental destruction is characteristic of the present waste techniques. The use of wasteless technologies reduces the direct impact on the environment. However, any technology is meant to intensify the anthropogenic impact on natural biota by direct action and by withdrawing its resources. The recent anthropogenic and perturbed land biota impacts on the environment coincide within the order of magnitude. Therefore, an important program for the transition to wasteless industry is insufficient to solve the problem of stabilizing the environment and the biosphere with continued (beyond permissible limits) destruction of natural biospheric communities.

In this connection it should be emphasized that the preservation of living species is necessary not only because of the unique nature of their genetic makeup but mainly because their ability to maintain of environmental stability. It is also clear that the functions of global stabilization of the environment and the biosphere cannot be fulfilled by the species communities living only within the protected areas constituting not more than 3% of the land. Only the global biosphere can selfmaintain the stable development in the presence of external impacts, not exceeding the threshold ones.

Along with the transition to wasteless technologies, it is extremely important, from the ecological viewpoint, to determine the thresholds of the disturbance of natural biota, beyond which (i) it looses the ability to compensate the external disturbances; and (ii) it becomes itself an environmental pollutant because of the broken closeness of the cycles of substances in it.

Therefore, a major objective of studies on the energy- and mass-exchange in the environment and the biosphere must become the determination of the most important characteristics of the biota governing its ability to maintain the environmental stability at definite disturbances not exceeding the threshold ones. On these bases, the problem of the principal possibility (or impossibility) of creating artificial communities (not existing in nature before) can be solved with the same ability.

THE QUANTITATIVE DESCRIPTION OF THE BIOSPHERE

The biosphere contains more than 4 million species, of which less than 1.5 million have been recorded (Grant, 1980). The genetic makeup of each eucaryotic species involves about 100 thousand genes determining different characteristics of the living organisms (Ayala, 1984). Therefore, a detailed study of all the species living in the biosphere and their interaction within the communities is impossible.

Regional and global numerical simulation models of the interaction between the main components of the biota and the environment gave the possibility to obtain certain results in some cases (Grant, 1980; Moisseev *et al.*, 1985; Svirezhev and Logofet, 1978). Such models involve, however, a consideration of a great number of poorly known input parameters. Therefore, the forecasts based on these models have a very low reliability.

The quantitative description of the biospheric communities can be made in terms of statistic distribution over major measurable variables as, for example, in the description of various states of gas molecules in statistical physics. The most important characteristic of a living organism is the size (or mass) of its body. It is well known that the rate of the energy- and mass-exchange of an organism is highly correlated to the size of its body. For each community the distributions of the number of species can be measured as well as of the fluxes of the synthesis and decomposition over the sizes of the organism bodies responsible for, respectively, the synthesis and decomposition of organic matter. Such distributions in ecology are called the body size spectra (Guilyarov, 1944; Gorshkov, 1984).

An analysis of a great number of various natural communities with different species composition has shown that the body size distribution of the decomposition of heterotrophic organisms is universal. In all the communities more than 90% of the decomposition of the synthesized organic substances is carried out by the smaller organisms. Large organisms are responsible for less than 1% of the decomposition (Whittaker and Likens, 1975; Sheldon *et al.*, 1972) (Fig. 3).

The reason of the observed universality of the size spectra of the decomposition may be a well-known law of large numbers, according to which the fluctuation of any quantity decreases with the growing number of randomly interacting parts which determines the value of this quantity. Apparently, the highly accurate equality of the fluxes of the synthesis and decomposition can only be reached if random fluctuations of these fluxes do not exceed the given accuracy. Hence, it is required that most of the decomposition in the community be accomplished by a large number of microscopic organisms.

The closeness of the cycles of substances and observed body size spectra in the communities can only be maintained by the Darwinian selection of spatially limited communities. Communities with a distorted size spectrum violate the closeness of the cycles of substances. They cause local changes in the environment and are forced out by the adjacent communities. A very important problem is the determination of the size of the community, *i.e.*, the spatial area in which the closed cycle of substances takes place and the fluxes of synthesis and decomposition are mutually correlated (Gorshkov, 1984, 1987).

The ousting of the communities with the broken closeness of the cycles of substances takes place only when the depletion of resources increases more rapidly compared to an expansion of various species of large animals. This condition is fulfilled if the expansion is caused by a slow evolutionary process of changing the genetic makeup of species (Gorshkov, 1987). However,

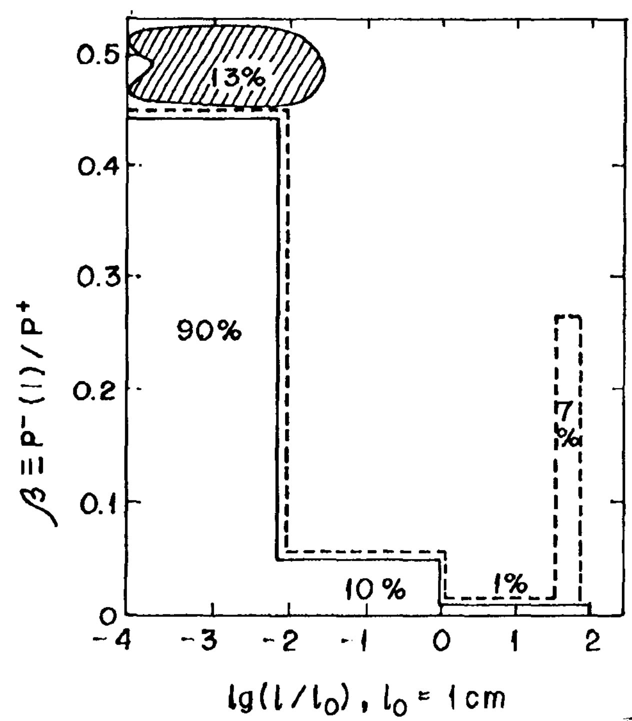

Fig. 3. Natural and disturbed distributions of relative decomposition of land organisms by their size. $\beta = P^{-}(1)/P^{+}$ is the spectral density of decomposition produced by heterotrophs with the size "1", P^{+} is net primary land production. The solid line is the universal distribution for undisturbed ecosystems (Gorshkov, 1981). The area under the solid curve is unity. Figures in percent are the relative contribution of various parts of the histogram. The dotted curve is the present distribution on land with account of anthropogenic disturbance. The area under the anthropogenic peak (7%) corresponds to the food for men, animals and to wood consumption (Gorshkov, 1987). Total difference of areas under the dotted and solid curves was obtained from the data of variations in the components of global carbon cycle and is close to the area under the anthropogenic peak (Budyko, 1985).

the technological progress is so fast that the depletion of the environmental resources does not lead to a decrease of the competition ability of the resource-depleting technologies compared to the resource-preserving technologies. Therefore, it is difficult for the wasteless resource-preserving technologies to compete with the resource-depleting ones.

The cultural agrocenoses, meant for excess productivity of organic substances used by man, have a broken closeness of the cycles of substances: the openness of the biochemical cycles in the recent cultural agrocenosis is of about 50%. They are not ousted by natural communities only due to considerable expenditure of energy and nutrients by man for land ploughing, fertilizing, weed-killing, etc. (Whittaker and Likens, 1975; Gorshkov, 1986).

BIOSPHERE OR NOOSPHERE

From the viewpoint of the role of large animals, the whole biota of the Earth can be considered as an energetic machine providing large animals with all needed nutrients and stabilizing the environmental conditions, but having the coefficient of efficiency of the energy transfer to a level of large animals not exceeding 1%.

Man consumes about 10% of biospheric production which is about 10 times higher than the permissible share of the consumption of biotic resources by large animals in the stationary biosphere. The global anthropogenic impact on natural biospheric terrestrial communities should break the closed cycles of substances and gradually destroy the biosphere (Gorshkov, 1987; Whittaker and Likens, 1975; Vitousek *et al.*, 1987).

An analysis of changes in global carbon cycle made during the last decade has shown that the mass of biospheric terrestrial organic carbon decreases at a rate of about 2 gigaton carbon per year (GtC/yr) (Gorshkov, 1987; Lovelock and Watson, 1982; Schlesinger, 1986; Houghton, 1986). This rate coincides within one order of magnitude with the rate of carbon release by the burnt fossil fuel. In this case a compensation takes place only of the first significant digit in the difference of the quantities of production and decomposition of organic land substances (instead of four significant digits in the undisturbed communities). As a result, now the biosphere is damaged both by the use of waste technologies and by breaking natural closeness of the cycles of substances in the biota. This shows that the transition of wasteless technologies alone does not solve the problem of preservation of the biosphere.

Tactical measures to ensure the ecologically stable socio-economic development planned for the next 10-15 years will be economically useful only if they are taken in the right strategic direction. Otherwise, the situation will appear when the expenditures on tactical measures are unjustified. At present, two strategies of ecologically sustainable long-term development of civilization can be discussed:

1. The preservation of the natural biota able to provide both the closeness of the cycles of substances and the stability of the environmental and biospheric properties at a needed level (not only in the genetic banks and biospheric reserves). Extremely urgent are further studies of permissible thresholds of disturbances of natural biota, above which it looses its ability to self-stabilize. As has been mentioned, there are sound grounds to believe that the permissible thresholds of disturbances have been already surpassed. In case it is confirmed by further studies, mankind will have to cut down its share in the expenditure of biospheric production, population, and, also, industrial production (Fig. 4). In this case, natural biota can preserve its ability to utilize the industrial waste and there will be no need to use wasteless technologies. The whole energy consumption ensuring the persistent socio-economic development will be completely compensated by renewable resources of the biosphere and the environment without being afraid of breaking the ecologic stability. The possibility of persistent development according to this strategy is confirmed by the stable existence of natural biota for billions of years.

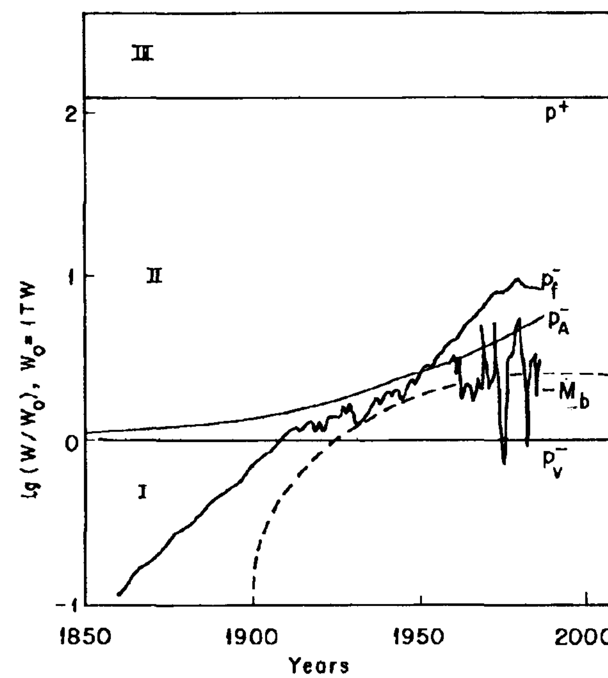

Fig. 4. The anthropogenic energy consumption. P_{max} is the climate limit of the energy consumption (calculated from the data on the annual mean temperature fluctuations (Kondratyev, 1987; Gorshkov, 1987; Ajtay *et al.*, 1979; Gorshkov, 1984) coinciding with the power of organic synthesis of the whole biosphere; $-\dot{M}_b$ is the reduction rate of organic carbon on land (Gorshkov, 1986; Gorshkov, 1987) (the dashed line is obtained from the dashed line in Fig. 2); P_f^- is the rate of fossil fuel burning (Gorshkov, 1987; Odum, 1984); P_A^- is the rate of consumption of wood and food for men and animals (Vitousek, 1987; Gorshkov, 1984); P_n^- is the permissible threshold of the consumption of food by land vertebrates in a stationary biosphere, nearly coinciding with the power of accessible renewable non-biospheric energy sources. The regions of the energy consumption by men: I - the stationary biosphere (permitted), II - the destructing biosphere (ecologically forbidden), III - the climatically forbidden biosphere (noosphere).

2. The development in the direction of creating the man-governed wasteless technology and artificial (cultural) biotic communities able to close the cycles of substances, *i.e.*, in the direction of creating the "noosphere". In this case, natural species of living organisms can be preserved in the genetic banks and

zoological gardens (only from the viewpoint of their unique genetic reserves), and natural communities of the biosphere - in the reserves (only as natural monuments for the purpose of aesthetics). The possibility of creating the noosphere governed by man is still an open problem. Probably, the stable existence of the noosphere requires the closed cycles of substances as in the undisturbed biosphere. The possibility of reaching such closed cycles in the absence of the law of large numbers is rather doubtful. Even if this is possible, it is unlikely to create a stationary noosphere with the coefficient of efficiency greater than that of a stationary biosphere. But in this case, more than 99% of the energy- and mass-exchange in the noosphere must be spent on the maintenance of the closed cycles of substances and the stabilization of the environment. Less than 1% falls on the socioeconomic development. Apparently, the expenditure of energy by the noosphere can only be provided with the use of non-renewable fossil fuel (coal, oil, gas, uranium, and, probably, in the future, deuterium). Bearing in mind that the climatic stability confines total consumption of energy by mankind to a quantity approximately coinciding with that of biospheric production (Fig. 3), mankind will obtain for the development of civilization less energy and nutrients than it had in the stationary biosphere. In this connection, one has to emphasize that the energy flux equivalent to 99% of primary production needed to maintain the environmental stability, is maintained automatically in the stationary natural biosphere and needs neither management nor human labour. In the stationary noosphere the same flux can only be ensured by human control as well as with adequate expenses and labour.

CONCLUSION

There are serious grounds to believe that the biosphere (which consists of natural biota developed in the course of evolution, interacting with the environment) presents the only system capable of stabilizing the environment under any external perturbations. Hence, the preservation of natural communities and the existing species in the amounts capable to satisfy Le Chatelier principle with respect to global perturbations of the environment, must be envisaged as a main condition of further life on this planet. To do that, virginal nature has to be preserved on most of the Earth surface, instead of tiny reservations, zoos, parks, and genetic banks.

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APPENDIX 1

Let us introduce the quantitative characteristics of the closeness of the cycles of substances. In the synthesis of organic matter, the biologically active chemical elements (biogenes) are absorbed in definite ratios. With the masses and fluxes of certain biogenes known, one can retrieve from these ratios the masses of other biogenes. Therefore, below all the quantitative relationships are written for carbon. We denote, respectively, the masses of carbon in the biologically active reservoirs (atmosphere, ocean, biota, soil) in organic and inorganic forms as M^+ and M^-; the fluxes of carbon in the synthesis (production) and decomposition (destruction) of organic substances as P^+ and P^-; small pure fluxes from the non-active into active reservoirs as F^+ (entering of organic carbon in sediments) and F^- (the difference between fluxes of volcanic ejections and filtering of inorganic carbon out of the mantle and its deposition in the sediments). The law of matter preservation is expressed with the equation:

$$\dot{M}^+ = P^+ - P^- - F^+; \quad \dot{M}^- = P^- - P^+ + F^-, \quad \dot{M} = dM/dt \qquad (1)$$

The observed ratios $F^\pm/P^+ \sim 10^{-4}$. The times of the biogenic cycle $\tau^\pm = M^\pm/P^+ \sim (10\text{-}30)$ years. The times of the geologic cycle $M^\pm/F^\pm \sim 10^5$ years. In terms of relative variables, Eq.(1) becomes:

$$T^+ = \frac{\tau^+}{|\chi + \mu^+|}, \quad T^- = \frac{\tau^-}{|-\chi + \mu^-|}, \quad T^\pm = \frac{M^\pm}{|\dot{M}^\pm|},$$
$$\tau^\pm = \frac{M^\pm}{P^+}, \quad \mu^\pm = \frac{F^\pm}{P^+}, \quad \chi = \frac{P^+ - P^-}{P^+} \qquad (2)$$

where $T^\pm$ is the time for complete destruction of active reservoirs of biogenes, χ the openness of biochemical cycles, $\mu^\pm$ the net openness of active reservoirs. Eqs. (1, 2) are valid for each individual active reservoir. In the latter case, one should bear in mind that net fluxes $F^\pm$ are equal to the difference between input (F_{in}) and output (F_{out}), and a net openness of the reservoir $\mu_{in} = F_{in}/P^+$ can largely exceed the net μ. In the non-stationary case with $|\chi| \geq \mu$ from (2) we obtain $T = \tau/|\chi|$, *i.e.*, at $|\chi| \sim 1$, the reservoirs become destroyed during a decade, at $|\chi| \sim 10^{-1}$ during a hundred years, at $|\chi| \sim 10^{-2}$ during a millenium, etc. In the stationary state ($\dot{M} = 0$) from (2) we have

$$\chi = \chi_0 = \mu^- = -\mu^+ \sim 10^{-4} \qquad (3)$$

The value of stationary openness χ_0 (3) is confirmed by paleodata as well as by the value of the ratio between the ion sink and land productivity. The conclusion can be drawn from these data that the relative fluctuations of the χ_0 annual mean value do not exceed the χ_0 from (3) The conditions of Eq.(3) mean that the biota can maintain the openness at a very low positive level which would provide the deposition of all the volcanic ejections in sediments and strictly stationary concentrations of biologically active chemical elements in the environment.

APPENDIX 2

The dissolved inorganic carbon is supplied in the ocean as dissolved CO_2, bicarbonate ions HCO_3^- and carbonate ions $CO_3^=$. The sum of concentrations of all these components is called total dissolved inorganic carbon and denoted as ΣCO_2 (Takahashi *et al.*, 1981). The ΣCO_2 concentration is approximately 200 times higher than the concentration of CO_2 (Takahashi *et al.*, 1981). The supply of total dissolved carbon in the ocean is two orders of magnitude greater than in the atmosphere. The concentrations of ΣCO_2 and CO_2 are in chemical equilibrium. A 1% change in ΣCO_2 leads to a 10% change in CO_2, and *vice versa*. This determines the buffer character of absorption of atmospheric CO_2 by the ocean. The ratio of relative increments of the concentrations of ΣCO_2 and Co_2 is called the buffer factor $h \equiv (\Delta[CO_2] / [CO_2]) / (\Delta[\Sigma CO_2] / [\Sigma CO_2])$. The buffer factor depends on the concentration of ΣCO_2 and is almost independent of CO_2 concentration. The difference between ΣCO_2 concentrations in deep waters and near the ocean surface constitutes 20% (Takahashi *et al.*, 1981). The respective difference of CO_2 concentrations is 200%. Hence, the deep-water and surface concentrations of CO_2 differ by a factor of 3.

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