KNOWLEDGE OF THE ENVIRONMENT

V.G. Gorshkov and A.M. Makarieva
Department of Theoretical Physics, Petersburg Nuclear Physics Institute, Russia

Keywords: Environment, biological community, ecosystem, ecology, solar energy, information, natural biota, biotic regulation of the environment, cultural heritage, science and technology, environmental stability, climate

Contents

Summary

Accumulation of environmental knowledge in the form of science and technology has resulted in huge impacts as humans have transformed their environment into a state favorable for humans. Natural ecosystems have been destroyed on vast tracts of land. On the other hand, development of industry and agriculture accompanied by global population growth has led to increasing rates of anthropogenic environmental pollution. As a result, the stabilizing capacity of the global natural biota has been exceeded and global environmental changes have been initiated.

At present, most efforts are being directed at finding technological solutions to environmental problems that are based on creation of no-waste technologies and improved cleaning facilities. Yet it is not clear whether it is in principle possible to maintain a stable environment on earth by technological means, replacing the natural mechanism of biotic regulation of the environment. On the contrary, studies of information fluxes that can be processed by humankind and are processed by natural biota show that there is a gap of more than 10 orders of magnitude between the two fluxes. Thus, information available to humankind will never be sufficient to maintain a

stable environment on a global scale.

Thus, the further long-term development of environmental knowledge—that at present is substantially technology-biased—should be concentrated on fundamental studies of natural biota and its stabilizing properties. The ultimate goal of these studies is to quantify the ecologically permissible amount of anthropogenic transformation of natural biota that is still compatible with environmental stability. Meanwhile the technological dimension of environmental knowledge should be given serious attention when solving problems of local pollution caused by human settlement.

1. Introduction

All living organisms on the earth exist in an environment that surrounds them. The environment provides suitable physical and chemical conditions for life—temperature, air pressure, humidity. The environment provides all living beings with nutrition necessary to support metabolic processes of organisms and assure normal life. Plants consume solar radiation and synthesize organic matter. Animals consume organic matter produced by plants and other animals.

Living organisms on earth not only exist in the environment, they also have a considerable impact on it, changing its chemical and physical properties. Life on earth occupies nearly all the planet’s surface. The activity of living organisms is so powerful that it can change the major properties of the environment by several hundred percent over a period of decades. By contrast, geophysical and outer space processes take thousands of years to cause changes of the same magnitude. Thus, the impact of life on the environment is the governing factor of environmental changes and exceeds by orders of magnitude the impact of all possible abiotic factors.

Life can exist in only a very narrow interval of environmental physical properties. Life is able to exist in a temperature interval corresponding to the liquid state of water—under atmospheric pressure this is from 0°C up to 100°C. The temperature interval that is optimal for life is narrower: between 10°C and 20°C. Life on land is only possible given sufficient humidity.

The stable existence of life on earth for many millions of years is a well-documented fact. This leads unambiguously to the conclusion that the environmental impact of certain organisms is completely counteracted by the impact of other organisms. This means that the environmental impact of each organism is not arbitrary. Impacts of different organisms need to be rigidly correlated with one another for the environment to be maintained in a relatively stable state. Thus, all organisms living on the same territory form an internally correlated biological community. It is organized in such a way that biogeochemical processes inside the community can form closed cycles, and the combined environmental impact of all organisms of the community can be close to zero. Such organization makes it possible for a community to maintain its environment in a stable state in the absence of external disturbances.

The huge power of the potential environmental impact of living organisms becomes evident when one considers the intensity of closed biological cycles of different elements. Measured as biological productivity, the intensity of biological cycles exceeds the power of the present-day energy consumption of humankind by approximately an order of magnitude (Table 1). The high intensity of biological cycles makes it easy for communities to compensate for any abiotic environmental disturbances. This can be done by biological induction of directional deviations in closed matter cycles. Biological communities can remove from active cycling excess concentrations of all life-important biogens (e.g. concentration of atmospheric carbon dioxide (CO_2) that is important for plants and also determines the temperature regime on the planet) by transforming them into inert (inactive) organic substances (e.g. soil humus and dissolved organic carbon in the ocean). The deficient concentrations of inorganic substances in the environment can be replenished by decomposition of organic matter accumulated in such inert organic reservoirs.

	Power	
Power source / sink	**TW**[a]	**Fraction relative to solar power**
Solar power and processes of its dissipation:		
Total solar power coming from the sun to the earth	$1.7\cdot10^5$	1.0
Solar power absorbed by the earth's surface[b]	$8\cdot10^4$	0.47
Evaporation from the total surface of earth	$4\cdot10^4$	0.24
Evaporation from land (evapotranspiration)	$5\cdot10^3$	$3\cdot10^{-2}$
Heat fluxes from the equator to the poles: Atmospheric Oceanic	 $3\cdot10^3$ $2\cdot10^3$	 $2\cdot10^{-2}$ 10^{-2}
Wind power	$2\cdot10^3$	10^{-2}
Oceanic waves	10^3	$6\cdot10^{-3}$
Maximum available hydraulic power of rivers	1	$6\cdot10^{-6}$
Biota		
Transpiration of plants	$3\cdot10^3$	$2\cdot10^{-2}$
Photosynthesis of plants	10^2	$6\cdot10^{-4}$
Non-solar sources of power:		
Total flux of geothermal heat Volcanoes and geysers Chemosynthesizing life	30 0.3 10^{-4}	$2\cdot10^{-4}$ $2\cdot10^{-6}$ $6\cdot10^{-10}$
Tidal power	1	$6\cdot10^{-6}$
Moonlight	0.5	$3\cdot10^{-6}$
Humankind at the end of the 20th century:		
Energy consumption (mainly fossil fuel combustion)	10	$6\cdot10^{-5}$
Human-induced increase of greenhouse effect	10^3	$6\cdot10^{-3}$

[a] 1 TW = 10^{12} Watts

[b] Solar power absorbed by the earth's surface is equal to the total solar power coming from sun to earth minus solar power reflected by earth back to space minus solar power absorbed by the atmosphere.

Source: V.G. Gorshkov, V.V. Gorshkov, and A.M. Makarieva, *Biotic Regulation of the Environment: Key Issue of Global Change* (London: Springer-Verlag, 2000)

Table 1. Energy fluxes at the earth's surface

The complex and correlated properties of the functioning of different organisms inside a community are genetically programmed in genomes of all natural species. Deviations from the normal genetic program of a species or invasion of an alien species can substantially disintegrate community's functioning and lead to degradation of its environment. Any activity that is performed through transforming the external energy fluxes into certain ordered processes can be termed "work." In this sense, the functioning of all species of the community represents concrete work on stabilizing their natural environment. In a normal community there cannot be any species-lazybones arbitrarily adapted to conditions inside the community and not doing any work on stabilizing the environment. Communities loaded with such lazybones inevitably lose out in competition with communities that do not have such species. Similarly, in a normal community there cannot be any species-gangsters—alien species that disintegrate the normal functioning of aboriginal species.

Paleontological data show that many extant species were absent in the past. Their places in communities were occupied by species that are now extinct. But the stable existence of life over the last three billion years suggests that biological species of the past also formed internally correlated communities that were able to maintain a suitable environment. Evolutionary changes in a community's species composition that were determined by the extinction of old species and the origin of new ones did not affect this most important property of biological communities. This means that during the evolutionary process species-survivors were not those that were just adapted to a certain environment, but those who could also maintain that environment by working on environmental stabilization in the framework of the correlated community.

The totality of all natural biological species that form natural biological communities is called "biota." Biota includes all natural flora and fauna of the earth. The global environment together with biota functioning in it is called the "biosphere." The science that describes the interaction of living organisms with their environment is called "ecology."

Homo sapiens, as well as all other species, originated in the process of biological evolution. Modern paleontological data provide an opportunity to trace the whole succession of evolutionary events that led to the origin of Homo sapiens. Thus, Homo sapiens, as all other species, originally belonged to a certain biological community. Inside the community Homo sapiens, as well as all other species, did a certain amount of work aimed at stabilizing the environment. Unlike all other species, however, Homo sapiens proved to be able to accumulate cultural information that, like the genetic information of a species, can be transmitted from generation to generation. Unlike genetic information, the amount of cultural information increased from generation to generation. At present, the cultural information of the whole of humankind is comparable to the genetic information of Homo sapiens as a species. Most present cultural information of humankind is represented by scientific information about surrounding phenomena (i.e. about the environment of humans). Fundamental studies of physical, chemical, and biological laws of nature gave humans an opportunity to work out technology-based applications of their acquired knowledge. Thus, humans were able to inhabit all continental areas of the earth and even began actively to explore outer space. Note, however, that life in space is not possible without regular contacts with the environment of Earth.

When inhabiting new territories, people transformed nature into a state most favorable to them. People cut down forests and dried out bogs to build houses, turned large territories into fields and pastures to get food. People built mines, roads, and factories. All these activities were accompanied by industrial and agricultural wastes emitted into the transformed environment.

People changed the structure of natural biological communities, reducing population numbers of those species they were not dependent upon, and increasing population numbers of "useful" species that gave necessary products like meat, crops, timber, etc. People also changed genetic programs of species, creating new breeds of cattle and new sorts of agricultural plants. As a result, biological communities began to lose their ability to compensate for environmental disturbances, while the mainly human-induced degradation of the environment became the most important destabilizing factor.

People long ago began to pollute the environment. However, until the beginning of the twentieth century natural biota had been able to counteract anthropogenic pollution. Pollution was noticeable only in local areas, where it was easily coped with. Meanwhile on regional and global scales the environment was maintained by natural biota in a clear and stable state. Ecology as a science was mainly concerned about interactions of species of natural communities with their environment and was considered a branch of biology.

When the rate of anthropogenic pollution began to increase, together with the rate of human-induced degradation of natural biological communities, natural biota began to lose the ability to stabilize the environment on regional and global scales. It became clear that the current state of the environment very much depends on the anthropogenic impact on it. As a result, ecology turned into a much wider branch of knowledge, and began to address not only biological, but also economic, political, and ethical issues.

Ecological problems of civilization manifested themselves clearly when the anthropogenic disturbance of natural biological communities closely approached a certain threshold beyond which biota loses the ability to stabilize the environment. Evidently, the "below-threshold" stable existence of civilization of the past is possible in the future as well. To ensure it, modern anthropogenic activities on the planet must be substantially reduced and, inevitably, constraints must be imposed on the growth of the world's population. Therefore, possibilities of unlimited economic growth are currently being widely discussed at various levels in various societies, as the concept of unlimited economic growth is in apparent contradiction with the abovementioned principles of the stable existence of civilization. It is evident that unlimited growth will finally lead to overexploitation of natural biota and complete loss of its stabilizing properties. Then people will have to maintain an environment suitable for living in, using available scientific and technological knowledge. If this prospect of the future development of civilization is real or not can only be determined through a scientific approach **(see *Section 6.2. The Future of Ecology as a Science*)**.

The functioning of natural species that assures biotic regulation of the environment is determined by the genetic information coded in genomes of these species. This information is hereditary and remains unchanged during the whole period of a species' existence. In this sense, the genetic program of humans does not differ from the genetic programs of other biological species. Under natural conditions, the genetic program of any species determines the correct actions of individuals of this species for maintaining a stable environment. All major aspirations of modern people—to increase living standards, to leave progeny, to care for progeny—and many others are based on the genetic program of Homo sapiens. Environmental conditions of modern civilization differ drastically from the natural environment of humans as a species. In such conditions the genetic program and behavior determined by it no longer ensures environmental stability. The correct behavior of people that would meet the conditions for the maintenance of a stable environment favorable for life on the planet can be worked out only by most comprehensive investigation of Homo sapiens as a species and its ecological problems. So the scientific approach that once gave people sufficient power to destroy their own environment now has to give people a concrete plan of how to avoid a global ecological catastrophe and how to survive in the future.

-
-
-

Bibliography

Ayala F.J. and Fitch W.M. (1997). Genetics and the origin of species: an introduction. *Proceedings of the National Academy of Sciences of the United States of America* **94**, 7691–7697. [This work presents an overview of modern approaches to the problem of genetic variability and evolution of species.]

Bormann F.H. and Likens G.E. (1979). *Pattern and Process in a Forested Ecosystem*, 153 pp. New York: Springer-Verlag. [This work considers processes in forest biological communities after external disturbances.]

Degens E.T., Kempe S., and Spitzy A. (1984). Carbon dioxide: a biogeochemical portrait. *The Handbook of Environmental Chemistry*, Vol. 1, Part C (ed. O. Hutziger), pp. 127–215. Berlin: Springer-Verlag. [This work describes major reservoirs and fluxes of carbon in biota and global environment.]

Foley R. (1987). *Another Unique Species. Pattern in Human Evolutionary Ecology*, 244 pp. London: Longman. [This work describes evolution of species-specific characteristics of Homo sapiens.]

Gorshkov V.G. (1995). *Physical and Biological Bases of Life Stability. Man, Biota, Environment*, 340 pp. Berlin: Springer-Verlag. [This is a detailed quantitative description of the mechanism of the natural biotic regulation of the environment.]

Gorshkov V.G., Gorshkov V.V., and Makarieva A.M. (2000). *Biotic Regulation of the Environment: Key Issue of Global Change* (Springer-Praxis Series in Environmental Sciences), 343 pp. London: Springer-Verlag. [This book develops a general theoretical approach to description of the biota-environment interaction. Stabilizing impacts of the natural biota on Earth's climate and global biogeochemical cycles are quantitatively considered, as well as genetic bases of the biotic regulation of the environment.]

Gould S.J. and Eldridge N. (1993). Punctuated equilibrium comes of age. *Nature* **366**, 223–227. [This is an overview of modern data on the discreteness of extinct species and the tempo and mode of evolution.]

Keeling R.F., Piper S.C., and Heimann M. (1996). Global and hemispheric CO_2-sinks deduced from changes in atmospheric O_2 concentration. *Nature* **381**, 218–221. [This work considers the application of oxygen data to the global carbon cycle.]

Mitchell J. (1989). The "greenhouse" effect and climate change. *Reviews of Geophysics* **27(**1), 115–139. [This work considers the impact of the balance between solar and thermal radiation on climate on Earth and other planets.]

North G.R., Cahalan R.F., and Cookley J.A. (1981). Energy balance climate models. *Reviews of Geophysics and Space Physics* **19**(1), 91–121. [This work considers various aspects of climate stability.]

Whittaker R.H. (1975). *Community and Ecosystems*, 385 pp. New York: Macmillan. [This book considers major principles of organization of natural biological communities and their environment.]

Biographical Sketches

Victor Gorshkov was born on July 12, 1935 in Leningrad, Russia, and graduated in 1958 from Leningrad (St. Petersburg) State University's Faculty of Physics. He was awarded a Ph.D. in nuclear physics by Leningrad State University in 1963, and a Doctor of Science (nuclear physics) by the Physical Technical Institute, Leningrad, in 1973. He was appointed in 1991 to a professorship in the Department of Biophysics, St. Petersburg State Technical University, and is currently a leading scientific researcher at the Theoretical Department of Petersburg Nuclear Physics Institute, St. Petersburg, Russia. In 1997 he was made an Academician of the Russian Academy of Noosphere, and an Academician of the Russian Ecological Academy. In 1997 he was an organizer of the international symposium "An Organism and Its Milieu: Adaptation to or Regulation of the Environment?" held in Arnhem, The Netherlands, August 24–28, by the VI European Congress of Evolutionary Biology. The following year he was an organizer of the international seminar "The Role of Virgin Terrestrial Biota in the Modern Processes of Global Change: Biotic Regulation of the Environment" held at Petrozavodsk, Karelia, Russia, October 12–16. In 2000–2002 he was elected as a member of the Scientific Committee of the International Geosphere Biosphere Program.

Anastasija Makarieva was born on February 14, 1974 in Leningrad, Russia, and graduated in 1996 from St. Petersburg State Technical University's Faculty of Physics and Mechanics, Department of Biophysics. In 1999 she graduated from the Faculty of Phylology, Department of Scandinavian Languages and Literature, St. Petersburg State University. In 2000 she was awarded a Ph.D. in atmospheric physics by St. Petersburg State University. Dr. Makarieva is currently a scientific researcher at the Theoretical Department of Petersburg Nuclear Physics Institute, St. Petersburg, Russia. In 1997 she was an organizer of the international symposium "An Organism and Its Milieu: Adaptation to or Regulation of the Environment?" held in Arnhem, The Netherlands, August 24–28, by the VI European Congress of Evolutionary Biology. The following year she was an organizer of the international seminar "The Role of Virgin Terrestrial Biota in the Modern Processes of Global Change: Biotic Regulation of the Environment" held at Petrozavodsk, Karelia, Russia, October 12–16.