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Favorable conditions for human life on the earth are ensured by the incessant work of natural ecosystems. The efficiency of biospheric regulation mechanisms is provided by biodiversity at the global, biocenotic, specific, and population levels. The current scale of the destruction of the planet's living cover makes us advance the conservation of the existing natural systems as a strategic goal. The task of this article below is to attract the attention of the scientific community to the need of conserving biodiversity as the basis of biosphere stability.

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Biodiversity and Life Support of Humankind

D. S. Pavlov and E. N. Bukvareva*

On August 4, 2005, E. Collins, the commander of the space shuttle Discovery, reported from orbit that she was shocked by the view of the damage caused by humans to the earth's nature [1]. Owing to the Google Earth project [2], today everyone who has an access to the Internet can see this. At the turn of the millennia, it became apparent that the 20th century was not only an era of scientific and technological revolution, but also an epoch of the previously unprecedented mass destruction of the earth's living cover.

ALARMING RESULTS OF THE MILLENNIUM

Since 1972, the United Nations has been holding conferences once per a decade on the problems of the environment and global development. The most important documents were adopted in 1992 in Rio de Janeiro: *Agenda 21* [3], which proclaimed the concept of sustainable development, and the Convention on Biological Diversity [4].[1]

Unfortunately, more than ten years after these documents were adopted, one has to admit that no considerable successes have been achieved on the way to stopping biospheric degradation [5]. The Synthesis Report of the international project Millennium Ecosystem Assessment [6], published in 2005, convincingly proves the rapid global loss of natural ecosystems and biodiversity. By now, almost all land ecosystems have undergone deep changes as a result of anthropogenic activity; in natural zones favorable for life and agricultural activity, people have transformed and are using 20 to 75% of the territory [6]. Very few productive ecosystems remain on the planet; one can see this if deserts, semideserts, ice caps, and territories that have undergone considerable anthropogenic changes are removed from the map (Fig. 1).

Simultaneously with a decrease in the area of the earth's living cover, its simplification takes place. The latest generalizing report prepared within the framework of the Convention on Biological Diversity [7] repeatedly warns that life richness is decreasing at all levels of its organization, from genetic diversity within individual populations to the diversity of species and ecosystems in the biosphere. The rates of this destructive process do not decrease. One of the global indicators of the state of biodiversity is the Living Planet Index, which generalizes the tendencies of changes in the number of vertebrate animals in the world. Today it includes data on approximately 3600 populations for 1300 species in land, freshwater, and marine ecosystems in different regions of the earth. From 1970 through 2003, this indicator decreased by 30% [8].

The disappearance of species is an irreversible process of biosphere impoverishment. Their distribution becomes increasingly homogenous as a result of the loss of local forms and endemics and expansion of alien species. According to the criteria of the World Conservation Union (IUCN), 10 to 50% of species among well-studied groups of plants and animals are under threat [9]. It is impossible to evaluate precisely the scale of losses in poorly studied groups of organisms because the overwhelming majority of species is disappearing, remaining unknown to science.[2] These facts make it possible to speak about the "sixth

[1] According to the convention, *biological diversity* means "the variability among living organisms from all sources, including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems" [4]. However, the term *biodiversity* is also often used in a wider sense to denote biosystems themselves with an accent on the characteristics of their diversity. In this paper, the authors use it in this broad sense.

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[2] Today, 1.7–2 million species of living organisms are known to science, which comprises only a small part of the diversity of species on the earth, which, according to different estimates, reaches 5–30 million species.

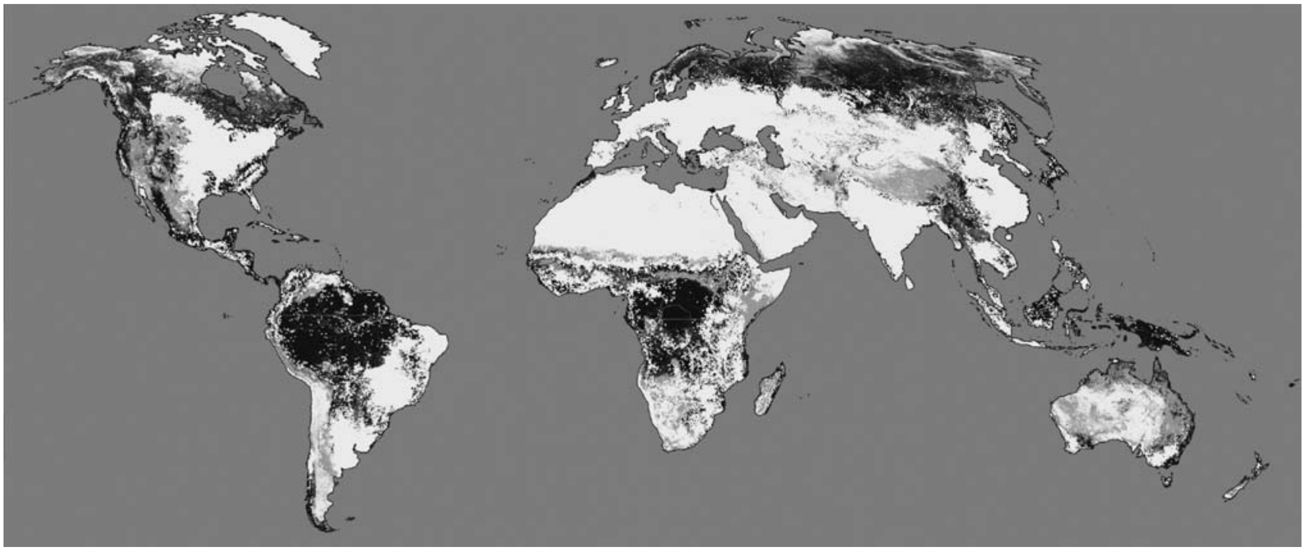

Fig. 1. Preserved bodies of productive natural land ecosystems.
White denotes low-efficient territories (deserts, semideserts, and glaciers), as well as territories in which more than one-third has been changed and used by humans (according to data of [6]); *gray* shows herbaceous and shrub communities; *black*, forests. The map has been plotted on the basis of data of the Global Land Cover, 2000 (http:/www-gvm.jrc.it/glc2000/ProductGLC2000.htm).

mass extinction" (hundreds of links to respective publications are on *The Current Mass Extinction* site http:/www.well.com/~davidu/extinction.html).

Thus, the biosphere is being destroyed in two directions, intensifying each other:

on the one hand, the living envelope of the planet is becoming smaller in area and volume, natural ecosystems are being replaced by anthropogenic territories, the population and ranges of species are decreasing, and the biomass of communities is becoming smaller; on the other hand, the structure of remaining natural systems is being disturbed, specific and intraspecific diversity is being lost, and the simplification and homogenization of the living cover are observed.

The anthropogenic impact on the biosphere continues to increase. According to the estimates of experts from the Global Footprint Network [8], it has already exceeded the critical level that could be compensated by the biosphere. From 1961 through 2001, the use of renewable natural resources (global *ecological footprint*)[3] increased 2.5 times and today exceeds the total biological productivity of the earth by 25%. The critical point was passed in the late 1980s. Today, biosphere resources are spent more rapidly than they can recover.

ENVIRONMENT-FORMING FUNCTIONS OF BIODIVERSITY

The concept of ecosystem functions is not new for biologists; it formed parallel to the concept of an *ecosystem*, denoting its integral effect on the environment (for instance, carbon fixation and water accumulation by swamps, a decrease in the wind velocity in forests, etc.). The desire to give an economic assessment of these functions led to the appearance of the concept of *ecosystem services*, i.e., to consideration of them with regard to their usefulness for humans.

Ecosystem functions and services may be grouped into three main categories:

• the formation and maintenance of environmental parameters suitable for human life—*environment-forming functions*;[4]

• the biomass taken by humans from nature (seafoods, timber, fodders, fuel, raw materials for pharmaceutics and industry, etc.)—*productional functions and the so-called ecosystem goods*; and

• information present in natural systems and their cultural, scientific, and educational significance—*information and spiritual–aesthetic functions.*

Of key importance for humankind are environment-forming functions of natural ecosystems (otherwise called biospheric and life-supporting functions). The current conditions of life on the earth, which are suitable for humans, are the result of the evolution and incessant work of living nature over billions of years. The most striking example is well known: the oxygen atmosphere of the earth formed and is maintained due to the activity of photosynthesizing organisms. The theory of biotic regulation, elaborated by Russian scien-

[3] The ecological footprint is an index indicating humanity's demand on the biosphere. It is expressed via a land or water area with an average biological productivity (*global hectares*), which is necessary to produce renewable resources consumed by humans and to utilize anthropogenic wastes [8].

[4] In the latest documents of the secretariat of the Convention on Biological Diversity and in the reports of the Millennium Ecosystem Assessment project [6], environment-forming functions are divided into two groups: regulating services, i.e., profits from regulating ecosystem processes,; and maintaining services, i.e., services needed for the production of all other ecosystem services.

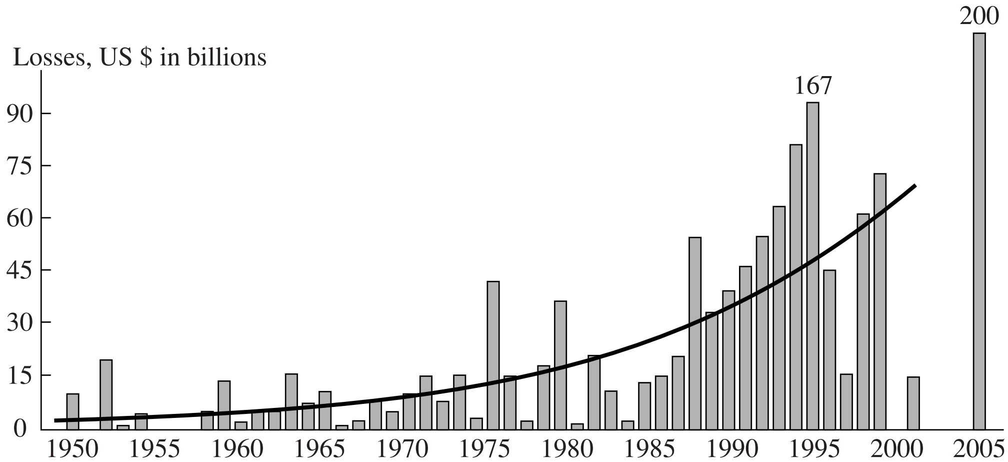

Fig. 2. Economic losses from natural calamities (according to data of [3]).

tists [10–12] on the basis of V.I. Vernadsky's ideas of the biosphere, convincingly shows that the state of the atmosphere, hydrosphere, and climate is maintained by millions of species of living organisms. If their work stops, the planet will transfer to one of two physically stable states, both equally unfit for complex forms of life: the state of complete water evaporation or complete glaciation.

The scale of the impact of living systems on the formation of our planet's characteristics has not yet been studied. For instance, the concept of the organization of the underground biosphere, elaborated under the RAS Presidium research program Scientific Fundamentals of Russia's Biodiversity Conservation, has considerably broadened the ideas of the boundaries of living organisms' activity to the interior part of the earth. It was shown that the organic matter of the lithosphere is formed not only from the buried biomass but also as a result of chemosynthesis in bacterial communities of deep and ultradeep horizons [13]. These processes also contribute to the formation of the hydrogen balance in the atmosphere.

The following functions may be considered the main *environment-forming functions of ecosystems*:

• the maintenance of the parameters of the atmosphere and the global climate;

• local environmental stabilization, i.e., the leveling of extreme weather phenomena (decreasing the possibility and strength of floods, droughts, and other natural cataclysms);

• the formation of fertile soils and their protection from erosion;

• water purification and the maintenance of stable hydrologic conditions of territories; and

• the biological treatment and control of many types of wastes and pollution.

One of the most important ecosystem functions is climate regulation. The world ocean is of key importance in this respect; in this article, however, we consider only land ecosystems that clearly demonstrate an intimate relationship between the processes of biodiversity degradation and the loss of ecosystem functions.

The last UN summit on sustainable development (Johannesburg, 2002) acknowledged that the unfavorable consequences of climate changes and the increase in the frequency and strength of natural calamities were among the primary problems of humankind [14]. The economic damage from them increased from year to year, reaching an unprecedented level of more than $200 billion US in 2005 [5] (Fig. 2).

Specialists in different scientific fields have offered a great number of hypotheses (including astronomical and geological) with respect to the mechanisms of the earth's climate fluctuations. There are controversies on whether the leading cause of modern climate changes is anthropogenic activity or natural processes.[5] However, irrespective of how this "big climate debate" is solved, it is obvious that one of the most intensive factors influencing climate today is the anthropogenic destruction of natural ecosystems. Even if the initial driver of climate processes was of geological or astronomical nature, human activity most strongly modifies this process.

The large-scale anthropogenic transformations of natural ecosystems affect the climate system of the earth in two ways: via the shift of atmospheric gas balance and as a result of changes in the physical characteristics of the earth's surface.

The most actively discussed cause of climate changes today is the increase in the concentration of

[5] On February 2, 2007, a report of the working group on scientific aspects of the climate system of the Intergovernmental Panel on Climate Change (IPCC) was published, which stated the unambiguous conclusion that modern climate changes are the result of human activity [15].

greenhouse gases in the atmosphere.[6] The main focus is on the Kyoto Protocol that asserts the necessity of decreasing hydrocarbon emissions from fuel combustion into the atmosphere. At the same time, equally important factors, such as the destruction of natural ecosystems and irrational land management, remain neglected. As a result of the effect of these factors, more carbon dioxide was emitted into the atmosphere than by global industry [16, 17].[7] However, a still more dangerous circumstance is that, by destroying natural ecosystems, humans interrupt the natural mechanism of atmospheric carbon dioxide fixation, which could compensate for the anthropogenic emissions. The point is that CO_2 is not a pollutant but a "life gas" along with oxygen, and, if the global ecosystem becomes unable to respond adequately to an increase in its concentration by an increase in its absorption, it will be the fault of humans who destroy the living cover of the planet.

The remaining natural ecosystems (primarily, soil and phytomass) continue to perform the role of large hydrogen reservoirs; according to the IPCC estimates, its largest accumulations are in boreal forests. Therefore, the destruction of these ecosystems will lead to additional emission of considerable amounts of carbon dioxide into the atmosphere. Of serious danger is an increase in the emission of carbon dioxide and methane by swamps and boreal forests as a result of processes caused by climate warming: permafrost degradation, the acceleration of organics decay, and the increasing frequency of fires.

Still another important cause of modern climate anomalies is disturbance of the balance between heat exchange and water exchange on land. Natural vegetation, primarily, forests, exerts a moistening and cooling effect on the ground-level atmosphere. On hot days, we try to move from the red-hot asphalt or dusty fields to the cooling shade of trees; in this way we feel the microclimate function of the forest. However, today forests have been replaced by agricultural lands and anthropogenic and urbanized territories, whose size is comparable to continents, which has led to a global climate effect. It has been shown that the change in heat exchange and water exchange processes on land is a no less significant cause of the increase in the average temperature of the ground-level air layer than the greenhouse effect [18].

As a result of the global anthropogenic transformation of nature, the biomass of land vegetation has decreased almost twofold as compared to natural conditions. The energy not utilized by biological systems is involved in abiotic processes and intensifies them [18], destabilizing the climate system and causing weather anomalies and natural calamities.

Natural ecosystems very significantly mitigate the consequences of extreme climate phenomena. For instance, the damage made to European countries by the heaviest downpours and drought in 2005 was so tremendous because most natural ecosystems had been destroyed there: forests cut, swamps dried, rivers straightened, meadows plowed, and vast areas covered with asphalt.

It is noteworthy that climate regulation is only one of the environment-forming functions of natural ecosystems. Correspondingly, the consequences of their destruction are varied: these are soil erosion and degradation, desertification, a decrease in sources of pure fresh water, etc.

Humans continue to destroy natural ecosystems although there is nothing to replace natural mechanisms of biosphere regulation. The artificial maintenance of the unstable biosphere in a state suitable for humans is a task unsolvable for modern civilization. This was clearly demonstrated by the extraordinarily expensive Biosphere-2 experiments, as well as by those on creating an artificial environment for human habitation at space stations [19]. It is impossible today to replace biotic regulation by technical devices since the complexity and amount of information flows in the biosphere exceed the parameters of all modern technical systems by many orders of magnitude [20]. The earth's biosphere is the only life-supporting system for humankind at the present and in the visible future.

BIODIVERSITY AND ECOSYSTEM FUNCTIONS

Biodiversity is the most important factor of ecosystems functioning. Today the conviction that the disappearance of species is an irreversible loss of genetic resources is accompanied by the recognition that this process may result in much more serious consequences—the loss of specific ecosystem functions. The uniqueness of each species lies not only in its genetic pool but also in the role it plays in an ecosystem. The idea that the functioning of ecosystems is determined by the diversity (composition and abundance) of species that they include was introduced into textbooks on ecology long ago. However, the increasing destruction of living nature makes us seek additional arguments in favor of maintaining biodiversity.

Over the past 20 years, studies of the role of biodiversity in exercising ecosystem functions have become one of the most topical and rapidly developing trends in

[6] The main greenhouse gases in the earth's atmosphere include water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ozone (O_3), sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs). The last report of the IPCC working group states that the greatest contribution to climate change is made by carbon dioxide, then follow methane, halocarbons, and nitrous oxide [15].

[7] Over the whole history of humankind, carbon dioxide emissions into the atmosphere because of the destruction of natural ecosystems (primarily, steppe plowing and deforestation) comprised 180 billion t and industrial wastes (prior to 1980), 160 billion tons. From 1991 through 1994, the flow of carbon dioxide to the atmosphere as a result of the destruction of ecosystems and agricultural management reached 6.7 Gt/year and as a result of fuel combustion, 5.9 Gt/year [17].

ecology. The increase in the number of works in this field was avalanche-like. Within the framework of the international program DIVERSITAS, one of the main projects (ecoSERVICES) is dedicated to the study of ecosystem functions of biodiversity. Since the early 1990s, large-scale long-term experimental projects in this field have been performed:

• the Ecotron project—study of artificial laboratory communities consisting of plants and invertebrate animals [21];

• the program of long-term ecological studies in the United States (Long-Term Ecological Research (LTER)) [22]; and

• the BIODEPTH projects (BIODiversity and Ecosystem Processes in Terrestrial Herbaceous Ecosystems)—experiments with herbaceous communities of different natural zones in eight European countries [23].

Despite considerable differences in particular results, these and many other studies have proved on the whole that biodiversity is a key factor of maintaining ecosystem functions [24, 25, 26]. This is manifested in two main forms.

(1) The experimental decrease in the diversity of species or of their functional groups causes a decrease in the intensity of ecosystem functions, whose indices are usually the total biomass of a community, the intensity of respiration, and productivity. To explain this dependence, two mechanisms have been suggested:

• the sampling effect, implying that with an increase in the number of species, the probability of the presence of the most productive forms among them increases; and

• the complementary effect, based on the division of ecological niches and a fuller use of resources in a community with a large number of species.

(2) Biodiversity promotes stability (elasticity, reliability) of ecosystem functions. To explain this effect, the following main mechanisms have been suggested:

• asynchronous and oppositely-directed responses of different species to fluctuations in environmental conditions;

• the stabilization of the total biomass of a community, determined by competition among species, as a result of which an increase in the abundance of any species leads to a decline in the numbers of its competitors;

• the "arithmetic" effect of stabilization under an increase in the total biomass of a community: if the absolute values of the amplitude of fluctuations persist, their relative indices decrease; and

• the "insurance" hypothesis, implying that some species functionally duplicate each other (the so-called redundant species); however, in the case of environmental changes, they may turn out to be more efficient, providing the stability of the total function (in other words, the community may insure itself against environmental changes).

Thus, the obtained result has a critical importance for the theory and practice of environmental protection: it was proved that *an anthropogenic decrease in the diversity of species leads to the degradation and destabilization of ecosystem functions.* Therefore, of great danger are not only a complete destruction of natural ecosystems, but also a decrease in their biological diversity and the disturbance of their natural structure. In particular, one of the most important results of anthropogenic disturbances is the replacement of mature natural communities by early successional stages and different variants of secondary communities. For example, the overwhelming part of forests preserved in developed countries are secondary communities or forest plantations. The biodiversity and total biomass (per unit of area) of the secondary European forest is two times smaller than in an undisturbed forest, and in forest plantations, these indices are even lower [16]. For different communities (tundra, forest, and steppe), it has been shown that the resource of phytomass at early successional stages is many times smaller than in mature communities [27]. The main danger is that their ecosystem functions decrease in this case. Other forms of anthropogenic disturbances of natural ecosystems, for instance, pollution, also lead to a decrease in ecosystem functions.

A key importance of biodiversity for maintaining environmental stability and the sustainable development of society is emphasized in the Convention on Biological Diversity [4], the National Strategy of Conserving Russia's Diversity, and the Millennium Ecosystem Assessment report [6]. Among the main tasks of the national ecological policy, the ecological doctrine of the Russian Federation, approved by the Russian government in 2002, proclaims "the conservation and recovery of the landscape and biological diversity, sufficient for maintaining the capacity of natural systems for self-regulation and compensation of consequences of anthropogenic activity."

The pattern of the dependence of ecosystem functions on biosystems diversity. The issue of the pattern of the dependence of ecosystem functions on biodiversity has not only of theoretical but also of practical significance since this dependence determines the rates of changes in ecosystem functions as a result of anthropogenic and natural transformations of biodiversity. In this respect, several dozen hypotheses [28] have been advanced; they may be classified into three groups.

(1) Species largely duplicate each other's functions. As a result, in the presence of a large number of species, ecosystem functions change only slightly under the removal (addition) of any of them; however, as the number of species decreases, the effect from each loss becomes increasingly stronger. The dependence has an asymptotic pattern (1 in Fig. 3), which is usually detected in experiments and studies of communities [26].

(2) Species perform quite different functions in a community; therefore, the removal/addition of any of them considerably affects the ecosystem functions. Examples: linear dependence under the equal contribution of all species to the functioning of a community and the hypothesis of "key species," implying that their loss leads immediately to noticeable changes (2 and 3 in Fig. 3).

(3) The impact of species on ecosystem functions depends only on their characteristics and not on their number. The change in functions under the removal/addition of species is unpredictable.

In addition, suggestions were made concerning a steplike pattern of changes in ecosystem properties (5 in Fig. 3) and different forms of the dependence during an increase and decrease in diversity (4 in Fig. 3).

The principle of the optimal diversity of biosystems, formulated within the framework of the program of the RAS Presidium Scientific Fundamentals of Conserving Russia's Biodiversity [29], may be regarded as another hypothesis. It is based on the assumption that the viability and efficiency of biosystems are maximal at certain optimal values of their inner diversity, which are close to the characteristics of undisturbed natural systems (6 in Fig. 3).

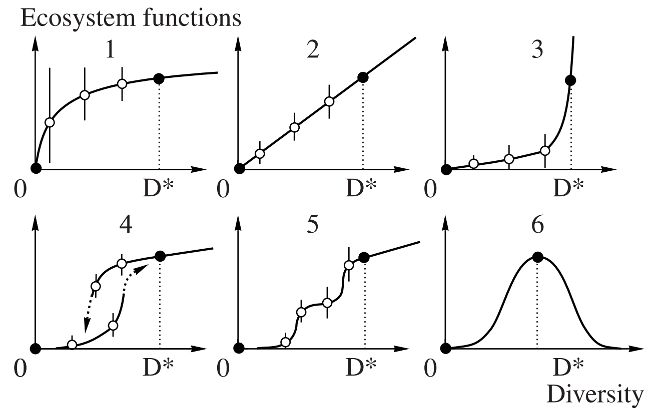

Fig. 3. Hypotheses on the form of dependence of ecosystem functions on biodiversity (D* is the natural level of diversity).

The importance of intraspecific diversity. As a rule, the majority of papers concerns specific diversity. Meanwhile, intraspecific diversity is no less important. Representatives of each species of living organisms in the composition of a community play a certain role (occupy a certain ecological niche). Their impact on the biotic and abiotic components of the environment may be considered the ecosystem function of this species or population. From this point of view, it is suggested to regard populations as "service-providing units" [30]. In the long run, the functioning of an ecosystem is determined by the efficiency and stability of the functions of the species and populations it includes, which, in turn, depends on their inner diversity.

New examples supporting this important regularity were obtained in realizing the aforementioned program of the RAS Presidium. In particular, a considerable level of the genetic uniqueness of geographic forms was revealed in several species of pinaceous trees of the pine family [31]. The efficiency of functioning of these species under these or those conditions depends on preserving local forms and the integral ecosystem function over a wide area, i.e., on the preservation of the entire intraspecific diversity. The studies of lacustrine populations of Arctic char in the Transbaikal region [32] and of Altai osmans in water bodies of Central Asia [33] have revealed the formation of complexes of intraspecific forms in these species, differing both morphologically and ecologically (first of all, in specific features of feeding). These results confirm the previously shown key role of intraspecific diversity in the formation of a wide range of ecological variations in several fish species, which enable them to exist stably under unstable and severe conditions.

One of the most striking examples was obtained while studying Kamchatkan populations of rainbow trout (a species of salmonids). The local populations of this fish in different rivers are characterized by specific ratios of life strategies (Fig. 4), which may be regarded as the adaptation of the populations to local conditions: the availability of food resources and spawning grounds, temperature conditions of the water bodies, etc. [34]. The complex structure of intraspecific diversity ensures rainbow trout stability and maximum use of resources in the varying environment. Complexes of different life strategies are also typical of other salmonids. If one takes into account their leading role in the ecosystems of salmon rivers and their determining effect on the substance–energy flows between marine, river, and land ecosystems, the importance of intraspecific diversity from the point of view of ecosystem functions becomes evident.

Thus, the performed studies have demonstrated the key role of intraspecific diversity for the stability of species and the optimization of their ecological functions both in local ecosystems and over a wide area under unstable environmental conditions.

Studies according to the program of the RAS Presidium permitted making theoretical generalizations, stressing the key role of intraspecific and intrapopulation diversity in ensuring ecosystem functions. The concept of the system of compensation mechanisms [35] considers processes taking place in communities and biotic systems in stress conditions under impoverished species diversity. Some of them may be regarded as a means of optimizing and stabilizing the ecological function of species and populations at the expense of their inner diversity, including

• compensation by density, permitting the use of ecological niches that become vacant under stress conditions;

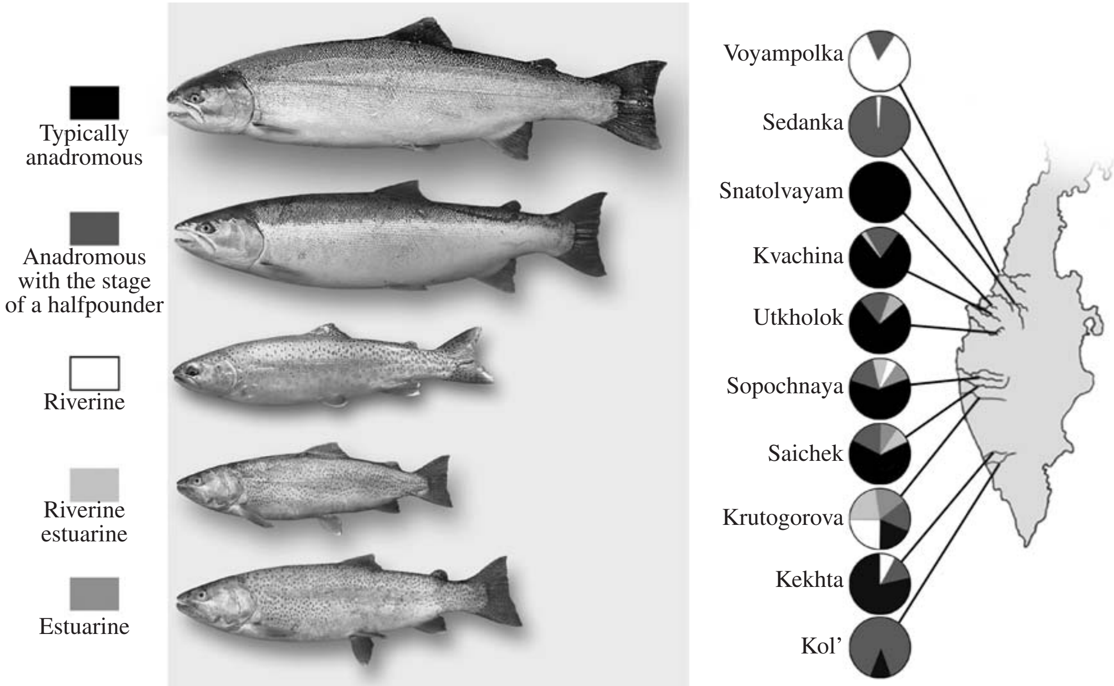

Fig. 4. Complexes of rainbow trout life strategies in local populations of Western Kamchatka.

• the extension of species' ecological niches;

• the domination of one species in a wide range of communities; and

• the formation of complexes of intraspecific forms within one ecosystem.

By modeling the optimum diversity of biosystems [29], it has been shown that biosystems increase intraspecific diversity under a decrease in the number of the community's species, which is their adaptive response to the anthropogenic or natural destabilization of the environment. Proceeding from this, one can say that, under less stable conditions, the regulatory load is redistributed *from specific diversity to intraspecific and intrapopulation diversities*, which ensures the stable functioning of individual populations and ecosystems as a whole.

THE CONSERVATION OF ENVIRONMENT-FORMING FUNCTIONS OF NATURAL SYSTEMS IS A MODERN ECOLOGICAL IMPERATIVE

Functions of biodiversity and purposes of controlling natural systems. For millennia, humans pursued only a purely utilitarian benefit from using living nature: biological produce. Productional functions (especially the production of seafoods and wood) continue to play a considerable role in the world economy. However, today it is necessary to change radically our attitude towards living nature and to recognize that its environment-forming function is the most important. This shift in understanding the value of nature is essentially important since it determines the choice of control purposes in the sphere of nature management.

To analyze the purposes of controlling the entire set of the main biodiversity functions, it is necessary to take into account not only the *productivity* of biosystems (the amount of the biomass removed from them) but also their *diversity* and *the amount of the constantly maintained biomass* (table).

Thus, when using environment-forming and information functions, the purposes of control coincide with the maintenance of the natural level of biodiversity, while in using the productional function, the purpose of control contradicts it. When maximal amounts of the biomass are removed from ecosystems and populations, as well as when their productivity is artificially increased by different kinds of "fertilizers," the degradation of their diversity and environment-forming functions is highly probable. The results of long-standing studies of freshwater ecosystems confirm this conclusion by demonstrating that the structure of communities under an artificial increase in their productivity is inevitably simplified [36]. As noted above, the degradation of environment-forming functions is also observed during land ecosystem exploitation, including deforestation. In communities recovering their structure after large amounts of the biomass have been removed from them, the capacity for the biotic regulation of environmental parameters is weakened [20]. Numerous examples of disturbance in environment-forming functions as a result of a directed modification of ecosystems to increase production are listed in the report "Ecosystems and Human Well-Being" [6].

If we cannot completely stop removing bioproduction from natural ecosystems, this task must be subjugated to the priority of maintenance of the environment-forming function in determining the purposes of control; the volumes and forms of resource exploitation must be limited accordingly.

The economic underestimation of the environment-forming function of biodiversity. The report "Ecosystems and Human Well-Being" [6] stresses that natural ecosystems and their "services" are the most important capital of each country. However, because they are not included into standard systems of economic indicators, their disturbance does not affect formal indices of countries' richness and well-being. Forests may be destroyed and fish resources depleted, but the gross domestic product may increase: the instantaneous illusion of an economic growth will form at the expense of the destruction of the main natural capital, undermining the potential of future development.

The situation is much worse with the economic assessment of the most important function of biodiversity, the environment-forming one. This kind of ecosystem services, opposite to bioproduction, is not in the market and has no monetary value. What is the cost of the biosphere, atmosphere, or the entire soil of the earth? The question about the cost of global environment-forming factors is meaningless: they are invaluable. However, attempts to assess the economic scale of global ecosystem services have been undertaken and have led to the following conclusions [19]:

• the cost of estimated ecosystem services considerably exceeds the global gross product;[8] and

• the cost of productional functions (foodstuffs and raw materials) is only about 6% of the total cost of ecosystem services.

Specific economic estimates may be obtained at the national, regional, and local levels, which may be used in decision making. Even a partial consideration of only some environment-forming functions (including that via the value of the possible damage to economy and human health at their loss) indicates that the economic effect from maintaining natural ecosystems far exceeds the profit that may be gained during their intensive exploitation or transformation into agricultural lands [6].

One of the possible approaches is to assess the cost of the reproduction of ecosystem services by technological devices. The case with the New York water supply has become widely known. The destruction of natural ecosystems and housing and agricultural development on the territory of its drainage basin resulted in an inadmissible decrease in water quality in the mid-1990s. The calculations demonstrated that the recovery of environment-forming functions of ecosystems on the territory of the basin (organizing water-protective zones and limiting the commercial use of the territory) was cheaper than building additional water-cleaning facilities [37].

Purposes of controlling natural systems when using different biodiversity functions

Functions used	Purposes
Environment-forming functions	The conservation of diversity and the continually maintained biomass of biosystems at the natural level
Information and aesthetic functions	The conservation of the diversity of biosystems at the natural level
Productional function	Maximal productivity (the maximal volume of the biomass stably removed from the system)

Today, under the support of the largest international organizations (the United Nations, World Bank, and European Community), the economic criteria and indicators taking into account the damage from environment destruction are being developed actively. It has been demonstrated that the economic growth of many countries is accompanied by the degradation of their true richness and reserves for sustainable development [6]. The actually working mechanisms of determining strategic purposes and making the most important decisions in national and international nature management are still very far from taking into account the value of environment-forming functions of nature.

Repeated underestimations of biodiversity, first of all, of its environment-forming function, inevitably leads to its destruction; at a given moment, utilitarian–commercial projects of using bioresources and the commercial transformation of natural territories seem more profitable. This disastrous mechanism continues to work despite the fact that the boomerang has already returned: the damage from the destruction of natural ecosystems has become a considerable economic factor.

The conservation of natural ecosystems is an essential condition for the survival of humanity. The maintenance of global biotic regulation needs vast (global in size) territories occupied by natural communities [20]. The modern scale of destruction of the living cover of the earth makes it obligatory to conserve all preserved natural ecosystems. In fact, it is more correct to speak about the necessity of a planned "retreat" and nature recovery on a considerable part of territories where it has been destroyed rather than about ceasing human advancement on nature [16]. As for ecosystems partially transformed by humans (which occupy about 24% of land today), they need a policy of strict obedience to the requirements of *conserving biodiversity and*

[8] The estimates of the minimal cost of global ecosystem services averages US \$33 × 10^{12} (in prices of 1994), which is 1.8 times more than the then global gross national product [19].

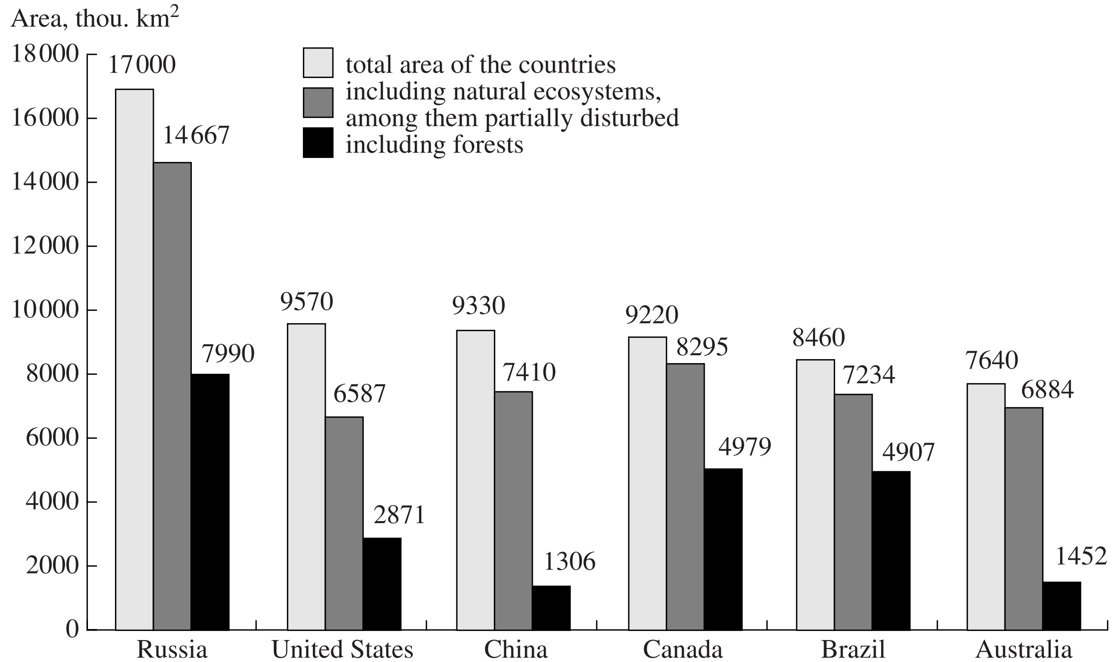

Fig. 5. Total area and the share of natural land ecosystems in the largest countries of the world (according to data of [39]).

its environment-forming functions in the course of any nature management.

It is necessary to make unprecedented efforts to decrease the rates of biodiversity loss since most mechanisms of this process will preserve or intensify their activity in the nearest future. One should understand that this route does not promise immediate profits; on the contrary, it requires considerable efforts and means; however, the earlier humanity recognizes this necessity and passes from the destruction of nature to its recovery, the lower these costs will be.

THE KEY ROLE OF RUSSIA IN THE CONSERVATION OF BIOSPHERE STABILITY

The environment-forming function of Russia's ecosystems. The report on the development of human potential in Russia (2005) within the UN Development Program states that the global awareness of the fact that our country is the main environmental donor of the planet, which makes the greatest contribution to biosphere stability, is increasing [38]. Russia still preserves the largest natural bodies (Fig. 5), almost all types of ecosystems, and the main specific diversity of the largest continental region of the planet—Northern Eurasia. About 22% of the world's forest ecosystems, which are particularly valuable for biosphere regulation, are concentrated in Russia.

According to the Kyoto Protocol concepts on mechanisms of modern climate changes, Russia occupies a unique place. Its natural ecosystems play a key role in maintaining gas balance in the atmosphere. It is boreal forests that accumulate the most considerable amount of carbon both in absolute values and per unit of area. The largest bodies of such ecosystems are in Russia, Canada, and the United States; however, it is our forests that preserve and annually accumulate the greatest amount of carbon [17]. The swamp ecosystems of Russia, as has been demonstrated by studies supported by a RAS Presidium program, make an equally important contribution to biosphere regulation. With rational control, steppe ecosystems in the chernozemic zone may also play the role of a strong regulator since they are capable of accumulating much carbon in the soil [27].

The water-controlling and water-protective functions of Russia's ecosystems are also of global importance. The deficiency of high-quality fresh water became a global problem long ago. Russia has the largest freshwater resources: its reserves in our lakes comprise more than 20% of global resources [40] and the volume of the annual river runoff is inferior only to that of Brazil.[9] We can easily lose this wealth if natural ecosystems are destroyed.

Speaking about the value of natural ecosystems for maintaining biosphere regulation, one should note that criteria in this case should be their environment-forming functions and the extent of preservation (unaffected

[9] According to the data of the second UN World Water Development Report [41], the total renewable freshwater resources from all sources (total runoff) by country are the following: Brazil, 8.2 km^3/year; Russia, 4.5 km^3/year; the United States, 3.0 km^3/year; Canada, 2.9 km^3/year; and China and Indonesia, 2.8 km^3/year, each.

by human activities) rather than formal indices of specific diversity, which are often used for singling out natural territories that should be conserved in the first place. The attention of the world environmental protection community has long been focused on tropical countries where the main diversity of species is concentrated. The special term "megadiversity countries" was even invented. However, from the point of view of maintaining biosphere stability, this approach is unjustified. According to indices of specific diversity, northern ecosystems are incomparable to tropical ones; however, it does not diminish their role in biosphere regulation. Natural ecosystems, species, and populations are characterized by almost optimal levels of differentiation for those conditions under which they have been developing for a long time. As noted above, under conditions of the North, which are more severe and less stable compared to the tropics, the relatively low level of species diversity is compensated by a higher intraspecific and intrapopulational variation, which ensures an efficient performance of biosphere functions.

We have always known that our country has the richest natural resources, meaning first of all that we can take much from nature: mineral resources, forest, fish, furs, etc. Now it is high time to recognize that the environment-forming function of Russia's natural ecosystems is the most valuable and vitally important global resource. The value of this resource will only increase in the future; however, we should ensure its conservation to achieve this. The well-being of not only Russia but also of the entire planet depends on how we use this richness.

Threats to Russia's biodiversity. We are gradually wasting the greatest natural wealth in the world. Russia's natural ecosystems have been destroyed on almost 15% of the territory and partially destroyed on 35% [42]. Some types of ecosystems are on the verge of extinction: in particular, the biomes of European steppes and broad-leaved forests have almost disappeared (today they are represented by small fragments on natural areas of preferential protection and closed test sites). Hundreds of species have been recognized as rare or disappearing; 414 species and subspecies of animals [43], 516 plant species, and 17 species of fungi [44] are included into the Red Data Book of the Russian Federation. Poaching has assumed an industrial scale; as a result, the unique resources of sturgeons have been almost lost and the most valuable forests are being cut out without control. Fires, which are usually due to anthropogenic causes, annually destroy forests on the level of millions of hectares. The large-scale water engineering and mass invasions of alien species have led to the fact that ecosystems of the largest Russian rivers have lost their natural habit, the structure of biocoenoses has radically changed, and the productivity has decreased. Because of the excessive fishery at the end of the 20th century, the resources of the main commercial fish in the European seas of Russia are undermined; the colossal increase in the abundance of invading species in the Black Sea and the Sea of Azov has led to such strong rearrangements of the marine biota that the modern state of these seas may be characterized as an ecological catastrophe. Thus, the situation in maintaining biological diversity in the country gives rise to concern.

More than ten years have passed after the ratification by Russia of the international Convention on Biodiversity (1995) and five years after the adoption of the National Strategy of Maintaining Biodiversity of Russia (2001). In 2002, the government of the Russian Federation approved the Ecological Doctrine of the Russian Federation, which determined the conservation of biological diversity as one of the main tasks of the state ecological policy. However, in fact, the situation with the conservation of living nature has not improved and has even radically worsened over the past few years. Today, a complex of interrelated socioeconomic and political processes leading to the disturbance of natural ecosystems has formed in Russia.

The "antienvironmental" orientation of our economic development may be considered the main cause of this. During the last 15 years, the economy was restructured in favor of its raw material and environment-polluting sectors against the background of the degradation of resource-saving and high-technology branches[10] and the energy capacity of the economy increased by 16%, exceeding the indices of developed countries by 2.5 to 4 times [38]. The leading place in the economy of Russia is occupied by the mineral–raw material sector: it accounts for 25–28% of the gross domestic product and 65–70% of currency earnings of the budget [45]. The economic growth of the turn of the centuries may be characterized as "dirty"; during the last few years, a tendency toward an increase in the wastes and emissions of pollutants has been observed in industry [38, 45].

According to the value of the ecological footprint per capita, Russia occupies an intermediate place among economically developed countries [8]: each person in our country consumes approximately the same amount of resources as an average European. However, living standards are far lower in our country. When the index of the ecological footprint is recalculated per one dollar of the gross domestic product, we are among countries that remove the greatest amount of resources from nature.[11] According to this index, our economy is

[10]For instance, from 1990 through 2003, the share of fuel branches in industry increased by 2.5 times, that of machine building and metal working decreased from 31 to 20%, and the share of light industry dropped from 12 to 1% [38].

[11]The indices of the ecological trace footprint per one dollar of the gross domestic product are no more than 0.2 in the United States, China, India, and European countries; and about 0.4 in Russia, Kuwait, and the United Arab Emirates. Calculated according to the IMF data on the purchasing power parity [46].

comparable only to the oil-producing Near Eastern countries (Kuwait and the United Arab Emirates).

Against the background of the GDP growth, the ecologically corrected indices of development have been worsening during the last few years.[12] For instance, in 2000, when the GDP gain was 9%, the index of genuine savings, calculated by WB methods, demonstrated their decrease by 13% [38]. The studies of Russian specialists revealed a similar pattern: if one takes into account the loss from environmental pollution, our GDP decreases by 3–15% per year [47]. The modern increase in economic indices is only an instantaneous illusion of economic growth, which is formed due to wasting the country's natural capital.

The danger of the destruction of natural ecosystems, related to the possibility of increasing the exploitation of natural resources, is many times increased by several other factors:

• the weakening of the state control system in the sphere of the protection and use of living nature and the system of controlling natural areas of preferential protection;

• changes in the legislation in the field of nature management and property rights on natural resources, which even more weaken state and social control in this field;

• low living standards of the main part of the population; and

• the absence of interest in preserving living nature among the population and businesspeople.

* * *

The environment-forming function of Russia's natural complex, the largest "natural capital" in the world, determines the central role of our country in solving the task of the conservation of biodiversity stability. Owing to this, Russia must occupy a leading place in the international process aimed at conserving the biosphere and maintaining global ecological safety, which is no less important than in forming the system of international energy preparedness.

From the point of view of national interests, the preservation of natural ecosystems of Russia and their environment-forming functions is also a key problem. This is an essential condition for the sustainable and progressive development of our country. The damage from the destruction of natural ecosystems and unbalance in ecosystem and biosphere processes as a result of the intensification of mining of natural resources may many times exceed the profit. The adoption of decisions on realizing any economic projects, primarily those directed at the exploitation of natural resources, must be based on estimates of balance between the planned profits and the possible loss because of environment-forming functions. In the long run, the preservation of natural ecosystems is much more profitable from the economic point of view than their irrational use for obtaining a momentary profit.

Obeying rigid nature-protective requirements is no hindrance on the way of economic development. On the contrary, this is an efficient mechanism simulating progressive structural transformations and ensuring the priority development of resource-saving and high-tech industries that determine the status and competitiveness of national economies in the modern world. It is necessary to change priorities in the national ecological policy of nature management, stop increasing the extraction of natural resources, and adopt a new strategic goal—the conservation of ecosystems and of their environment-forming function.

[12] The UN Integrated Environmental and Economic Accounting; the WB indices of genuine savings; and GARP1, GARP2, and TEPI projects of the European community [38]

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REFERENCES

1. http://news.bbc.co.uk/1/hi/sci/tech/4745963.stm.
2. http://earth.google.com.
3. Agenda for the 21st Century. Adopted by the UNO Conference on the Environment and Development. Rio de Janeiro, July 3–14, 1992, http://www.un.org/russian/sonferen/wssd/agenda21/.
4. Convention on Biological Diversity. Adopted by the UNO Conference on the Environment and Development. Rio de Janeiro, July 3–14, 1992, http://www.un.org/russian/dosumen/sonvents/biodiv.htm.
5. Global Environment Outlook 3. Past, Present and Future Perspectives. UNEP, 2002, http://www.unep.org/geo/geo3/russian/pdf.htm; Global Environment Outlook Yearbook. UNEP: 2006; www.unep.org/geo/yearbook.
6. Millennium Ecosystem Assessment. Ecosystems and Human Well-Being: Synthesis; Biodiversity Synthesis. World Resources Institute. Wash., DC: Island Press, 2005, http://www.maweb.org/en/Reports.aspx#; http://www.millenniumassessment.org/en/Reports.aspx#.
7. Global Biodiversity Outlook 2. Montreal: Secretariat of the Convention on Biological Diversity, 2006, http://www.biodiv.org/gbo2/default.shtml.
8. Living Planet Report 2006. Gland: WWF-World Wide Fund for Nature, 2006, http://www.panda.org/news_facts/publications/living_planet_report/lp_2006/index.cfm;

http://www.footprintnetwork.org/newsletters/gfn_blast_0610.html.

9. *2004 IUCN Red List of Threatened Species*, Ed. by J. E. M. Baillie, C. Hilton-Taylor, and S. N. Stuart (IUCN, Cambridge, 2004).
10. V. I. Zakharov, K. G. Gribanov, V. E. Prokop'ev, and V. M. Shmelev, "The Effect of the Band of Atmosphere Transparency of 8–13 m on the Stability of the Thermal State of the Earth," At. Energ. **72** (1) (1992).
11. V. G. Gorshkov, *Physical and Biological Bases of Life Stability* (VINITI, Moscow, 1995) [in Russian].
12. V. V. Gorshkov, V. G. Gorshkov, V. I. Danilov-Danil'yan, et al., "Biotic Regulation of the Environment," Ekologiya, No. 2 (1999) [J. Russ. Ecol., No. 2, 87–93 (1999)].
13. A. A. Oborin, L. M. Rubinshtein, V. T. Khmurchik, and N. S. Churilova, *The Concept of Organization of Underground Biosphere* (Ural. Otd. Ross. Akad. Nauk, Yekaterinburg, 2004) [in Russian].
14. Johannesburg Declaration on Sustainable Development. UN, 2002. http://www.un.org/esa/sustdev/documents/WSSD_POI_PD/English/POI_PD.htm
15. *Climate Change 2007: The Physical Science Basis. Summary for Policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). 10th Session of Working Group I of the IPCC* (February, Paris, 2007).
16. V. I. Danilov-Danil'yan, K. S. Losev, and I. E. Reif, *Faced with the Main Challenge of Civilization. A Glance from Russia* (INFRA-M, Moscow, 2005) [in Russian].
17. M. Ch. Zalikhanov, K. S. Losev, and A. M. Shelekhov, "Natural Ecosystems—the Most Important Natural Resource of Humanity," Vestn. Ross. Akad. Nauk, No. 7 (2006).
18. S. P. Gorshkov, "Natural Calamities, Nature, and Humans," in *Nature Management and Sustainable Development. World Ecosystems and Russia's Problems* (Tovarishchestvo Nauchnykh Izdanii KMK, Moscow, 2006).
19. R. Costanza, R. d' Arge, et al., "The Value of the World's Ecosystem Services and Natural Capital," Nature **387** (1997).
20. V. G. Gorshkov, A. M. Makar'eva, and K. S. Losev, "A Strategy for the Survival of Humanity Is on the Agenda," Vestn. Ross. Akad. Nauk, No. 4 (2006) [Herald Ross. Akad. Nauk, No. 2, 139–143 (2006)].
21. S. Naeem, K. Hakansson, J. H. Lawton, et al., "Biodiversity and Plant Productivity in a Model Assemblage of Plant Species," Oikos **76** (1996).
22. A. J. Symstad, S. Chapin III, D. H. Wall, et al., "Long-Term and Large-Scale Perspectives on the Relationship between Biodiversity and Ecosystem Functioning," BioScience **53** (2003).
23. E. M. Spehn, A. Hector, J. Joshi, et al., "Ecosystem Effects of Biodiversity Manipulations in European Grasslands," Ecol. Monogr. **75** (2005).
24. P. Balvanera, A. Pfisterer, N. Buchmann, et al., "Quantifying the Evidence for Biodiversity Effects on Ecosystem Functioning and Services," Ecol. Lett., No. 9 (2006).
25. D. Hooper, F. Chapin III, J. Ewel, et al., "Effects of Biodiversity on Ecosystem Functioning: A Consensus of Current Knowledge," Ecol. Monogr. **75** (1) (2005).
26. A. Hector, J. Joshi, S. P. Lawler, et al., "Conservation Implications of the Link between Biodiversity and Ecosystem Functioning," Oecologia **129** (2001).
27. A. A. Tishkov, *Biosphere Functions of Natural Ecosystems of Russia* (Nauka, Moscow, 2005) [in Russian].
28. F. Schlapfer and B. Schmid, "Ecosystem Effects of Biodiversity: A Classification of Hypotheses and Exploration of Empirical Results," Ecol. Applic. **9** (3) (1999).
29. E. N. Bukvareva and G. M. Aleshchenko, "The Principle of Optimal Diversity of Biosystems," Usp. Sovrem. Biol. **125** (4) (2005).
30. G. Luck, G. Daily, and P. Ehrlich, "Population Diversity and Ecosystem Services," Trends Ecol. Evol. **18** (7) (2003).
31. *Dynamics of Population Gene Pools under Anthropogenic Impacts*, Ed. by Yu. P. Altukhov (Nauka, Moscow, 2004) [in Russian].
32. S. S. Alekseev, M. Yu. Pichugin, and V. P. Samusenok, "Diversity of Arctic Charrs from Transbaikalia in Meristic Characters, Their Position in the Complex *Salvelinus alpinus* and the Origin of Sympatric Forms," Vopr. Ikhtiol., No. 3 (2000) [J. Ichthyol., No. 4, 279–297 (2000)].
33. Yu. Dgebuadze, *Ecological Regularities of Variation in Fish Growth* (Nauka, Moscow, 2001) [in Russian].
34. D. S. Pavlov, K. A. Savvaitova, K. V. Kuzishchin, et al., *True Salmon and Trout of Asia* (Nauchnyi Mir, Moscow, 2001) [in Russian].
35. Yu. I. Chernov, "Species Diversity and Compensation Phenomena in Communities and Biotic Systems," Zool. Zh., No. 10 (2005).
36. A. F. Alimov, "The Role of Biological Diversity in Ecosystems," Vestn. Ross. Akad. Nauk, No. 11 (2007).
37. *Valuing Ecosystem Services: Toward Better Environmental Decision-Making* (National Academies Press, Wash., DC, 2004).
38. Russia in 2015: Tasks and Priorities of Development. Report on the Development of Human Potential in the Russian Federation for 2005. Program of Development of UNO. 2005, http://www.undp.ru/index.phtml?iso = RU&lid = 2&cmd = publications1&id = 49.
39. *Economy of Preservation of Biodiversity,* Ed. by A. A. Tishkov (Institut Ekonomiki Prirodopol'zovaniya, Moscow, 2002) [in Russian].
40. N. I. Alekseevskii and G. I. Gladkevich, "Water Resources in the World and Russia for 100 Years," in *Russia in the Surrounding World: 2003. Analitical Yearbook* (MNEPU, Moscow, 2003).

41. *Water, a Shared Responsibility. The United Nations World Water Development Report 2* (UNESCO, 2006), http://www.unesco.org/water/wwap/wwdr2/table_contents.shtml.

42. K. S. Losev, *Ecological Problems and Perspectives of Sustainable Development in Russia in the 21st Century* (Kosmosinform, Moscow, 2001) [in Russian].

43. *The Red Data Book of the Russian Federation. Animals* (AST, Moscow, 2001) [in Russian].

44. *The Red Data Book of the Russian Federation. Plants* (Rosagropromizdat, Moscow, 1988) [in Russian].

45. *State Report on the State and Protection of the Environment of the Russian Federation in 2004* (Ministerstvo Prirodnykh Resursov RF, Moscow, 2005) [in Russian].

46. International Monetary Fund. World Economic Outlook Database. September 2006, http://www.imf.org/external/pubs/ft/weo/2006/02/data/weoselgr.aspx.

47. E. V. Ryumina, "Coordination of Financial Mechanisms Providing the Preservation of Biodiversity with Strategies of Economic Development of Russia and Its Regions," in *New Financial Mechanisms of Preservation of Biodiversity* (Moscow, 2002).