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Study of Developmental Homeostasis: From Population Developmental Biology and the Health of Environment Concept to the Sustainable Development Concept

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Abstract—The study of the indices of developmental homeostasis in natural populations leads to the definition of the fundamentals of population developmental biology, which is associated with the assessment of the nature of phenotypic diversity and the mechanisms of population dynamics and microevolutionary changes. Characterization of environmental quality based on the assessment of population status by developmental homeostasis determines the fundamentals of the health of environment concept. The use of the ideas of developmental homeostasis and the health of environment in the studies of homeostatic mechanisms of biological systems of different levels (from the organism and population to the community and ecosystem) is promising. This gives new opportunities for understanding the mechanisms that provide sustainability and their ratio at different levels as well as for the characterization of ontogenetic stability significance. The notion of developmental homeostasis, or homeorhesis, is promising for the elaboration of the ecological and biological basics of sustainable development.

Keywords: developmental homeostasis, health of environment, sustainable development

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INTRODUCTION

The study of developmental homeostasis as one of the most general developmental characteristics, which is assessed using various approaches, from embryology to physiology and morphology (Waddington, 1957; Zakharov, 1987; Zotin, 1988; Detlaf, 2001), is central not only in developmental biology but also opens up new prospects and directions of research in other fields of science, such as ecological developmental biology and evolutionary developmental biology (Gilbert, 2004; Gilbert and Barresi, 2016).

The study of developmental homeostasis indices in natural populations leads to the definition of the foundations of developmental population biology. This approach seems promising for assessing the nature of phenotypic diversity and the microevolutionary transformation mechanisms (Zakharov et al., 2001).

The new approach based on the study of organism's condition by developmental homeostasis also open up an opportunity for solving the problem of assessment and monitoring of the quality of environment and its auspiciousness for living beings, including humans. Given the increasing global and local anthropogenic impacts, the importance of this task steadily increases. This leads to the formulation of the health of environment concept, which is based on the ontogenetic characterization of natural populations of different species of living beings (Zakharov et al., 2000).

It is relevant to consider the opportunities for the development of studies of the homeostatic mechanisms of biological systems with the application of the concepts of developmental homeostasis and health of environment using various approaches to characterizing the processes that take place at different levels (from organism to ecosystem), including the sustainable development concept.

ASSESSMENT OF DEVELOPMENTAL HOMEOSTASIS IN NATURAL POPULATIONS: DEVELOPMENTAL POPULATION BIOLOGY AND THE HEALTH OF ENVIRONMENT CONCEPT

Homeostasis, as the ability to maintain the structural and functional parameters of a system at a required level, is the basic characteristic of the sustainability of any biological system (from organism to ecosystem). Developmental homeostasis, or homeorhesis, is one of the most comprehensive characteristics of a developing organism and means the ability to provide sustainable development along the certain trajectory (chreod) (Waddington, 1957; Zakharov, 1987; Zotin, 1988).

Developmental homeostasis depends on both genetic and environmental stress. The ideas about genetic and environmental stress are largely close. When environment changes, the previous genetic coadaptation can be considered ineffective, and vice versa, when coadaptation is disturbed, the previous optimum conditions for a given genotype become nonoptimal. The response to any adverse impacts from both the genotype and the environment is the same: the organism's conditions changes, which is detected by the developmental stability deterioration. It can be defined as environmental or genetic stress only by the nature of its causative factors. The indices of developmental homeostasis give an assessment of an organism's condition, which depends both on the power of the system itself (genetic coadaptation) and on the external conditions (environmental stress) and serves as an ontogenetic characteristic of an organism's condition, as a measure of genetic coadaptation and environmental stress.

The study of natural populations showed that developmental homeostasis is maintained by genetic coadaptation under optimum developmental conditions. This makes it possible to identify changes in a developing organism's condition caused by genetic or environmental stress using the population biology approaches (Zakharov et al., 2001).

In the population dynamics studies, this provides an opportunity to assess the mechanisms underling different types of dynamics on the basis of information about the possible changes in organism's condition from the ontogenetic standpoint.

This approach allows approximate assessment of the nature of the observed phenotypic diversity and its possible changes taking into account the significance of both directed deviations in development due to genetic or environmental differences the "ontogenetic noise" and the consequences of the "genotype–environment" interaction.

The assessment of the mechanisms underlying microevolutionary transformations allows taking into account two aspects of developmental homeostasis, including not only the stability (as the ability to minimize the "ontogenetic noise") but also the developmental canalization. Developmental canalization means the ability to ensure development along a certain trajectory (chreod) even when conditions are changed, in contrast to plasticity, which means a change in the trajectory with changing conditions. Evolutionary transformations in the course of adaptation to new environmental conditions and optimum change are accompanied by switching to another trajectory, with subsequent stabilization of development along this new trajectory, associated with genetic determination of the new norm of reaction (Zakharov, 1987).

Developmental homeostasis can be characterized using various approaches associated with the assessment of developmental stability indices, cytogenetic homeostasis, immune status, and a number of physiological and biochemical parameters (Zakharov et al., 2000).

When using the morphogenetic approach, which is associated with the study of developmental stability, assessment is reduced to characterizing the "ontogenetic noise" (the value of which is usually estimated by the fluctuating asymmetry of bilateral structures of an organism) (Waddington, 1957; Zakharov, 1987). The significance of the characteristics obtained with this approach is determined by a number of fundamentally important features. First of all, at the level of population estimates, the asymmetry of different traits is usually highly correlated. The consistency of their changes can be regarded as reliable evidence that, indeed, the developmental stability in the studied group of sample differs. To elucidate the significance of changes in developmental stability, their correlation with changes in other indices of organism's condition, which provides a multifaceted characteristic of developmental homeostasis, is extremely important (Zakharov et al., 2001). Numerous examples of such concerted changes in different indices of homeostasis of an organism were obtained in the studies of the impact of anthropogenic factors (Zakharov et al., 2000).

This approach makes it possible to assess the health of environment and characterize its auspiciousness for living beings, including humans. The essence of this approach consists in assessing the condition of living beings by developmental homeostasis. This direction can be defined as the characterization of the condition of a natural population by the state of health of its constituent organisms or, more generally, as the assessment of the health of environment.

It is fundamentally important to assess the degree of deviation from the norm. Such scales have been developed for the main approaches of the proposed methodology. As a result, within each approach, we can talk about the degree of change in an organism's condition within a given characteristic (morphological, genetic, or immunological). The comparison of scores obtained in different species using different approaches showed that, in many cases, the scale is universal for different species and the results obtained using different approaches give a similar picture. This suggests the possibility of scoring the living organism's condition as a whole (Zakharov et al., 2000).

Despite some differences between the data obtained by different parameters and species, the resulting picture is similar. Instead of the usual mosaic of biological responses obtained by different methods for different objects, the main indices of the proposed approach give a correlated response. This consistency of responses is one of the basic principles of the methodology for assessing the health of environment and is

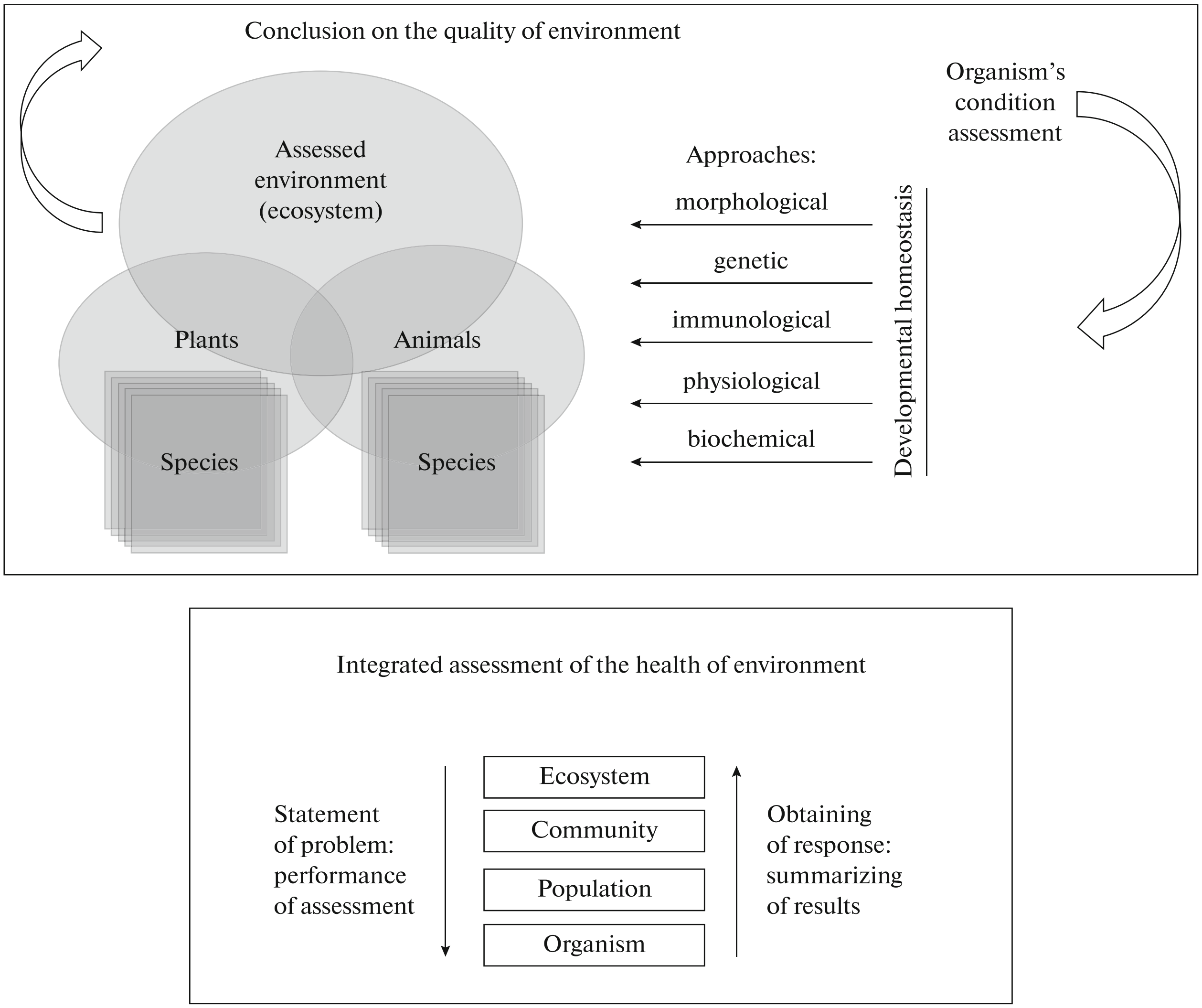

Fig. 1. Schematic representation of the health of environment assessment methodology.

always observed if the following two conditions are met: if the used indices characterize the organism's condition by the developmental homeostasis and if the given characteristic does change in the considered sample group. The consistency of changes in different indices of "ontogenetic noise" for different traits indicates a change in the overall developmental stability. The consistency of indices for different approaches to assessing the developmental homeostasis indicates a change in the overall condition of an organism. The consistency of responses of different species indicates a change in the health of environment (Fig. 1).

This means that, in case of homeostasis deterioration, the entire life support system of an organism begins to "crumble," which is reflected in changing various indices of an organism's condition. However, the first, still reversible changes can be detected at the early stages by sufficiently sensitive indices of developmental homeostasis, which provides an opportunity to use this approach as an "early warning system."

This determines the importance of this approach for assessing both the environmental quality and the condition and homeostatic mechanisms at the level of populations, communities, and ecosystems. This provides the necessary information for the development of indicators of sustainable development, which is aimed at ensuring the health of humans and environment and maintaining homeostasis at the level of both individual ecosystems and the biosphere.

The proposed methodology for assessing the condition (health) of living systems by developmental homeostasis is not just one of the methods but is a fundamentally different, new approach to solving the problem of assessment and monitoring of the environment.

An important feature of this approach is the detection of adverse changes, even against the background of positive effects, in such indices as the size and growth rate of an organism, abundance, and biodiversity. Another important feature of this approach is the level of determined conditional norm. The latter, in turn, depends on the sensitivity of the indices used. The range of conditions in the gradient of increasing degree of impact, which is characterized by a substantial change in the developmental stability indices, usually fits within the survival zone range, when deviations in the commonly used indices of viability are not observed (Zakharov and Trofimov, 2014).

Thus, the assessment of organism's condition by developmental homeostasis allows the assessment of the condition of populations of different species (population developmental biology), which, in turn, opens up the possibility for characterizing the condition of community and ecosystem (the health of environment concept).

HOMEOSTATIC MECHANISMS OF BIOLOGICAL SYSTEMS: POSSIBLE APPROACHES

Developmental homeostasis can be assessed using various approaches that usually give similar results. Such an assessment is important to characterize not only an organism's condition but also the processes occurring in populations, communities, and ecosystems. In many cases, the changes at these levels are preceded by the changes in an organism's condition. At the same time, changes at higher levels affect the condition of individuals.

Homeostatic mechanisms can be assessed using the following different approaches. The analysis of morphological diversity from the standpoint of the morphological space and its structure gives an estimate of its organization. In terms of individual development, this approach makes it possible to identify the dynamics of approaching and deviation from the stationary state in the course of ontogeny and the transitions between the more and less organized states. The multivariate nature of development and its stabilization on a certain channel is a manifestation of developmental homeostasis. A change in the degree of multivariate nature of development depending on environmental conditions is the resultant of homeostatic mechanisms at the organismal and population levels. Parallel studies of different aspects of developmental homeostasis, including the stability and canalization of development, make it possible to assess the nature of the phenotypic diversity and its transformation in the course of population dynamics and microevolution. At the ontogenetic level, morphogenetic mechanisms are regarded as a manifestation of fractality, consistent patterns of formation of large-scale invariant structures.

A multifaceted characterization of developmental homeostasis significance implies the use of different approaches. In particular, the evaluation of cytogenetic stability is a measure of both a developing organism's condition and the genetic homeostasis. This approach makes it possible to evaluate the population status by the ratio of homeostatic mechanisms that maintain stability at the organismal and population levels (*Gomeostaticheskie*..., 2014).

Similar methodological approaches, apparently, can be used to assess homeostatic mechanisms of different levels.

A promising approach is to assess fractality against the background of implementation of the mechanisms of homeostasis (in particular, the developmental homeostasis, homeorhesis). The very presence of fractality, in a sense, can be considered as a manifestation of homeostasis. Fractality, as a manifestation of large-scale invariance of biosystems, can be represented as a resultant of implementation of the homeostatic mechanisms of biological systems at different levels, from molecular to ecosystem. At the same time, the directional effect of some mechanisms that provide homeostasis under certain conditions or in the course of development along a certain trajectory may lead to deviations from the latter. This is especially true when considering the consequences of implementation of homeostatic mechanisms at different levels of organization, from organism to ecosystem.

Such studies are especially relevant and important to assess the consequences of global environmental changes observed today. Anthropogenic transformation of the environment causes adverse effects at all levels (from organismal to ecosystem), which indicates the importance of assessment of homeostatic mechanisms maintaining the stability of biological systems at all levels. Here, the most universal and sensitive indicator is developmental homeostasis. This direction of research has led to the development of the health of environment assessment methodology (Zakharov and Clark, 1993; Zakharov et al., 2000).

The study of the ratio of the mechanisms aimed at both ensuring a certain state of homeostasis as such, on the one hand, and maintaining the sustainability of development along a particular trajectory (developmental homeostasis, or homeorhesis), on the other, is worth special attention. This leads to the understanding of developmental homeostasis as a "chain of homeostases" or stabilization of development along a particular trajectory (chreod) (Waddington, 1957, 1970; Zakharov, 1987; Zotin, 1988; Zakharov and Trofimov, 2014). Here, the buffer mechanisms that provide primarily the directional processes of changes and development rather than a certain state acquire a fundamental importance.

At the obvious necessity to provide the stability of any ecological–biological system (from an organism to an ecosystem) at any given time moment and its ability to tolerate or compensate for different disturbing impacts, which may result in its deviation from the predetermined required condition, including noise minimization (as an important characteristic of the system condition), the maintenance of homeostasis should lead to a certain inhibition and delay in the possible changes in the system itself, which is particularly important in ensuring changes along a certain developmental trajectory.

Inhibition or deceleration of the response of a system to a certain impact owing to homeostatic mechanisms is known as the hysteresis phenomenon (Fig. 2) (Vedyushkin et al., 1995).

The zones of negligible or very slow changes in the phenological trends in plants in more southern areas (at an approximately equal temperature increase in southern and northern areas in the central part of the European part of Russia in 1970–2015) (Fig. 3) can be regarded as an example of implementation of homeostatic mechanisms (Minin and Voskova, 2014; Minin et al., 2016). It is a question of assessing the consequences of the global warming trend, which is 2.5 times more pronounced in Russia than on average in the world (*Doklad*..., 2017). The phenological changes do not directly follow the temperature changes, probably due to the implementation of the homeostatic mechanisms counteracting such external impacts. It can be assumed that the plants in northern latitudes have greater reserves for shortening the winter dormancy period in favor of the vegetation season under climate warming conditions than the plants of the southern latitudes. Different responses of different plant populations to the climate change trends, which were identified as a result of long-term phenological observations, apparently support the assumption about the fundamental importance of homeostatic mechanisms.

Another example of the manifestation of hysteresis at a higher level, which is also of interest for assessing the possible consequences of climate changes, is the previously mentioned areas where the equilibrium vegetation of biomes is ambiguously determined by climatic factors. The existence of zones with drastic changes in phytomass production can hardly be explained from the standpoint of the idea about strict determination of vegetation type by climatic factors and can be regarded as evidence of spatial hysteresis (Vedyushkin et al., 1995). The areas adjoining Eurasian boreal forests from the north and south, as areas characterized by an ambiguous relationship between the annual aboveground phytomass production and the complex climate characteristics (vaporizability) can be classified with such zones. The position of the boundaries between biomes depends primarily on the historical (paleogeographical) rather than climatic factors, which differs hysteresis from a monotonic inertia of a system. This makes it possible to explain the observed relatively low determinancy of vegetation types by climatic factors and to assume that boundaries of biomes begin to change only at a sufficiently severe climate change, indicating the existence of a certain buffer capacity and a threshold effect.

A possible ratio of homeostatic mechanisms at different levels (from organism and populations to communities and ecosystems) can be considered by a number of examples.

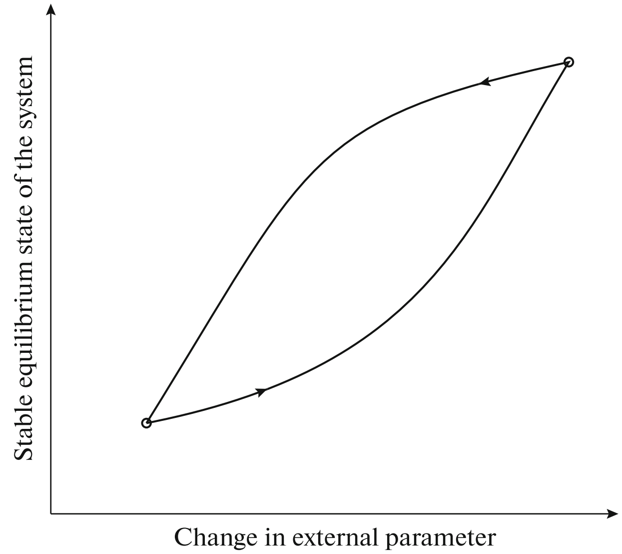

Fig. 2. Schematic representation of the hysteresis phenomenon. The trajectories of possible transition of the system from one condition to another and back show the suppression of the system's response to an external impact.

It was repeatedly shown that major changes in developmental homeostasis in different species of animals and plants (detected by indices of developmental stability, cytogenetic homeostasis, immune status, and other physiological and biochemical parameters, to score five on a five-point scale of deviation of an organism's condition from the conventional norm (critical condition)) may be observed against the background of the same or even increased biodiversity, abundance of certain species, and high productivity of ecosystems (Zakharov et al., 2000). Deterioration of developmental homeostasis in populations of different species under conditions of both natural and anthropogenic ecological periphery of a range is the "fee" for the possibility of existence under nonoptimal conditions at the limit of capacity of a species. Up to a certain threshold level of certain detrimental impacts, the environment-forming function, the carrier and assimilative capacity of ecosystems may be retained despite the fact that the conditions of living beings during the implementation of their role in the ecosystem may be extremely adverse. At the same time, in the absence of any detrimental impacts (primarily related to environmental pollution), a high level of homeostasis may also be observed under conditions of inevitably altered or depleted biodiversity in the transformed landscapes in developed areas.

Sustainable existence of ecosystems of Central Siberia has been provided for a long time against the background of a pronounced 4-year cyclicity of the community of small mammals (including the representatives of insectivores and rodents). This implied

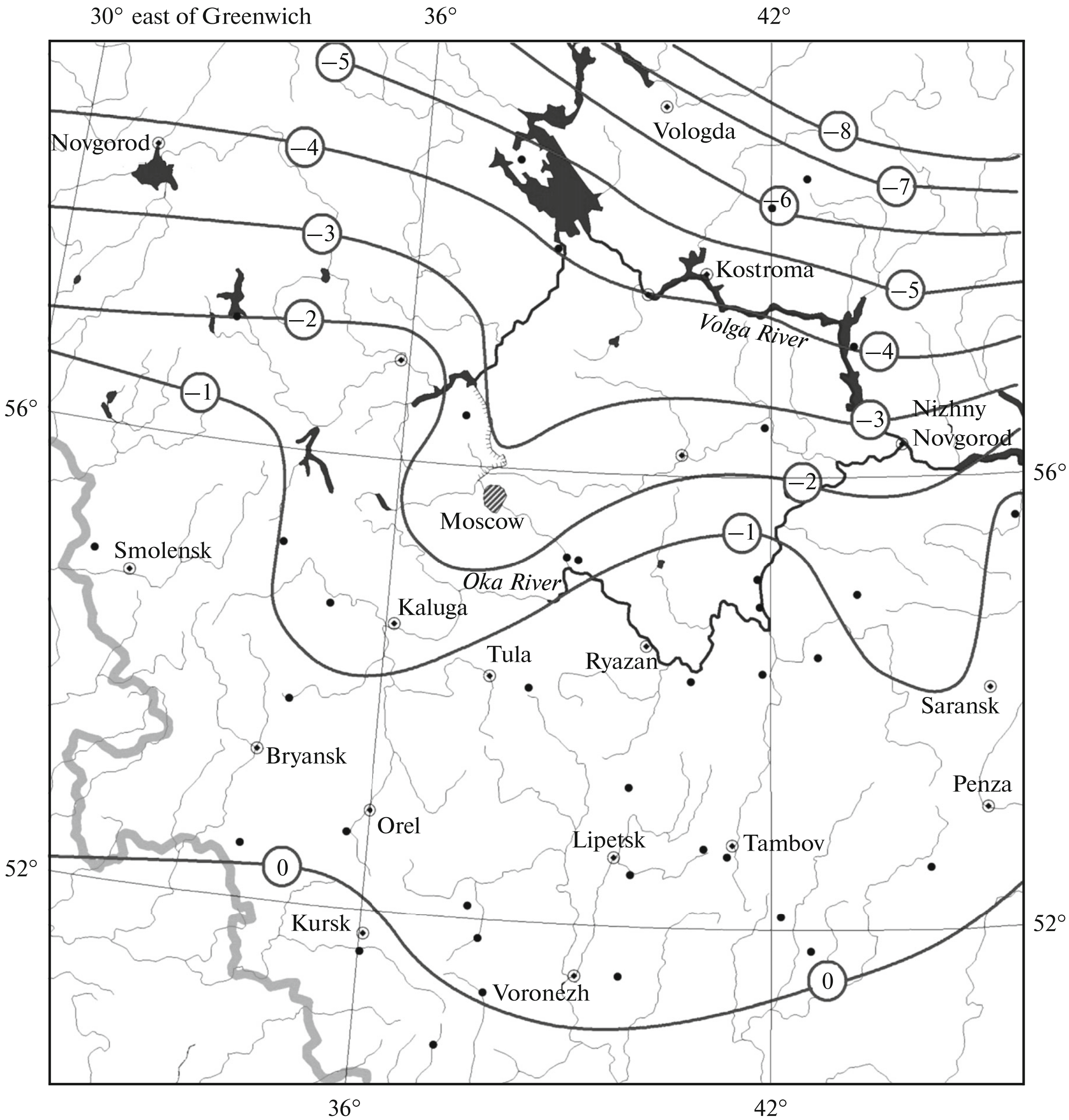

Fig. 3. Shift in the date of occurrence of the first leaves in silver birch (*Betula pendula*) in the period 1970–2010 in days (dots show the observation points).

the autoregulatory mechanisms of the population dynamics under conditions of the same climatic stability and maintenance of high snow cover in winter. An increase in abundance over 3 years led to significant change in organism's condition, which manifested itself in the deterioration of homeostasis in the population compaction phase. Under the current conditions of the clear trend of rising temperatures and climatic instability, against the background of the beginning changes in the biodiversity towards more southern species and increase in habitat productivity, another type of dynamics—fluctuations, which, apparently, are largely determined by climatic conditions—is observed. Such oscillations in abundance are not accompanied by significant changes in the organism' condition (Zakharov et al., 2011).

Thus, at different ratios of homeostatic mechanisms of different levels and significance of developmental homeostasis assessments at the ontogenetic level, the mechanisms that ensure homeostasis at a higher level are of primary importance for the indication of possible changes in the organism's condition.

All above examples show the crucial importance of the notion of developmental homeostasis for the assessment of sustainability mechanisms and possible changes not only at the organismal and population levels but also at higher levels of organization—at the level of communities and ecosystems. This approach opens up new possibilities for a multifaceted assessment of consequences of various impacts, including the consequences of global climate change.

ECOLOGICAL AND BIOLOGICAL BASES OF SUSTAINABLE DEVELOPMENT: FORMULATION OF THE PROBLEM

Fundamentals of the Concept of Sustainable Development

It is reasonable to consider the possibility of applying the ideas about developmental homeostasis to the concept of sustainable development.

The concept of sustainable development was adopted as the basic developmental paradigm at the UN Conference in Rio de Janeiro in 1992. For the first time, the crucial role of ecology in human development was defined at the international community level at the UN Conference on the Environmental Problems in Stockholm in 1972. Earlier, there were proposals on the feasibility of changing this paradigm. However, at the "Rio+20" UN Conference on the Sustainable Development in 2012, only its increasing relevance and importance for the search of answers to current challenges was acknowledged. The Agenda to 2030 and the purposes of sustainable development, adopted in 2015, emphasize the importance of providing environmental sustainability and health of environment (*Itogovyi…*, 2012; *Itogovyi…,* 2015). Not many political appeals have lived for so long. Apparently, this is determined by the fact that the concept is based on an ecological and biological rationale—the necessity to fit our ever-increasing demand into the natural possibilities of the planet. Although the question about changing some wordings and definitions can be posed, the essence of the concept remains the same: this is the condition of survival and development.

The motive for the call for sustainable development was the realization that a long-term successful development of mankind implies the solution of social and economic problems within the planet's environmental capacity. This postulate was formulated by three leading international environmental organizations, including the International Union for Conservation of Nature (IUCN), the United Nations Environment Program (UNEP), and the World Wildlife Fund (WWF) in the "Caring for the Earth" document (1991). A scheme of harmonious combination of three pillars of sustainable development, including the economic, social, and environmental ones, has been proposed as a basis for the development concept for implementing this priority. This principle was the basis of all major documents on sustainable development starting with the UN Conference in 1992, where not only the new development concept was proclaimed but also a number of environmental conventions, including the Convention on Biological Diversity (1992), were adopted.

At the same time, the recent decisions on sustainable development ("The Future We Want" and the Agenda to 2030) (*Itogovyi…*, 2012; *Itogovyi…*, 2015) are much less categorical than the earlier proposals. This is due to a number of reasons. Previously, tasks were formulated, whereas today is the time to summarize the results of their implementation. In many countries, acute life support problems do not allow paying sufficient attention to other problems. The financial crisis of recent years restricts the possibilities to provide a global stability. All this has led to an underestimation of the significance of environmental aspects and the environmental substantiation of the concept in general.

The practice of implementation of the concept of sustainable development has led to a situation when the three aspects (environmental, economic, and social), which were initially announced as equal, are quite differently distributed in terms of importance. As before, the economic aspects are maximum in importance. They are followed by the social aspects, and minimum attention is given to the environmental problems, which initially formed the basis of the proposed developmental concept. In practice, the environmental recommendation does not receive adequate attention and is often not taken into account in decision making at various levels. Against the background of escalating environmental problems, which pose a real threat to the survival and successful development, the assessment of the current situation, its consequences, and possible ways of optimization requires special analysis.

It becomes apparent that it is very urgent to pay special attention to a number of points that are fundamentally important for the further development and implementation of the concept of sustainable development from the ecological and biological standpoint.

Notion of Sustainable Development

First of all, it concerns the very definition of the concept of sustainable development. Both the possibility and reasonability of combining the concepts of sustainability and development and the feasibility of plans for implementing the sustainable development principles still cause doubts. The situation can be optimized taking into account the experience of research in developmental biology, which led to the concepts, such as stability or developmental homeostasis, homeorhesis (or stabilized flow), that mean a system of mechanisms providing a successful development of any system. The fundamental importance of maintenance of developmental homeostasis, the deterioration of which entails the "crumbling" of the entire life support system at all levels (from organism to ecosystem), has been repeatedly demonstrated in real models (Waddington, 1957, 1970; Zakharov, 1987, 2000; Zotin, 1988). The experience of ecological and biological research not only shows the reality of sustainable development processes but also demonstrates the importance of the distribution of these ideas when defining the ways of development of the society and the biosphere in general. Despite all the technical and socioeconomic achievements, mankind remains a part of the biosphere, and the concept of sustainable development, in fact, is an application of the ideas about stability, or developmental homeostasis, with regard to the problems of social development. The very term "sustainable development" indicates the ability of the system to provide its development.

Purpose of the Concept of Sustainable Development

The environmental and biological substantiation is also of fundamental importance in defining the key motivations for the emergence of the concept of sustainable development.

The balance of the environmental pressure and capacity both within an individual ecosystem (from organism to community) and the biosphere in general is provided by the regulatory mechanisms (primarily the natural selection). These mechanisms limit the abundance of each species and ensure its harmonious combination with the capacities of other species and the ecosystem in general. This provided harmony between man and nature at the early stages of evolution. Further development opened up new opportunities, which allowed mankind partially to escape from the direct impact of natural selection. Using technical inventions, man managed to gain new opportunities for development, population growth, and satisfaction of needs. The man as if "segregated from nature," which gave an impression of the possibility of an unlimited growth and development. However, at the same time, this determined the emergence of a new challenge: whether man may go beyond the natural capabilities of the biosphere in the case of realization of the possibility of such an unrestrained growth (Meadows et al., 1994; Colborn et al., 1996; Brown, 2009; Pavlov et al., 2009). The awareness of the real threat of such growth for the biosphere and his own existence has led man to the formulation of the necessity to "bring himself back"—to fit his own steadily increasingly activity into the natural capabilities of the planet. The posing of this problem and the attempt to solve it determines the next stage of development. It is marked by the appearance of the concept of sustainable development.

In this aspect, the task of the noosphere development (Kamshilov, 1974; Teilhard de Chardin, 2002; Vernadsky, 2004) can be defined as the possibility of finding an answer to the major challenge: whether man himself, having largely escaped from the direct control of the natural regulatory mechanisms (primarily the natural selection), can provide his successful development within the natural capacity of the planet. Here, in a sense, we can talk about the possibility of distinguishing two aspects. The first aspect pertains to providing the balance of man and nature, technosphere and biosphere (homeostasis as such), and the second aspect is associated with providing the developmental stability (developmental homeostasis). In practice, these aspects are linked. On the one hand, the study of the homeostatic mechanisms providing the sustainability of biological systems of different levels (from organism to ecosystem) is increasingly becoming the subject the ecology. On the other hand, the mechanisms of homeorhesis are intended for providing sustainable development under conditions of continuous changes of various environmental factors.

The currently forming priority of increasing the value of natural resources and natural wealth in general, as well as man, his life, and health, which ultimately determines the level of development of any society, is evidence of awareness of the importance of the ecological and biological foundation of sustainable development (*Prioritety...*, 1999). In fact, this priority is the continuation of the general trend of progressive evolution to increase the value and importance of each individual by improving the homeostatic mechanisms and capacities at the organismal level (Zakharov and Trofimov, 2015).

From the ecological standpoint, it is clear that a necessary condition for the existence of mankind is the necessity to harmonize its demands (including both demographic and socioeconomic indices) with the capacities of the biosphere. Similarly, the solution of any problems must come from the existing biodiversity at both interpopulation and intrapopulation levels.

From the ecological and biological standpoint, it is clear that the coevolution of man and the biosphere began with his emergence and will continue throughout their coexistence. A critical challenge is to answer the question as to what this coevolution will be—a chain of accidents or a progressive development and what the results will be for the biosphere and, ultimately, for man himself. Everything that mankind can do to improve the environmental situation is not an act of humanity with regard to nature but only a condition of its own existence. Thus, careful attention to the solution of environmental problems does not contradict the priority of satisfaction of the needs of human development (anthropocentrism). Providing the health and a long-term successful development of mankind requires a careful attention to the well being and health of the environment as a prerequisite for such development (anthropomorphism) (Zakharov, 2000). The optimal solution to this problem should be based on providing the developmental homeostasis at all levels, from the human health and the harmonization of the development of society and biosphere to the health of the environment.

Sustainable Development: Relevant Environmental Problems

The necessity of the "greening" of human development is currently announced as the task of providing "green" growth and development. The main environmental problem today can be, apparently, defined as the widespread increase in global and local detrimental anthropogenic impacts. In this regard, the attention that is currently given to the world's climate change problem can only be welcomed. It should only be born in mind that this does not settle the problem of the detrimental anthropogenic impact, including the exhaustion of resources, landscape degradation, and environmental pollution. Even the elimination of the climate problem does not reduce the significance of the increase in the global anthropogenic impact. The task of extending the economic mechanisms that are being currently developed to reduce the greenhouse gas emissions to all types of anthropogenic impact (including various types of pollution) and all types of natural resources becomes increasingly obvious.

The steadily increasing anthropogenic impact poses a number of new challenges to environmentalists, which require the development of new approaches to solve them.

Due to the ubiquity of different types of local and global anthropogenic impacts, the search for the control rather than the study of impact ecosystems is becoming an increasingly complex task. This poses the task on the agenda to organize monitoring and to find new approaches to the definition of the concept of a conditionally normal background state of natural ecosystems (Zakharov and Trofimov, 2014).

The assessment of the climate change consequences requires an increasingly attentive attitude. The task shifts from the assessment of coastal and mountainous areas to the continental ecosystems, which appeared to be even more sensitive to these unusual climatic fluctuations. The problem of biodiversity conservation, recognized at the international community level, which implies the conservation of the original natural complexes, requires updating in view of the worldwide changes in the biodiversity due to climate changes (*Izmenenie*…, 2007, 2008).

In connection with the shift of the major types of anthropogenic impact on the nature from the transformation of landscapes to the increasingly wide spread of various types of pollution, the priority direction in the assessment of the consequences of these changes shifts from the biodiversity monitoring to the health of environment monitoring, which is associated with the assessment of the auspiciousness of conditions for the state of different species of living beings, including humans (Zakharov and Trofimov, 2011).

Stringent allowable thresholds of a certain impact or the deviations from the conditional norm caused by this impact, followed by irreversible changes, which are in high demand for management decision making in the field of sustainable development, usually do not have an unambiguous strictly scientific solution. Of fundamental importance in this case is the selection of approaches for adequately determining the "danger bar" level when making decision on the allowability of various impacts, determination of the assimilative capacity of ecosystems, and the health of environment assessment. Overstatement of the "danger bar" leads to an underestimation of the risk severity for both natural complexes and human health. The health of environment concept, which is based on the provision of developmental homeostasis, is aimed at establishing the "danger bar" at a level required to provide an auspicious environment for living beings, including humans, as well as at determining the conditional norm and environmental standardization in general.

Sustainable Development Provision

Currently, the top priority in sustainable development is to provide the compliance with the principles of "green" economy, implying the solution of socioeconomic problems at a minimized depletion of natural capital and detrimental impact on the environment (*Navstrechu*…, 2011). It requires the compliance with the environmental rules of harmonizing the needs with the natural capacities of an ecosystem. The growing needs of mankind can be met only if the environmental capacity of ecosystems is increased due to certain technical innovations. Today, this environmental thesis is formulated as the principle of "decoupling," i.e., the separation of the still tightly linked processes of economic growth, on the one hand, and the exhaustion of natural resources and the detrimental impact on the environment, on the other (*Decoupling*…, 2011). An increasingly complete characterization of the importance of the natural capital and ecosystem services is becoming a fundamentally important approach. Ideas about the natural wealth importance for the health of humans and the environment are being formulated (Bobylev and Zakharov, 2009, 2011). Here, the approaches aimed at assessing the homeostasis of living systems come again to the fore, because they are used in such assessments for different species of living beings, including humans.

In discussing the problems of sustainable development, politicians and economists more and more often express criticism of the market economy (Bobylev and Zakharov, 2011). Perhaps, from the environmental point of view, it would be worth raising the question of the necessity to separately consider certain target indices and the mechanism of their achievement. The "market" itself is a natural mechanism that is formed to meet specific needs. In this regard, it is, to some extent, similar to natural selection. If there is a request for certain goods and services, the market economy copes with its tasks perfectly. The essence of the problem is in the absence of a request of consumers (including the population and the state) for the "greenness" of products. Here again, the priority task is to provide an increasingly comprehensive economic assessment of natural resources and services (including in the cost the external positive and negative impacts—the so-called "internalization of externalities") taking into account the priority of increasing the value of natural resources and natural wealth in general.

The environmental priority of sustainable development can be formulated as the conservation of natural resources and the entire natural wealth to provide the planet's ecosystem homeostasis. To ensure an environmentally sustainable development, support should be aimed at introducing modern "green" technologies and conservation and enhancement of the natural wealth. To this end, the task of recruiting the countries with rich natural resources into this process is of principal importance. The maintenance of balance, homeostasis of the biosphere, and, therefore, the possibility of further development of all countries depends on how these countries will dispose of their natural resources in solving the problem of provision of economic growth. Environmentally posing the problem of the development of compensation payments required for the conservation and enhancement of natural ecosystems is extremely important.

In general, the success of advancement on the pathway of sustainable development, apparently, is largely defined by both the level of our environmental awareness and cultural level, which is a necessary condition for recognition of the importance of environmental priorities, and the economic opportunities for their implementation.

Success of Sustainable Development: Ecological and Biological Priority Provision

Thus, the ecological and biological priority as a necessity to fit our steadily increasing needs into the natural capacities of the planet, which originally served as a basis for the concept of sustainable development, retains its relevance, and its value only increases. This determines the necessity to include environmental considerations into the foundations of modern economy and general development plans. The "greening" of development should be implied when implementing the new Agenda to 2030 in achieving each of the specific objectives of sustainable development. The formulation of each objective should imply a mandatory provision of environmental sustainability as the basis for the survival and development of mankind.

The implementation of the environmental priority as a basis for sustainable development implies both a proactive stance of environmentalists in determining the pathways of development and the understanding of the importance of environmental considerations in decision-making in the field of sustainable development provision from a broad range of experts in socioeconomic problems.

CONCLUSIONS

Thus, the notion of developmental homeostasis, originating from the developmental biology, is of fundamental importance for the understanding of the processes taking place at all levels, from organism to ecosystem. It also offers new opportunities for the substantiation of the ecological and biological bases of sustainable development. Its application is constructive both in studying the ratio of homeostatic mechanisms of different levels and in assessing the significance of developmental homeostasis of an organism and population using the approach based on assessing the population status from the ontogenetic standpoint (population developmental biology and the health of environment concept).

REFERENCES

Bobylev, S.N. and Zakharov, V.M., *Ekosistemnye uslugi i ekonomika* (Ecosystem Services and Economics), Moscow: Institut ustoichivogo razvitiya/Tsentr ekologicheskoi politiki Rossii, 2009.

Bobylev, S.N. and Zakharov, V.M., *Modernizatsiya ekonomiki i ustoichivoe razvitie* (Modernization of Economy and Sustainable Development), Moscow: Ekonomika, 2011.

Brown, L.R., *Mobilizing to Save Civilization*, New York: W.W. Norton & Company, 2009.

Colborn, T., Dumanosky, D., and Peterson Myers, J., *Our Stolen Future*, New York: A Dutton Book, 1996.

Decoupling Natural Resource Use and Environmental Impacts from Economic Growth, UNEP, 2011.

Detlaf, T.A., *Temperaturno-vremennye zakonomernosti razvitiya poikilotermnykh zhivotnykh* (Temperature–Temporal Patterns of Development of Poikilothermic Animals), Moscow: Nauka, 2001.

Doklad ob osobennostyakh klimata na territorii Rossiiskoi Federatsii za 2016 god (Report on Climate Features in the Russian Federation for 2016), Moscow: Rosgidromet, 2017.

Gilbert, S.F., Ecological developmental biology: developmental biology meets the real world, *Russ. J. Dev. Biol.*, 2004, vol. 35, no. 6, pp. 346–357.

Gilbert, S.F. and Barresi, M.J.F., *Developmental Biology*, 11th ed., Sinauer Associates, Inc., 2016.

Homeostatic mechanisms of biological systems, *Russ. J. Dev. Biol.*, 2014, vol. 45, no. 3.

Itogovyi dokument Konferentsii OON po ustoychivomu razvitiyu "Rio+20" "Budushchee, kotorogo my khotim" (The Outcome Document of the UN Conference on Sustainable Development "Rio+20" "The Future We Want"), Rio de Janeiro, 2012 [Electronic resource]. http://daccessddsny.un.org/doc/UNDOC/GEN/N11/476/12/PDF/N1147612.pdf?OpenElement.

Itogovyi dokument sammita Organizatsii Ob"edinennykh Natsii po prinyatiyu povestki dnya v oblasti razvitiya na period posle 2015 goda: Preobrazovanie nashego mira:

Povestka dnya v oblasti ustoychivogo razvitiya na period do 2030 goda (The Outcome Document of the United Nations Summit on the Adoption of the Development Agenda for the Period after 2015: Transforming Our World: The Agenda for Sustainable Development for the Period up to 2030) [Electronic resource]. http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=R.

Izmenenie klimata i bioraznoobrazie Rossii (Climate Change and Biodiversity in Russia), Pavlov, D.S. and Zakharov, V.M., Eds., Moscow: Akropol', 2007.

Izmenenie klimata i bioraznoobrazie Rossii (Climate Change and Biodiversity in Russia), Pavlov, D.S. and Zakharov, V.M., Eds., Moscow: Akropol', 2008.

Kamshilov, M.M., *Evolyutsiya biosfery* (The Evolution of the Biosphere), Moscow: Nauka, 1974.

Meadows, D.H., Meadows, D.L., and Randers, J., *Za predelami rosta. Uchebnoe posobie* (Beyond Growth: Tutorial), Moscow: Izd. Gr. Progress, Pangeya, 1994.

Minin, A.A. and Voskova, A.V., Homeostatic responses of plants to modern climate change: spatial and phenological aspects, *Russ. J. Dev. Biol.*, 2014, vol. 45, no. 3, pp. 127–133.

Minin, A.A., Ran'kova, E.Ya., Rybina, E.G., Buivolov, Yu.A., Sapel'nikova, I.I., and Filatova, T.D., Phenoindication of climate changes for the period 1976–2015 in the central part of European Russia: white birch (*Betula verrucosa* Ehrh. (*B. pendula* Roth).), *Probl. Ekol. Monitor. Model. Ekosist.*, 2016, vol. 27, no. 2, pp. 17–28.

Navstrechu "zelenoi" ekonomike: puti k ustoichivomu razvitiyu i iskoreneniyu bednosti – obobshchayushchii doklad dlya predstavitelei vlastnykh struktur (Towards a "Green" Economy: Pathways to Sustainable Development and Poverty Eradication: Progress Report for the Representatives of Authority Structures), YuNEP, 2011.

Pavlov, D.S., Striganova, B.R., and Bukvareva, E.N., Ecological-centric concept: change in goals and principles of nature management, *Na Puti Ustoich. Razv. Rossii*, 2009, no. 50, pp. 25–29.

Prioritety natsional'noi ekologicheskoi politiki Rossii (Priorities of the National Environmental Policy of Russia), Zakharov, V.M., Ed., Moscow: Nauka, 1999.

Teilhard de Chardin, P., *Fenomen cheloveka. Vselenskaya messa* (The Phenomenon of Man: Universal Mass), Moscow: Airis-press, 2002.

Vedyushkin, M.A., Kolosov, P.A., Minin, A.A., and Khlebopros, R.G., Climate and terrestrial vegetation: a view from the standpoint of the phenomenon of hysteresis, *Lesovedenie*, 1995, no. 1, pp. 3–14.

Vernadskii, V.I., *Biosfera i noosfera* (Biosphere and Noosphere), Moscow: Airis-press, 2004.

Waddington, C.H., *The Strategy of the Genes*, London: George Allen & Unwin, 1957.

Waddington, C.H., Basic biological concepts, in *Na puti k teoreticheskoi biologii* (On the Way to Theoretical Biology), Moscow: Mir, 1970, vol. 1, pp. 11–38.

Zabota o Zemle. Strategiya ustoichivogo sushchestvovaniya. Rezyume. MSOP/YuNEP/VVF (Caring for the Earth. Strategy for Sustainable Existence. Summary of IUCN/UNEP/WWF), Gland, Switzerland, 1991.

Zakharov, V.M., *Asimmetriya zhivotnykh: populyatsionno-fenogeneticheskii podkhod* (The Asymmetry of Animals: A Population-Phenogenetic Approach), Moscow: Nauka, 1987.

Zakharov, V.M. and Clark, D.M., *Biotest: integral'naya otsenka zdorov'ya ekosistem i otdel'nykh vidov* (Biotest: An Integrated Assessment of the Health of Ecosystems and Individual Species), Moscow: Moskovskoe Otdelenie Mezhdunarodnogo Fonda "Biotest," 1993.

Zakharov, V.M. and Trofimov, I.E., Assessment of the health of environment: environmental regulation (assessment of the condition of natural populations by the developmental stability), in *Voprosy ekologicheskogo normirovaniya i razrabotka sistemy otsenki sostoyaniya vodoemov* (Problems of Environmental Regulation and Development of a System for Assessment of Water Bodies), Moscow: Tovar. Nauch. Izd. KMK, 2011, pp. 102–120.

Zakharov, V.M. and Trofimov, I.E., *Ekologiya segodnya. Ekologiya kak mirovozzreniye. Chelovek i priroda* (Ecology Today. Ecology as a World View. Man and Nature), Moscow: Departament Prirodopol'zovaniya i Okhrany Okruzhayushchey Sredy Moskvy, 2015.

Zakharov, V.M. and Trofimov, I.E., Homeostatic mechanisms of biological systems: development homeostasis, *Russ. J. Dev. Biol.*, 2014, vol. 45, no. 3, pp. 105–116.

Zakharov, V.M., Chubinishvili, A.T., Dmitriev, S.G., Baranov, A.S., Borisov, V.I., Valetskii, A.V., Krysanov, E.Yu., Kryazheva, N.G., Pronin, A.V., and Chistyakova, E.K., *Zdorov'e sredy: praktika otsenki* (Health of Environment: Practice of Assessment), Moscow: Tsentr ekologicheskoi politiki Rossii, 2000.

Zakharov, V.M., Zhdanova, N.P., Kirik, E.F., and Shkil', F.N., Ontogenesis and population: evaluation of developmental stability in natural populations, *Russ. J. Dev. Biol.*, 2001, vol. 32, no. 6, pp. 336–351.

Zakharov, V.M., Sheftel', B.I., and Dmitriev, S.G., Climate change and population dynamics: possible consequences (a case study of small mammals in Central Siberia), *Usp. Sovrem. Biol.*, 2011, vol. 131, no. 5, pp. 435–439.

Zotin, A.I., *Termodinamicheskaya osnova reaktsii organizmov na vneshnie i vnutrennie factory* (The Thermodynamic Basis of the Response of Organisms to External and Internal Factors), Moscow: Nauka, 1988.

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