ISSN 2079-0864, Biology Bulletin Reviews, 2013, Vol. 3, No. 4, pp. 247–260. © Pleiades Publishing, Ltd., 2013.
Original Russian Text © D.V. Risnik, S.D. Belyaev, N.G. Bulgakov, A.P. Levich, V.N. Maksimov, S.V. Mamikhin, E.S. Mil'ko, P.V. Fursova, E.L. Rostovtseva, 2013, published in Uspekhi Sovremennoi Biologii, 2013, Vol. 133, No. 1, pp. 3–18.

Approaches to Standardization of Environmental Quality: Alternatives to the Standardization System in Use in the Russian Federation

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Abstract—The main principles of the environmental standardization of hazardous impacts experienced by natural ecosystems and approaches to this standardization based on the analysis of in situ biological and physicochemical monitoring are described. The possibilities of applying standardization methods are discussed, including methods based on background and averaged values of the characteristics to be standardized, a model analysis of the effect of abiotic components on natural communities, and in situ technology of establishing local environmental standards. Some principles underlying the environmental standardization are presented. The classification of ecosystems by their environmental quality is described.

Keywords: environmental standardization, background values, mean values, model analysis, effect of abiotic factors on ecosystems, field standards, standard limits, assessment of environmental quality, diagnostics of the state of the ecosystem, causes of troubles, forecast of the state of the ecosystem

DOI: 10.1134/S2079086413040075

APPROACHES TO ENVIRONMENTAL STANDARDIZATION, ALTERNATIVES TO MAC

Standardization of Chemical Impacts Based on Background and Averaged Values of the Characteristics to Be Standardized

In the previous paper, we discussed the use of the background value of some characteristic as its admissible value. Thus, limiting values of the concentrations of phosphates and sulfates, as well as the mineralization are calculated in evaluating the ecotoxicological criterion of water pollution (Moiseenko, 1995).

A biogeochemical approach is also known to evaluating the limiting concentrations of chemical elements (especially, heavy metals), which, at the same time, are natural microcomponents in the water composition and common components of seawater (Patin, 1979). Each such element should have its own biologically admissible concentration range, which provides optimal conditions for the vital activity and functioning of organisms and communities in the ecosystem, respectively. The biogeochemical thresholds of this environmental tolerance can be evaluated as

$$L_{\mathrm{u}} = \bar{C} + 2S_L, \quad L_{\mathrm{l}} = \bar{C} - 2S_L,$$

where L_{u} and L_{l} are the upper and lower thresholds, respectively; $\bar{C}$ is the mean solute concentration in water; and S_L is the standard deviation of the sample used to evaluate $\bar{C}$. The factor 2 is a rounded value of Student's *t*-test with 95% confidence probability (the significance level $\alpha = 0.05$). The formulas given above neglect the number of observations in the sample and can be incorrect because the sample standard deviation is not exactly the real root-mean-square deviation, but rather an estimate with some error. When the number of observations is small, the procedure of interval estimation becomes incorrect. The normal distribution law should be replaced by Student's distribution.

Some researchers (Grodzinskii, 1988; Fedorov et al., 1977) proposed using the normal distribution law (the values that are most frequent or close to the mean correspond to environmental well-being) when searching for critically admissible points on the factor scale. With this assumption, the maximal and minimal values of a factor ($x_{\max}$ and $x_{\min}$) can be calculated from

$$\Phi\left(\frac{\bar{x} - x_{\min}}{\sigma_x}\right) = \frac{1 - P(\alpha)}{2},$$

$$\Phi\left(\frac{\bar{x} + x_{\max}}{\sigma_x}\right) = 1 - \frac{1 - P(\alpha)}{2},$$

where Φ is standard cumulative normal distribution function; $\bar{x}$ is the mean value of the factor; σ_x is its root-mean-square deviation; and $P(\alpha)$ is the confidence probability, which is commonly taken equal to 0.8, 0.9, 0.95, or 0.99. Transformed to a more common form, the formula becomes: $C_{\max} = \bar{C} + t_{\alpha;\infty}\frac{\sigma_C}{\sqrt{n}}$, $C_{\min} = \bar{C} - t_{\alpha;\infty}\frac{\sigma_C}{\sqrt{n}}$, where $\bar{C}$ is the mean solute concentration in water, σ_C is its root-mean-square deviation, and $t_{\alpha;\infty}$ is Student's coefficient at the given confidence probability and infinite number of degrees of freedom. As can be seen from the transformed formulas, the infinite number of degrees of freedom of Student's *t*-test makes this equation only applicable when the number of observations of the factor is in excess of 30–50.

G.S. Rozenberg et al. (Rozenberg et al., 2000, 2011) suggest introducing regional water-quality standards or basin-scale allowable concentrations (BACs) in the standardization of the anthropogenic load for dual-genesis substances or substances that form under the effect of natural and anthropogenic factors.

The concept of regional environmental standardization is based on the following principles:

—the anthropogenic impact should not lead to a deterioration of the environmental state of water bodies and a decline in their water quality;

—a specific water-quality characteristic of a given drainage area forms in any individual basin or its part (water management area) depending on natural and climatic conditions;

—the development and introduction of regional allowable concentrations are aimed at the preservation and restoration of favorable habitat of aquatic organisms and the normal functioning of ecosystems;

—the allowable regional concentrations will be evaluated based on systematic observational data in different ecological seasons.

As an example of evaluating BACs from data of observations at stationary points, regional water-quality standards (C_{RWQS}) were calculated for phosphates and nitrates for the Saratov Reservoir (Rozenberg et al., 2011). The C_{RWQS} was taken to be the upper boundary of the possible mean values of concentrations of this substance calculated by observational data using the following formula, which was discussed in detail in the monograph of A.V. Selezneva (Selezneva, 2007):

$$C_{\mathrm{RWQS}} = C_C + t_{\alpha;n}\frac{\sigma_{(C_c)}}{\sqrt{n}},$$

where C_C is the mean concentration of the solute in a background section, $t_{\alpha;n}$ is Student's coefficient with significance level $\alpha = 0.05$ (a confidence probability $P = 0.95$), n is the number of observations, and $\sigma_{(C_c)}$ is the root-mean-square deviation.

C_{RWQS} is a quantitative characteristic of solute concentrations in a water body at the most unfavorable situations caused by natural and anthropogenic factors of water-quality formation in the water body. Introducing C_{RWQS} allows the natural climate features of water bodies to be taken into account. Thus, the concept of evaluating C_{RWQS} is based on the principle of the inadmissibility of changes in water quality by value that exceed the natural variations of nitrate and phosphate concentrations.

In this case, this means that the basin-level or regional standardization refers to a narrow range of dual-genesis substances, i.e., the substances formed by both natural and anthropogenic factors (Selezneva and Seleznev, 2011). A natural feature is the fact that they characterize mineralization; these substances incldue cations and anions, as well as nutrients that form the specificity of natural water bodies. When speaking about basin-scale characteristics, we mean their narrow spectrum, which is to correct 15 or 20 CC of MAC in order to introduce this factor to take into account the natural features of each natural object. The term "basin standard" is used for a small river. In the case of large rivers, such as the Volga, Lena, Irtysh, or Amur, we should speak about the regional character of formation of surface water in the appropriate areas.

Calculations for the Saratov Reservoir have shown (Rozenberg et al., 2011) that C_{RWQS} radically differs from the MAC for fishery water bodies (*CMAC*) (*Perechen' rybokhozyaistvennykh normativov* ..., 1999). C_{MAC} are 2.85 times greater than C_{RQWS} in the case of phosphates and 23.33 times greater in the case of nitrates.

It should be mentioned that, essentially, C_{RWQS} corresponds to the maximal allowable load (Izrael', 1984). For the above formulas to be applicable to calculating such limiting concentrations, the concentration distribution of a solute must be normal; otherwise, the use of characteristics such as mean, variance, and Student's coefficient will be incorrect. This means that, before applying the above formulas, one should check whether the distribution of input data is normal; the concentrations that characterize the limiting values of the factor can only be calculated if it is normal. The normal distribution of solute concentrations is not common under natural conditions; therefore, it appears reasonable to evaluate the limiting concentration as the 95th quantile (the quantile for the confidence probability $P = 0.95$) of the distribution of concentrations in a background section. This will imply that 95% of the concentration values obtained by measurements in the background section are below the limiting concentration; this approach yields estimates independent of the type of distribution. In the particular case of a normal distribution, the value of the limiting concentration, which corresponds to the 95th quantile of the concentration distribution, will approximately coincide with the value obtained from the sum of the mean and confidence interval (see formulas above), and the closeness of those values will increase with the number of observations.

An alternative approach to taking into account the distribution type of the source data was proposed in the hydrological–biochemical method of estimating the environmentally allowable levels of heavy-metal concentrations (Frumin, 2000; Frumin et al., 1999). This approach is based on the incorporation of three aspects.

1. Hydrological aspect. The reference sample of normal functioning of an aquatic ecosystem should be taken based on the values of its characteristics in the period of full-scale water exchange. Thus, the analysis of metal concentrations in the water body over the given period makes it possible to evaluate the statistical standard (background concentrations).

2. Biogeochemical aspect. Based on the fact that aquatic organisms adapted to the environmental chemical factors during some period, we can state that the current mean concentrations of metals in water bodies are optimal for the biota inhabiting them, and the limits reflect the critical levels of metal concentrations in water. Thus, it is supposed that the mean metal concentrations over the full water-exchange cycle are optimal for the biota, since it has adapted to them.

3. Mathematical–statistical aspect. The approach used to determine the biogeochemical thresholds for metal concentrations consists of coordinating the threshold values with the natural variations in concentrations intrinsic to the water body. These variations are described using probability distributions. The sought threshold values are p quantiles x_p found from the equation

$$p = \int_0^{x_p} dF(t),$$

where $F(t)$ is the cumulative probability distribution function of metal concentration in the water body. The values of p are chosen within the interval 0.9–0.99, depending on the rigidity of requirements to the threshold values ($p = 0.9$ corresponds to the most rigid and $p = 0.99$, to the softest limitation). The construction of the probability distribution function is intended to reject outliers among the concentration values and to check the heterogeneity of observational series at different observation stations and for different seasons. Then, a homogeneous observational series can be formed and unified distribution functions can be constructed for each metal and used to calculate the admissible concentration levels.

It should be mentioned that all approaches mentioned above, except for the approach used by G.S. Rozenberg et al. (Rozenberg et al., 2000, 2011), suggest using the mean concentrations of solutes in the examined area over the examined period as the optimal characteristics of solute concentrations. However, there are no grounds to suppose that the mean concentrations are the optimal values. For example, pollutant concentrations at the sites of wastewater discharge are commonly high (hence their high mean concentrations), though this gives no grounds to claim that such high pollutant concentrations are optimal for the given area. Moreover, in this approach, an increase in pollutant discharges raises the boundaries of the standard. A way out of the situation is to use background values of solute concentrations, as was done by G.S. Rozenberg et al. (Rozenberg et al., 2000, 2011). Again, it is clear that, when assessing the state of a water body, one should take into account the state of biota, and not only concentrations or physicochemical characteristics.

Model Analysis of Effect of Abiotic Components on Natural Communities

Relationships between pollutants and biotic responses are often studied using various models and by analyzing the dose–effect relationship (Armand et al., 1991; Barinova, 1998; Vorobeichik et al., 1994; *Kompleksnaya ekologicheskaya otsenka* ..., 1992; Krivolutskii, 1988; Saliev, 1988; Stepanov, 1988, 1990, 1991; Tsvetkov, 1990; Hoek, 1997; Simpson, 1997). However, even positive correlations obtained using these models cannot adequately answer the question as to where the boundary between well-being and ill-being of biota is to be placed on the curves derived from these models and what will be the corresponding limiting pollutant standard. Since these standards (critical levels) were most likely chosen arbitrarily, no reasons for their selection are given in publications (Vorobeichik et al., 1994).

E.L. Vorobeichik et al. (Vorobeichik et al., 1994) consider three main approaches to more accurate environmental standardization. The first approach is based on the search for the limiting load as a specific critical point on the dose–effect curve, which relates the input (abiotic loads) and the output (ecosystem responses) characteristics. The construction of a full dose dependence based on experimental data over all gradient of the load is an indispensable condition for determining such point. The specific functions that have been used for the search for the critical point are given in the studies of M.D. Grodzinskii (Grodzinskii, 1988); Yu.G. Puzachenko (Puzachenko, 1990); R.B. Gate, Jr. and L.A. Nelson (Gate and Nelson, 1971); P.H. Becket, R.D. Davis (Becket and Davis, 1977); R.H. Jones, B.A. Molitoris (Jones and Molitoris, 1984); A.K. Singh, R.K. Rattan (Singh and Rattan, 1987) (cited by (Vorobeichik et al., 1994)).

The latter approach is a considerable reduction of the former, in that expert estimates are used to determine a single value of the output characteristic (irrespective of the loads), i.e., the value of parameter variation under natural conditions. The load corresponding to the output characteristic in this single point is taken as the limiting value. According to this approach, the limiting load is the maximal ineffective one, i.e., the load at which the indication characteristics do not differ significantly from the control value, Harrington's psychophysical scale (first two columns) with authors' supplements

Linguistic estimate	Intervals of values of desirability function		Linguistic estimate
Very good	1.00–0.80	1.00–0.63	Good quality
Good	0.80–0.63		
Satisfactory	0.63–0.37	0.63–0.37	Medium quality
Poor	0.37–0.20	0.37–0.00	Low quality
Very poor	0.20–0.00		

which has been established once and for all. This is the principle underlying the hygienic standardization in the establishing of MAC.

The third approach requires the involvement of external data, which, for example, relates to the improvement of the productivity of the water body.

For the environmental assessment of the state of soils and their quality standardization based on the dose–effect relationship, the following equation for the function of the state was derived in the general form (Yakovlev et al., 2009):

$$p = \gamma e^{\left(-\frac{\alpha}{R}\right)},$$

where p is a quantitative characteristic of soil state and R is a characteristic of soil response to the load. The unknowns γ and α are to be determined for each individual response to a specific load. In the practice, they are determined by solving the system of the two above equations for the pair of values R of the dose–effect response function, one of the values to be obtained for the maximal load that does not shift the soil beyond normal limits (the threshold load accepted in ecotoxicology or the lower environmentally allowable level (EAL) under biotic approach to standardization), and the second value to be determined for the minimal load that certainly shifts the soil beyond the limits of its possible rehabilitation (accordingly, the maximum of toxic impact or the upper EAL). This approach was used to introduce a scale of environmental assessment and soil quality. The methods and procedures that have been substantiated and specified include the estimation of the state of eroded soils, the estimation of air quality above an uncontrolled source of dust, the integral estimation of the state of soils under a multifactor load, and the environmental–economic assessment of the quality of land and waste disposal facilities. It is worth mentioning that, in this model, the boundary value of the maximal load under which the soil state remains standard ($R = 1$) is specified by the researcher, while the boundaries between other quality classes are obtained by dividing the response characteristic scale (from 0 to 1) into equal segments.

In the system of environmental control, E.L. Vorobeichik et al. (Vorobeichik et al., 1994) suggest that the standardization should be based on the methods of determining the limiting load as a critical point of a logistic function. The logistic function is chosen because the majority of dose relationships for ecosystem characteristics at technogenic pollution are S-shaped, so they can be adequately approximated by logistic equation. In this case, the inflection points of the logistic curve are the critical points (limiting values) that characterize the transfer of the system from one state to another at an increase in the value of the abiotic component. For this approximation, E.L. Vorobeichik et al. (Vorobeichik et al., 1994) used a logistic curve of the type

$$y = \frac{A - a_0}{1 + \exp(\alpha + \beta x)} + a_0,$$

where y is parameter estimate; x is load estimate; α, β are coefficients; a_0 is the minimal level of y; and A is the maximal level of y. In this case, the coefficients evaluated by the least-square method or by Marquardt iteration method of numerical evaluation can be radically different.

E.S. Bikbulatov and I.E. Stepanova (Bikbulatov and Stepanova, 2011) theoretically analyzed the potentialities of applying the Harrington desirability function to assessing the state of natural ecosystems. A partial Harrington desirability function (d_i) has the form

$$d_i = \exp(-\exp\{-x_i\}), \quad 0 \le d_i \le 1,$$

where x_i is a coded value of the ith characteristic, i.e., its value at a conventional scale. This function allows the desirability values to be obtained by one of the four methods:

(1) by specifying the most desirable value of the parameter based on the form of its empirical distribution function;

(2) by the left and right boundaries of the range of desirable values;

(3) by the left boundary and the position of optimal desirability;

(4) by the right boundary and the position of optimal desirability.

The desirability function, which takes values within the range of 0–1, characterizes the transformation of the quantitative value of a specific characteristic to be standardized into a qualitative estimate of the desirability (preferability) of some state of the object being estimated; the conditions were evaluated based on the concentrations of some chemical components (Bikbulatov and Stepanova, 2011). Among the methods of realizing the desirability function for the appropriate assessment, the authors chose Harrington psychophysical scale, which is widely used in different fields (table). The numerical preference system represented in this table is dimensionless.

To assess the well-being of a system based on an individual initial characteristic by specifying the left and right optimal boundaries, the right boundary (x_r), which corresponds to a domain that is satisfactory or better, was taken to be equal to the arithmetic mean plus the root-mean-square deviation ($x_m + \sigma$), and the left boundary (x_l) was taken to equal the arithmetic mean minus the root-mean-square deviation ($x_m - \sigma$).

After all particular characteristics were converted into their dimensionless desirabilities, a generalized Harrington desirability function can be constructed as follows:

$$D = \sqrt[n]{d_1 d_2 d_3 \ldots d_n}.$$

The particular desirability functions were used to determine the ranges of quality classes (five-point scale from the table) for the concentrations of ions of ammonium, nitrites, nitrates, phosphates, total nitrogen and phosphorus, organic carbon, BOD_5, and COD for experimental stations on the Rybinsk Reservoir. Tables were compiled, which enables the results of subsequent measurements to be used to assess the current state of the Rybinsk Reservoir ecosystem in terms of biogenic elements and organic matter.

It was emphasized (Bikbulatov and Stepanova, 2011) that, if at least one particular response or particular function does not meet the requirements, the general estimate based on D can be unsatisfactory, whatever good the other characteristics (properties) of the studied system may be.

A more rigid condition of the estimate being unsatisfactory is a value of $D = \min_i \{d_i\}$.

In situ Technology for Establishing Local Environmental Standards

Because of its environmental inefficiency, the MAC-based standardization should be replaced by the biotic concept of environmental control as follows (Abakumov and Sushchenya, 1991; Levich, 1994; Maksimov, 1991):

—the state of natural ecosystems should be assessed by the characteristics of biological components (biological indicators), rather than the levels of the environmental factors;

—this assessment should be made in situ, rather than in vitro;

—the boundaries of the standards of environmental factors should be introduced as levels that do not disturb the standard of the environmental state established by biological indicators.

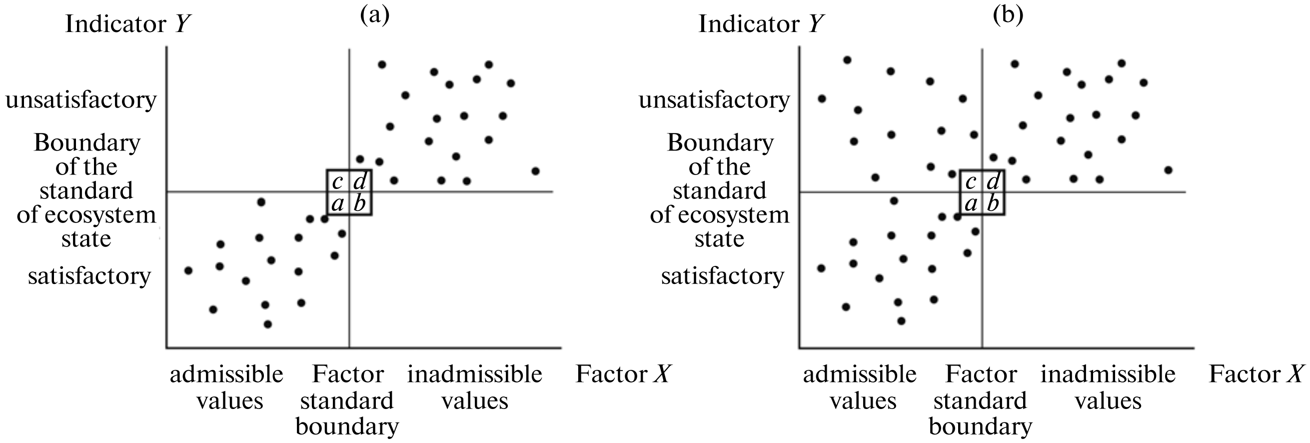
The idea of implementing the biotic concept of transfer from laboratory MACs to field standards seems to be obvious; one should analyze the dose–effect relationship for environmental factors and bioindicators. However, the implementation of this idea faces fundamental and, hence, methodological difficulties.

1. In the establishment of standards in the laboratory, the concept of an environmental standard appears to be a conventionally assumed threshold of a test parameter for test organisms. This standard can be, e.g., the death rate in the laboratory population declared by experts. In the case of natural ecosystems, it is reasonable to abandon the expert (subjective) establishment of the threshold value. Another example is that the deviation from the environmental standard is assumed to be a statistically significant excess of test parameter values in a check experiment. This approach is also impractical as applied to natural objects, since the researchers have no other (check) experiment except for the passive experiment that humans are carrying out in the nature at their habitat and at the sites of their economic activity. Therefore, a scientifically sound definition (and a determination method) should be introduced for the notion of the "environmental standard of a natural object."

2. Scientific, technological, and managerial criteria should be developed for the selection of biological indicators that characterize the state of natural objects and that correspond to the objectives of environmental control.

3. Under the controlled conditions of laboratory experiments, well-organized dose–effect relationships are single-valued functions, which can be studied using correlation, regression, and other types of statistical analysis. In natural ecosystems, biological characteristics are subject to the joint effect of many environmental factors, only a part of which is included in monitoring programs. The dose–effect diagram in this case is a poorly organized cloud of points. Therefore, a method should be found that enables one to establish a relationship between the variables and to find correlations that one cannot see when analyzing pair dependences between the bioindicator and individual factors.

A method for analyzing poorly organized data is the passage from quantitative variables to their qualitative classes (Levich, 2011; Levich and Mil'ko, 2011). These classes can be low, medium, and high values; satisfactory and unsatisfactory, admissible and inadmissible values, etc. After the qualitative classes are identified, correlations and other types of relationships between the qualitative classes of different variables can be sought. The application of the analysis of qualitative variables faces at least two difficulties. The first is the choice of an objective criterion for identifying qualitative classes, i.e., what criteria should be used to classify the values as high or low, admissible or inadmissible. The second difficulty can be most clearly seen in the search for a relationship between biotic and abiotic characteristics of natural ecosystems. It is related to the above-mentioned irremovable effect of all environmental factors on the indicators, i.e., any combination of factors that can cause environmental



Classes of values of an indicator and a factor in (a) an ideal case where the indicator is only affected by one factor and (b) in a real observation, where the indicator is affected by a number of factors.

ill-being. The consequences of this circumstance in the analysis of field dose–effect relationships should be considered in more detail.

The qualitative classes for a biological indicator are classes of satisfactory and unsatisfactory values, which indicate the environmental well-being or ill-being of the biota, respectively. In the case of a factor, these are classes of admissible and inadmissible values. If some biological characteristic Y is indeed an indicator of the effect exerted on biota by factor X, then the satisfactory values of indicator Y will occur in ecosystem observations only combined with admissible values of factor x, while unsatisfactory values of indicator Y will only occur when combined with inadmissible values of factor X. This ideal case is reflected in figure (a), where the boundary between satisfactory and unsatisfactory values is called “the boundary of ecosystem standard state,” while the boundary between admissible and inadmissible values of the factor is called “the boundary of the standard of the factor.”

Figure (b) presents a typical real distribution of the results of observations of indicator characteristic Y and some factor X. This distribution differs from the ideal case given in Figure (a) by the presence of observation points in domain c. The large number of points in domain c is due to the effect of all factors that exist in the environment on the indicator. While the correlation is high for the qualitative classes in Figure (a), the correlation analysis for real distributions (Figure (b)) may give no convincing results. However, if indicator Y really reflects a significant response to the effect X, domain b in Figure (b) must be empty. In other words, inadmissible values of factor X should never lead to satisfactory values of the indicator, whatever the effect of other factors. However, some points can occasionally fall into domain b, so the requirement that it must be empty should be softened to the requirement that the number of points in domain b should be as small as possible.

The approach that can be called a method of establishing local environmental standards (LES method) or a method of partial correlations between qualitative variables realizes the idea of searching for domain b, which contains a minimal number of points (Levich et al., 2011). The name and essence of the method has a history, including the method of environmentally admissible concentrations (Zamolodchikov, 1993), the method of environmentally admissible levels (Levich et al., 2004; Levich and Terekhin, 1997), the method of environmentally admissible standards (Levich et al., 2010), and the method of establishing environmental standards (Levich and Mil’ko, 2011).

In those studies, the authors analyze the relationship between bioindicators and factors in the context of LES method using Chesnokov’s accuracy criterion, i.e., the degree of emptiness of domain b relative to domains a and d is characterized by the accuracy of indicator $T_{\text{ind}} = \dfrac{n_a}{n_a + n_b}$ and the accuracy of factor $T_{\text{fact}} = \dfrac{n_d}{n_d + n_b}$; here n_a, n_b, n_c, and n_d are the numbers of observations in the appropriate domains in the figure.

However, the accuracy coefficient characterizes the degree of emptiness of domain b irrespective of whether this emptiness is due to the dependence of bioindicator on the factor or the individual distributions of the bioindicator and the factor. For example, boundaries of standards were drawn for the indicator and the factor, where satisfactory values of the indicator accounted for 10% of all its values, while the inadmissible values of the factor accounted for 15% of them. In the case where there is no dependence, the shares of satisfactory and unsatisfactory values of the bioindicator do not depend on the qualitative class of the factor, i.e., the share of satisfactory bioindicator values for both admissible and inadmissible values of the factor is 10%, implying the accuracy of the factor of 0.9. Similarly, the share of inadmissible factor values for both satisfactory and unsatisfactory bioindicator values is 15%, which implies that the accuracy of the indicator is 0.85. Thus, we have high accuracy determined only by the distributions of the bioindicator and the factor, where the bioindicator does not depend on the factor. Therefore, we need to modify the accuracy criterion to take into account the effect of the specificity of statistical distributions of each characteristic on the accuracy. S.V. Chesnokov referred to the modified criterion as essentiality coefficient (Chesnokov, 1982).

Essentiality characterizes the increment in the share of correct forecasts of one characteristic attained using data on the values of the other (Mirkin, 1980). In other words, the essentiality is the accuracy of determination, e.g., the accuracy of an indicator (the degree of emptiness of domain b as compared with domain a) less the analogous accuracy in the case where there is no relationship between the examined bioindicator and factor, i.e., the accuracy determined by the distribution of the factor alone. The essentiality of the determination, which characterizes the degree of emptiness of domain b as compared with domain a (the essentiality of the indicator) is calculated as $C_{\text{ind}} = \frac{n_a}{n_a + n_b} - \frac{n_a + n_c}{N}$. The essentiality of determination, which characterizes the degree of emptiness of domain b compared to domain d (the essentiality of the factor) is calculated as $C_{\text{fact}} = \frac{n_d}{n_d + n_b} - \frac{n_d + n_c}{N}$. The resulting essentiality of determination, which characterizes the emptiness of domain b compared to domains a and d can be described by the coefficient $C = \sqrt{C_{\text{ind}} C_{\text{fact}}}$.

The algorithm of the method consists of trying all possible positions of boundaries for both the biological indicator and the physicochemical factor in order to choose two boundaries for which the coefficient of resulting essentiality is maximal. The algorithm includes several additional conditions.

1. The number of observations in domains a and d of the plot (figure) should be representative enough for the result of the search to be reliable. The representativeness of an indicator can be described by the value $\text{REP}_{\text{ind}} = \frac{n_a}{N}$, and the representativeness of a factor by the value $\text{REP}_{\text{fact}} = \frac{n_d}{N}$; here, n_a and n_d are the numbers of observations in domains a and d, respectively, and N is the total number of observations. Each representativeness should be greater than a specified search parameter $\text{REP}_{\min}$ ($\text{REP}_{\min}$ generally varies in the range of 0.15–0.25).

2. The reliability of search results can be guaranteed if the total number of observations N is not too small, i.e., $N > N_{\min}$, where $N_{\min}$ is one more search parameter (it is commonly chosen in the range of 30–80). Moreover, to judge the significance of the relationship by the χ^2 test, one should take into account the minimal number of observations for the test to be applicable. For two quality classes by both characteristics, the minimal number of observations is 20 (for the applicability of Yates correction for continuity); the minimal number of observations for three and more classes is 40 (Afifi and Eisen, 1982). It is worth mentioning that this parameter can be found in any method based on the analysis of some experimental data, but it is not generally declared (though it is clear) that the result derived from three observations is less reliable than that derived from 1000 observations. For example, the softest empirical rules regarding sample volume for correlation analysis $N_{\min} = 58$ (Green, 1991) and factor analysis $N_{\min} = 50$ (Pedhazur and Schmelkin, 1991).

3. The significance of the established relationship is determined by whether χ^2 is greater than some tabulated value depending on the specified significance level. Therefore, the significance level of the χ^2 test is also a parameter in the search to be specified by the researcher (the significance level $\alpha = 0.05$–0.10 is generally used).

4. To make it possible to state that domain b is empty compared to domains a and d, the chosen criteria of the accuracy of the indicator and factor should be not less than a search parameter $T_{\min}$ specified by the researcher (the value of $T_{\min}$ is commonly taken within the range of 0.8–0.9).

The algorithm of the method simultaneously evaluates both boundaries of the standard (for both the indicator and factor) if they exist. The boundary of the standard for a biological characteristic separates the indication of satisfactory and unsatisfactory states of the ecosystem, while the boundary of the standard for a factor separates its admissible and inadmissible values.

If the algorithm with the specified search parameters finds a domain b that is empty enough in the configuration of data, this means that the examined factor is significant for environmental ill-being reflected in the examined indicator. When there are no search results, this can mean the following:

(1) that all values of the factor in the examined array were only admissible and, hence, the factor is insignificant for environmental ill-being;

(2) that all values of the factor were inadmissible, as a result of which its contribution to ill-being is significant;

(3) that all values of the indicator were only satisfactory, i.e., none of the factors had an adverse effect;

(4) that all values of the indicator were only unsatisfactory, i.e., in any observation, at least one cause led to environmental ill-being;

(5) the examined biological characteristic is not a good indicator of the effect of the factor under consid-

eration. The algorithm of the method makes it possible to analyze those possibilities.

In some cases, ecosystem ill-being can be caused by low rather than high values of a factor (e.g., oxygen content of water) or both very high and very low values (e.g., the concentrations of biogenic elements in soil or water). The algorithm of the method enables one to search for either upper or lower boundaries of the standard separately or double-sided search. The boundaries of standards for indicators can also be lower (e.g., low values are bad for the efficiency of photosynthesis), upper (e.g., high values are bad for the death rate of organisms), or double-sided (e.g., both low and high diversity of communities can be an indication to the ill-being of biota). The algorithm of the method allows all variants to be examined. The approach to the search of relationships between biotic and abiotic characteristics of ecosystems can serve as a basis for a set of methodologies for environmental control using joint data of biological and physicochemical monitoring of natural objects. This set can be called the in situ approach, including several methodologies.

1. The methodology of evaluating the biological characteristics of ecosystems, which are taken as bioindicators of their state.

2. The methodology of environmental diagnostics of the state of ecosystems, which is understood as a procedure for identifying environmental factors significant or insignificant for the environmental ill-being of biota.

3. The methodology of environmental standardization, including both the establishment of a standard of ecosystem well-being (a boundary between the satisfactory and unsatisfactory values of state bioindicator) and the establishment of standards for significant factors, i.e., boundaries between their admissible and inadmissible values, where the latter corresponds to the ill-being of the ecosystem.

4. The methodology of ranking significant factors by their contribution to environmental ill-being, which is based on the completeness criterion $\Pi = n_d/N^-$ for the examined factor, where n_d is the number of observations unsatisfactory in terms of the indicator and inadmissible in terms of the factor and N^- is the number of observations unfavorable in terms of the indicator in the entire data body under study (i.e., at any values of all factors). The higher the completeness of a factor, the greater the share of unfavorable observations it accounts for, i.e., the greater its contribution to the ill-being of biota.

5. The methodology that allows one to determine the sufficiency of the monitoring program of environmental factors that cause environmental ill-being. The criterion of sufficiency is based on the value $D = M^-/N^-$, where M^- is the number of observations inadmissible in terms of at least one factor, N^- is the total number of observations unsatisfactory in terms of the indicator. The larger the sufficiency, the grater the share of environmental ill-being described by the factors included in the monitoring program.

6. The methodology of environmental quality assessment in individual observation points of biological and physicochemical characteristics of the ecosystem for certain observation date. The estimate (KI) was introduced in (Bulgakov et al., 2010) as the ratio of the value of bioindicator (I) for the given point and date to the value of the boundary of the ecosystem state standard (BES), which was established for this indicator by the LES method as follows: KI = I/BES. The formula is given for the case of the lower boundary of the standard for indicator; it can be readily generalized for other cases of ranking of indicator values. The methodology can also be generalized in a standard manner to the cases of assessing the state of the territory (basin) and/or observation period, including a set of dates and points, by averaging individual KI estimates over them.

7. The methodology of revealing the causes of environmental ill-being for individual dates and points and their sets by comparing the current values (F) of environmental factors with factor boundary standards (FBS) established by LES method. The value of criterion KF = F/FBS allows one to reveal the factors that contribute most to ill-being.

8. The methodology for predicting the state of an ecosystem by scenarios of anticipated impacts, i.e., the comparison of factor values from a scenario with established values of FBS makes it possible to uniquely determine the degree of environmental well-being for the natural object subject to impacts (Bulgakov et al., 1977).

9. The methodology of environmental quality control, including a comparison of the actual values of environmental factors with FBS values, allows one to choose the most hazardous factors and optimal ways of reducing the load onto the natural object for it to reach the state of environmental well-being.

The choice of a correct bioindicator of the environmental state is a key point in the entire in situ technology. The application of this technology to different indicators makes it possible to choose them reasonably, since it provides some quantitative criteria for this choice, i.e., the degree of universality of the indicator boundary standard for different factors, the ability to indicate a wide range of factors, the sensitivity to variations of factors, criteria of accuracy and representativeness of the search of boundaries, the sufficiency of monitoring program, etc.

The LES method establishes two LES boundaries (figure). The first is the boundary of ecosystem state standard; it separates the values of the indicator that correspond to satisfactory and unsatisfactory states of the ecosystem. In fact, we speak about quality classes for an ecosystem. In this study, the method is considered in the simplest case of two quality classes. The methodology and the procedure of calculations in the

LES method can be generalized to an arbitrary number of quality classes that correspond to different degrees of environmental well-being. This generalization preserves the rejection of the subjective (expert) introduction of boundaries of classes, which instead suggests their quantitative substantiation. Second, the factor standard boundary separates the admissible and inadmissible values of the factor; those values should lead to satisfactory and unsatisfactory values of the factor, respectively.

From the viewpoint of environmental control problems, the boundaries of the factor standard in the zones subject to local monitoring from the data on which they have been derived can be identified with local field standards, which can replace universal laboratory MACs. This means that they could be replaced in all methodological instruments of environmental control, including the evaluation of standards of admissible impact levels, evaluation of discharges and releases, schemes of integrated use of natural objects, etc.

Some regulatory documents (e.g., RF Water Code, Cl. 33) propose means for nature protection activities, such as target values of biological and physicochemical environmental characteristics. However, there are no approved methodological approaches to evaluating these characteristics. The procedure of LES calculations can become the required regulatory document for calculating target characteristics.

Another environmental problem, the solution of which can be facilitated by LES, is the assessment of background concentrations of solutes. Universal laboratory MAC standards are useless as applied to geochemical provinces with radically different background concentrations of solutes. In environmental calculations, the standard is commonly taken to be one of two values, i.e., MAC or background level. To assess background values, one must have areas that are not subject to anthropogenic load, as well as a fairly long time series of measured solute concentrations. The problem is the lack of either the areas not subject to anthropogenic load or observation data on such areas when they are available. The replacement of laboratory MAC by field standards, i.e., the boundaries of factor background standards, eliminates the problem of evaluating background concentrations, since LESs are certainly found taking into account the background concentrations and the adaptation of biota to them in the natural objects, data on which are used in the method.

The advantages of field standards (FSs) over laboratory MAC are as follows:

1. FSs are local, rather than universal, in both space and time, i.e., they can be different in different regions, in individual natural objects, at different stages of biological season, and in different periods of ecosystem development.

2. FSs take into account the background concentrations of substances with no need to measure them.

3. FSs take into account full complexes of hazardous impacts that exist in the nature rather than their isolated impacts.

4. FSs take into account many indirect effects of impacts, the joint effect of whichcan be stronger than their direct effect.

5. FSs take into account long-term effects of impact on biota.

6. FSs can be calculated not only for pollutants, but also for factors of a nonchemical nature, such as thermal, radiation, and hydrological factors (Levich et al., 1998; Maksimov et al., 2009);

7. Both the upper and lower values can be calculated for FSs.

8. FSs can be differentiated for natural objects used for different purposes and for different requirements to environmental quality.

9. The values of FSs can be improved with the accumulation of new data and the adaptation of biota to disturbing impacts.

Note some assumptions and limitations of the LES method. The concept of environmental standard (and environmental quality) can only be correctly formulated for a certain biological indicator. The accepted notion of an environmental standard is only associated with the prehistory of a natural object. The method does not introduce any model concepts or hypotheses into the analysis of monitoring data. The method consists exclusively of calculating the occurrence of satisfactory and unsatisfactory, and admissible and inadmissible values of environmental characteristics in the prehistory, i.e., it deals only with the primary monitoring data. However, the method does not use a priori ideas regarding well-being and admissibility. The establishment of appropriate boundaries is the main result of using the method. It does not require the distributions of input data to satisfy any statistical criteria.

The standards established using the method are local, since they are based on local monitoring data.

The method does not allow one to calculate the boundaries of a standard when the prehistory does not contain effects that lead to environmental ill-being (or, contrary to that, does not contain satisfactory states). The method works only when a fairly large body of data on both the biological and physicochemical characters is available (the sufficiency is understood as the necessity to exclude random and unreliable configurations of data according to the specified search parameters).

If there are no monitoring data available, the application of laboratory MAC standards is justified. MAC standards can play a preliminary role; new substances can be analyzed in the laboratory long before the necessary data are accumulated in the nature. Let us consider some data to explain the role of LES method in the control system based on MAC standards. About 5×10^7 substances that circulate in the biosphere have some effect on the biota. MAC standards are available for about 10^3 substances. The programs of physicochemical monitoring in Russia involve the measurement of about 10^2 characteristics. Accordingly, the LES method can propose the improvement of about 100 MAC standards (along with new standards for factors of nonchemical or chemical nature, for which there are no MAC standards at all). However, these 100 characteristics are essential to environmental well-being in regions; because of this, they were included in local monitoring programs. The number of possible LESs is small compared to the number of established MACs because of the limitedness of monitoring programs rather than limitations of the method. The demand for new LES can serve as a stimulus for extending monitoring programs.

For in situ technology, bioindicators are not used for academic purposes, but rather for the inclusion of methods determining them in the nationwide system of mass environmental control. We emphasize two circumstances, which, among others, can influence the choice of bioindicators. The first can be called the principle of instrumentality; instrumental methods of biological data analysis should be preferred to manual methods. Let us illustrate this idea in the case of the choice of indicator characteristics for phytoplankton communities.

The use of saprobity index involves calculating the number of cells for the saprobity indicator species in each sample. Phytoplankton researchers should know hundreds of species included in tables of indicator organisms by their appearance. This work requires one to have high biological qualification and experience.

On the other hand, when using the diversity characteristics of communities, one need not know the names of individual species, but one should be able to distinguish between them. However, the difficult work of counting the cells is still a manual procedure for a qualified performer.

There are reasons to propose dimensional structure characteristics (DSCs) of phytoplankton communities as a bioindicator (Risnik, 2011; Risnik et al., 2011). The measurement of cell sizes can be fully automated in the real-time regime (method of flow cytofluorometry, evaluation of cell number and volume using a Coulter counter, and digital image processing) (Lyakh et al., 2002). The application of DSCs for bioindication implies qualified preprocessing, i.e., the substantiation of the division of the set of cells in the sample into dimensional classes, the choice of a method for DSC evaluation, the development of a procedure for isolating the effect of factors associated with environmental quality on DSC from the effects of other factors, studying the effect exerted on the indicator properties of DSC by errors in the evaluation of sizes and numbers of cells, the search for a threshold in the range of DSC measurements that separates the environmental well-being and ill-being, and the development of software for an instrumental system for evaluating cell sizes and numbers that will transform the results of measuring the results of environmental control. The latter refers to evaluating states of the ecosystem that are applicable to the implementation of all other stages of in situ technology, i.e., diagnostic, standardization, prediction, quality control, etc. After the methodological work is completed, the hardware and software complexes will be able to work on a consistent basis all over the environmental control network and will not require the involvement of experts for processing biological samples at each observation point.

A characteristic that is even more promising for bioindication is photosynthesis efficiency indicator based on the instrumental measurement of plant fluorescence. Photosynthesis, which forms the basis of all biological processes on the planet, is sensitive to a wide range of factors; therefore, it can be proposed as a basic and widespread indicator of environmental quality in different biotopes. The instrumental base for fluorescence measurements has been developed long ago, and is now in widespread use in biological and environmental observations (Matorin et al., 2010; Pogosyan et al., 2009). The development of a methodological and information base that makes it possible to use fluorescence characteristics to assess the environmental state of natural objects will make fluorescence measurements an efficient online instrument of environmental control.

The second circumstance of importance for environmental control system can be called the principle of anthropocentrism. The environmental control has many purposes. In addition to broadly understood nature protection, it is aimed to ensure the environmental safety of the population. With this aim in view, would not it be more reasonable to use human population characteristics as bioindicators? The necessary indicator characteristics are available from a large body of long-term data of medical statistics. These include the local birth and death rate characteristics, as well as the incidence of diseases differentiated by age groups and groups of diseases. The method of establishing LES can identify the effect of environmental quality against a background of many other factors that govern the values of demographic and medical characteristics.

The implementation of in situ technology will face many managerial problems, including the following:

—the decision-making authorities disregard the imperfectness of the environmental quality standards now in force, i.e., laboratory MACs;

—natural objects are not fully covered by the biological monitoring system;

—the potentialities of modern express instrumental methods of biological monitoring do not receive adequate attention;

—the retrospective and current data of state and sectoral environmental monitoring and medical statistical data are difficult to access.

Some Principles Underlying Environmental Standardization: Classification of Ecosystems Based on Environmental Quality

The environmental standard is a result of the procedure of measuring some environmental characteristics and their joint analysis. Therefore, these procedures form the methodological basis of the environmental metrology, i.e., the science of measurement and methods, as well as means for ensuring their integrity and required accuracy (Nikiforov, 2002). The subject of environmental metrology is the comprehensive control of the environmental state of a natural object and the choice of the most informative criteria for assessing its state by biotic and medical–demographic indices.

In the assessment of the environmental state of natural ecosystems and the implementation of environmental standardization, it is reasonable to identify several classes of states (Zykov and Chernyshov, 2008):

(1) the zone of environmental standards, which contains natural objects that show no appreciable decrease in production, sustainability, or stability;

(2) the zone of environmental risk, which contains natural objects with an appreciable decrease in production and stability and an unstable state that leads to the future spontaneous degradation of ecosystems, albeit with reversible disturbances;

(3) the zone of environmental crisis, which contains natural objects with a large drop in production, a loss of stability, and nearly irreversible disturbances;

(4) the zone of environmental disaster, which contains natural objects with the complete loss of production and practically irreversible disturbances that exclude the ecosystems from economic use.

Based on the notions of metrology, the concept "environmental standardization" refers to the scientifically sound regulation of economic or other activity or the restriction of its effect on biosphere resources aimed at protecting both the socioeconomic interests of the society and its environmental demands (Zykov and Chernyshov, 2008). The developed and approved regulations become environmental standards. Russia has no unified scientific classification of these standards. The authors propose three major categories of environmental standards to be identified and used or developed for nature development control, i.e., (1) environmental standards for ecosystems; (2) quality standards for environmental components; (3) standards of environmental anthropogenic impacts, including technical and technological standards. The environmental standard thus defined is a boundary of the quantitative variations of ecosystem parameters established to ensure the preservation of ecosystem structure and functions, as well as all ecological components to be taken into account in economic activity.

V.N. Zykov and V.N. Chernyshov (Zykov and Chernyshov, 2008) give the basic principles underlying the environmental standardization as follows:

(1) the principle of objective, i.e., the priority of long-term consequences for society and nature over short-term economic interests of individual nature users;

(2) the advance principle, i.e., studies for the development of standards are to be carried out before the anticipated impact begins;

(3) the threshold principle, i.e., the establishment of critical threshold levels of the impact of economic activity, which ensure the environmental safety;

(4) the self-regulation principle, i.e., both positive and negative feedbacks are to be taken into account in economic activity; the positive and negative environmental effects in the systems of stimulation of socioeconomic development are to be in balance;

(5) the weak-link principle, i.e., the environmental well-being of the system as a whole will be attained with the attainment of the well-being of its most vulnerable component;

(6) the principle that more does not mean better, i.e., the intensification of technical–economic development by qualitative transformations, possibly without an increase in the quantitative characteristics;

(7) the jujitsu principle, i.e., the maximal use of intrasystem forces that can act in a positive direction and compensate for the negative anthropogenic impact;

(8) the principle of reduction of specific risk, i.e., the development and stimulation of ways of material consumption that reduce the anthropogenic load on the unit area and unit production.

CONCLUSIONS

When compiling this analytical review, the authors tried to generalize many current works in the field of environmental standardization that combine this with some scientific criticism with respect to individual approaches and methods. The main results of this analytical work appears to be the conclusion that the most promising up-to-date methods and approaches to ensuring the appropriate environmental quality are those that enable the comparison of some indicator biological characteristics of ecosystems derived from in situ observations with the values of physicochemical characteristics of these ecosystems, the identification of factors of potential hazard for biota based on this analysis, and the evaluation of boundaries of standards for both indicators and factors. The efficiency of environmental control based on these methods depends on (1) the simplicity and practicability of bioindication methods and (2) the availability of a large enough body of joint data on bioindicators and physicochemical components of ecosystems over a fairly long period. The authors believe that these are the directions in which environmental standardization in Russia should develop.

ACKNOWLEDGMENTS

This study was partially supported by the Russian Foundation for Basic Research, project no. 12-07-00580-a, "Theoretical Substantiation of in-situ Methodology for Establishing Local Boundaries of Standards of Biological and Physicochemical Characteristics of Natural Ecosystems," "Search for the Boundaries of Standard for Bioindicators of Environmental State: Characteristics of Rapid Fluorescence of Phytoplankton in Natural Waters").

REFERENCES

Abakumov, V.A. and Sushchenya, L.M., Development of hydrobiological monitoring of freshwater ecosystems, in *Ekologicheskie modifikatsii i kriterii ekologicheskogo normirovaniya. Trudy mezhdunar. simpoziuma* (Trans. Int. Symp. "Ecological Modifications and Criteria of Ecological Standardization"), Leningrad: Gidrometeoizdat, 1991, pp. 41–51.

Armand, A.D., Kaidakova, V.V., Kushnareva, G.V., and Dobrodeev, V.G., Determination of resistance limits of geosystems by example of suburb of Monchegorsk metal plant, *Izv. Akad. Nauk SSSR, Ser. Geogr.*, 1991, no. 1, pp. 93–104.

Afifi, A. and Eisen, W., *Statistical Analysis: The Approach of Using COMPUTER*, Prentice-Hall, 1979.

Barinova, S.S., Assessment of aquatic ecosystems in Novaya Zemlya archipelago (Novozemel'skii reserve, Russia), *Al'gologiya*, 1998, vol. 8, no. 1, pp. 57–62.

Beckett, P.H. and Davis, R.D., Upper critical levels of toxic elements in plants, *New Phytol.*, 1977, vol. 79, pp. 95–106.

Bikbulatov, E.S. and Stepanova, I.E., Implementation of Harrington's desirability function for natural water monitoring, *Ekol. Khim.*, 2011, vol. 20, no. 2, pp. 94–109.

Bulgakov, N.G., Levich, A.P., and Maksimov, V.N., Forecast of ecosystem conditions and standartization of environmental factors in the Low Don basin, *Izv. Ross. Akad. Nauk, Ser. Biol.*, 1997, no. 3, pp. 374–379.

Bulgakov, N.G., Risnik, D.V., Levich, A.P., and Mil'ko, E.S., Ecological water conditions analysis for lower Volga points based on phytoplankton bioindication, *Voda: Khim. Ekol.,* 2010, no. 12, pp. 27–34.

Fedorov, V.D., Kondrik, E.K., and Levin, A.P., Range distribution of phytoplankton population in the White Sea, *Dokl. Akad. Nauk,* 1977, vol. 236, no. 1, pp. 264–267.

Frumin, G.T., Ecologically permissible levels of metals in water ecosystems, *Biol. Vnutr. Vod*, 2000, no. 1, pp. 125–131.

Frumin, G.T., Krylenkova, N.L., and Grigor'ev, A.S., Assessment of ecologically permissible levels of phenols in water ecosystems "Lake Ladoga–Neva River–eastern part of the Gulf of Finland", *Mezhd. Akad.*, 1999, nos. 13–14, pp. 95–98.

Chesnokov, S.V., *Determinatsionnyi analiz sotsial'no-ekonomicheskikh dannykh* (Determination Analysis of Social-Economic Data), Moscow: Nauka, 1982.

Gate, R.B., Jr. and Nelson, L.A., A simple statistical procedure for partitioning soil test correlation data into two classes, *Soil Sci. Soc. Am. Proc.*, 1971, vol. 35, pp. 658–660.

Gree, S.B., How many subjects does it take to do a regression analysis?, *Multivar. Behav. Res.*, 1991, vol. 26, pp. 499–510.

Grodzinskii, M.D., Empirical and statistical-formal determination of the intervals of possible and normal states, in *Nauchnye podkhody k opredeleniyu norm nagruzok na landshafty* (Scientific Approaches to Determination of Load Standards on the Landscapes), Moscow, 1988, pp. 215–224.

Hoek, G., Groot, B., Schwartz, J.D., and Eilers, P., Effects of ambient particulate matter and ozone on daily mortality in Rotterdam, the Netherlands, *Arch. Environ. Health*, 1997, vol. 52, no. 6, pp. 455–463.

Izrael', Yu.A., *Ekologiya i kontrol' sostoyaniya prirodnoi sredy* (Ecology and Environmental Monitoring), Moscow: Gidrometeoizdat, 1984.

Jones, R.H. and Molitoris, E.A., A statistical method for determining the breakpoint of two lines, *Anal. Biochem.*, 1984, vol. 141, no. 1, pp. 287–290.

Kompleksnaya ekologicheskaya otsenka tekhnogennogo vozdeistviya na ekosistemy yuzhnoi taigi (Comprehensive Environmental Assessment of Technogeneous Impact on Ecosystems of Southern Taiga), Moscow: TsEPL, 1992.

Krivolutskii, D.A., Stepanov, A.M., Tikhomirov, F.A., and Fedorov, E.A., Ecological standardization by example of radioactive and chemical pollution, in *Metody bioindikatsii okruzhayushchei sredy v raionakh AES* (Environmental Bioindication in the Areas of Atomic Power Plant), Moscow, 1988, pp. 4–16.

Levich, A.P., Biotic concept of environmental monitoring, *Dokl. Ross. Akad. Nauk*, 1994, vol. 337, no. 2, pp. 280–282.

Levich, A.P., The results of environmental standardization for determination of interaction between biotic and abiotic features of natural ecosystems, in *Antropogennoe vliyanie na vodnye organizmy i ekosistemy* (Anthropogenic Impact on Aquatic Organisms and Ecosystems), Borok: Inst. Biol. Vnutr. Vod, Ross. Akad. Nauk, 2011, part 2, pp. 138–142.

Levich, A.P., Bulgakov, N.G., Abakumov, V.A., and Terekhin, A.T., Ecologically permissible levels of water discharge determined using hydrobiological parameters, *Vestn. Mosk. Univ., Ser. 16: Biol.*, 1998, no. 3, pp. 49–52.

Levich, A.P., Bulgakov, N.G., and Maksimov, V.N., *Teoreicheskie i metodicheskie osnovy regional'nogo kontrolya prirodnoi sredy po dannym ekologicheskogo monitoringa* (Theoretical and Methodological Principles of the Regional Environmental Monitoring), Moscow: NIA-Priroda, 2004.

Levich, A.P., Bulgakov, N.G., Maksimov, V.N., and Risnik, D.V., "In situ" technology used for determination of ecological standards, in *Voprosy ekologicheskogo normirovaniya i razrabotka sistemy otsenki sostoyaniya vodoemov* (Environmental Standardization and Assessment Systems of Conditions of Water Resources), Moscow: KMK, 2011, pp. 32–57.

Levich, A.P. and Mil'ko, E.S., Standardization of environmental quality and bioindication of natural objects as analysis of dependence "dose-effect" for multivariate functions, in *Aktual'nye problemy ekologii i prirodopol'zovaniya* (Relevant Problems in Environment and Nature Management), Moscow: Ross. Univ. Druzhby Narodov, 2011, pp. 16–25.

Levich, A.P., Risnik, D.V., Bulgakov, N.G., Mil'ko, E.S., and Leonov, A.O., Methodological aspects of implementation of parameters of species diversity of phytoplankton applied for water quality analysis in the Low Don, *Ispol'z. Okhr. Vodn. Resur. Rossii*, 2010, no. 5, pp. 44–48, no. 6, pp. 33–37.

Levich, A.P. and Terekhin, A.T., A method to calculate ecologically admissible levels of impact on freshwater ecosystems, *Wat. Resour.*, 1997, vol. 24, no. 3, pp. 302–309.

Lyakh, A.M., Suvorov, A.M., and Bryantseva, Yu.V., The methods of quantitative registration of phytoplankton, in *Sistemy kontrolya okruzhyushchei sredy. Sb. nauchn. tr. NAN Ukrainy* (Systems of Environmental Monitoring, Scientific Works of National Academy of Sciences of Ukraine), Sevastopol: MGI, 2002, pp. 425–430.

Maksimov, V.N., Problems of comprehensive assessment of natural water quality (ecological aspects), *Gidrobiol. Zh.*, 1991, vol. 27, no. 3, pp. 8–13.

Maksimov, V.N., Solov'ev, A.V., Levich, A.P., Bulgakov, N.G., Abakumov, V.A., and Terekhin, A.T., Method of ecological standardization of the impact on water bodies that cannot be standardized by bioassay: case study of water bodies in Don basin, *Wat. Res.*, 2009, vol. 36, no. 3, pp. 319–324.

Matorin, D.N., Osipov, V.A., Yakovleva, O.V., and Pogosyan, S.I., *Opredelenie sostoyaniya rastenii i vodoroslei po fluorestsentsii khlorofilla* (Determination of the Plant and Algae Conditions Based on Chlorophyll Fluorescence), Moscow: MAKS Press, 2010.

Mirkin, B.G., *Analiz kachestvennykh priznakov i struktur* (Analysis of Quantitative Features and Structures), Moscow: Statistika, 1980.

Moiseenko, T.I., Methodological approaches to standartization of anthropogenic loads on Subarctic reservoirs (by example of Kola North), in *Problemy khimicheskogo i biologicheskogo monitoringa ekologicheskogo sostoyaniya vodnykh ob"ektov Kol'skogo severa* (Problems of Chemical and Biological Monitoring of Environmental Conditions of Water Basin of the Kola North), Apatity: Kol'sk. Nauch. Tsentr, 1995, pp. 7–23.

Nikiforov, A.D., *Metrologiya, standartizatsiya i sertifikatsiya: Ucheb. posobie* (Metrology, Standardization, and Certification: Handbook), Moscow: Vysshaya Shkola, 2002.

Patin, S.A., *Vliyanie zagryazneniya na biologicheskie resursy i produktivnost' mirovogo okeana* (Impact of Pollution on Biological Resources and Productivity of the World Ocean), Moscow: Pishchepromizdat, 1979.

Pedhazur, E.J. and Schmelkin, L.P., *Measurement, Design and Analysis: An Integrated Approach*, Hillsdale, NJ: Erlbaum, 1991.

Perechen' rybokhozyaistvennykh normativov: predel'no dopustimykh kontsentratsii (PDK) i orientirovochno bezopasnykh urovnei vozdeistviya (OBUV) vrednykh veshchestv dlya vody vodnykh ob"ektov, imeyushchikh rybokhozyaistvennoe znachenie (The List of Fishery Standards: Maximum Permissible Concentrations (MPC) and Temporary Safe Reference Action Level (TSRAL) of Hazardous Substances for Water Objects Important for Fishery), Moscow: Vseross. Nauch. Inst. Ryb. Ozer., 1999.

Pogosyan, S.I., Gal'chuk, S.V., Kazimirko, Yu.V., Konyukhov, I.V., and Rubin, A.B., Implemintation of fluorimeter MEGA-25 for quantitative determination of phytoplankton and assessment of its photosynthetic apparatus, *Voda: Khim. Ekol.*, 2009, no. 2, pp. 34–40.

Puzachenko, Yu.G., Problems of sustainability and standardization, in *Strukturno-funktsional'naya organizatsiya i ustoichivost' biologicheskikh sistem* (Structural and Functional Organization and Stability of Biological Systems), Dnepropetrovsk, 1990, pp. 122–147.

Risnik, D.V., Approaches applied for dimensional classes and determination of dimensional structure of phytoplankton communities in Volga basin, *Izv. Samar. Nauch. Tsentra Ross. Akad. Nauk*, 2011, vol. 13, no. 1(4), pp. 882–890.

Risnik, D.V., Levich, A.P., Bulgakov, N.G., and Radchenko, I.G., Indexes of dimensional structure of phytoplankton communities and assessment of their variability on the background of seasonal, geographic, and metrological changes, in *Aktual'nye problemy ekologii i prirodopol'zovaniya. Sbornik nauchnykh trudov* (Relevant Problems of Ecology and Nature Management: Collection of Scientific Works), Moscow: Ross. Univ. Druzhby Narodov, 2011, no. 13, pp. 171–187.

Rozenberg, G.S., Dunin, D.P., Kostina, N.V., Morozov, V.G., Pogodin, I.V., and Shitikov, V.K., Informational technologies used for assessment of ecological conditions of the large region (by example of Volga basin and Samara oblast), in *Problemy regional'noi ekologii* (Problems of Regional Ecology), Tomsk: Sib. Otd. Ross. Akad. Nauk, 2000, no. 8, pp. 213–216.

Rozenberg, G.S., Evlanov, I.A., Seleznev, V.A., Mineev, A.K., Selezneva, A.V., and Shitikov, V.K., Experience of ecological standardization of anthropogenic influence the water quality (by example of Central and Low Volga basin), in *Voprosy ekologicheskogo normirovaniya i razrabotka sistemy otsenki sostoyaniya vodoemov* (Ecological Standardization and Development of Assessment System of Water Conditions), Moscow: KMK, 2011, pp. 7–31.

Saliev, A.V., Modeling of the effect of atmospheric phytotoxins on the plant—spatial aspect, in *Osnovy biologicheskogo kontrolya zagryazneniya okruzhayushchei sredy* (Principles of Biological Control and Environmental Pollution), Moscow: Gidrometeoizdat, 1988, pp. 137–160.

Selezneva, A.V., *Ekologichekoe normirovanie antropogennoi nagruzki na vodnye ob"ekty* (Ecological Standardization of Anthropogenic Burden on Water Reservoirs), Samara: Samar. Nauch. Tsentr, Ross. Akad. Nauk, 2007.

Selezneva, A.V. and Seleznev, V.A., Registration of natural regional features during standardization of anthropogenic burden on water reservoirs, in *Voprosy ekologicheskogo normirovaniya i razrabotka sistemy otsenki* *sostoyaniya vodoemov* (Ecological Standardization and Development of Assessment System of Water Conditions), Moscow: KMK, 2011, pp. 145–148.

Simpson, R.W., Williams, G., Petroeschevsky, A., Morgan, G., and Rutherford, S., Associations between outdoor air pollution and daily mortality in Brisbane, Australia, *Arch. Environ. Health*, 1997, vol. 52, no. 6, pp. 442–454.

Singh, A.K. and Rattan, R.K., A new approach for estimating the phytotoxicity limits, *Environ. Monit. Assess.,* 1987, vol. 9, no. 3, pp. 269–283.

Stepanov, A.M., Bioindication and background monitoring of the land ecosystems, in *Ekotoksikologiya i okhrana prirody* (Ecological Toxicology and Nature Protection), Moscow: Nauka, 1988, pp. 28–108.

Stepanov, A.M., Experimental determination of permissible anthropogenic burden on the forest ecosystem, in *Problemy ustoichivosti biologichekikh sistem* (Problems of Biological Systems Stability), Kharkov, 1990, pp. 352–353.

Stepanov, A.M., Bioindication at ecosystem level, in *Bioindikatsiya i biomonitoring* (Bioindication and Biological Monitoring), Moscow: Nauka, 1991, pp. 59–64.

Tsvetkov, V.F., Standardization of the influence of the propellant on forest vegetation, in *Tez. dokl. mezhd. nauch. konf. "Vliyanie atmosfernogo zagryazneniya i drugikh antropologicheskikh i prirodnykh faktorov na destabilizatsiyu sostoyaniya lesov Tsentral'noi i Vostochnoi Evropy"* (Int. Sci. Conf. "Influence of Atmospheric Pollution and Other Anthropogenic and Natural Factors on Destabilization of Forest Conditions in the Central and Eastern Europe", Abstracts of Papers), Moscow, 1990, vol. 1, pp. 49–51.

Vorobeichik, E.L., Sadykov, O.F., and Farafontov, M.G., *Ekologicheskoe normirovanie tekhnogennykh zagryaznenii* (Ecological Standardization of Technogeneous Pollutions), Yekaterinburg: Nauka, 1994.

Yakovlev, A.S., Gendugov, V.M., Glazunov, G.P., Evdokimova, M.V., and Shulakova, E.A., Ecological assessment of soil condition and quality standardization, *Pochvovedenie*, 2009, no. 8, pp. 984–995.

Zamolodnikov, D.G., Assessment of ecological permissible norms of anthropogenic impact on freshwater ecosystems, in *Problemy ekologicheskogo monitoringa i modelirovanie ekosistem* (Problems of Environmental Monitoring and Ecosystem Simulation), St. Petersburg: Gidrometeoizdat, 1993, pp. 214–233.

Zykov, V.N. and Chernyshev, V.I., *Standartizatsiya i metrologicheskoe obespechenie v ekologii* (Standardization and Metrological Tools Used for Environmental Monitoring), Moscow: Ross. Univ. Druzhby Narodov, 2008.

Translated by G. Krichevets