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An Analysis of Human-Induced Succession in a Fresh Water Ecosystem by Means of Bioindication.

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ABSTRACT

The article presents an analysis of possible change scenarios in water ecosystems as a result of various types of anthropogenic succession. The analysis established a correlation between the normalized well-being functions of an aquatic community and the resultant level of pollution impact, defined as Y. The article proposes an equation describing the effect on aquatic communities of the type of pollution impact characteristic of large industrial enterprises, including mining and ore-processing facilities.

Keywords: Assessment of anthropogenic succession, aquatic community, bioindication, hydroecosystems.

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INTRODUCTION

Anthropogenic impact on water resources has been studied by several branches of science for more than a century. Today there is particular emphasis on the issue of assessing and regulating the anthropogenic impact on the biological systems of water bodies. This impact is a result of increasingly complex combinations of factors. The methods used to assess and regulate them are far from perfect. At best, it is recommended to add up the estimated impacts of several toxicants with common receptors while the other factors are considered separately and no attempt is made to take into account their effect on each other. It is common knowledge that the vast majority of chemicals affect a living organism differently when acting in combination rather than on their own. Their joint impact can be either stronger or weaker than a purely additive impact would be. Moreover, new effects can emerge that are entirely atypical for the ingredients involved. Taken together, these considerations expose the in adequacy of assessing natural environments on the basis of the existing framework of sanitary and hygiene regulations.

More accurate and reliable results can be obtained by bioindication techniques, provided that both the bioindicator itself and its testing parameters are selected correctly. In our opinion, the most promising bioindication techniques are those that use quantifiable patterns in the bioindicator's reaction to changes in its environment. Such techniques make possible more adequate monitoring of human-induced transformations in water ecosystems and provide a basis for standardizing and regulating human interference in natural processes.

However, there are factors that complicate the study of human-induced succession patterns in water ecosystems.

DETERMINATION AND NORMALIZATION OF WELL-BEING FUNCTION OF THE WATER BIOTA

Firstly, in order to develop a correct model, we must determine the most appropriate well-being function of the water biota. As a rule, the following indicators are used as the well-being functions of a given species: growth and development rate, fecundity, life expectancy, mortality rate, nutrition, metabolism, and motion [1]. At higher levels of organization of biological systems, the most reliable indicators of a community's well-being can be the biomass, species diversity, species number, and the average weight of a given species [2,3,4]. Various parameters of a biological system differ significantly in their vulnerability to impact. For this reason, the reaction of a biological system to the impact of the environmental factor (or combination of factors) under study is usually assessed by means of a comparative analysis of various well-being functions. To facilitate such analysis, it is necessary to uniformly normalize the values of the different well-being functions with respect to their possible value range:

$$\psi(X)_i = \frac{f(X)_i - f(X)_t}{f(X)_0 - f(X)_t} , \qquad (1)$$

Where

$f(X)_i$ and $\psi(X)_i$ are respectively the absolute and normalized i-values of well-being function f (X);

$f(X)_o$ is the value of well-being function f (X) that is optimal for the biological system (if the system retains its resistibility: $f(X)_i = f(X)_o$);

$f(X)_t$ is the maximum allowable value of the function; any further deviation of the function from its optimal value is incompatible with normal functioning of the system and signifies the beginning of irreversible pathological changes in the system or its destruction (if the system loses its resistibility but retains its resilience: $|f(X)_t| \le |f(X)_i| < |f(X)_o|$; if the system loses its resilience: $|f(X)_i| < |f(X)_t|$).

Such normalization of the values of different well-being functions allows their consistent interpretation:

when ψ = 1,the relevant parameter of the biological system retains its optimal value, i.e. it is not affected by the impact, which means that, with regard to this parameter, the system retains its resistibility, not to mention its resilience;

when 0 ≤ ψ < 1,the relevant parameter is limited by the impact, and the system loses its resistibility while retaining its resilience;

when ψ > 1,the parameter is pathologically affected by the impact, and the system loses its resistibility while retaining its resilience;

when ψ < 0,the parameter reaches its critical value, at which the system has exhausted its adaptive potential and undergoes irreversible changes or ceases to exist; the system has lost its resilience.

Thus, this normalization allows a comparative analysis of different well-being functions of a biological system which initially have different measurable parameters and incommensurable values.

ADEQUATE MEASURE FOR THE RESULTANT IMPACT ON BIOTA

Another issue complicating the study of reaction patterns of biological systems to external factors is choice of an adequate standard measure for the resultant impact on biota that would take into account the effect of all factors affecting the aquatic community, regardless of their nature or measurable parameters. In this paper, such a measure is designated asY [5]. Indicator Y is isobolic, which means that its given value corresponds to those (and only those) combinations of interacting factors that produce a certain identical reaction in the bioindicator. The special structure of the indicator allows an adequate account of the synergy of the combined factors as well as the resistibility and resilience retention thresholds for each of the factors involved.

The use of an isobolic indicator allowed us to analyze, unify, formalize and categorize the major quantitative reaction patterns of an aquatic community (the research was done on bottom ecosystems, or macrozoobenthos) to different types of a human-induced pollution impact (Figure 1).

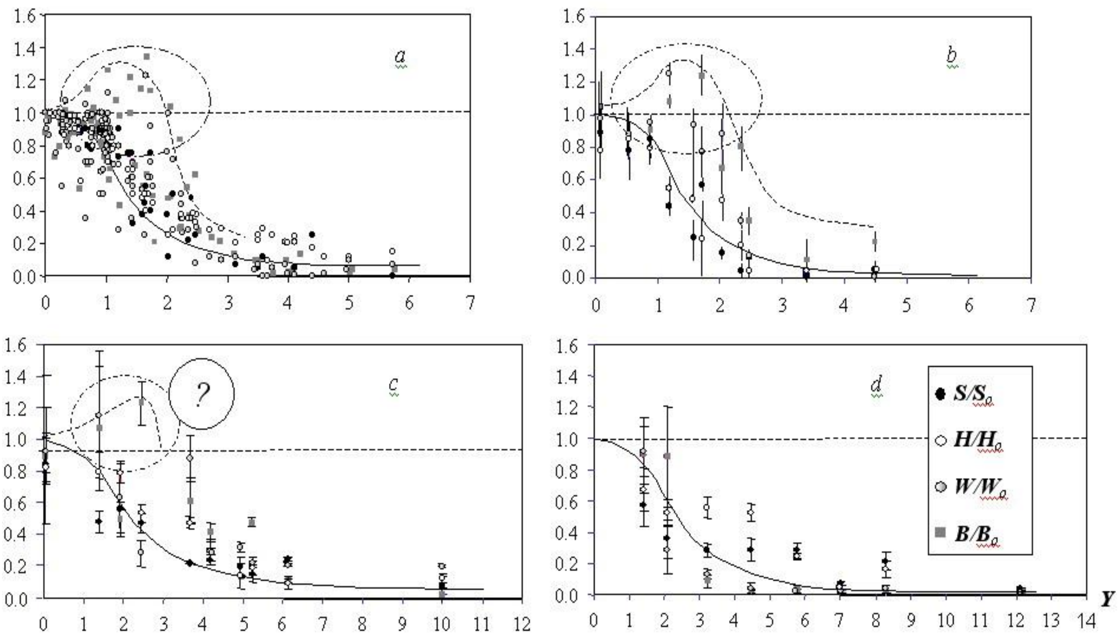

Figure 1: The reaction of the macrozoobenthos in several rivers of the Leningrad Oblast to eutrophication.

S/S_o is species wealth; H/H_o is species diversity; B/B_o is biomass; W/W_o is average species weight (the values of the parameters are normalized with respect to the background values).

Thus, if human-induced succession follows the ‘classical’ scenario of anthropogenic eutrophication (in the absence of human-induced toxification), biotopes with weakly silted, hard substrates display a stimulation effect on the biomass and average species weight when subjected to moderate pressure ($Y \approx 1\text{-}2$) (Fig. 1, diagrams *a* and *b*) [6]. On soft soils (or, in the presence of human-made toxicants, on all substrates) this stimulation effect is either marginal (Fig. 1, diagram *c*) or absent (Fig. 1, diagram *d*) [7]. As the impact level increases ($Y > 2$), the changes in the listed parameters are limited in all biotopes.

The parameters dependent on the species composition (the number of characteristic species and Shennon’s diversity index) fall evenly and regularly in the entire $Y > 1$ range regardless of the impact type.

Any impact with $Y > 3$ causes irreversible degradation of the bottom ecosystem. As a result, the system retains only a few highly eurybiontic species, whose populations are either small or only observed sporadically. The values of most well-being functions lie below 20 % of the background values, regardless of how the corresponding parameters of the system react to the given impact type.

INDICATOR Y APPLICATION FEATURES

Depending on the properties of the biotope and on the nature of the impact, the stimulation effect can vary dramatically. For instance, it is never observed in biotopes with hard, weakly silted soils. Thus, there are no clear boundaries between the three major types of well-being functions for macrozoobenthos subjected to a multifactor impact; any intermediary values are possible. It is also important to note that, in the vast majority of observed cases, succession of water bodies in the impact zone of large industrial enterprises (including mining and ore-processing facilities) follows the scenario of anthropogenic eutrophication, further exacerbated by large quantities of toxic pollutants in the water.

It is therefore reasonable to regard the least complex type of macrozoobenthos reaction to multifactor impact as universal. This type of well-being function can be reliably approximated by the following logistic equation:

$$f / f_o = 1 - \frac{1}{1 + a \times e^{bY}}, \quad (2)$$

where f/f_o is the macrozoobenthos parameter whose value in the impact conditions under study is normalized with respect to the relevant background value; $a = const = (1 - f / f_{0min}) / (f / f_{0min})$; $b = const$; $f/f_{omin} = const$ is the lower value limit of the function (when $Y \to \infty$).

CONCLUSION

A comparative analysis of specific values of the parameters in equation (2), which show the reaction of different macrozoobenthos features to various types of multifactor impact, demonstrates that their value variability and difference validity are usually small. As a result, we were able to formulate a unified equation for the correlation between normalized macrozoobenthos parameters and Y, an isobolic indicator of a multifactor anthropogenic impact, with the following parameters: $a = 22.8 \pm 2.4$, $b = -1.53 \pm 0.13$.

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