Use of Structural Characteristics of Bacterio- and Zoobenthos for Assessing the Quality of Bottom Deposits: Case Study of Water Bodies in the Upper Volga Basin

G. A. Vinogradov*, N. A. Berezina*, N. A. Lapteva*, and G. P. Zharikov**

* Institute of Inland Water Biology, Russian Academy of Sciences, Borok, Nekouzskii raion, Yaroslavl oblast, 152742 Russia
** Yaroslavl State Medical Academy, ul. Revolyutsionnaya 5, Yaroslavl, 150000 Russia

Received October 11, 2000

Abstract—Analysis is given of the modern approaches and methods used to assess the quality of bottom deposits based on the conditions of bacterio- and zoobenthos communities. The structural characteristics of bacterio- and zoobenthos communities of small rivers in the Upper Volga basin are studied. The type of substrate is shown to have appreciable effect on the quantitative characteristics of both the communities. The analysis of these data is used to create a generalized classification of the quality of bottom deposits and assess the extent of their pollution in the examined water bodies.

INTRODUCTION

Bottom deposits play an important role in the turnover of matter and energy in aquatic ecosystems. They always include detrital particles, which are necessary for the formation of various types of benthic bacteria and invertebrates. A rich set of enzymes allows the microorganisms to utilize, transform, and transfer to the next trophic levels various organic (in particular, anthropogenic) and inorganic compounds in bottom deposits. The presence and the extent of development of certain groups of bacteria and invertebrates in the soils allows establishing the presence of mineral and organic compounds of both natural and anthropogenic origin, that is, makes it possible to determine the type of pollution. Therefore, bacterio- and zoobenthos communities can serve as useful biological indicators of bottom deposits quality. Moreover, pollutants accumulate in soils, and bottom deposits become the source of secondary pollution of water [11]. That is why, the techniques for assessing the quality of bottom deposits need to be developed. The results of assessing the quality of soils in some water bodies in Russia based on the comprehensive analysis of the amount of pollutants, the characteristics of zoobenthos conditions, and the level of bottom deposits toxicity (triad approach) are given in [19]. However, no systematic approach has been developed for this type of estimate, whereas the methods for assessing the quality of surface water based on the composition communities of microorganisms and benthic invertebrates have been developed and successfully used for many years [1, 9, 15]. The objective of this study is to develop new and to apply known modern techniques and approaches for assessing the quality of bottom deposits based on the characteristics of the conditions of bacterio- and zoobenthos communities using rivers of the Upper Volga basin as an example. The rivers include the Kotorosl, Sara, Veksa, Ust’e, Lakhost, Mogza, and Pakhma.

Many researchers have accumulated to date a great body of data on the correlation between the level of biotopes pollution with quantitative characteristics of microorganism communities [7, 8, 17, 23, 29], which suggest that the development of method for assessment and classification of soil quality should be based on the structural and functional indices of specific groups of bacterial benthos as well as on the rates of sulfate reduction, denitrification, cellulose decomposition, and methanogenesis. The most important microbiological indices, which can be used to control the quality of bottom deposits are the total population of bacteria \(N_{b, tot}\) and the number of saprophytes \(N_s\), as well as the total level of accumulation of organic substances of municipal origin, the population of bacteria of the colibacillus group \(N_{b, col}\), determining the level of fecal pollution of water, oil- and phenol-decomposing bacteria \(N_{o, p, p}\) and \(N_{p, p}\), respectively. The absolute indices of organic matter production and destruction (either aerobic or anaerobic) cannot serve as criteria of soil pollution, but characterize the composition and physiological conditions of bacterial benthos and the direction of microbiological processes [12].

Many structural characteristics of other important component of aquatic ecosystems (zoobenthos), including the species diversity, biomass, population, and production, depend on the physical properties of the soil (particle size distribution and chemistry) and the amount of bacteria-transformed readily assimilable organic matter, on the one hand, and on the quality of sediments, on the other hand. Studies of the correlation between the soil structure and quality and the composi-
tion of benthic communities showed the characteristics of the latter to correlate better with the type of substrate rather than with its quality [21, 34]. Different representatives of zoobenthos show different response to the composition and type of soil. The chironomids are known to prefer sand to clay and silt to sand [30]. Silty substrates are unfavorable for mollusk development. Notwithstanding that the prime cause of the absence of some species and the poor species diversity is the lack of necessary habitats rather than the quality of sediments and water, many researchers, who had compared the structures of benthic communities living on the same substrates, mentioned the degrees of community degradation to be different [20]. Anthropogenic pollution of bottom deposits inevitably results in changes in many structural and functional characteristics of macrozoobenthos communities. These changes can be distinctly seen in comparing disturbed biocenoses with those formed not subject to anthropogenic impact, that is, reference biocenoses [22, 26, 33]. Such changes have complicated character and depend on the tolerance level of benthic invertebrates to the given type of pollutant. Accordingly, the species either increase or decrease their population, or attain its maximum [35]. Data of many studies [32] suggest a close correlation between the occurrence of representatives of different subclasses and families of zoobenthos and the level of sediment pollution, although absolutely no correlation is recorded between the level and the indices of taxonomic diversity of benthic communities. Therefore, the quality criteria of bottom deposits should be based on indices accounting for the level of quantitative development of zoobenthos and its groups.

Once the zoobenthos structures under background conditions and in polluted areas are known and the extent of degradation of the latter is assessed, the extent of sediment pollution can be analyzed. Pollution by polycyclic aromatic hydrocarbons and heavy metals results in a decrease in \( N_{\text{h, tot}} \) and the common rheophilic species of benthic invertebrates are replaced by species highly tolerant to these types of pollutants [26]. Heavy pollution reduces the species diversity and the total zoobenthos population and the community commonly consists of 1–2 oligochaeta species most tolerant to this type of pollutant [6]. Living under the conditions of chronic pollution often increase the tolerance of many benthic species and make them more eurybiontic, thus making it difficult to assess the environmental conditions from the species composition. For example, the species diversity of zoobenthos in some areas in the Caspian Sea becomes poorer only in the case of heavy pollution by oil products [2].

The difference between the response of different invertebrate group to pollution should be taken into account. An abrupt drop in the number of oligochaeta is a typical consequence of the general increase in sediment pollution [31, 35]. The level of pollutant accumulation in the bodies of aquatic insects spending in the soil only a part of their life cycle is low, and many authors point to the inadequacy of the absolute characteristics of these insects for assessing the quality of bottom deposits [25, 28]. Of greatest use as sediment pollution indicators among insects are chironomid larvae, which are abundant in soft substrates in different types of freshwater bodies [27]. The rate of pollutant accumulation strictly correlates with the type of nutrition. The characteristics of development of invertebrate filter feeders are better indicators to the water mass conditions. The quantitative development of invertebrates feeding on detritus (detritophages), can be a reliable characteristic of bottom sediment pollution [25].

Small-size organisms were found to accumulate more pollutant than large organisms [36]. The level and rate of pollutant accumulation are maximal in the bacterial film, medium in the macroinvertebrates bodies, and minimal in fish. Bottom sediment pollution should be assessed simultaneously by bacterio- and macrozoobenthos. Zoobenthos is most quick in responding to pollutant effect, which is of importance for recognizing a single impact. Representatives of macrozoobenthos need more time to release the accumulated pollutants into the environment. Benthic invertebrates retain the traces of pollutant impact for longer time and change the composition physicochemical structure of bottom sediment through the exchange processes at the bed–water mass interface [10, 24]. Therefore, benthic invertebrates are an important indicator of secondary pollution in environmental monitoring.

MATERIALS AND METHODS

The Kotorosl River, which originates from the confluence of the Veksas and Ust’e rivers, is the largest tributary of the Volga within the territory of the Yaroslavl province. The Kotorosl is 160 km long. Its basin embraces five districts (Uglichskii, Borisoglebskii, Gavrilov-Yamskii, Rostovskii, and Yaroslavskii). The river alimentation is mainly due to groundwater. Its water has moderate salinity (200–300 mg/l) and belongs to the category of moderately hard waters and to the bicarbonate class of the first type of calcium group. The Kotorosl annually brings 88 million m³ of water into the Volga and contributes largely to the formation of the Volga water quality [18].

Samples of bacterio- and macrozoobenthos were taken at 15 standard stations (figure) within the vegetation period (spring, summer, autumn) of 1997. Macrozoobenthos was sampled by Mordukhai-Boltovskoi dredger (1/250 m² in area), bacteriobenthos was sampled by the microbenthic soil-sampling tube (three and more repetitions at each station).

The main hydrological and morphimetric characteristics of the examined biotopes of the rivers are given in Table 1. The quality of bottom sediment quality was assessed based on the microbiological indices as follows: \( N_{\text{h, tot}} \), \( N_{\text{s, b}} \), \( N_{\text{b, tot}} \), \( N_{\text{e}} \), and \( N_{\text{p}} \). \( N_{\text{b, tot}} \) was analyzed by...