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Features of the surface water oxygen regime in the Ukrainian Polesie Region

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Abstract

The research analyzed seasonal changes of the oxygen regime and related indicators on the example of water objects of the Ukrainian Polesie Region. The region shows different directions of economic use. Zebrafish (*Danio rerio* Hamilton–Buchanan) and the Prussian carp (*Carassius auratus gibelio* Bloch) were used as test objects to investigate survival responses. Dissolved oxygen (*DO*) concentration in water, pH values and temperatures were determined by standard methods. Based on research results, the main problems were determined pertaining to the oxygen regime of investigated waters, i.e. the increase in temperature and toxicity of the aquatic environment in the summer. A rather dangerous decrease in *DO* concentration, almost up to the levels of maximum allowable concentration (MAC) (4.10 mg·dm^{-3} in group E1 and 6.07 mg·dm^{-3} in group E2), was observed in August and it was typical for the reservoirs with a slow water movement. Flowing river waters (group E3) were eliminated due to their better aeration compared to other groups. The correlation analysis based on the presented data revealed a high and average degree of probable correlation between the *DO* concentration and water temperature, as well as an average degree of correlation with general toxicity determined on sensitive species of *D. rerio*, and in group E1 on the persistent species *C. auratus gibelio* as well. The interrelations and equations of the rectilinear regression can be used to predict the oxygen regime of the waters investigated and other surface waters having similar problems.

Key words: *correlation analysis, dissolved oxygen, fish, oxygen regime, pH, seasonal fluctuations, surface water, temperature, toxicity*

INTRODUCTION

The current state of water pollution in the Ukrainian Polesie Region has been caused by a long-lasting ecological crisis and complicated by climate changes. The pollution reaches enormous proportions and is the main cause of the progressing deterioration of the surface water quality [ARYSTARKHOVA 2017a, b; SPELLERBERG 2005; ZAPOLSKYI, SHUMYGAI 2015]. The crisis is primarily caused by the loss of the self-cleaning capability level as a result of industrial, municipal, and domestic wastewater discharges, most of which are unauthorized.

Solving this extremely complex problem requires the use of fast and reliable methods to assess the state of the aquatic environment and defining of overall toxicity rather than individual parameters of water composition [AFANASIEV 2002; FEDONIUK *et al.* 2019; 2020; LASHEEN *et al.* 2012; ORLOV *et al.* 2021; RADIĆ *et al.* 2013; ROMANCHUK *et al.* 2017; 2018; SZCZERBIŃSKA, GAŁCZYŃSKA 2015; ULITZUR *et al.* 2002].

One of the most common indicators of water quality is dissolved oxygen (*DO*). This indicator is considered to be the basic sanitary parameter determining the status of surface water, since it is a mediated integral characteristic of aquatic toxicity [BILIAVSKYI, BUTCHENKO 2006; FENT

2013]. In general, it signifies the impact of a chemical substances and their mixtures on organisms living in water. In addition, *DO* is an indicator of biological activity and metabolism that occurs in aquatic ecosystems [Directive 2000/60/EU], in particular the process of oxidation and decomposition of organic residues, photosynthesis, self-purification of water, etc.

A lot of publications have been devoted to the study on the water body oxygen regime, in which special attention is paid to seasonal changes of *DO* [BARTNIK, MONIEWSKI 2016; OSADCHYI 2006; OSADCHYI, OSADCHA 2007]. The researchers note that oxygen concentrations can vary significantly in surface waters, from 0 to 14 mg·dm^{-3}. Its lowest values are often associated with the organic pollution of the aquatic environment [BILYAVSKYI, BUTCHENKO 2006; ROMANENKO 2004].

After getting into water bodies, contaminants can alter their physical and chemical parameters [BARTNIK, MONIEWSKI 2016]. Since most of organic pollutants are biologically active substances, they quickly oxidize in water. This can lead to *DO* deficiency and has a negative impact on the status of aquatic organisms, as well as diminishes their diversity. Extremely low *DO* concentrations (below 2 mg·O_2 dm^{-3}) may kill fish and other aquatic organisms, which further degrades water quality, including its oxygen content. Most often, *DO* deficiency is observed in water bodies due to unauthorized organic wastewater discharge and in eutrophic reservoirs containing a large amount of biogenic and humus substances [ARYSTARKHOVA 2018; OSADCHYI 2001; PENA 2010; ROMANENKO 2004].

If water contamination with toxicants coincides with oxygen deficiency, the intoxication of the aquatic organisms can be extremely fast, especially at the temperature above 25°C. Under such conditions, it is impossible to ensure a significant reduction in the toxicity of the aquatic environment by oxidizing pollutants [DUDNIK, YEVTUSHENKO 2013; ROMANENKO 2004].

Although *DO* is regarded as a mediated indicator of the surface water toxicity. According to the literature, its links with toxicity have proven to be rather ambiguous, dependent, for example, on the temperature regime [ROMANENKO 2004; ZAPOLSKYI, SHUMYGAI 2015]. This requires a more detailed study of the relationship between the *DO* concentration, water temperature and toxicity. To elucidate these relationships, it is advisable to use model organisms of different sensitivity to aquatic pollution [FROEHLICHER *et al.* 2009; KLYMENKO *et al.* 2018; OIKARI 2006; SCARDI *et al.* 2006; SZCZERBIŃSKA, GAŁCZYŃSKA 2015].

Therefore, the purpose of the research has been to identify the relationship between the *DO* concentration in water and other parameters (temperature, acidity and toxicity), with the toxicity of water determined on model fish species (*Danio rerio* and *Carassius auratus gibelio*) of different sensitivity to pollution.

MATERIALS AND METHODS

The research of the surface water oxygen regime was carried out in the Zhytomyr Region (Ukrainian Polesie) in 2017 (Fig. 1).

Water was sampled (1 dm^3) from the rivers of Zvizdal (right tributary of Uzh), Ocheretianka (right tributary of Irsha) and the water intake of Vidsichne, and the Teteriv River (right tributary of Dnieper). Control (K) water samples were taken from the water supply network of the municipal enterprise "Zhytomyrvodokanal".

Control and experimental groups were formed according to the following scheme:

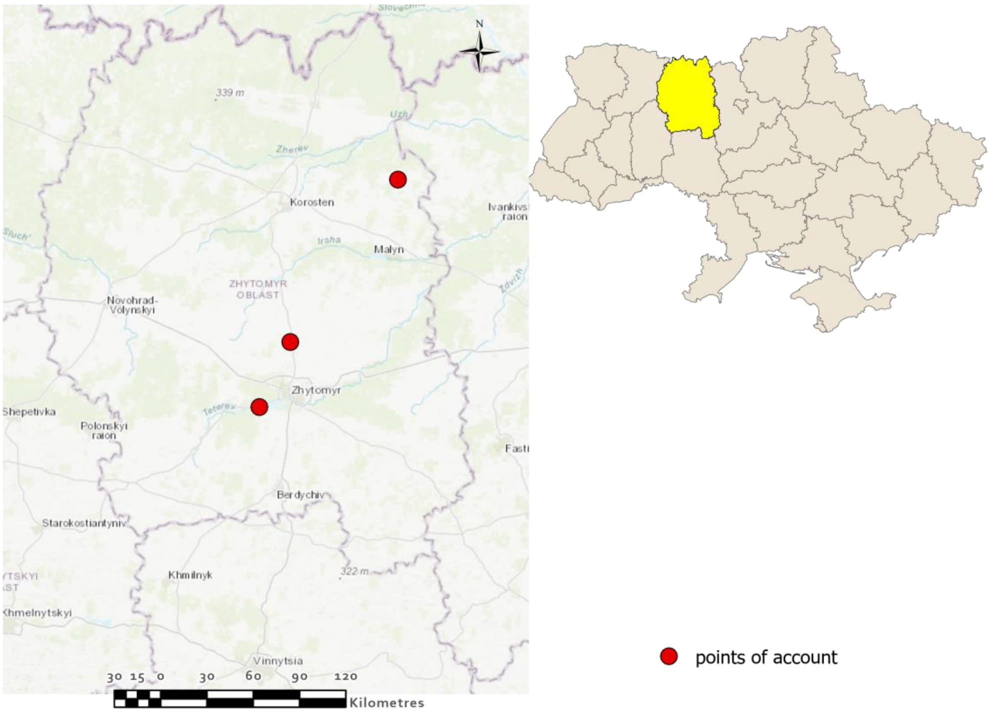

Fig. 1. The 2017 research of surface water in the Zhytomyr Region (Ukrainian Polesie); source: own elaboration

– control group – samples of clean (24 h) tap water;
– experimental group E1: water samples from the water intake Vidsichne;
– experimental group E2: water samples from the Ocheretianka River;
– experimental group E3: water samples from the Zvizdal River.

Test objects: female zebrafish (*Danio rerio*) and Prussian carp (*Carassius auratus gibelio*) at the age of 3 weeks.

Keeping: aquariums with 10 dm^3 of water, the oxygen concentration in water not less than 4 $mg \cdot dm^{-3}$, temperature 20°C ± 2.5°C, fish density – 10 specimens per aquarium, natural lighting conditions and with the water replacement to the appropriate quality in 2 days.

Feeding: from the 2nd to the 4th day, dry animal feed (daphnia, cyclops) twice a day and live plant feed (algae, leaves of aquatic plants) constantly.

Test reaction: immobilization and mortality.

Exposure: acute lethal toxicity – for 4 days.

Biotesting: daily count of active and immobilized (including dead) specimens from the 1st to the 4th day.

The data obtained were compared with the control group. For each test sample, the toxicity index (*T*, %) according to SSRN 2.2.4-171-10 was calculated using the following formula:

$$T = \frac{I_k - I_0}{I_k} 100 \quad (1)$$

where: T = toxicity index (%), I_k = value of the test response of specimens in control; I_0 = the value of the test response of specimens in the experiment.

The aquatic acute lethal toxicity was determined according to an international standard [ISO 7346-1:1996]. The biotesting data were evaluated on the scale of the aquatic toxicity levels [ARYSTARKHOVA 2017a, b; 2018]. It was assumed that the water toxicity index should not exceed 50% regardless of test objects used in the research [SSRN 2.2.4-171-10]: 1–25% – acceptable level of toxicity; 26–50% – low toxicity; 51–75% – average toxicity; 76–100% – high toxicity.

Dissolved oxygen (*DO*) concentration ($mg \cdot dm^{-3}$) in water was determined using a *DO* 4000 Dissolved Oxygen Meter. The value of the hydrogen indicator was monitored with a pH-meter, millivoltmeter 121, and temperature with a TM-10 mercury thermometer with a split of 0.2°C, hardness ($mg \cdot dm^{-3}$) – by the method of formation of a stable complex trilon B compound with calcium and magnesium ions in the ammonia buffer solution (pH 9.5) [BILIAVSKYI, BUTCHENKO 2006; SCARDI *et al.* 2006].

To determine the relationship of *DO* concentration in water and temperature, pH, and toxicity, a correlation analysis was performed to determine correlation coefficients and to obtain linear regression equations. The likelihood of these indicators was determined by the Student's *t*-test.

RESULTS

Tendencies in seasonal changes in *DO* concentration in all investigated waters were similar. The highest concentrations were observed in spring, late autumn and early winter, whereas the lowest in late summer and early autumn (Fig. 2).

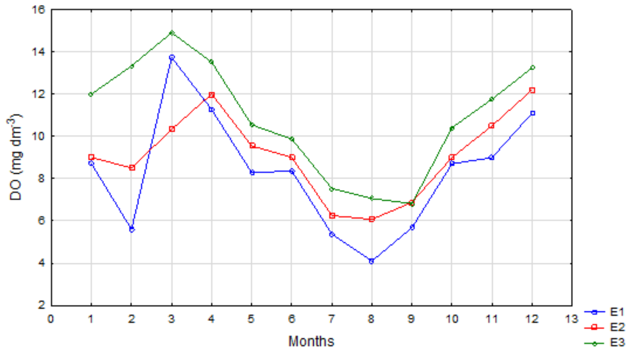

Fig. 2. Dissolved oxygen concentration in experimental groups; E1 = water samples from the water intake Vidsichne; E2 = water samples from the Ocheretianka River; E3 = water samples from the Zvizdal River; source: own study

The decrease in *DO* concentration in August–September (groups E1–E3) was most likely related to the development of phytoplankton groups, in particular cyanobacteria, and in February (groups E1 and E2) it was caused by the formation of an ice sheet.

The water temperature also had a significant influence on seasonal fluctuations in *DO* concentration. According to existing data, with the increase in temperature, *DO* concentration should decrease [BILYAVSKY, BUTCHENKO 2006; HUANG, SCHMITT 2014; LOWELL, CULP 1999]. In our research, this tendency was clearly followed (Fig. 3).

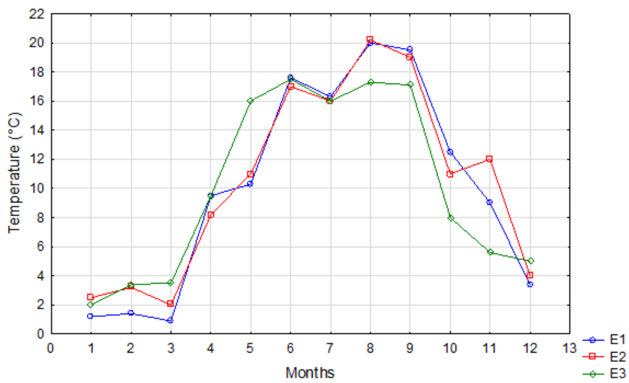

Fig. 3. Seasonal fluctuations of water temperature in experimental groups; E1–E3 as in Fig. 2; source: own study

Compared with temperature fluctuations, changes in the acidity of waters were not sufficiently pronounced (in the range of 6.5–8.5) and to a lesser extent corresponded to seasonal *DO* fluctuations (Fig. 4).

The toxicity of waters, determined by the susceptible and pollutant fish species, reached the highest levels in summer and the lowest in winter. During a year, the toxicity index fluctuated, and its changes were inversely proportional to the changes in *DO* (Fig. 5).

Among the water bodies under study, the best values of water quality indicators for *DO* were recorded in the Zvizdal River (group E3), which corresponded to lower values than temperature and toxicity in groups E1 and E2. The quality

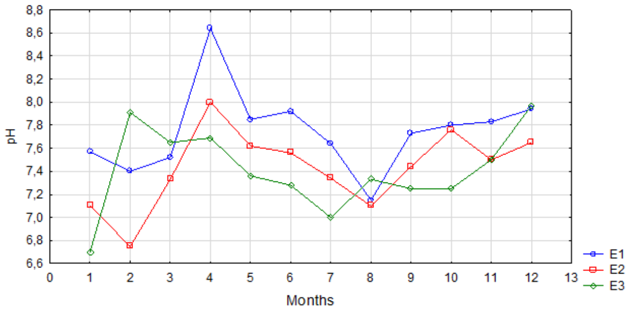

Fig. 4. Water acidity in experimental groups; E1–E3 as in Fig. 2; source: own study

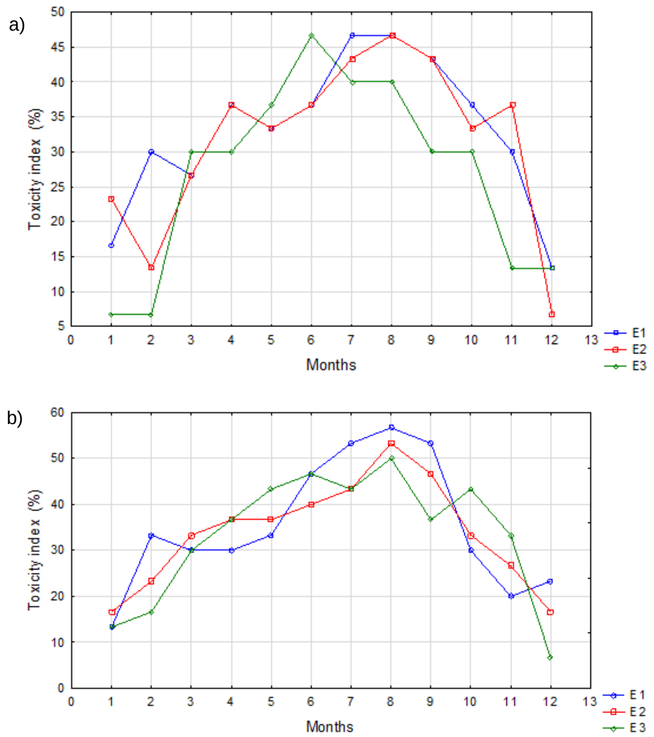

Fig. 5. Toxicity of the investigated waters determined using the *Carassius auratus gibelio* (a) and *Danio rerio* (b); source: own study

of water for industrial fishing and drinking by these indicators is significantly inferior to the quality of flowing river waters. Thus, *DO* concentration in August decreased to levels of 4.10 mg·dm^{-3} in group E1 (for MAC$_{water}$ 4.0 mg·dm^{-3}) and 6.07 mg·dm^{-3} in group E2 (for MAC$_{fish}$ 6.0 mg·dm^{-3}). The data obtained are consistent with the results of studies by other authors who believe that the slow water exchange inherent in reservoirs and overlapped rivers is one of the main factors that have negative impact on the oxygen regime of water and related indicators [BILYAVSKY, BUTCHENKO 2006; ROMANENKO 2004; SCHMITT *et al.* 2008].

Results of the correlation analysis should be considered to further determine the relationship between the indicators. The data obtained revealed mainly an average degree of correlation between *DO* concentration and temperature and water toxicity for *D. rerio* in all experimental groups, as well as the water toxicity for *C. auratus gibelio* in group E1. The calculated correlation coefficients (according to Student's *t*-test) were probable at level $p \leq 0.05$, except for the relationship between *DO* concentration and water temperature in group E3, where the probability was the highest – $p \leq 0.001$ (Tab. 1).

Table 1. Correlation relationship of dissolved oxygen (*DO*) concentration with temperature, acidity and toxicity of water for *Danio rerio* (T_D) and *Carassius auratus gibelio* (T_C); $n = 12$

Parameters of water quality affecting *DO*	Correlation coefficient (*r*)	Linear regression equation
Surface water sources		
Temperature (°C)	–0.6000±0.2530*	$y = -0.2342x + 10.696$
pH	0.5120±0.2716	$y = 3.963x - 22.387$
Toxicity index T_D	–0.6477±0.2409*	$y = -0.1293x + 12.885$
Toxicity index T_C	–0.6153±0.2493*	$y = -0.1637x + 13.734$
Waters for industrial fishing		
Temperature (°C)	–0.6894±0.2291*	$y = -0.2083x + 11.211$
pH	0.5431±0.2655	$y = 3.2482x - 15.026$
Toxicity index T_D	–0.6395±0.2431*	$y = -0.1122x + 12.907$
Toxicity index T_C	–0.5755±0.2586	$y = -0.0948x + 12.107$
River water of cultural and domestic use		
Temperature (°C)	–0.8265±0.1780**	$y = -0.3577x + 14.513$
pH	0.5622±0.2615	$y = 4.1755x - 20.018$
Toxicity index T_D	–0.6294±0.2457*	$y = -0.1209x + 14.942$
Toxicity index T_C	–0.5588±0.2623	$y = -0.1105x + 13.889$

Explanation: * $p \leq 0.05$, ** $p \leq 0.001$.
Source: own study.

Of all the factors considered, temperature had the largest influence on *DO* concentration (with probability $p \leq 0.001$ in group E3 and $p \leq 0.05$ in other groups). It is known that its decrease in the aquatic medium enhances the process of oxygen dissolution [BECKER *et al.* 2001; HUANG, SCHMITT 2014; RAJWA-KULIGIEWICZ 2015]. This pattern was the strongest in group E1 with the reliability of correlation coefficient $p \leq 0.001$. This was most likely due to the much better quality of flowing waters in the Zvizdal River compared to other groups in the absence of significant external influences that could disrupt oxygen dissolution due to temperature fluctuations. With poorer water quality in groups E2 and E1, the levels of likelihood of a relationship between temperature and *DO* concentration were significantly lower ($p \leq 0.05$ in both groups) [ROMANENKO 2004; SCHMITT 2008].

Under high water contamination (group E1), the levels of correlation of toxicity and *DO* concentration, determined on the sensitive (*D. rerio*) and resistant (*C. auratus gibelio*) fish species, were probable and very similar. In less polluted waters (Groups E2 and E3), the response of the sensitive fish species was significantly different from the stable species, both in the case of aquatic toxicity and *DO* concentration. The correlation coefficients between these indicators showed a significantly lower dependence of *C. auratus gibelio* on the change in the oxygen regime during the year compared to *D. rerio*. Therefore, the levels of established association between *DO* concentration and toxicity for *C. auratus gibelio* in these groups were improbable.

DISCUSSION

The oxygen regime significantly influences the functioning of aquatic ecosystems. The minimum *DO* concentration that ensures normal development of aquatic animal populations is about 5 mg·dm^{-3}. According to the regulatory requirements of MAC_{water}, oxygen in surface waters must not be lower than 4 mg·dm^{-3} in any period of the year. In the case of waters used for industrial fishing, these standards are somewhat more stringent: not lower than 4 mg·dm^{-3} in winter (in ice-cover period) and 6 mg·dm^{-3} in summer [BILYAVSKY, BUTCHENKO 2006; SNIZHKO 2001;].

However, some species of organisms are much more demanding regarding *DO* concentration and require more than 8–10 mg·dm^{-3} oxygen for comfortable existence. Therefore, the determination of *DO* in surface waters is included in hydrobionts monitoring programs, and it is also taken into account, among other indicators, in biological testing of waters for toxicity [BILYAVSKY, BUTCHENKO 2006; DUDNIK, YEVTUSHENKO 2013; SNIZHKO 2001].

As a rule, problems with the oxygen regime occur in summer when the temperature is the highest [RAJWA-KULIGIEWICZ 2015], water level decreases, concentration of pollutants, and so on, than in winter during the formation of an ice sheet. These periods of the year should be considered critical as regards the provision of aquatic organisms with sufficient amounts of *DO* [ROMANENKO 2004].

In our research, we identified the main seasonal trends in the oxygen regime (based on *DO* and related indicators, e.g. temperature, pH, toxicity) in waters designated for drinking (group E1), industrial fishing (group E2), as well as in flowing river waters (group E3). The most dangerous decrease in *DO* concentration, almost to the limit of MAC, was observed in August and applied to reservoirs with slow movement of water. Although flowing river waters (group E3) have managed to avoid most detrimental processes due to a better water quality than in other forms of the aquatic environment, the problem of reduced *DO* concentration in summer was also quite severe for them. In winter, a significant decrease in *DO* concentration in February (up to 5.58 mg·dm^{-3}) was observed in drinking water sources only, for which gas exchange disturbances due to slow water movement and stagnation were considered to be typical. For other water bodies, there were no such problems due to a better water exchange, as well as due to the proper maintenance of small rivers in winter. In other words, measures were implemented to enhance the aeration of the aquatic environment, which in the conditions of larger reservoirs is much more difficult.

Seasonal fluctuations of the investigated parameters that determined the oxygen regime (except for pH of aquatic medium) showed opposite tendency to the fluctuations in *DO*. To clarify the specific relationship with *DO* concentration, a correlation analysis was conducted to determine the role of each factor in the formation of the oxygen regime in water bodies designated for different use. The closest relationship was found between *DO* concentration and water temperature. Correlation coefficients that reflected the association of *DO* concentration with the toxicity identified in fish species of different sensitivity were only probable in group E1. The contamination of the reservoir might have reached such an extent that the aquatic environment became hazardous not only for sensitive but also for persistent fish species.

According to the researchers, when a certain biological limit is reached, reactions of individual specimens become similar regardless of their sensitivity to pollution. In addition, there are cases of increased sensitivity to pollutants among resistant fish species, including the *Carassius auratus gibelio*, at low *DO* concentrations in water [DUDNIK, YEVTUSHENKO 2013; ROMANENKO 2004]. This can be explained by the analogy in the response of different fish species to the changes in the oxygen regime of water, which is reflected in corresponding indicators. This pattern is confirmed by the presence of plausible relations in groups E2 and E3 between *DO* concentration and the toxicity of water determined regarding sensitive species of *D. rerio* fish ($p \leq 0.05$), as well as the absence of such relations regarding stable species under normal conditions of the oxygen regime.

The equations of linear regression have allowed to create statistical models that can predict effects of certain environmental factors on the formation of oxygen regime in the future. This includes the requirements of sensitive and stable fish species in experimental water bodies.

CONCLUSIONS

In investigated water bodies designated for different use, problems with the oxygen regime have resulted from the increase in temperature and toxicity of the aquatic environment for the sensitive species of *Danio rerio* fish and oxygen deficiency. In the case of the stable species *Carassius auratus gibelio*, its sensitivity increased under similar conditions.

As regards *DO* disturbance, the situation was more severe in reservoirs that had slow water movement and subject to intensive abstraction of water and industrial fishing (reduced *DO* concentration to almost MAC 4.10 mg·dm^{-3} in group E1 and 6.07 mg·dm^{-3} in group E2) compared to flowing rivers that were less affected by inadequate aeration.

Probable correlations of *DO* concentration, temperature and toxicity, as well as linear regression equations, can be used to predict the oxygen regime in water bodies. Thus, the regime can be controlled to reduce the negative impact of temperature and toxicological factors due to intensive processes of water and gas exchange.

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