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CONCENTRATION-DEPENDENT BIOREMEDIATION POTENTIAL OF *DREISSENA BUGENSIS* UNDER COPPER CONTAMINATION OF THE AQUATIC ENVIRONMENT

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The contamination of aquatic ecosystems by heavy metals, particularly copper (Cu), poses a serious environmental threat, which is further exacerbated by armed conflicts and the use of munitions. Given the limitations and high costs of traditional physicochemical remediation methods, biotechnological approaches, particularly the use of bivalve mollusks, are gaining importance. The aim of this study was to assess the bioremediation potential of Dreissena bugensis and to characterize its concentration-dependent morphofunctional responses under conditions of experimental copper contamination of the aquatic environment.

Adult specimens of D. bugensis were exposed for 28 days to copper concentrations equivalent to 1, 5, 10, 50, and 100 maximum permissible concentrations (MPC) for fishery water bodies. Survival, growth parameters, condition index, aggregation, filtration activity, and the efficiency of copper ion removal from the aquatic environment were evaluated.

It was experimentally established that D. bugensis exhibits high tolerance to copper ions in the range of 1–50 MPC, at which survival was high and did not differ from the control. Increasing the concentration to 100 MPC caused an acute toxic effect: mass mortality began on day 5, and complete mortality occurred within three days (RMST - 5.4 days out of 28 possible). This indicates the nonlinear nature of survival and a limit of physiological resistance within the range of 50–100 MPC. At the same time, the preservation of viability did not mean the absence of physiological changes: body mass decreased at 5–50 MPC, and the condition index decreased at 50 MPC (to 28%) and 100 MPC (to 21.93%), indicating the depletion of energy reserves due to valve closure, starvation, and detoxification costs. Aggregation behavior was maintained at 1–10 MPC, restricted at 50 MPC (aggregation index not higher than 4), and completely suppressed at 100 MPC. Filtration capacity significantly decreased in all treatment groups; however, the efficiency of copper removal from water increased throughout the experiment and reached its maximum at 10 MPC. This suggests that water purification is ensured not only by biofiltration but also by metal accumulation in tissues, passive sorption on shells and byssus, and deposition within feces and pseudofeces.

Keywords: Dreissena bugensis, bioremediation, heavy metals, copper, water purification, bivalve mollusks, filtration activity, condition index, aggregation index, bioaccumulation

Introduction. Heavy metals, unlike many organic pollutants, do not undergo biodegradation, which causes their long-term persistence in aquatic ecosystems, their ability to bioaccumulate in aquatic organisms, and their transfer through trophic chains. Their migration between the water column, suspended particles, and bottom sediments contributes to their prolonged presence in water bodies and the formation of secondary pollution hotspots. The accumulation of these elements in the components of aquatic ecosystems can cause disruptions in the physiological and biochemical processes of aquatic organisms, changes in the structure of aquatic communities, and a decrease in the functional stability of hydrobiocenoses.

Among heavy metals, copper (Cu) deserves special attention. Being an essential trace element necessary for the functioning of various enzyme systems and the maintenance of cellular metabolism, copper exhibits pronounced toxicity at excessive concentrations, comparable to the effects of non-essential heavy metals. Its entry into the organism can be accompanied by the disruption of ionic homeostasis, induction of oxidative stress, enhancement of lipid peroxidation, and damage to cellular structures. At the same time, the bioavailability and toxicity of copper are determined not only by its total concentration but also by its chemical forms, pH value, water hardness, and dissolved organic matter content, which complicates the prediction of the ecological consequences of pollution (Mebane, 2023).

The problem of metal input into aquatic ecosystems becomes particularly relevant in the context of armed conflicts, which are accompanied by the formation of additional sources of anthropogenic pollution. In particular, copper and its alloys are widely used in the production of certain ammunition components, creating the potential for its release as a result of military actions with subsequent migration

within hydrosystems. Such processes can cause the formation of localized pollution hotspots with long-term ecological impacts, especially under conditions of metal accumulation in bottom sediments and their re-entry into the water column (Semenenko et al., 2022; Broomandi et al., 2020). This, in turn, highlights the need to develop effective, economically accessible, and environmentally safe approaches to restoring the quality of the aquatic environment.

Traditional physicochemical methods of water purification, despite their effectiveness under certain conditions, may require significant material and energy resources, involve the use of chemical reagents, and be accompanied by the formation of metal-containing sludges (Fu & Wang, 2011). At the same time, the mechanical removal of contaminated bottom sediments can cause their resuspension and the re-entry of metals into the water column (Soetan et al., 2023). Given these limitations, biotechnological purification approaches, based on the natural physiological and biochemical properties of living organisms, are gaining increasing significance and are of interest for the restoration of aquatic ecosystems in both the wartime and post-war periods.

Among aquatic organisms promising for use in bioremediation, bivalve mollusks of the genus *Dreissena* occupy a special place. As seston-feeding filter feeders, they pass significant volumes of water through their mantle cavity, retaining particles ranging in size from 0.7 to 1200 μm, while the formation of dense aggregations (druses) ensures high total filtration activity. The attached lifestyle, wide distribution, and high tolerance to fluctuations in environmental parameters are combined in *Dreissena* with the ability to accumulate metals in the gills, digestive gland, and shell (Magni et al., 2015). The combination of these features determines their bioremediation potential.

The practical use of *Dreissena* for bioremediation requires determining the concentration limits of toxicants at which their filtration capacity is still maintained. Exceeding the limits of physiological tolerance can lead to the death of the mollusks, and the subsequent decomposition of their biomass creates a risk of secondary pollution due to the re-entry of accumulated metals into the aquatic environment. Establishing such limits involves a comprehensive assessment of the efficiency of copper removal from the aquatic environment and the concentration-dependent morphofunctional responses of the mollusks, which makes it possible to characterize their adaptive response. Considering the above, the aim of our work was to assess the bioremediation potential of bivalve mollusks of the genus *Dreissena* and to characterize their concentration-dependent morphofunctional responses under conditions of experimental copper contamination of the aquatic environment.

Materials and Methods. The object of the study was adult individuals of the bivalve mollusk *Dreissena bugensis* Andrusov, 1897, collected in the Dniester Reservoir (Chernivtsi Region, Ukraine). Collection was carried out at a depth of 2-4 m by extracting natural substrates colonized by mollusks, including stones and submerged branches. Prior to setting up the experiment, the individuals were acclimatized for 14 days. During this period, the mollusks were kept in 35-L aquariums with previously settled, dechlorinated, and UV-treated tap water at a temperature of 15 °C, with constant aeration and a photoperiod of 16 hours of light / 8 hours of darkness (Auclair et al., 2020). Feeding was conducted three times a week with a suspension of lyophilized *Arthrospira platensis* biomass.

To model copper contamination in the aquatic environment, six treatment groups were established: a control group with no additional metal introduced, and five treatment groups with Cu concentrations equivalent to 1, 5, 10, 50, and 100 maximum permissible concentrations (MPC), in accordance with the standards for fishery water bodies (1 MPC = 1 μg/L of copper ion) (Mussakulkyzy et al., 2025). Mollusks with a shell length of 25 ± 5 mm were placed in 1 L containers at a stocking density of 10 individuals/L. The maintenance conditions corresponded to the established acclimatization regime. The duration of the experiment was 28 days.

Changes in the copper concentration in the aquatic environment were investigated through periodic sampling at three-day intervals. The quantitative metal content was determined by atomic absorption spectrophotometry using an S-115M1 spectrophotometer. Simultaneously, a daily count of live individuals was performed to assess survival across the different pollution levels.

For the integral assessment of mollusk survival, the Restricted Mean Survival Time (RMST) was determined as the area under the Kaplan–Meier survival curve within the exposure period (Royston & Parmar, 2013).

To characterize behavioral responses during the first 10 days of exposure, the ability of mollusks to form aggregates was evaluated daily. The quantitative criterion was the proportion of aggregated individuals, calculated as the percentage of live mollusks grouped in clusters of two or more individuals relative to the total number of live mollusks in the respective treatment group at the time of observation (Uguen et al., 2025). Additionally, the aggregation index was calculated as the sum of values

obtained by subtracting one from the number of individuals in each formed cluster, excluding solitary mollusks (Antoł et al., 2018).

The filtration activity of *D. bugensis* was assessed weekly using the clearance method (water purification from suspended particles). *Chlorella vulgaris* was used as the model organism. The method is based on determining the rate of decrease in algal cell concentration in the aquatic environment due to their removal by the filtration apparatus of the mollusks. The water clearance rate was determined by the formula:

$$Cl = \frac{V}{mt} \ln\left(\frac{C_0}{C_t}\right)$$

where (V) is the volume of the aquatic environment; (*m)* is the mass of the mollusks; (*t)* is the duration of the measurement; (C_0) and (C□) are the concentrations of *C. vulgaris* cells at the beginning and end of the respective interval (Riisgård, 2001).

To evaluate changes in the mass characteristics of the mollusks during the exposure, weighing was conducted weekly. Based on the obtained values, the relative weight change (WI) was determined as the percentage ratio of the difference between the final and initial mass to its initial value (Hossain et al., 2023).

The average daily specific growth rate (SGR) was expressed in %/day and calculated as the difference between the natural logarithms of the final and initial mass, divided by the duration of the corresponding period of the experiment and multiplied by 100 (Chatzivasileiou et al., 2022).

The morphophysiological state of the mollusks was additionally characterized by the condition index (CI), which was calculated as the ratio of the dry mass of the soft tissues to the dry mass of the shell (Babarro et al., 2020).

Statistical evaluation of the study results was performed using a two-way analysis of variance (two-way ANOVA). Pairwise comparisons of the mean values were carried out using Tukey's test. Differences were considered statistically significant at $p < 0.05$.

Results and Discussion. A comprehensive assessment of the use of *Dreissena bugensis* as an agent for the bioremediation of waters contaminated with heavy metals should be based on the analysis not only of mollusk survival but also of a combination of their physiological and behavioral parameters. Only a combination of these parameters allows determining not just the tolerance limits of the organisms, but also the actual bioremediation potential of the species under different levels of toxic load.

The analysis of survival indicators revealed a high tolerance of *Dreissena* to copper exposure in the concentration range from 1 to 50 MPC. Under these conditions, the survival rate was 100% and did not differ from the control group throughout the entire experiment (Table 1).

Table 1.

Survival and morphofunctional parameters of Dreissena bugensis under exposure to different concentrations of copper

Experimental group	Survival, %	RMST, days	Relative weight change, %	SGR, %×days^{-1}	Condition index (CI), %
Control	100^{e}	28^{e}	$3{,}063 \pm 0{,}184^{abcd}$	$0{,}144 \pm 0{,}009^{abcd}$	$37{,}09 \pm 4{,}24^{de}$
Cu 1 MPC	100^{e}	28^{e}	$2{,}083 \pm 0{,}138^{bcdk}$	$0{,}098 \pm 0{,}010^{bcdk}$	$37{,}66 \pm 3{,}26^{de}$
Cu 5 MPC	100^{e}	28^{e}	$-10{,}669 \pm 0{,}327^{acdk}$	$-0{,}537 \pm 0{,}015^{acdk}$	$37{,}25 \pm 3{,}26^{de}$
Cu 10 MPC	100^{e}	28^{e}	$-9{,}098 \pm 0{,}218^{abdk}$	$-0{,}454 \pm 0{,}021^{abdk}$	$38{,}44 \pm 2{,}55^{de}$
Cu 50 MPC	90^{e}	$27{,}3 \pm 0{,}7^{e}$	$-14{,}087 \pm 0{,}451^{abck}$	$-0{,}723 \pm 0{,}019^{abck}$	$28{,}21 \pm 2{,}17^{abcek}$
Cu 100 MPC	0^{abedk}	$5{,}4 \pm 0{,}22^{abedk}$	-	-	$21{,}93 \pm 2{,}39^{abcdk}$

Note: a, significant difference from the 1 MPC group; b, from the 5 MPC group; c, from the 10 MPC group; d, from the 50 MPC group; e, from the 100 MPC group; k, from the control ($p \leq 0.05$).

However, increasing the toxicant level to 100 MPC caused the manifestation of an acute toxic effect: mass mortality of the mollusks began on day 5 of exposure and led to 100% lethality in just three days. This is objectively confirmed by a sharp decrease in the RMST indicator, which for the 100 MPC group was only 5.4 days out of 28 possible. The established nonlinear nature of survival indicates that the limit of physiological resistance of *Dreissena* to copper ions lies within the range of 50-100 MPC, beyond which rapid death is observed.

The preservation of high mollusk viability at concentrations up to and including 50 MPC is explained by the effective operation of intracellular detoxification systems. It is known that with the influx of heavy metals at moderate concentrations, mollusks undergo intensive synthesis of metallothioneins and compartmentalization of ions in

the form of insoluble granules, which allows them to maintain homeostasis and prevent oxidative stress (Lemus et al., 2016).

In turn, the mass mortality delayed by several days at 100 MPC indicates the use of a primary toxicity avoidance strategy by the mollusks: in response to a lethal dose of the toxicant, they hermetically close their valves, physically isolating the mantle cavity from the contaminated environment, and switch to an anaerobic metabolic pathway. However, such behavioral isolation is temporary. The depletion of energy reserves, the increase in tissue hypoxia, and the accumulation of toxic metabolic products force the mollusks to open their valves at a certain point to restore respiration (Vereycken & Aldridge, 2023). This causes a massive influx of copper ions, which, against the background of a general weakening of the organism, leads to a rapid overload of the detoxification systems and the subsequent death of the animals.

In turn, the analysis of growth parameters revealed significant differences in the morphofunctional state of the experimental mollusks (Table 1). In the control group and the 1 MPC group, an increase in the total mass of the individuals was observed, indicating the preservation of positive growth dynamics. Conversely, increasing the copper concentration in the medium to 5 and 10 MPC was accompanied by a decrease in body mass of approximately 10%, which was also reflected in the negative values of the specific growth rate. One of the possible reasons for such dynamics is the suppression of trophic activity as a result of the protective closure of the valves. At the same time, the maintenance of the condition index (CI) at a level close to the control (37.09%) may indicate that the decrease in total mass is not necessarily accompanied by a proportional loss of soft tissues. In particular, fluctuations in the content of mantle fluid without significant destruction of structural tissues may make a certain contribution to the formation of these changes.

With a further increase in the copper concentration to 50 MPC, negative changes in growth parameters became more pronounced. Despite maintaining high survival, a significant decrease in total mass was recorded in this group (the condition index decreased to 28%). The obtained results may indicate a gradual depletion of the organism's energy reserves and a decrease in the relative mass of soft tissues under the influence of prolonged toxic load. This is due to a combination of enhanced catabolism of internal resources resulting from starvation with closed valves and additional energy costs for copper detoxification. Under the extreme load of 100 MPC, this process transitions into an acute phase: a critical decrease in CI to 21.93% reflects the rapid degradation and necrosis of soft tissues, preceding the abrupt mass mortality of the mollusks.

The analysis of the dynamics of the aggregation behavior of the mollusks *Dreissena bugensis* revealed concentration-dependent changes in the intensity of druse formation (Fig. 1).

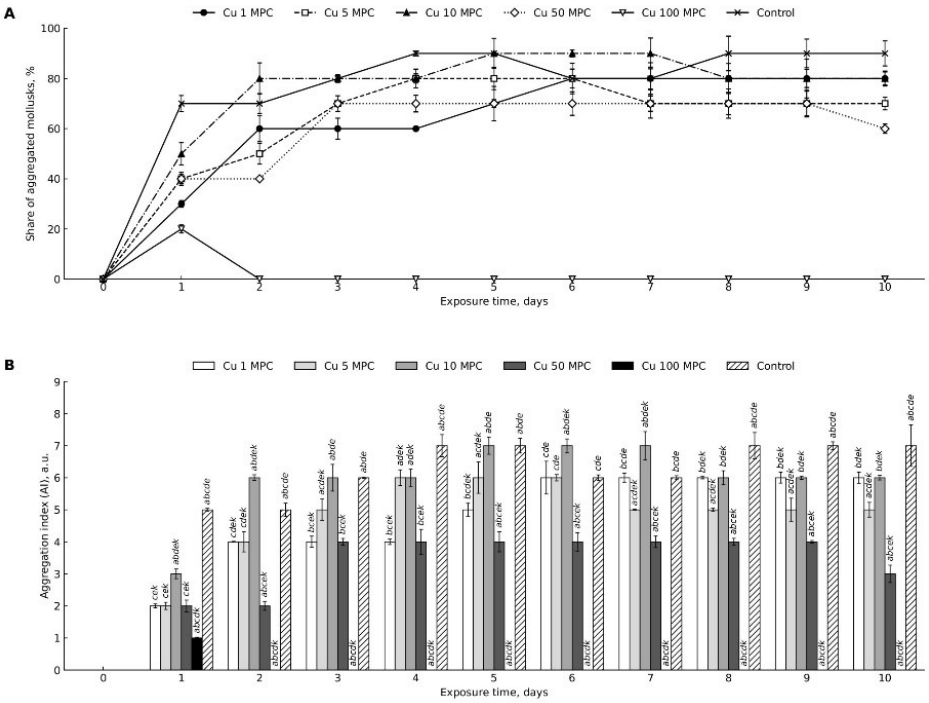


Fig. 1. Dynamics of the aggregation activity of Dreissena bugensis under exposure to different concentrations of copper: A, proportion of aggregated individuals, %; B, aggregation index (AI), arbitrary units.

Note: a, significant difference from the 1 MPC group; b, from the 5 MPC group; c, from the 10 MPC group; d, from the 50 MPC group; e, from the 100 MPC group; k, from the control ($p \leq 0.05$).

The observations covered the first 10 days of exposure, after which the aggregation parameters reached relatively stable values and did not change further.

High aggregation activity was observed in the control group: the proportion of individuals united in clusters reached 80-90%, and the aggregation index was 6-7. A similar trend persisted under the influence of copper at concentrations of 1-10 MPC. Hypothetically, the intensive formation of large druses under such conditions can be considered a potential adaptive response of the mollusks, aimed at partially limiting the contact of individual specimens with the contaminated environment due to the mutual overlap of shells in dense clusters.

Increasing the copper concentration to 50 MPC was accompanied by a noticeable suppression of aggregation activity. Despite maintaining a relatively high proportion of aggregated individuals (60-70%), the aggregation index did not exceed 4, indicating the predominant formation of smaller clusters. Such changes may point to a limitation in the mollusks' ability to form large druses under toxic load. This is consistent with the decrease in mass and condition index of individuals in this group and may be related to insufficient reserves required for active movement and the synthesis of byssal threads. It can also be assumed that the formation of small clusters potentially limits the effectiveness of aggregation as a protective response, as it provides a lesser degree of mutual shell overlap compared to large druses.

The most pronounced suppression of aggregation behavior was observed at a concentration of 100 MPC. Slight cluster formation was recorded only on the first day of exposure, when the proportion of aggregated mollusks was 20% and the aggregation index was 1. Subsequently, no druse formation was recorded until the complete death of the mollusks. Such dynamics indicate a significant suppression of behavioral responses associated with movement and cluster formation under conditions of acute toxic exposure to copper.

The filtration capacity of bivalve mollusks is a direct indicator of their functional activity and bioremediation potential. The analysis of the dynamics of this parameter over 28 days of exposure revealed statistically significant suppression in all treatment groups compared to the control (Fig. 2).

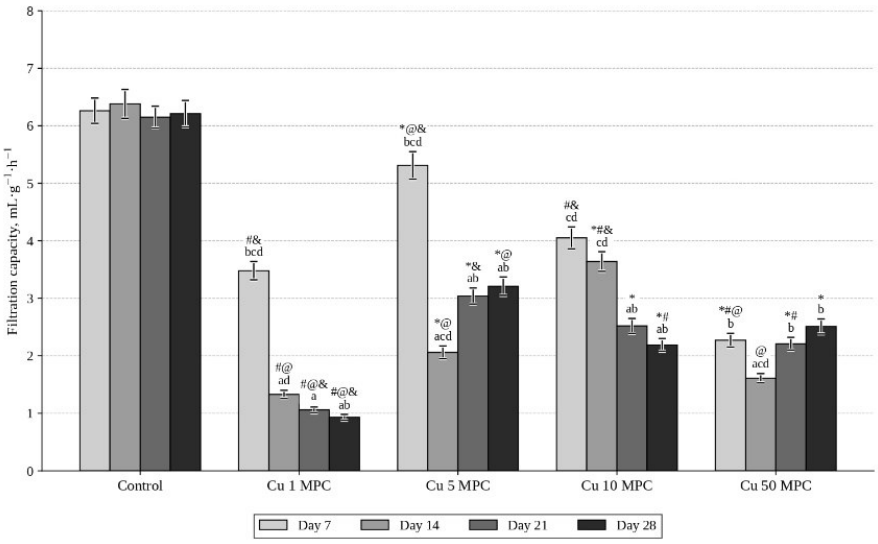


Fig. 2. Filtration capacity of Dreissena bugensis under exposure to different concentrations of copper, mL·g⁻¹·h⁻¹

*Note: Latin letters above the bars indicate a statistically significant difference ($p \leq 0.05$) between days within the same group: a, from day 7; b, from day 14; c, from day 21; d, from day 28. Symbols indicate a statistically significant difference ($p \leq 0.05$) between groups within the same day: *, from 1 MPC Cu; #, from 5 MPC Cu; @, from 10 MPC Cu; &, from 50 MPC Cu. In all treatment groups, filtration capacity was significantly lower ($p \leq 0.05$) than in the control on all days of exposure.*

At the minimum copper concentration (1 MPC), a gradual decrease in filtration capacity was observed throughout the entire exposure period. Presumably, this level of toxic load was insufficient to immediately trigger a chemoreceptor protective response: the mollusks did not perceive the environment as acutely dangerous, so their valves remained open, continuing active filtration of the medium. This could contribute to the gradual accumulation of the metal in the tissues, followed by the development of cellular damage and suppression of ciliary apparatus activity.

At a concentration of 5 MPC, the dynamics of filtration capacity were characterized by a biphasic response, manifested as initial suppression followed by partial recovery of activity. Presumably, this trend is associated with the gradual activation of biochemical defense systems, in particular the induction of metallothionein synthesis. Conversely, the decrease in filtration capacity at higher copper

concentrations (10-50 MPC) may indicate that the organism's protective capacity was exceeded, with an excessive influx of copper ions causing oxidative stress and damage to the gill epithelium, disrupting the functioning of the ciliary apparatus and limiting the mollusks' ability to filter water effectively.

Changes in the functioning of the filtration apparatus affect the overall ability of the mollusks to remove copper ions from the aquatic environment. Thus, the analysis of the dynamics of toxicant removal from the aquatic environment revealed a general trend toward increased purification efficiency throughout the experiment (Fig. 3).

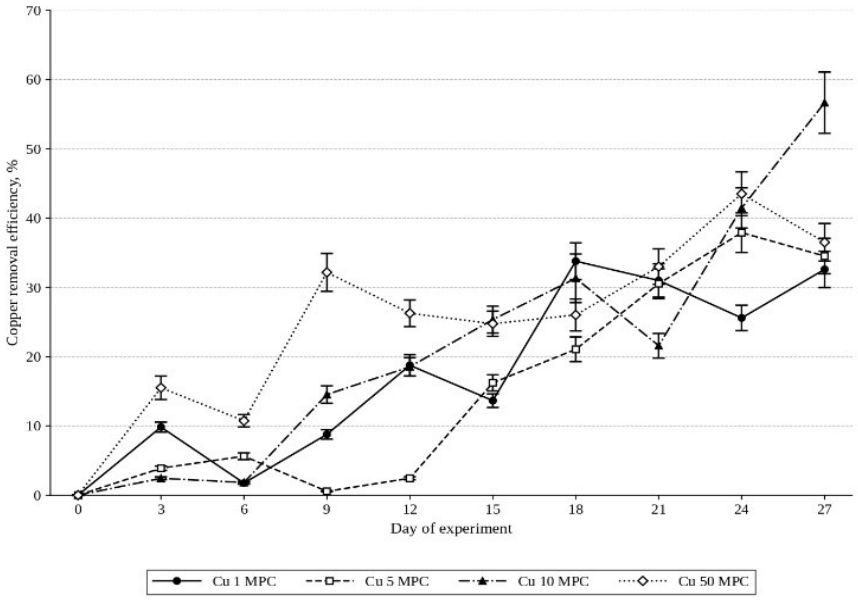


Fig. 3. Dynamics of copper ion removal from the aquatic environment by Dreissena bugensis

In the 1 MPC group, copper removal occurred gradually, with minor fluctuations in the initial stages and subsequent stabilization of the parameter. Presumably, under such a load, continuous biofiltration with gradual accumulation of the metal in mollusk tissues played the primary role.

In the 5 MPC group, the removal dynamics clearly correlated with the biphasic change in filtration capacity. In the first half of the experiment, purification efficiency remained minimal, corresponding to the period of initial stress and restricted filtration. Subsequently, the indicator began to increase steadily, confirming the hypothesis of successful physiological adaptation and partial recovery of active water purification following the induction of detoxification systems.

In contrast, in the range of 10-50 MPC, an intensive increase in copper removal efficiency was observed, reaching its highest values in the 10 MPC group by the end of the experiment. Given the simultaneous decrease in filtration capacity, such dynamics likely cannot be explained solely by active biofiltration. One possible mechanism is enhanced accumulation of the metal in the mollusk tissues. On the other hand, passive metal-binding mechanisms may play a significant role in this process, in particular adsorption of the metal onto the surfaces of shells and byssal threads. It is known that the byssus of bivalve mollusks is capable of accumulating heavy metals both as a result of their excretion from tissues and through direct sorption from the aquatic environment (Yap, 2012). Therefore, even with a potential suppression of new thread formation, the existing byssus can remain an additional sorptive substrate. Another potential pathway for metal removal is their binding to suspended particles and subsequent deposition within feces and pseudofeces (Yap, 2012). In particular, studies in Lake Erie have shown that this mechanism can provide up to 92% additional deposition of metals from the water column (Klerks et al., 1997). Thus, water purification efficiency at high metal concentrations may be determined not only by the intensity of biofiltration but also by passive sorption processes.

Conclusions. A high tolerance of *Dreissena bugensis* mollusks to copper exposure was established in the concentration range of 1-50 MPC, at which survival during the 28-day exposure was 100%. At the same time, increasing the metal concentration to 100 MPC caused an acute toxic effect, leading to the complete mortality of the individuals. Despite the maintenance of viability at lower concentrations, an increase in toxic load was accompanied by a gradual deterioration of the morphofunctional state of the mollusks, manifested as decreased body mass and condition index and disrupted aggregation behavior. The obtained results indicate the concentration-dependent nature of the

responses of *Dreissena* to copper contamination of the aquatic environment and the limited adaptive and compensatory capacity of the mollusks.

Filtration capacity significantly decreased in all treatment groups; however, the efficiency of copper removal from water increased throughout the experiment, reaching a maximum at 10 MPC. This suggests that water purification is ensured not only by biofiltration but also by the accumulation of the metal in tissues, passive sorption on shells and byssus, and deposition within feces and pseudofeces. Overall, *D. bugensis* can be considered a promising organism for the bioremediation of copper-contaminated waters, particularly at concentrations up to 10 MPC, where survival, aggregation activity, and a high level of toxicant removal are maintained.

***Conflict of Interest**. The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.*

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КОНЦЕНТРАЦІЙНО-ЗАЛЕЖНИЙ БІОРЕМЕДІАЦІЙНИЙ ПОТЕНЦІАЛ *DREISSENA BUGENSIS* ПРИ ЗАБРУДНЕННІ ВОДНОГО СЕРЕДОВИЩА КУПРУМОМ

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Забруднення водних екосистем важкими металами, зокрема купрумом (Cu), становить серйозну екологічну загрозу, яка додатково посилюється внаслідок збройних конфліктів і використання боєприпасів. З огляду на обмеження та високу вартість традиційних фізико-хімічних методів очищення дедалі більшого значення набувають біотехнологічні підходи, зокрема застосування двостулкових молюсків. Метою дослідження було оцінити біоремедіаційний потенціал Dreissena bugensis та охарактеризувати його концентраційно-залежні морфофункціональні реакції за умов експериментального забруднення водного середовища купрумом.

Дорослих особин D. bugensis упродовж 28 діб експонували за концентрацій купруму, еквівалентних 1, 5, 10, 50 і 100 гранично допустимим концентраціям (ГДК) для рибогосподарських водойм. Оцінювали виживаність, ростові показники, індекс кондиції, агрегацію, фільтраційну активність та ефективність вилучення іонів купруму з водного середовища.

Експериментально встановлено, що D. bugensis виявляє високу толерантність до іонів купруму в діапазоні 1–50 ГДК, за якої виживаність була високою й не відрізнялася від контролю. Підвищення концентрації до 100 ГДК спричинило гострий токсичний ефект: масова загибель розпочалася на 5-ту добу, а повна летальність настала за три дні (RMST - 5,4 доби з 28 можливих). Це вказує на нелінійний характер виживаності та межу фізіологічної резистентності в межах 50–100 ГДК. Водночас збереження життєздатності не означало відсутності фізіологічних змін: за 5–50 ГДК знижувалася маса тіла, а індекс кондиції зменшувався за 50 ГДК (до 28 %) і 100 ГДК (до 21,93 %), що свідчить про виснаження енергетичних резервів унаслідок закриття стулок, голодування та витрат на детоксикацію. Агрегаційна поведінка зберігалася за 1–10 ГДК, обмежувалася за 50 ГДК (індекс агрегації не вище 4) і повністю пригнічувалася за 100 ГДК. Фільтраційна здатність достовірно знижувалася в усіх дослідних групах, проте ефективність вилучення купруму з води зростала впродовж експерименту й досягала максимуму за 10 ГДК. Це свідчить, що очищення води забезпечується не лише біофільтрацією, а й накопиченням металу в тканинах, пасивною сорбцією на черепашках і бісусі та осадженням у складі фекалій і псевдофекалій.

Ключові слова: Dreissena bugensis, біоремедіація, важкі метали, купрум, очищення води, двостулкові молюски, фільтраційна активність, індекс кондиції, індекс агрегації, біоакумуляція

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