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CONTENT OF ZINC AND LEAD IN WATER AND IN ALGAE FROM SELECTED BLACK SEA BAYS NEAR SEVASTOPOL

ZAWARTOŚĆ CYNKU I OŁOWIU W WODZIE I GLONACH Z WYBRANYCH ZATOK MORZA CZARNEGO W OKOLICACH SEWASTOPOLA

Abstract: For many years there has been intensified human pressure in the region of Sevastopol, arising out of its strategic role as the main city in the region as well as a port where the Russian or Soviet Black Sea fleet was stationed. The industry in Sevastopol, municipal sewage as well as agriculture are important sources of pollutants that enter the Black Sea in the region of this city. In terms of shaping the environmental protection policy (not only in the research region but in the whole basin), it is important to conduct monitoring research connected with the pollution of the Black Sea in regions with different levels of human pressure. The aim of this study was to assess the content of zinc and lead in water and in algae from selected Black Sea bays near Sevastopol. The samples of water and algae were collected in August 2012 from eight bays of Sevastopol (Galubaja, Kozacha, Kamyshova, Kruhla, Striletska, Pishchana, Pivdenna and the Sevastopol Bays) as well as one sample from the open sea near Fiolent. *Cystoseira barbata* and *Ulva rigida* algae were taken from the same places. The collected water samples were conserved *in situ* and after being brought to the laboratory their zinc and lead contents were determined. The collected algae were rinsed in distilled water, dried, and then homogenized and mineralized. The lead content was determined in mineralisates by AAS method with electrothermal atomization, and the zinc content was determined using the ICP-OES method.

The zinc content in water ranged from 36.43 to 233.3 μg Zn · dm^{-3}, and the lead content was between 1.32 and 38.32 μg Pb · dm^{-3}. Considerable differences in contents of the studied elements in water of individual bays were found. Variability of zinc and lead concentration in the studied water samples was 69 and 112%, respectively. The highest zinc contents were found in water from the Striletska, Kozacha, and Sevastopol Bays, and the highest lead contents from the Kozacha and Kruhla Bays. Their lowest concentration was found in the water collected in the open sea. Moreover, the lower zinc concentration was in water from Pivdenna and

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Pishchana Bays, and the lowest lead concentration was found in the Galubaja and Pishchana Bays. The zinc content in the algae ranged between 6.517 and 30.21 mg · kg^{-1}. The *Cystoseira barbata* algae contained over twice more zinc than the *Ulva rigida*. The lead content in the algae ranged between 0.567 and 7.692 mg Pb · kg^{-1}. Compared with the *Ulva rigida*, almost a half more lead was found in the *Cystoseira barbata*. No statistically significant correlation between the content of the studied elements in water and the algae biomass was observed. However, a significant positive correlation between the content of these metals in both species of algae was found. The values of the zinc bioaccumulation coefficient varied from 32 to 642, and of lead from 30 to 1,273. Contents of the studied elements, both in biotic and abiotic part of the studied ecosystems, point at anthropogenic enrichment. However, the results obtained for the Sevastopol, Kozacha, and Striletska Bays point to a danger of their excessive bioaccumulation and a potential risk to the life of aquatic organisms as well as seafood consumers.

Keywords: Black Sea, water, *Cystoseira barbata*, *Ulva rigida*, pollution, bioaccumulation

Introduction

The Black Sea is a basin with strategic importance on a regional scale as well as on a world scale. Due to the location (within densely populated, urbanized and industrial terrains), considerable amounts of pollutants that worsen the water quality and developmental conditions for biological life enter this basin. In basins which are under the influence of human pressure, worsen of water quality can always be observed [1].

Many seaside cities discharge municipal sewage directly into the sea, and rivers that feed this basin carry considerable amounts of biogenic substances, heavy metals as well as durable organic compounds. The coastal zone of this basin is the most polluted, which is especially dangerous since these are reproduction regions for many species of ichthyofauna as well as zone colonized by macroalgae which play an important role in sea ecosystems. Containing the degradation of the Black Sea belongs to the priorities of the EU policy connected with an environmental protection. In order to implement effective mechanisms within this range, it is necessary to start cooperation among all the users of the Black Sea basin. Research on water quality and quantity is necessary for understanding the changes taking place in the Black Sea ecosystem and for preserving biodiversity. In recent years the importance of the Black Sea area in European Union politics has been increasing, which is a direct consequence of Romania and Bulgaria entering the Union. To meet the established goals of protecting the Black Sea environment, a number of organizations were appointed. These organizations are supposed to help strengthen the cooperation among the Black Sea countries as well as create instruments of political and economic pressure on the governments of these countries. One of them is the “Black Sea synergy – a new regional cooperation initiative” [2]. The aim of cooperation within this program is supposed to be actions that could solve the long-term conflicts, enhance trust, and later eliminate the existing obstacles. Development of cooperation among the Black Sea countries could also bring about beneficial effects that would go beyond their area. Elaboration of the environmental protection policy must, however, be preceded by accurate inventory and by indicating the most important problems. In order to do so, it is important to monitor the quality of the environment and to record any changes from the perspective of space and time. Monitoring data constitute input data for designing the environmental protection policy and are the basis for its evaluation.

Zinc and lead enter the water environment mainly from anthropogenic sources. Surface runoffs from agricultural and urbanized areas, and also sewage, both industrial and municipal, as well as combustion of fuels are the sources of these elements in the water environment. Zinc present in water is easily uptaken, both by plant and animal organisms, that is why in aquatic ecosystem where high amounts of this element can be found in abiotic parts of the environment, a phenomenon of high bioaccumulation of this element is observed. In a highly saline environment lead forms easily soluble complex compound $PbCl_3^-$. This can lead to excessive inclusion of this element into biocirculation. Under normal conditions, both studied elements that enter the water environment are very quickly bond with bottom sediments, undergoing immobilization [3]. Bioindication is an often used tool in evaluation of environmental risks of trace elements [4–6]. Determining the accumulation of harmful elements in organisms living in certain environmental conditions allows not only to evaluate the pollution degree but also to predict changes in structures of biocoenoses, both from the quantitative and qualitative perspective. Biomonitoring research results are an extremely useful tool for shaping the policy of environmental protection and nature protection. Depending on the trend in utilizing environmental resources, the level and specificity of pollutants, organisms on different levels of the trophic chain are used for biomonitoring research [7–9]. Utilize of larvae, spawn or young specimens is useful in solving problems connected with the effect of pollutants on reproductive success. For instance, research on accumulation of trace elements in adult specimens of fish for human consumption provides information on the issue of risk to humans. Utilization of macroalgae for monitoring purposes provides information on the danger coming from pollutants dissolved in water, on their resources deactivated in bottom sediments or bound with the suspension or in living organisms [7]. Based on monitoring studies with the use of autotrophic organisms it is easier to specify the effect of changes in water quality caused by periodic fluctuations or trends connected for example with the implementation of the environmental protection policy [9]. When utilizing aquatic organisms, both plants and animals, it is very important to choose the proper organ in which the content of trace elements is determined. Many authors draw attention to great differences in contents of trace elements in individual organs [10–12]. Algae are organisms of particular importance for biomonitoring due to their great affinity to heavy metals. These organisms are often use as biosorbents for heavy metals [13–15].

The aim of the research was to determine the level of pollution with zinc and lead in ecosystems of the bays in the region of Sevastopol. Content of the studied elements in water and in algae from the green and brown algae genera were the parameters used for the realization of the established goal.

Material and methods

Due to the shape of shoreline of the studied bays as well as differences in the level of human pressure, they were treated in the research as separate ecosystems. To reach the established goal, samples of water from 8 bays in the region of Sevastopol as well as one sample from the open sea near Fiolent were collected in August 2012 (Fig. 1).

Fig. 1. Points of sampling

The samples were collected from the top layer of water (from the depth of 0–120 cm). The sampling points were selected so as to obtain a sample as representative as possible for the whole bay. In order to do so, data on water movements and on flow of sea currents were used. The samples were collected from the following bays: Galubaja, Kozacha, Kamyshova, Striletska, Kruhla, Pishchana, Pivdenna, and the Sevastopol Bay as well as from the open sea in the region of Fiolent (Fig. 1). The cumulative sample consisted of 10 initial samples with a volume of about 100 cm^3, collected in different points. The laboratory sample was identical with the cumulative sample. Simultaneously, samples of *Cystoseira barbata* and *Ulva rigida* algae were collected in the same points. The cumulative sample was created from 10 initial samples, each of approximately 200 g. The laboratory sample was identical with the cumulative sample. The selected species of algae are common in the studied area. Due to high capacity for accumulation of heavy metals, they are often used in the evaluation of pollution of marine ecosystems with trace elements. After being collected, the water was filtrated and conserved by adding nitric acid with the concentration of 65%, in the quantity of 2 cm^3 per each 100 cm^3 water. The algae were washed in distilled water, dried and homogenized. Such prepared samples were transported to the laboratory. Laboratory samples of the algae were subjected to wet mineralization in a closed system with the use of microwave energy. The analytical sample amounted to approximately 0.5 g. The material was digested in a mixture of HNO_3 and H_2O_2, in the 5:1, *v/v* ratio. Water samples to be analyzed were thickened ten times by evaporation. The lead concentration in the obtained solutions was determined by atomic absorption spectrometry with electrothermal atomization, in an M6 device manufactured by Thermo, at wavelength of 217.0 nm. The limit of determination for lead in the used method of measurement was 0.06 $\mu g \cdot dm^{-3}$. The uncertainty of measurement of the used methods was ± 8%. The limit of detection for the method to 2.7 $\mu g \cdot kg^{-1}$ d.m. of the biological material, and 0.07 μg · dm^{-3} water. The zinc concentration was determined by atomic emission spectrometry, on Optima 7600 DV manufactured by Perkin Elmer, at wavelength of 206.200 nm. The limit of determination for zinc in the used method of measurement was 5.9 μg · dm^{-3}. The uncertainty of measurement of the used methods was ±6%. The limit of detection for the method to 0.118 μg · kg^{-1} d.m. of the biological material, and 6 μg · dm^{-3} water.

Certified reference material CRM 16-050 was used to check the correctness of the analyses. On the basis of the obtained results, the bioaccumulation coefficients of the studied metals in the biomass of the algae were calculated. The bioaccumulation coefficient was calculated by dividing the content of an element in the biomass by its concentration in the water. Moreover, Spearman's correlation coefficients were calculated between the concentration of the element in the water and its content in the algae biomass, and also between the element content in *Cystoseira barbata* and *Ulva rigida.*

Results and discussion

The zinc concentration in the water collected from individual bays of Sevastopol was within the range from 36.43 to 233.3 μg · dm^{-3}. The average concentration of this element was 112.77 μg · dm^{-3} (Fig. 2).

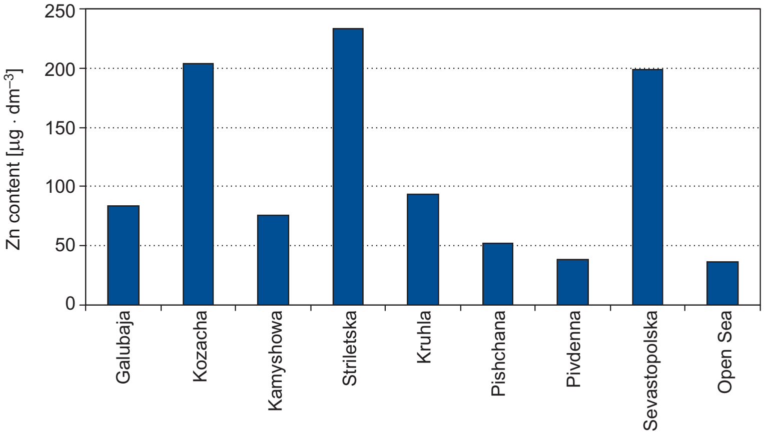

Fig. 2. Concentration of zinc in water

Considerable differences in the zinc concentration in the water in individual research sites were found. The relative standard deviation (RSD) of this element concentration was 69%. The highest zinc concentration was in the water from the Striletska, Kozacha and Sevastopol Bays, where it was: 233.3, 203.6 and 199.2 μg Zn · dm^{-3}, respectively. The least zinc was recorded in the water collected in the open sea and from the Pivdenna Bay. The concentrations in the water collected from these points were, 36.43 and 38.11 μg Zn · dm^{-3}, respectively.

The zinc concentration in the unpolluted waters of Hannah Lake was at a level of 14 μg · dm^{-3}, whereas in Whitson Lake it was 10 μg · dm^{-3} [16]. Zinc concentration in water found by these researchers can be regarded as natural. Norris et al [17] determined the concentrations of this element in Colorado River at a level of 1090 μg · dm^{-3}. Kahle and Zauke [18] provide that zinc concentration in the water from the Arctic Sea amounted 0.3 μg Zn · dm^{-3}. Generally higher zinc concentrations are found in fresh waters, and lower ones in marine ecosystems [19].

Ulva rigida is one of alga from the genus Ulva suitable as bioindicator of water pollution with trace metals [20]. The zinc content in the *Ulva rigida* algae ranged between 6.517 and 15.03 mg · kg^{-1} d.m., whereas in *Cystoseira barbata* between 19.083 and 30.208 mg · kg^{-1} d.m. Insignificant differences in contents of this element in algae collected in individual bays were found. The relative standard deviation for zinc content in *Cystoseira barbata* was 17%, whereas in *Ulva rigida* it was 27%. On average, 2.5 times less zinc was determined in *Ulva rigida* compared with *Cystoseira barbata.* In the case of *Cystoseira barbata,* the least of this element was found in the algae collected in the open sea. Almost in each sample of *Ulva rigida* collected from the bays, a higher zinc content compared with the algae collected in the open sea was found (Fig. 3). The Kozacha Bay was the only exception.

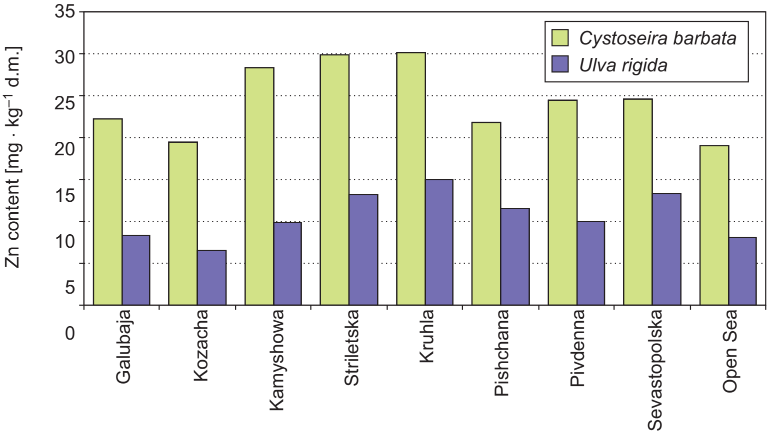

Fig. 3. Content of zinc in macroalgae

The algae collected in the Striletska and Kruhla bays contained the highest amount of zinc. Zinc contents in *Cystoseira barbata* collected in these bays were 29.84 and 30.21 mg Zn · kg^{-1} d.m., respectively, and in *Ulva rigida* they were 15.03 and 13.20 mg Zn · kg^{-1} d.m., respectively. The statistical data analysis did not reveal a significant correlation between the zinc content in water and algae. A statistically significant correlation ($r_{0.05}$ = 0.767) between the zinc content in both species of algae was found. Other authors also provide high correlation coefficients between zinc content in different species of algae living in certain conditions of water pollution [7, 21]. Such results confirm a similar suitability of both species in the monitoring research. Results on zinc contents in the algae, obtained in the authors' own research, are not high and close to the content of this element in algae from areas with a low human pressure index. Brito et al [7] provide results of zinc contents in algae of different species from a region with high level of human pressure in Brazil that are close to those obtained in the authors' own research. On the other hand, Caliceti et al [21] provide a much higher mean zinc contentration (64 mg Zn · kg^{-1} d.m.) in algae from the Venice Lagoon, at significant differences of this element content in the algae collected in regions with a various level of human pressure. It shows high sensitivity of the bioindication methods. High contents of this element in the algae biomass are a consequence of this element concentration in water. The mentioned authors draw attention to the value of this type of research for defining the long-term trends in changes in environmental pollution, for instance in order to evaluate the environmental protection programs. Rodriguez Figueroa et al [22] recorded 63 mg Zn · kg^{-1} in the seaweed *Padina durvillaei* in a copper mining region on the east coast of the Californian Peninsula. In their opinion, it is the natural content and does not prove anthropogenic enrichment, despite strong pollution of bottom sediment with this metal. Denton et al [23] determined even over 100 mg Zn · kg^{-1} d.m. in the algae collected from polluted regions of the Mariana Islands, at very big differences in its concentration in samples collected from individual sites. The zinc content in the algae for consumption in Spain varied in wide limits, from 1.2 to 73 mg Zn · kg^{-1} d.m., and in the case of *Ulva rigida* between 5.61 and 6.14 mg Zn · kg^{-1} d.m. [24]. Similarly high concentrations of this element were found in the algae from the Azores region subjected to the effect of human pressure connected with urbanization [25]. Strezov and Nonova [26] provide similar zinc contents in *Ulva rigida* and *Cystoseira barbata* collected in the Bulgarian coastal zone of the Black Sea to the ones found in the authors' own research. These authors did not find any differences in the content of this element in either of the two species of algae.

The value of the bioaccumulation cofficient for zinc in the algae from individual bays in the region of Sevastopol varied from 32 (*Ulva rigida*) to 642 (*Cystoseira barbata*) (Table 1).

Table 1

Value of bioaccumulation coefficients of zinc and lead in algae from individual research points

Points of sampling	Bioaccumulation coefficent of Zn		Bioaccumulation coefficent of Pb	
	Cystozeira barbata	*Ulva rigida*	*Cystozeira barbata*	*Ulva rigida*
Galubaja Bay	267	100	582	458
Kozacha Bay	95	32	41	33
Kamyshowa Bay	372	130	676	582
Striletska Bay	128	64	628	562
Kruhla Bay	324	141	39	30
Pishchana Bay	421	223	1273	775
Pivdenna Bay	642	263	401	303
Sevastopol Bay	124	67	569	383
Open Sea	524	221	688	429

Considerable differences were found in the value of this parameter, depending on the type of organism used in the research. The highest values of bioaccumulation coefficient for zinc in *Cystoseira barbata* and *Ulva rigida* were found in the Pivdenna Bay 642 and 263, respectively. The very high values of the coefficients at that research point resulted from a low content of this element in water. The zinc content in the algae of both species collected in the Pivdenna Bay points at anthropogenic enrichment. The lowest values of the zinc bioaccumulation coefficient in the studied part of biocoenoses were found in the Kozacha Bay, and then in the Sevastopol and Striletska Bays. Low values of this parameter at those research sites results from high zinc concentration in water. Melville and Pulkownik [27] provide much higher values of the zinc bioaccumulation coefficient in different species of algae collected from several estuaries of Western Australia than the ones determined in the authors' own research, reaching even 8000. The provided by these authors zinc contents in algae varied from 45 to 394 mg Zn · kg^{-1} d.m.

Lead concentration in the studied water samples was in a wide range from 1.32 to 38.32 µg Pb · dm^{-3} (Fig. 4), and the mean value was 11.14 µg Pb · dm^{-3}.

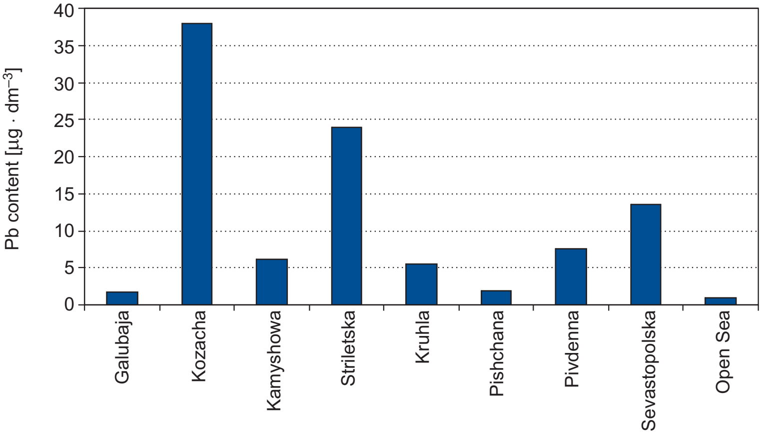

Fig. 4. Concentration of lead in water

Lead concentration in sea waters is generally lower than in fresh waters, but due to the specificity of metabolism of animals living there, high concentrations of this element in tissues of even such sea animals that lived in an unpolluted environment are seen very often. The most of this element was found in the water collected from the Kozacha Bay, and then in the Kruhla and Sevastopol Bays 38.32, 23.91 and 13.52 µg Pb · dm^{-3}, respectively. The lowest lead concentration was found in the water collected from the open sea and from the Pishchana and Galubaja Bays. Lead concentration in the water from the Arctic Sea was 0.6 µg Pb · dm^{-3} [18]. The lead contents determined in all the samples can suggest anthropogenic enrichment of the ecosystem with this element [28, 29].

The lead content in the collected algae ranged between 0.567 mg Pb · kg^{-1} d.m. (*Ulva rigida*) and 7.692 mg Pb · kg^{-1} d.m. (*Cystoseira barbata*) (Fig. 5), and its mean value

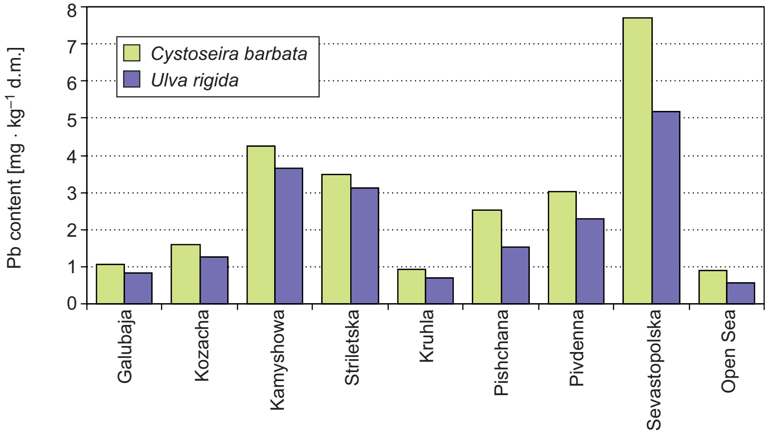

Fig. 5. Content of lead in macroalgae

reached 2.477 mg · kg^{-1}. No significant correlation between the content of this element in water and in the biomass of the algae that were used in the research was observed, whereas a statistically significant correlation ($r_{0.01} = 0.977$) between the lead content in both species of algae was found. The content of this element in the *Cystoseira barbata* collected in the bays ranged from 0.925 to 7.692 mg Pb · kg^{-1} d.m., and in the *Ulva rigida* from 0.708 to 5.183 mg Pb · kg^{-1} d.m. The most lead was found in both species of algae collected from the Sevastopol Bay, and then in the Kamyshchowa and Striletska Bays. Lead contents in the *Cystoseira barbata* from these bays were 7.692, 4.233 and 3.492 mg Pb · kg^{-1} d.m., respectively, while in the *Ulva rigida* they were 5.183, 3.642 and 3.125 mg Pb · kg^{-1} d.m. The lead content in the *Ulva rigida* algae was by, on average, approximately 25% lower than determined in the *Cystoseira barbata*. The lowest amount of lead was noted in the algae collected in the open sea, and then in the Kruhla and Galubaja Bays. High variability of the obtained results at individual research points indicatives of a various level of human pressure. The relative standard deviation for the lead content in the biomass of both species of algae was approximately 75%.

Results obtained in the authors' own research, in the light of literature data, are very high and indicative of possible excessive accumulation of this element in organisms of all trophic levels. In the research of Rodriguez Figueroa et al [22], the seaweed *Padina durvillaei* in a copper mining region on the east coast of the Californian Peninsula contained 7.8 mg Pb · kg^{-1}, which was regarded as the natural content despite a severe pollution of bottom sediments with lead. Horta-Puga et al [30] provide much lower lead contents in different species of algae collected from areas near from Veracruz coral reef in Mexico, within the range from 0.016 to 0.8 mg Pb · kg^{-1} d.m. Similarly low contents were found in the algae of different species from the region of the Azores [25]. The lead content in the algae available in sales nets and intended to be used for consumption in Spain was within limits from trace quantities to 1.25 mg Pb · kg^{-1} d.m., and in the *Ulva brigida* algae it was between 1 and 1.05 mg Pb · kg^{-1} d.m.

Lead contents obtained in the authors' own research are comparable to the ones determined in various species of algae from areas with a high coefficient of human pressure in Brazil, amounting from 2 to 5 mg Pb · kg^{-1} d.m. [7]. Lead contents similar to the ones obtained in the authors' own research were found by Denton et al [23] in the algae from polluted regions of the Mariana Islands. Caliceti et al [21] provide 3.2 mg Pb · kg^{-1} d.m. as the mean lead content in the *Cystoseira barbata* algae from the Venice Lagoon, and 7.3 mg Pb · kg^{-1} d.m. in the *Ulva rigida*. These authors found a considerable diversification in lead concentration in algae from individual sampling points which were located in zones with different intensity of anthropopressure. Considerably higher contents were determined in the *Ulva rigida*, which is divergent with results obtained in the authors' own research. Strezov and Nonova [26] provide similar lead contents in *Ulva rigida* and *Cystoseira barbata* collected in the Bulgarian coastal zone of the Black Sea to the ones found in this research at points of the lowest accumulation of this element. The majority of algae from the research points in the region of Sevastopol showed a much higher accumulation of lead.

Values of lead bioaccumulation coefficient in the studied algae were in a wide range from 30 (*Ulva rigida*) to 1,273 (*Cystoseira barbata*) (Table 1). The highest values of bioaccumulation factors in both species of algae, reaching 1,273 for *Cystoseira barbata* and 775 for *Ulva rigida,* were observed in the Pishchana Bay. The lowest value of the bioaccumulation coefficient in the studied organisms was recorded in the Kruhla Bay 39 and 30 for *Cystoseira barbata* and *Ulva rigida*, respectively (Table 1).

The values of the lead bioaccumulation coefficient in different species of algae collected from several estuaries of Western Australia ranged widely, from around 1,000 to over 500,000. With lead concentration in water at a level of 0.4 μg Pb · dm^{-3}, contents of this element in the algae varied from 0.5 to 264 mg Pb · kg^{-1} d.m. [27].

Conclusions

1. Zinc and lead contents in the water collected from individual bays of Black Sea and from the open sea in the region of Sevastopol showed considerable diversification. The determined amounts point at anthropogenic enrichment.

2. Zinc contents in the *Cystoseira barbata* and *Ulva rigida* algae differed slightly due to the location of sampling points. The determined contents of this element were low, characteristic for ecosystems unpolluted with zinc.

3. The zinc bioaccumulation coefficient took very low values. Despite considerable amounts of this element in water, there is no risk of its excessive accumulation in the parts of biocoenosis.

4. The lead content in the algae was high, comparable with literature data for ecosystems polluted with this element.

5. The lead bioaccumulation coefficient reached significantly higher values and showed greater diversity than in the case of zinc, which points out to a risk of excessive accumulation of this metal in living organisms.

6. Generally, a higher zinc and lead content was found in all the samples taken from bays (both in water and in the algae) than in those collected in the open sea.

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ZAWARTOŚĆ CYNKU I OŁOWIU W WODZIE I GLONACH Z WYBRANYCH ZATOK MORZA CZARNEGO W OKOLICACH SEWASTOPOLA

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Abstrakt: Od wielu lat w rejonie Sewastopola ma miejsce nasilona antropopresja wynikająca ze strategicznej jego roli jako głównego miasta w regionie oraz portu, w którym przez wiele lat stacjonowała rosyjska lub radziecka flota czarnomorska. Ważnymi źródłami zanieczyszczeń trafiających do Morza Czarnego w rejonie Sewastopola są przemysł zlokalizowany w tym mieście, ścieki komunalne oraz rolnictwo. Prowadzenie badań monitoringowych związanych z zanieczyszczeniem Morza Czarnego w rejonach o różnym poziomie antropopresji jest istotne z punktu widzenia kształtowania polityki ochrony środowiska nie tylko w rejonie badań, ale w całym basenie tego akwenu. Celem pracy była ocena zawartości cynku i ołowiu w wodzie oraz glonach z wybranych zatok Morza Czarnego w okolicach Sewastopola. Próbki wody oraz glonów pobrano w sierpniu 2012 r. z ośmiu zatok Sewastopola (Gałubaja, Kozacha, Kamyshova, Kruhla, Striletska, Pishchana, Pivdenna i Sewastopolska) oraz jedną próbkę z otwartego morza w okolicach Fioletu. Z tych samych miejsc pobrano glony *Cystoseira barbata* i *Ulva rigida*. Pobraną wodę konserwowano na miejscu i po przewiezieniu do laboratorium oznaczono w niej zawartość cynku i ołowiu. Pobrane glony wypłukano w wodzie destylowanej, suszono, a następnie homogenizowano i mineralizowano. W mineralizatach oznaczono zawartość cynku metodą ICP-OES, a zawartość ołowiu oznaczono metodą ASA z atomizacją elektrotermiczną.

Zawartość cynku w wodzie mieściła się w zakresie od 36,43 do 233,3 μg Zn $\cdot$ dm^{-3}, a ołowiu w zakresie od 1,32 do 38,32 μg Pb $\cdot$ dm^{-3}. Stwierdzono znaczne różnice zawartości badanych pierwiastków w wodzie z poszczególnych zatok. Względne odchylenie standardowe stężenia cynku i ołowiu w badanych próbkach wody wynosiła odpowiednio 69 i 112%. Największe zawartości cynku stwierdzono w wodzie z zatok Striletska, Kozacha i Sewastopolska, a ołowiu w zatokach Kozacha i Kruhla. Najmniejsze ich stężenie stwierdzono w wodzie pobranej na otwartym morzu, a ponadto cynku z zatok Pivdenna i Pishchana, a ołowiu z zatok Gałubaja i Pishchana. Zawartość cynku w glonach wahała się w granicach od zakresie od 6,517 do 30,21 mg $\cdot$ kg^{-1} s.m. Glony *Cystoseira barbata* zawierały ponad dwukrotnie więcej cynku w porównaniu z *Ulva rigida*. Zawartość ołowiu w glonach wahała się w zakresie 0,567 do 7,692 mg Pb $\cdot$ kg^{-1} s.m. Prawie o połowę więcej ołowiu stwierdzono w *Cystoseira barbata* w porównaniu z *Ulva rigida*. Nie stwierdzono statystycznie istotnej korelacji pomiędzy zawartością badanych pierwiastków w wodzie i w biomasie glonów. Wykazano natomiast istotną dodatnią korelację pomiędzy zawartością cynku i ołowiu w obydwu gatunkach glonów. Wartość współczynnika bioakumulacji cynku wahała się w granicach od 32 do 642, a ołowiu od 30 do 1273. Zawartości badanych pierwiastków, zarówno w biotycznej, jak i abiotycznej części badanych ekosystemów wskazują na antropogeniczne wzbogacenie, jednakże wyniki uzyskane w próbkach z zatok Sewastopolska, Kozacha i Striletska wskazują na niebezpieczeństwo nadmiernej ich bioakumulacji i potencjalne zagrożenie życia organizmów wodnych oraz konsumentów owoców morza.

Słowa kluczowe: Morze Czarne, woda, *Cystoseira barbata*, *Ulva rigida*, zanieczyszczenie, bioakumulacja