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CONTENT OF Ni AND Cr IN WATER AND IN ALGAE FROM SELECTED BLACK SEA BAYS IN THE REGION OF SEVASTOPOL

ZAWARTOŚĆ Ni I Cr W WODZIE I GLONACH Z WYBRANYCH ZATOK MORZA CZARNEGO W REJONIE SEWASTOPOLA

Abstract: Trace metals play an important role in functioning of marine and ocean ecosystems. The particular importance of these elements in ecosystems of salt water basins results from their low concentrations in waters of these basins. The content of trace elements in ocean waters is from a few to several dozen times lower than in fresh waters. Such conditions caused that sea organisms developed, by means of evolution, the ability to intensive absorption of trace elements from water in order to meet the physiological demand for them. However, such abilities can cause excessive bioaccumulation of trace elements in ecosystems with elevated their supply, caused by human pressure or enrichment of the water environment from natural sources. The aim of this paper was to assess the nickel and chromium content 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 in the region of Sevastopol (Galubaja, Kozacha, Kamyshova, Kruhla, Striletska, Pishchana, Pivdenna, the Sevastopolska Bay) as well as one sample from the open sea near Fiolent. *Cystoseira barbata* and *Ulva rigida* algae were collected from the same places. The collected water samples were conserved *in situ* and after being brought to the laboratory their contents of nickel and chromium were determined. The collected algae were rinsed in distilled water, dried, and then homogenized and mineralized. Content of the studied elements was determined in mineralisates by AAS method with electrothermal atomization.

It was found that both elements concentrations in water from individual bays were 2–3 times different. The nickel content ranged between 1.74 and 4.14 μgNi · dm^{-3}, and the chromium content was between 1.56 and 5.97 μgCr · dm^{-3}. Water from the Striletska Bay contained the highest amount of the studied elements. The nickel content in the studied algae ranged between 1.967 and 12.87 mg · kg^{-1} d.m., and the chromium content between 0.342 and 7.650 mg · kg^{-1} d.m. A higher accumulation of these elements was found in *Cystoseira barbata* than in *Ulva rigida.* Algae collected in the Sevastopolska Bay contained the highest amount of nickel, and algae from the Pivdenna Bay contained the highest amount of chromium. The content of the studied

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elements in biomass of the algae was not correlated with their concentration in water. On the other hand, a significant correlation between the nickel content in the algae of both species was found. Values of nickel bioaccumulation coefficients in the studied ecosystems were close to values recorded in environments with high human pressure, whereas in the case of chromium they were very low, much lower than values given in available literature. It was a result of a very high concentration of this element in water, and its moderate content in the algae. Generally, a higher content of the studied elements, both in water and in the algae, was found in all the bays than in samples collected in the open sea. The highest threat of the studied metals was found in the Sevastopolska and Pivdenna Bays.

Keywords: Black Sea, pollution, water, algae, nickel, chromium, monitoring, bioaccumulation

Introduction

Trace metals play an important role in functioning of marine and ocean ecosystems. Some of them, for instance iron and manganese, are essential for development of living organisms, whereas physiological role of others has not been discovered yet. According to Aparicio-Gonzalez et al [1] as well as Mehera et al [2], the reason that trace elements are of particular importance to ecosystems of sea and ocean basins is that their concentration in salt waters is very low. Concentration of these elements in ocean waters is from a few to several dozen times lower than in fresh waters. Moreover, bioassimilability of trace elements in the sea environment is usually lower than in freshwater ecosystems. Such conditions caused that sea organisms developed, by means of evolution, the ability to intensively absorb trace elements from water in order to meet the physiological demand for them. However, such abilities can cause excessive bioaccumulation of trace elements in organisms living in ecosystems with elevated supply of these elements, caused by human pressure or enrichment of the water environment from natural sources [3]. Such conditions usually occur in coastal zones or estuaries, with low depth, where good thermal conditions and a higher amount of biogenic substance can be found. In coastal zones, shallow bays and estuaries, there are good conditions for development of phytoplankton, macroalgae as well as a lot of animal species.

Chromium is an element widely used in many fields of human activity, that is why its elevated contents in sewage, both industrial and municipal, are often found. Chromium is widely used in the tannery industry, in protective coatings for metal objects, in paints, and in biocidal agents [4, 5]. This element enters the water environment in consequence of leaching processes from protected surfaces, or along with industrial and municipal sewage. This element is delivered to seas and oceans with river waters, and together with dry and wet deposition. River supply has limited importance for ocean waters, since a greater part of chromium load remains in estuary areas or in coastal regions [6].

Nickel is an element commonly occurring in the water environment. In zones of strong human impact on the environment, elevated concentration of this element is always found, because it is widely used in many fields of human activities. It gets into the water environment from sewage, both industrial and municipal, and as a result of dry and wet deposition. Nickel gets into seas and oceans from materials transported by rivers and as a result of atmospheric deposition. In ocean ecosystems, atmospheric deposition of this element plays the greatest role. Delivery of nickel together with river waters may be of high importance in coastal areas, in estuaries, and inland seas.

Nickel in river water, as a result of changes in salinity arising out of mixing river waters with sea waters, quickly migrates to bottom sediments, which leads to its increased concentration on small areas. In such regions, high bioaccumulation of this element in organisms from all levels of the food chain is often observed [7, 8]. The reaction of most sea waters favors the occurrence of nickel mainly in the form of Ni^{2+}. Increase in pH values favors the formation of hydroxides of this element. Under conditions of high redox potential, this metal is generally adsorbed on iron and manganese compounds, whereas under anaerobic conditions it forms insoluble nickel sulfide. It is an element indispensable for life of plants and land animals. Its physiological role in aquatic animals has not been discovered yet. Symptoms of toxicity of excessive amount of nickel in marine ecosystems are rare to be seen, but the danger from this element is connected with its genotoxic effect [9].

The aim of the research was to assess the content of nickel and chromium in water and in algae from selected Black Sea bays in the region of Sevastopol.

Material and methods

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 were collected in August 2012. The samples were collected from the top layer of water (from the depth of 0–120 cm) using a scoop sampler with 200 cm^3 capacity. The cumulative sample, with a volume of 3 dm^3, consisted of 15 initial samples with a volume of about 200 cm^3, collected in different points which had been averaged. An average laboratory sample had volume of 500 cm^3. Sample collection points were selected so as a sample as representative as possible for a 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 Sevastopolska Bay, as well as from the open sea in the region of Fiolent (Fig. 1).

Samples of *Cystoseira barbata* and *Ulva rigida* algae were collected in the same points. The cumulative sample of the algae was a sum of approximately 10 initial samples with the mass of approximately 50 g f.m. each. The laboratory sample was identical with the cumulative sample and amounted approximately 200 g. 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 marine ecosystems pollution with trace elements. Water samples were conserved *in situ* with concentrated nitric acid (of 65 %), in a quantity of 2 cm^3 per each 100 cm^3, and next being brought to the laboratory. Whereas the algae were washed in distilled water, dried at a temperature of 65 ^oC, and homogenized. 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. Concentration of nickel and chromium in the obtained solutions was determined

Fig. 1. Points of sampling

by atomic absorption spectrometry with electrothermal atomization, in an M6 device manufactured by Thermo. Nickel was determined at a wavelength of 232.0 nm. The limit of determination for nickel in the applied methods of measurement amounted to 12 $\mu g \cdot kg^{-1}$ d.m. of the biological material, and 0.5 $\mu g \cdot dm^{-3}$ water, and the uncertainty of measurement was ±7 %. Chromium was determined at a wavelength of 357.7 nm. The limit of determination for this element in the applied methods of measurement amounted to 2.5 $\mu g \cdot kg^{-1}$ d.m. of the biological material, and 0.09 $\mu g \cdot dm^{-3}$ water, and the uncertainty of measurement was ±7 %. Certified reference material CRM 16–050 was used to check the correctness of the analyses.

Results and discussion

The nickel concentration in the water collected from individual research points in the region of Sevastopol was within the range from 1.74 to 4.14 $\mu gNi \cdot dm^{-3}$ (Fig. 2).

The mean content of this element was 2.47 $\mu g \cdot dm^{-3}$, and the relative standard deviation (RSD) was 35 %. The lowest nickel concentration was recorded in the water collected in the open sea. Concentrations of this element in the water collected from the Galubaja, Kruhla, Pishchana, and Pivdenna Bays were little different (between 1 and 10 %) than the contents found in a sample from the open sea. It suggests that in those bays there are no significant sources of pollution with this element, and there is no risk of its accumulation in individual parts of biocoenosis. Water from the other bays showed an enrichment in nickel. The highest nickel concentration was determined in the water from the Striletska Bay, and then from the Kozacha, Sevastopolska and

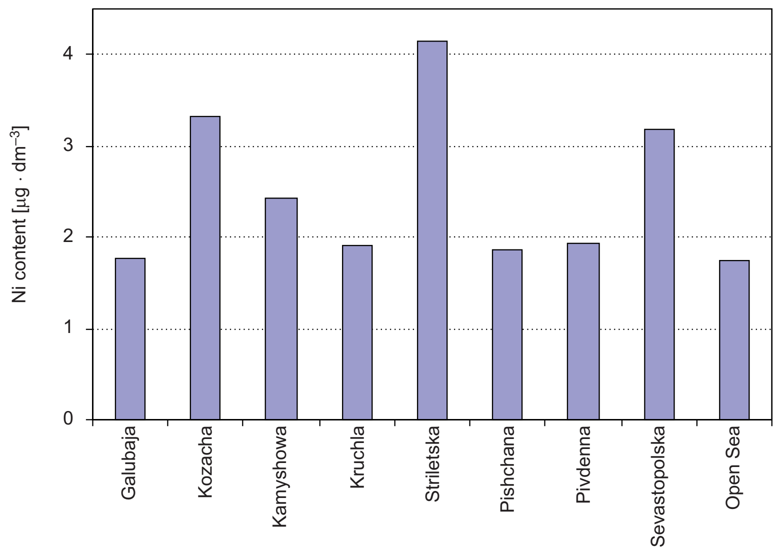

Fig. 2. Content of nickel in water

Kamyshova Bays, in which 2.4, 1.9, 1.8 and 1.4 times more nickel was found, respectively, than in the open sea water.

Sea algae have high affinity to trace elements. Due to the specificity of physiological processes, they can accumulate extremely high amounts of trace elements, even in environments with low content of them in the abiotic parts of the ecosystem, particularly in water [10]. Thanks to this, they can be used as sorbents of trace elements or for bioindication of marine ecosystems pollution [11, 12] as well as freshwater ecosystems [13] with these elements.

The *Cystoseira barbata* algae contained between 1.16 and 3.29 times more nickel than *Ulva rigida*. The nickel content in the *Cystoseira barbata* algae varied from 3.833 to 12.87 mg · kg^{-1} d.m. (Fig. 3), and the relative standard deviation was 37 %. The lowest amount of nickel was found in algae of the species from the Galubaja Bay, by 24 % lower than in the algae collected on the open sea. The content of this element in *Cystoseira barbata* from most of the other bays was between 36 and 50 % higher than in the algae collected in the open sea, which contained 5.075 mgNi · kg^{-1} d.m. Only algae from the Sevastopolska Bay contained approximately 2.5 times more of this metal. Many authors draw attention to considerable differences in the nickel content in algae collected at points located close to one another, with various intensity of human pressure or other water parameters, shaping the bioavailability of this element [14, 15].

The highest amount of nickel (8.867 mgNi · kg^{-1} d.m.) was found in *Ulva rigida* from the Sevastopolska Bay, and its lowest amount (1.967 mgNi · kg^{-1} d.m.) in the algae collected in the Striletska Bay (Fig. 3). The nickel content in samples from most of the bays (Kruhla, Kamyshova, Kozacha, Galubaja, and Striletska) was lower (between 3 and 42 %) than its content determined in the algae from the open sea, which

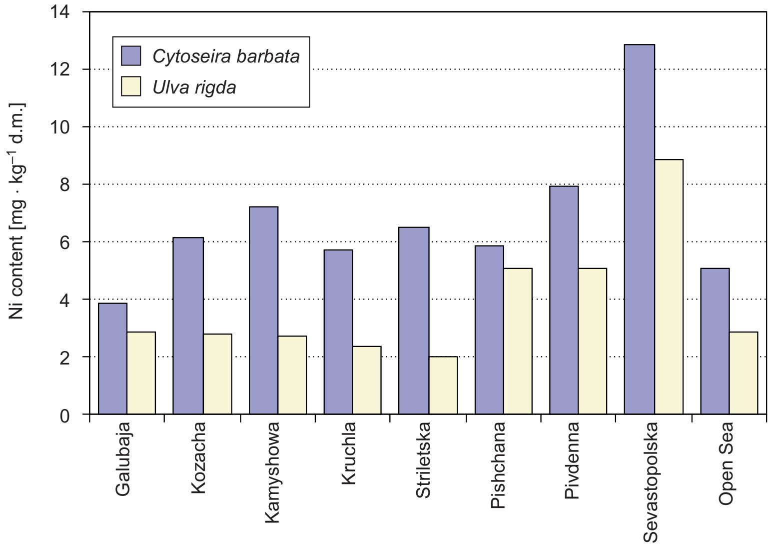

Fig. 3. Content of nickel in macroalgae

contained 2.892 mgNi · kg^{-1}. Nickel contents determined in *Ulva rigida* from the Pivdenna, Pishchana, and especially Sevastopolska Bays were 1.75, 1.76 and 3.07 times higher, respectively, than in the algae collected in the open sea, which points out to a danger of excessive accumulation of this metal in organisms occurring in these ecosystems.

The statistical analysis showed that the nickel content in the biomass of the algae did not correlate with its concentration in the water. On the other hand, a significant correlation between the nickel content in both algae was found ($r_{0.05}$ = 0.843).

In most cases, nickel contents in algae determined in the authors' own research are low and close to the content of this element in algae from areas with low human pressure index. Brito et al [16] provide nickel contents several times higher in algae of different species from a region with high level of human pressure in Brazil. The nickel content in the algae from *Ulva* genus collected in the San Jorge Bay in Argentina varied from 0.9 to approximately 4 [17], and was close to results obtained in the authors' own research. Caliceti et al [18] provide 2.6 mgNi · kg^{-1} d.m. as the mean nickel amount in *Ulva rigida* from the Venice Lagoon, and 1.8 mgNi · kg^{-1} d.m. in *Cystoseira barbata* at insignificant differences in content of this element in the algae collected in regions with a various level of human pressure. Wallenstein et al [19] provide a much lower nickel content, approximately 1 mgNi · kg^{-1} d.m., in *Cystoseira humilis* from areas near the Azores from stands with different intensity of anthropopressure. The nickel content in green algae collected in the coastal zone of the Arabian Gulf in the polluted region of Saudi Arabia varied between 25 and 44 mgNi · kg^{-1} [20]. On the other hand, Rodríguez-Figueroa et al [21] provide 28 mgNi · kg^{-1} d.m. as the maximum nickel content in algae from the Mexican Gulf in the region of impact of a copper mine.

Dhaneesh et al [22] provide very low contents of this element, below 0.2 mgNi · kg^{-1} d.m., in algae from the Indian Ocean from areas near the Maldives. The nickel content in the algae for consumption in Spain varied in the wide limits, between 1.2 and 73 mgNi · kg^{-1} d.m., and in the case of *Ulva rigida* between 5.61 and 6.14 mgNi · kg^{-1} d.m. [14]. The nickel content in algae collected from a few estuaries of Western Australia was between 1 to approximately 10 mgNi · kg^{-1} d.m. [23]. At the same time, algae collected in Admiralty Bay in Antarctica, which is an area of insignificant anthropopressure, contained less than 1 mgNi · kg^{-1} d.m. [24].

The values of the bioaccumulation coefficient for nickel in the algae utilized in biomonitoring ranged widely from 475 to 2797 for *Ulva rigida,* and from 1562 to 4111 for *Cystoseira barbata* (Table 1).

Table 1

Values of bioaccumulation coefficients (BC) of nickel and chromium in algae from individual studied points

Number	Sampling points	Bioaccumulation coefficent of Ni		Bioaccumulation coefficent of Cr	
		Cystoseira barbata	*Ulva rigida*	*Cystoseira barbata*	*Ulva rigida*
1	Galubaja Bay	2178	1595	156	124
2	Kozacha Bay	1860	836	371	164
3	Kamyshowa Bay	2975	1112	418	371
4	Kruhla Bay	2980	1226	283	243
5	Striletska Bay	1562	475	156	127
6	Pishchana Bay	3168	2737	644	960
7	Pivdenna Bay	4111	2621	3493	1077
8	Sevastopolska Bay	4059	2797	2016	237
9	Open Sea	2917	1662	288	219

The highest value of this coefficient for algae of both species was found in the Sevastopolska Bay, 4059 and 2797 for *Cystoseira barbata* and *Ulva rigida,* respectively. The lowest values of the bioaccumulation coefficient for nickel were found in the algae from the Striletska Bay. Low values of this parameter at that research point are the result of a high nickel concentration in water, which was not reflected in greater uptake of this metal by the studied organisms. Melville and Pulkownik [23] provide values of the bioaccumulation coefficient for nickel in different species of algae gathered from several estuaries of Western Australia similar to the ones determined in the authors' own research.

A statistical analysis did not show a significant correlation between nickel content in the water and algae. The highest concentration of this metal was recorded in the water from the Striletska and Kozacha Bays, and in the algae collected from the Sevastopolska, Pivdenna and Kamyshchowa Bays. Therefore, concentration of elements in water is not a reliable index of environmental risk, which is pointed out by a number of researchers [11, 12, 16, 25]. Only determination of accumulation of elements in living organisms may provide reliable information on environmental pollution. However, it is important to choose adequate animal or plant species, because the assimilability of trace elements does not depend only on environmental factors, but the intensity of uptake of trace elements is influenced also by population, species, and even ontogenetic predispositions [12, 16, 25]. Improper selection of organisms for bioindication may lead to obtainment of distorted results.

Chromium concentration in the water samples collected from individual research points ranged from 1.56 to 5.97 μgCr · dm^{-3} (Fig. 4), and the mean for all the samples was 3.154 μg Cr · dm^{-3}.

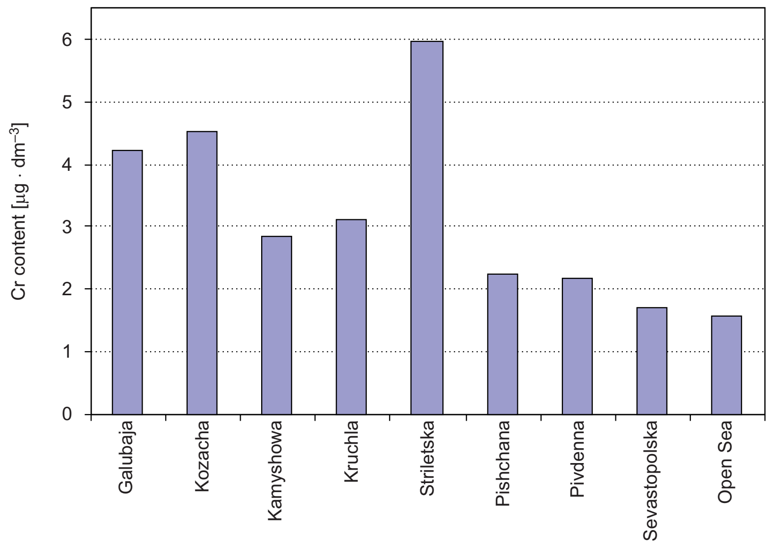

Fig. 4. Content of chromium in water

A high diversity in the content of this element in water from individual research stands was found. The relative standard deviation for chromium water concentration was 46 %.

Chromium is a special element in the sea environment. It can occur at different degrees of oxidation, but only compounds that contain Cr(VI) and Cr(III) forms are stable enough to occur in natural environment. Its toxicological effects in biocoenoses depend on the degree of oxidation. In waters with high redox potential, the dominant form is Cr(VI), which may constitute even more than 90 % of the total amount of this element [26]. Chromium in the form of Cr(VI) compounds is well soluble in water, whereas chromium in the reduced form is slightly soluble, and under conditions of oxygen deficit its quick binding with bottom sediments can be observed. Moreover, the oxidized form of chromium is significantly more easily uptaken by living organisms, which intensifies the problem of water ecosystems being polluted with this element. Chromium in the Cr(III) form is indispensable for proper functioning of mammals. It participates in the metabolism of sugars and lipids, as well as regulation of blood sugar level [27]. Concentration of this element in sea and ocean waters is generally below 1 μg · dm^{-3} [28], and the natural content of this element in water is below 0.2 μg Cr · dm^{-3} [29]. However, nickel concentration in fresh waters is approximately 10 times higher.

The least chromium was recorded in the water collected in the open sea. Chromium concentration in the water collected from all the bays suggests enrichment in this element. The water taken in the Striletska Bay, and then in the Kozacha and Galubaja Bays contained the most chromium, *ie* 3.75, 2.88 and 2.66 times more, respectively, than the water collected in the open sea. Chromium concentrations in water, determined in the authors' own research, are high and characteristic for ecosystems polluted with this element. Such chromium contents in water can endanger organisms living in these ecosystems, as well as people who eat seafood obtained in these regions. Chromium content in waters of Sargasso Sea was significantly lower and varied between 0.13 and 0.3 μgCr · dm^{-3} [26].

The *Cystoseira barbata* and *Ulva rigida* algae contained various amounts of chromium, between 0.342 and 7.650 mgCr · kg^{-1} d.m. (Fig. 5), 1.525 mgCr · kg^{-1} d.m. on average. Mean chromium contents in the algae of these species were 2.039 and 1.011 mgCr · kg^{-1} d.m., respectively. The *Cystoseira barbata* algae collected in the Pivdenna Bay contained the highest amount of this element, and the ones collected in the Sevastopolska Bay contained approximately 2 times less. Whereas in the case of the *Ulva rigida* algae, the highest amount of chromium was found in samples collected in the Pivdenna and Pishchana Bays. The *Cystoseira barbata* algae collected at research points contained between 1.09 and 8.75 times more chromium than *Ulva rigida*. Only in the Pishchana Bay a reverse relation was recorded, and the *Ulva rigida* algae contained 1.57 times more chromium than *Cystoseira barbata*. Chromium content in algae from

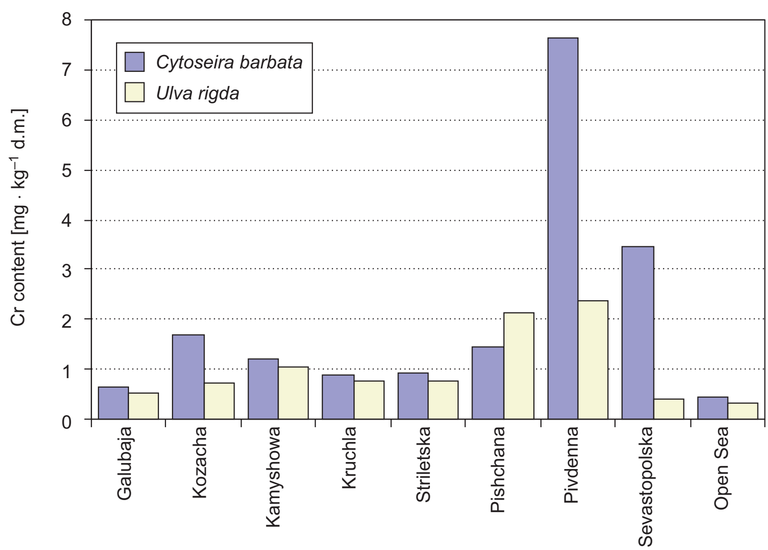

Fig. 5. Content of chromium in macroalgae

unpolluted areas fluctuates between 1 and 3 mgCr · kg^{-1} d.m. [15]. The statistical analysis did not show a significant correlation between the content of this element in water and biomass of the studied algae. Other authors [25, 30] have also determined that concentration of this element in water is rarely significantly correlated with its content in living organisms.

A significantly higher variability in the chromium content in the algae collected from individual research points, compared with the variability in concentration of this element in the water, was found. The highest chromium content in both species of algae was found in the algae living in the Pivdenna Bay, and in that bay also the area with the highest risk to living organisms was defined. Chromium contents in different species of algae taken from the Aegean Sea in coastal regions of Turkey were slightly higher than the ones obtained in the authors' own research, and concentration of this element in water was at a several times lower level than its concentrations present in the water of the bays of the Sevastopol region [30]. Like in the authors' own research, these authors found a higher accumulation of this element in the algae from the *Cystoseira* genus compared with the content of this element in the algae from the *Ulva* genus.

Brito et al [16] provide approximately twice higher contents of this element in biomass of different species of algae from areas with high anthropopressure index in Brazil, whereas accumulation of this element in the algae collected in the Turkish coastal zone of the Black Sea was comparable to the one obtained in the authors' own research [31]. These authors found a significant relationship between the level of human pressure and the chromium content in algae. In areas with the highest level of anthropopressure [31], chromium accumulation was comparable to the one determined in the authors' own research in the Pivdenna Bay. Caliceti et al [18] provide approximately 1 mgCr · kg^{-1} d.m. as the mean chromium content in the *Cystoseira barbata* algae collected from the Venice Lagoon in regions with different intensity of anthropopressure. The contents of this element in the algae from the *Ulva* genus were higher, approximately by a half, than their accumulation in *Cystoseira*. In the authors' own research, the chromium contents in the algae were generally similar to the ones found in the algae collected in the Tanapag Lagoon in a region of the Marian Islands [15]. Samples collected from the Sevastopol and Pivdenna bays were exceptions. In these samples, contents of this element were significantly higher than the ones found by those authors. Chromium contents in *Ulva rigida* and *Cystoseira barbata* collected in the Bulgarian coastal zone of the Black Sea [32] were similar to the ones found in this research in points with the lowest accumulation of this element. In the authors' own research, chromium contents were higher than the ones presented by these authors only in the algae collected in the Sevastopolska and Pivdenna Bays.

Values of bioaccumulation coefficient for chromium in the studied algae range widely, from 124 to 3493 (Table 1). The highest values of bioaccumulation coefficients in both algae species were observed in the Pivdenna Bay: 3493 for *Cystoseira barbata* and 1077 for *Ulva rigida*. The lowest value of the bioaccumulation factor for chromium in the studied organisms was observed in the Galubaja Bay, 156 for *Cystoseira barbata* and 124 for *Ulva rigida* (Table 1). Literature data indicate much higher bioaccumulation factors for chromium in macroalgae from various regions of the world. Akcali and

Kucuksezgin [30] provide values of this factor in algae collected from the Aegean Sea reaching from a few to a dozen or so thousand. Melville and Pulkownik [23] state that the values of the bioaccumulation coefficient for chromium in different species of algae collected from several estuaries of Western Australia are from a few to several dozen thousand.

Conclusions

1. Chromium and nickel concentrations in the water collected from individual bays and from the open sea in the region of Sevastopol suggest anthropogenic enrichment. Such contents, according to literature data, suggest that there is a risk of excessive bioaccumulation of these elements.
2. Nickel contents in the studied algae were not high, but the differences in accumulation of this element in the organisms collected in individual bays point out to a potential risk to living organisms.
3. Chromium contents in the studied algae were low and only accumulation of this element in the samples collected in the Pivdenna Bay was at a level found in polluted environments.
4. Bioaccumulation coefficients for nickel in the studied ecosystems were close to its values in environments with high anthropopressure index, provided in scientific literature.
5. Bioaccumulation coefficients for chromium in the studied algae were very low, much lower than their values provided in literature. It was a result of a very high concentration of this element in water at its moderate content in the algae.
6. Generally, a higher content of the studied elements (both in water and in the algae) was found in all the bays compared with the samples collected in the open sea. The highest threat of the studied metals was found in the Sevastopolska and Pivdenna Bays.

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ZAWARTOŚĆ Ni I Cr W WODZIE I GLONACH Z WYBRANYCH ZATOK MORZA CZARNEGO W REJONIE SEWASTOPOLA

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Abstrakt: Metale śladowe odgrywają ważną rolę w funkcjonowaniu ekosystemów morskich i oceanicznych. Szczególne znaczenie tych pierwiastków w ekosystemach zbiorników wód słonych wynika z bardzo małych ich stężeń spotykanym w wodach tych akwenów. Zawartość pierwiastków śladowych w wodach oceanicznych jest od kilku do kilkudziesięciu razy mniejsza niż w wodach słodkich. Takie warunki sprawiły, że organizmy morskie wykształciły na drodze ewolucji zdolność do intensywnego pobierania pierwiastków śladowych z wody w celu zaspokojenia zapotrzebowania fizjologicznego na nie. Takie zdolności mogą jednak powodować nadmierną bioakumulację pierwiastków śladowych w ekosystemach o podwyższonej ich podaży, spowodowanej antropopresją lub wzbogaceniem środowiska wodnego ze źródeł naturalnych. Celem pracy była ocena zawartości niklu i chromu w wodzie oraz glonach z wybranych zatok Morza Czarnego w okolicach Sewastopola.

Próbki wody oraz glonów pobrano w sierpniu 2012 r. z ośmiu zatok w rejonie Sewastopola (Gałubaja, Kozacha, Kamyshova, Kruhla, Striletska, Pishchana, Pivdenna, 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 przywiezieniu do laboratorium oznaczono w niej zawartość niklu i chromu. Pobrane glony wypłukano w wodzie destylowanej, suszono, a następnie homogenizowano i mineralizowano. W roztworach oznaczono zawartość badanych pierwiastków metodą ASA z atomizacją elektrotermiczną.

Stwierdzono 2–3-krotne różnice stężenia obydwu pierwiastków w wodzie z poszczególnych zatok. Zawartość niklu mieściła się w zakresie od 1,74 do 4,14 μgNi $\cdot$ dm^{-3}, a chromu w zakresie od 1,56 do 5,97 μgCr $\cdot$ dm^{-3}. Najwięcej badanych pierwiastków zawierała woda z zatoki Striletska. Zawartość niklu w badanych glonach wahała się w zakresie od 1,967 do 12,87 mg $\cdot$ kg^{-1} s.m., a chromu od 0,342 do 7,650 mg $\cdot$ kg^{-1} s.m. Stwierdzono większe nagromadzenie tych pierwiastków w *Systoseira barbata* niż w *Ulva rigida*. Najwięcej niklu zawierały glony pobrane w zatoce Sewastopolskiej, a najwięcej chromu zawierały glony z zatoki Pivdenna. Zawartość badanych pierwiastków w biomasie glonów nie była skorelowana z ich stężeniem w wodzie. Stwierdzono natomiast istotną korelację między zawartością niklu w glonach obydwu gatunków. Wartości współczynników bioakumulacji niklu w badanych ekosystemach były zbliżone do notowanych w środowiskach o dużym nasileniu antropopresji, natomiast w przypadku chromu były bardzo małe, dużo mniejsze niż podawane w dostępnej literaturze. Powodem było bardzo duże stężenie tego pierwiastka w wodzie i umiarkowanej jego zawartości w glonach. Generalnie we wszystkich zatokach stwierdzono większą zawartość badanych pierwiastków (zarówno w wodzie, jak i w glonach) niż w próbkach pobranych na otwartym morzu. Największe zagrożenie badanymi metalami stwierdzono w zatokach Sewastopolska i Pivdenna.

Słowa kluczowe: Morze Czarne, zanieczyszczenia, woda, glony, nikiel, chrom, monitoring, bioakumulacja