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HEAVY METALS IN SURFACE WATER OF THE ATLANTIC SECTOR OF THE ANTARCTIC DURING THE 79TH CRUISE OF THE RESEARCH VESSEL "AKADEMIK MSTISLAV KELDYSH"

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Relevance of monitoring heavy metals content in the water of the Atlantic sector of the Antarctic is due to the need for a current assessment of quality of the marine environment for making responsible decisions on the conservation of marine living resources in this unique area of the World Ocean. The aim of the study was to obtain new data on levels and spatial distribution of concentrations of trace elements, mainly heavy metals, in surface water. Sampling of surface seawater was carried out during the Antarctic expedition of the 79th cruise of the RV "Akademik Mstislav Keldysh" at 21 stations in the area of the Drake Passage, the Bransfield Strait, and the Antarctic Sound, as well as in Weddell and Scotia seas. Extracting and concentrating of dissolved form of 13 trace elements (Be, Se, Sb, Tl, V, Pb, Cd, Cu, Zn, Ni, Mo, Co, and Fe) were performed using sodium diethyldithiocarbamate and carbon tetrachloride (CCl_4). The elements were measured by mass spectrometry. Among all trace elements content, only Mo concentration in seawater at 9 stations, located in the Drake Passage, the Bransfield Strait, northern Weddell Sea, and off the southern coast of Tierra del Fuego Island, exceeded 1.2–2.8 times maximum permissible concentration of trace elements in fishery water bodies of the Russian Federation (MPC_F). According to international regulatory legal acts, such as "Dutch sheets", there were single cases of exceeding MPC (maximum permissible concentration under short-term exposure) for Cd and Zn, as well as exceeding TV (target value under chronic exposure) for Cu, Pb, Cd, Zn, Se, and Co at several stations. The research has shown as follows: despite limited anthropogenic pressure on this area of the Southern Ocean, in seawater of some regions of the Atlantic sector of the Antarctic, increased concentrations of several trace elements, *inter alia* heavy metals, are recorded. Further study of the sources of trace elements intake and the peculiarities of their distribution in seawater of the Atlantic sector of the Antarctic is required in order to account for ongoing processes, take measures for rational management, and provide ecologically acceptable use of natural resources in the Antarctic.

Keywords: heavy metals, surface seawater, Atlantic sector of the Antarctic

The 79th cruise of the RV "Akademik Mstislav Keldysh" to the Atlantic sector of the Antarctic was held on 30.11.2019–08.05.2020 (Morozov et al., 2020) within the framework of international obligations of the Russian Federation as a party to the Antarctic Treaty (Dogovor ob Antarktike…., 2020) and the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR)

(Commission for the Conservation…, 2020). Expedition was organized and managed by P. P. Shirshov Institute of Oceanology. During the cruise, several fundamental tasks, assigned to the Russian scientists in a number of strategic documents, were solved (Strategiya nauchno-tekhnologicheskogo razvitiya…, 2016 ; Strategiya razvitiya morskoi deyatel'nosti…, 2010 ; Strategiya razvitiya deyatel'nosti…, 2010). They indicate the need to obtain new results for a comprehensive assessment of the state of Antarctic ecosystems, as well as the effect of climate change and other factors, including limited anthropogenic impact, on them.

Trace elements are known to be among the most important components of the marine environment, playing an essential role in the functioning of living organisms (Bowen, 1988 ; Mertz, 2013). However, exceeding a certain limit for the content of these substances can lead to toxic effects (Fuentes et al., 2016 ; Rainbow, 2002). For example, V, Co, Ni, Cu, and Zn are moderately hazardous toxicants, while Cd and Pb are highly hazardous ones (Kharakteristika zagryaznyayushchikh veshchestv…, 2016). Hence, these chemical elements and a number of other heavy metals are included in the list of substances, the amount of which in natural environments, *inter alia* oceanic water and seawater, is subject to regular monitoring (Klenkin et al., 2007). The issue of studying both levels and redistribution of heavy metals is also relevant for the Antarctic. According to international agreements (Dogovor ob Antarktike…., 2020 ; Commission for the Conservation…, 2020), limited anthropogenic activity is allowed on the Antarctic continent and in the waters of the Southern Ocean. This applies to members of research expeditions, station personnel, and crews of ships, fishing for seafood and ensuring tourism functioning. Previous studies have shown that an increase in heavy metals concentration in Antarctic waters can also result from natural processes (Ahn et al., 1996, 2004 ; Samyshev & Minkina, 2019). They include, in particular, the washout of tectonic elements from the mainland as a result of the increased glaciers melting, caused by global warming in recent decades (Ahn et al., 1996, 2004 ; Samyshev & Minkina, 2019 ; Sanchez et al., 2019), and the rise of deep waters (Honda et al., 1987).

The relevance of heavy metals monitoring in the waters of the Atlantic sector of the Antarctic is mainly due to the fact as follows: in this area, favorable conditions are formed for stable aggregations of Antarctic krill (*Euphausia superba* Dana, 1852), with its highest biomass density in the Southern Ocean (Bykova et al., 2004 ; Samyshev & Minkina, 2019). This area is currently the site of krill fishery. Many representatives of aquatic biota, including krill, accumulate heavy metals to concentrations, being many times higher than their content in water (Polikarpov et al., 1986 ; Chudinovskikh, 2016 ; Honda et al., 1987 ; Mertz, 2013). At the same time, they can not only be affected by toxicants themselves (especially at their most sensitive stages of development: eggs, larvae, and juveniles), but also serve as a "transport link" for toxic substances along trophic chains up to the human, consuming seafood (Casas et al., 2008 ; Samyshev & Minkina, 2019). Therefore, monitoring of concentration levels of heavy metals in the waters of the Southern Ocean is of considerable scientific and practical interest.

The aim of this study was to obtain new data on the levels and spatial distribution of trace elements, mainly heavy metals, in surface water in order to assess the current quality of the marine environment of natural complexes in the Atlantic sector of the Antarctic.

MATERIAL AND METHODS

Research areas and material. Seawater sampling, aimed at determining the content of dissolved forms of trace elements, *inter alia* heavy metals, was carried out from 10.02.2020 to 01.03.2020 during the Antarctic expedition of the 79th cruise of the RV "Akademik Mstislav Keldysh" in the Atlantic sector of the Antarctic at 21 stations in the area of the Drake Passage, the Bransfield Strait, and the Antarctic Sound, separating the Antarctic Peninsula from the Joinville group of islands, as well as in the Weddell and Scotia seas (Fig. 1). Coordinates of sampling stations and characteristics of the marine environment (temperature and salinity) are shown in Table 1.

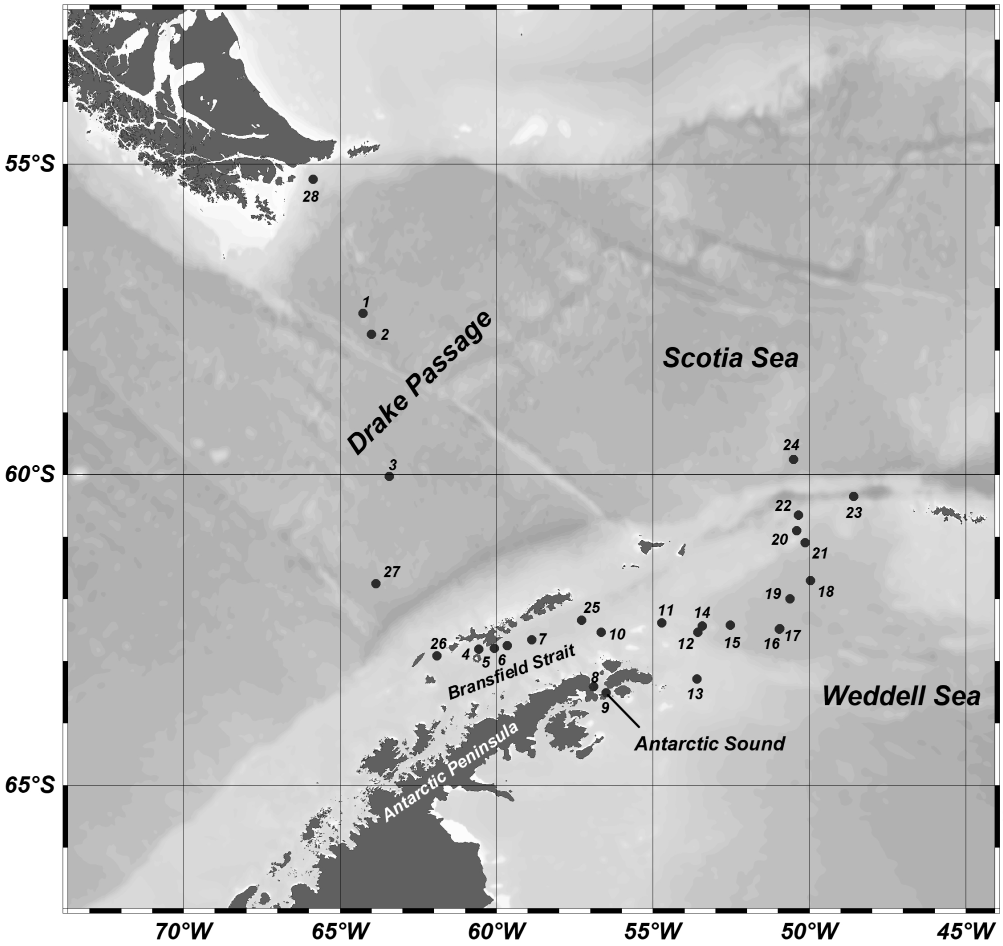

Fig. 1. Map of studied area and location of sampling stations

Methods for trace elements determination. To determine trace elements, including heavy metals, 21 samples of surface (0–5 m) seawater were collected from the marine environment of the studied area (Fig. 1, Table 1). Water temperature and salinity (see Table 1) were measured automatically by a SBE 911plus CTD probe with a cassette, containing 21 5-L bottles. In water samples, 13 trace elements were identified: Be, Se, Sb, Tl, V, Pb, Cd, Cu, Zn, Ni, Mo, Co, and Fe. Samples were processed in the onboard laboratory in accordance with the guiding document RD 52.10.243-92 (Rukovodstvo po khimicheskomu analizu…, 1993). Sample preparation method was based on extracting and concentrating trace amounts of metals using sodium diethyldithiocarbamate as a complexing agent and carbon tetrachloride (CCl_4) as extractant, with the following acid re-extraction. Nitric acid solutions of the extracts were delivered to the onshore laboratory; measurements of the studied elements were performed at IBSS “Spectrometry and Chromatography” core facility, using inductively coupled plasma mass-spectrometer PlasmaQuant MS Elite (Analytik Jena AG) (GOST R 56219-2014. Water…, 2015 ; Mass-spektrometriya…, 2014). The spectrometer was calibrated with a standard solution “Multi-element calibration standard IV-28, HNO_3/HF, 125 mL” (Inorganic Ventures). Measurement mode on the mass-spectrometer included 7 replicates of 10 scans for each identified element from 10,000 to 100,000 μs, depending on its expected concentration. Calculation and registration of measurement results were carried out in accordance with the all-union state standard GOST R 56219-2014 and guiding document RD 52.10.243-92 (GOST R 56219-2014. Water…, 2015 ; Rukovodstvo po khimicheskomu analizu…, 1993). The average relative determination error was not higher than ± 10 %.

Table 1. Metadata of sampling stations

Station number	Sampling date	Coordinates		Ocean depth, m	Water temperature, °C	Salinity, PSU
		S	W			
2	10.02.2020	57°44.4074′	63°59.9839′	4130	+8.62	33.92
3	11.02.2020	60°01.5902′	63°25.3325′	3778	+5.73	33.63
4	12.02.2020	62°48.3626′	60°33.7133′	373	+3.16	34.11
7	12.02.2020	62°39.3628′	58°52.8365′	1574	+4.19	34.14
8	13.02.2020	63°24.4219′	56°53.5885′	187	–0.91	34.28
9	13.02.2020	63°30.5974′	56°29.7344′	736	+0.64	34.27
10	14.02.2020	62°32.0215′	56°39.2660′	345	+1.64	34.04
11	14.02.2020	62°23.0395′	54°43.0033′	362	–0.72	34.21
12	15.02.2020	62°32.2922′	53°33.7689′	1030	–0.67	34.32
13	15.02.2020	63°17.4354′	53°35.9791′	362	+0.25	33.88
14	16.02.2020	62°26.0611′	53°25.7918′	1383	–0.02	33.66
16	17.02.2020	62°29.0724′	50°57.3809′	3290	–0.42	33.27
18	18.02.2020	61°42.2470′	49°58.2523′	1743	+0.26	32.74
19	19.02.2020	61°59.7085′	50°37.6094′	700	+1.00	33.97
20	19.02.2020	60°53.9809′	50°24.0082′	940	+0.89	34.03
21	20.02.2020	61°05.5251′	50°08.3302′	2766	+0.31	32.99
24	24.02.2020	59°45.2400′	50°30.7537′	3787	+2.94	34.12
25	26.02.2020	62°20.7280′	57°16.5980′	1331	+3.22	34.12
26	27.02.2020	62°55.1235′	61°54.2073′	800	+2.61	33.8
27	27.02.2020	61°45.3571′	63°50.9526′	3622	+4.17	33.64
28	28.02.2020	55°14.6157′	65°51.9639′	1098	+10.64	33.46

RESULTS

Among the studied heavy metals, as already noted, the most toxic pollutants are copper, zinc, cadmium, and lead (Klenkin et al., 2007). The results of measuring their concentrations are shown in Fig. 2.

Trace elements beryllium and thallium are also highly toxic substances (Kharakteristika zagryaznyayushchikh veshchestv…, 2016), but their concentrations in seawater samples from all the stations were very low: they did not exceed 0.005 μg·L^{-1} (Be) and 0.001 μg·L^{-1} (Tl). The measured values were 60 times lower than maximum permissible concentration (hereinafter MPC) of trace elements in fishery water bodies of the Russian Federation (MPC$_F$) for Be and 1000 times lower than MPC in water bodies for drinking and cultural-domestic water use for Tl (Kharakteristika zagryaznyayushchikh veshchestv…, 2016). Molybdenum, cobalt, and nickel are toxic substances, but they are also characterized as having carcinogenic and mutagenic effects on living organisms (Kharakteristika zagryaznyayushchikh veshchestv…, 2016). The results of determining these trace elements distribution are shown in Fig. 3.

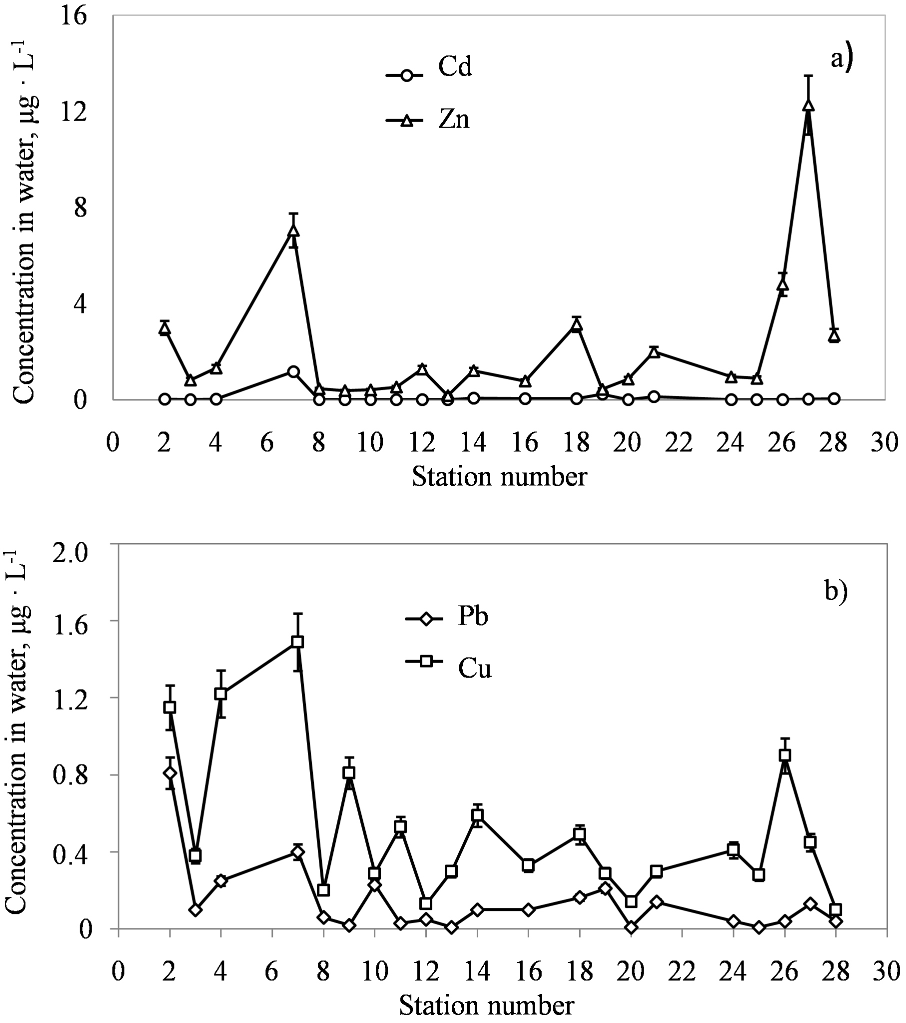

Fig. 2. Concentration of Cd and Zn (a) and Pb and Cu (b) in surface seawater in the studied areas of the Antarctic

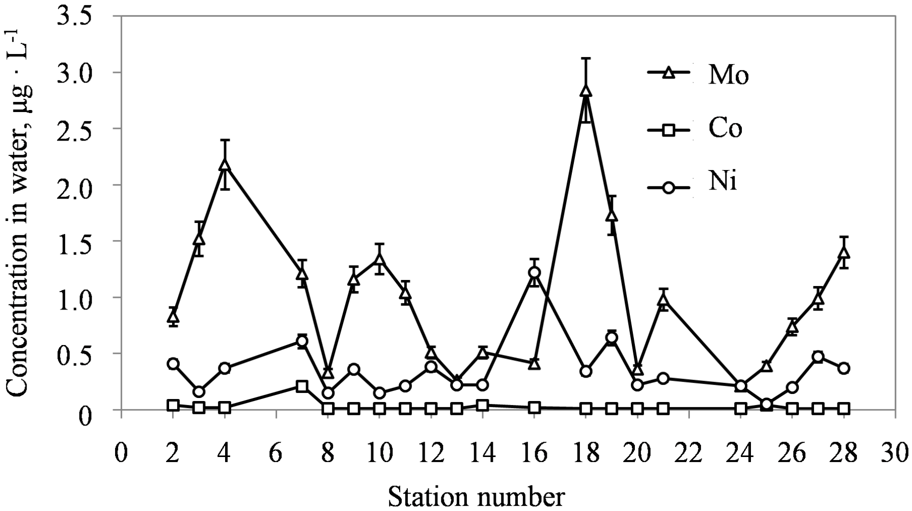

Fig. 3. Concentration of Mo, Co, and Ni in surface seawater in the studied areas of the Antarctic

Among trace elements studied, there were toxic substances selenium and vanadium, as well as a toxic hazardous substance antimony and less toxic iron (Kharakteristika zagryaznyayushchikh veshchestv…, 2016). Data on changes in concentrations of these chemical elements in surface seawater are shown in Fig. 4.

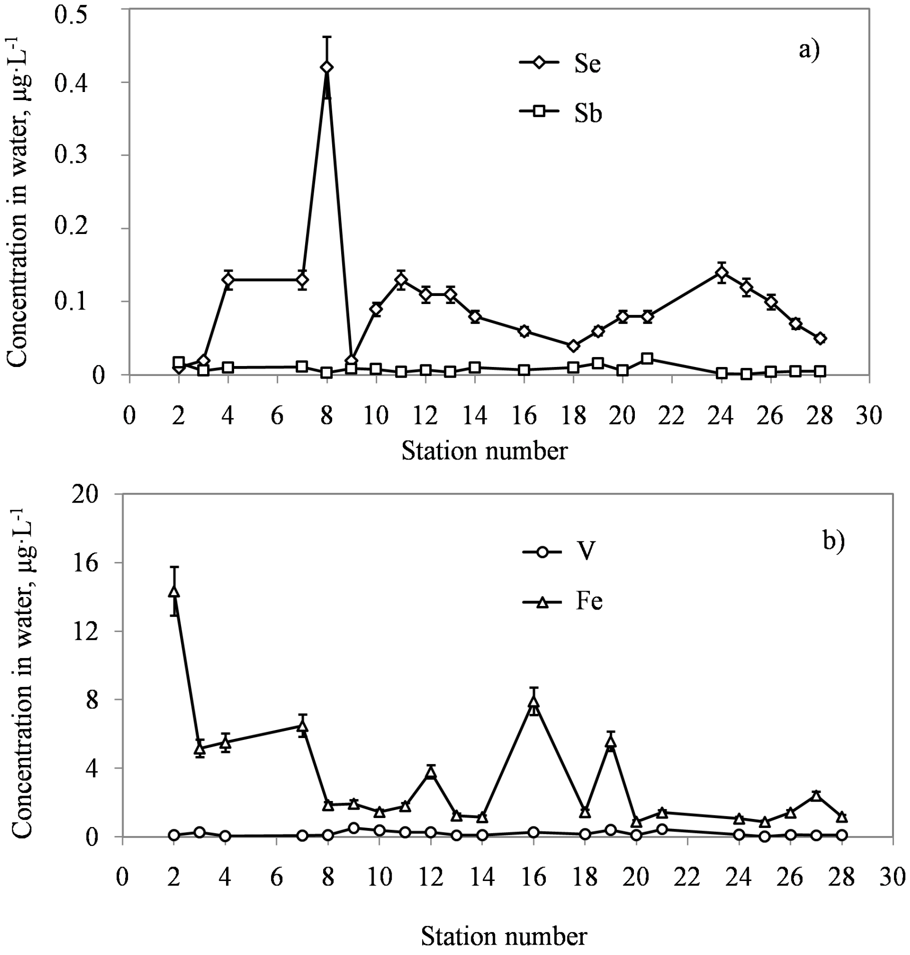

Fig. 4. Concentration of trace elements Se and Sb (a) and V and Fe (b) in surface seawater in the studied areas of the Antarctic

Since studied water areas belong to Antarctic krill fishery area, the data were compared with MPC$_{F}$ in order to estimate the current ecological state of Antarctic waters (Kharakteristika zagryaznyayushchikh veshchestv…, 2016). Moreover, the results were compared with the reference values given in “Dutch sheets”: with MPC (maximum permissible concentration of dissolved form of a pollutant under short-term exposure) and with TV (target value of the inactive concentration for dissolved form of a pollutant under chronic (long-term) exposure in surface water) (Warmer & van Dokkum, 2001), as well as with background concentrations of the studied elements in surface seawater (Crommentuijn et al., 1997) and in surface water in the open ocean (Israel & Tsyban, 2009).

DISCUSSION

The analysis of the results obtained (Figs 2, 3, and 4) indicates relatively low levels of trace elements concentrations in surface seawater in studied water areas of the Antarctic. However, when comparing our data with these trace elements content in waters of the open ocean (Israel & Tsyban, 2009), it was recorded as follows: maximum concentrations of most chemical elements studied (Pb, Cd, Zn, Cu, Be, Mo, Co, and V) in the Antarctic were higher than those, typical for the waters of open ocean: in the range from 2.3 times for Se to 211.3 times for Zn (Table 2).

Table 2. Comparison of the measured values of trace element concentrations in surface ocean waters in the Antarctic with their background and normatively established concentrations, accepted in the Russian Federation and given in "Dutch sheets" (μg·L^{-1})

Chemical element	Range of measured values of concentration of dissolved form of the element in water	Background concentrations		Normatively established reference values for chemical elements		
		C_{open}^{*}	C_{SWB}^{**}	MPC_F^{***} for fishery water bodies	MPC^{****} – MPC in "Dutch sheets"	TV^{*****} – target value according to "Dutch sheets"
Pb	0.01…0.90	$\frac{0.001}{0.034}$	0.02	10	11	0.3
Cd	< 0.002…1.17	$\frac{0.00010}{120}$	0.025	10	0.4	0.08
Zn	0.39…12.26	$\frac{0.003}{0.058}$	0.35	50	9.4	2.9
Cu	0.10…1.49	–	0.25	5	1.5	0.5
Tl	< 0.01	–	–	–	1.6	0.06
Be	< 0.005	–	–	0.3	0.2	0.02
Mo	< 0.21…2.84	–	–	1	290	4.3
Co	0.003…0.21	–	–	5	2.8	0.2
V	< 0.01…0.67	$\frac{1.02}{1.78}$	–	1	4.3	0.9
Ni	0.05…1.22	$\frac{0.116}{0.70}$	–	10	5.1	3.3
Se	< 0.01…0.419	$\frac{0.04}{0.18}$	–	2	5.3	0.09
Sb	< 0.001…0.02	–	–	–	0.4	1.6
Fe	0.76…14.33	$\frac{0.005}{0.140}$	–	50	–	–

Note:

* C_{open} is concentration of an element in surface water of the open ocean (background) (minimum value is above the line, maximum value is below the line) (Israel & Tsyban, 2009);

** C_{SWB} is background concentration of an element in surface seawater (Crommentuijn et al., 1997);

*** MPC_F is maximum permissible concentration of an element for fishery water bodies, accepted in the Russian Federation (Kharakteristika zagryaznyayushchikh veshchestv…, 2016);

**** MPC is maximum permissible concentration for dissolved form of an element in surface water (under short-term exposure) (Warmer & van Dokkum, 2001);

***** TV is target value of concentration for dissolved form of an element in surface water considered safe under chronic (long-term) exposure (Warmer & van Dokkum, 2001).

Studied water areas belong to Antarctic krill fishery area; so, the data obtained were compared with MPC_F, established for fishery water bodies (Kharakteristika zagryaznyayushchikh veshchestv…, 2016). The comparison showed that concentrations of Pb, Cd, Zn, Cu, Co, Be, Ni, V, Se, and Fe did not reach MPC_F (Figs 2, 3, and 4). Their content in all studied areas was many times lower than MPC_F values (Table 2). The only exception was obtained for Mo, with exceeding MPC_F 1.2–2.8 times at nine stations (Fig. 3). Thus, increased Mo content was recorded in the central area of the Drake Passage (st. 3), along the Bransfield Strait (st. 4, 7, 10, and 11), and along the northern coast of the Weddell Sea (st. 9, 18, and 19) (Figs 1 and 3). Exceeding MPC_F value for molybdenum was also recorded off the southern coast of Tierra del Fuego Island (st. 28) (Figs 1 and 3). According to “Dutch sheets” (Table 2), Mo concentrations did not reach MPC and TV, established for acute and chronic exposure of the pollutant (Warmer & van Dokkum, 2001).

We assume that intake of a certain amount of Mo into the Atlantic sector of the Antarctic may have South American origin, since Chile ranks third in the world in terms of molybdenum reserving and mining (National Minerals Information Center…, 2020). As known (Medenosnyi poyas Yuzhnoi Ameriki…, 2004), continental surface water with possible admixtures of molybdenum and other metals, coming from the regions of development of South America copper belt, enters Pacific Ocean surface layer from the territory of Chile. Copper reserves in Chile account for 82 % of the total inventory in South America; for example, the El Teniente copper mine has been developed since 1904, and Chuquicamata – since 1915 (Medenosnyi poyas Yuzhnoi Ameriki…, 2004). Molybdenum reserves in molybdenum ores in Chile are estimated at 2.3 million tons, and reserves of Mo as a by-product of copper ore processing are estimated at 2.5 million tons (13 % of global reserves) (Medenosnyi poyas Yuzhnoi Ameriki…, 2004 ; Mirovoi rynok molibdena…, 2020). Molybdenum, entering oceanic water, is afterwards transported by currents and possibly further distributed in seawater, *inter alia* along Antarctic coast. The highest Mo concentrations were recorded at stations in the central area of the Bransfield Strait (st. 7) and in the northeastern Weddell Sea (st. 18) (see Fig. 1). This peculiarity can also be explained by molybdenum intake with meltwater of continental Antarctic ice into the marine environment (Samyshev & Minkina, 2019), as well as by possible effect of hydrological processes on the distribution of dissolved elements, in particular transfrontal water masses transport from the north by powerful synoptic eddies, observed in the Drake Passage (Koshlyakov & Tarakanov, 2011). In this publication, the authors identified water transport by eddies to the south only in the thermocline, without considering the upper layer separately.

In the Drake Passage, the powerful Antarctic Circumpolar Current transports surface water from the Pacific Ocean to the east. Due to the presence of significant synoptic eddies in the Drake Passage, surface water can also be transported to its southern area. The current in the Bransfield Strait, flowing northeastward along the South Shetland Islands, is the southernmost stream of the Antarctic Circumpolar Current.

The group of stations 13–17 is located in the western Weddell Sea. There, the cyclonic (clockwise) circulation in the Weddell Sea carries waters from its southern area, and the content of metals is low, since there is no industrial metal mining on the Antarctic continent. The authors of (Sanchez et al., 2019) have shown as follows: along the eastern border of the Antarctic Peninsula, the currents carry to the north iron compounds, entering from a natural source in the south. This was confirmed by our measurements at st. 16 and 19. On the border of the Scotia and Weddell seas (in the Weddell-Scotia confluence zone), waters of the Antarctic Circumpolar Current merge with waters of the cyclonic circulation of the Weddell Sea. This leads to the inflow into the area of both Pacific Ocean and Weddell Sea waters, with their impurities of metals.

According to "Dutch sheets", for Tl, Sb, Be, Ni, V, and Fe, the measured concentrations were significantly lower than MPC and TV (Warmer & van Dokkum, 2001) (see Table 2) at all stations in the Atlantic sector of the Antarctic. In studied water areas, according to "Dutch sheets" (Warmer & van Dokkum, 2001), exceeding MPC was registered for Cd at st. 7 and for Zn at st. 27 (Fig. 2a); exceeding TV was observed for Cu at seven stations, for Zn – at three, for Cd and Pb – at two, for Se – at nine, and for Co – at one station (Table 2, Figs 2, 3, and 4).

The importance of hydrological processes, primarily currents, in the distribution of increased concentrations of dissolved forms of trace elements in Antarctic water is proved by the similarity of the distribution of the studied trace elements in seawater at sampling stations (Figs 2, 3, and 4). The coastal boundary current in the Bransfield Strait is known to be an important factor in water circulation in this area. Together with the Antarctic Circumpolar Current in the Drake Passage, it plays an essential role in water transport to the east (Morozov, 2007).

It is difficult to establish the main sources of trace elements intake into the Antarctic water by the data of one study. The intake can result from both anthropogenic and natural processes on the mainland, in the water column, and in different areas of the planet; moreover, trace elements can reach the Antarctic as a result of transboundary transport of substances (Klenkin et al., 2007 ; Kharakteristika zagryaznyayushchikh veshchestv…, 2016 ; Fuentes et al., 2016 ; Samyshev & Minkina, 2019 ; Sanchez et al., 2019).

Conclusion. New data on the current levels and spatial distribution of 13 trace elements (Be, Se, Sb, Tl, V, Pb, Cd, Cu, Zn, Ni, Mo, Co, and Fe), including heavy metals, in the Antarctic have been obtained. Only Mo concentrations exceeded $\mathrm{MPC_F}$ at nine stations.

According to "Dutch sheets", there were single cases of exceeding MPC for Cd and Zn, as well as exceeding TV for Cu, Pb, Cd, Zn, Se, and Co at several stations.

The observed levels of trace elements content in seawater of the Antarctic indicate the presence of increased concentrations of some heavy metals, despite limited anthropogenic pressure on that area of the Southern Ocean.

Increased concentrations of elements in comparison with established $\mathrm{MPC_F}$, MPC, and TV in the northern Drake Passage are likely to be related to a water runoff from industrial enterprises in Chile, mining and processing copper and molybdenum for more than a hundred years. The impact of natural sources cannot be excluded as well. Increased iron content in the northern Weddell Sea (the Powell Basin) is most likely determined by the intake of iron compounds from natural sources in the western Weddell Sea, which is consistent with earlier studies.

This work has been carried out within the framework of IBSS government research assignment "Comprehensive studies of the current state of the ecosystem of the Atlantic sector of the Antarctic" (No. AAAA-A19-119100290162-0) and IO RAS government research assignment "Assessment of the current state of natural complexes in the Atlantic sector of the Southern Ocean and their variability of different periods (ecosystems, bioproductivity, hydrophysics, hydrochemistry, and geochemistry)" (No. AAAA-A18-118051490130-3).

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REFERENCES

1. Bykova V. M., Bykov V. P., Krivosheina L. I., Radakova T. N., Groisman M. Ya., Glazunov O. I. The main directions in complex use of krill. *Trudy VNIRO*, 2004, vol. 143, pp. 17–32. (in Russ.)
2. *GOST R 56219-2014. Water. Determination of 62 elements by inductively coupled plasma mass spectrometry (ICP-MS) method* : data vvedeniya 01.01.2016. Moscow : Standartinform, 2015, 36 p. (in Russ.)
3. Dogovor ob Antarktike. Mezhdunarodnyi dogovor ot 01 dekabrya 1959 goda (s dopolnitelnym protokolom ot 04 oktyabrya 1991 goda) // *Tekhekspert. Elektronnyi fond pravovoi i normativno-tekhnicheskoi dokumentatsii* : ofitsial'nyi sait. 2020. (in Russ.)]. URL: http://docs.cntd.ru/document/1901494 [accessed: 14.09.2020].
4. Israel Yu. A., Tsyban A. V. *Anthropogenic Ecology of the Ocean.* Moscow : Flinta : Nauka, 2009, 519 p. (in Russ.)
5. Klenkin A. A., Korpakova I. G., Pavlenko L. F., Temerdasheva Z. A. *Ekosisema Azovskogo morya: antropogennoe vozdeistvie* / Azovskii nauchno-issledovatel'skii institut rybnogo khozyaistva. Krasnodar : AzNIIRKh, 2007, 324 p. (in Russ.)
6. *Mass-spektrometriya s induktivno-svyazannoi plazmoi (IPS-MS): PlasmaQuant MS i PlasmaQuant MS Elite.* Instruktsiya po ekspluatatsii. Analytik Jena AG. Izdanie 12/2014. Germany, 2014, 143 p. (in Russ.)
7. *Medenosnyi poyas Yuzhnoi Ameriki.* Bol'shaya rossiiskaya entsiklopediya. 2004 : [site]. (in Russ.). URL: https://bigenc.ru/geology/text/2197422 [accessed: 14.09.2020].
8. Mirovoi rynok molibdena // *Mirovye tovarnye rynki* : [site]. 2020. (in Russ.)]. URL: https://www.cmmarket.ru/markets/moworld.htm [accessed: 17.09.2020].
9. Morozov E. G. Techeniya v Prolive Bransfild. *Doklady Akademii nauk*, 2007, vol. 415, no. 6, pp. 823–825. (in Russ.)
10. Morozov E. G., Spiridonov V. A., Molodtsova T. N., Frey D. I., Demidova T. A., Flint M. V. Investigations of the ecosystem in the Atlantic sector of Antarctica (Cruise 79 of the R/V Akademik Mstislav Keldysh). *Oceanology*, 2020, vol. 60, no. 5, pp. 823–825. (in Russ.). https://doi.org/10.31857/S0030157420050172
11. Polikarpov G. G., Egorov V. N. *Morskaya dinamicheskaya radiokhemoekologiya.* Moscow : Energoatomizdat, 1986, 176 p. (in Russ.)
12. *Rukovodstvo po khimicheskomu analizu morskikh vod* : rukovodyashchii dokument RD 52.10.243-92. Saint Petersburg : Gidrometeoizdat, 1993, 264 p. (in Russ.)]. URL: https://meganorm.ru/Data2/1/4293815/4293815261.pdf [accessed: 14.09.2020].
13. Strategiya nauchno-tekhnologicheskogo razvitiya Rossiiskoi Federatsii : ukaz Prezidenta RF ot 01 dekabrya 2016 goda no. 642 // *Sobranie zakonodatel'stva RF*, 2016, no. 49, st. 6887. (in Russ.)
14. Strategiya razvitiya morskoi deyatel'nosti Rossiiskoi Federatsii do 2030 goda :

rasporyazhenie Pravitel'stva RF ot 8 dekabrya 2010 goda no. 2205-r // *Sobranie zakonodatel'stva RF*, 20.12.2010, no. 51, st. 6954. (in Russ.)

15. Strategiya razvitiya deyatel'nosti Rossiiskoi Federatsii v Antarktike na period do 2020 goda i na bolee otdalennuyu perspektivu : rasporyazhenie Pravitel'stva RF ot 30 oktyabrya 2010 goda no. 1926-r // *Sobranie zakonodatel'stva RF*, 08.11.2010, no. 45, st. 5914. (in Russ.)
16. *Kharakteristika zagryaznyayushchikh veshchestv* : iz razdela "II. Dlya vodnykh ob"ektov" … spravochnik / N. V. Kostyleva, Y. K. Rogachev (Contrs). Perm : Izd-vo FGBU UralNII "Ekologiya", 2016, 296 p. (in Russ.)
17. Chudinovskikh E. S. Sostav i raspredelenie fitoplanktona v raione Ukrainskoi antarkticheskoi stantsii "Akademik Vernadskii" v 2007/8 gg. In: *Prirodnaya sreda Antarktiki: sovremennoe sostoyanie izuchennosti* : materialy II Mezhdunar. nauch.-prakt. konf., Naroch, Belarus, 18–21 May 2016. Minsk : Konfido, 2016, pp. 370–378. (in Russ.)
18. Ahn I.-Y., Lee S. H., Kim K. T., Shim J. H., Kim D. Y. Baseline heavy metal concentrations in the Antarctic clam, *Laternula elliptica* in Maxwell Bay, King George Island, Antarctica. *Marine Pollution Bulletin*, 1996, vol. 32, iss. 8–9, pp. 592–598. https://doi.org/10.1016/0025-326X(95)00247-K
19. Ahn I.-Y., Chung K. H., Cho H. J. Influence of glacial runoff on baseline metal accumulation in the Antarctic limpet *Nacella concinna* from King George Island. *Marine Pollution Bulletin*, 2004, vol. 49, no. 1, pp. 119–127. https://doi.org/10.1016/j.marpolbul.2004.03.008
20. Bowen H. J. M. Trace elements in biological samples. In: *Nuclear Analytical Techniques in Medicine* / R. Cesareo (Ed.). Amsterdam ; Oxford ; New York ; Tokyo : Elsevier, 1988, chap. 1, pp. 1–17. (Techniques and Instrumentation in Analytical Chemistry ; vol. 8). https://doi.org/10.1016/S0167-9244(08)70218-X
21. Casas S., Gonzalez J. L., Andral B., Cossa D. Relation between metal concentration in water and metal content of marine mussels (*Mytilus galloprovincialis*): Impact of physiology. *Environmental Toxicology and Chemistry*, 2008, vol. 27, iss. 7, pp. 1543–1552. https://doi.org/10.1897/07-418.1
22. *Commission for the Conservation of Antarctic Marine Living Resources* (CCAMLR) : [site]. URL: https://www.ccamlr.org/ [accessed: 14.09.2020].
23. Crommentuijn T., Polder M. D., van de Plassche E. J. *Maximum Permissible Concentration and Negligible Concentration for Metals, Taking Background Concentration Into Account.* Bilthoven, Netherlands : National Institute of Public Health and the Environment, 1997, 260 p. (RIVM Report no. 601501 001).
24. Fuentes V., Alurralde G., Meyer B., Aguirre G. E., Canepa A., Wölfl A.-C., Hass A. C., Williams G. N., Schloss I. Glacial melting: An overlooked threat to Antarctic krill. *Scientific Reports*, 2016, vol. 6, art. no. 27234. https://doi.org/10.1038/srep27234
25. Honda K., Yamamoto Y., Tatsukava R. Distribution of heavy metals in Antarctic marine ecosystem. *Proceedings of the NIPR Symposium on Polar Biology*, 1987, vol. 1, pp. 184–197.
26. Koshlyakov M. N., Tarakanov R. Yu. Water transport across the subantarctic front and the global ocean conveyer belt. *Oceanology*, 2011, vol. 51, no. 5, pp. 721–735. https://doi.org/10.1134/S0001437011050110
27. Mertz W. (Ed.) *Trace Elements in Human and Animal Nutrition.* 5th edition. Orlando, FL : Academic Press, 2013, 499 p.

28. National Minerals Information Center. *Molybdenum Statistics and Information* : [site]. URL: http://minerals.usgs.gov/minerals/pubs/commodity/molybdenum/mcs-2016-molyb.pdf [accessed: 14.09.2020].
29. Rainbow P. S. Trace metal concentrations in aquatic invertebrates: Why and so what? *Environmental Pollution*, 2002, vol. 120, iss. 3, pp. 497–507. https://doi.org/10.1016/S0269-7491(02)00238-5
30. Samyshev E. Z., Minkina N. I. Coastal ecosystem contamination by heavy metals as an indicator of climate change in Antarctica. *Journal of Computational and Theoretical Nanoscience*, 2019, vol. 16, no. 1, pp. 228–236. https://doi.org/10.1166/jctn.2019.7729
31. Sanchez N., Reiss C. S., Holm-Hansen O., Hewes C. D., Bizsel K. C., Ardelan M. V. Weddell-Scotia confluence effect on the iron distribution in waters surrounding the South Shetland (Antarctic Peninsula) and South Orkney (Scotia Sea) Islands during the Austral Summer in 2007 and 2008. *Frontiers in Marine Science*, 2019, vol. 6, art. no. 771 (16 p.). https://doi.org/10.3389/fmars.2019.00771
32. Warmer H., van Dokkum R. *Water Pollution Control in the Netherlands : Policy and Practice 2001*. Lelystad, Netherlands : RIZA, 2002, 76 p. (RIZA report 2002.009).

ТЯЖЁЛЫЕ МЕТАЛЛЫ В ПОВЕРХНОСТНОЙ ВОДЕ АТЛАНТИЧЕСКОГО СЕКТОРА АНТАРКТИКИ В 79-М РЕЙСЕ НАУЧНО-ИССЛЕДОВАТЕЛЬСКОГО СУДНА «АКАДЕМИК МСТИСЛАВ КЕЛДЫШ»

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Актуальность мониторинга содержания тяжёлых металлов в водах Атлантического сектора Антарктики определяется необходимостью современной оценки качества водной среды для принятия ответственных решений по сохранению морских живых ресурсов в этом уникальном регионе Мирового океана. Цель проводимых исследований — получить новые данные об уровнях и пространственном распределении концентрации микроэлементов, преимущественно тяжёлых металлов, в поверхностной воде. Отбор проб поверхностной морской воды производили в антарктической экспедиции 79-го рейса НИС «Академик Мстислав Келдыш» на 21 станции в районе проливов Дрейка, Брансфилда, Антарктика, а также в морях Уэдделла и Скотия. Экстракцию и концентрирование растворённой формы 13 микроэлементов (Be, Se, Sb, Tl, V, Pb, Cd, Cu, Zn, Ni, Mo, Co и Fe) осуществляли с помощью диэтилдитиокарбамата натрия и четырёххлористого углерода (CCl_4). Измерение элементов проводили масс-спектрометрическим методом. Только для Mo на девяти станциях, расположенных в проливах Дрейка и Брансфилда, в северном районе моря Уэдделла, а также возле южного побережья острова Огненная Земля, отмечали превышение его концентрации в морской воде в 1,2–2,8 раза по отношению к ПДК микроэлементов в воде рыбохозяйственных объектов РФ ($ПДК_{РХ}$). Согласно международным нормативно-правовым актам, таким как «Голландские листы», зарегистрированы единичные случаи превышения MPC (maximum permissible concentration — ПДК при краткосрочном воздействии) для Cd и Zn, а также превышение TV (target value — контрольные уровни при хроническом воздействии) для Cu, Pb, Cd, Zn, Se и Co на нескольких станциях. Исследования показали, что, несмотря на ограниченный режим антропогенной нагрузки в этом регионе Южного океана, в морской воде отдельных районов Атлантического сектора Антарктики в современный период зафиксированы повышенные концентрации некоторых микроэлементов, включая тяжёлые металлы. Необходимо дальнейшее изучение источников поступления и особенностей распределения микроэлементов в морских водах Атлантической части Антарктики для объяснения происходящих процессов, а также для принятия мер по рациональному управлению и экологически приемлемому природопользованию в Антарктическом регионе.

Ключевые слова: тяжёлые металлы, поверхностная морская вода, Атлантический сектор Антарктики