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Composition and Structure of Marine Benthic Community Regarding Conditions of Chronic Harbour Pollution

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Abstract : Seasonal fluctuations of physico-chemical and biological aspects of the environment were studied in Vladivostok harbour (Golden Horn Bay, the East Sea/Sea of Japan). The benthic community structure was described with a focus on size-spectra (bacteria, meio- and macrofauna) related with the chemical environment and chemical fluxes in sediment and to reveal their possible ecological role in the process of bioremediation of the environment. Samples from two sites with different concentrations of heavy metals (Fe, Zn, Cu, Pb, Mn, Cr, Ni Cd, Co) and petroleum hydrocarbon were assessed by a number of methods. These included plate counts of culturable bacteria, observation through a scanning electron (SEM) and transmission electron microscope (TEM). These approaches were complemented with microscopic assessments of the diversity of the benthic community. The specific communities had a limited number of species, tolerant to abnormally high levels of toxic compounds. The dominant species were presented by several short-lived small polychaetes (*Capitella capitata*) and nematodes (*Oncholaimium ramosum*). The highest population density was recorded in microbenthos, in various diatoms, various physiological groups of bacteria which participate in biomineralization: marine heterotrophic bacteria, which oxidized oil, black oil in addition to groups resistant to heavy metals. They have the entire set of mechanisms for neutralizing the negative effect of those compounds, forming the detrital food web and biogeochemical circulation of material in sediments, which results in the biological self-recycling of sea basins. Macro- and meiobenthic organisms were more sensitive to a greater extent of H₂S and petroleum hydrocarbons than to metal content, but the within-site rankings were the same as those achieved for microbiological analyses.

Key words : physico-chemical environment, heavy metals, petroleum hydrocarbons, heterotrophic bacteria, *Capitella capitata*, *Oncholaimium ramosum*.

1. Introduction

In recent years, an increase in waste effluent produced by human activity around the sea has had a serious impact on the coastal marine ecosystem. The concentrations of chemical compounds in overlying bottom sediment and in interstitial water are much higher than those found in bodies of water. The biota can affect the fate of many contaminants by contributing to their removal through uptake, degradation (for organic contaminants) or transformation (for metals and other contaminants) (Capone and Bauer 1992; White *et al.* 1997; Ford 2000). The

marine organisms are capable of using a huge spectrum of compounds in the environment. Contaminants can influence community composition and food-web interactions. Excessive toxification can impair the capacity of entire communities to detoxify. On the other hand, the accumulation of toxicants not susceptible to degradation or aggravated by transformation to more persistent forms can change the community structure and function. However, the literature on the composition and structure of the marine community in terms of conditions of chronic pollution in harbour sediments is limited (Bernard and Fenchel 1995; Papadopoulou *et al.* 1998; Fadeev and Fadeeva 1999; Carman *et al.* 2000).

High levels of contaminants have been reported in sediments from Golden Horn Bay (Vladivostok Port) and

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the industrial sites receiving significant anthropogenic inputs (Tkalin *et al.* 1993). At present, Golden Horn Bay (the East Sea/Sea of Japan) is one of the most polluted water areas. It is estimated that $264 \times 10^6 \text{ M}^3$ of wastewater is released into the Bay annually and 55% or more of this input may be without any or very little treatment (Tkalin *et al.* 1993; Vaschenko 2000).

The sediments have a high organic content (approximately 8%) and higher levels of contaminants may be required to elicit toxic effects in sediments that are high in organic materials. Practically the entire surface water of Golden Horn Bay is constantly covered with a petroleum film. The thickness of the contaminated petroleum layer ranges from 1 up to 3 meters in the sediment and concentration of petroleum hydrocarbons varies from 20 up to 96 mg/g dry weight, which exceeds the maximum permissible concentration for Russian coastal marine waters. The mouth of the bay has been classified as a 'dead area' (Tkalin *et al.* 1993; Vaschenko 2000).

Our knowledge of the pollution impact on the structure and function of the natural ecosystem is far from complete. Benthos is the optimal domain for studying the effects of disturbance on the environment, as it has been demonstrated that soft bottoms represent 'retentive systems' that are able to record biological processes occurring in the entire ecosystem (Danovaro 2000).

The purpose of this study is to examine the influence of the environmental contaminants on the soft-sediment benthic community structure with a focus on size-spectra (bacteria, meio- and macrofauna) related to the chemical environment and chemical fluxes in sediment and to reveal their possible ecological role in the process of bioremediation of the environment.

2. Materials and methods

Sediment and water samples were collected from the seasonal station in Golden Horn Bay (Vladivostok Port) from May 2000 to March 2001, at a depth of 13 m. The sediment samples were taken by using a 0.025 m² improved Petersen Grab. The quantitative subsamples for identification of the quantitative and qualitative structure of the macrobenthic community, without taking account of microorganisms, were taken with a cylinder. A sediment core sample (diameter 5 cm, length 4 cm) was selected and preserved in 4% buggered formaldehyde. Benthofauna were extracted by the decantation technique, counted and identified.

Simultaneously, the sediment samples were taken from

the site for the granulometric and heavy metal analyses. The sediment was washed through the mesh sets to divide particles into a fraction (for particles larger than 0.1 mm) and analyzed with the sedimentary method (for particles smaller than 0.1 mm). Minerals were identified by using characteristic d-spacings from the X-ray powder diffraction (Rigaku goniometer, CuK α -radiation) (Tazaki 2000). The quantitative determination of heavy metals of sediment samples was carried out on an atomic absorbed spectrophotometer (Nippon Jarrel Ash) AA-885. The chemical composition of the sediment was analyzed by X-ray fluorescent spectroscopy beams (XRF, JEOL JSX-3201) (Tazaki 2000). Organic carbon, sulfur and nitrogen contents were determined using an automatic gas chromatographic elemental analyzer (CE Instruments NA 2500-NCS) at 1,000°C with 20 ml oxygen.

Sediment and water samples were selected and placed in sterile test-glasses for the microbiological analysis. The samples of sediments and water were examined under a polarizing optical and fluorescent microscope (NIKON EFD-3) using 4,6-diamidino-2-phenylindol (DAPI) staining. The total number of colony-forming units (CFU) of heterotrophic bacteria was determined via nutrient medium CMM (Youchimizu and Kimura 1976) with a 1.5% agar. The control medium did not contain the additives of metal salts. Metal-resistant bacteria were counted on selective media CMM with the addition of metal chlorides (Cu, Cd, Co, Cs, Ni, Zn and Fe) and nitrate of Pb under the condition of inhibitory concentrations for metal-sensitive bacteria (Dimitrieva and Bezverbnaya 2002).

The method for determining metal concentrations, which helped to distinguish metal-resistant bacteria was similar to Duxbury's method used for soil bacteria (Duxbury and Bicknell 1983). The inhibitory concentrations of metal salts Cd, Cu, Co and Zn were comparable with the concentrations used by Duxbury. The concentrations of Ni and Pb salts used in studying metal resistance of the bacteria from the Russian Far East closely resemble the published data on maximal concentrations from other sites (Trevors *et al.* 1985). The analysis of bacterial numbers that are indicators of various types of organic contaminants was carried out on selective media. The media were prepared on the basis of seawater with the addition of 1% fuel-oil residue (mazut), crude oil or diesel fuel as a carbon source, respectively (Seki 1982; Tsyban 1992).

Both microorganisms and sedimentary materials were observed by scanning electron microscopy (SEM; JEOL-JSM-5200LV) equipped with an energy dispersive X-ray analyzer (EDX), operating at 15 kV. Transmission electron

microscopy (TEM; JEOL 2,000EX, operating at 120 kV) was used for obtaining an image of bacteria from water and sediments.

The determination of a stable isotopes ratio of carbon ($^{12}\text{C}/^{13}\text{C}$) in petroleum hydrocarbons in the sediments and tissues of hydrobionts of Golden Horn Bay were presented in a separate paper (Kiyashko *et al.* 2001).

3. Results

The physical structure of the sediments

The underwater landscapes of Golden Horn Bay have accumulated silt and clay materials. The contents of a fraction with a diameter of particles less than 0.05 mm constitute about 45%. The results of sediments analysis by powder XRD showed the presence of mainly quartz, feldspars, illite and kaolinite.

The sediment is painted black and has a semiliquid consistency with a strong smell of H_2S . The homogeneity of sediment is disturbed by layers including the remains of petroleum and organic compounds. Petroleum hydrocarbons are accumulated in a suspended layer of the sediment. This type of bottom sediment migrates with weak turbulent currents along a berthing wall in the Golden Horn Bay. The degree of petroleum hydrocarbon penetration into sediment is high, since silt and clay deposits have a significant absorption capacity. The first few centimeters of the surface of the sediment are penetrated by numerous biogenic structures - polychaetes tubes.

The results describing the hydrochemical parameters of superficial water and parameters of the uppermost sedimentary layer are presented in Table 1. The salinity ranges from 24.4 up to 32.9‰ in a superficial horizon of water and increases up to 31.9-33.5‰ near the horizon, which proves there is a fluctuation in salinity. In the area studied, a deficiency of the dissolved oxygen both in water and on the sediment surface has been recorded. Data on the element composition of the sediments of the

seasonal station, which were obtained by a method of the spectral fluorescent analysis in x-ray beams (XRF), confirm the fact that there is a significant accumulation of trace metals (Cu, Pb, Fe). Data on the contents of metals in the sediments during the investigated period, shows ranges which indicate a probable working concentration (PWC) of a number of polluting substances (Long 1992) which cause not only a decrease in the abundance of species diversity of benthic organisms, but also a 50% destruction of animals in the toxicological experiments, as indicated in Table 2.

The content of N, C and S is given in Table 3. The content of N ranges from less than 0.01 to 1.22% in bottom deposits of the seas and oceans (Romankevich 1977). The results obtained are close to the content of C_{org} in the shallow diatomic silts (Romankevich 1977), and also that found in the strongly polluted bays (Papadopoulou *et al.* 1998; Fadeev and Fadeeva 1999). The ratio C/N in the bay exceeds the accepted 'Redfield ratio' (6.6) for organic substances in the sea. It proves there is an inflow of terrestrial organic compounds into bottom sediments

Table 2. Ranges of probably working concentration (PWC) for macrobenthos in the sediment and concentrations of acid-soluble forms of heavy metals ($\mu\text{g/g}_{\text{dry wt}}$).

Metal	PWC	Month		
		May 2000	September 2000	March 2001
Fe	-	20250	17250	19500
Zn	271-410	182.5	180.0	182.5
Cu	108-270	422.5	285.0	432.5
Pb	112-218	925	600.0	800.0
Mn	-	150.0	112.5	150.0
Cr	160-370	90.0	57.5	62.2
Ni	43-52	17.5	15.0	15.0
Cd	4.2-9.6	9.5	3.75	0.125
Co	-	7.5	6.25	6.25

The note: - there are no data.

Table 1. Chemical parameters (temperature, salinity, dissolved oxygen, pH) of surface water (1) and uppermost sedimentary (2) horizon of the Golden Horn Bay.

Month	T (°C)		S (‰)		O ₂ , m//l		pH	
	Horizon							
	1	2	1	2	1	2	1	2
May 2000	6.6	3.1	31.8	33.4	7.32	7.43	8.06	8.09
July 2000	21.0	12.1	30.8	32.9	10.10	6.19	8.30	8.28
September 2000	19.5	17.5	24.0	32.1	9.10	4.2	8.80	7.86
December 2000	2.3	2.6	32.4	33.5	8.80	8.75	8.83	8.75
March 2001	3.5	2.0	32.7	33.3	6.15	11.59	8.46	8.22

Table 3. Carbon (%) and carbon isotope ratios (‰), nitrogen (%) and sulfur (%) for the uppermost sedimentary layer.

Parameter	Mean ($n = 4$)	Range
C, %	6.98 ± 1.01	6.1-7.9
$\delta^{13}\text{C}^*$	-27.0 ± 0.10	-27.1–-26.8
N, %	0.35 ± 0.05	0.3-0.4
S, %	1.83 ± 0.09	1.72-1.91
C/N	19.9 ± 2.1	19.6-20.3

Note: C/N-carbon nitrogen ratios, mean $\pm$ standard deviation; *Kiyashko et al. 2001.

(Tsyban et al. 1992). Organic enrichment leads to a complete depletion of oxygen in the sediments below the first few centimeters of the surface. The high content of silicon in the analyzed samples is due to the fact that there are many skeletons of pelagic diatom species like *Coscinodiscus*, *Thalassiosira* and *Skeletonema* in benthic deposits. As a result of biodegradation, the dissimilatory sulfate reduction is the major process by which a sulfide of metals and hydrogen sulfide are formed in anoxic environments. The dissolved forms of metals (Cu, Zn, Pb, Hg) in the forms of sulfides become less dissolved. Sediments contained high levels of sulfur (Table 3), the main part of which was represented by hydrogen sulfide, pyrite and iron sulfide. The organically enriched sediments of Golden Horn Bay had $\delta^{13}\text{C}$ in average values of $-27.0 \pm 0.1\text{‰}$ (Kiyashko et al. 2001) and the values did not change throughout the year. Isotope ratios of the petroleum hydrocarbons in the bay were $-29.25 \pm 0.2\text{‰}$ and were closed to those of crude petroleum $\delta^{13}\text{C}$ -22.3‰ and gas -38.7‰ (Reed and Kaplan 1977). The values of ratios were significantly more negative in the Golden Horn Bay than $\delta^{13}\text{C}$ of -22.8‰ in Amursky Bay.

Structure and composition of the benthos

The metazoan fauna are concentrated in the topmost 5 cm of the muddy sediment and consist mainly of organisms ranging up to 2-5 cm in size. Throughout the year, the dominant species in biomass are polychaetes *Capitella capitata*, *Nereis vexillosa*, *N. zonata*, *Schistomeringos japonica*, *Cirratulus cirratus*, *Polydora* sp., but in abundance, the free-living nematodes *Oncholaimium ramosum*, *Paramonohystera pellucida*, and less numerous varieties are harpacticoides *Tisbe furcata* and *Amonardia* sp. and turbellarians. We have found 20 species of polychaetes, nematodes, harpacticoides, turbellarians with a total abundance of 650×10^3 ind. m^{-2} and a biomass of less than 2 g C m^{-2} . These values are lower as compared

Fig. 1. Seasonal fluctuations of density of (A) *Capitella capitata* and (B) *Oncholaimium ramosum* (ind. $\times 10^{-2} \text{ m}^{-2}$, mean $\pm$ standard deviation).

to the control sediments from Amursky Bay (similar sample size, water depth and sediment grain size) having a diverse and abundant macrofauna (45 species), dominated by polychaetes *Glycera capitata* and *Scoloplos armiger* and *Raeta pulchella* and *Macoma calcarea* with a biomass up to 400 g C m^{-2} . The tube-buildings of polychaetes prevent the silt sediments from destruction, fastening then with their secrets. The polychaetes *C. capitata* and the nematodes *O. ramosum* live in a close neighborhood in the sediment column. The polychaete epithelium secretes a mucopolysaccharide around the body. In the mucous burrows, we found actively eating nematodes. The seasonal fluctuations in the population density of the polychaete *C. capitata* at the station are shown in Fig. 1A. The highest density (about 22 000 ind. m^{-2}) was recorded in May at $t = 4^\circ\text{C}$. The population experiences a substantial decrease in August when the content of dissolved oxygen in the sediments of the near-bottom seawater decreases. In autumn, the temperature falls and the number increases, which is connected to the new settling of juveniles in the sediment. The nematode density of *O. ramosum* fluctuated seasonally (Fig. 1B). Its highest densities were recorded in the spring and decreased from the summer to winter months.

The number of heterotrophic colony-forming bacteria fluctuates between 66.0 and 148.1×10^3 cells g^{-1} wet sediment (Table 4). In that community, the highest population density was recorded in microbenthos, in various diatoms, and in various physiological groups of bacteria, which participate in biomineralization, i.e. marine heterotrophic bacteria, which oxidized oil, black oil and phenols, and

Table 4. Absolute colony-forming heterotrophic microorganism (CHM) number and relative (%) metal-resistant number form in the water (1) and sediment (2).

Variable	Month									
	May 2000		July 2000		September 2000		December 2000		March 2001	
	1	2	1	2	1	2	1	2	1	2
CHM ($\times 10^4$ cell/ml)	1.20 $\pm$ 0.14	10.0 $\pm$ 0.11	4.25 $\pm$ 0.35	-	6.58 $\pm$ 1.38	14.8 $\pm$ 1.8	2.37 $\pm$ 0.23	2.61 $\pm$ 0.24	0.86 $\pm$ 0.11	6.60 $\pm$ 0.02
Metal-resistant to:	Cd	0.3	0.2	1.8	-	8.4	0.3	1.4	0	0.3
	Cu	40.0	3.9	15.3	-	2.2	0.4	21.2	0.4	24.4
	Zn	17.0	2.7	6.8	-	12.9	0.5	10.5	0	7.4
	Pb	2.6	100	100	-	2.3	35.1	37.9	39.3	8.1
	Ni	17.5	4.8	11.5	-	56.7	0.3	40.6	0.4	14.7
	Co	17.0	5.0	20.6	-	10.5	1.1	24.4	0.2	28.8
	Cs	8.5	0.1	5.8	-	1.0	0.1	27.9	0.4	-
	Fe	7.6	16.0	2.3	-	5.9	94.5	2.1	9.4	3.17

The note: - there are no data.

Table 5. Number ($\times 10^4$ cell/ml sediment) of heterotrophic colony-forming marine microorganisms in the sediment.

Microbial groups	Month		
	May 2000	September 2000	March 2001
Destroyers of:			
Oil	-	6.5 $\pm$ 1.6	3.2 $\pm$ 0.38
Fuel oil	86.0 $\pm$ 2.8	10.9 $\pm$ 2.0	2.5 $\pm$ 0.20
Diesel fuel	9.8 $\pm$ 2.0	6.1 $\pm$ 1.2	-

The note: - there are no data.

also groups resistant to the effects of heavy metals (Tables 4, 5). Colorless sulfur bacteria *Beggiatoa mirabilis* and ciliates *Euplotes* spp. were found in summer in the sediment.

The optical and fluorescent microscopic observations of sediment samples have shown an increase in the number of cocci-form up to 40% as compared with water samples. The microbial community in the water consists of bacilli (about 80%) mainly. Predominantly, bacteria were aggregated with substrate particles and with particulate organic carbons

Fig. 2. Optical micrographs (A, C, E, G) and fluorescence micrographs (B, D, F, H) of samples from shallow sea water (A, B), bottom sea water (C, D) and sediments (E, F, G, H). Bacteria aggregate with organic remains and mineral particles. Bacilli compose considerable proportion of bacteria in water (B, D). In bacterial community of sediments the part of coccus increases (F, H). There are a lot of emulsified fuel droplets being showed on micrographs A and E.

(Fig. 2). A quantitative plating method on selective media and CMM-medium showed that Pb- and Fe-resistant bacteria accounted for a great part of the colony-forming bacteria in the microbial community of the sediments (Table 4).

In contrast to the microbial community of the sediments,

a wide variety of metal-resistant bacteria was clearly recognized in the microbial community in the water. Cu-, Co- and Ni-resistant bacteria have been found in the community. It may be the result of waste discharge containing soluble forms of metals. It is quite possible that wastewaters with Pb have arrived in the bay. The

Fig. 3. SEM micrographs and EDX spectra showing Fe accumulation in bacteria from sediments (1, 3).

Fig. 4. SEM micrographs and EDX spectra of samples from sediments showing the presence of Pb and Fe in form of galena - PbS (1) and flamboyant pyrite - FeS_2 (4). It suggests reductive environment and biogenic origin.

quantitative plating method has shown a periodical presence of considerable numbers of Pb-resistant bacteria in the microbial community of the water (from 50% to 100% of total heterotrophic colony-forming bacteria). The SEM observations and the energy dispersive X-ray (EDX) analysis showed the availability of Fe-accumulating bacteria in the samples of the sediments (Fig. 3). Iron and lead in the sediment are present in the sediments as lead and iron sulfides. It may be justified that bacteria contributes to the formation of pyrite and galena fractions in the sediments (Fig. 4). A quantitative plating method showed wide range of changes in the amount of metal-resistant bacteria and little changes in the total number of heterotrophic colony-forming bacteria in the water community throughout the year. The number of colony-forming bacteria in the bottom water varied from 3.0×10^5 cells/ml in August to 9.5×10^4 cells/ml in December. In the shallow water, they are 4.43×10^5 cells/ml and 1.13×10^5 cells/ml, respectively. The water temperatures varied from +18.16°C (in bottom) and +22.57°C (on surface) in August to +2.58°C (in bottom) +2.25°C (on surface) in December. In Amursky

Bay with similar physicochemical conditions, the variations in the number of colony-forming bacteria are more significant. They comprised from 1.82×10^5 cells/ml in August (with water temperature +19.27°C) to 6.5×10^3 cells/ml in December in the bottom water (+2.13°C). In the shallow water, they were 4.05×10^5 cells/ml (+21.3°C) and 3.8×10^3 cells/ml (+1.03°C), respectively (Bezverbnaya *et al.* 2003).

Fig. 5 shows an example of the bacterial inoculation in control and in selective medium from seawater samples. The presence of a great amount of Cu- and Pb-resistant bacteria has been evident in the microbial community. The colonies of the bacteria become colored if they grew on the medium with Cu- or Pb-addition. These colors of colonies are typical for the salts of these metals. This fact may be the result of the bacterial absorption or the accumulation of metals. The presence of transparent regions around colonies of the bacteria growing on the medium with Zn addition has been evident. It may be the result of bacterial excretion of the substances having an influence on consistent forms of metal from the media.

Fig. 5. Examples of colony-forming bacteria growth in Petri dishes: bacteria growth on the control media without metals adding (b); metal-resistant bacteria growth on the selective media with addition of Cu (a), Pb (c), Cd (d), Zn (e). Color of bacteria colonies (a, c) corresponds with color of Cu- and Pb-salts. Transparent regions surround colonies of bacteria growing on media with addition of Zn (e).

Fig. 6. Transmission electron micrographs of bacilli and coccus from water (A, B, C, D) and sediments (E, F) with attributes of accumulation of specific material into and around the cells.

The TEM observations of microorganisms from the water and sediments have shown the presence of a great number of both rod and cocci-form bacteria with morphological changes. The changes may be the result of the absorption and accumulation of some different contaminants from the environment into the cell or the cell wall (Fig. 6).

4. Discussion

The information on the types of interactions between the natural microbiota of coastal areas and environmental contaminants is relatively rare which makes it difficult to generalize or to predict the fate and effects of contaminant compounds in the affected areas. In the harbor sediments contaminants accumulated, the relatively high levels, which caused changes in faunal abundance or diversity of microbiota (Pearson and Rosenberg 1978; Bernard and Fenchel 1995; Fadeev and Fadeeva 1999). The concentration of heavy metals and petroleum hydrocarbons in the sediments of Golden Horn Bay exceeded by 10-70 times

those of the background areas. With regard to the significant toxicological effects of polycyclic aromatic hydrocarbons (PAH), the benthic organisms have been observed at concentrations of < 1 mg PAH/kg dry sediment (Long 1992). Some of the major factors affecting PAH concentrations are the grain-size distribution (related to the surface area available for adsorption), the concentration and type of organic material present, the redox status of the sediments, and the biological activity within the sediments (bioturbation) (Law and Klungsøyr 2000).

Such habitats are practically devoid of macrofauna. Only a few species survive, which are either persistent or feed on contaminants. However, some macrobenthic and meiobenthic species (*C. capitata*, *O. ramosum*) have a high abundance in organic-rich sediments polluted with heavy metals and petroleum hydrocarbons throughout the year, and have a great impact on the biogeochemistry of these sediments in the Bay. Mainly, the special communities of small-size organisms are formed in this harbor environment.

The toxicity aggravated by the effects microbial transformation can persist with concomitant alteration in overall community structure and function. Apparently, the high contents of toxicants exceeding the maximal possible level effect on biota, the sharp decrease of concentration of dissolved oxygen, the increase of hydrogen sulfide and pyrite in the sediments, the silting of the bottom, leading to negative effects on macrobenthos and results in the destruction of its biomass.

In the silty eutrophic sediments with high petroleum hydrocarbons concentrations, the aerobic heterotrophs are insufficient in quantity to degrade all organic compounds. Very low concentrations of oxygen and a rather significant content (up to 8%) of C_{org} in the sediments have increased the existence of anaerobic microorganisms, from which sulfate reducing bacteria have the greatest geochemical value. The metabolism of these bacteria is based on the oxidation of organic matter and is connected with the reduction of sulfates up to the levels of hydrogen sulfide in the water contained in the silt sediments. In this habitat, heavy metals are present mainly in an insoluble sulfide form in deeper layers where the hydrogen sulfide is being formed. In most anaerobic coastal sediments, sulfate reduction predominates and can account for up to 50% of the total C oxidation of coastal sediments (Capone and Bauer 1992).

Our previous data on the Golden Horn Bay (Kiyashko et al. 2001) indicate that the ratio of stable isotopes of carboneum ($^{12}C/C^{13}$) in petroleum hydrocarbons in the

sediments and the tissues of hydrobionts (polychaetes and nematodes) in that area testifies to the fact that the carbon of petroleum carbohydrates is included in the food web of that community as an additional source of organic matter. Our results show that the carbon of petroleum hydrocarbons comprised 19-39% C_{org} of the biomass of the investigated worm species feeding on oil oxidizing microorganisms (Kiyashko *et al.* 2001). The detrital food web in the shallow harbor sediments are dependent, indeed, on the catalytic activities of bacteria and on protozoan links between bacteria, meiofauna and macrofauna. Small organisms use the various substances as a source of carbon, including petroleum hydrocarbons, facilitating self-recycling of marine coastal waters. In submarine conditions where hydrocarbon seeps (Montagna *et al.* 1986), higher rates of meiofaunal grazing on bacteria were reported, indicating that oil-induced enhancement of microbial production might be transferred to higher trophic levels. Therefore, the general picture of the benthic community structure shifts towards smaller organisms and carbon input from hydrocarbons.

In the sediments, there are high contents of sulfur mostly presented by pyrite and lead sulfide, beyond, the reduced sulfur is a fraction of the hydrogen sulfide and acid-soluble sulfide levels. The species resistant to high concentrations of heavy metals and PAH and to low contents of dissolved oxygen have a certain mechanism of detoxication, which enables the species to function and reproduce normally and to gain priority for development in that community.

Reduced sulfur compounds that are generated in conditions of low oxygen content in the sediments are highly toxic for the cells of bottom organisms. The chemical oxidation of hydrogen of reduced sulfur compounds and related endocellular accumulation of sulfur globules by superoxide radicals of oxygen and by peroxide is known now for its colorless sulfur bacteria of *Beggiatoa* and *Thiothrix* and the polychaete species the *Capitella capitata* complex (Gamenick *et al.* 1998). The sulfide oxidation resulting in the formation of sulfur inclusions has been shown as an option for reducing the risks of sulfide poisoning in nematodes *Oncholaimus campylocercoides* (Thiermann *et al.* 2000). We have discovered that the nematode *Oncholaimus ramosus* is also capable of accumulating sulfur in hypoderms. Such an adaptive mechanism for detoxification of sulfides is apparently one of the most widespread among the benthos.

The bacteria have an ability for bioremediation and play a key role in the elimination of heavy metals (Tazaki *et al.* 2002). The results of the ecotoxicological tests displayed

that polychaetes and nematodes are maximally resistant to higher contents of heavy metals in sediments, as compared with other multicellular benthic organisms (Howell and Smith 1983; Vranken and Heip 1986). Some explorers assume that collagenoid proteins of nematode cuticle are proteins of the metallthioneine type (Howell and Smith 1983).

The specific benthic communities presented by a limited number of species tolerant to abnormally high levels of toxic compounds are formed in sediments of the East Sea (Sea of Japan) in areas where there are large ports under conditions of chronic anthropogenic pollution. They have an entire set of mechanisms neutralizing the negative effects of those compounds. On the other hand, all small organisms of this community, which are presented by a few species, form the detrital food web and permit the sustaining of biogeochemical circulation of material in sediments, which results in the biological self-recycling of sea basins.

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