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The Seawater Pollution Survey in the Northern Black Sea

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Abstract

For the first time the integral scene of the toxicological field in the northern Black Sea as it was in the 1990s, with characteristic seasonal and spatial variations, was obtained by means of the integral indices. Priority pollutants during the investigation time were iron, chrome and copper, the registered concentrations of which exceeded maximum allowable concentrations (MAC). In the surface micro layer of the sea total petroleum hydrocarbons and chlorine organic compounds (PCB, HCCH and DDT and its products) were also found in quantities exceeding MAC.

Most probably, the spring (March, May) peak of pollution observed in the pelagic zone developed as a result of the spring flood. In July, the relative well-being of the sea was owing to that spring-summer phase of plankton succession completed in a mass descent of dead plankton to the sea floor that, together with intensive sedimentation of pollutants by suspended matter, favored natural purification.

Keywords: Index of water pollution, main pelagic layers, priority pollutants, sedimentation, bioaccumulation, spatial and seasonal variability.

Introduction

Ecosystem responses to anthropogenic contamination are among key challenges faced and investigated by marine ecology. A large variety of pollutants have been acknowledged as gravely endangering marine ecosystems. Assessing impacts that toxicants produce on ecosystem as a whole and on its elements, it is expedient to integrally study environmental factors such as water, bottom substrate, suspended matter and hydrobionts which determine the quality of marine environment (Borga *et al*., 2008; Chainho *et al*., 2008; Korshenko *et al*., 2008, 2009; Wilson *et al*., 2008). This approach proved to be more productive compared to tracing distribution of pollutants one by one, as they largely vary both spatially and temporally. In the Black Sea the quality of marine environment is regularly assessed and reported by researchers of The N.N. Zubov Russian Oceanographic Institute; these studies are an integral part of the National Program of monitoring of marine environment and involve using the integral index of water pollution (IWP) which takes into consideration such factors as dissolved oxygen content (DOC) and concentrations of three key pollutants (Romankevich and Aibulatov, 2004; Korshenko *et al*., 2008, 2009). The resulting array of evidence refers mainly to coastal zones of cities, the localities receiving river inflow and to some close-to-norm inshore seawater areas and discloses background contamination levels. Measurements were performed in the upper and near-bottom seawater layers in the relatively shallow sea and in standard hydrological horizons in the pelagic zone (Romankevich and Aibulatov, 2004; BSC, 1998; Korshenko *et al*., 2008, 2009; Zonn *et al*., 2008; Burgess *et al*., 2009). These data do not cover hydrological structure of the studied seawater areas and therefore are of little use to hydrobiologists.

In 1992 – 1993, a series of research cruises was organized by the Ukrainian Research Center of Marine Ecology (UkrRCME, Odessa) of Ministry of Natural Environment Protection within the framework of the project ECOMONOK of the State Program «Global change of natural environment and climate» of the State Committee on Science and Technique of the USSR (Medinets *et al*., 1994a). Specialists from the Institute of Biology of the Southern Seas (IBSS, Sevastopol) of NAS of Ukraine also participated in the research work. Unique experiment which focused on the annual cycle of main elements composing

pelagic ecosystem has brought comprehensive knowledge about the content of pollutants in pelagial of the Black Sea. Results obtained during these expeditions, in particular about spatial and seasonal variations observed in the distribution of the basic classes of pollutants in the marine environment, have been published (Den'ga *et al*., 1994; Medinets *et al*., 1994b; Orlova, 1994). At the same time, integral assessment of pollution in the basic pelagic layers and the seawater quality classification based on relevant estimates have been the subjects in waiting as yet. Our article is intended to fill up the gap by discussing spatial and seasonal aspects of the by-depth contamination in the pelagic zone of the northern Black Sea based on the integral indices.

Material and Methods

Estimates measured during the four seasonal surveys performed in the northern Black Sea were used in computations underpinning this paper. Measurings were made during the 60th and 61st expeditions of the R/V "Georgy Ushakov" (March and May, 1992) and during the 57th and 58th expeditions of the R/V "Ernst Krenkel'" (July and September, 1992) launched by UkrRCME; the uniform map of sampling stations did not change. Research interests focused on the seawater area of economic zones of Ukraine, Russia and Georgia. Figure 1 shows how the topography of zero horizon (0 m) changed depending on month in 1992 (see Georgiev *et al*., 1994 for details). Figure 2 shows position of the stations at which pollutants were measured in standard photic layers to 100 m depth. In these expeditions, researchers from UkrRCME collected seawater samples and then determined the content of eight heavy metals (Hg, Zn, Ni, Cu, Pb, Cr, Cd, and Fe), arsenic, total petroleum hydrocarbons (TPHs), chlorine organic pesticides (DDT, DDE, DDD, hexachlorcyclohexan HCCH) and polychlorinated biphenyls (PCB).

X-ray-fluorescent technique was used for measuring total content of Cr, Cu, Ni, Pb, Zn, and As on Spectroscope Max-G (Spectron, Russia). The content of Fe was measured by extraction-activation analysis. The concentrations of oil hydrocarbons in seawater were determined by infrared spectrometry method with the employment of the infrared spectrophotometer IR-20 (Germany). For extraction, from the uppermost thin surface of the sea (micro layer) 1-l sample and from other depths 10-l samples of sea water were collected. Gas-liquid chromatography technique was used in chemical tests conducted for chlorinated hydrocarbons on a Tsvet-100 equipped with chromatographic columns; in the identification procedure we used a blend of standard α, γ-HCCH solutions, solutions of 'DDT, 'DDE, 'DDD and "Clophen A-50" as a PCB standard. Detailed description of the methods is given elsewhere (Den'ga *et al*., 1994; Medinets *et al*., 1994; Orlova, 1992, 1994). Weight-average concentrations of the toxicants were computed from the pertinent estimates measured in the surface micro layer (SML, 0-1m), in the upper mixed layer (UML), in the thermocline and in the depth from the lower boundary of thermocline to 100 m depth.

The importance of SML in accumulating the pollutants, primarily petroleum products, has been proved by researches carried out over the World Ocean and in the Black Sea in particular. From the standpoint of hydrobiology, SML is neuston biotope. The underlying UML, homogeneous in every aspect, is biotope of epiplanktonic community. Deeper, the layer of density gradient (thermocline) retains light fractions of a variety of pollutants. The content of pollutants in the depth below thermocline suggests deeper sources of contamination and pollutants' removal from the active layer with sinking suspended particles. Finally, the depth from below thermocline down to HS zone harbors bathyplanktonic community.

Deriving IWP (or IWP, index of water pollution) index, we used the formula according to Korshenko *et al*. (2008, 2009):

$$IWP = \frac{\frac{norm\ O_2}{C_{O_2}} + \sum_{i=1}^{3} \frac{C_i}{MAC_i}}{4}$$

where C_i is the content of three priority pollutants and Co_2 – dissolved oxygen content evaluated by dividing the norm by the actual content; and MAC – maximum allowable concentration adopted from ITVA Neue Niederlandishe Liste, 1993. Seawater quality was assessed in conformity with Table 1 (Korshenko *et al*., 2008, 2009).

Table 1. The classification of seawater quality based on the index of water pollution (IWP) by Korshenko *et al*. (2008, 2009)

Grade of seawater quality	Definition	IWP
I	Very pure	IWP < 0.25
II	Pure	0.26 < IWP ≤ 0.75
III	Moderately polluted	0.76 < IWP ≤ 1.25
IV	Polluted	1.26 < IWP ≤ 1.75
V	Dirty	1.76 < IWP ≤ 3.00
VI	Very dirty	3.01 < IWP ≤ 5.00

Results

The average and maximum concentrations of pollutants measured in the seawater column in the northern Black Sea during 1992 are given in Table 2 (A, B, C, and D). Table 3 specifies priority pollutants found in the inspected seawater layers during the observation periods. Iron, chrome and copper (Figures 3, 4 and 5, correspondingly) persistently prevailed throughout the pelagic depth including SML in which, additionally, PP (Figure 6) and chlorine organic compounds (COC) such as PHB, HCCH and DDT and its metabolites (Figure 7) were also found in concentrations larger than MAC. Such factors as hydrological conditions, sedimentation and the influx of pollutants from economic activity provide explanation to the complicated character of pollutants' distribution. Noteworthily, in the Sea of Azov iron, chrome and mercury were identified as priority pollutants (Klionkin, 2008).

The special character of spatial, by-depth and temporal distribution of the priority pollutants determines the distribution of indices of seawater pollution (Figure 8). According to IWP, the SML was classified as varying from moderately polluted (III grade) in March to very dirty (VI grade) in September (NW Black Sea), and the UML – from dirty in March (NW Black Sea) to pure in July and in September. Thermocline was ranked as dirty only in May, in the central convergence area of the sea, through concentration and descent of more polluted surface and subsurface seawater mass (Figure 1). Density gradient partly screens this seawater area from pollutants; therefore the layer below thermocline is classified as moderately polluted.

Discussion

Seasonal variations of seawater pollution can be traced through comparing IWP estimates averaged for the season (Table 4). The averages derived from the entire seawater area under the study indicate the best situation in July; in all probability, it was owing to seasonally high temperature and extensive growth of phyto- and bacterioplankton, which adsorbed, transformed and, dying, sank down onto the sea bed thereby removing the pollutants from the active seawater.

The rate at which the toxicants were removed from the photic layer through sedimentation and biosedimentation was computed from the settling rates of total suspended matter (TSM) and suspended organic matter (SOM) measured during the abovementioned research cruises (Samyshev, 2009). Evidently, TPM and SOM sedimentation rates were largest in July, therefore the seasonally safe sea (Figure 9).

Accumulation of chlorine hydrocarbons in suspended matter, mesozooplankton, zoobenthos and bottom sediment was estimated as ratio between the pollutant content in the tested object and in the marine environment. PCB, DDT and its products were found in all samples of suspended matter and HCCH – in the majority of the samples. Estimates obtained for chlorine organic compounds were largest in the NW Black Sea. In the tested samples of mesozooplankton *Calanus euxinus* prevailed. Zooplankton abundantly accumulated PCB; compared to DDT, the corresponding estimates were one to two orders of magnitude greater (Figure 10). The concentrations of chlorine organic compounds measured in the samples of Black Sea mesozooplankton were 2 to 3 times larger than in the samples from the North Atlantic (Orlova, 1992).

Conclusions

For the first time the integral scene of the toxicological field in the northern Black Sea as it was in the 1990s, with characteristic seasonal and spatial variations, was obtained by means of the integral indices (Dzitsky *et al*., 2011).

Priority pollutants during the investigation time were iron, chrome and copper, the registered concentrations of which exceeded maximum allowable concentrations (MAC). In the surface micro layer (SML) of the sea total petroleum hydrocarbons and chlorine organic compounds (PCB, HCCH and DDT and its products) were also found in quantities exceeding MAC.

Most probably, the spring (March, May) peak of pollution observed in the pelagic zone developed as a result of the spring flood. In July, the relative well-being of the sea was owing to that spring-summer phase of plankton succession completed in a mass descent of dead plankton to the sea floor that, together with intensive sedimentation of pollutants by suspended matter, favored natural purification.

The gradation of seawater pollution based on the distribution of pollution indices derived from the basic seawater layers provides a tool that permits to integrally assess contamination in pelagic biotopes. Methodologically, this approach is significantly important in studying various impacts that anthropogenic contamination produces on structure and functioning of components of biota in pelagic ecosystems.

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Table 2 A. Average and maximum concentrations of pollutants derived for the seawater layers, the northern Black Sea, 1992 (March-April)

Location	Number of stations	Layer		The pollutants and the concentrations									
					Heavy metals								
				As	Hg	Zn	Ni	Cu	Pb	Cr	Cd	Fe	TPHs
				μg/L	μg/L					mg/L			mg/L
North western	1	SML		-	-	-	-	-	-	-	-	-	0,050
		UML		3.0	0.034	15.60	1.30	2.30	5.60	3.80	0,15	0,440	-
		Thermocline		-	-	-	-	-	-	-	-	-	-
		Below thermocline to 100m depth		-	-	-	-	-	-	-	-	-	-
Central	3	SML	Av.	2.5	0.035	6.15	0.75	4.00	9.30	0.70	0.15	0.134	0.130
			Max	3.0	0.047	8.10	0.80	4.20	13.60	0.74	0.15	0.142	0.200
		UML	Av.	3.7	0.039	5.01	1.84	2.66	5.80	1.08	0.15	0.080	-
			Max	4.0	0.040	11.50	4.10	4.50	8.80	1.80	0.15	0.150	-
		Thermocline	Av.	6.0	0.029	15.60	0.94	5.40	11.00	1.00	0.15	0.082	-
			Max	6.0	0.029	15.60	0.94	5.40	11.00	1.00	0.15	0.082	-
		Below thermocline to 100m depth	Av.	4.7	0.045	20.35	0.82	11.05	5.28	0.88	0.15	0.108	-
			Max	5.5	0.049	52.50	1.27	27.35	10.80	1.23	0.15	0.241	-
Eastern	2	SML	Av.	6.0	0.048	7.70	0.55	2.15	3.90	0.75	0.15	0.097	0.088
			Max	10.0	0.059	12.80	0.55	2.40	5.00	1.00	0.15	0.134	0.100
		UML	Av.	6.3	0.038	1.75	1.31	1.70	2.03	0.59	0.15	0.023	-
			Max	6.5	0.051	2.45	1.95	1.75	2.55	0.62	0.15	0.023	-
		Thermocline	Av.	-	-	-	-	-	-	-	-	-	-
			Max	-	-	-	-	-	-	-	-	-	-
		Below thermocline to 100m depth	Av.	6.0	0.049	4.02	0.79	1.60	1.50	0.55	0.15	0.029	-
			Max	7.0	0.055	6.29	1.00	1.80	1.50	0.57	0.15	0.032	-
Maximum allowable concentrations				10,0	0,100	50,00	10.00	5.00	10.00	1.00	10.00	0.050	0.050

Table 2B. Continued (May)

Location	Number of stations	Layer		The pollutants and the concentrations									
				As	Heavy metals								TPHs
					Hg	Zn	Ni	Cu	Pb	Cr	Cd	Fe	
				µg/L	µg/L					mg/L			mg/L
North western	1	SML		1.0	0.040	183.00	1.70	9.00	10.10	5.00	0.18	0.382	0.050
		UML		4.0	0.053	101.25	2.15	3.65	1.55	0.98	0.15	0.049	0.010
		Layer of thermocline		6.0	0.070	105.40	3.00	2.90	2.20	0.83	0.15	0.049	0.010
		Below thermocline to 100m depth		8.0	0.066	5.35	1.60	3.10	4.10	1.30	0.19	0.034	0.060
Central	3	SML	Av.	0.7	0.029	47.80	1.39	5.40	5.17	5.07	0.15	0.167	0.130
			Max	2.0	0.051	105.50	2.80	5.80	6.70	8.90	0.15	0.208	0.200
		UML	Av.	1.5	0.031	46.97	1.29	3.58	3.87	1.32	0.15	0.078	-
			Max	2.0	0.045	104.55	1.50	5.20	5.80	2.33	0.15	0.127	-
		Layer of thermocline	Av.	7.0	0.035	9.75	0.56	3.33	3.27	1.34	0.16	0.153	-
			Max	2.0	0.053	14.80	0.56	5.50	4.30	2.00	0.19	0.303	-
		Below thermocline to 100m depth	Av.	2.0	0.017	5.30	1.30	1.63	1.80	1.12	0.15	0.080	-
			Max	2.0	0.026	7.60	2.80	2.20	2.00	1.80	0.15	0.167	-
Eastern	2	SML	Av.	2.0	0.027	20.35	0.96	5.30	2.60	1.60	0.15	0.124	0.088
			Max	2.0	0.031	24.80	1.10	6.40	2.90	1.70	0.15	0.131	0.100
		UML	Av.	8.0	0.048	4.58	1.49	3.30	1.50	0.66	0.15	0.022	-
			Max	12.0	0.055	5.25	2.04	3.35	1.50	0.69	0.15	0.024	-
		Layer of thermocline	Av.	2.0	0.034	3.90	0.71	2.10	1.50	0.71	0.15	0.033	-
			Max	2.0	0.035	4.60	0.72	2.50	1.50	0.84	0.15	0.049	-
		Below thermocline to 100m depth	Av.	6.0	0.031	4.10	0.74	3.40	1.60	1.06	0.15	0.050	-
			Max	12.0	0.031	5.30	0.83	3.90	1.70	1.30	0.15	0.051	-
Maximum allowable concentrations				10.0	0.100	50.00	10.00	5.00	10.00	1.00	10.00	0.050	0.050

Table 2C. Continued (July)

Location	Number of stations	Layer		The pollutants and the concentration														
					Heavy metals								COP				PCB	TPHs
				As	Hg	Zn	Ni	Cu	Pb	Cr	Cd	Fe	DDE	DDD	DDT	HCCH		
				µg/L	µg/L					mg/L			ng/L		ng/L		ng/L	mg/L
Northwestern	4	SML	Av.	-	-	-	-	-	-	-	-	-	3.78	0.02	0.96	1.08	20.767	0.153
			Max	-	-	-	-	-	-	-	-	-	5.04	0.05	1.12	1.61	27.600	0.200
		UML	Av.	1.0	0.060	3.40	1.00	2.10	1.50	1.40	0.15	0.03	0.21	0.25	0.05	0.03	1.225	0.070
			Max	1.0	0.060	3.40	1.00	2.10	1.50	1.40	0.15	0.03	0.34	0.69	0.08	0.06	2.100	0.070
		Layer of thermocline	Av.	1.0	0.048	4.00	2.80	4.40	7.10	1.40	0.15	0.08	-	-	-	-	-	0.040
			Max	1.0	0.048	4.00	2.80	4.40	7.10	1.40	0.15	0.08	-	-	-	-	-	0.040
		Below thermocline to 100m depth	Av.	-	0.062	7.10	1.90	2.90	3.30	2.50	0.15	0.07	0.24	0.37	0.07	0.04	1.137	0.170
			Max	-	0.062	7.10	1.90	2.90	3.30	2.50	0.15	0.07	0.67	0.80	0.16	0.12	2.300	0.170
Central	4	SML	Av.	-	-	-	-	-	-	-	-	-	1.68	0.21	1.06	1.00	22.933	0.300
			Max	-	-	-	-	-	-	-	-	-	2.52	0.63	1.50	1.84	31.400	0.600
		UML	Av.	0.5	0.070	5.15	2.75	3.40	1.60	1.28	0.15	0.04	0.42	0.11	0.12	0.14	2.523	-
			Max	0.5	0.075	6.50	4.20	3.60	1.70	1.35	0.15	0.06	0.69	0.30	0.21	0.28	4.980	-
		Layer of thermocline	Av.	1.0	0.062	7.37	1.09	2.53	1.60	1.40	0.15	0.10	0.59	0.84	0.09	0.12	2.680	-
			Max	1.0	0.083	12.00	1.40	2.80	1.70	1.70	0.15	0.15	1.40	2.47	0.21	0.28	4.160	-
		Below thermocline to 100m depth	Av.	2.0	0.043	8.10	1.24	4.00	1.93	1.33	0.15	0.06	0.19	0.25	0.10	0.11	1.705	-
			Max	2.0	0.062	11.50	1.70	4.70	2.30	1.60	0.15	0.11	0.34	0.52	0.18	0.16	2.530	-
Eastern	2	SML	Av.	-	-	-	-	-	-	-	-	-	1.89	0.00	0.85	1.04	24.150	0.250
			Max	-	-	-	-	-	-	-	-	-	2.10	0.00	0.94	1.15	30.500	0.300
		UML	Av.	0.8	0.049	3.73	1.47	2.53	1.55	0.92	0.15	0.05	0.25	0.39	0.11	0.42	1.720	-
			Max	1.0	0.054	3.85	1.84	2.55	1.60	0.97	0.15	0.05	0.29	0.58	0.13	0.70	2.110	-
		Layer of thermocline	Av.	0.8	0.048	4.00	1.95	2.65	1.50	0.91	0.15	0.04	0.25	0.70	0.12	0.50	1.885	-
			Max	1.0	0.050	5.60	2.70	3.50	1.50	0.96	0.15	0.04	0.29	1.00	0.13	0.80	2.140	-
		Below thermocline to 100m depth	Av.	1.0	0.061	5.65	2.40	4.05	2.80	0.86	0.15	0.05	0.39	0.56	0.35	0.16	2.045	-
			Max	1.0	0.075	8.90	3.30	6.10	4.10	0.97	0.15	0.06	0.49	1.12	0.60	0.21	2.290	-
Maximum allowable concentrations				10.0	0.100	50.00	10.00	5.00	10.00	1.00	10.00	0.05	2.50		1.10		10.000	0.050

Table 2D. Continued (September)

Location	Number of stations	Layer		The pollutants and the concentration														
				As	Heavy metals								COP				PCB	TPHs
					Hg	Zn	Ni	Cu	Pb	Cr	Cd	Fe	DDE	DDD	DDT	HCCH		
				µg/L	µg/L					mg/L			ng/L		ng/L		ng/L	mg/L
Northwestern	4	SML	Av.	-	0.082	3.80	0.49	18.10	260.60	1.60	0.25	0.22	6.20	2.10	1.38	1.50	23.300	0.153
			Max	-	0.082	3.80	0.49	18.10	260.60	1.60	0.25	0.22	6.20	2.10	1.38	1.50	23.300	0.200
		UML	Av.	1.0	0.048	6.00	0.49	4.95	4.30	1.71	0.24	0.11	0.20	0.28	0.07	0.10	1.040	-
			Max	1.0	0.048	6.00	0.49	4.95	4.30	1.71	0.24	0.11	0.30	0.62	0.08	0.13	1.370	-
		Layer of thermocline	Av.	-	-	-	-	-	-	-	-	-	0.20	0.04	0.07	0.10	1.240	-
			Max	-	-	-	-	-	-	-	-	-	0.21	0.07	0.11	0.12	1.410	-
		Below thermocline to 100m depth	Av.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.100
			Max	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.100
Central	4	SML	Av.	0.5	0.049	7.65	1.41	10.55	12.15	1.45	0.15	0.33	3.32	0.68	1.07	1.02	18.300	0.300
			Max	1.0	0.057	10.80	2.20	17.50	14.20	1.70	0.15	0.37	3.54	0.75	1.38	1.72	19.300	0.600
		UML	Av.	0.5	0.052	2.70	1.22	2.65	3.05	1.22	0.15	0.05	0.12	0.21	0.06	0.05	1.113	-
			Max	1.0	0.066	3.00	1.70	2.70	4.60	1.50	0.15	0.07	0.13	0.38	0.07	0.10	1.340	-
		Layer of thermocline	Av.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			Max	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Below thermocline to 100m depth	Av.	0.3	0.046	4.58	3.44	3.15	5.65	0.89	0.15	0.05	0.31	0.21	0.11	0.08	0.940	-
			Max	0.5	0.057	6.20	6.50	4.10	9.80	0.90	0.15	0.05	0.41	0.41	0.25	0.09	1.010	-
Eastern	2	SML	Av.	0.7	0.039	6.77	1.08	12.57	6.93	1.12	0.15	0.15	3.10	0.50	0.88	1.24	15.300	0.233
			Max	1.0	0.057	10.80	2.20	17.50	10.10	1.20	0.15	0.29	3.99	0.75	1.11	2.86	17.300	0.300
		UML	Av.	1.0	0.041	4.70	0.46	2.65	1.95	0.76	0.19	0.05	0.21	0.05	0.06	0.08	0.715	-
			Max	2.0	0.044	5.40	0.64	2.70	2.40	0.78	0.22	0.05	0.24	0.08	0.08	0.09	1.340	-
		Layer of thermocline	Av.	0.0	0.039	6.95	2.41	6.15	4.70	0.81	0.15	0.24	0.17	0.15	0.05	0.06	1.065	-
			Max	0.0	0.045	9.30	4.20	9.30	6.30	0.95	0.15	0.44	0.18	0.21	0.06	0.06	1.200	-
		Below thermocline to 100m depth	Av.	1.3	0.044	6.15	1.58	3.30	2.80	0.84	0.22	0.08	0.18	0.04	0.05	0.05	0.730	-
			Max	2.0	0.048	8.80	2.70	3.40	3.00	0.98	0.29	0.10	0.18	0.05	0.06	0.06	0.730	-
Maximum allowable concentrations				10.0	0.100	50.00	10.00	5.00	10.00	1.00	10.00	0.05	2.50		1.10		10.000	0.050

Table 3. Priority pollutants in the seawater column, the northern Black Sea, 1992

Concentration	March-April			May			July			September		
% of MAC	Surface microlayer (SML)											
	Fe	PP	Cr	Cr	Fe	PP	PP	PCB	DDE	Pb	PP	Fe
Mean	231.0	205.0	72.5	390.0	377.3	205.0	462,0	224,3	100,8	591.2	462.0	417.6
Maximum	284.0	400.0	100.0	890.0	764.0	400.0	1200,0	314,0	201,6	2606.0	1200.0	748.0
	Upper mixed layer (UML)											
	Fe	Cr	Cu	Fe	Cr	Zn	Cr	Fe	Hg	Fe	Cr	Cu
Mean	241.7	137.0	45.6	109.3	104.5	83.8	115.8	84.0	59.4	125.6	113.2	62.2
Maximum	880.0	380.0	90.0	254.0	233.0	209.1	140.0	118.0	75.0	216.0	171.0	99.0
	Layer of thermocline											
	Fe	Pb	Cu	Fe	Cr	Cu	Fe	Cr	Cu	Fe	Cu	Cr
Mean	164.0	108.0	164.0	191.3	104.5	57.0	149.3	123.5	57.7	486.0	123.0	80.5
Maximum	164.0	108.0	164.0	606.0	200.0	110.0	308.0	170.0	88.0	872.0	186.0	95.0
	Layer from the lower boundary of thermocline to 100 m depth											
	Fe	Cu	Cr	Fe	Cr	Cu	Cr	Fe	Cu	Fe	Cr	Cu
Mean	153.2	145.4	74.8	124.3	112.8	49.3	137.0	111.7	76.7	128.0	86.3	64.5
Maximum	482.0	547.0	123.0	334.0	180.0	78.0	250.0	220.0	122.0	208.0	98.0	82.0

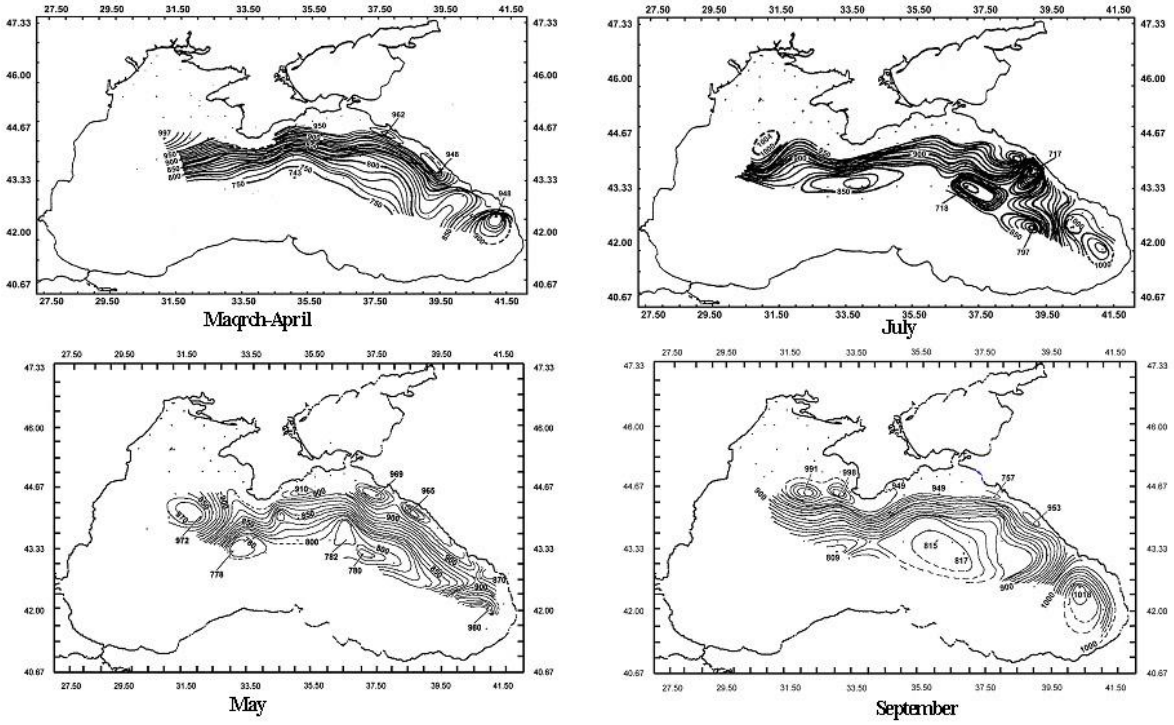

Figure 1. The dynamic topography of horizon 0 m from the spring to the autumn, 1992 by Georgiev *et al*. (1994).

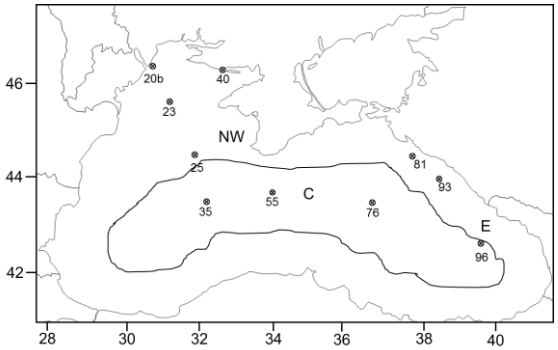

Figure 2. The map of sampling stations at which the pollutants were measured in 1992: stations 23, 35, 55, 81, 93, 96 (March-April, May), stations 20b, 23, 25, 35, 40, 55, 76, 81, 93, 96 (July, September). NW, C and E – northwestern, central and eastern parts of the Black Sea, correspondingly.

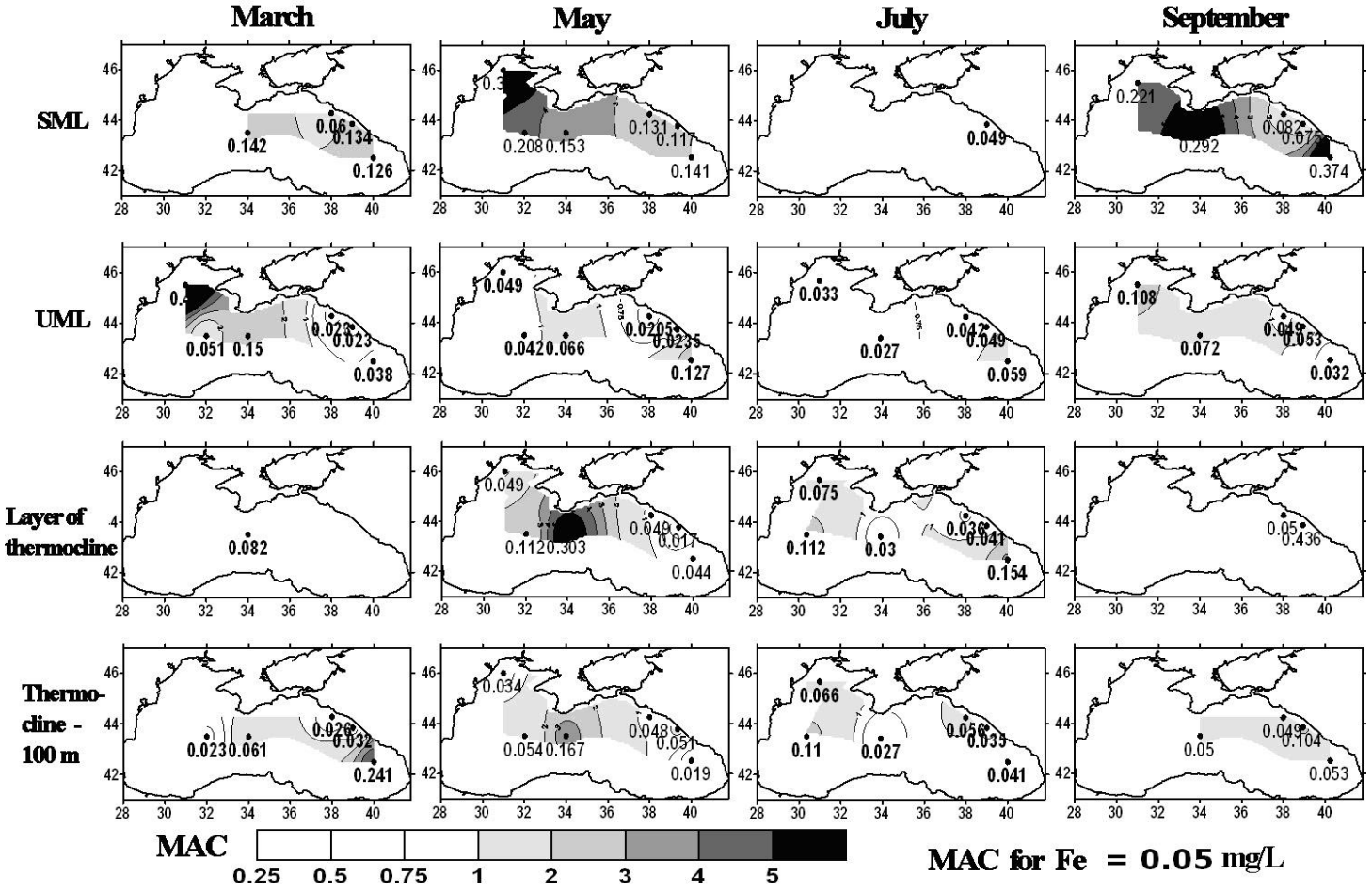

Figure 3. The content of Fe (as percent of the maximum allowable concentration MAC) measured in the main pelagic layers (SML: surface micro layer, UML: upper mixed layer) of the northern Black Sea during 1992. Shaded areas describe the increase of seawater pollution (estimates greater than MAC). The absolute values are plotted (mg L^{-1}).

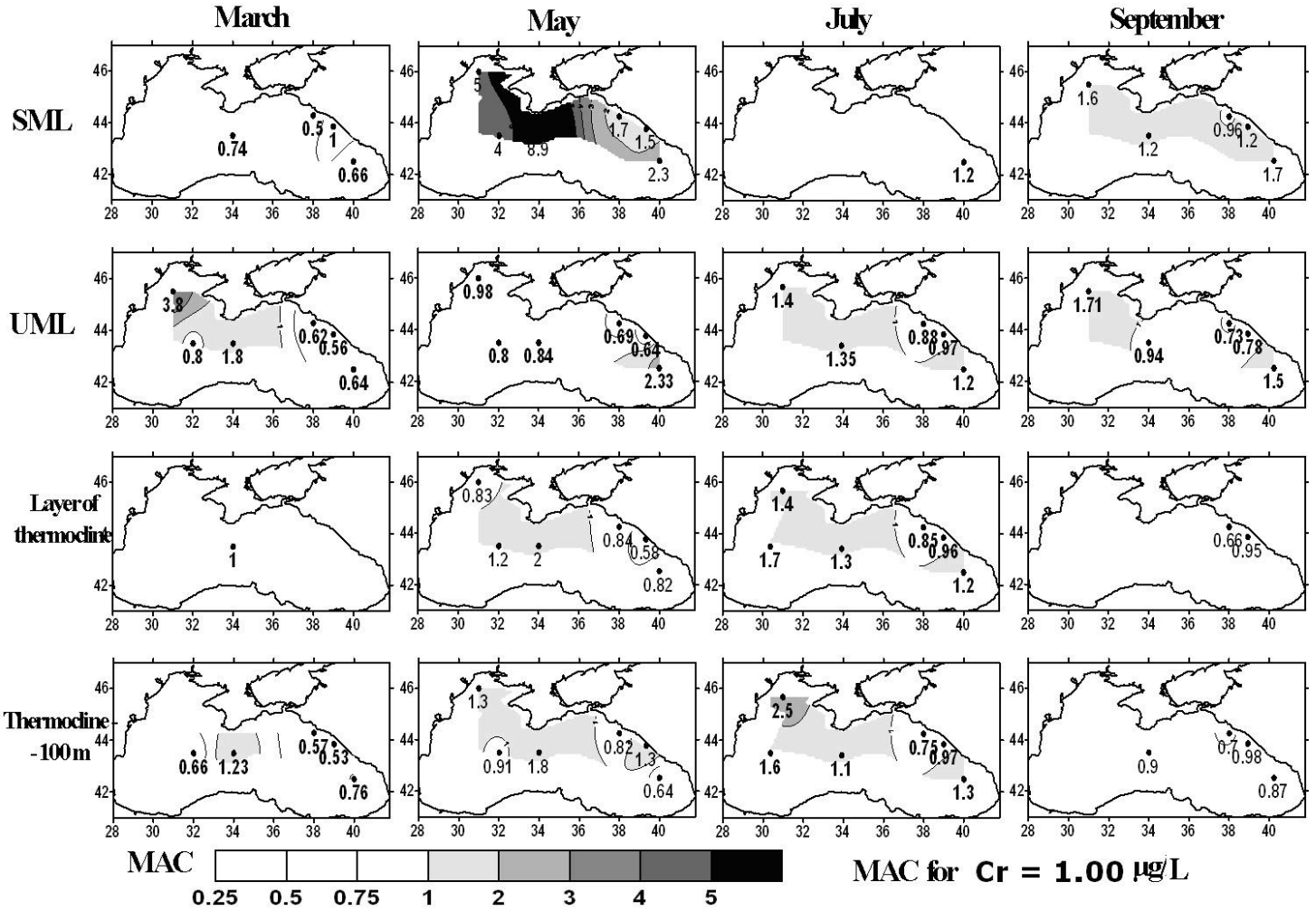

Figure 4. The content of Cr (as percent of the maximum allowable concentration, MAC) measured in the main pelagic layers of the Black Sea during 1992. The absolute values are plotted (µg L^{-1}).

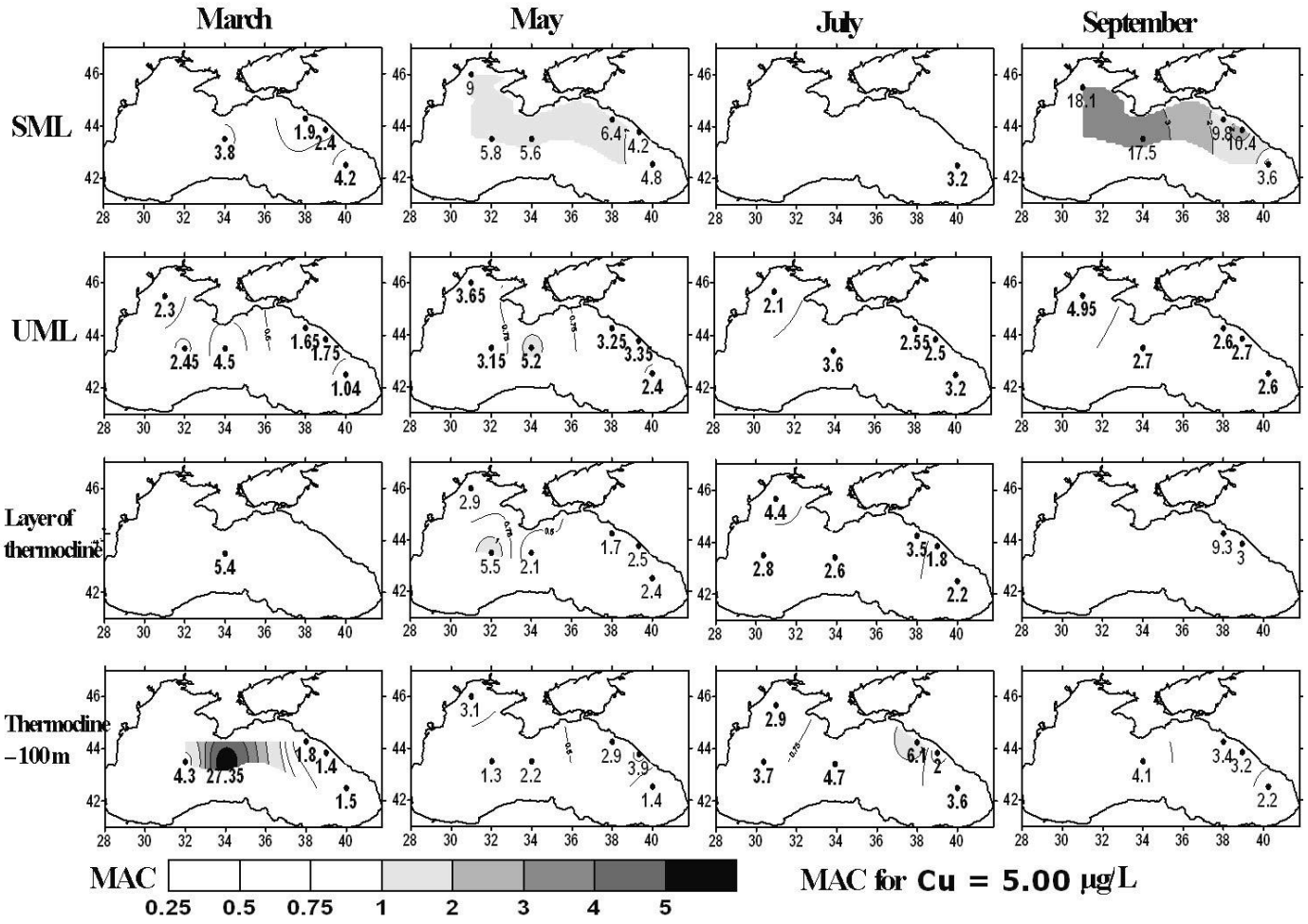

Figure 5. The content of Cu (as percent of the maximum allowable concentration, MAC) measured in the main pelagic layers of the Black Sea during 1992. The absolute values are plotted (µg L^{-1}).

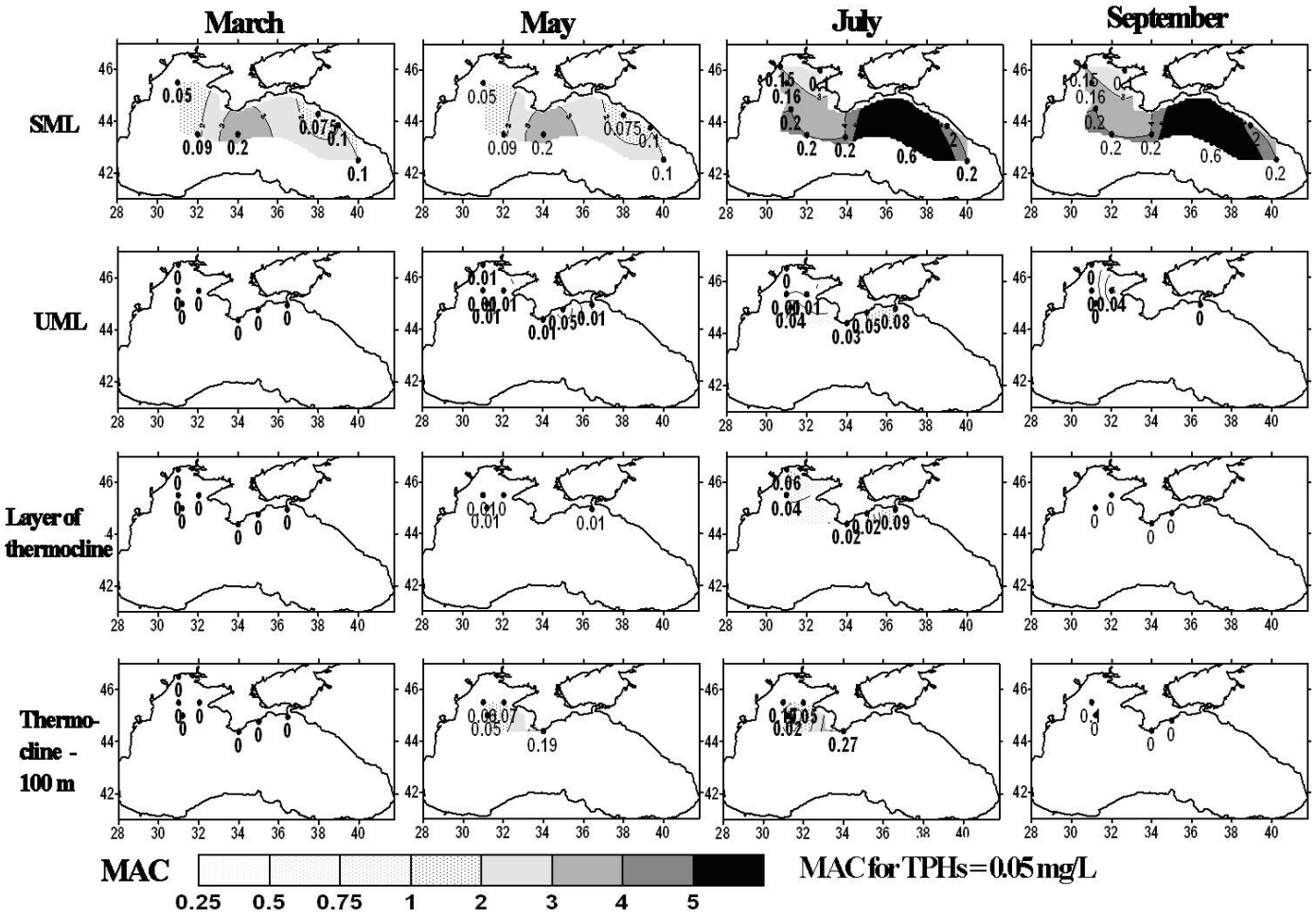

Figure 6. The content of total petroleum hydrocarbons (TPHs, as percent of the MAC) assessed in the main pelagic layers of the Black Sea during 1992. The absolute values are plotted (mg L^{-1}).

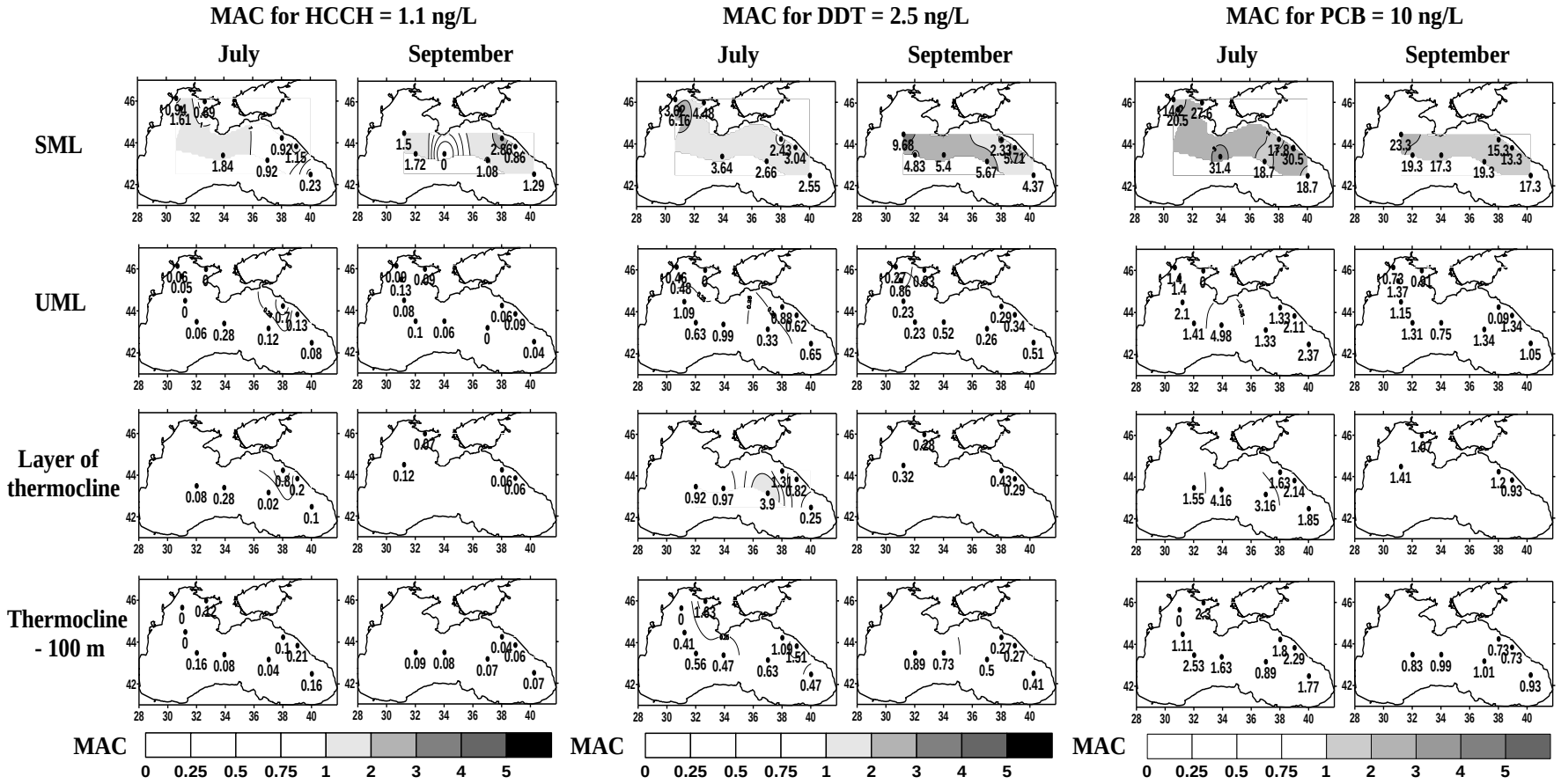

Figure 7. The contents of HCCH, total DDT and PCB (as percent of the MAC) measured in the main pelagic layers of the Black Sea during 1992.
The absolute values are plotted (ng L^{-1}.)

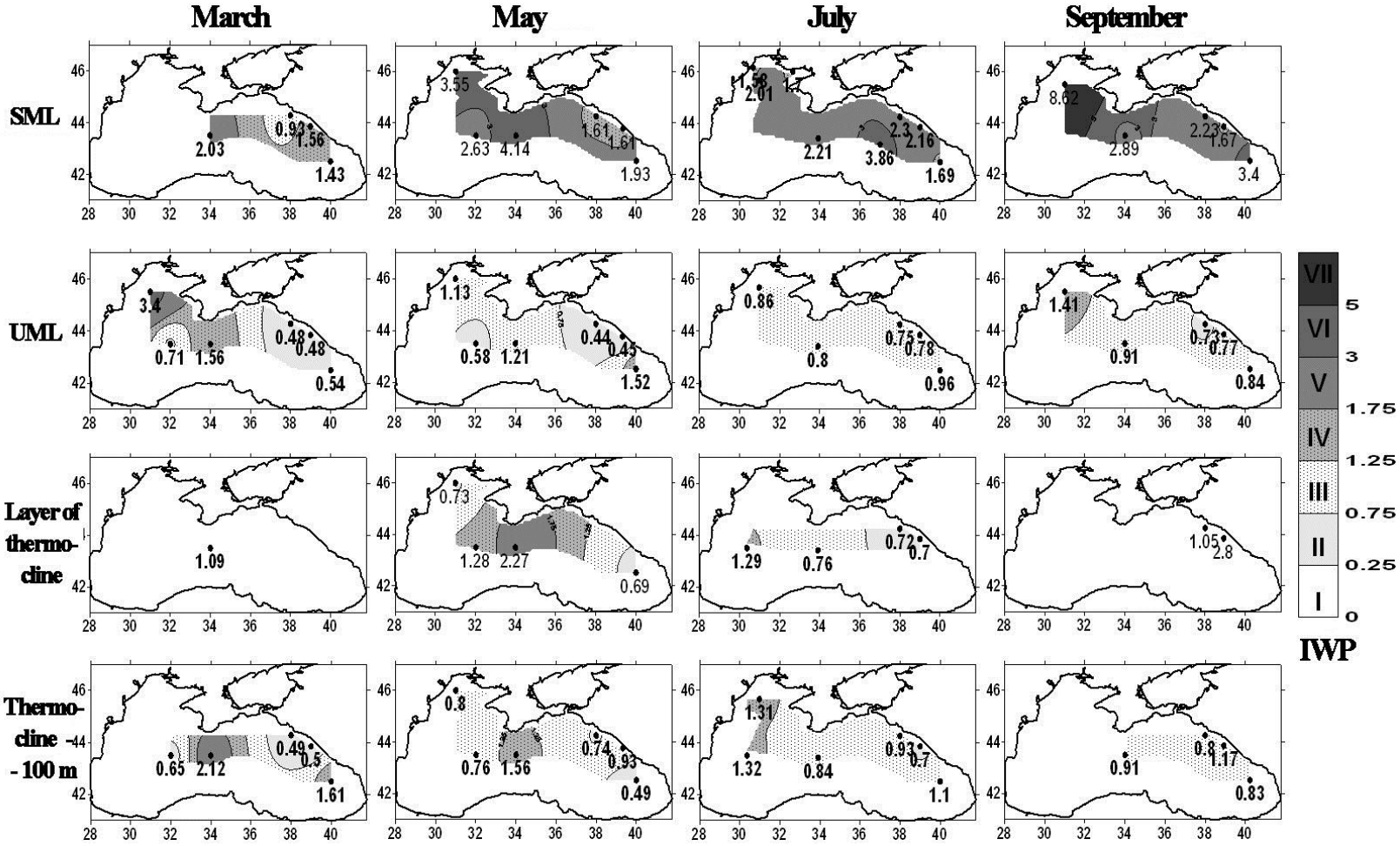

Figure 8. The distribution of indices of water pollution (IWP) estimated in the main pelagic layers of the Black Sea during 1992. The absolute values of IWP are plotted.

Table 4. Seasonal variability of the average indices of water pollution (IWP) and the classification of seawater quality in the northern Black Sea, 1992

Layer	March-April	May	July	September	Average annual index
SML	1.31 (IV)	2.58 (V)	2.22 (V)	3.05 (VI)	2.29 (V)
UML	0.85 (III)	0.89 (III)	0.83 (III)	0.93 (III)	0.88 (III)
Thermocline	-	1.03 (III)	0.93 (III)	1.93 (V)	1.30 (IV)
Layer from the lower boundary of thermocline to 100 m depth	1.07 (III)	0.88 (III)	1.00 (III)	0.8 (III)	0.94 (III)

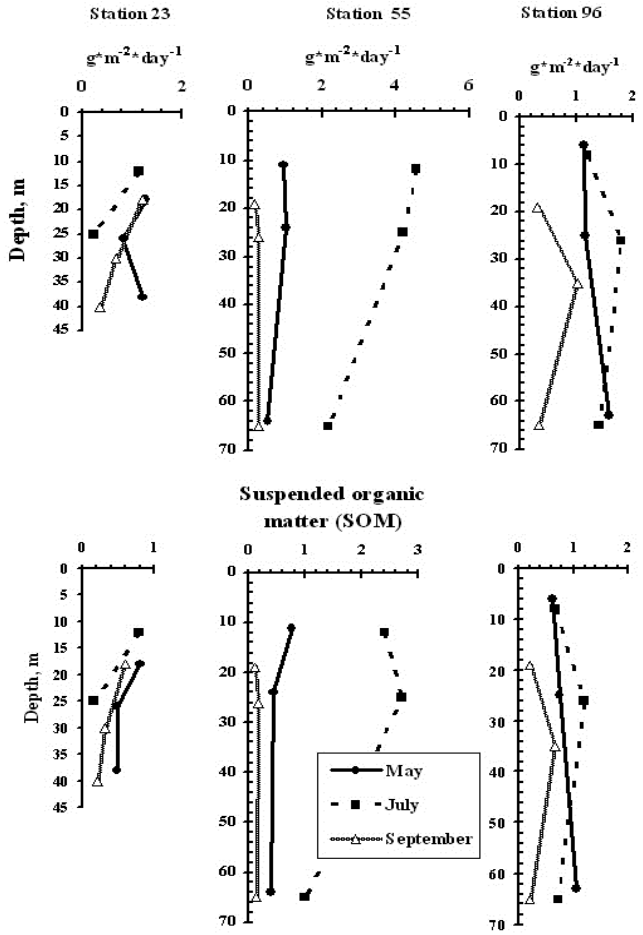

Figure 9. The sedimentation rates of total suspended matter (TSM) and suspended organic matter (SOM) in photic layer of the Black Sea (Samyshev, 2009); see Figure 2 for the map of sampling stations

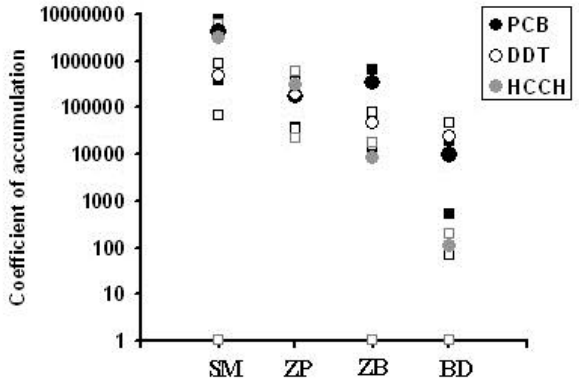

Figure 10. The coefficients of chlorine organic compounds accumulation in the basic ecosystem elements (SM: suspended matter, ZP: zooplankton (primarily *Calanus euxinus*), ZB: zoobenthos, BD: bottom deposits) of the Black Sea (1992-1993) by Orlova, 1994. The averages are circled. The rectangle's color deepens describe the range of the obtained coefficients.

Popov (UkrRCME) who offered hydrological data; to V.I. Medinets, A.A. Kolosov and V.A. Kolosov who measured the content of toxic metals in the sea water; and to Yu.M. Den'ga, Yu.V. Zarubin, and B.O. Treskunov for measuring total petroleum hydrocarbons.

References

Borga, A., Bricker, S.B., Dauer, D.M., Demetriades, N.T., Ferreira, J.G., Forber, A.T., Hatchings, P., Jia, V. and Kenchington, R. 2008. Overview of integrative tools and methods in assessing ecological integrity in estuarine and coastal systems worldwide. Mar. Poll. Bull., 56: 1519-1537.

Burgess, R.M., Terletskaya, A.V., Milyukin, M.V., Povolotskii, M., Demchenko, V.Y., Bogoslavskaya, T.A., Topkin, Y.V., Vorobyova, T.V., Petrov, A.N., Lyashenko, A. and Ho, K.T. 2009. Concentration and distribution of hydrophobic organic contaminations and metals in the estuaries of Ukraine. Mar. Poll. Bull., 58: 1103-1115.

BSC 1998. State of the Environment of the Black Sea (2001-2006/7). T. Oguz (Ed.). Chapter 3. A. Korshenko, *et al*. The state of chemical pollution. Publications of the Commission on the Protection of the Black Sea Against Pollution (BSC), Istanbul, 448 pp.

Chainho, P., Chaves, I.L., Costa, I.L., Costa, M.J. and Dauer, D.M. 2008. Use of multimetric indices to classify estuaries with different hydromorphological characteristics and different levels of human pressure. Mar. Poll. Bull., 56: 1128-1137.

Georgiev, V.T., Gerasimov, S.A. and Popov, Yu.I. 1994. Hydrodynamic conditions of open water masses of the north half of the Black Sea. In: V.I. Medinets (Ed.), Investigations of ecosystem of the Black Sea. 1. Ministry of Environmental Protection of Ukraine, Ukrainian Research Centre of Marine Ecology, Odessa: 17-23.

Den'ga, Yu.M., Zarubin, Yu.V. and Treskunov, B.O. 1994. Contamination of the Black Sea by petroleum and petroleum products. In: V.I. Medinets (Ed.), Investigations of Ecosystem of the Black Sea. Ministry of Environmental Protection of Ukraine, Ukrainian Research Centre of Marine Ecology, Odessa: 24-29. (In Russ.).

Dzitsky, V.S., Orlova, I.G., Samyshev, E.Z. and Minkina, N.I. 2011. Pollution of water and deposits in northern part of the Black Sea in different seasons in 1992. Black Sea Outlook Conference: Proceedings. 31 Oct-4 Nov., Odessa, 31 pp.

Klionkin, A.A. 2008. Ecoanalytic estimation of the Azov Sea conditions in long-term dynamics. DSc thesis. (Chem.) Krasnodar: Cuban State University, 47 pp. (In Russ.).

Korshenko, A.N., Matveichuk, I.G., Plotnikova, T.I., Ivanov, D.B., Panova, A.V. and Kir'yanov, V.S. 2008. Chemical contamination of the Russian seas. Marine waters quality according to hydrochemical indices. Annual Report of Federal Department on Hydrometeorology and Environmental Monitoring. Artifex, Obninsk, 21 pp. (In Russ.).

Korshenko, A.N., Matveichuk, I.G., Plotnikova, T.I. and Udovenko, A.V. 2009. Marine waters quality according to hydrochemical indices. Annual Report of Federal Department on Hydrometeorology and Environmental Monitoring, Artifex, Obninsk: 13 pp. (In Russ.).

Medinets, V.I., Gruzov, L.N., Orlova, I.G., Vasileva. V.N. and Popov, Yu.I. 1994a. Investigation of annual cycle of basic elements of ecosystem of the Black Sea. V.I. Medinets (Ed.). Investigations of ecosystem of the Black Sea. Ministry of Environmental Protection of Ukraine, Ukrainian Research Centre of Marine Ecology, Odessa: 12-16. (In Russ.).

Medinets, V.I., Kolosov, A.A. and Kolosov, V.A. 1994b. Toxic metals in marine environment. In: V.I. Medinets (Ed.). Investigations of ecosystem of the Black Sea. Ministry of Environmental Protection of Ukraine, Ukrainian Research Centre of Marine Ecology, Odessa: 47-53. (In Russ.).

ITVA, Fachausschuß FA-H1 Technologien und Verfahren 1993. Entwurf der Arbeitshilfe "Schadstoffeinbindung durch Verfestigung als Möglichkeit der Immobilisierung", Neue Niederlandishe Liste Stand 5/93, Altlastenspektrum 3/93, S. 170

Orlova, I.G. 1992. Chlorine hydrocarbons in marine ecosystems. Hydrometeoizdat, S. Petersburg: 107 pp. (In Russ.).

Orlova, I.G. 1994. Chlorine hydrocarbons in the ecosystem of the Black Sea. In: V.I. Medinets (Ed.). Investigations of ecosystem of the Black Sea. Issue 1. Ministry of Environmental Protection of Ukraine, Ukrainian Research Centre of Marine Ecology, Odessa: 36-46. (In Russ.).

Romankevich, E.A. and Aibulatov, N.A. 2004. Geochemiical conditions of the Russian seas and human health. Bulletin of Section of Sciences on Earth of RAS: Electronic Popular Science Magazine, 1(22): 16 pp. (In Russ.).

Samyshev, E.Z. 2009. Level of suspended organic matter and rate of its sedimentation in photic layer of waters in the Black Sea. Monitoring systems of environment. Marine Hydrophysical Institute of NAS of Ukraine, Sevastopol: 352-359. (In Russ.).

Wilson, J.G., Komakidze, A., Osadchaya, T., Alyomov, S., Romanov, A. and Tediashvili, M. 2008. Evaluating ecological quality in the north-eastern Black Sea coastal zone. Mar. Poll. Bull., 57(1-5): 202-207.

Zonn, I.S., Fashchuk, D.I. and Ryabinin, A.I. 2008. Environmental issues of the Black Sea. The Handbook of Environmental Chemistry, 5: 407-421