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Assessment of Pollution of the Yalta Bay Ecosystem Components with Organochlorine Xenobiotics

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Abstract

Assessment of pollution of water, brown algae of the genus *Cystoseira* sp., and bottom sediments of Yalta Bay with organochlorine xenobiotics, which include DDT and polychlorinated biphenyls (PCBs), was conducted according to 2017–2020 data. The concentration of these organochlorine compounds was compared with the recommended standards for their content in the marine environment: threshold limit value in water as well as international threshold levels of threshold effect concentration (TEC) and probable effect concentrations (PEC) in sediments. In spring 2017, the average concentration of PCBs in water exceeded 1.2 times the threshold limit value for seawater, which is 10 ng/L. In *Cystoseira* sp., organochlorine compounds accumulated with high accumulation coefficients varying for DDT and its metabolites DDE and DDD and six indicator congeners of PCBs in the range from $1 \cdot 10^3$ to $2 \cdot 10^4$, which indicated high bioavailability of the studied substances. Extremely high concentrations of DDT were detected in the surface layers of bottom sediments, exceeding by a factor of 46 the recommended TEC threshold levels, equal to 5.3 ng/g dry weight for the sum of concentrations of DDT and its metabolites (∑DDT). The distribution profiles of ∑DDT in soil cores at the two stations show a general tendency for their content to decrease with depth increasing. In the cores, the sum of six PCB indicator congeners concentrations (∑6PCB) did not exceed the TEC for PCBs, equal to 60 ng/g dry weight. The source of pollution of Yalta Bay with organochlorine compounds was the Vodopadnaya River runoff, due to which ∑DDT intake was 1.5 g/year and that of ∑6PCB was 5.2 g/year.

Keywords: DDT, PCB, water, sediments, *Cystoseira* sp., Vodopadnaya River, Yalta Bay

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Оценка загрязненности хлорорганическими ксенобиотиками компонентов экосистемы Ялтинского залива

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Аннотация
По данным 2017–2020 гг. проведена оценка загрязненности хлорорганическими ксенобиотиками, к которым относятся ДДТ и полихлорбифенилы (ПХБ), воды, бурых водорослей рода *Cystoseira* sp. и донных отложений Ялтинского залива. Сравнивали концентрации данных хлорорганических соединений с рекомендованными нормами их содержания в морской среде: ПДК в воде, международными пороговыми уровнями *TEC* (*Threshold Effect Concentration*) и *PEC* (*Probable Effect Concentrations*) – в донных отложениях. В весенний сезон 2017 г. средняя концентрация ПХБ в воде превышала в 1.2 раза ПДК в морской воде, составляющую 10 нг/л. В цистозире определены высокие коэффициенты накопления хлорорганических соединений, изменяющиеся для ДДТ, его метаболитов ДДЭ и ДДД и шести индикаторных конгенеров ПХБ в интервале от $1 \cdot 10^3$ до $2 \cdot 10^4$, что свидетельствует о высокой биодоступности исследуемых веществ. В поверхностных слоях донных отложений обнаружены экстремально высокие концентрации ДДТ, превышающие в 46 раз *TEC*, равный 5.3 нг/г сухой массы для суммы концентраций ДДТ и его метаболитов (∑ДДТ). На профилях распределения ∑ДДТ в керне грунтов на двух станциях проявляется общая тенденция к уменьшению содержания пестицидов группы ДДТ с увеличением глубины. Сумма концентраций шести индикаторных конгенеров ПХБ (∑6ПХБ) в кернах не превышала *TEC* для ПХБ, равного 60 нг/г сухой массы. Источником загрязнения Ялтинского залива хлорорганическими соединениями являлся сток р. Водопадной, с которым поступление ∑ДДТ составляло 1.5 г/год, а ∑6ПХБ – 5.2 г/год.

Ключевые слова: ДДТ, ПХБ, вода, донные отложения, *Cystoseira* sp., река Водопадная, Ялтинский залив

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Introduction

The entry into the marine environment of a large volume of technogenic pollutants has led to the formation of the so-called critical zones in certain areas of the Black Sea, where natural biogeochemical processes do not provide self-purification of the ecosystem from incoming pollutant flows, including organochlorine compounds (OCs) [1]. When studying the self-purification mechanisms of such areas on the example of Sevastopol Bay, it was determined that in the 21st century the priority organic pollutants of technogenic origin are OCs, which include

polychlorinated biphenyls (PCBs) and compounds of the p,p'-dichlorodiphenyltrichloroethane (DDT) group [2]. OCs are persistent organic pollutants that degrade extremely slowly under environmental conditions and can accumulate in hydrobionts and bottom sediments. High concentrations of OCs have an acute toxic effect on living organisms, while low concentrations have a chronic effect, which over time causes malignant tumors [3], decrease in reproductive function, and other homeostasis disorders [4]. DDT and PCBs enter the Black Sea environment mainly with river, industrial, agricultural, domestic effluents, atmospheric fallout, and discharges in dumping areas.

Yalta Bay is one of the most important recreational areas of Crimea. Yalta is located at its top. It is known that since the 1970s sewage runoff from Yalta goes through the system of deep-water discharge of domestic and waste water, the commissioning of which has led to a decrease in pollution of the coastal zone of Yalta, a decrease in the eutrophication of Yalta Bay and an improvement in its ecological state as a whole [5]. Currently, the sources of pollution of Yalta Bay in the Yalta region are economic activities of the seaport, the flow of the Vodopadnaya and Derekoika Rivers, storm surface runoff and melting snow cover. In the data yearbooks on the seawater quality of the FSE SOI named after N.N. Zubov there is information about high water pollution of Yalta Bay with organochlorine pesticides (OCPs) in the 1980s, when the DDT concentration in the port water reached 26, and lindane – 100 ng/L, and about the decrease of their content in 2008–2013 to concentrations below the threshold limit value for seawater, which is 10 ng/L [1)]. In recent years, it has been shown that in the spring season, the content of OCs in the water near the mouth of the Vodopadnaya River can exceed the threshold limit value in seawater [6, 7].

OCs entering marine areas are included in the cycle of substances in ecosystems, and due to their physicochemical properties, they are adsorbed on suspended mineral and organic particles, accumulate in hydrobionts and eventually enter bottom sediments, where OCs concentrations can reach extremely high values and remain unchanged for a long period of time [8].

To date, no comprehensive studies of the content of OCs in water, hydrobionts and bottom sediments of Yalta Bay have been carried out. In this regard, the purpose of the work is to assess the contamination of the biotope and biocenosis components of Yalta Bay ecosystem with organochlorine xenobiotics.

Materials and methods

The study area is located in Yalta Bay, which juts out into the southern coast of Crimea for 3 km. The sampling of water, *Cystoseira* and bottom sediments (BS) was carried out in the mouth area of the Vodopadnaya River, flowing into the water area of Yalta Bay within the boundaries of Yalta; and in the open area of the bay from 2017 to 2020 at the stations, the diagram of which is shown in Fig. 1. The coordinates and station depths are presented in Table. 1.

[1)] Order no. 552 of Ministry of Agriculture of the Russian Federation as of 13 December 2016. Available at: http://docs.cntd.ru/document/420389120 [Accessed: 13 September 2022]. (in Russian).

Fig. 1. Scheme of the water, *Cystoseira* and sediments sampling area in Yalta Bay: 1–5 – water sampling stations; 4 – *Cystoseira* sampling station near the Vodopadnaya River outlet; 1, 5 – sediment core sampling stations (https://yandex.ru/maps/11470/yalta/?ll=34.200931%2C44.472756&z=13.08).

The samples of river and seawater from the surface layer were taken into glass containers with screw caps and stored in a refrigerator at 4°C until analysis. The sample volume was 5 litres. *Cystoseira* samples were taken at station 4 (Fig. 1) in the coastal area, subject to the influence of the Vodopadnaya River runoff. At stations 1 and 5 with a gravity-type tubular sampler, the bottom sediment cores were sampled without disturbing the sediment stratification. After sampling with a piston extruder, the bottom sediment columns were divided into layers 1 cm thick, which were weighed, dried to constant weight to determine the amount of natural moisture, carbonate content, and OCs content in them.

OCs in water were determined by gas chromatography method in accordance with the guidelines of federal environmental regulations 14.1:2:3:4.204-04 (2014). The extraction of OCs from unfiltered samples was carried out with hexane (*Cryochrome*, Russia) no later than 24 h after sampling. If necessary, the extracts were purified with concentrated sulfuric acid (high purity grade).

To assess the content of OCs in hydrobionts, the perennial brown alga *Cystoseir*a sp., which is very sensitive to pollution of the marine environment, was chosen [9]. Before analysis, the algae were purified from epiphytes, washed with distilled water, dried to constant weight, and thoroughly ground. OCs were extracted three times from an aliquot (5 g) of the sample with a mixture of hexane and acetone in an ultrasonic bath at 30 °C, the extracts were combined, and concentrated on a rotary evaporator. The concentrated extract was purified through a column with florisil. OCs were eluted with hexane.

Table 1. Coordinates of sampling stations in Yalta Bay

Station number	Lat, N	Lon, E	Depth, m
1	44° 29.2234′	34° 10.9130′	29.4
2	44° 29.1806′	34° 10.9530′	31.0
3	44° 28.6701′	34° 10.3051′	33.9
4	44° 29.3294′	34° 09.8040′	1.0
5	44° 28.4208′	34° 10.0072′	34.0

Preparation of bottom sediment samples and analysis of OCs in them was carried out in accordance with GOST R 53217–2008. OCs were extracted twice from 5 g of dried and homogenized bottom sediments with a mixture of n-hexane and acetone (*EKOS-1*, Russia) in a ratio of 3:1. The combined extract was concentrated to 1 ml on a rotary evaporator and then the extract was purified by column chromatography method with 2 g of florisil (*Merk*, Germany). Sulfur was removed from the bottom sediment extracts using activated metallic copper (*Komponent-Reaktiv*, Russia).

Determination of OCs in the prepared extracts of water, *Cystoseira* and bottom sediments was carried out at the Spectrometry and Chromatography Research Center of the Institute of Biology of the Southern Seas on a Kristall 5000 gas chromatograph (*Khromatek*, Russia) with an electron capture microdetector (ECD) and a 30-meter capillary CR-5 stationary phase column. Separation in the presence of OCs was provided by the following conditions of the chromatographic system: evaporator temperature – 280 °C; initial column temperature – 150 °C (0 min); further heating at a rate of 5 °C/min to 220 °C (2 min), then 2 °C/min to 240 °C (2 min) and 5 °C/min to 290 °C (10 min), ECD temperature – 300 °C, carrier gas – nitrogen, flow divider – 1:20.

The concentrations of DDT and its metabolites p,p'-DDE and p,p'-DDD (hereinafter DDE and DDD), as well as six PCB indicator congeners (numbers are given according to the IUPAC nomenclature) were measured in the samples: 28, 52, 101, 138, 153 and 180. Quantitative calculations were carried out by the absolute calibration method. OCs standards were purchased from *Sigma-Aldrich*. The error in the determination of OCs did not exceed 30 % at their content up to 1, 20 % – from 1 to 10, 15 % – over 10 ng/l in water or ng/g dry weight in bottom sediments and *Cystoseira*.

In bottom sediment samples, the natural moisture content was determined by the gravimetric method, and the carbonate content (in calcite equivalent) was determined by the fast gasometric method after decomposition of carbonates with hydrochloric acid [10].

To assess the intensity of OCs influx from water into *Cystoseira* and bottom sediments, the accumulation coefficients AC were calculated according to the formula

$$AC = Co \cdot 1000/Cw, \quad (1)$$

where *C*o – concentrations of OCs in the object of study: *Cystoseira* or bottom sediments, ng/g dry weight; *C*w – concentration of OCs in water, ng/l.

Estimation of the average annual removal of OCs R_{ocs} (g) was calculated according to the formula [2)]

$$R_{ocs} = C_{ocs} \cdot W,$$

where C_{ocs} is average concentration of OCs in water in the mouth area of the river, g/m^3; W is average annual runoff of the Vodopadnaya River, m^3.

The ecotoxicological assessment of sediment pollution was analyzed by comparing the measured concentrations with the threshold effect level

[2)] Hydrochemical Institute, 1983. [*Temporal Recommended Practice for Calculation of Organic Substances, Nutrients, Pesticides and Trace Elements Removal with River Runoff*]. Moscow: Gidrometeoizdat, 32 p. (in Russian).

in bottom sediments, below which side effects were not expected (TEC, Threshold Effect Concentration), and with the probable effect level (PEC, Probable Effect Concentrations), above which adverse effects would be observed. According to the 2003 recommendations [3)] for precipitation quality, TEC for ∑DDT is 5.3, and for ∑PCB it is 60 μg/kg dry weight, PEC is 572 and 670 μg/kg dry weight, respectively.

Results and discussion

Table 2 shows the average annual concentrations of DDT, its metabolites and six PCB indicator congeners in the surface water layer in the Yalta sea area and in the water of the Vodopadnaya River.

From 2017 to 2020, the sum of concentrations of DDT and its metabolites DDE and DDD (∑DDT) in the surface water layer of the Yalta sea area varied from 3.8 to 40.0 % (average 14.2 %) of the threshold limit value in seawater, the sum of six PCB indicator congeners (∑6PCB) – from 22.3 to 127.5 % (average 68 %) of the threshold limit value, which is 10 ng/l for OCs in seawater. In the summer seasons, relatively low concentrations of OCs were observed in the water of Yalta Bay, the maximum values of which did not exceed the threshold limit value. An excess of the threshold limit value was observed for PCBs in the spring season of 2017, which may be due to the intake of PCBs with terrigenous runoff during floods. In 2020, the concentration of ∑6PCB in the Vodopadnaya River turned out to be on average twice lower than in the adjacent Yalta sea area. DDT with metabolites at the sampling point in the bay was not found, while DDT and DDE were determined in the river water, and their concentration did not exceed 2.5 % of the threshold limit value.

To assess the removal of OCs with the runoff of the Vodopadnaya River in the Yalta sea area, the mean long-term annual flow of river water in its mouth area was taken, which was 0.151 m³/s [11]. About 0.005 km^3 of water enters the water area of Yalta Bay with the river runoff per year. Calculations of OCs

Table 2. Average concentration of OCs (ng/L) in the water of the surface layer of the Yalta sea area and the Vodopadnaya River

Region	Year	p,p' DDE	p,p' DDD	p,p' DDT	PCB congeners					
					28	52	101	153	138	180
Yalta sea area	2017	0.40	N/D	0.45	N/D	3.00	1.85	1.18	3.32	1.56
	2019	1.17	0.69	0.77	0.63	0.11	1.68	0.53	1.22	2.58
	2020	N/D	N/D	N/D	N/D	1.63	0.21	N/D	0.22	N/D
Vodopadnaya River	2020–2021	0.25	N/D	0.14	N/D	0.66	0.37	0.19	0.23	0.15

Note: N/D – not detected.

[3)] Contaminated sediment standing team, 2003. *Consensus-Based Sediment Quality Guidelines. Recommendations for Use and Application*. Wisconsin, 2003. 35 p. Available at: https://dnr.wi.gov/doclink/rr/RR088.pdf [Accessed: 12 September 2022].

removal using formula (1) based on the average concentration of ∑DDT and ∑6PCB in the mouth area of the Vodopadnaya River, which was 0.32 and 1.09 ng/l, respectively, and the annual water runoff showed that the intake of ∑DDT was 1.50 g/year. The intake of ∑6PCB turned out to be 3.4 times higher than that of ∑DDT and amounted to 5.19 g/year.

A comparison was made of the obtained OCs fluxes in the sea with the runoff of the Vodopadnaya River and the results obtained in 2020 of the OCs removal from the Chernaya River into Sevastopol Bay. With an average annual concentration of ∑DDT and ∑6PCB in the mouth area of the Chernaya River equal to 0.57 and 3.45 ng/l, the discharge into the bay with the river runoff was 21 and 126 g/year, respectively [8]. The obtained values showed that with a difference in the average concentration in water of ∑DDT by 1.7 and ∑6PCB by 3.2 times, the contribution of the Vodopadnaya River in the OCs pollution of the sea area was lower than the contribution of the Chernaya River, an average of 22 times, which is associated with a lower annual runoff of the Vodopadnaya River. The same results were previously obtained when considering the pollution of the Sea of Azov with pesticides coming from small rivers, the contribution of which was proportional to their runoff [12].

As an alternative to the assessment of OCs pollution in the water area by water analysis, the determination of pollutants in marine macroalgae is used [13]. The data on macroalgae contamination was first published in the early 1950s and is still widely used to assess the ecological state of marine ecosystems. However, most studies (97 %) dealt with inorganic pollutants, and only 3 % of them were devoted to organic pollution [14].

At present, the state of macrophytes of Yalta Bay has hardly been studied. According to the oral testimonies of the staff of the NBG-NSC, the *Cystoseira* phytocenosis of the coastal region of Yalta is in a depressed state and occurs in the form of fouling on artificial substrates: moorings, breakwaters, etc. In April and June 2017, OCs contamination of the brown alga *Cystoseira* sp. was studied for the first time in the Yalta sea area. Despite more than a 50-year ban on the use of DDT and a 30-year ban on PCBs, *Cystoseira* samples contained both the parent pesticide and its metabolites DDE and DDD and all six PCB indicator congeners, the highest of which was the concentration of low-chlorinated congener 28 (Table 3).

The accumulation coefficients for individual OCs in *Cystoseira* varied from $1 \cdot 10^3$ to $2 \cdot 10^4$, which indicates a significant bioavailability of OCs.

Table 3. OCs concentration (ng/g dry weight) in algae *Cystoseira* sp. in the coastal area of Yalta Bay

Date	DDE	DDD	DDT	PCB congeners					
				28	52	101	153	138	180
19.04.2017	0.65	0.44	0.63	2.16	1.11	0.56	0.90	1.19	0.52
28.06.2017	0.75	0.37	0.42	2.48	0.96	0.85	1.28	1.57	0.43

There is some published data on OCs contamination of marine brown algae, which indicates that the maximum OCs contamination of the algae *Cystoseira* sp. was observed in the 1980s (Table 4), when OCs were widely used in industry and agriculture in many countries [15]. OCs in brown algae were found not only in the coastal areas of inland seas, but also in the southern latitudes of the Antarctic region [16, 17].

Comparison of the obtained results with the published data (Table 4) showed that the concentrations of PCBs in Yalta Bay *Cystoseir*a exceeded those in the Cape Martyan marine area by more than twice, and the DDT content, taking into account the determination error of 20 %, was approximately equal [18].

Fig. 2 shows the results of layer-by-layer measurements of the initial moisture content and carbonate content of bottom sediments at stations 1 and 5. The moisture content of bottom sediments characterizes their porosity associated with granulometric composition [19]. Precipitation with low humidity values (30–40 % or less) is characteristic of bottom sediments formed by lithogenic material entering water bodies as a result of abrasion of the coastal zone and with slope water runoff. The values of carbonate content obtained in this work, which at station 1 changed

Table 4. Mean OCs concentration (ng/g dry weight ± SD) in *Cystoseira* sp. and other brown algae in different areas of the World Ocean

Region	Years	Name	∑DDT	∑PCB	Reference
East coast of Sicily, Italy	1979	*Cystoseira stricta* *Cystoseira fimbriata*	20.1 3.2	84.2 66.4	[14]
Coastal areas of the Southern coast of Crimea	1982–1993	*Cystoseira* sp.	ND	556–724	[15]
The Gulf of Venice	1999	*Cystoseira barbata* *Fucus virsoide*	ND	2.5±1.6 3.0±1.7	[17]
Admiralty Bay, the Antarctic	1993–1994	*Desmarestia* sp.	ND	0.46–3.86	[16]
Cape Martyan marine area	2017–2020	*Cystoseira* sp.	2.39	2.87	[18]
Yalta Bay	2017	*Cystoseira* sp.	1.63	7.01	this paper

Note: ND – no data.

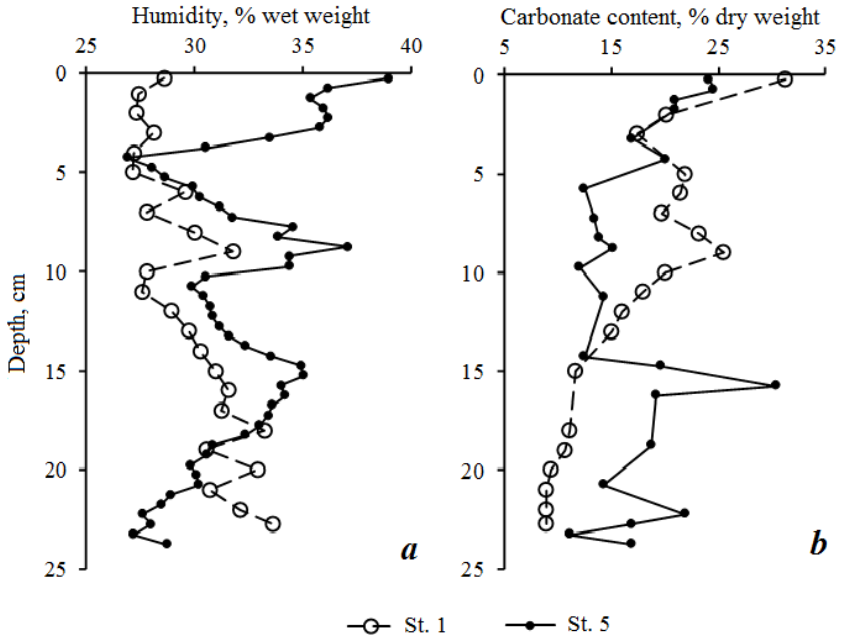

Fig. 2. Distribution of natural moisture (*a*) and carbonate content (*b*) in sediment at St. 1 and 5

from 8.9 to 31.3 %, and at station 5 changed from 12.5 to 24.6 % wet weight (Fig. 2, *b*), and bottom sediment humidity (from < 40 % in the uppermost layer to 27 % in the lower layers (Fig. 2, *a*)) indicate the predominance of lithogenic suspension in them. Porosity and carbonate content of the sediment at station 5 decreased exponentially down the core (R^2 = 0.28 and R^2 = 0.34, respectively), at station 1, porosity increased linearly (R^2 = 0.67), while carbonate content decreased with depth (R^2 = 0.79) (Fig. 2). The uneven distribution of moisture and carbonate content in sediments is probably determined by the temporal variability of the composition of sedimented suspensions in the area of coastal stations.

ΣDDT concentration in bottom sediment cores at stations 1 and 5 varied in the range from 0.1 to 387.2 ng/g dry weight, Σ6PCB varied in a narrower range from 3.4 to 17.5 ng/g dry weight (Fig. 3). At station 1, in the surface layer of the bottom sediment from 0 to 1 cm, an extremely high concentration of ∑DDT was found, which averaged 230 ng/g, while in deeper layers from 2.5 to 23 cm, the average concentration of DDT was 1.53 ng/g (Fig. 3, *a*). The sampling area of the core at station 1 falls under the influence of the Vodopadnaya River runoff, with which ∑DDT could enter the water area of the bay and fall out with suspension in the bottom sediment.

At station 1, the vertical distribution profiles of ∑6PCB and ∑DDT were significantly different. The average concentration of ∑6PCB (10.21 ng/g) in the upper centimeter layer was 20 times lower than that of DDT, while in the lower layers, on the contrary, it was an order of magnitude higher on average (Fig. 3, *a*).

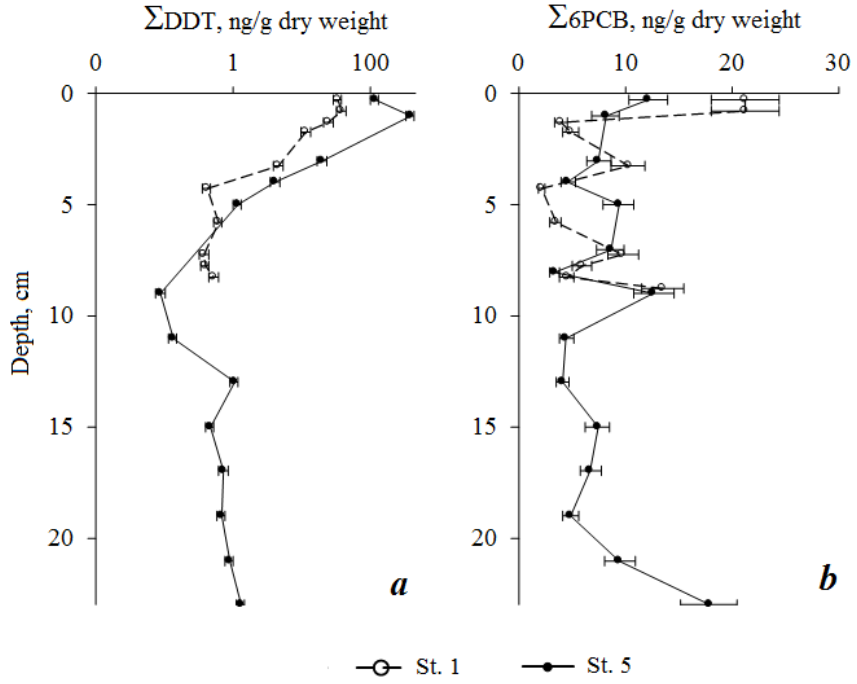

Fig. 3. Vertical distribution of ∑DDT (a) and ∑6PCB (b) in bottom sediments at St. 1 and 5

At station 5 in the upper bottom sediment layer, the concentration of ∑DDT was six times lower (36 ng/g) than at station 1, but the same as at station 1 was significantly higher than in the underlying layers, where it averaged 1.06 ng/g. Thus, on the distribution profiles of ∑DDT in the soil core at station 5, a tendency to decrease the content of pesticides with increasing depth appeared in common with station 1.

In the surface layers of both cores, the sum of concentrations of DDT and metabolites was dominated by the initial pesticide DDT (78 and 74 %), with the depth of sediments this ratio decreased to 34 and 22 % at stations 1 and 5, respectively. This indicates new DDT intakes into the water area of the bay in recent years.

The vertical profiles of OCs in the sediment core in Yalta Bay were compared with those in Sevastopol Bays, where the maximum ∑PCB contamination, reaching 400 ng/g, was observed in Sevastopol Bay at a depth of 15–20 cm, and in Streletskaya Bay, at a depth of 10–15 cm. Bottom sediments at these depths were accumulated taking into account the sedimentation rates in the 1970s–1980s. In the surface layers of Streletskaya and Sevastopol Bays, the concentration of OCs was significantly lower than at the indicated depths. In Balaklava Bay, as well as in Yalta Bay, the highest concentration of PCBs was found in the surface layers [6].

Based on the OCs concentration data in the water and surface layer of bottom sediments, using formula (1), the accumulation coefficients (AC) of OCs in the bottom sediments of Yalta Bay were calculated, and varied for individual OCs in a wide range from $0.6 \cdot 10^3$ to $4 \cdot 10^4$. The minimum AC were determined for heptachlorobiphenyl (IUPAC number 180), the highest were determined for DDT and tetrachlorobiphenyl (52).

The level of OCs contamination was compared with the TEC threshold values in bottom sediments. At stations 1 and 5, the PCB concentration did not reach TEC, and ∑DDT in the surface layers exceeded TEC, but did not reach the lower threshold level PEC.

Conclusion

For the first time, a comprehensive assessment of the ecological state of Yalta Bay in relation to OCs pollution was carried out. The studies showed that the levels of PCBs in water during the spring season exceeded the threshold limit value. The sources of OCs in Yalta Bay include the Vodopadnaya River. The high OCs accumulation coefficients in *Cystoseira* and bottom sediments indicate bioavailability of OCs and the ongoing process of OCs removal from the marine environment by macrophytes and soils. On the vertical distribution profiles of DDT concentration in the surface layers, the values were found that exceeded the recommended international standards by a maximum of 46 times. This registered fact indicates that in recent years the Yalta sea area received a significant amount of DDT, which managed to accumulate in the upper layers of bottom sediments. It should be noted that such high concentrations of DDT in recent years have not been recorded in the bottom sediments of Sevastopol bays and in the areas of the southern coast of Crimea, which indicates a local source of DDT entry into the water area of Yalta Bay. It remains unclear whether the high concentration of DDT pesticide in the surface layers in the sediment cores of Yalta Bay is the result of its entry into the water area with terrigenous runoff, atmospheric precipitation, river runoff, or from other sources. Further studies of both the spatial distribution of DDT and the vertical profiles in the bottom sediments of Yalta Bay are needed to determine the extent of their contamination.

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